# Analysis of compartment fires with a ceiling vent

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18th October 2022

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# Synopsis

- Introduction
- Fundamentals Concepts
- Modelling Techniques
- Task overview
- Gas phase Flame Extinction in FDS
- FDS Modelling (Approximate Replica of experiment)
- Input For Simulation
- Results
    - Mass loss affected by O2 and gas Temperature
    - Extinction Behavior
    - Gas Temperature profile
    - Volume Concentration
- Conclusion

# 1.Introduction

## Compartment Fires:

A compartment fire may be characterized by several phases: it starts from ignition and then moves into a growth stage.

If no action is taken to suppress the fire and there is enough fuel, it may eventually grow to a maximum intensity fire that is controlled by the amount of air available through ventilation openings.

When the fuel is consumed, the fire temperature will decrease.

# 1.Introduction

Pre-flashover:

In the the initial stages there is sufficient oxygen available for combustion and the growth of the fire entirely depends on the characteristics of the fuel and its geometry. The fire is limited to the amount of available fuel and can be defined as a **fuel controlled** or pre-flashover fire. If a flashover is reached, a fully developed fire occurs.

Flashover:

The transition from the fire growth period to the fully developed stage in the enclosure fire development.

Post-Flashover:

Fire burns at its maximum potential of the available air supply and can be defined as a **ventilation-controlled** or post-flashover fire.

# 2. Fundamental Concepts

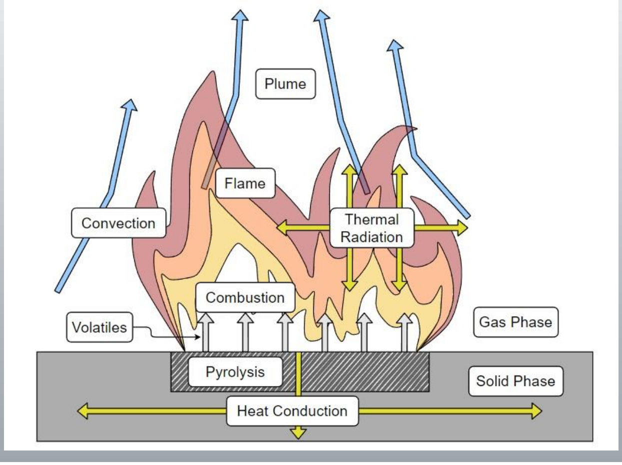
## Heat transfer

Heat can be transferred by three different mechanisms:

**Conduction**- Conduction is the transfer of energy from more energetic particles (higher temperature) of a solid to less energetic ones as a result of interaction between particles.

**Convection**- Convection is the transfer of energy between a solid surface and an adjacent fluid that is in motion

**Radiation**- Radiation is the transfer of energy due to emission of electromagnetic waves.

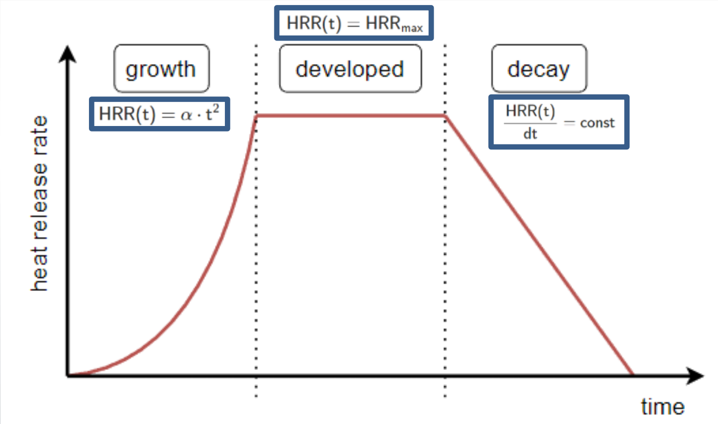


# 2. Fundamental Concepts

## Heat release rate(HRR)

When an object burns it releases a certain amount of energy per unit time, usually given in kW (= kJ/s) and denote $\dot{Q}$

The energy release rate changes with time.




It can also be expressed as heat flux ( $\dot{Q}''$ ) or Heat release rate per unit area (**HRRPUA**), typically in kW/(m²).

# 2. Fundamental Concepts

## Mass loss rate (MLR)

The mass rate of solid or liquid fuel vaporized and burned.

It is expressed as mass flow per unit time, typically in kg/s or g/s and is here denoted as $\dot{m}$

It can also be expressed as mass flux ( $\dot{m}''$ )or mass burning rate per unit area (**MLRPUA**), typically in kg/(m²s).

A distinction should be made between burning rate and mass loss rate (fuel supplied), since all of the fuel supplied may not be burned.

## Heat of Combustion (HoC)

A measure of how much energy is released when a unit mass of material combusts, typically given in kJ/kg or kJ/g.

$$\boxed{\text{HRR} = \text{MLR} * \text{HoC}}$$

# 3. Modelling Techniques

## Governing Equations in FDS

### Conservation of mass:

$$\partial_t(\rho Z_\alpha) + \underbrace{\nabla \cdot (\rho Z_\alpha \vec{v})}_{\text{advection}} = \underbrace{\nabla \cdot (\rho D_\alpha \nabla Z_\alpha)}_{\text{diffusion}} + \underbrace{\dot{m}'''_\alpha}_{\text{generation, reactions}} + \underbrace{\dot{m}'''_{b,\alpha}}_{generation, particles}$$

$\sum Z_\alpha = 1$ Sum of all mass fractions

$\sum \dot{m}'''_\alpha = 0$ Sum of all reaction productions

$\sum \rho D_\alpha \nabla Z_\alpha = 0$ Sum of all diffusion terms

The total density is described with

$$\partial_t \rho + \nabla \cdot (\rho \vec{v}) = \dot{m}'''_b = \sum \dot{m}'''_{b,\alpha}$$

### Conservation of Momentum:

$$\partial_t(\rho \vec{v}) + \underbrace{\nabla \cdot (\rho \vec{v}\vec{v})}_{\text{convection}} = \underbrace{\nabla p}_{\text{pressure}} + \underbrace{\rho \vec{g}}_{\text{gravity}} + \underbrace{\vec{f}_b}_{\text{particle drag}} + \underbrace{\nabla \cdot \tau_{ij}}_{\text{viscosity}}$$

### Conservation of Energy:

$$\partial_t(\rho h_s) + \underbrace{\nabla \cdot (\rho h_s \vec{v})}_{\text{advection}} = \underbrace{\frac{D\bar{p}}{Dt}}_{\text{pressure work}} + \underbrace{\dot{q}'''}_{\text{The Fire!}} + \underbrace{\nabla \cdot \vec{q}''}_{\text{heat conduction}}$$

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# 3. Modelling Techniques

Final set of Fluid equations (Navier stokes equation)

$$\partial_t \rho + \nabla \cdot (\rho \vec{v}) = \dot{m}_b'''$$
$$\partial_t (\rho Z_\alpha) + \nabla \cdot (\rho Z_\alpha \vec{v}) = \nabla \cdot (\rho D_\alpha \nabla Z_\alpha) + \dot{m}_\alpha''' + \dot{m}_{b,\alpha}'''$$
$$\partial_t (\rho \vec{v}) + \nabla \cdot (\rho \vec{v}\vec{v}) = \nabla p + \rho \vec{g} + \vec{f}_b + \nabla \cdot \tau_{ij}$$
$$\partial_t (\rho h_s) + \nabla \cdot (\rho h_s \vec{v}) = \frac{D\bar{p}}{Dt} + \dot{q}''' + \nabla \cdot \vec{q}''$$

FDS solves numerically a form of the Navier-Stokes equations appropriate for low speed, thermally-driven flow with an emphasis on smoke and heat transport from fires.

The core algorithm is an explicit predictor-corrector scheme, second order accurate in space and time.

Turbulence is treated by means of Large Eddy Simulation (LES).

# 3. Modelling Techniques

**Four basic modes of operation in FDS:**

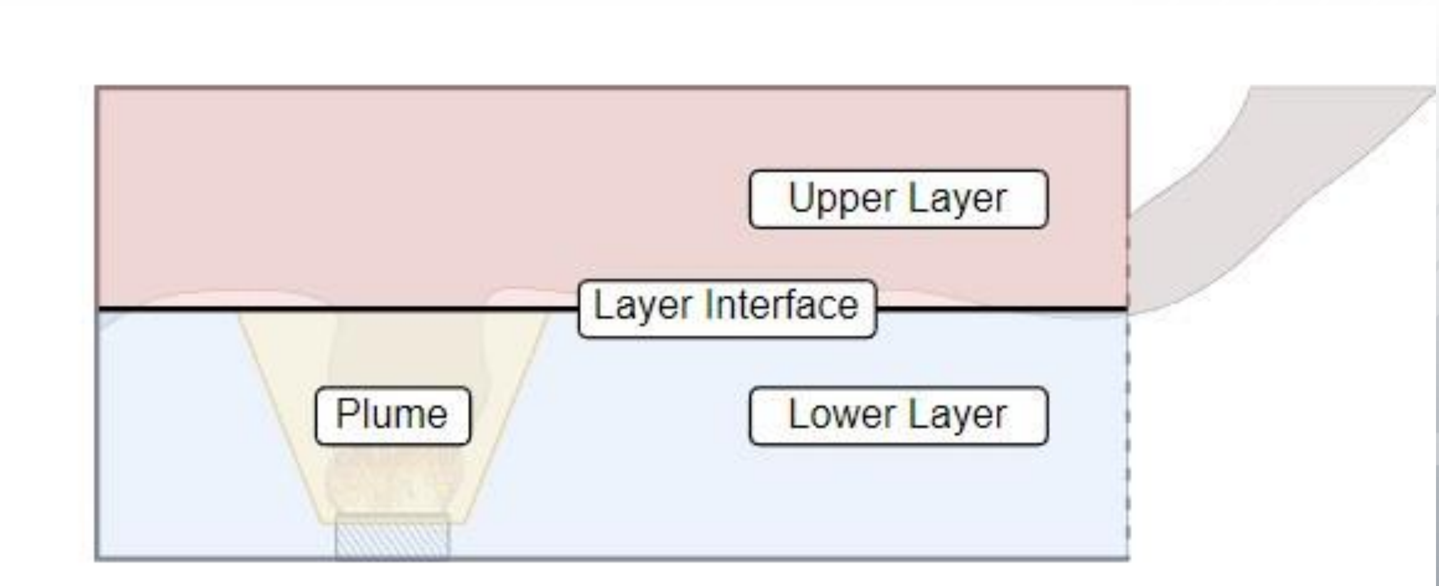
- ❑ DNS (Direction Numerical Simulation)
- ❑ LES (Large Eddy Simulation)
- ❑ VLES (Very Large Eddy Simulation)
- ❑ SVLES (Simple Very Large Eddy Simulation—VLES with simplified physics)

# 3. Modelling Techniques

## Zone Model (Heat transfer in a two-zone compartment fire)

One usually assumes that the room is divided into two effective areas:
one upper (with uniform gas and radiation temperatures)
one lower with ambient gas temperature at the compartment boundaries.

$T_{Upperlayer} > T_{lower\ layer}$

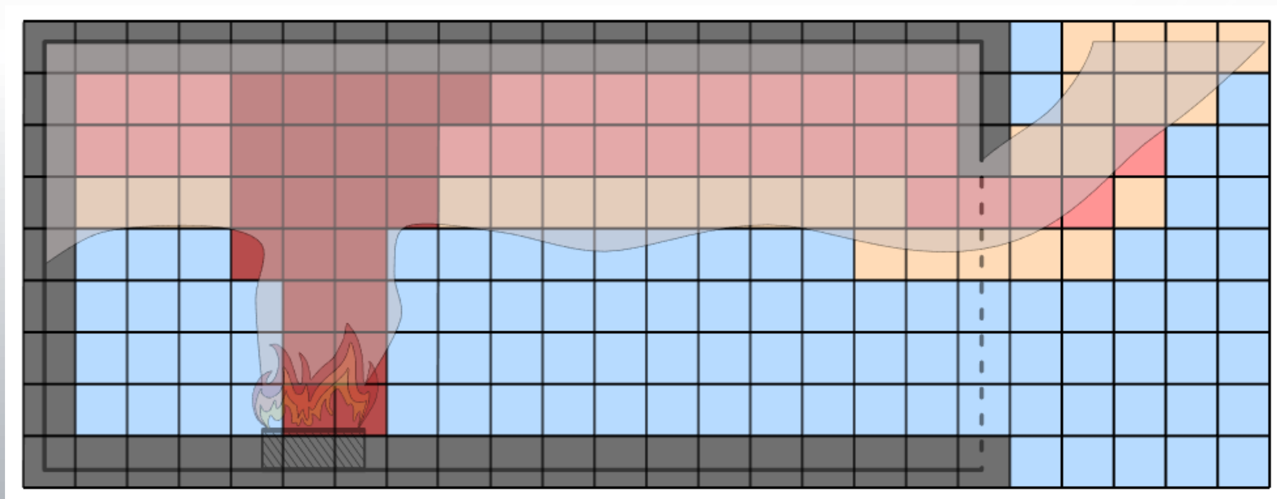


# 3. Modelling Techniques

## Field Model

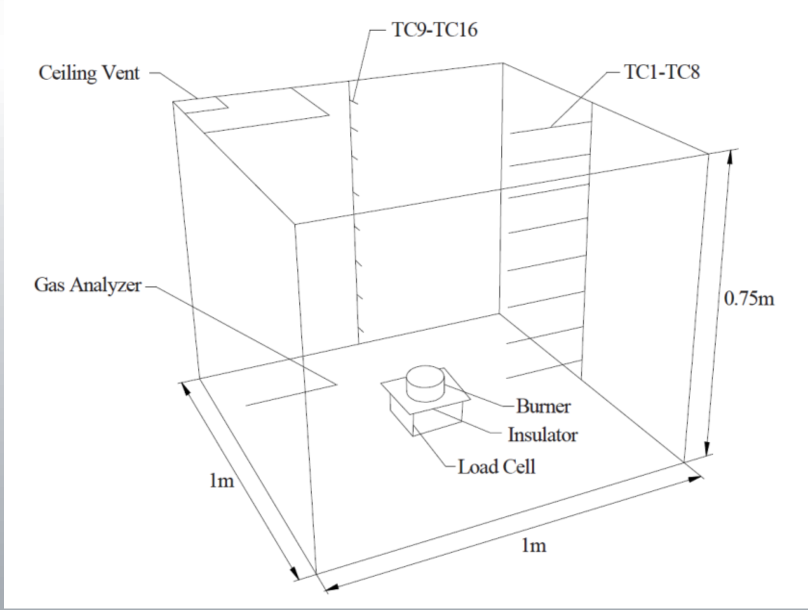
Field models discretize the volume with a three-dimensional mesh

This discretization is needed to numerically solve a set of partial differential equations for quantities like density, velocity, pressure and enthalpy in each node of the mesh.



# 4. Task Overview

- Gas phase flame extinction in FDS
- FDS Modelling of Experimental Setup.
- Grid Sensitivity
- Results and Discussion



# 5: Gas phase flame extinction in FDS

Flames are extinguished due to lowered temperatures and dilution of the fuel or oxygen supply.

There are two flame extinction models in FDS that determine whether or not combustion is viable based on the cell temperature and the oxygen and fuel concentrations.

’EXTINCTION 1’ model is the default in Simple Very Large Eddy Simulation (SVLES) mode, It considers only the cell temperature and oxygen concentration

’EXTINCTION 2’ model is used in all other modes. It invokes detailed thermophysical gas species properties.

# 5: Gas phase flame extinction in FDS

**Both extinction models make use of the CFT.**

The CRITICAL_FLAME_TEMPERATURE (CFT) is based on the oxygen index (OI) concept.

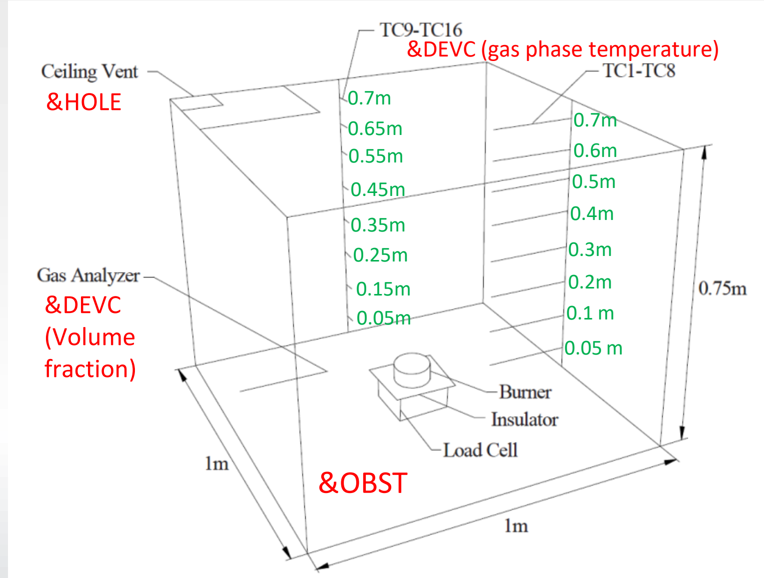
The oxygen index is the volume fraction of oxygen in the oxidizer stream when extinguishment occurs.

# 6. FDS Modelling (Approximate Replica of Experiment)

## Experiment Setup:

Inner dimensions of the enclosure were 1m by 1 m by 0.75 m high (5mm thick stainless steel).

6 Different Vent Areas - 0.0025 m2 (0.05 m × 0.05 m),
0.01 m2 (0.1 m × 0.1 m),
0.0225 m2 (0.15 m × 0.15 m),
0.04 m2(0.2 m × 0.2 m),
0.0 625 m2 (0.25 m × 0.25 m)
0.0 9 m2 (0.3 m × 0.3 m)




3 Different Burner diameter - 0.1, 0.141 and 0.2 m, depth of 40 mm (the top surface of burner is 0.12 m from ground)

18 test cases were carried out

Fuel (N-heptane)

Loadcell & Insulator

Thermocouples -16Nos (0.25 m from right wall, 0.05m from back wall)

Gas Analyzer- 2Nos (placed in a height of 0.0015m and 0.15 m)&(0.25 m from left wall)

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# 6. FDS Modelling (Approximate Replica of Experiment)

## Experiment Results:

| Case No. | Pan Diameter (m) | Vent Area ($m^2$) | Fire Duration (s) | Average Burning rate ($kg/(m^2 s)$) | Hot Gas Temperature[b] (°C) | Oxygen Concentration[c] (%) | Self-extinction |
|---|---|---|---|---|---|---|---|
| 1 | 0.1 | 0.0025 | 319-348[a] | 0.0077 | 104.7 | 14.1-14.3 | Yes |
| 2 | 0.1 | 0.01 | 323-360 | 0.0078 | 107.2 | 14.1-14.6 | Yes |
| 3 | 0.1 | 0.0225 | 383-388 | 0.0079 | 106.8 | 14.6-14.7 | Yes |
| 4 | 0.1 | 0.04 | 427-436 | 0.0079 | 102.4 | 15.5-15.7 | Yes |
| 5 | 0.1 | 0.0625 | 862-976 | 0.0088 | 105.8 | 16.8-17.9 | No |
| 6 | 0.1 | 0.09 | 813-822 | 0.0101 | 110.1 | 18.5-18.8 | No |
| 7 | 0.141 | 0.0025 | 148-155 | 0.0081 | 141.2 | 13.2-13.9 | Yes |
| 8 | 0.141 | 0.01 | 153-162 | 0.0085 | 144.1 | 12.9-13.1 | Yes |
| 9 | 0.141 | 0.0225 | 155-163 | 0.0082 | 143.9 | 14-14.1 | Yes |
| 10 | 0.141 | 0.04 | 157-173 | 0.0083 | 141.6 | 15.3-15.4 | Yes |
| 11 | 0.141 | 0.0625 | 190-225 | 0.0082 | 141.2 | 16.4-16.5 | Yes |
| 12 | 0.141 | 0.09 | 881-962 | 0.0115 | 163.6 | 16.9-17.8 | No |
| 13 | 0.2 | 0.0025 | 85-93 | 0.0084 | 188.6 | 13.1-13.2 | Yes |
| 14 | 0.2 | 0.01 | 82-97 | 0.0083 | 184.0 | 12.2-12.8 | Yes |
| 15 | 0.2 | 0.0225 | 84-96 | 0.0085 | 191.1 | 12.9-13.8 | Yes |
| 16 | 0.2 | 0.04 | 88-93 | 0.0087 | 185.2 | 14.1-14.3 | Yes |
| 17 | 0.2 | 0.0625 | 84-96 | 0.0084 | 188.3 | 15.2-16.1 | Yes |
| 18 | 0.2 | 0.09 | 94-99 | 0.0088 | 189.9 | 16.2-16.3 | Yes |

[a] The value with variation due to different experiment.
[b] The hot gas temperature is taken to be the value measured by the thermocouple at 65 cm high.
[c] The oxygen mole fraction at the base of fire at the time when the flame is extinguished.

Our Simulation results will vary from actual experiment results (Because of various Approximations)

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# 6. FDS Modelling (Approximate Replica of Experiment)

## Simulation Setup:

### Time and Fuel:

Time and Fuel are most important things for running FDS Simulation (default T_END = 1s). For Example this line will train FDS to run the simulation for 400 s .

```
## Time Limit
&TIME T_END = 400.0 / Boundary Value
&MISC TMPA =20.0 /
## Reaction Fuel
&REAC FUEL = 'N-HEPTANE'
FYI = 'Heptane, C_7 H_16'
C = 7.
H = 16.
CO_YIELD = 0.08
SOOT_YIELD = 0.015
CRITICAL_FLAME_TEMPERATURE=1497.0
LOWER_OXYGEN_LIMIT = 0.134/
&COMB EXTINCTION_MODEL='EXTINCTION 2' /
```

N-Heptane is fuel used during all our simulations.

Gas phase Extinction Modelling in FDS.

# 6. FDS Modelling (Approximate Replica of Experiment)

**BURNER**

Burner is a mechanical device that burns a gas or liquid fuel in a regular manner.
In the experiment, Circular Burner with 3 different diameters were used.

But in FDS, it is difficult to define the shape of the mesh for circular shapes.
Therefore, we approximated the diameter of the burner area to a square burner and placed it at an exact position.

To define the burner, we need a time-dependent HRRPUA value that depends on the MLRPUA values which we took from the graph in the primary article.

MLRPUA

```
time_list = [5,20,40,60,80,100,120,140,160,180,200,220,240,260,280,300,320,340,356,360]
mlr_list=np.array([0,0.001416,0.004876,0.007587,0.007526,0.007384,0.007080,0.007423,0.007807,0.008070,0.0
0.002803])
huc = 48073 # Effective heat of combustion huc = 44590 KJ / kg
hrr_list = abs(mlr_list*huc) # calculate HRR from mass loss
hrr_list = np.concatenate(([0], hrr_list))
print(hrr_list)
print(f"&SURF ID = 'BURNER', HRRPUA = {max(hrr_list):.2f}, RAMP_Q = 'fireramp', COLOR = 'RASPBERRY' /")
for time, hrr in zip(time_list, hrr_list):
    print(f"&RAMP ID='fireramp', T={time}, F={hrr/max(hrr_list):.2f} /")
```

Values taken from primary article

# 6. FDS Modelling (Approximate Replica of Experiment)

Maximum HRRPUA value

```
&SURF ID='FIRE', HRRPUA = 438.28, RAMP_Q = 'fireramp', COLOR = 'RASPBERRY'  /
&VENT XB=-0.05,0.05,-0.05,0.05,0.12,0.12, SURF_ID='FIRE'/ Diametre(0.1)
&RAMP ID='fireramp', T=0, F=0.00 /
&RAMP ID='fireramp', T=5, F=0.00 /
&RAMP ID='fireramp', T=20, F=0.15 /
&RAMP ID='fireramp', T=40, F=0.53 /
&RAMP ID='fireramp', T=60, F=0.82 /
&RAMP ID='fireramp', T=80, F=0.84 /
&RAMP ID='fireramp', T=100, F=0.86 /
&RAMP ID='fireramp', T=120, F=0.86 /
&RAMP ID='fireramp', T=140, F=0.86 /
&RAMP ID='fireramp', T=160, F=0.86 /
&RAMP ID='fireramp', T=180, F=0.87 /
&RAMP ID='fireramp', T=200, F=0.88 /
&RAMP ID='fireramp', T=220, F=0.88 /
&RAMP ID='fireramp', T=240, F=0.89 /
&RAMP ID='fireramp', T=260, F=0.89 /
&RAMP ID='fireramp', T=280, F=0.91 /
&RAMP ID='fireramp', T=300, F=0.93 /
&RAMP ID='fireramp', T=320, F=0.96 /
&RAMP ID='fireramp', T=340, F=1.00 /
&RAMP ID='fireramp', T=360, F=0.94 /
&RAMP ID='fireramp', T=370, F=0.84 /
&RAMP ID='fireramp', T=380, F=0.76 /
```

Burner surface area

Used Ramp function to define time dependent HRRPUA values

T = time

$$F = \frac{\text{HRRPUA}}{\text{Max. HRRPUA}}$$

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# 6. FDS Modelling (Approximate Replica of Experiment)

## Geometry:

### Walls and Ceilings:

```
## Compartment walls
&OBST XB= -0.5,-0.5 ,  -0.5,0.5 ,  0.0,0.75,  SURF_ID='SSteel'/ Wall 1
&OBST XB= -0.5,0.5,  -0.5,-0.5,    0.0,0.75,  SURF_ID='SSteel' / Wall 2
&OBST XB= 0.5,0.5 ,  -0.5,0.5 ,    0.0,0.75,  SURF_ID='SSteel' / Wall 3
&OBST XB= -0.5,0.5,   0.5,0.5,     0.0,0.75,  SURF_ID='SSteel'/ Wall 4
## Floor and ceiling
&OBST XB= -0.5,0.5 ,  -0.5,0.5 ,  0.75,0.75, SURF_ID='SSteel'/ Ceiling
&OBST XB= -0.5,0.5 ,  -0.5,0.5 ,  0.0,0.0,   SURF_ID='SSteel'/ Floor
```

```
## Stainless Steel 316
&MATL ID='steel',CONDUCTIVITY=16.26, SPECIFIC_HEAT=0.5021, DENSITY=8027.2 /
&SURF ID='SSteel', MATL_ID='steel', COLOR='GRAY',TRANSPARENCY=0.9,
THICKNESS=0.005 /
```

### Vent Area

```
## Vent area 1
&HOLE XB = -0.5,-0.35,   -0.35,-0.5,  0.745,0.755  / vent area =0.15m
```

# 6. FDS Modelling (Approximate Replica of Experiment)

## Thermocouple:

In the Experiment, they used Bare bead Thermocouple(TC)

```
## Thermocouples Diametre
&PROP ID='Thermocouple',DIAMETER=0.005, EMISSIVITY=0.85, DENSITY=8908.0, SPECIFIC_HEAT=0.44 /

## Thermocouples (RIGHT WALL)
&DEVC ID='TC-01', XYZ=0.0,0.25,0.05, QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-02', XYZ=0.0,0.25,0.1,  QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-03', XYZ=0.0,0.25,0.2,  QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-04', XYZ=0.0,0.25,0.3,  QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-05', XYZ=0.0,0.25,0.4,  QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-06', XYZ=0.0,0.25,0.5,  QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-07', XYZ=0.0,0.25,0.6,  QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-08', XYZ=0.0,0.25,0.7,  QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /

## Thermocouples (BACK WALL)
&DEVC ID='TC-09', XYZ=-0.45,0.0,0.7,  QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-10', XYZ=-0.45,0.0,0.65, QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-11', XYZ=-0.45,0.0,0.55, QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-12', XYZ=-0.45,0.0,0.45, QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-13', XYZ=-0.45,0.0,0.35, QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-14', XYZ=-0.45,0.0,0.25, QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-15', XYZ=-0.45,0.0,0.15, QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
&DEVC ID='TC-16', XYZ=-0.45,0.0,0.05, QUANTITY='THERMOCOUPLE', PROP_ID='Thermocouple' /
```

# 6. FDS Modelling (Approximate Replica of Experiment)

## Gas Analyzer:

```
##Gas Analyzer
&DEVC ID='Gas-Analyser', XYZ=0.0,-0.25,0.0015, QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN' /
&DEVC ID='Gas-Analyser-1', XYZ=0.0,-0.25,0.15, QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN' /
```

## Domain:

MESH is used to create domain

```
&MESH IJK =150,150,150, XB =-0.505,0.505,-0.505,0.505,0.0,1.01/
```

Number of Mesh in X,Y,Z Direction

Location in Space

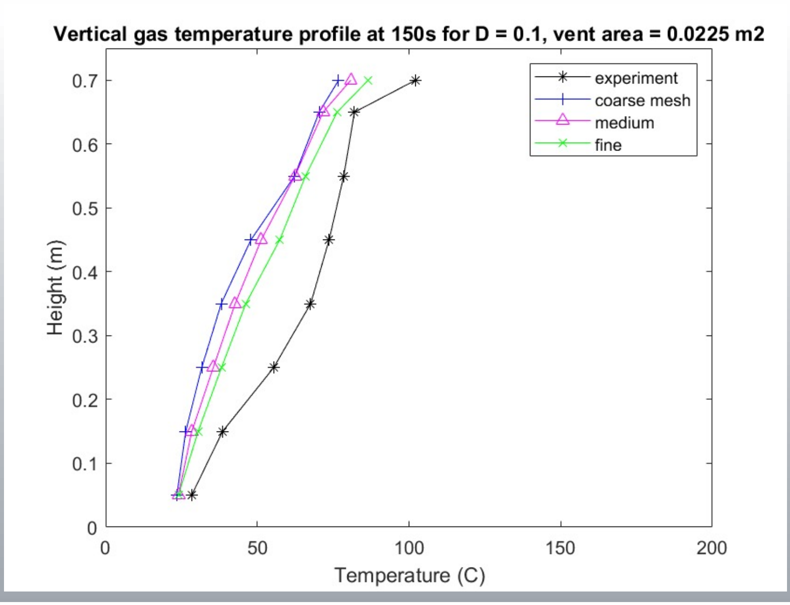
# 6. FDS Modelling (Approximate Replica of Experiment)

**Grid Sensitivity Analysis:**

- To better approximation of values as close as possible to the experiment.

```
&MESH IJK =150,150,150, XB =-0.505,0.505,-0.505,0.505,0.0,1.01/
```

Number of Total Mesh = 3.375.000

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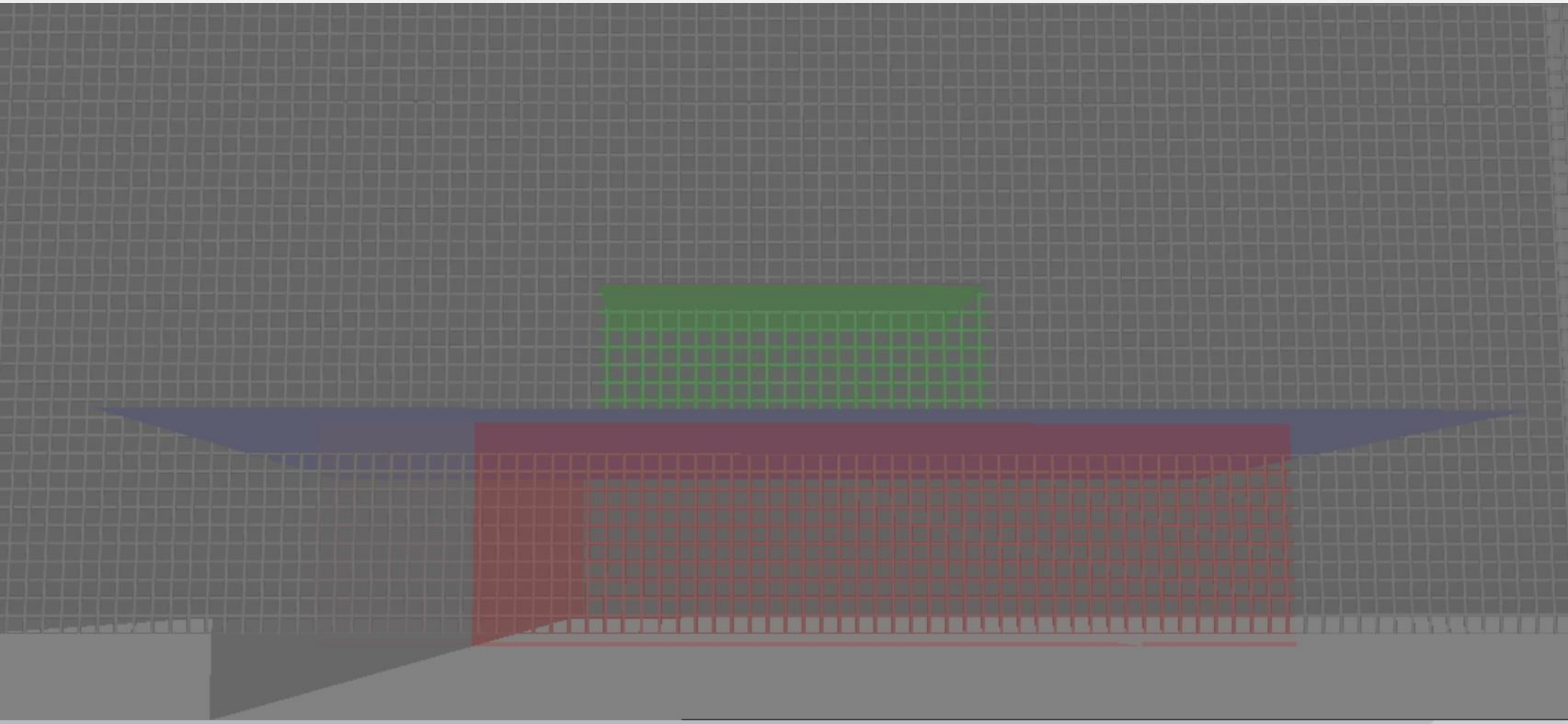
# 6. FDS Modelling (Approximate Replica of Experiment)



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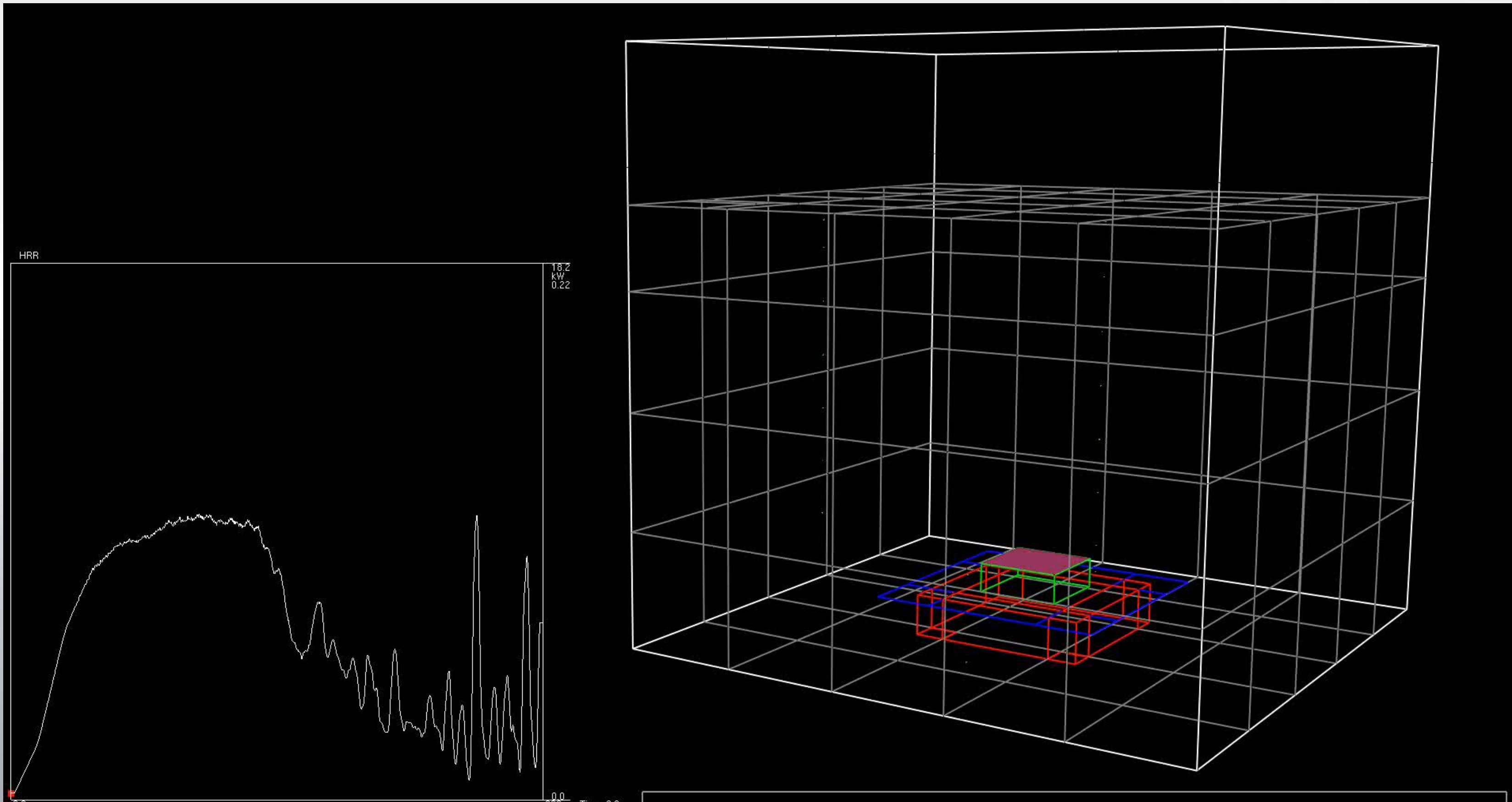
# 6. FDS Modelling (Approximate Replica of Experiment)

&MESH IJK =100,100,100, XB =-0.505,0.505,-0.505,0.505,0.0,1.01/

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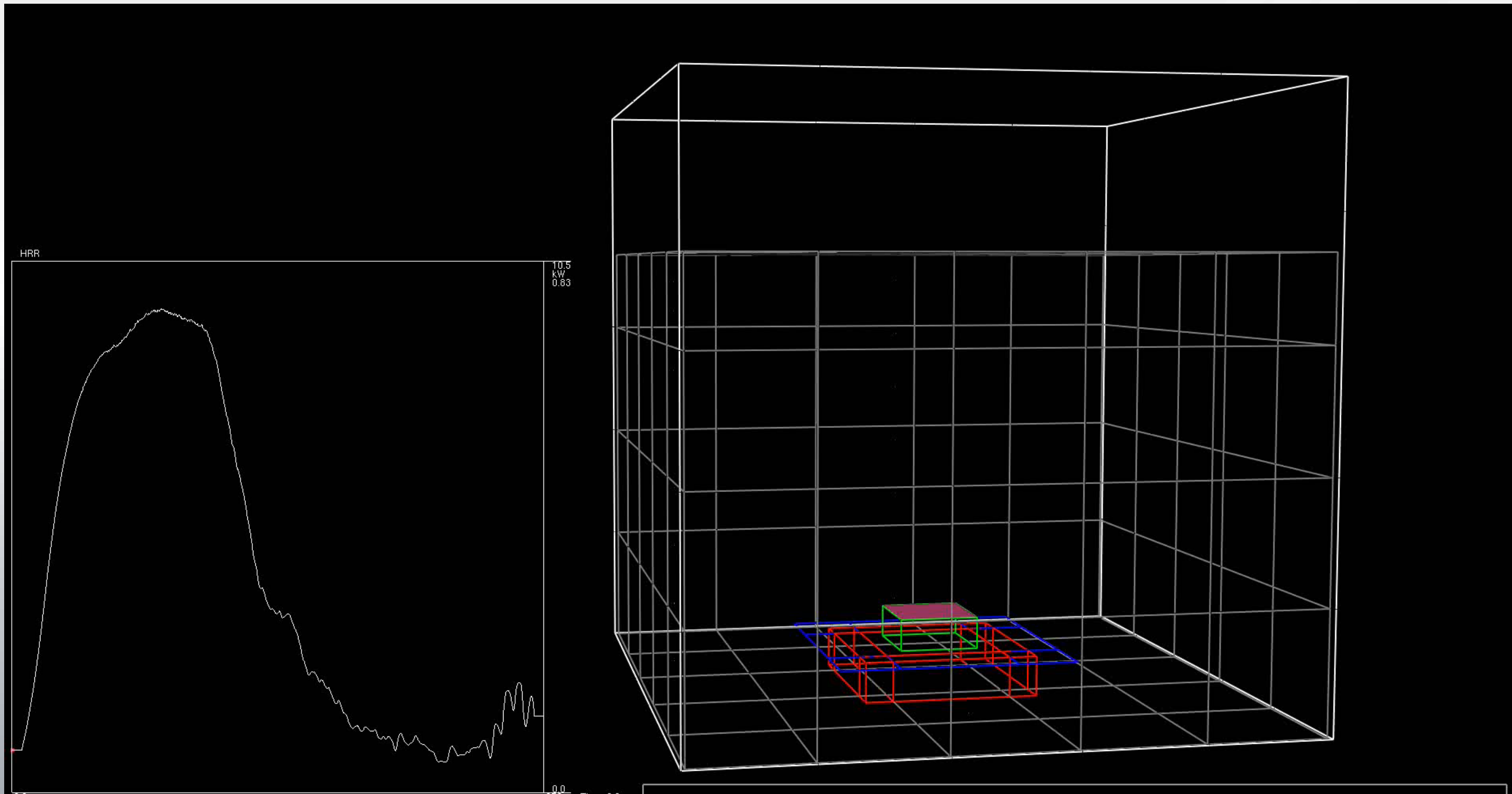
# 6. FDS Modelling (Approximate Replica of Experiment)

&MESH IJK =150,150,150, XB =-0.505,0.505,-0.505,0.505,0.0,1.01/

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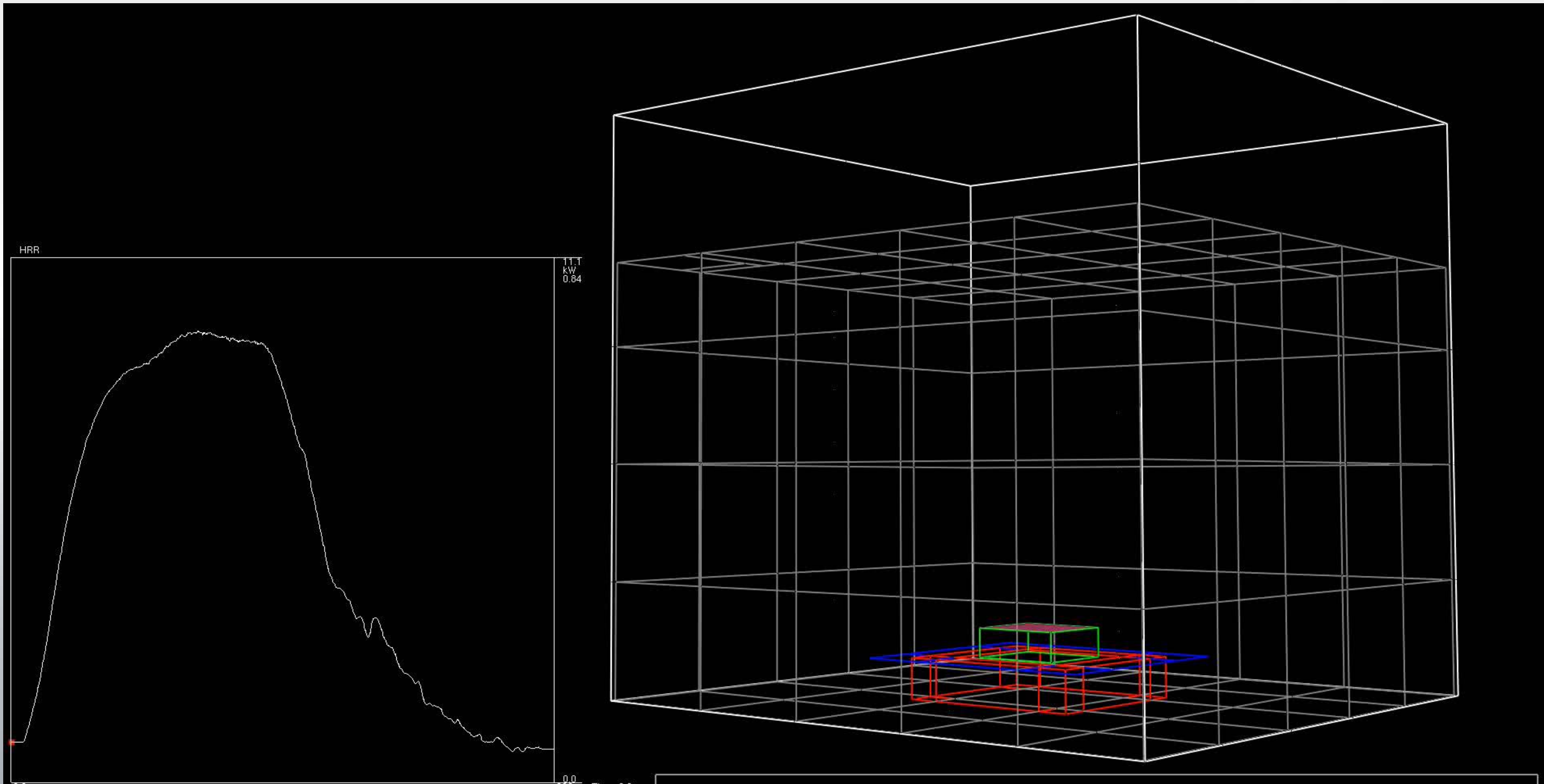
# 6. FDS Modelling (Approximate Replica of Experiment)

&MESH IJK =200,200,200, XB =-0.505,0.505,-0.505,0.505,0.0,1.01/

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# 6. FDS Modelling (Approximate Replica of Experiment)

## Decomposition of Mesh :

Decompose Mesh into Multiple meshes and assign them to individual MPI processes to reduce Computing times.

We used decompose_fds_mesh.py file provided in lecture to decompose mesh

```
> python decompose_fds_mesh.py "&MESH IJK=125,125,125 XB=-0.505,0.505,-0.505,0.505,0.0,1.01 /" “5,5,5"
raw input mesh: &MESH IJK=125,125,125 XB=-0.505,0.505,-0.505,0.505,0.0,1.01 /
raw input decomposition: 5,5,5
raw ijk: IJK=125,125,125
i: 125, j: 125, k: 125
raw xb: XB=-0.505,0.505,-0.505,0.505,0.0,1.01
x: -0.505,0.505
y: -0.505,0.505
z: 0.0,1.01
decomposition: 5, 5, 5
lx: 1.01, dx: 0.202, di: 25
ly: 1.0100, dy: 0.2020, dj: 25
lz: 1.0100, dz: 0.2020, dk: 25
resulting number of meshes: 125
```

# 6. FDS Modelling (Approximate Replica of Experiment)

## Simulation Results:

| Case No | Pan diameter (m) | Vent area (m2) | Fire Duration (s) | Hot gas Temp (C) | Oxy con (%) |
|---|---|---|---|---|---|
| 1 | 0.1 | 0.0025 | 275 | 92.5 | 13.11 |
| 2 | | 0.01 | 275 | 91.7 | 13.23 |
| 3 | | 0.0225 | 285 | 94.4 | 13.26 |
| 4 | | 0.4 | 310 | 98 | 13.42 |
| 5 | | 0.0625 | 741 | 134.2 | 14.5 |
| 6 | | 0.09 | 710 | 128.4 | 14.9 |
| 7 | 0.141 | 0.0025 | 122 | 114.1 | 12.52 |
| 8 | | 0.01 | 115 | 115.8 | 12.72 |
| 9 | | 0.0225 | 117 | 117 | 12.54 |
| 10 | | 0.4 | 119 | 120.4 | 12.59 |
| 11 | | 0.0625 | 140 | 129 | 12.64 |
| 12 | | 0.09 | --- | --- | --- |
| 13 | 0.2 | 0.0025 | 63 | 127.7 | 13.19 |
| 14 | | 0.01 | 60 | 123.4 | 12.45 |
| 15 | | 0.0225 | 58 | 106 | 12.37 |
| 16 | | 0.4 | 65 | 130.2 | 12.86 |
| 17 | | 0.0625 | 70 | 143.2 | 15.03 |
| 18 | | 0.09 | 78.3 | 156 | 15.6 |

# 7. Input For Simulation

## Mass loss rate:

- The burning rate is based on a continuous mass measurement from the beginning to the end of the fire.

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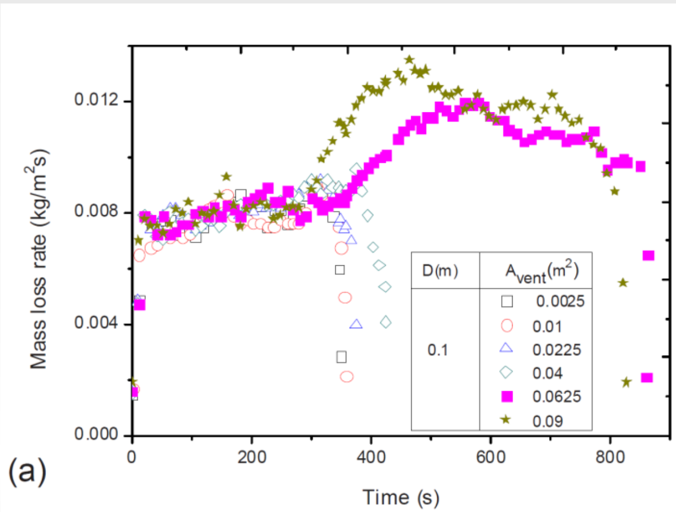
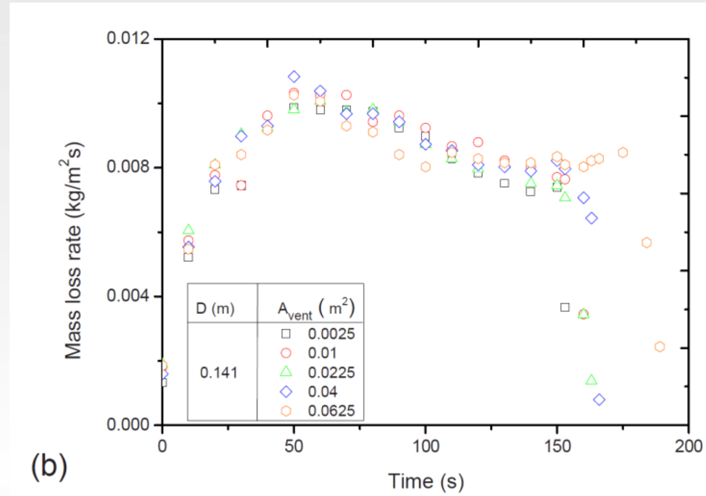
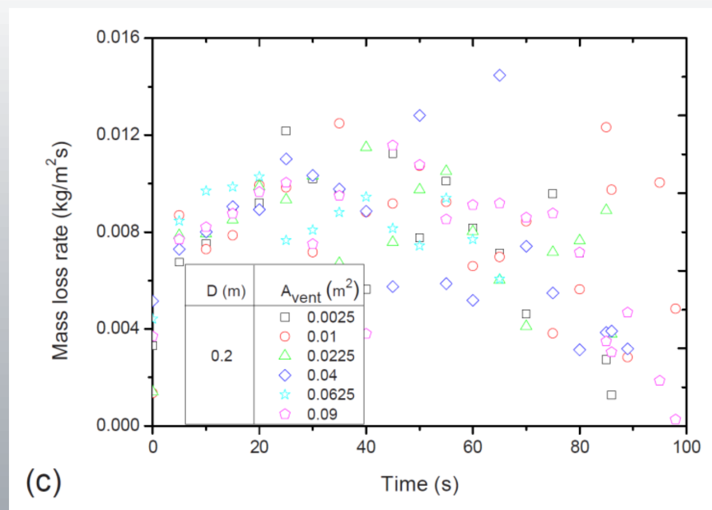
- The vent size has a very small influence on the mass loss rate of pool fires in the oxygen-controlled region.

- The mass loss rate does not change too much for three different sizes of pool fires.

# 7. Input For Simulation

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# 8. Results

## Extinction behavior:

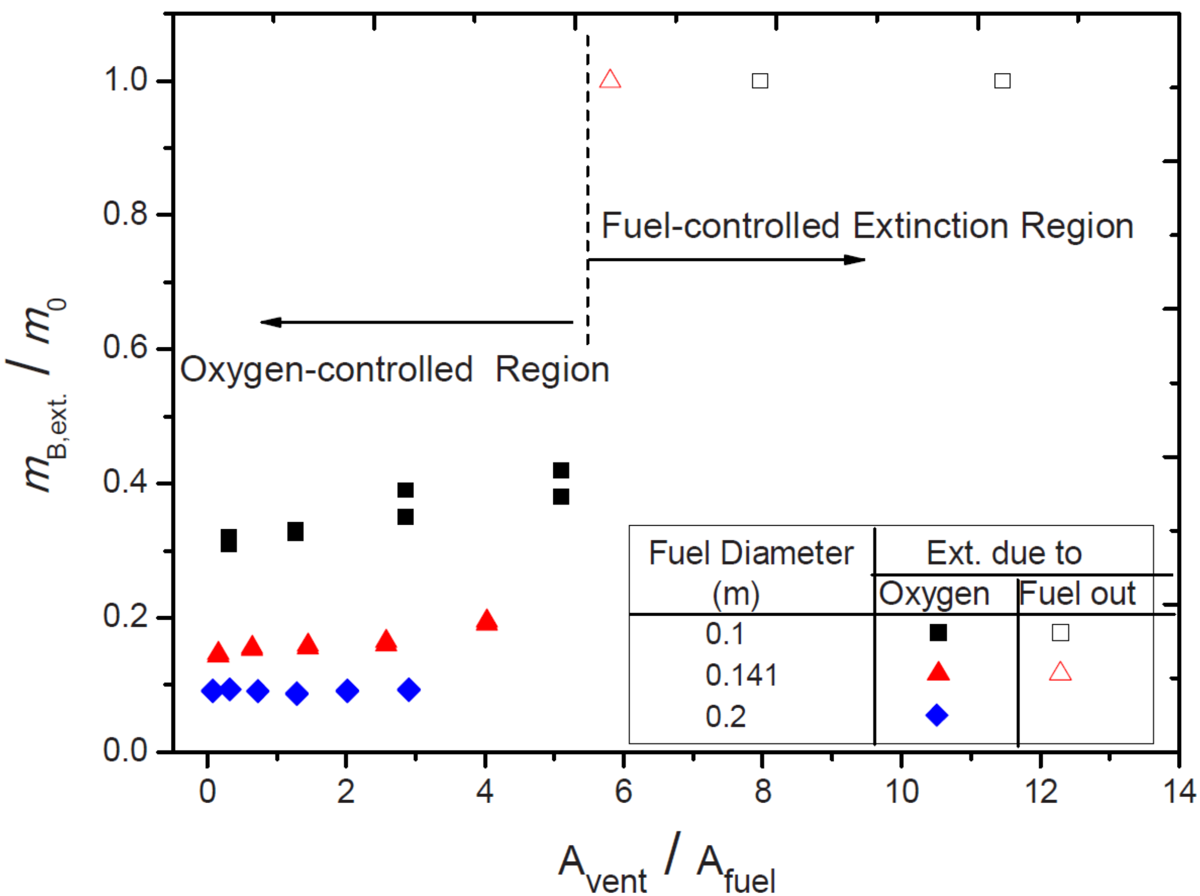
Fuel mass consumption rate is defined as the ratio of the total mass loss at extinction ( $m_{ext.}$ ) to initial fuel mass ( $m_0$ ).

Flame extinction behavior was recognized as two distinctive regimes:

**(I)** oxygen-controlled extinction regime where the flame self-extinction because of oxygen starvation

**(ii)** fuel controlled extinction regime where the combustion lasted until the fuel was completely exhausted.

# 8. Results

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# 8. Results

## Gas Temperature Profile:

**Oscillating flame**

Flame was shrinking to extinction at the rim of the vessel, but came back to the fuel surface and formed an attached flame again.

**Ghosting Flame**

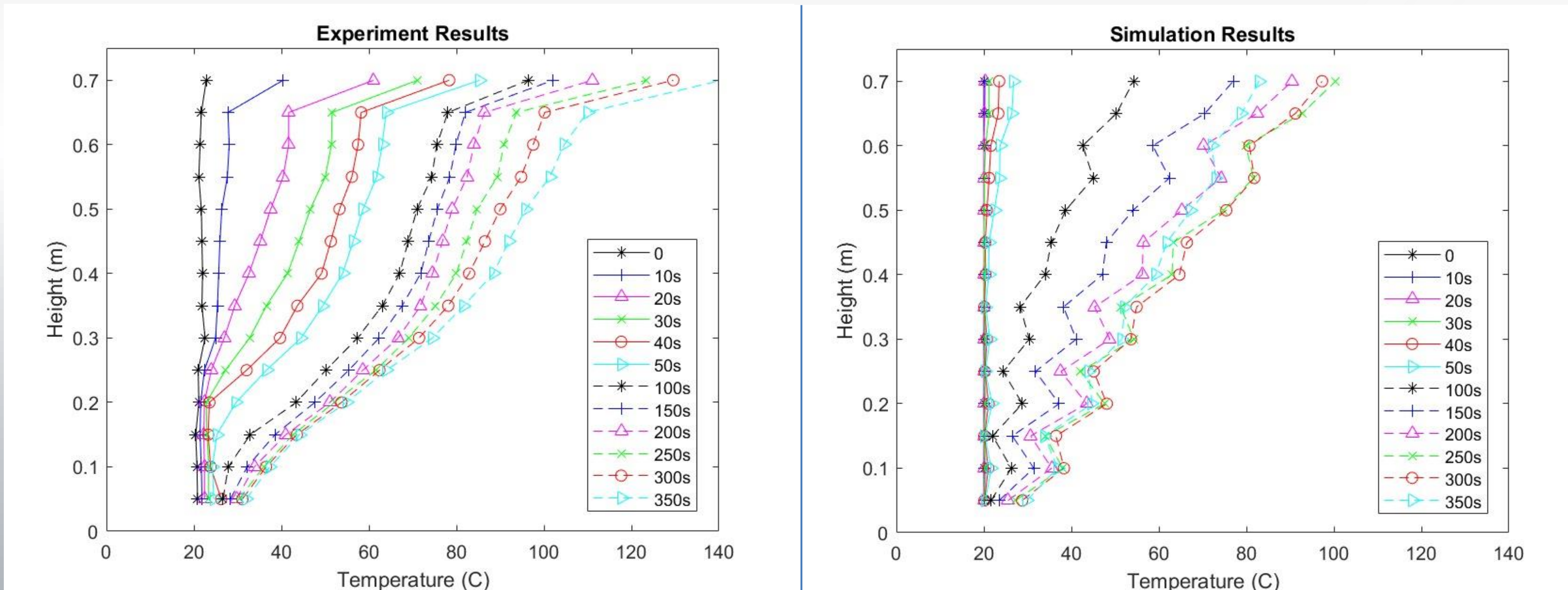
Flame began to detach partly from the circular pan edge and propagated from the vessel to the surrounding.

The temperature does not increase or decrease very much when the oscillation and the ghosting flame appear.

# 8. Results

- The gas temperature increases with time and reaches its peak before the flame extinction. The reason is that the fire heat release rate decreases as the fire decays.

- D = 0.1m and vent area = 0.0225 m2



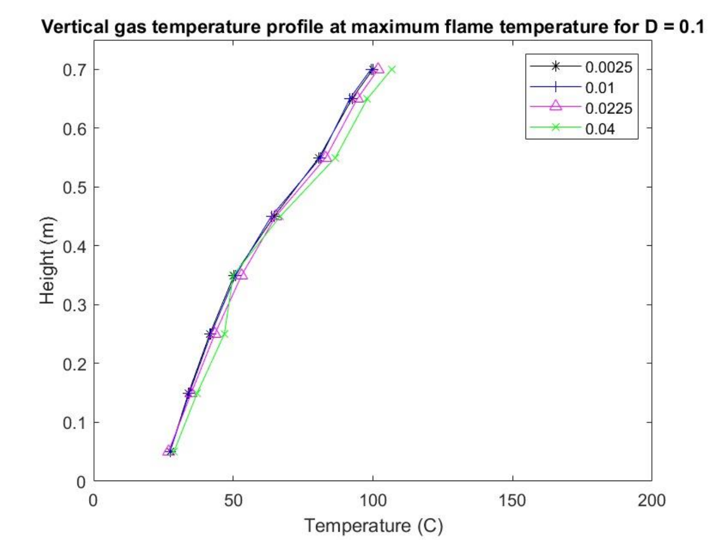
# 8. Results

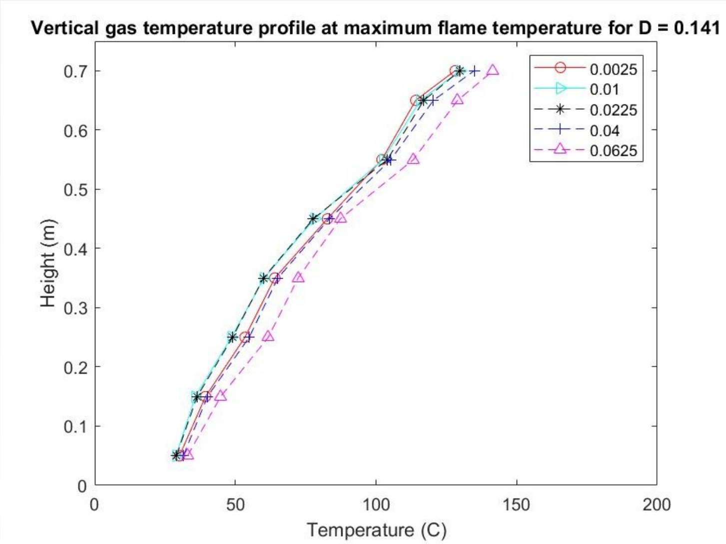
- For the fires in oxygen-controlled region, the gas temperature changes slightly, while it tends to increase as the vent size increase to the fuel-controlled region.
- Hot gas temperature also increases as the pan size becomes larger.
- For experiments, the ratio of time to reach peak temperature and the fire duration was estimated between 0.75 to 0.9.
- For simulations, it was mostly around 0.92 to 0.98 for D=0.1 and D = 0.141

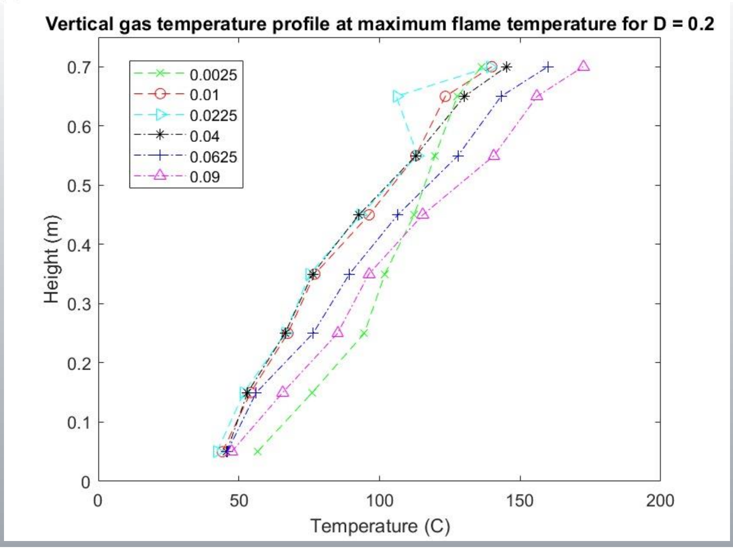
# 8. Results

| Case No | Pan diameter | Vent area | Fire Duration | Hot gas Temp (simulation) | Hot gas Temp (experiment) |
|---|---|---|---|---|---|
| | (m) | (m2) | (s) | (C) | (C) |
| 1 | 0.1 | 0.0025 | 275 | 92.5 | 104.7 |
| 2 | | 0.01 | 275 | 91.7 | 107.2 |
| 3 | | 0.0225 | 285 | 94.4 | 106.8 |
| 4 | | 0.4 | 310 | 98 | 102.4 |
| 5 | | 0.0625 | 741 | 134.2 | 105.8 |
| 6 | | 0.09 | 710 | 128.4 | 110.1 |
| 7 | 0.141 | 0.0025 | 122 | 114.1 | 141.2 |
| 8 | | 0.01 | 115 | 115.8 | 144.1 |
| 9 | | 0.0225 | 117 | 117 | 134.9 |
| 10 | | 0.4 | 119 | 120.4 | 141.6 |
| 11 | | 0.0625 | 140 | 129 | 141.2 |
| 12 | | 0.09 | --- | --- | 163.6 |
| 13 | 0.2 | 0.0025 | 63 | 127.7 | 188.6 |
| 14 | | 0.01 | 60 | 123.4 | 184 |
| 15 | | 0.0225 | 58 | 106 | 191.1 |
| 16 | | 0.4 | 65 | 130.2 | 185.2 |
| 17 | | 0.0625 | 70 | 143.2 | 188.3 |
| 18 | | 0.09 | 78.3 | 156 | 189.9 |

# 8. Results

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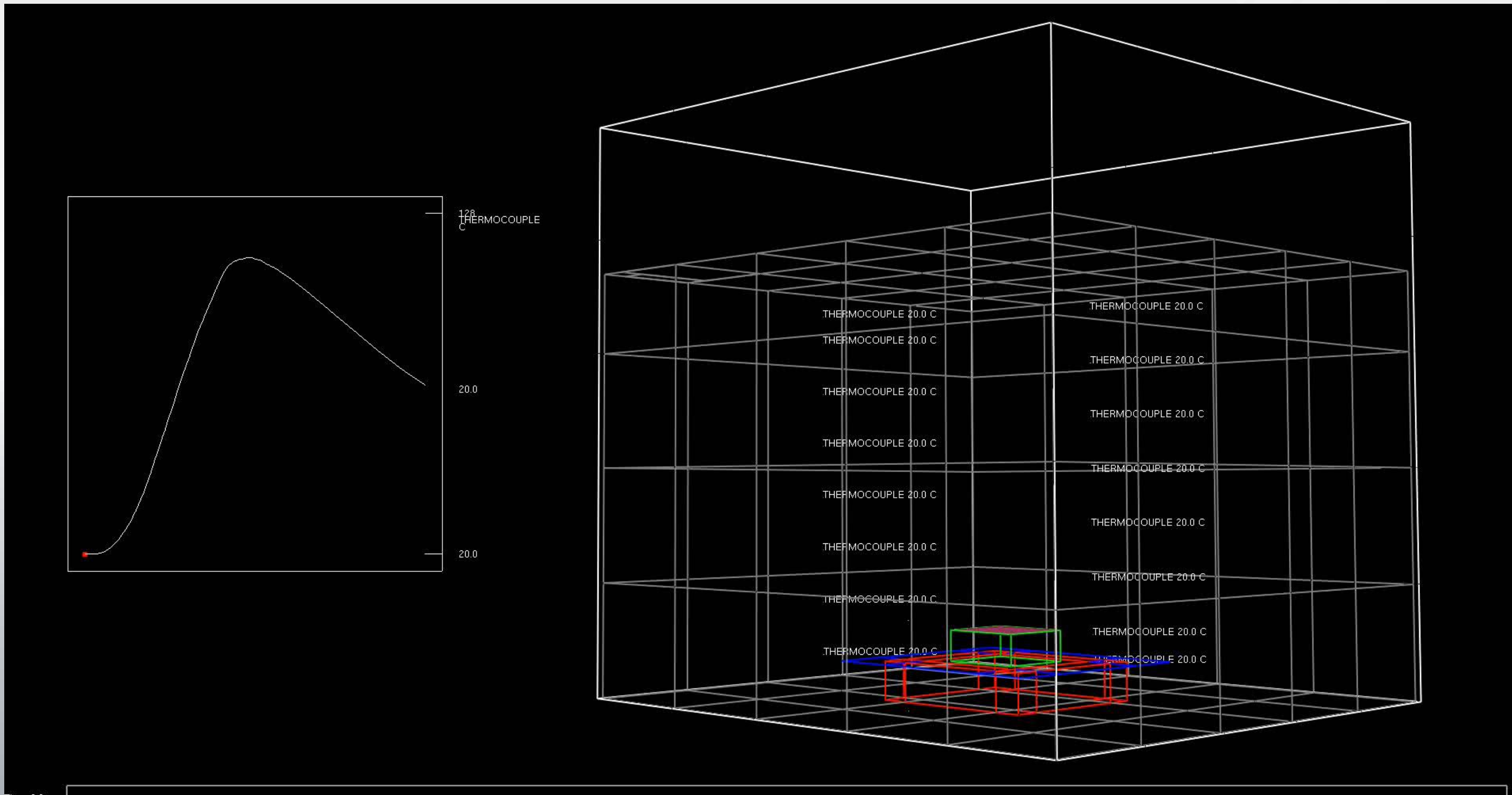
# 8. Results

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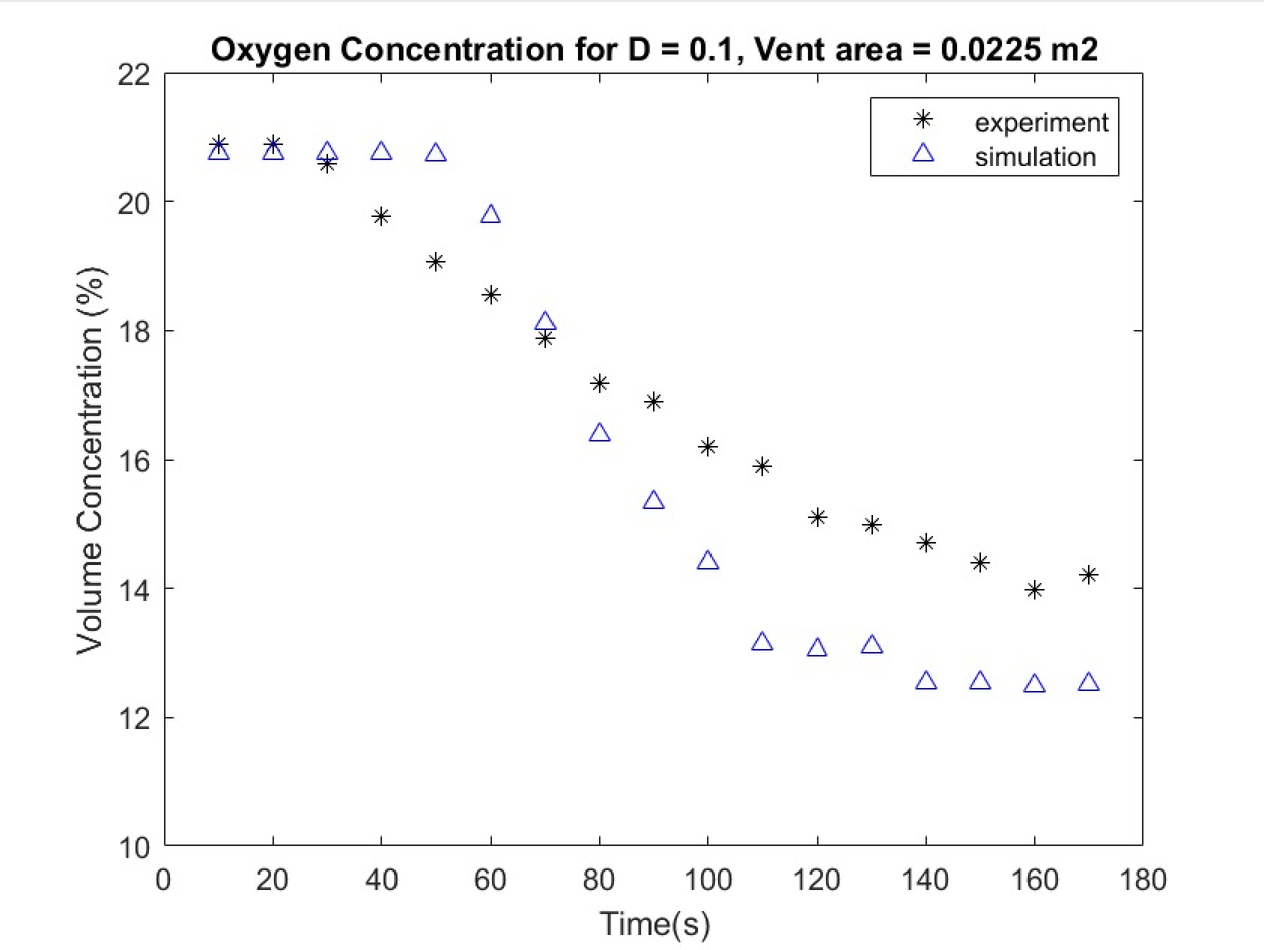
# 8. Results

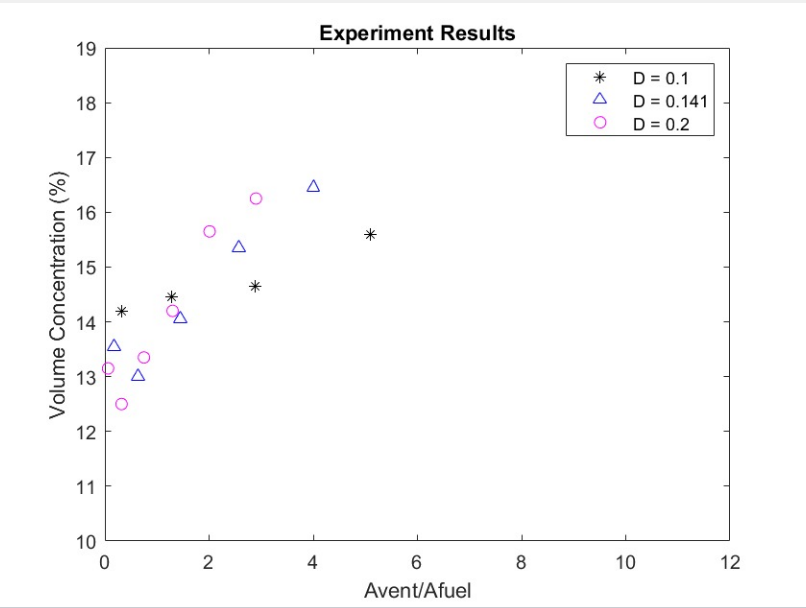
## Oxygen Concentration:

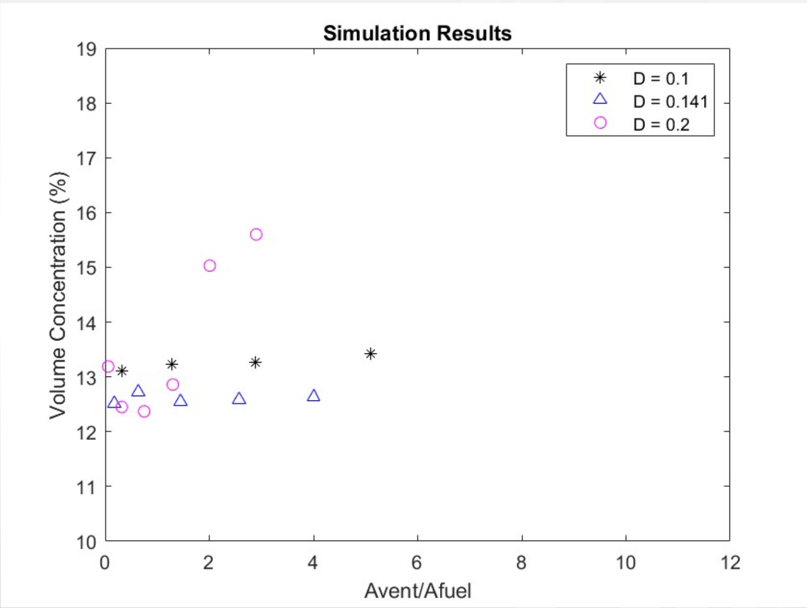
- For the compartment fire tests, the oxygen concentration at the base of the fire is measured to consider the fire behavior.
- In the experiment, oxygen concentration shows that it keeps constant at 20.9 vol.% till about 25 s after ignition and then decreases slowly to 14% when flame extinction occurs.
- The oxygen volume concentration reaches its lowest value before flame extinction.
- Oxygen concentrations increase linearly with the ratio of vent area to the fuel area.

# 8. Results


Oxygen Concentration for D = 0.1, Vent area = 0.0225 m2
experiment
simulation
Volume Concentration (%)
Time(s)
22
20
18
16
14
12
10
0
20
40
60
80
100
120
140
160
180

# 8. Results

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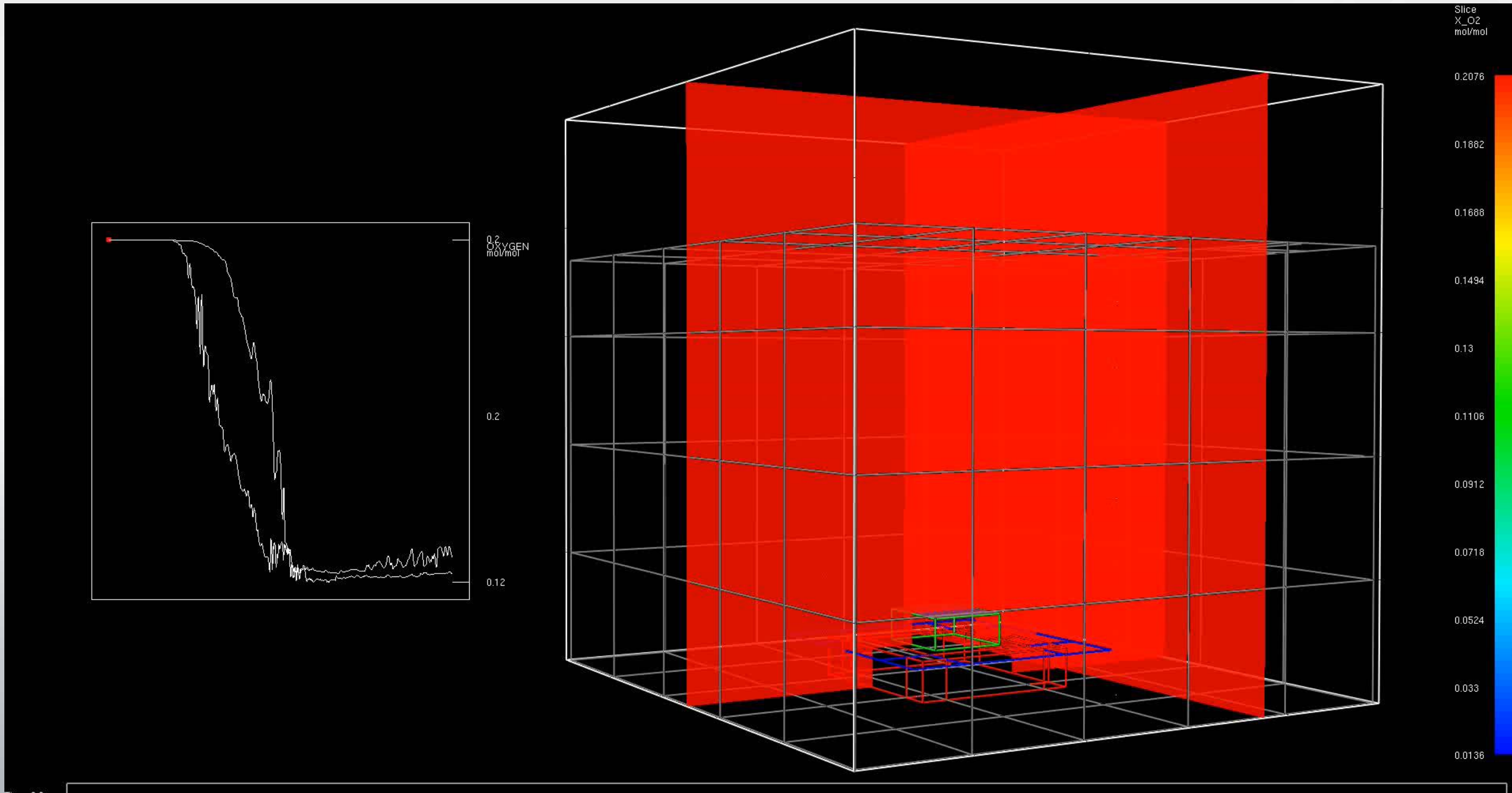
# 8. Results


Slice
X_O2
mol/mol
0.2076
0.1882
0.1688
0.1494
0.13
0.1106
0.0912
0.0718
0.0524
0.033
0.0136
0.2
OXYGEN
mol/mol
0.2
0.12
Time: 0.0

# 8. Results

**Mass loss rate affected by o2 and gas temperature :**

- For the fires in the compartment, we have to consider the two effects of ventilation and external heat feedback from smoke and the compartment wall.

- In general, ventilation has a negative impact on the flame-burning rate, whereas the external heat effect has a positive effect.

- A simplified correlation for predicting the mass loss rate in an under-ventilated
compartment

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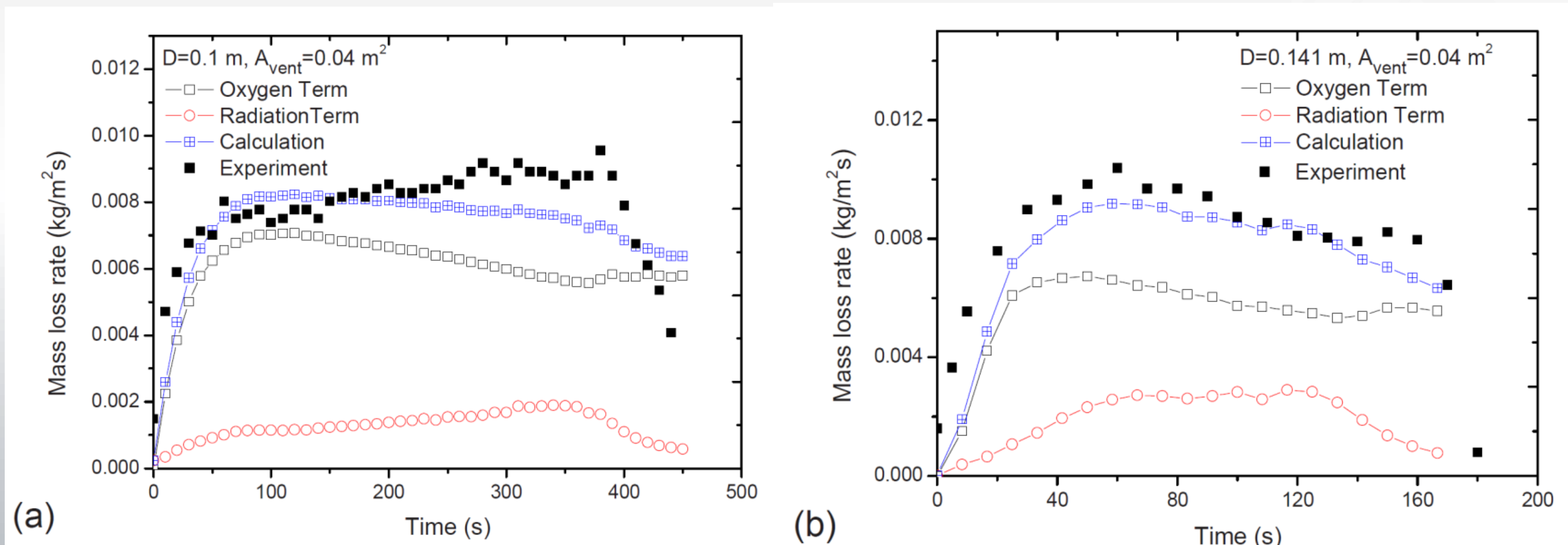
$$\dot{m}''_f = \dot{m}''_{f,\infty}(1-e^{-t/t_s})\left(\frac{Y_{O_2}}{Y_{O_2,\infty}}\right) + \frac{F\sigma(T^4 - T_\infty^4)}{L}$$

# 8. Results

- ➢ The radiation heat has a small influence on mass loss rate in 0.1 m fire because gas temperature is not high. And the radiation term shows a more significant effect in 0.141 m fire due to the higher gas temperature



# 8. Results

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# 9. Conclusion

- The influence of ventilation was tested in heptane pool fires of three different sizes.
- Gas temperature distribution and oxygen concentration at the base of flame were investigated.
- The vertical gas temperature profiles have a similar trend for pool fires in oxygen-controlled region.
- As the vent size increases, the oxygen concentration at the time of extinction becomes higher.

# References


1. Fire Simulation Lecture Notes (Chapter 3: Compartment Fires - https://firedynamics.github.io/LectureFireSimulation/content/modelling/03_compartments/01_fundamentals.html)
2. Bing Chen, ShouXiang lu, Changhai Li, and Man Yuan. "Anaylsis of Compartment fires with a ceiling vent". In: Procedia engineering 62(Dec. 2013). DOI: 10.1016/j.proeng.2013.08.063
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