Fires in Enclosures: a Comparison of Experimental Results with two Computational Fluid Dynamics Codes

by: ***G. Ferrara, M. D'Amico, S. Ditali***

Health, Safety & Environment – Design

Snamprogetti SpA, S. Donato Milanese (MI) - Italy

Refinery and gas plants;
chemical, petrochemical, and fertilizer plants;
onshore and offshore pipeline systems;
infrastructures; power and environmental plants .

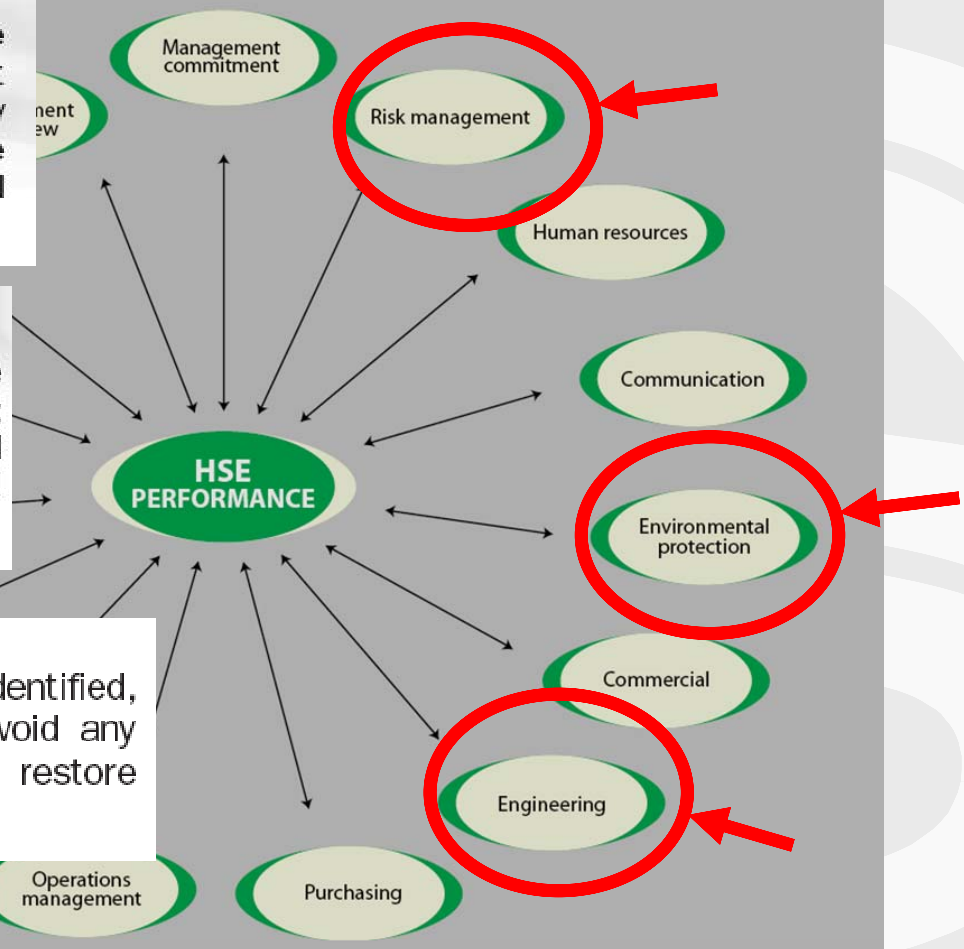
Snamprogetti S.p.A. formerly operated as a subsidiary of the Eni S.p.A.
As of March 27, 2006, Snamprogetti SpA is a subsidiary of Saipem SpA.

HSE-D department

Engineering
All facilities, plants and equipment are engineered in compliance with the best international HSE requirements, statutory legislation and that all risks associated with the final operation of the facilities, plants and equipment are suitably addressed.

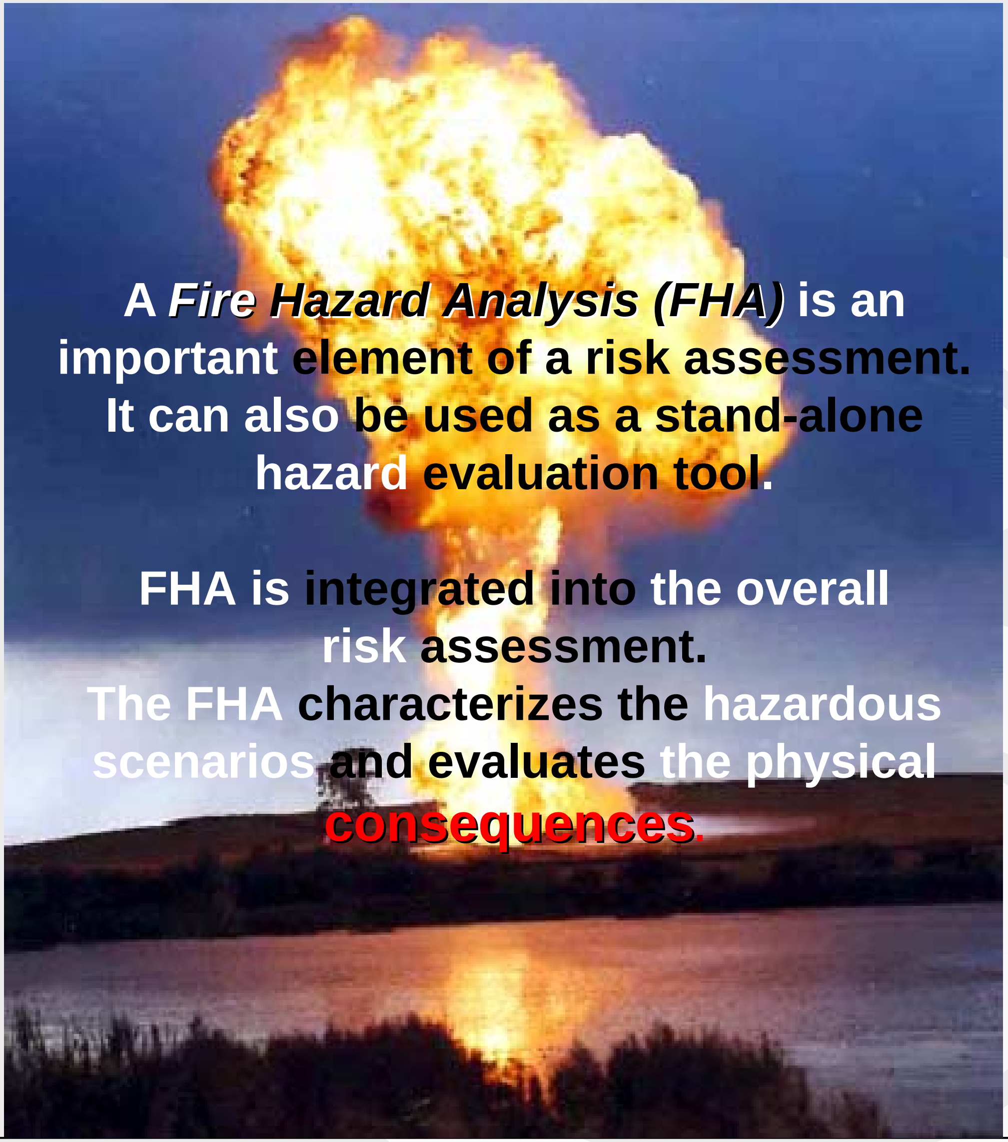
Risk Management
All hazardous operations and conditions are identified, the risks assessed and controlled; the relevant mitigation measures implemented throughout the activities in order to prevent all accidents and occupational diseases.

Environmental Protection
All potential environmental impacts are identified, evaluated and actions are taken to avoid any damage to the environment and to restore original conditions.



"For the thirty-year period of 1970 through 1999, in the hydrocarbon and petrochemical onshore industries ALL OVER THE WORLD, 116 fires resulted in large scale property damage (greater than $10MM) totaling over 4.5 billion dollars. This is an average of approximately 39 million US dollars per occurrence, and include losses in refineries, petrochemical plants, gas plants, marine terminals, and offshore oil and ags operations. Consequential business losses are two to three times property damage losses. Incidentes reinforce the importance of utilizing a systematic approach for addressing fire hazards in the hydrocarbon and petrochemical industries."

Center for Chemical Process Safety, 2003



The FHA accomplishes three objectives:

- Provides an understanding of the hazards
- Enables the specification of performance-based fire protection
- Forms part of an overall risk assessment

Prescriptive fire protection is standardized guidance or requirements without recognition of site-specific factors. Prescriptive approaches are a result of compliance with regulations, insurance requirements, industry practice or company procedures.

Performance-based design adopts an objective-based approach to provide a desired level of fire protection. The performance-based approach presents a more specific prediction of potential fire hazards for a given system or process. The FHA supports solutions for the performance-based design.

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The best practice tools for the FHA are available as state of the art reviews that cover the engineered solutions for fire safety problems one such an example being the SFPE Handbook.

Many of the proposed tools are in the form of empirical correlations and simplified computer models. While these tools are valuable as they allow a rapid assessment of the fire scenario quickly yielding a value for the variables of interest, they are heavily limited from the experimental conditions and the simplifying assumptions.

Computational Fluid Dynamics (CFD) models are in principle able to deal with complex geometries allowing to take into account case- and site-specific details.

Among the tools currently available at the HSE-D department of Snamprogetti for the FHA are two CFD codes:

KFX is a 3D, transient, Finite Volume CFD code:

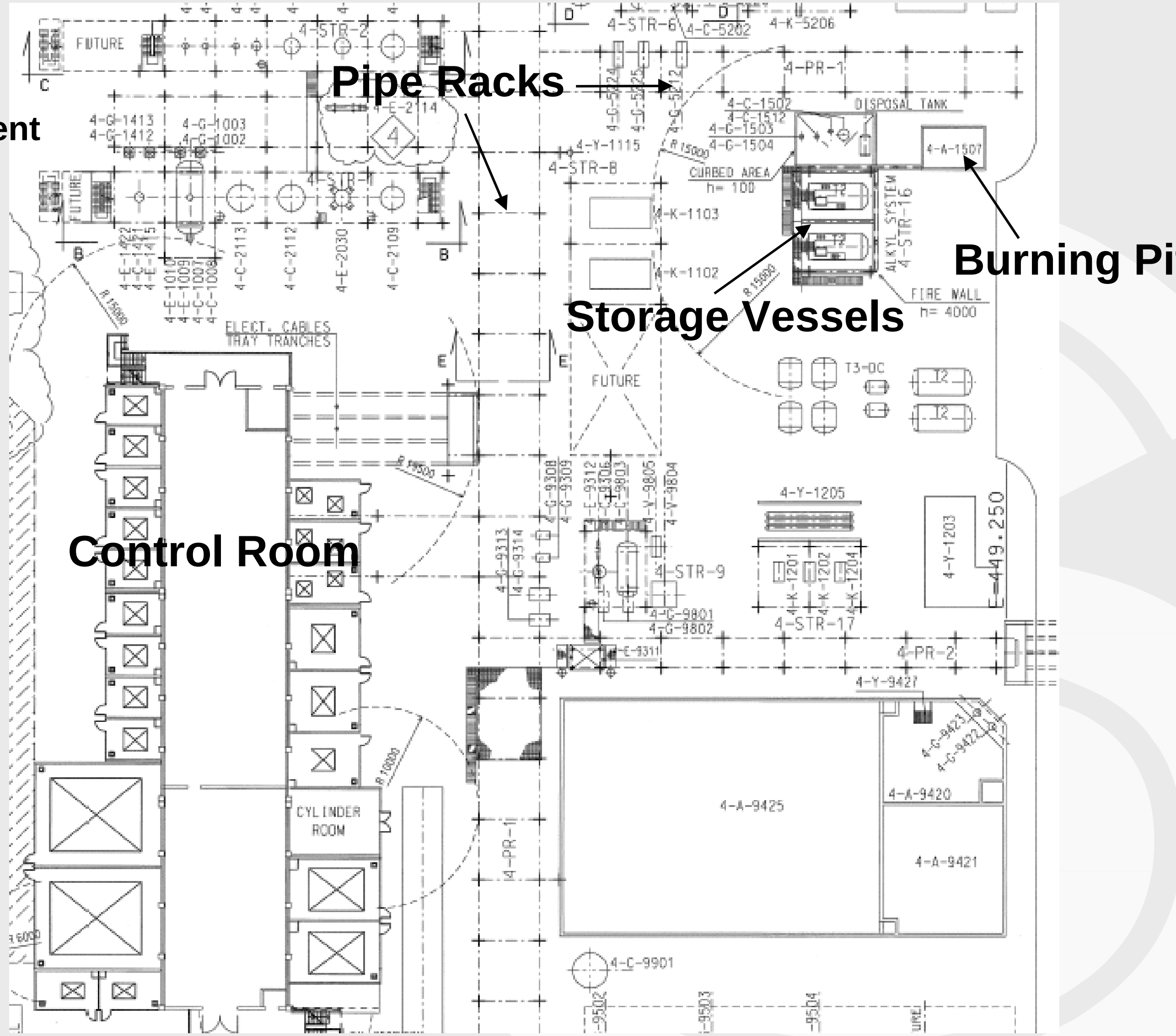
- Reynolds Averaged Navier Stokes (RANS) approach;
- k-ε model for turbulence
- Eddy Dissipation Model for turbulent combustion;
- Eddy Dissipation Soot Model for soot concentration prediction;
- Discrete Transfer Model for radiative heat transfer;
- Lagrangian two-phase spray modelling of water systems for fire suppression.
- CAD and GIS import capability for modelling complex geometries

FDS is a 3D, transient, Finite Volume CFD code:

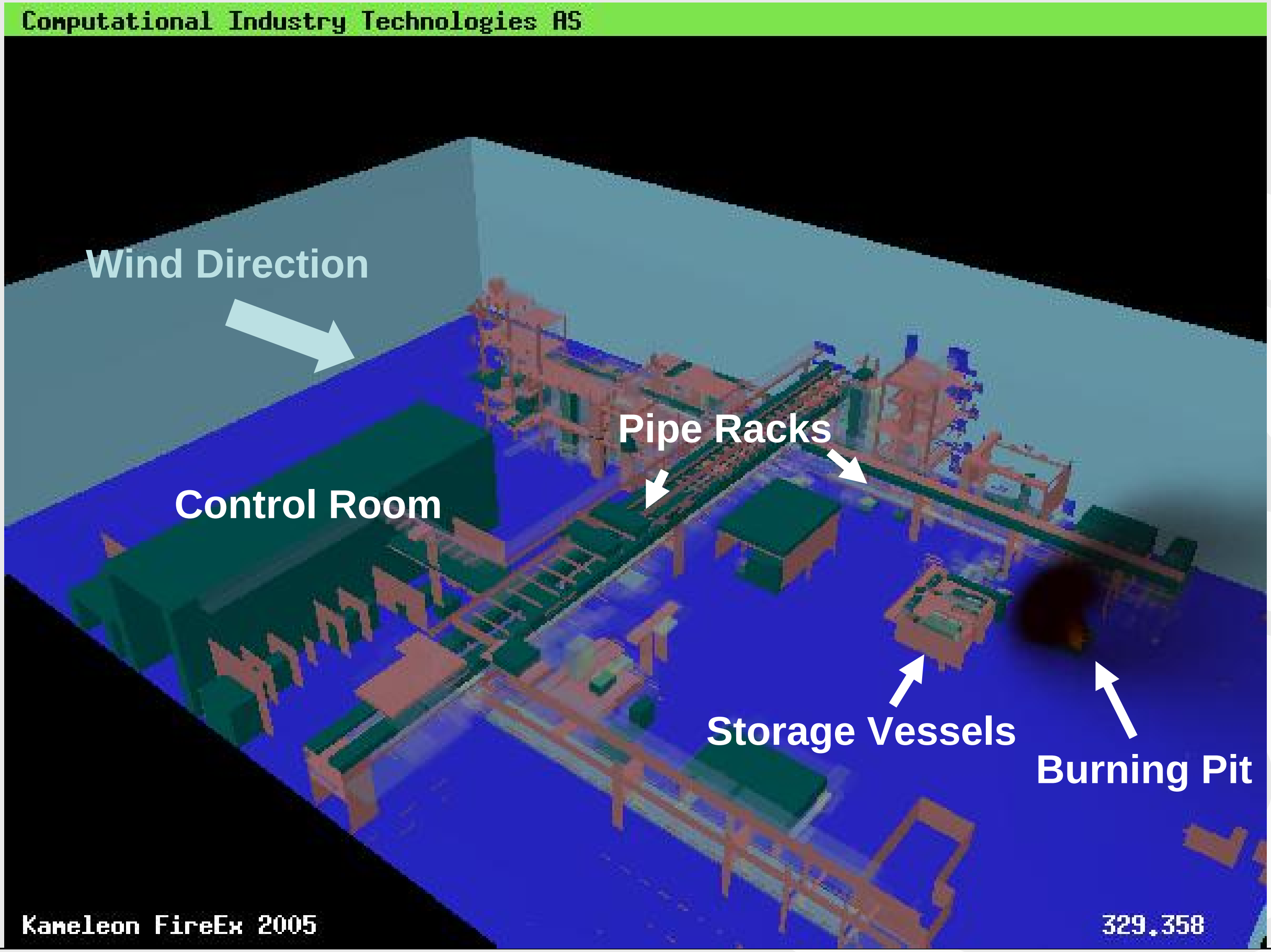
- Large Eddy Simulation (LES) approach
- Smagorinsky model for the eddy viscosity
- Mixture Fraction Model for combustion;
- Solid combustion (pyrolysis) modelling
- Discrete Transfer Model for radiative heat transfer;
- Lagrangian two-phase spray modelling of water systems for fire suppression.
- CAD import capability for modelling complex geometries.

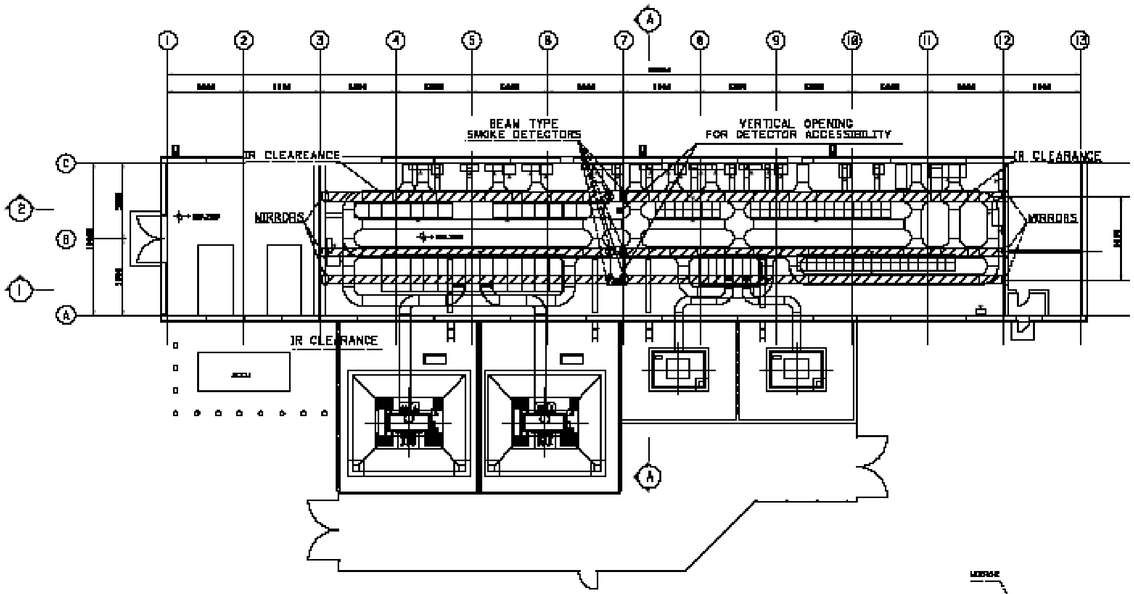
Some few flash examples of how Snamprogetti HSE-D department has used KFX and FDS where traditional models were likely to fail for the complexity of the scenarios under investigation.

(1) Evaluation of the impact on the surrounding structures of a fire issuing from a burning pit in a very congested area of a chemical plant; (plot plan)



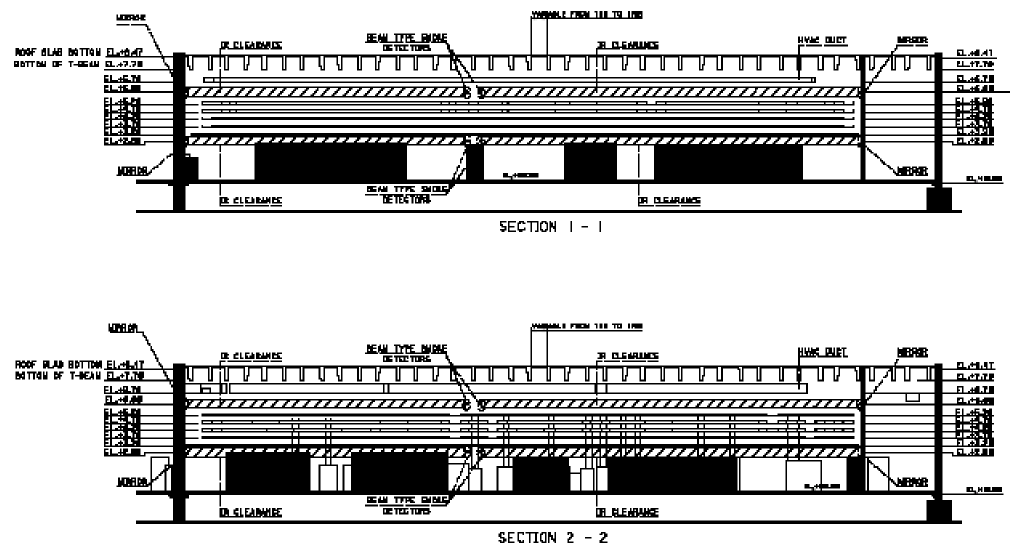
And the same scenario translated into a numerical geometry (next slide):


Computational Industry Technologies AS
Wind Direction
Control Room
Pipe Racks
Storage Vessels
Burning Pit
Kameleon FireEx 2005
329.358

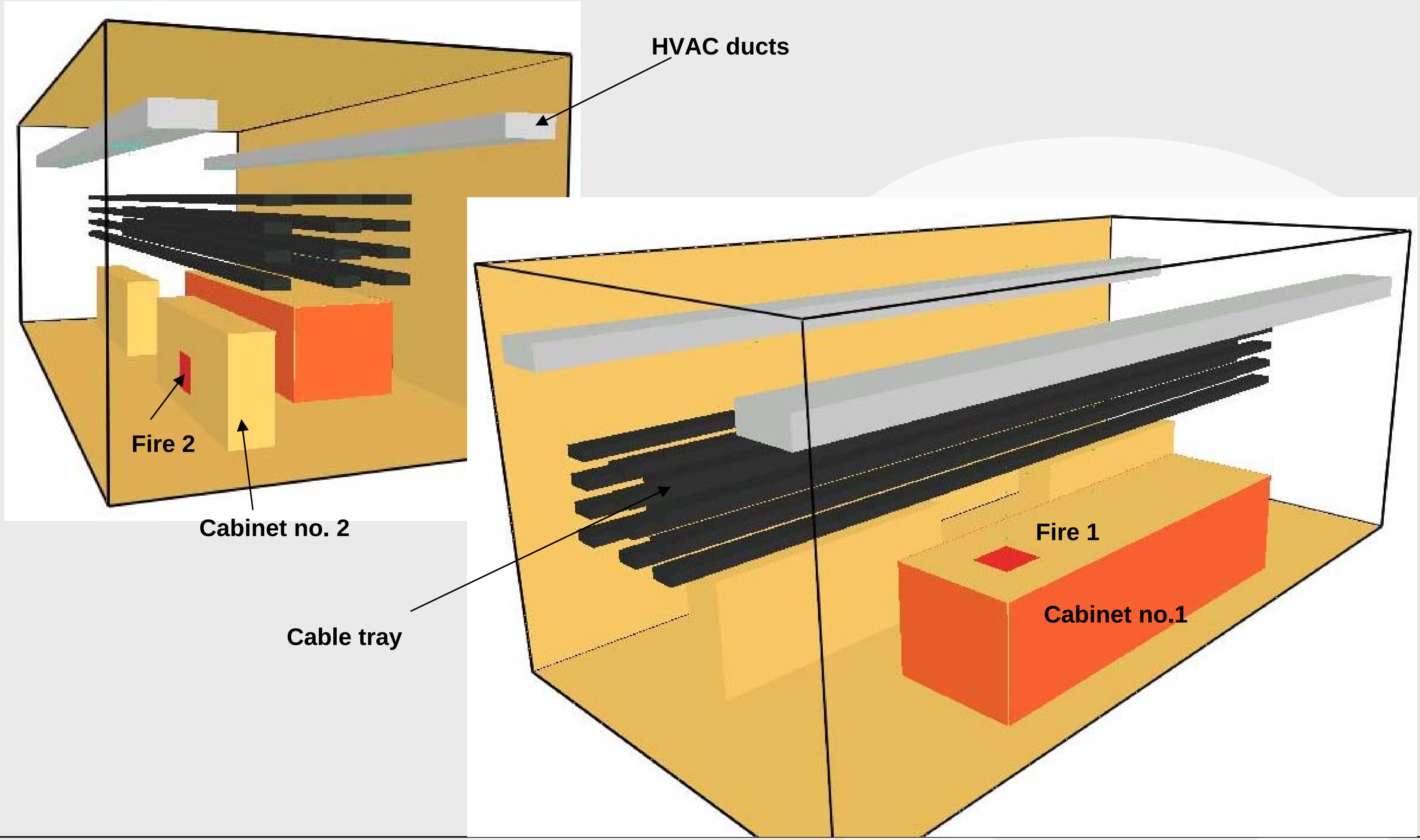


Plot plan and side views of the electrical substation

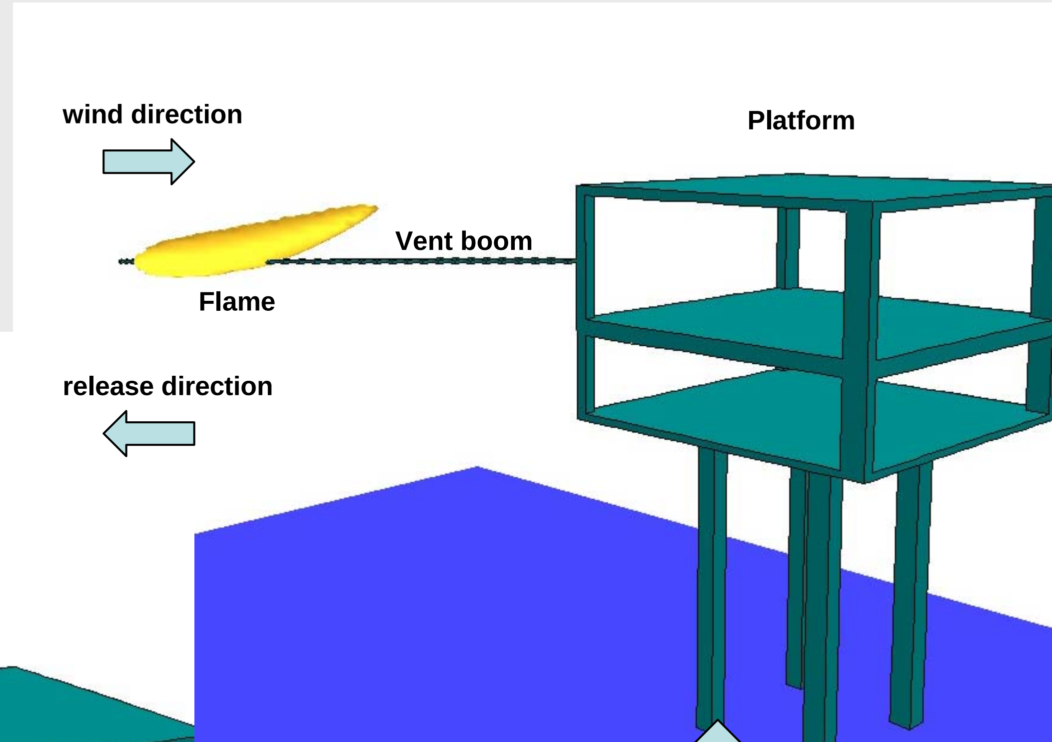
And the same scenario translated into a numerical geometry (next slide):

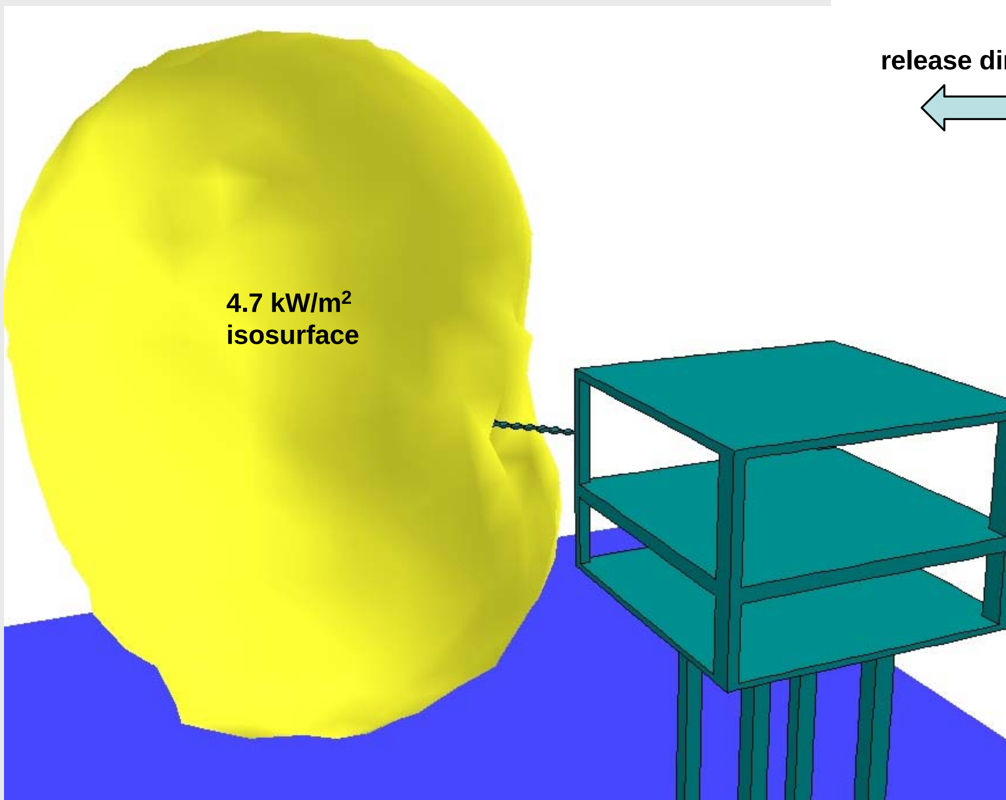


(2) Evaluation of the smoke flow pattern in an electrical substation as a consequence of accidental fires in the cabinets. Traditional correlations are deemed to be inadequate due to the complexity of the geometry and the presence of the HVAC system inducing forced flow patterns.


HVAC ducts
Fire 2
Cabinet no. 2
Cable tray
Fire 1
Cabinet no.1

(3) Evaluation of the heat radiation impact on an offshore platform as a consequence of an emergency release. The wind is assumed to blow in the opposite direction of the release. Traditional models only account for cross wind angles such that: $0 \leqslant \theta \leqslant 90^\circ$ (so they not allow for $\theta=180^\circ$).



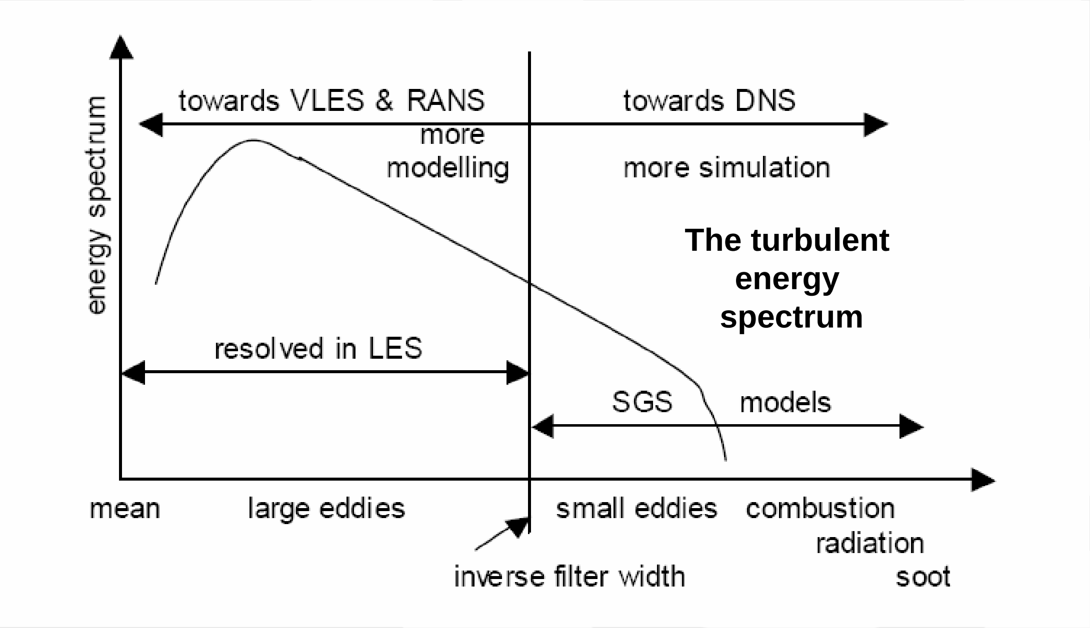


The computed flame and related heat radiation

The Large Eddy Simulation (LES) approach attempts the description of the largest turbulent vortices.

The LES approach is deemed to be more successful than the RANS approach for the following reasons:

- **No averaging of the equations is accomplished in the LES approach thus preserving the instantaneous meaning of the computed quantities.**
- **Since the largest turbulent eddies are the most energetic, the resolved structures are likely to influence the flow more than the smallest unresolved structures.**
- **Since the smallest structures of the flow are less influenced by the macroscopic boundary conditions of the flow, they are deemed to be more universal and then more viable to be successfully described by sub-models.**

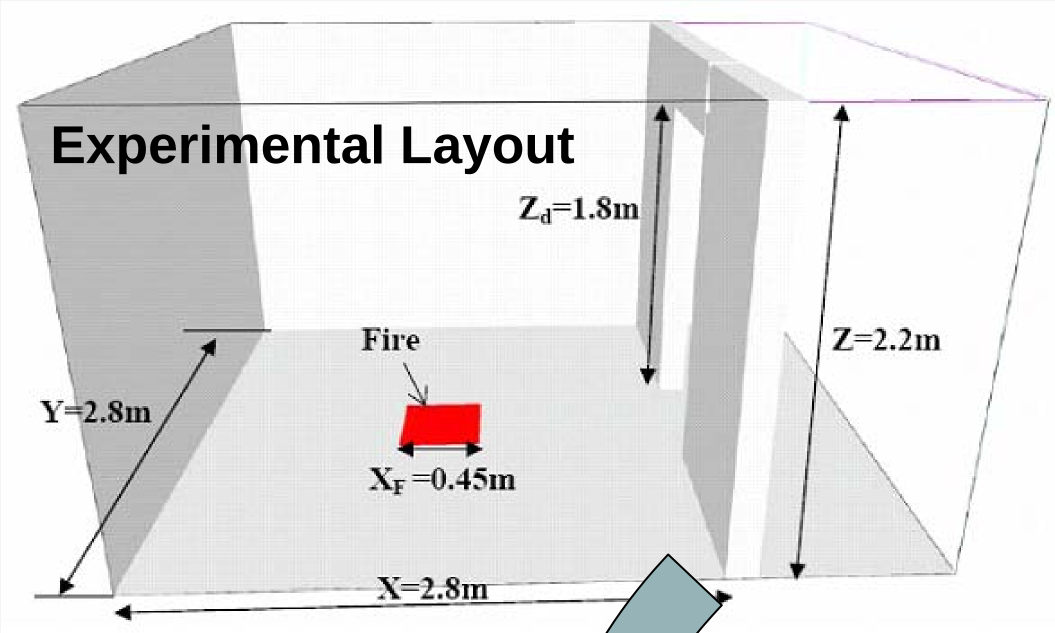


AIM OF THE WORK

- **Verify the stronger LES potential with respect to RANS assessing its capability by comparison with experimental data also in scenarios where the RANS approach have proved effective.**

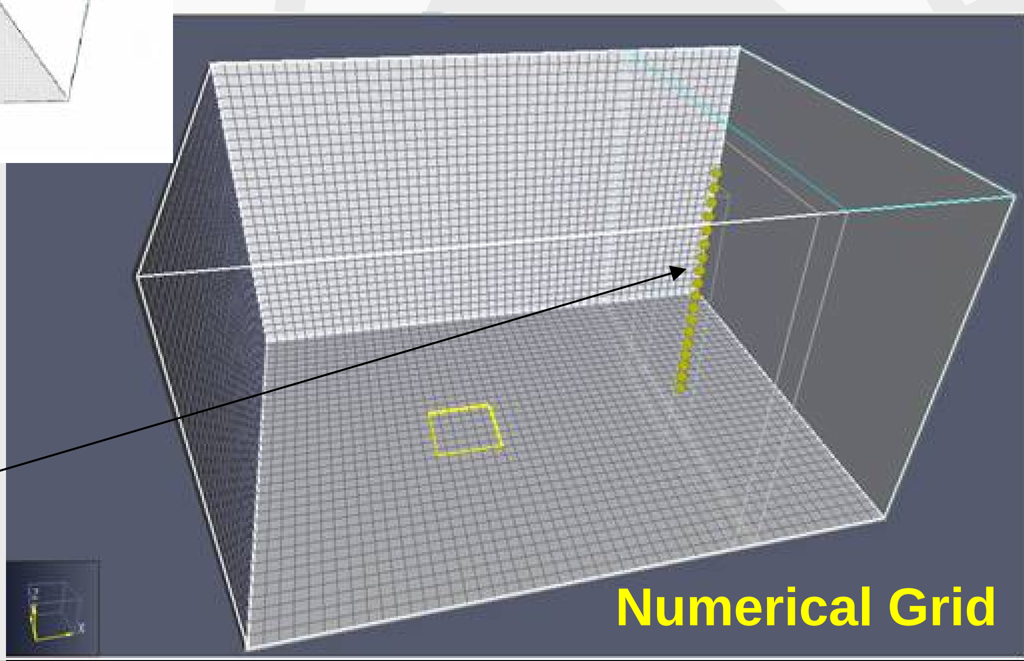
- **To assess whether it is possible to obtain (from LES) predictive accuracy without incurring in unacceptable computational costs.**

To this aim, numerical predictions of the FDS and KFX codes have been compared against experimental data collected for some well characterized enclosed fire configurations.



H. Xue, J. C. Ho, Y. M. Cheng (2001)

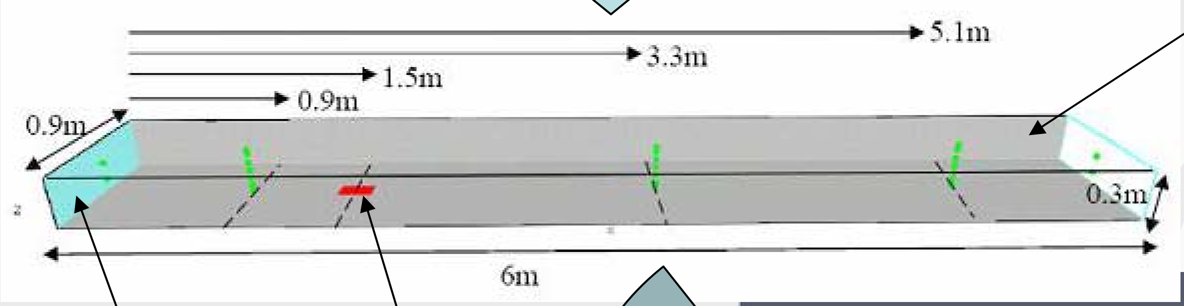
Fire characterization:
D_F=0.45m;
HRR=62.9 kW/m^2



Measuring probes are positioned along the vertical centerline of the door.

H. Xue, T.C. Chew, K. L. Tay and Y. M. Cheng (2000)

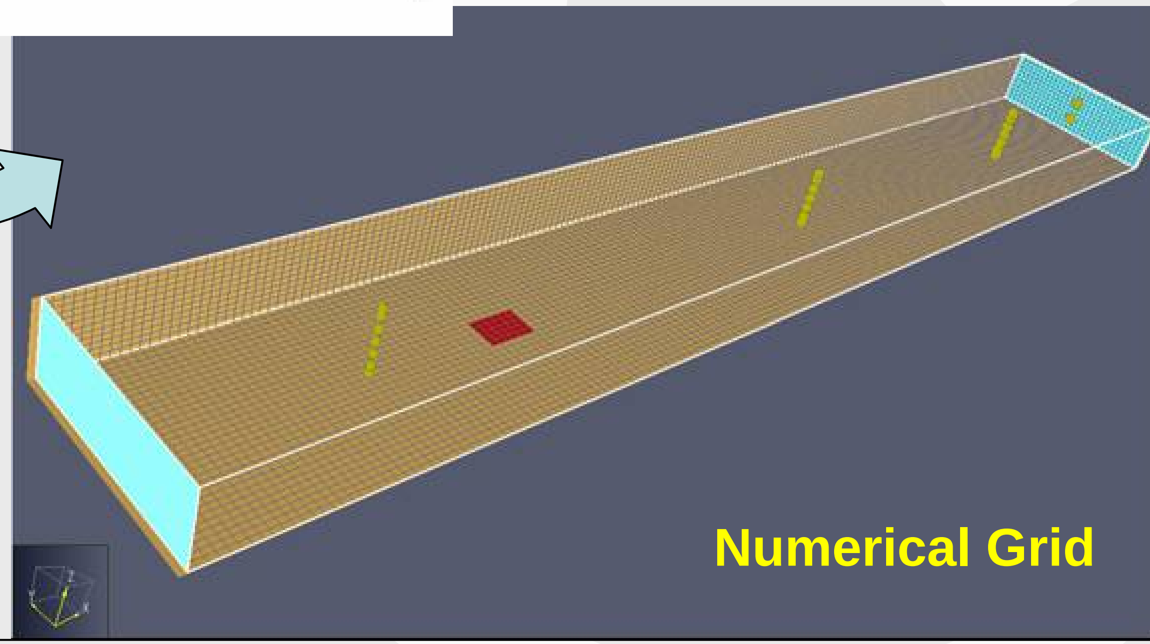
Experimental Layout

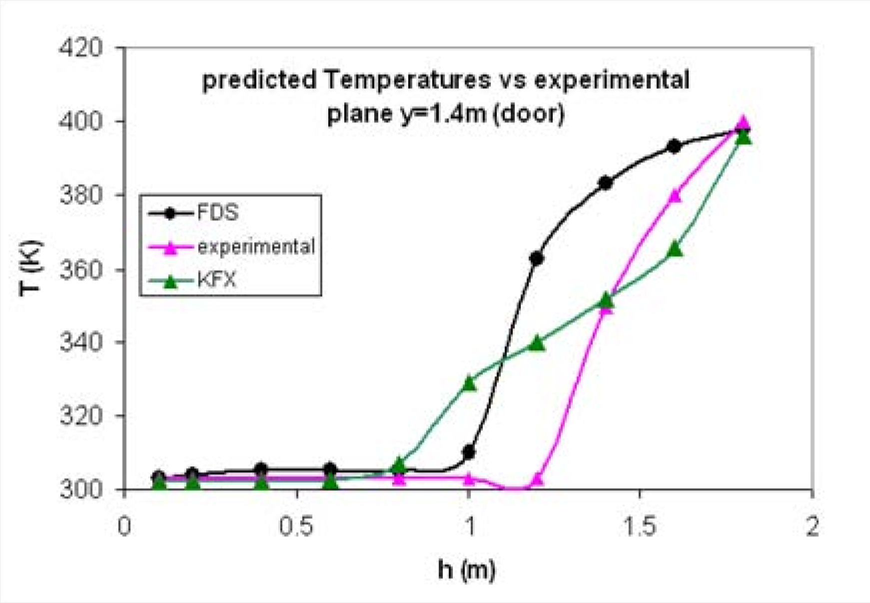


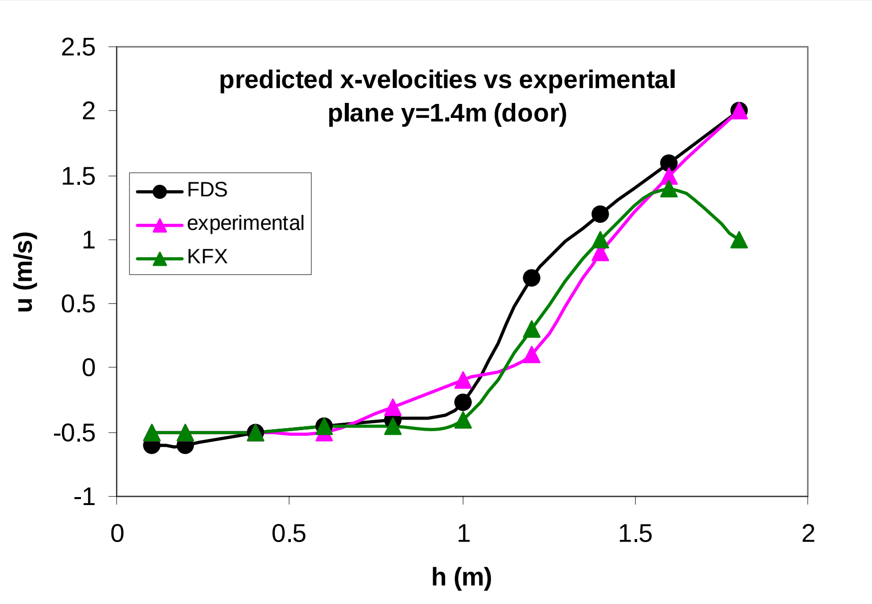
Wall properties
material: Perspex:
c_p=1.45 kJ kg^{-1}K^{-1}
k=0.189 (W m^{-1} K^{-1})
ρ=1170 (kg m^{-3})

Inlet:
u_{air}=0.13 (m/s)

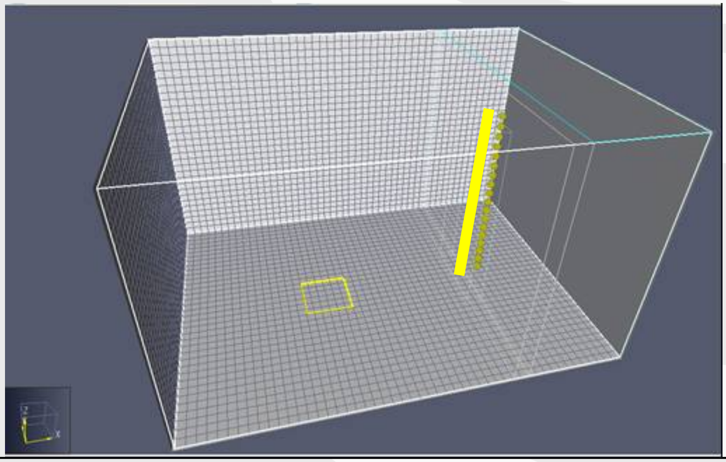
Fire characterization:
A_F=0.18x0.15m^2;
HRR=117 kW/m^2

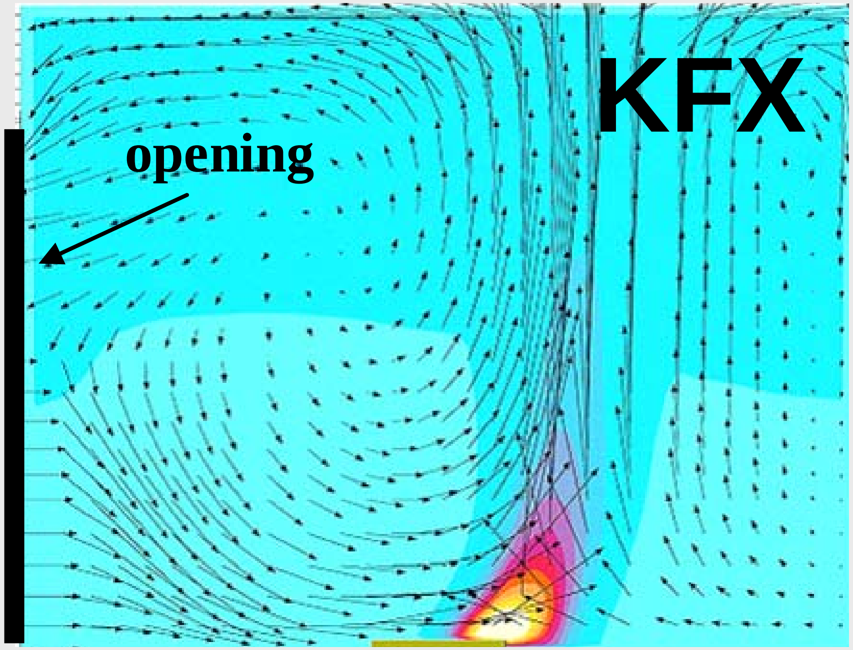


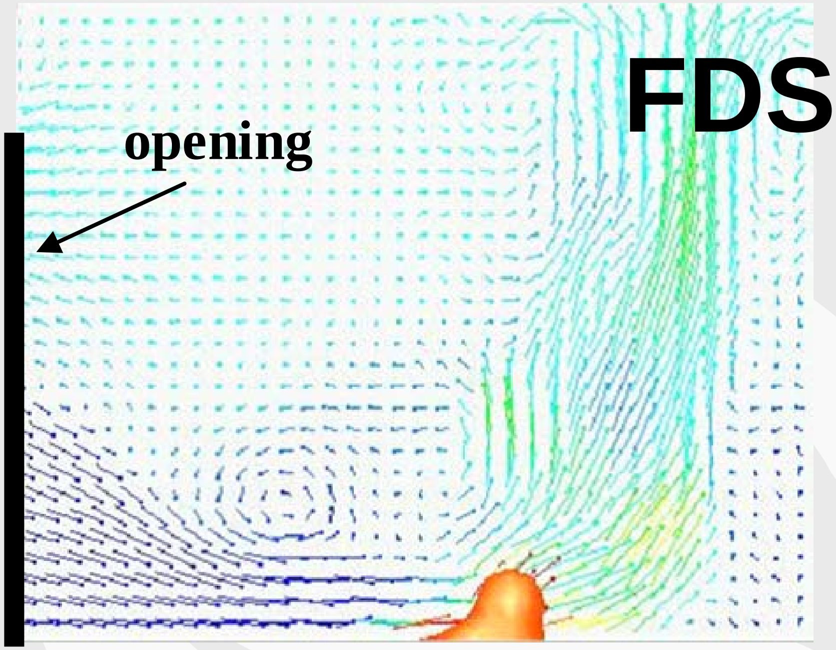




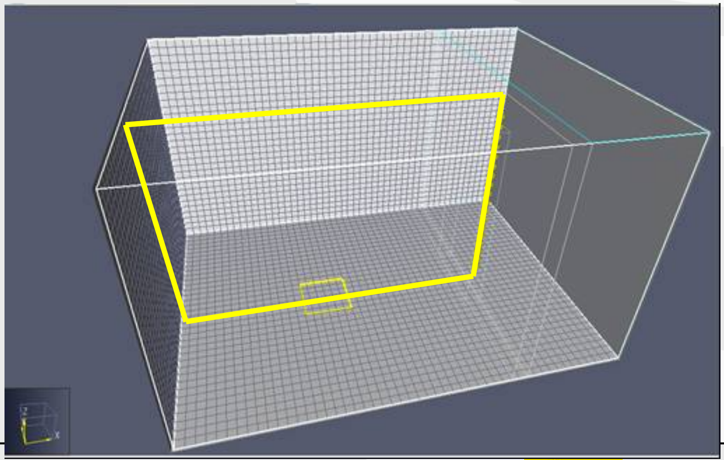
Comparison between calculated and experimental flow velocities and temperatures. The comparison is carried out along the displayed vertical array (centerline of the door)



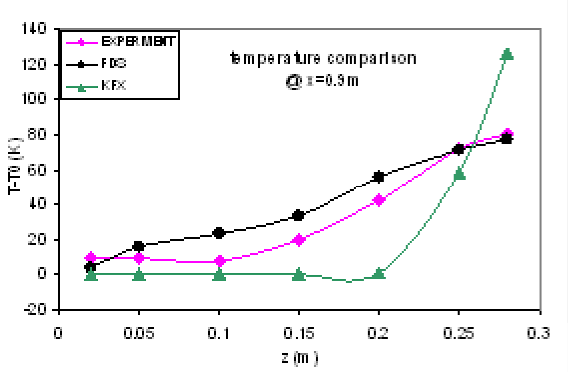


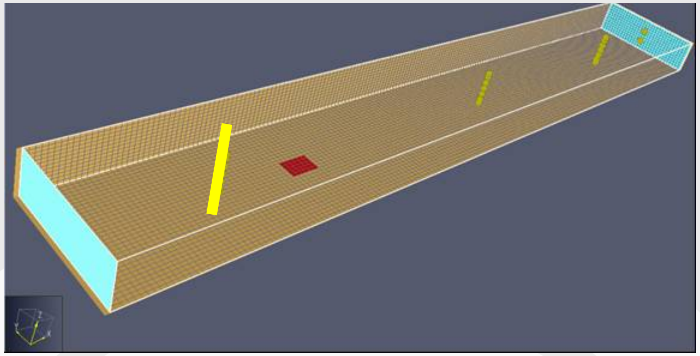


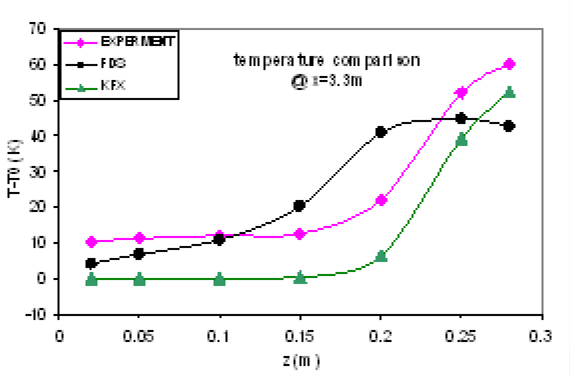
Comparison between the calculated flow fields (KFX and FDS)
The comparison is carried out on the displayed vertical plane (symmetry plane of the room)

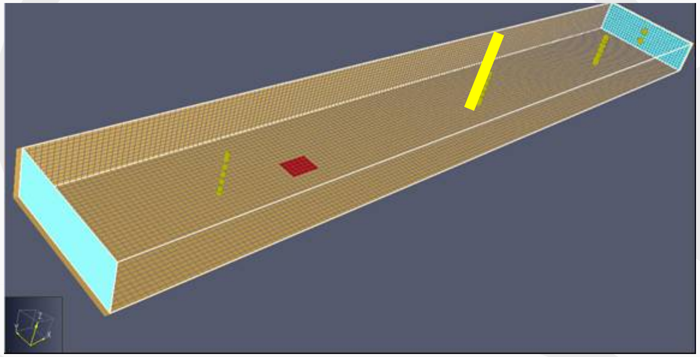


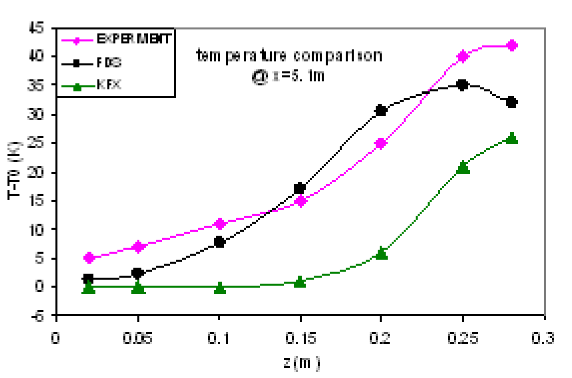
Comparison between calculated and experimental temperatures. The comparison is carried out along the displayed vertical arrays (x=0.9, 3.3 and 5.1m)

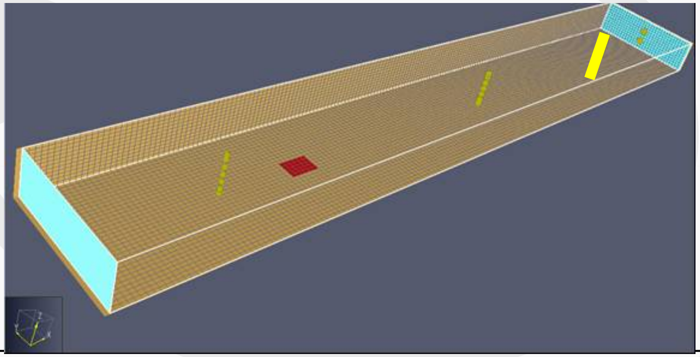




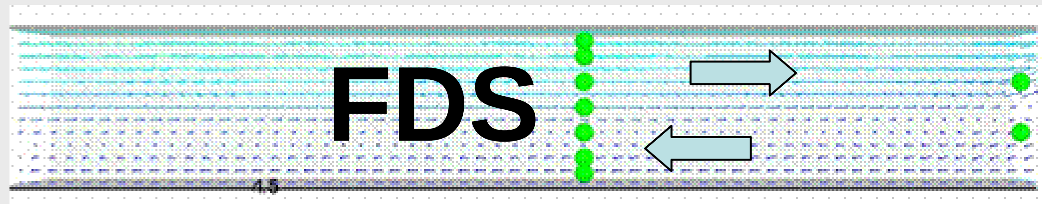


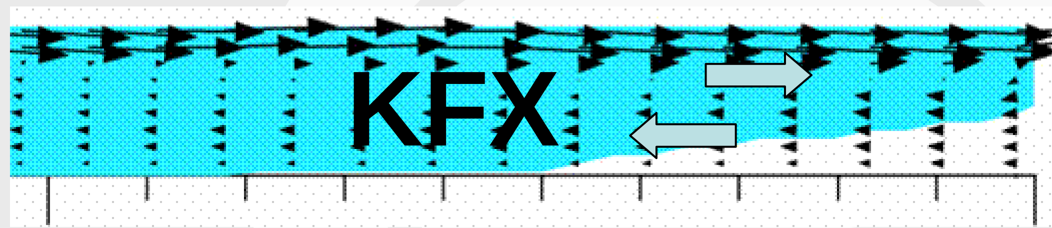


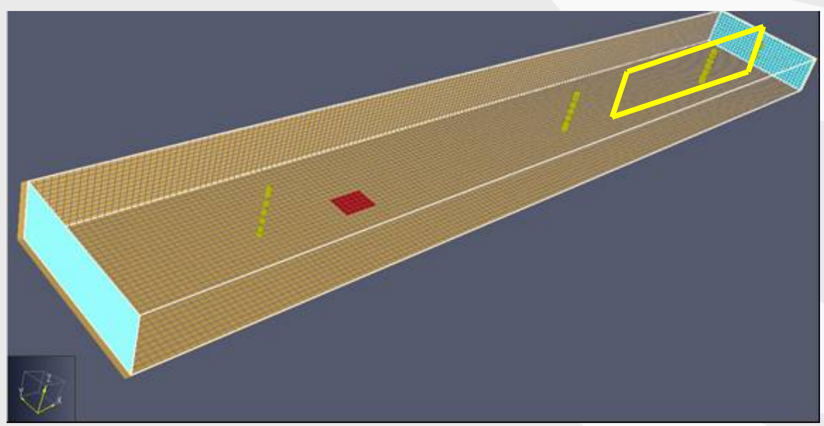




Comparison between the calculated flow fields (KFX and FDS)
The comparison is carried out on the displayed vertical plane at the end sections of the tunnel (4m<x<6m)







Conclusions and remarks

The study has shown that at least for the considered fire scenarios, the LES predictions are more than acceptable even without resorting to very refined grids and results are comparable if not improved with respect to the traditional RANS approach.

The finding might be related to the scarce importance of a detailed fire structure in the considered scenarios. For such scenarios, the fire dynamics is satisfactorily accounted for by imposing the Heat Release Rate of the fire that drives the flow dynamics and the behavior of the parameters of main importance.

Further work is necessary to thoroughly investigate the LES capabilities over a wide spectrum of experimental scenarios before exploiting with confidence the full potential of the LES approach that promises to embrace a larger deal of physics especially when considering the unsteady features of the fire dynamics.

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Thank you.

HSE MANAGEMENT PRINCIPLES

Management Commitment
Senior Management provides visible, strong and pro-active leadership and commitment to develop, implement, audit and maintain the HSE Management System and the relevant culture.

Risk Management
All hazardous operations and conditions are identified, the risks assessed and controlled; the relevant mitigation measures implemented throughout the activities in order to prevent all accidents and occupational diseases.

Human Resources
All personnel have adequate physical fitness, competency, training and attitude to carry out their duties in a safe manner.

Communication
An effective and open communication system on HSE matters is established and maintained for internal and external interested parties.

Environmental Protection
All potential environmental impacts are identified, evaluated and actions are taken to avoid any damage to the environment and to restore original conditions.

Commercial
Basic processes are adopted in order to guarantee that all cost factors and other commitments are assessed to carry out the activities in accordance with Saipem HSE Management System and Clients expectations.

Engineering
All facilities, plants and equipment are engineered in compliance with the best international HSE requirements, statutory legislation and that all risks associated with the final operation of the facilities, plants and equipment are suitably addressed.

Purchasing
Suppliers are selected, inspected and assessed in order to guarantee compliance with HSE requirements and that only safe material and equipment are purchased and used within Saipem activities.

Operations Management
Safe methods of work are implemented by carrying out all operations in compliance with Company HSE Procedures, Clients requirements and Statutory legislation.

Subcontractors and Services
Sub-contractors' and Service Companies are selected to ensure best available services and are in full compliance with Saipem HSE requirements. Their activities are audited and evaluated in order to ensure that healthy and safe conditions are maintained at the working sites.

Assets Management
All assets are maintained, examined and inspected in compliance with the Statutory requirements, Company and International safety standards.

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