COMUNICAÇÃO TÉCNICA

Nº 170775

CFD: computational fluid dynamics; dinâmica computacional dos fluídos

Rodrigo Machado Tavares

Palestra apresentada para os pesquisadores do CETAC-IPT, 2012, São Paulo

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CFD (Computational Fluid Dynamics)

(Dinâmica Computacional dos Fluídos)

by Rodrigo Machado Tavares, Ph.D.

CETAC – Centro Tecnológico do Ambiente Construído
LSF – Laboratório de Segurança ao Fogo

Breves explanações, com ênfase na área de Engenharia de Segurança/Proteção contra Incêndios

INSTITUTO DE PESQUISAS TECNOLÓGICAS

Conteúdo:

1. “Modelar é preciso?”
2. Um pequeno histórico de modelagem de incêndios
3. CFD
4. Algumas aplicações
5. Considerações adicionais
6. Tchau ☺

1. “Modelar é preciso?”

Fire Technology 2008

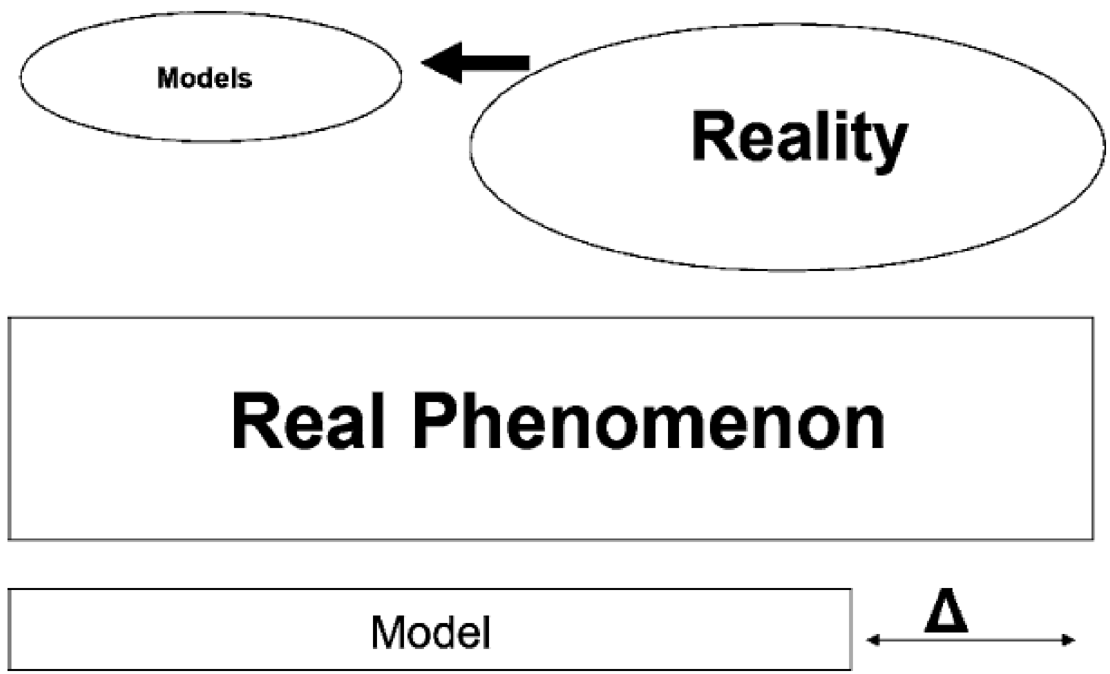
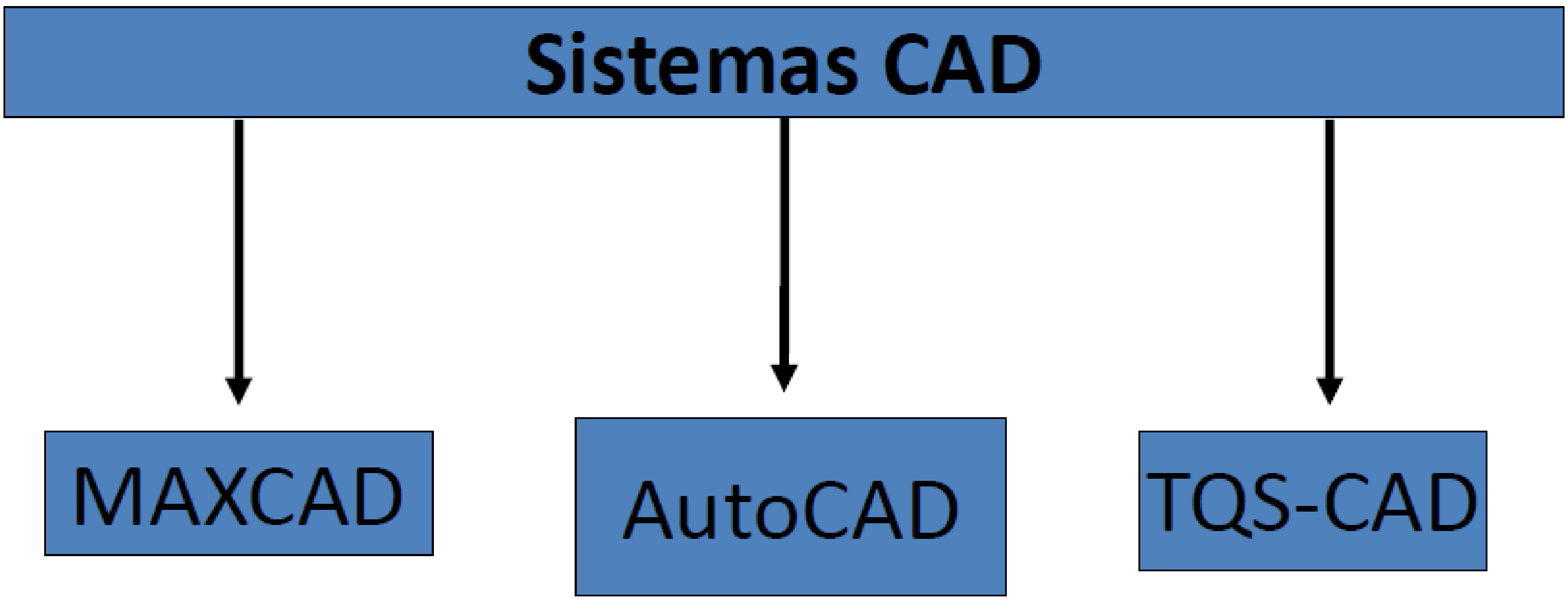


Figure 3. Model ‘‘versus’’ reality.

TAVARES, R.M., Evacuation Processes Versus Evacuation Models: “Quo Vadimus”?, Fire Technology, Springer Netherlands (2008), ISBN: 0015-2684

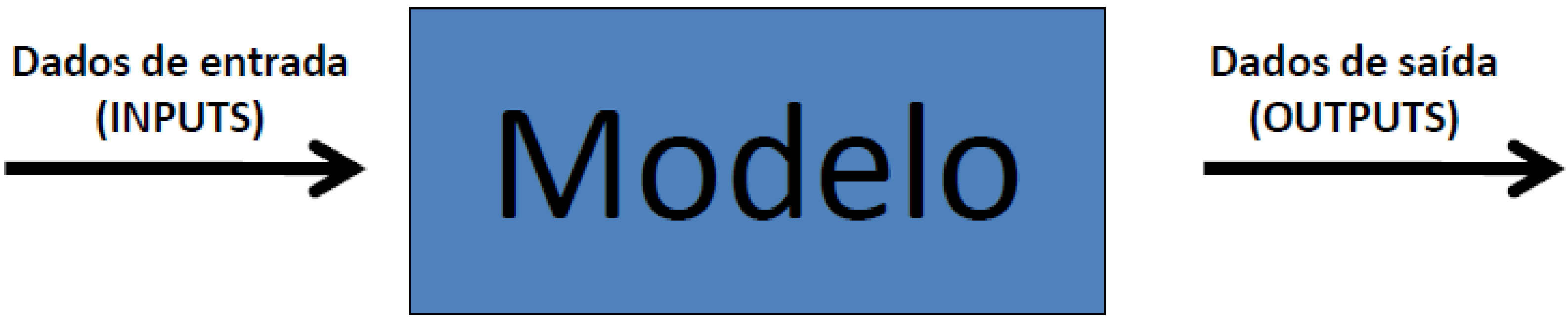
1.1 Modelos – breve discussão “filosófica”



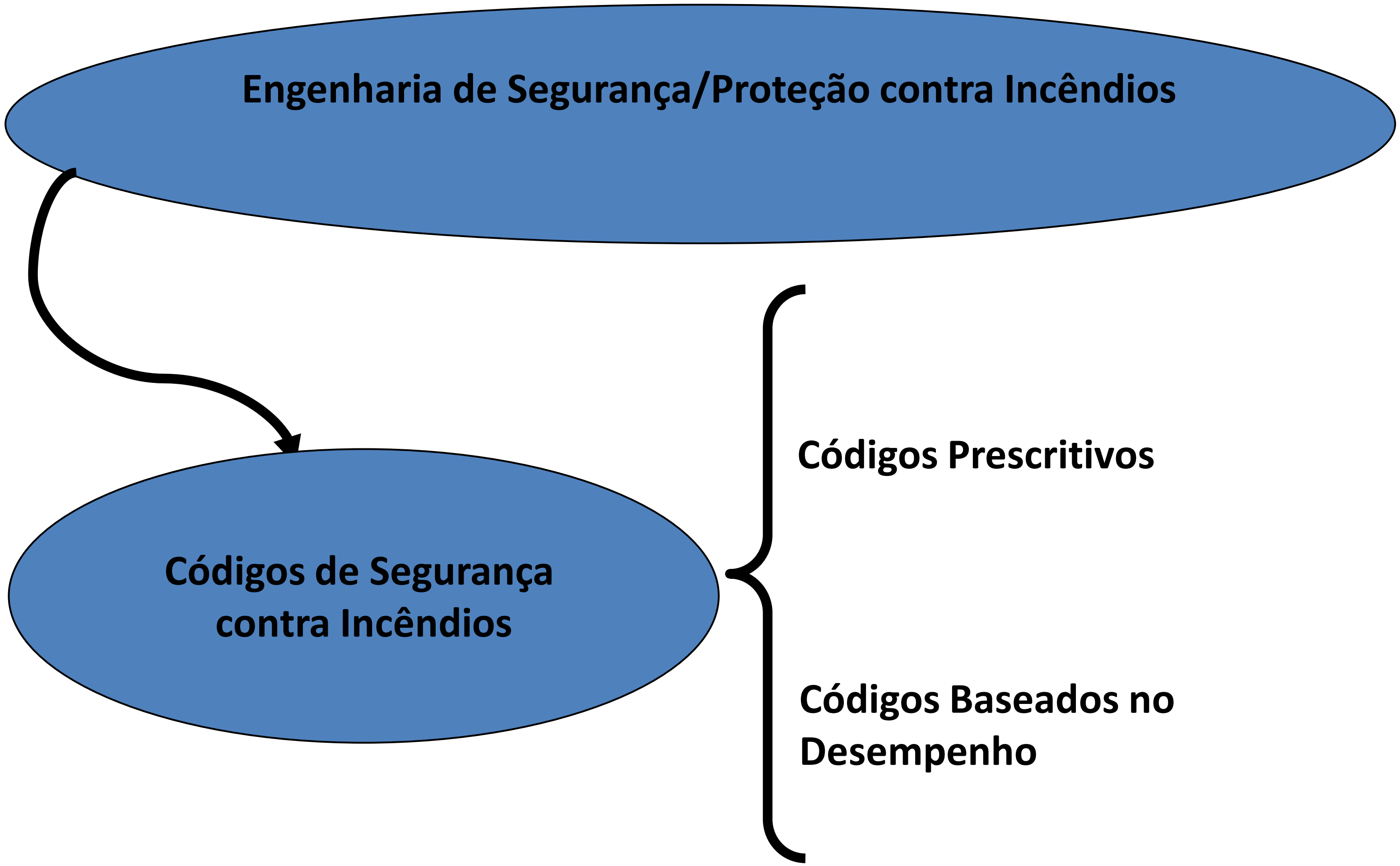
CAD: Computer-Aided Design

Rodrigo Machado Tavares

1.1 Modelos – breve discussão “filosófica”



```
for all outer_iterations
    for all groups
        if ( inner_iterations > 0 )
            calculate coefficients for group
            do normalisation of the system matrix
        endif
    endfor
    for all minimum_inner_iterations
        for all groups
            calculate interleave iterations
            for all interleave_iterations
                increment used iterations
                if ( used_iterations is even )
                    run forward marching SOR update for all cells in group
                else if ( used_iterations is odd )
                    run backward marching SOR update for all cells in group
                endif
                calculate solver residual
            endfor
            do convergence tests
        endfor
    endfor
endfor
do linear relaxation
```


Engenharia de Segurança/Proteção contra Incêndios
Códigos de Segurança contra Incêndios
Códigos Prescritivos
Códigos Baseados no Desempenho

Fire Safety Design: The "Code-compliant" Approach

Part B to the Building Regulations:

B1 - Means of warning and escape
B2 - Internal fire spread (linings)
B3 - Internal fire spread (structure)
B4 - External fire spread
B5 - Access and facilities for the fire service

Approved codes of practice:

- Approved Document B – Fire Safety
- BB100 – Design for Fire Safety in Schools
- HTM Firecode series

Other design guidance; BS 9999, (Green Guide) Guide to Safety at Sports Grounds, Railway Safety Principles and Guidance (RSPG)

Part B compliance often documented in a Fire Safety Strategy

Fire Safety Design: The "Code-compliant" Approach

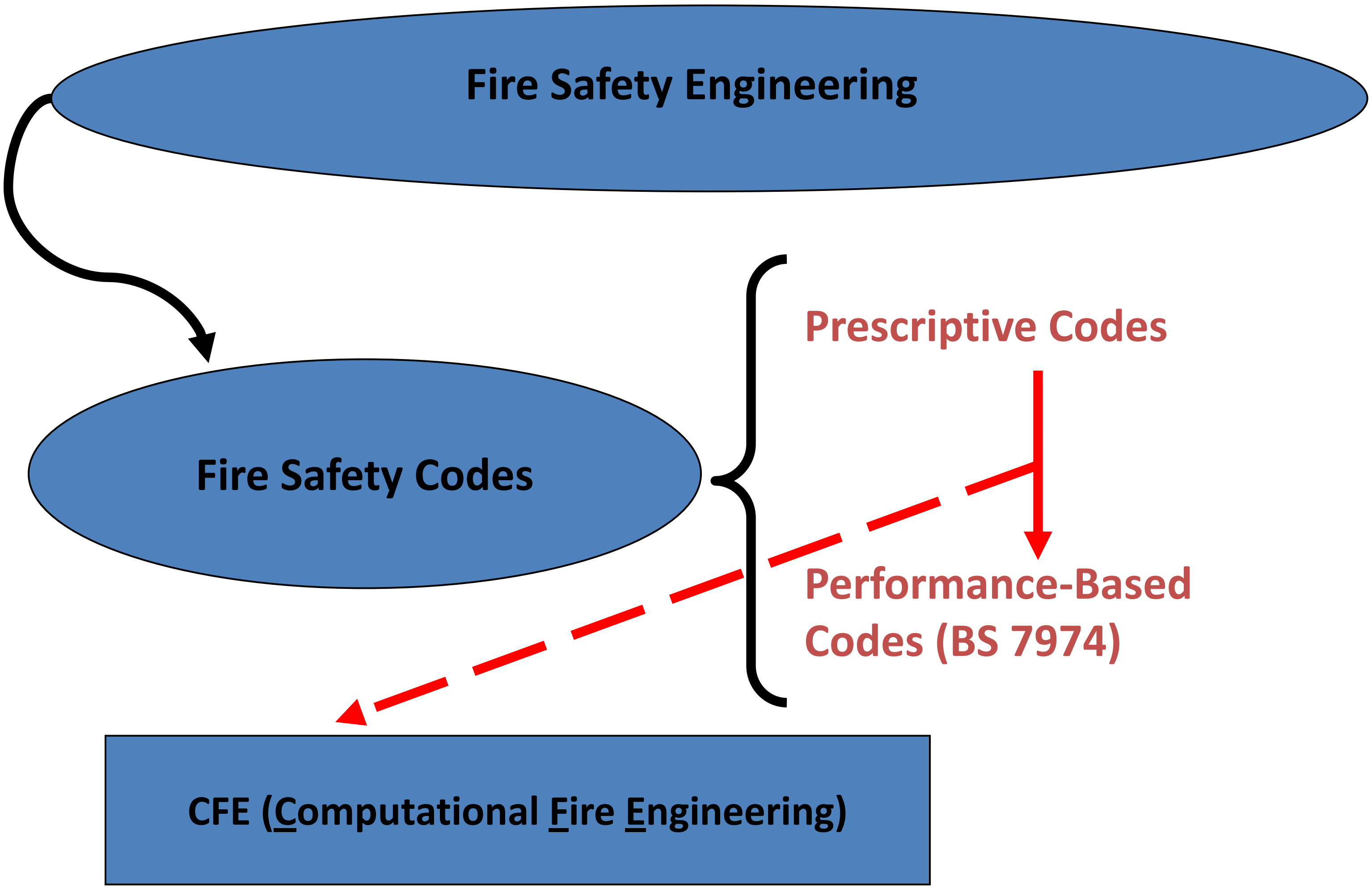
Benefits of adopting a "Code-compliant" Approach:

- Easy to apply; offers generic solutions for more common building designs
- Provides *safe* solutions that present *acceptable* life risk
- No approvals risk

Downsides of adopting a "Code-compliant" Approach:

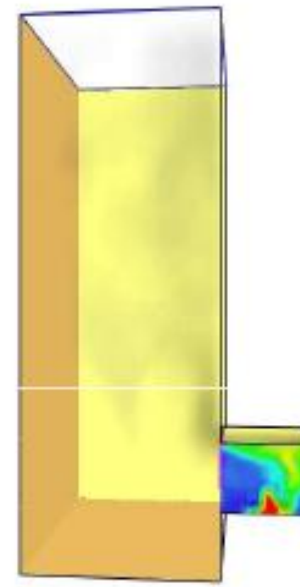
- Inflexible
- Prescriptive
- Development of approved codes reactive rather than pro-active (2.5 minutes for escape)

1. Why model?



BS 7974:2001
Application of fire safety engineering principles to the design of buildings. Code of practice

Fire Safety Design: The "Fire Engineered" Approach



Fire Engineering can provide:

- Extended travel distances
- Reduced number of escape exits
- Reduced number of escape stairs
- Allow design features such as atria
- Rationalise the applied structural fire resistance
- Increased compartment sizes

Fire Engineering methods:

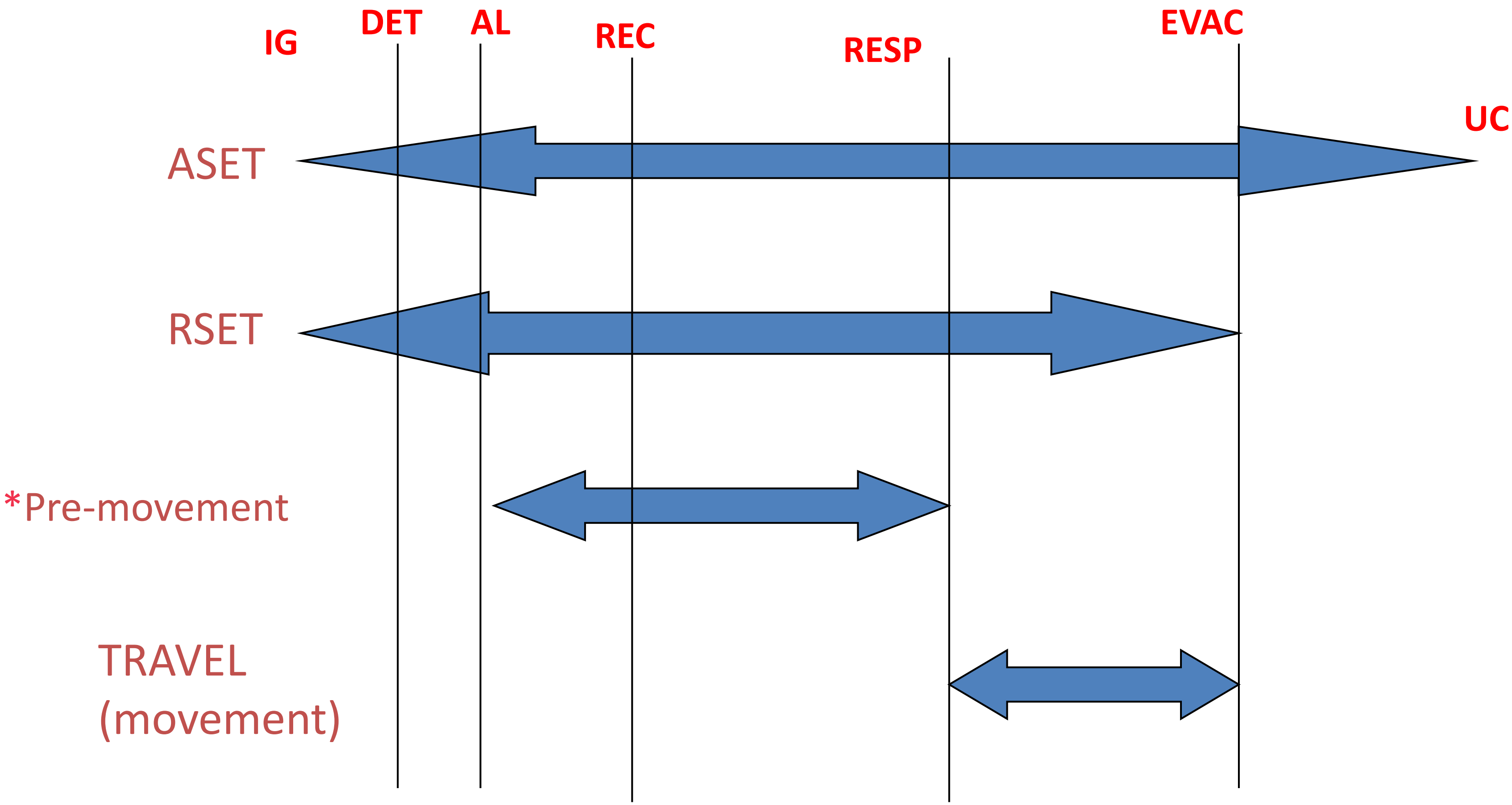
- Hand calculation (smoke control, ASET/RSET)
- Computational Fluid Dynamics (CFD)
- Computational Evacuation Modelling (CEM/PeMMA)
- Structural Finite Element Analysis (FEA)
- Qualitative argument

Fire Safety Design: The “Fire Engineered” Approach

In summary Fire Engineering offers:

- Flexible design solutions using performance based designs
- Innovation
- Added value to projects
- Often provides enhanced life safety standards
- Can also be used to improve standards of property protection
- Best efficiencies achieved at an early stage
- Where possible cost savings
- Savings in abortive redesign
- Reduced approval/PI risks
- **Not** a means of bending the rules

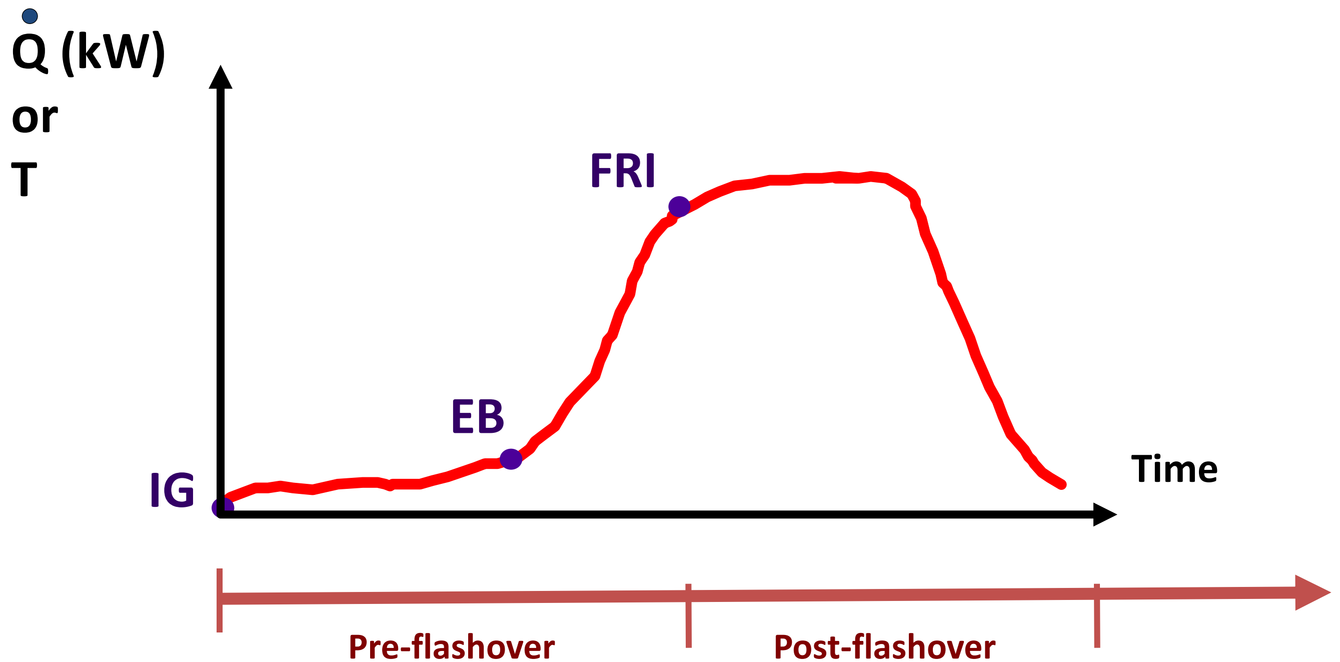
1. Why model?



ASET – Available Safe Egress Time
RSET – Required Safe Egress Time

*Pre-movement = Pre-evacuation

1. Why model?



Typical curve for a fire in an enclsoure
(adaptation from Kawagoe, K.[1])

IG – Ignition

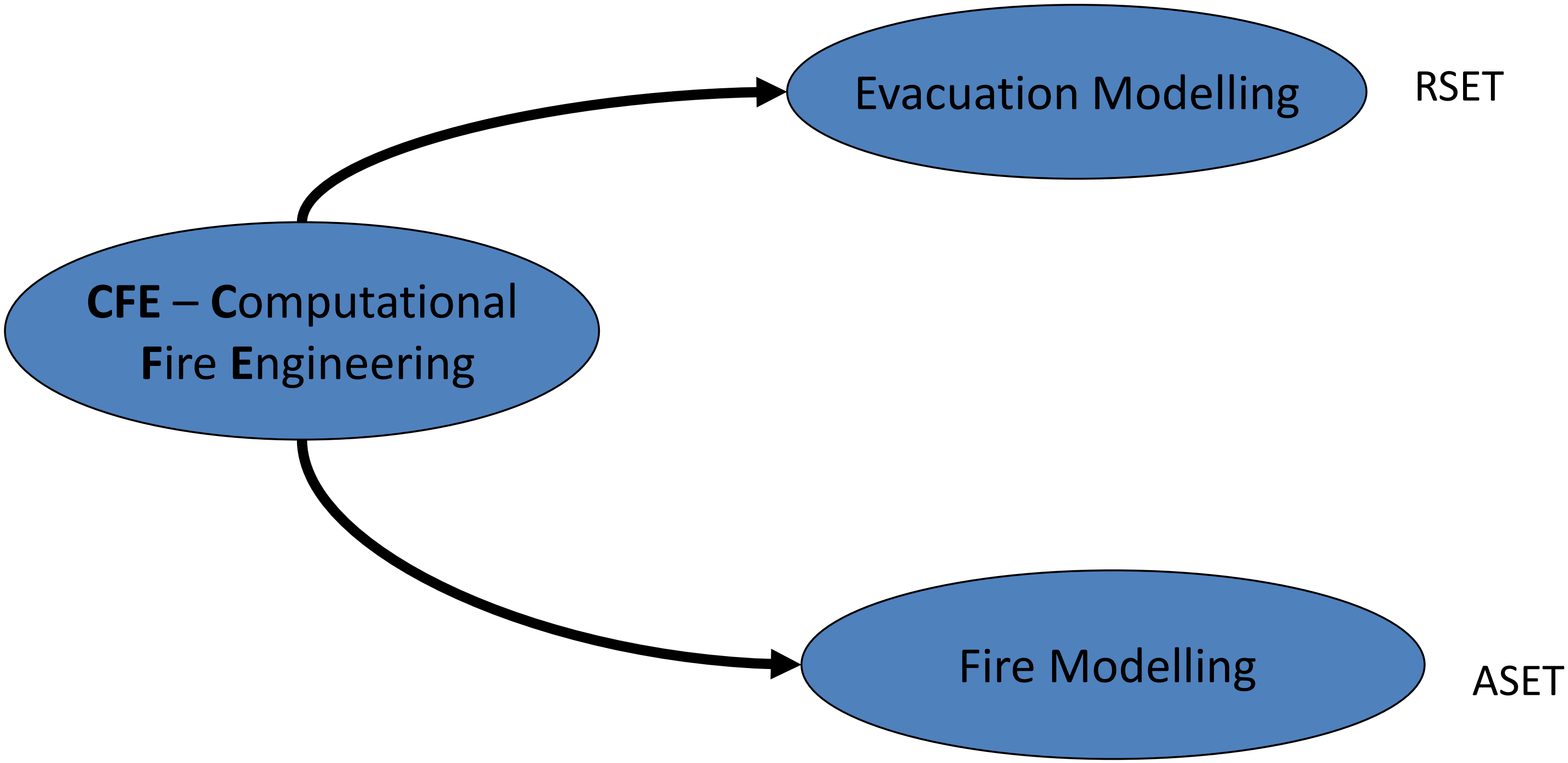
EB – Establishment of the Burning

FRI – Full Room Involvement

Q (kW) – maximum burning rate
(taxa de calor máximo)

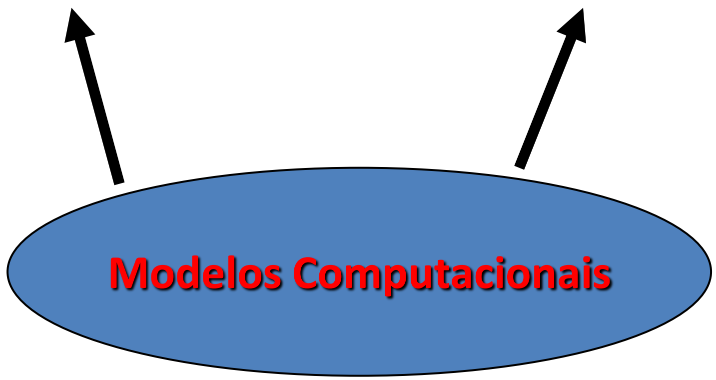
1. "Fire Behaviour in Rooms", Report No. 27, Building Research Institute, Tokyo, 1958

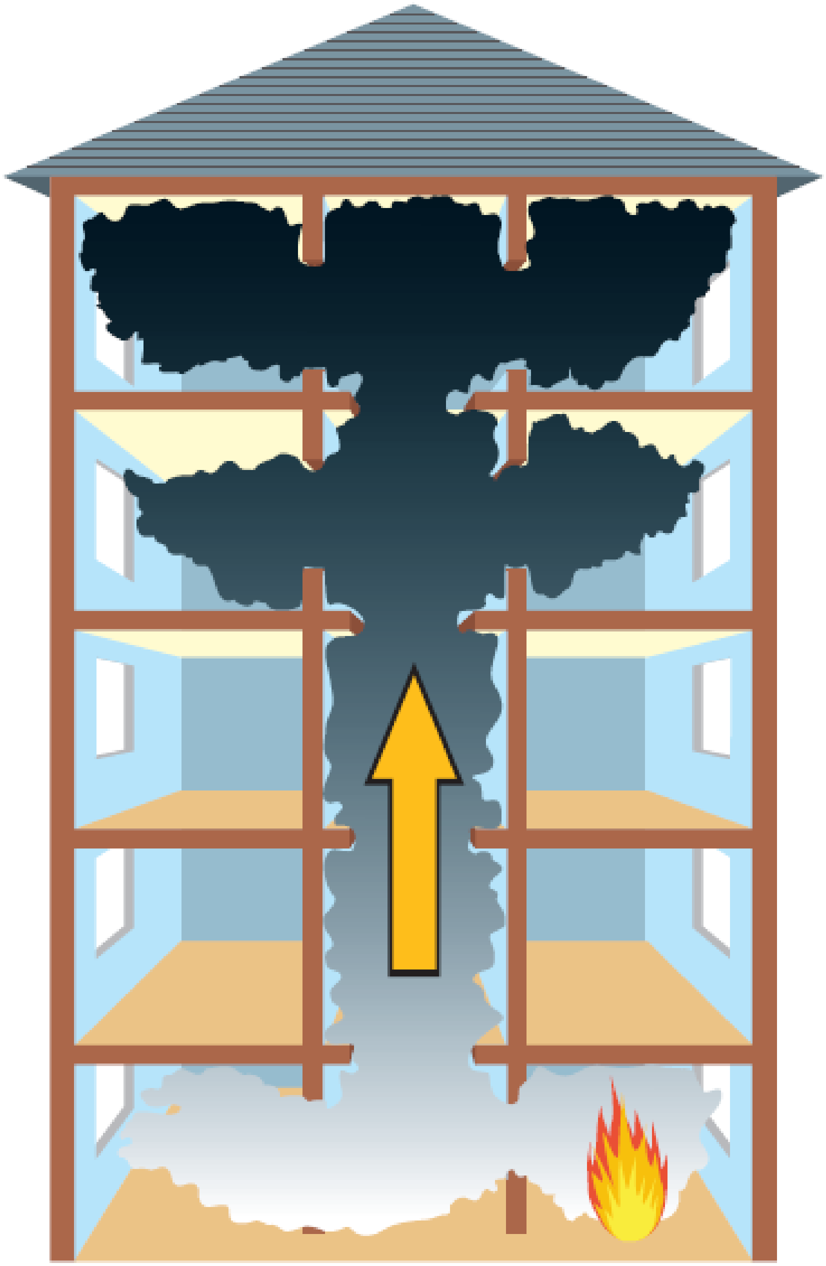
1. Why model?



RSET < ASET

RSET < ASET





1. A Brief History of Fire Modelling

1960's: First mathematical model for the simulation of fire within compartments (hand calculations)

1970's: First Accounts of Field Modelling Published

Computer based zone models developed

1980's: First general purpose CFD code developed by CHAM, UK

Fire specific FM begin to be developed

First zone model developed for the Personal Computer

First report of FM being used to explain unknown events – Kings Cross Disaster

1990's: Parallel Computer technology developed

One of the largest FM application undertaken at the Millenium Dome

2000+ Improvements in the speed and capacity of Personal Computers makes FM available to a wider community of FSE's

2. Types of Fire Models

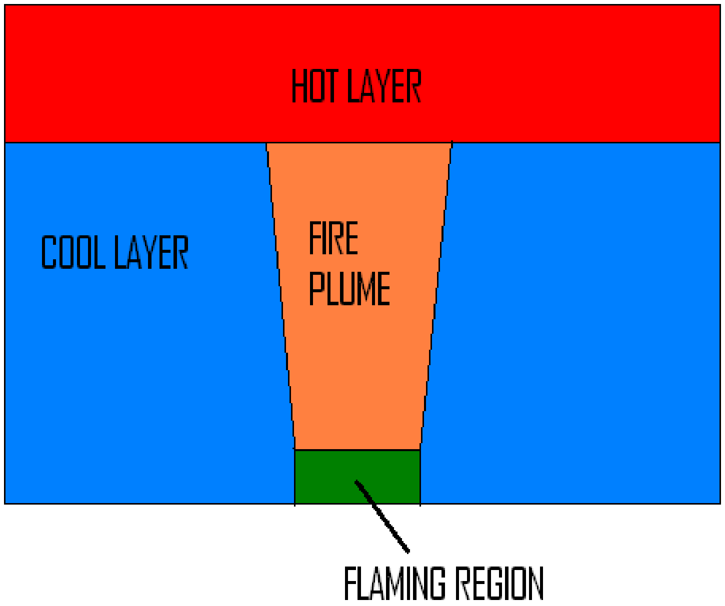
Two main types of fire models

- ZONE MODELS
- FIELD MODELS or COMPUTATIONAL FLUID DYNAMICS (CFD) MODELS

Zone Models

- Based largely on empirical data
- Two dimensional
- Core assumption- compartments are rectangular and have flat ceilings
- Divide room into two distinct zones – Hot and Cool
- Each zone is homogeneous – gradients do not develop within layers

- The hot layer increases in mass and descends to the floor in a uniform manner
- Generally conserve Mass and Energy
- Do not conserve Momentum, therefore, can not predict gas velocities or effect of momentum on plume development etc.
- Simple calculations which can be performed in seconds on any PC.
- Are still used in the design process today



Some existing Zone Models

FPETOOL

JET

CFAST

FIRST

COMPF2

BRANZFIRE

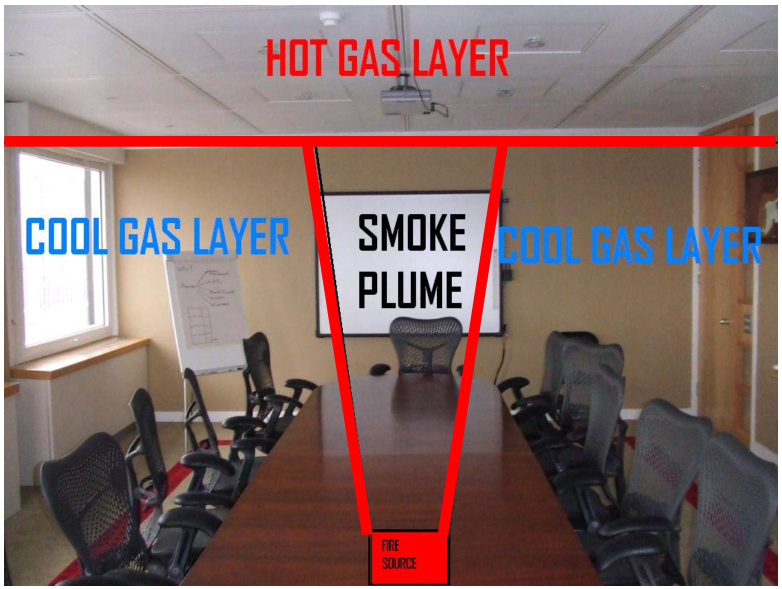
ASET

Zone models - conclusions

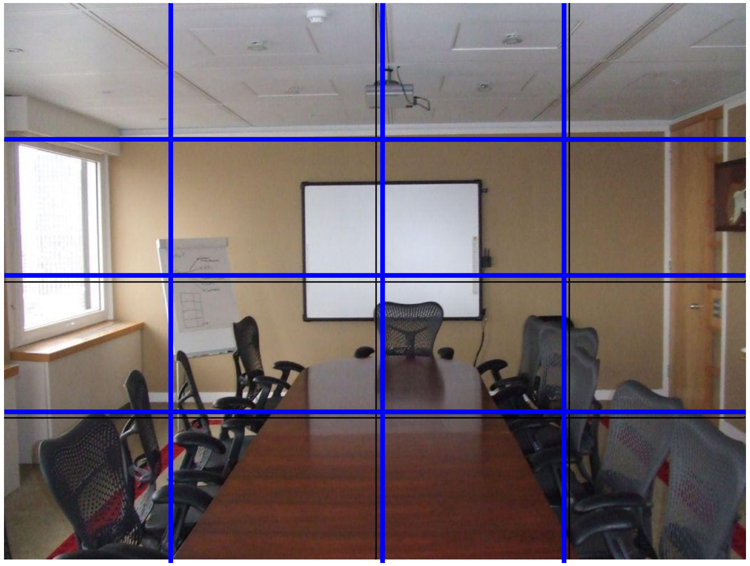
- Simple to use
- Simulations are fast (a matter of seconds)
- Only valid for certain size geometries and certain scenarios
- Assumes flat ceilings and rectangular rooms
- The limitations of zone models must be fully understood by the user.

Computational Fluid Dynamics (CFD)

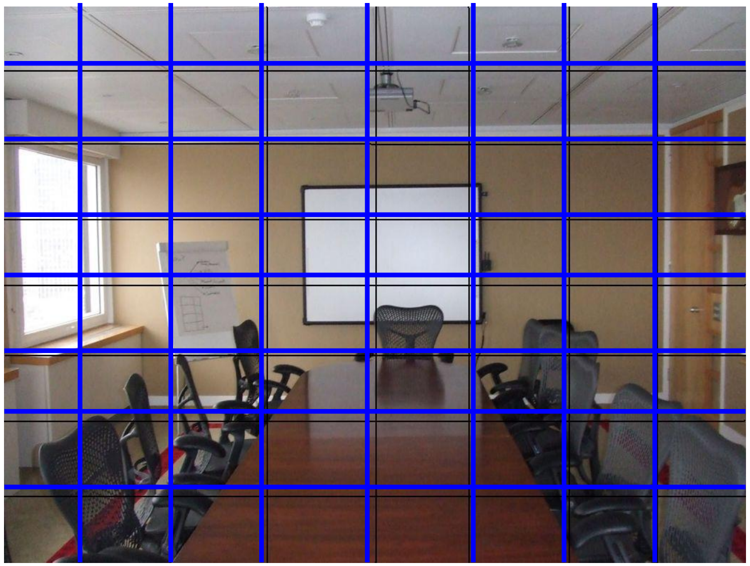
- Used in Aerospace, Automotive and other engineering professions
- Provides a three dimensional, time dependant solution to the conservation laws (mass, energy, momentum and chemical species).
- Lots of Maths are simplified through a process known as discretisation.
- Discretisation is achieved by sub-dividing the physical space into 1000's of smaller control volumes
- A set of Algebraic equations are then solved for each variable across every volume. This process is then repeated for each time step.
- E.g. A CFD model containing 10 dependant variables and 100,000 volumes in a simulation running over 300 seconds requires the solution of 300 million equations.



Zone Model



CFD – Course Mesh



CFD – Fine Mesh

Some existing CFD Models

PHEONICS

General Purpose CFD Codes

CFX

FLUENT

FDS

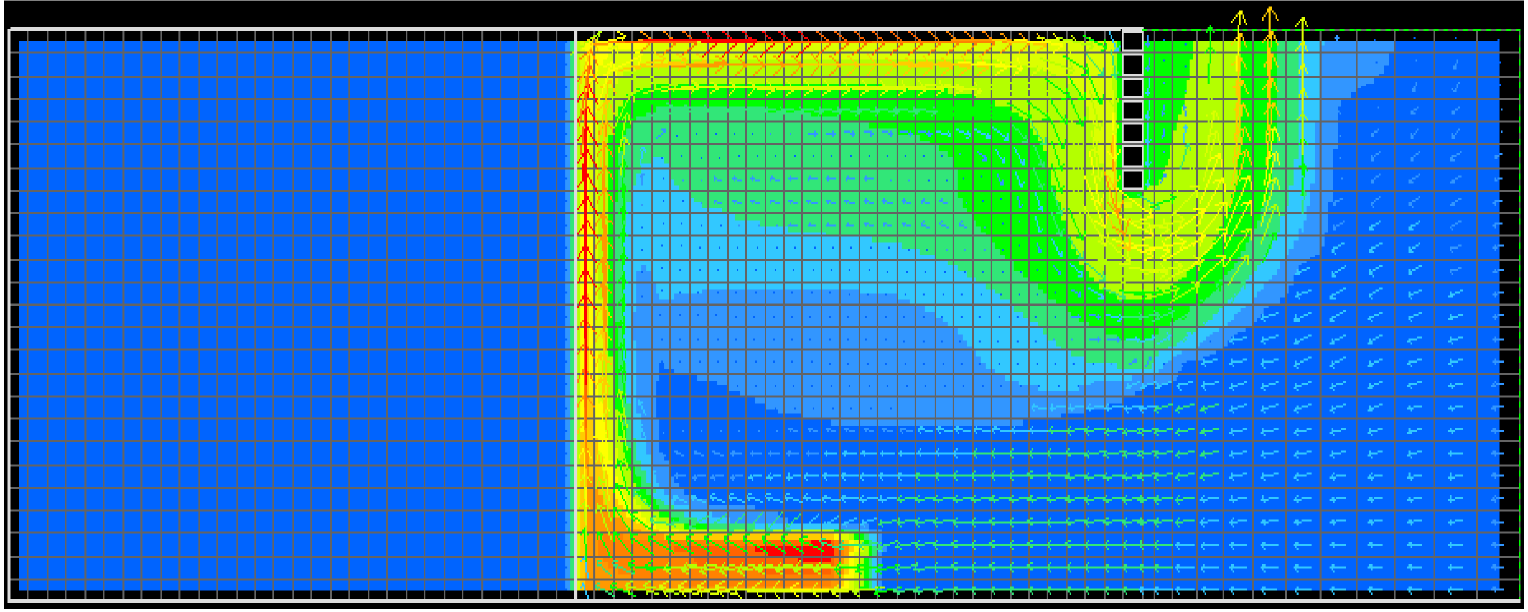
SOFIE

KAMELON

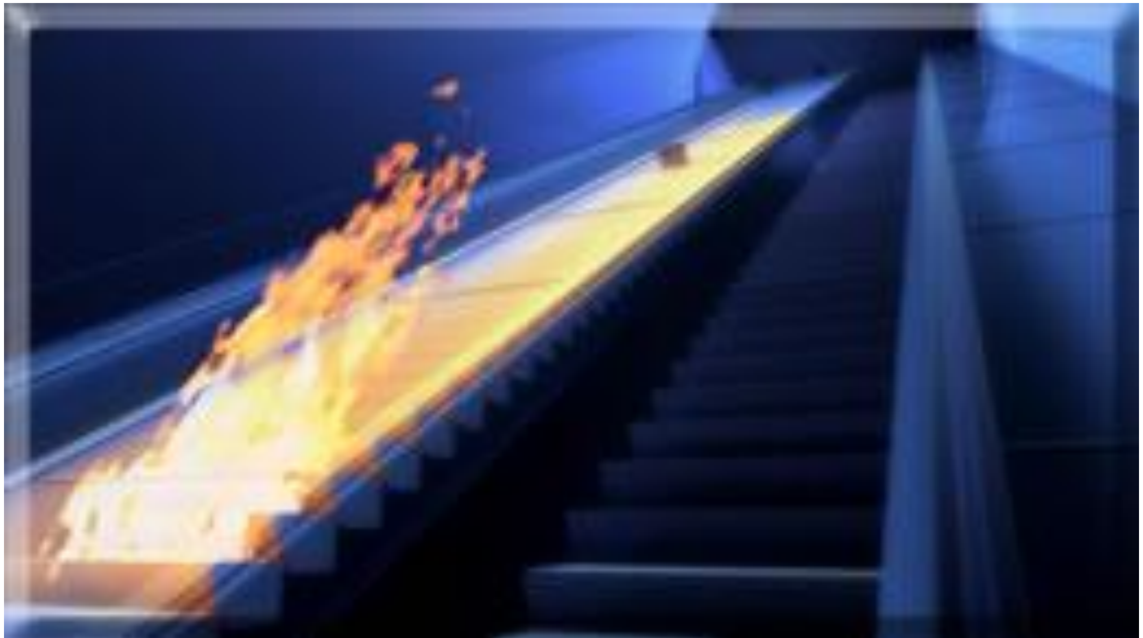
Specific Fire CFD Codes

SMARTFIRE

JASMINE



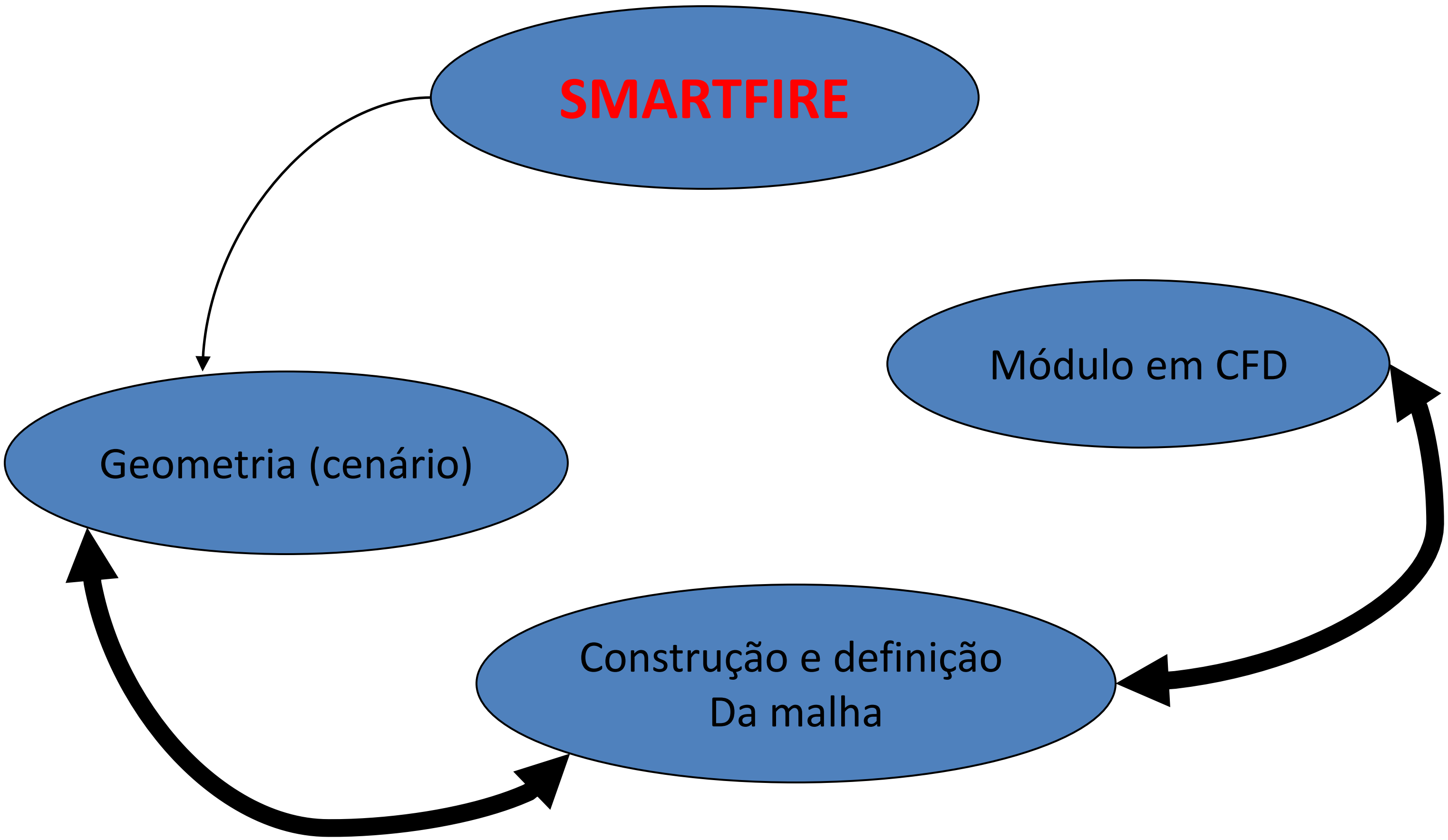
Variáveis: momento, pressão, radiação, entalpia, etc...



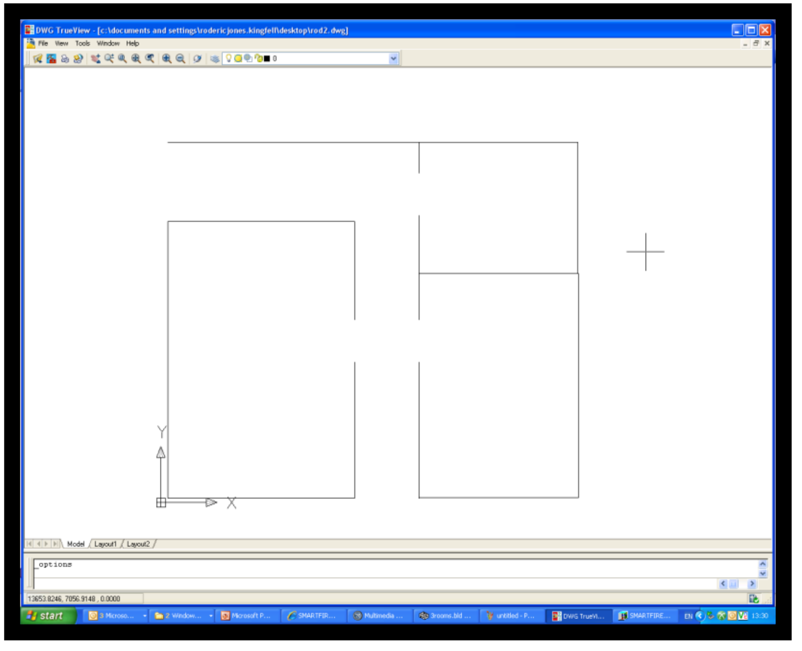
3. Zone Models v CFD

	Zone modelling	CFD
Simple rectangular geometries.	✓	✓
Complex geometries.	✗	✓
Conserves mass, energy and momentum.	✗	✓
Quick to setup and run.	✓	✗
Accuracy of the results can be increased.	✗	✓
Specialist knowledge and understanding required.	✓	✓

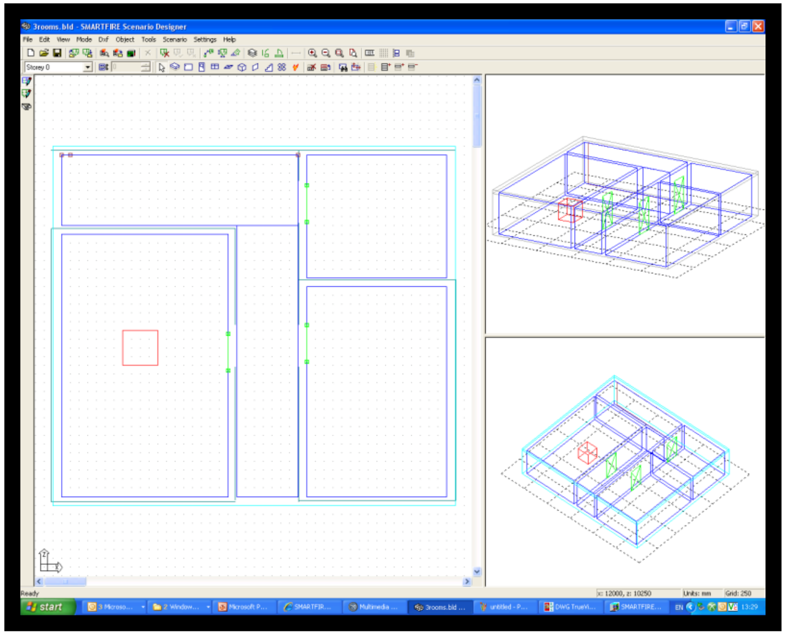
SMARTFIRE


SMARTFIRE
Módulo em CFD
Geometria (cenário)
Construção e definição
Da malha

Scenario Designer

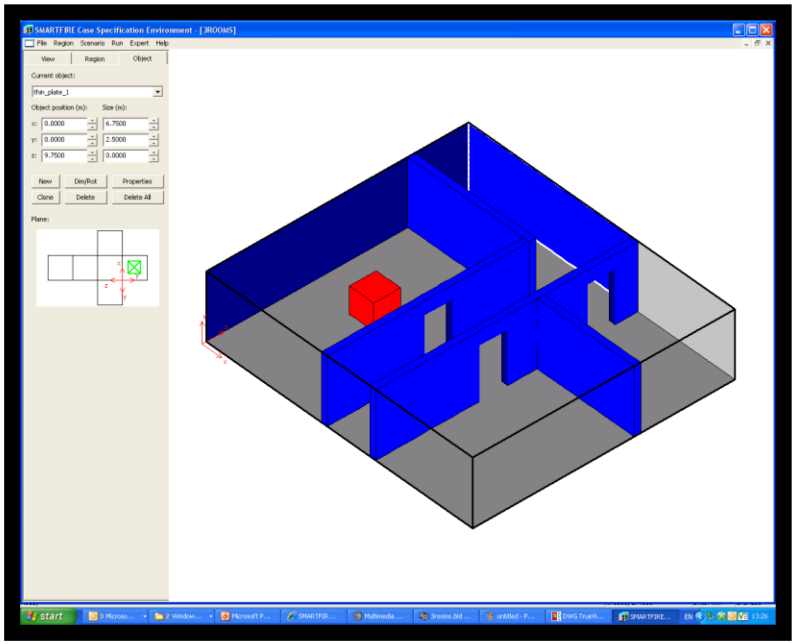


STEP 1: IMPORT CAD FILE (2D IMAGE OF GEOMETRY)

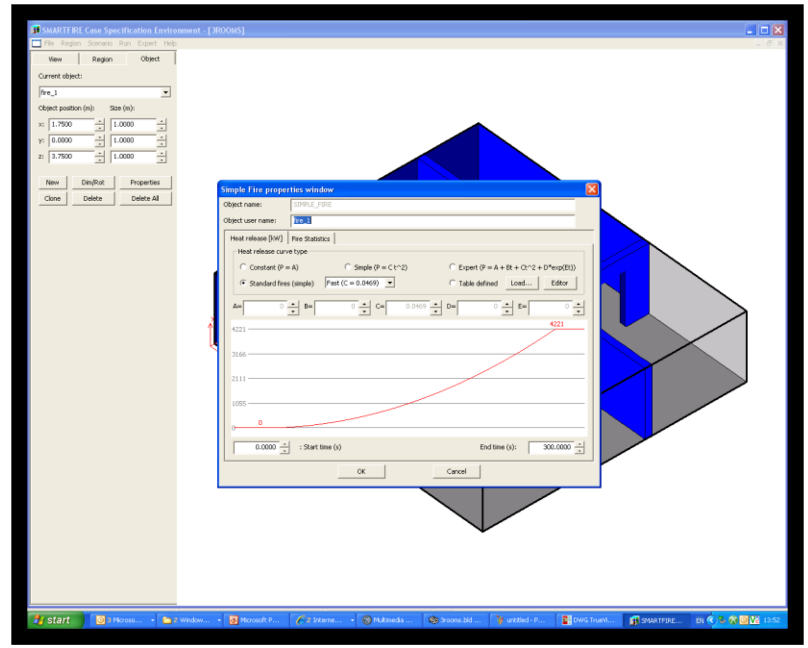


STEP 2: CREATE SCENARIO → PRODUCE 3D GEOMETRY

Case Specification Environment

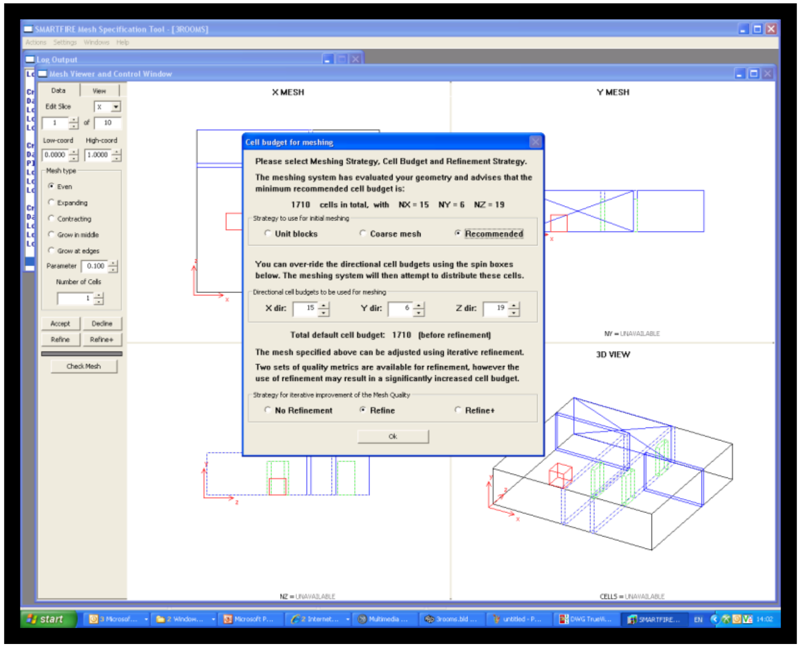


STEP 3: EXPORT THE 3D GEOMETRY TO THE CSE

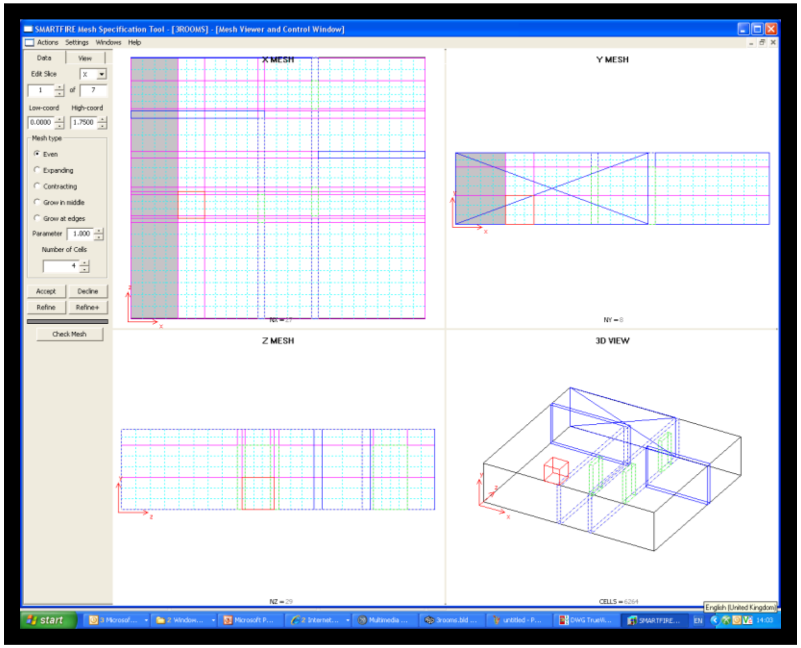


STEP 4: SPECIFY FIRE, SMOKE AND OTHER PARAMETERS

Automated Meshing System

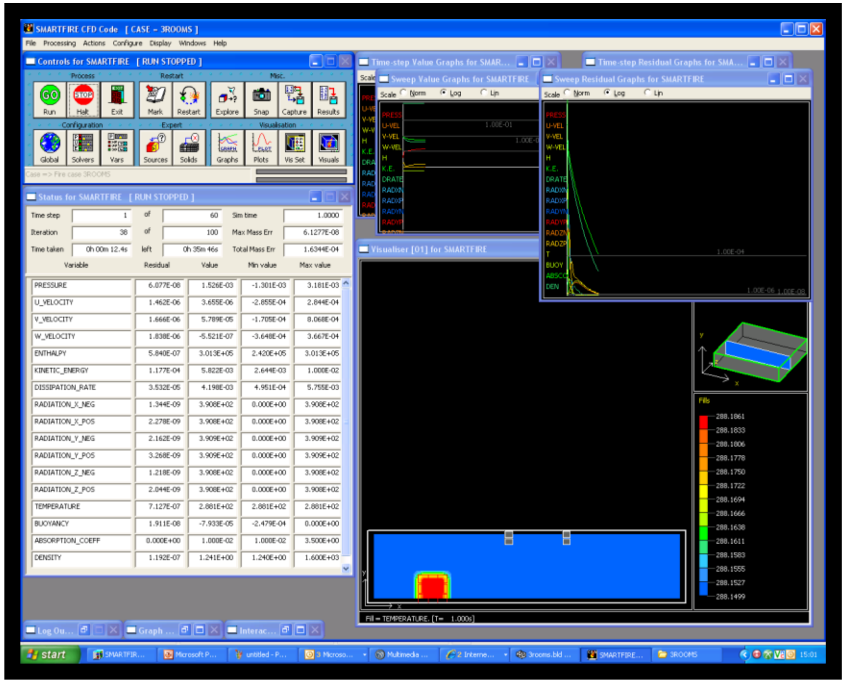


STEP 5: CHOOSE THE DENSITY OF THE MESH

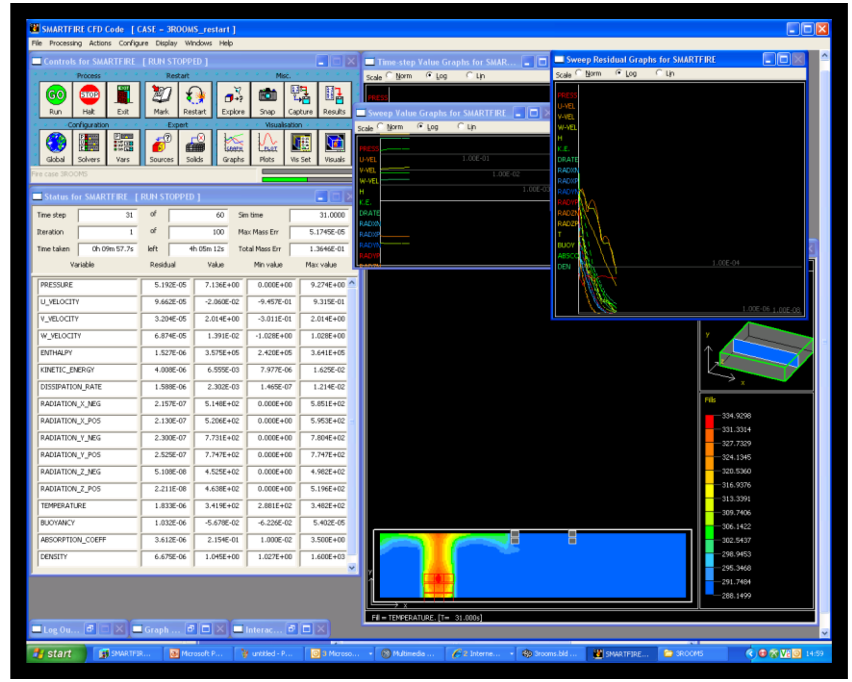


STEP 6: CHECK, MANUALLY CHANGE AND ACCEPT MESH

Interactive CFD Engine

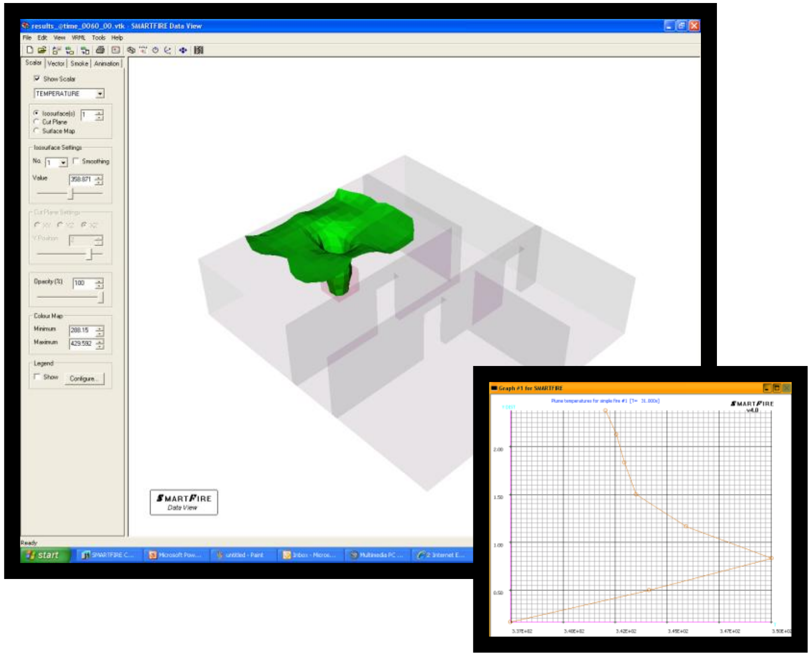


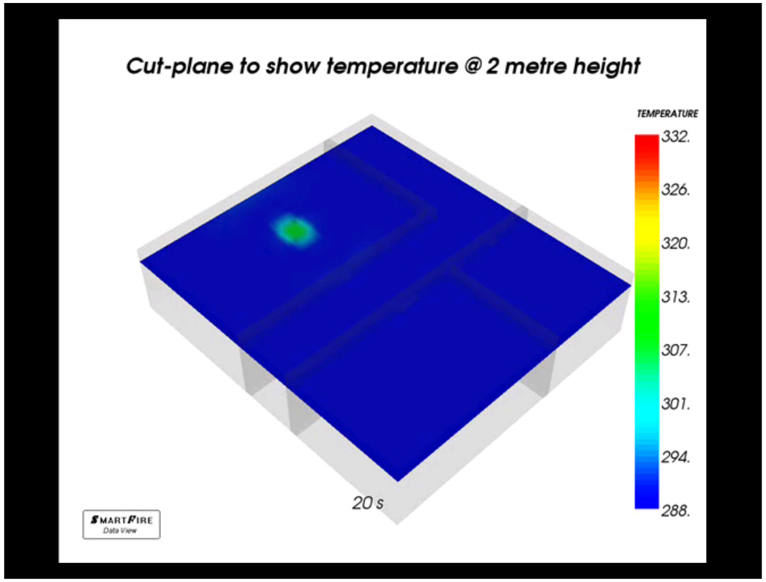
STEP 7: EXPORT TO CFD ENGINE



STEP 8: RUN SIMULATION AND CHECK TO ENSURE CONVERGENCE

Data Viewer

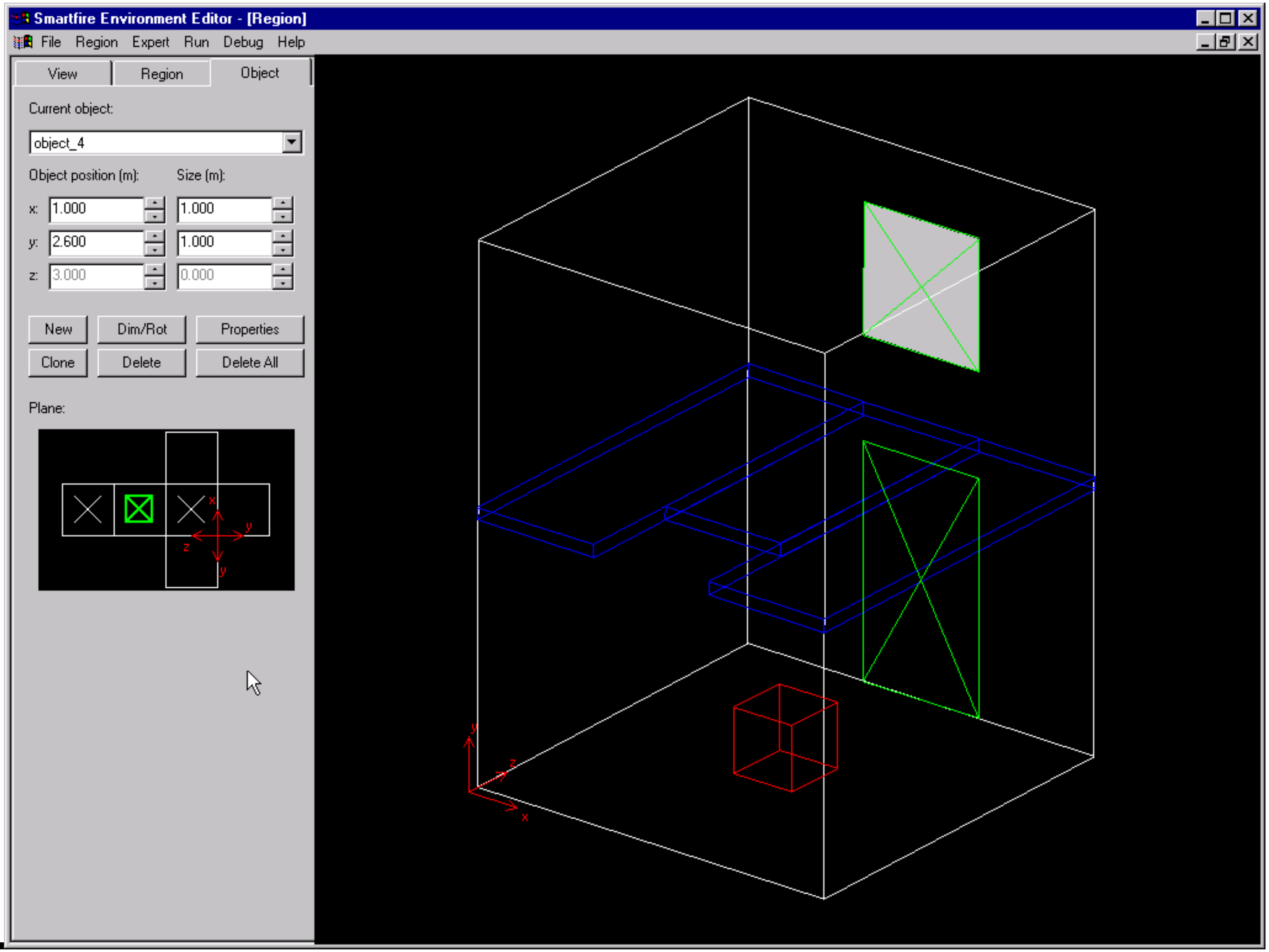




STEP 9: LOAD RESULTS INTO THE DATA VIEWER FOR ANALYSIS IN CONJUNCTION WITH GRAPH DATA

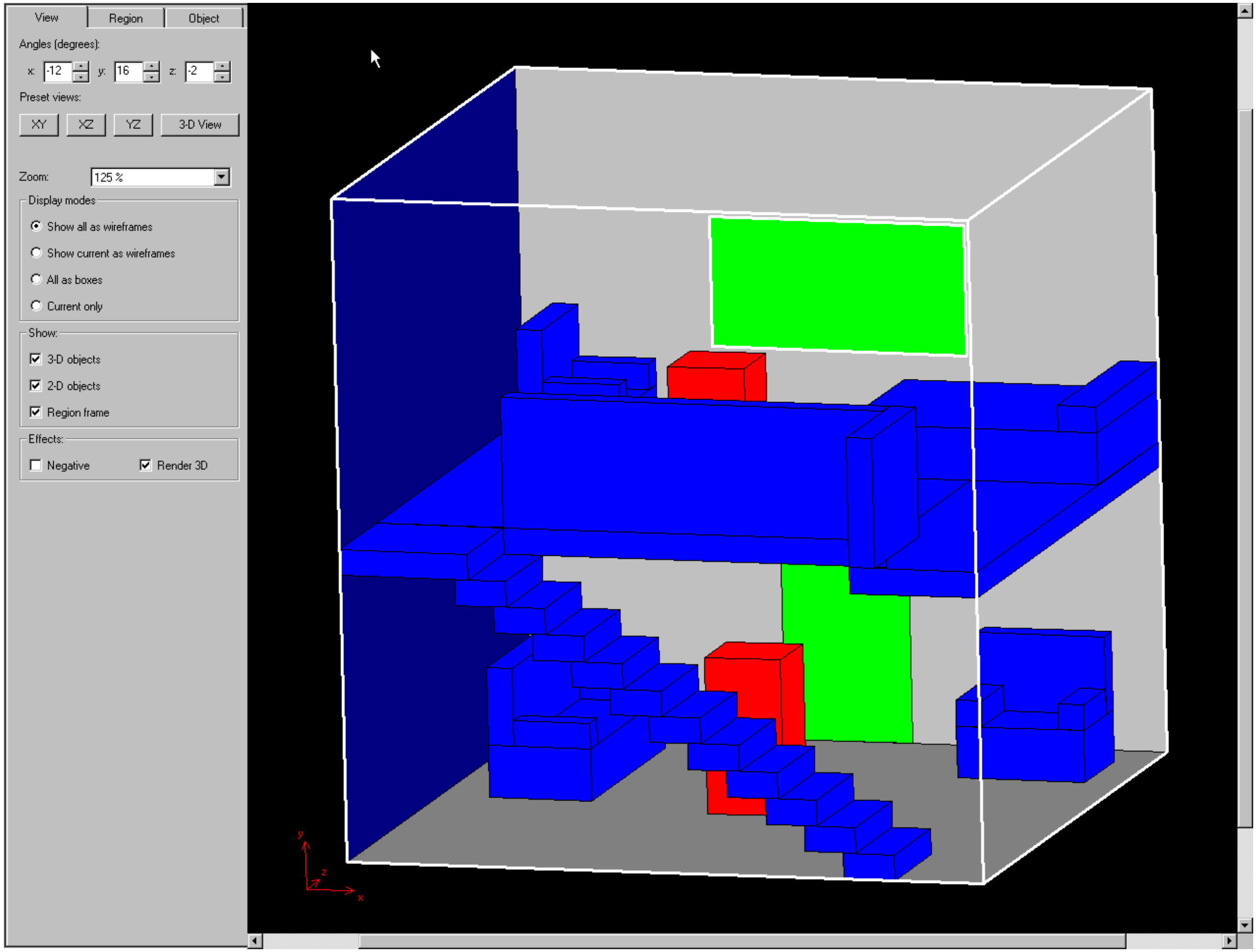
STEP 10: CREATE VIDEOS FOR VISUALISATION AND PRESENTATION TO CLIENT

4) SMARTFIRE

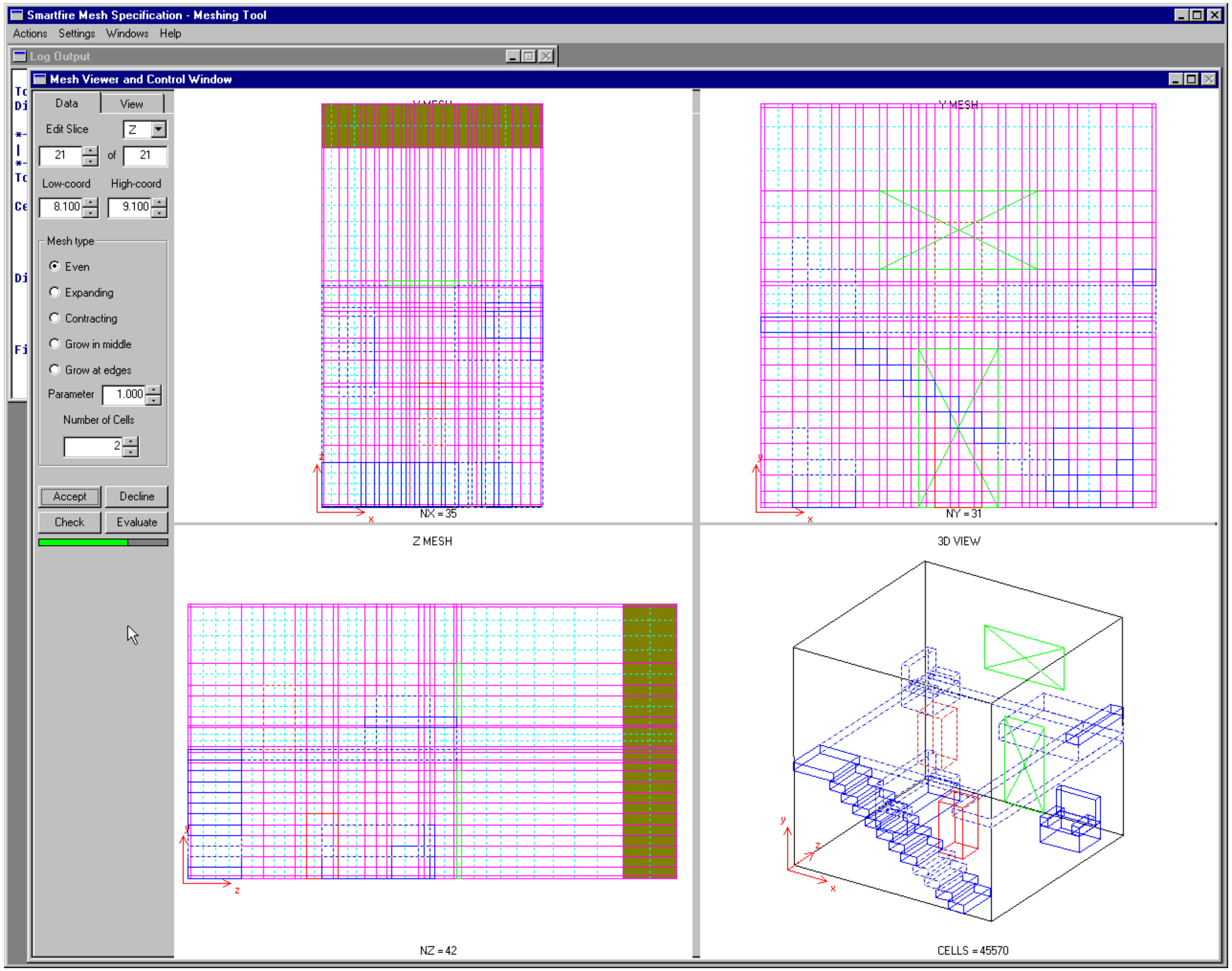


Smartfire Environment Editor - [Region]
File Region Expert Run Debug Help
View
Region
Object
Current object:
object_4
Object position (m):
Size (m):
x: 1.000
1.000
y: 2.600
1.000
z: 3.000
0.000
New
Dim/Rot
Properties
Clone
Delete
Delete All
Plane:

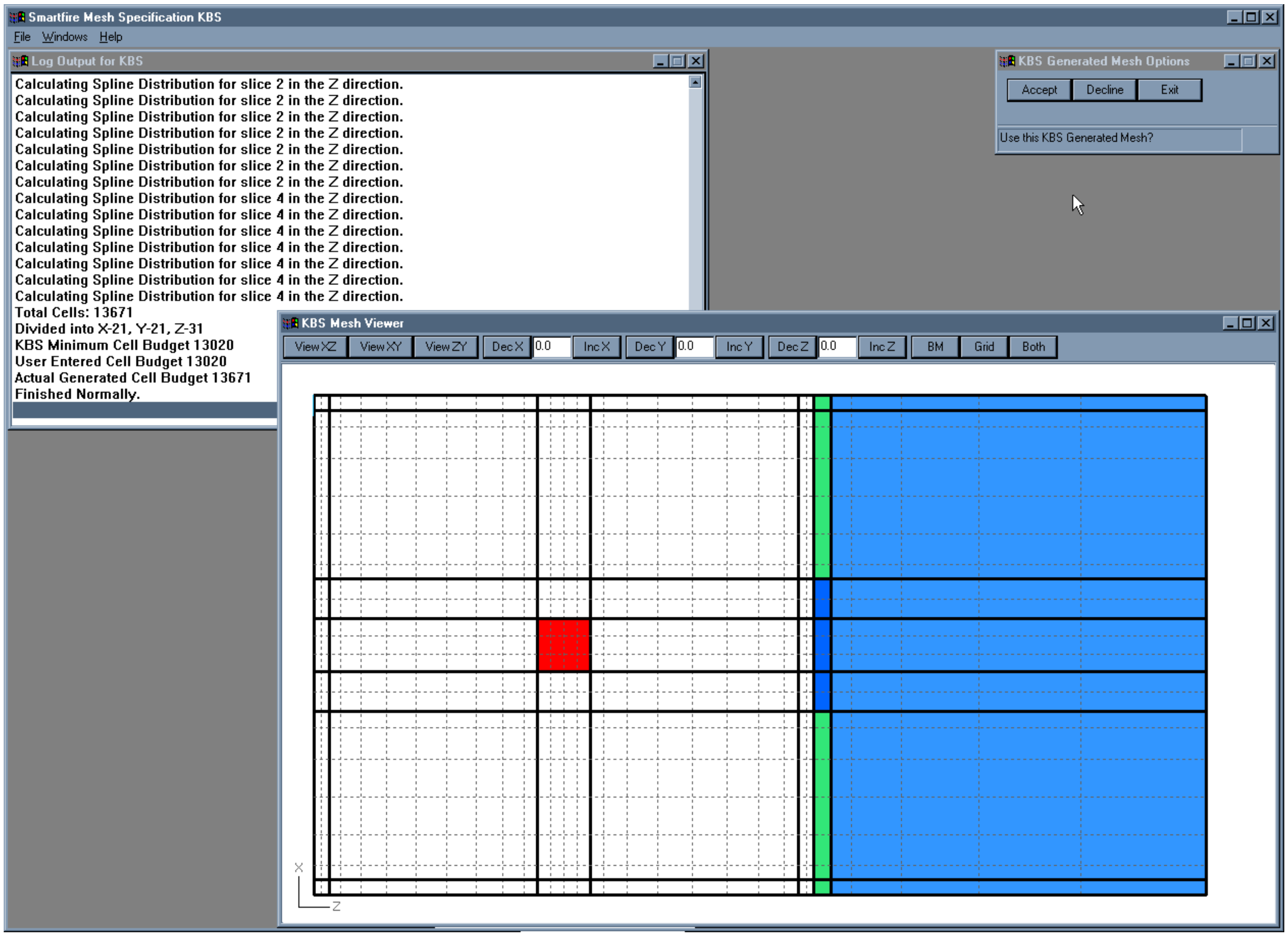
4) SMARTFIRE


View
Region
Object
Angles (degrees):
x: -12
y: 16
z: -2
Preset views:
XY
XZ
YZ
3-D View
Zoom:
125 %
Display modes
Show all as wireframes
Show current as wireframes
All as boxes
Current only
Show:
3-D objects
2-D objects
Region frame
Effects:
Negative
Render 3D
y
z
x

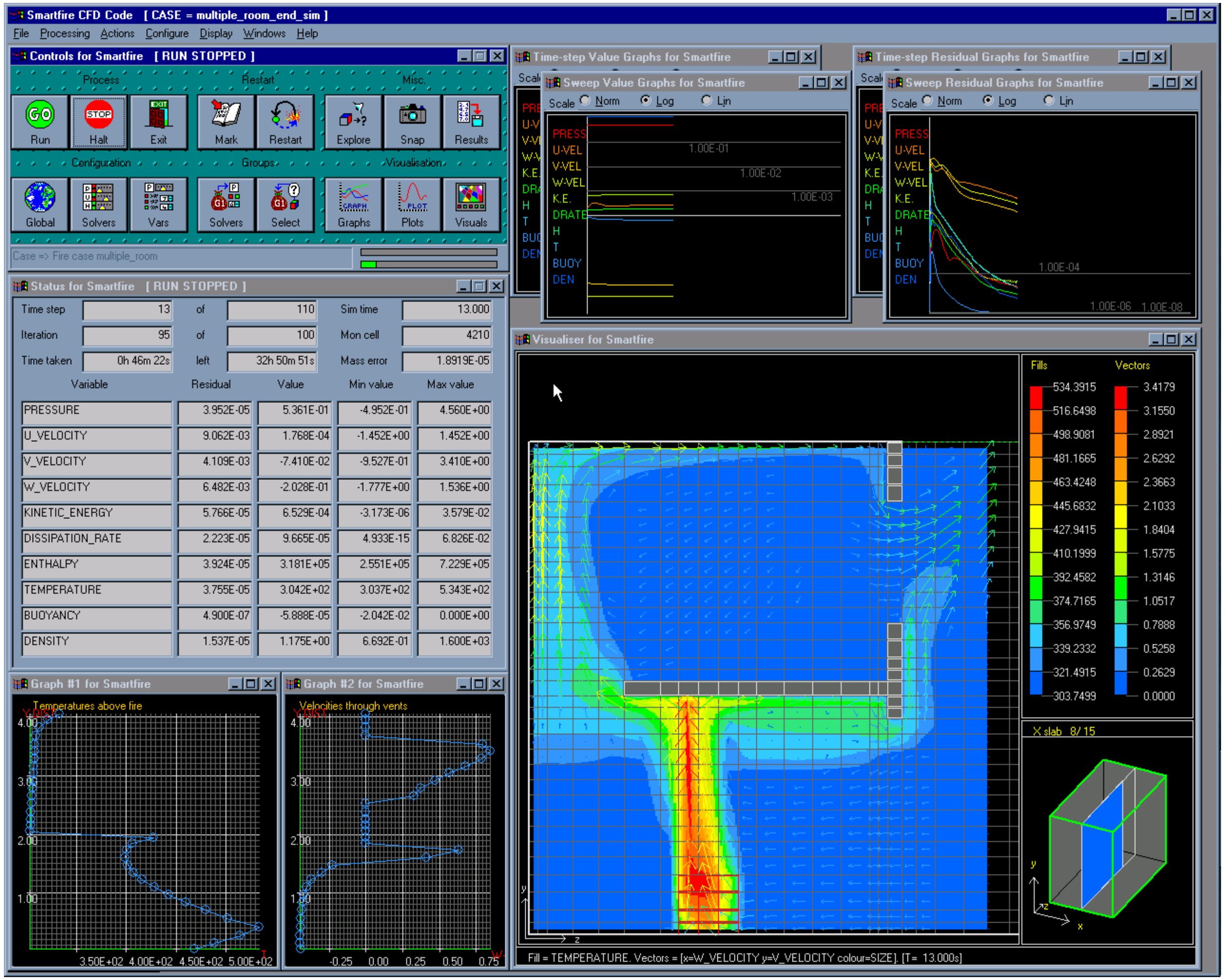
4) SMARTFIRE


Smartfire Mesh Specification - Meshing Tool
Actions Settings Windows Help
Log Output
Mesh Viewer and Control Window
Data View
Edit Slice Z
21 of 21
Low-coord High-coord
8.100 9.100
Mesh type
Even
Expanding
Contracting
Grow in middle
Grow at edges
Parameter 1.000
Number of Cells
2
Accept Decline
Check Evaluate
NX = 35
Y MESH
NY = 31
Z MESH
NZ = 42
3D VIEW
CELLS = 45570

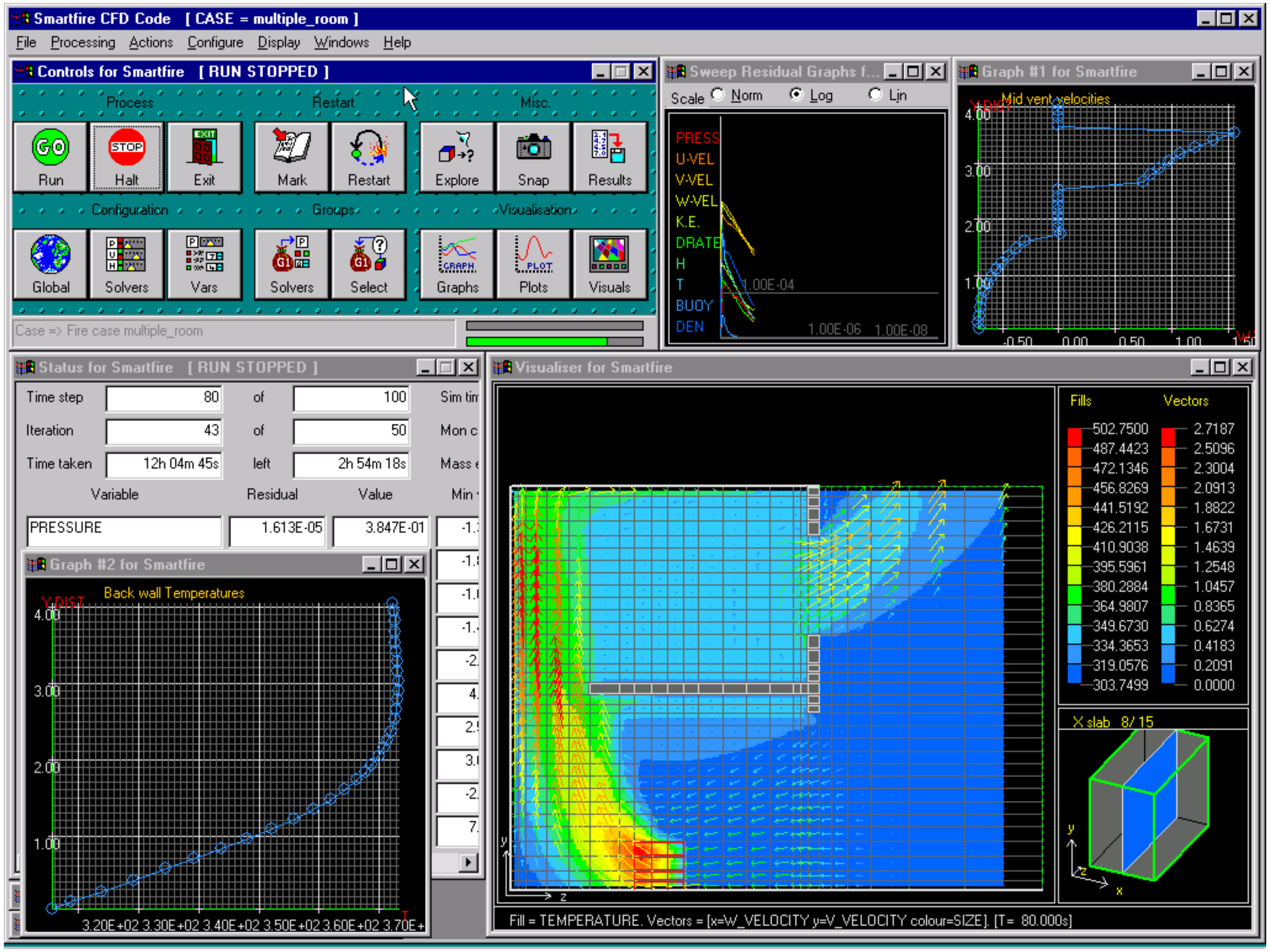
4) SMARTFIRE


Smartfire Mesh Specification KBS
File Windows Help
Log Output for KBS
Calculating Spline Distribution for slice 2 in the Z direction.
Calculating Spline Distribution for slice 2 in the Z direction.
Calculating Spline Distribution for slice 2 in the Z direction.
Calculating Spline Distribution for slice 2 in the Z direction.
Calculating Spline Distribution for slice 2 in the Z direction.
Calculating Spline Distribution for slice 2 in the Z direction.
Calculating Spline Distribution for slice 2 in the Z direction.
Calculating Spline Distribution for slice 4 in the Z direction.
Calculating Spline Distribution for slice 4 in the Z direction.
Calculating Spline Distribution for slice 4 in the Z direction.
Calculating Spline Distribution for slice 4 in the Z direction.
Calculating Spline Distribution for slice 4 in the Z direction.
Calculating Spline Distribution for slice 4 in the Z direction.
Calculating Spline Distribution for slice 4 in the Z direction.
Total Cells: 13671
Divided into X-21, Y-21, Z-31
KBS Minimum Cell Budget 13020
User Entered Cell Budget 13020
Actual Generated Cell Budget 13671
Finished Normally.
KBS Generated Mesh Options
Accept
Decline
Exit
Use this KBS Generated Mesh?
KBS Mesh Viewer
View XZ
View XY
View ZY
Dec X
0.0
Inc X
Dec Y
0.0
Inc Y
Dec Z
0.0
Inc Z
BM
Grid
Both
X
Z

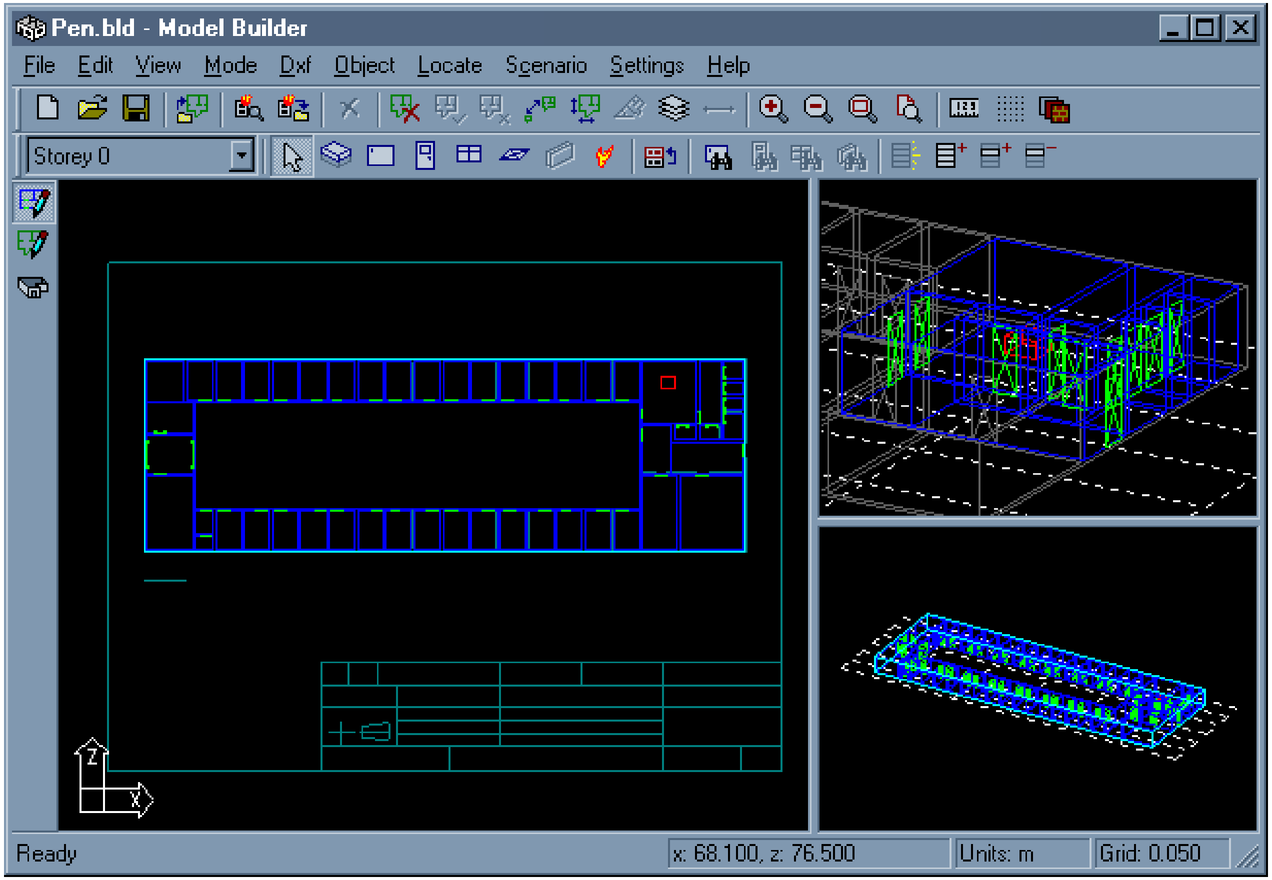
4) SMARTFIRE


Smartfire CFD Code [CASE = multiple_room_end_sim]
File Processing Actions Configure Display Windows Help
Controls for Smartfire [RUN STOPPED]
Process
Restart
Misc.
Run
Halt
Exit
Mark
Restart
Explore
Snap
Results
Configuration
Groups
Visualisation
Global
Solvers
Vars
Solvers
Select
Graphs
Plots
Visuals
Case => Fire case multiple_room
Status for Smartfire [RUN STOPPED]
Time step 13 of 110 Sim time 13.000
Iteration 95 of 100 Mon cell 4210
Time taken 0h 46m 22s left 32h 50m 51s Mass error 1.8919E-05
Variable Residual Value Min value Max value
PRESSURE 3.952E-05 5.361E-01 -4.952E-01 4.560E+00
U_VELOCITY 9.062E-03 1.768E-04 -1.452E+00 1.452E+00
V_VELOCITY 4.109E-03 -7.410E-02 -9.527E-01 3.410E+00
W_VELOCITY 6.482E-03 -2.028E-01 -1.777E+00 1.536E+00
KINETIC_ENERGY 5.766E-05 6.529E-04 -3.173E-06 3.579E-02
DISSIPATION_RATE 2.223E-05 9.665E-05 4.933E-15 6.826E-02
ENTHALPY 3.924E-05 3.181E+05 2.551E+05 7.229E+05
TEMPERATURE 3.755E-05 3.042E+02 3.037E+02 5.343E+02
BUOYANCY 4.900E-07 -5.888E-05 -2.042E-02 0.000E+00
DENSITY 1.537E-05 1.175E+00 6.692E-01 1.600E+03
Graph #1 for Smartfire
Temperatures above fire
3.50E+02 4.00E+02 4.50E+02 5.00E+02
Graph #2 for Smartfire
Velocities through vents
-0.25 0.00 0.25 0.50 0.75
Time-step Value Graphs for Smartfire
Sweep Value Graphs for Smartfire
Scale Norm Log Lin
PRESS
U-VEL
V-VEL
W-VEL
K.E.
DRATE
H
T
BUOY
DEN
1.00E-01
1.00E-02
1.00E-03
Time-step Residual Graphs for Smartfire
Sweep Residual Graphs for Smartfire
1.00E-04
1.00E-06 1.00E-08
Visualiser for Smartfire
Fills
Vectors
534.3915
516.6498
498.9081
481.1665
463.4248
445.6832
427.9415
410.1999
392.4582
374.7165
356.9749
339.2332
321.4915
303.7499
3.4179
3.1550
2.8921
2.6292
2.3663
2.1033
1.8404
1.5775
1.3146
1.0517
0.7888
0.5258
0.2629
0.0000
X slab 8/15
Fill = TEMPERATURE. Vectors = [x=W_VELOCITY y=V_VELOCITY colour=SIZE] [T= 13.000s]

4) SMARTFIRE

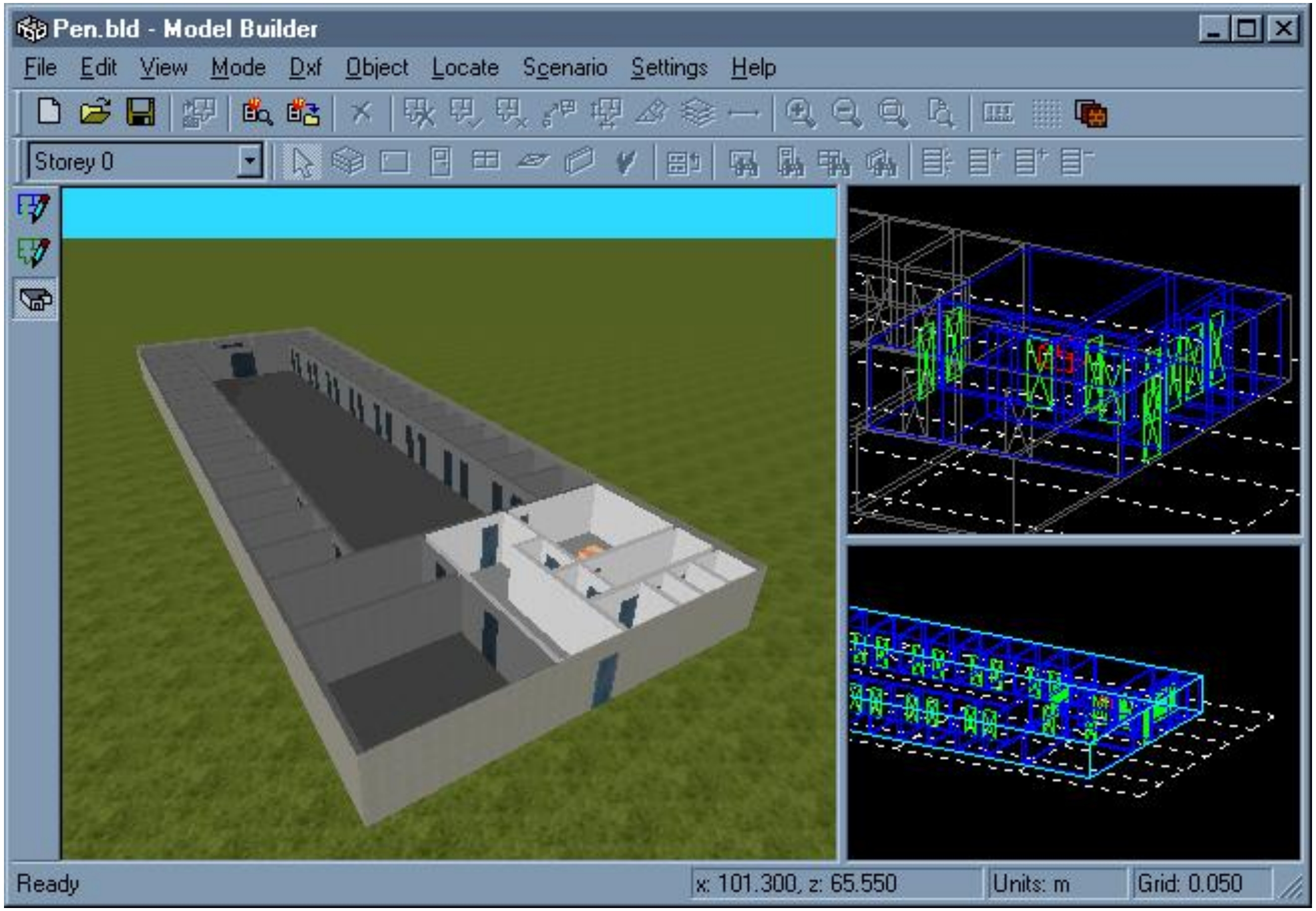

Smartfire CFD Code [CASE = multiple_room]
File Processing Actions Configure Display Windows Help
Controls for Smartfire [RUN STOPPED]
Process
Restart
Misc.
Run
Halt
Exit
Mark
Restart
Explore
Snap
Results
Configuration
Groups
Visualisation
Global
Solvers
Vars
Solvers
Select
Graphs
Plots
Visuals
Case => Fire case multiple_room
Sweep Residual Graphs f...
Scale Norm Log Lin
PRESS
U-VEL
V-VEL
W-VEL
K.E.
DRATE
H
T
BUOY
DEN
1.00E-04
1.00E-06 1.00E-08
Graph #1 for Smartfire
Mid vent velocities
Status for Smartfire [RUN STOPPED]
Time step 80 of 100
Iteration 43 of 50
Time taken 12h 04m 45s left 2h 54m 18s
Variable Residual Value
PRESSURE 1.613E-05 3.847E-01
Graph #2 for Smartfire
Back wall Temperatures
3.20E+02 3.30E+02 3.40E+02 3.50E+02 3.60E+02 3.70E+
Visualiser for Smartfire
Fills Vectors
502.7500 2.7187
487.4423 2.5096
472.1346 2.3004
456.8269 2.0913
441.5192 1.8822
426.2115 1.6731
410.9038 1.4639
395.5961 1.2548
380.2884 1.0457
364.9807 0.8365
349.6730 0.6274
334.3653 0.4183
319.0576 0.2091
303.7499 0.0000
X slab 8/ 15
Fill = TEMPERATURE. Vectors = [x=W_VELOCITY y=V_VELOCITY colour=SIZE]. [T= 80.000s]

4) SMARTFIRE

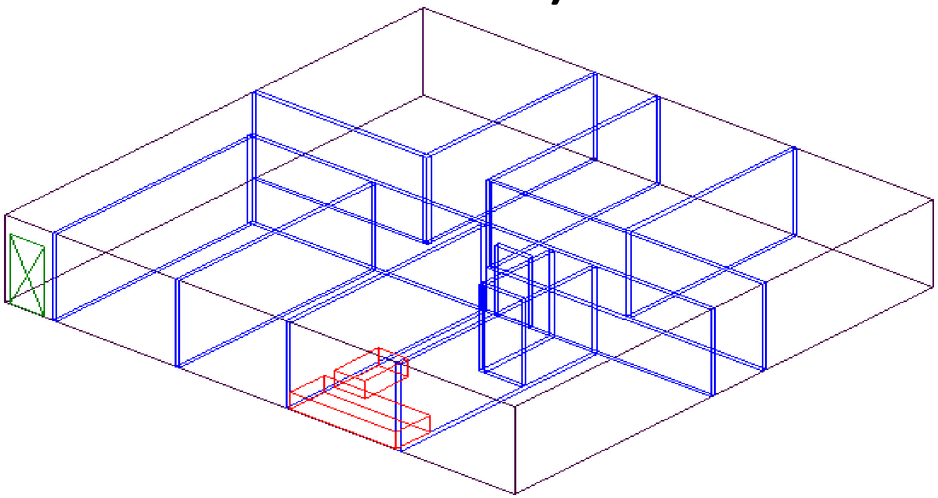


Pen.bld - Model Builder
File Edit View Mode Dxf Object Locate Scenario Settings Help
Storey 0
Ready
x: 68.100, z: 76.500
Units: m
Grid: 0.050

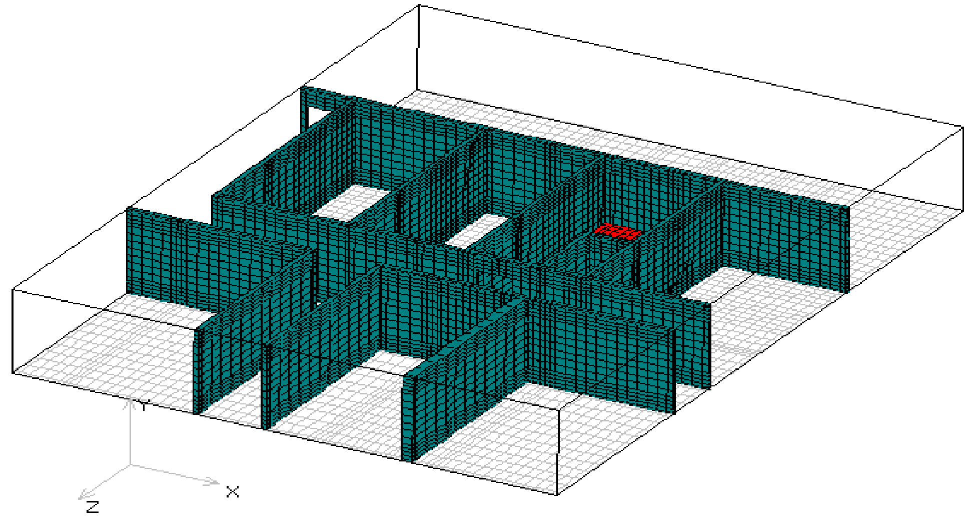
4) SMARTFIRE


Pen.bld - Model Builder
File Edit View Mode Dxf Object Locate Scenario Settings Help
Storey 0
Ready
x: 101.300, z: 65.550
Units: m
Grid: 0.050

4) SMARTFIRE

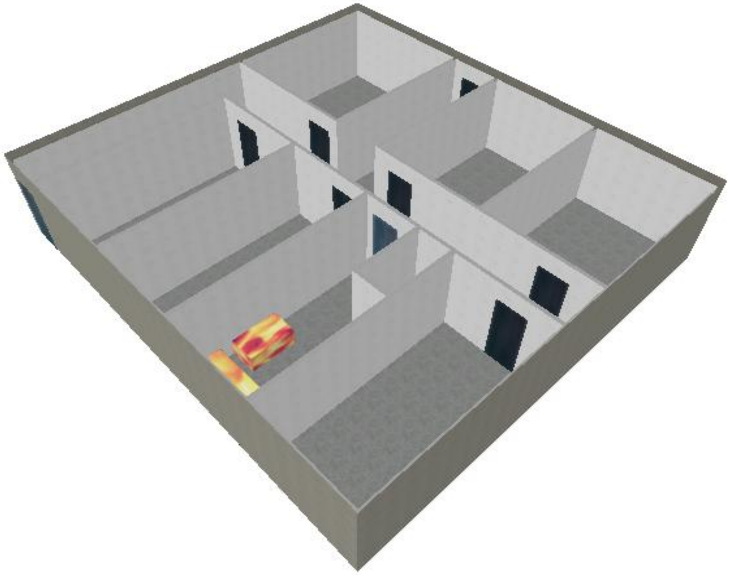


(a) Cenário importado

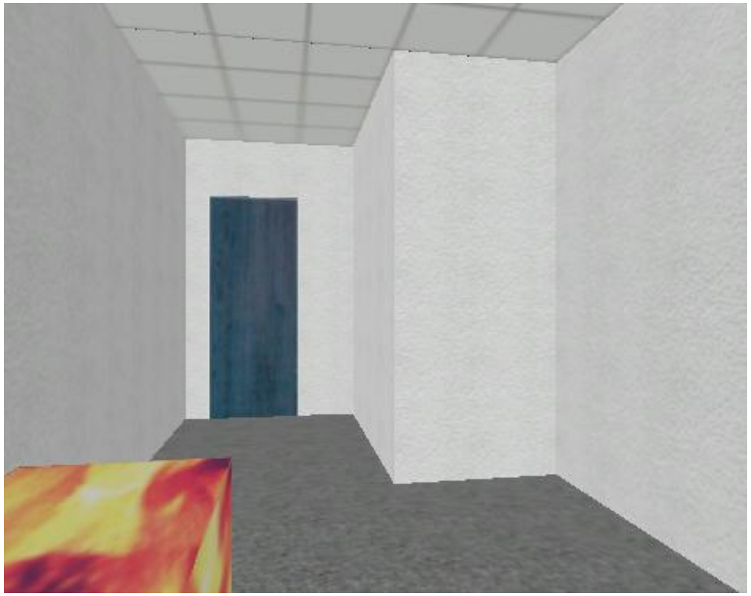


(b) Malha criada com o SMARTFIRE

4) SMARTFIRE

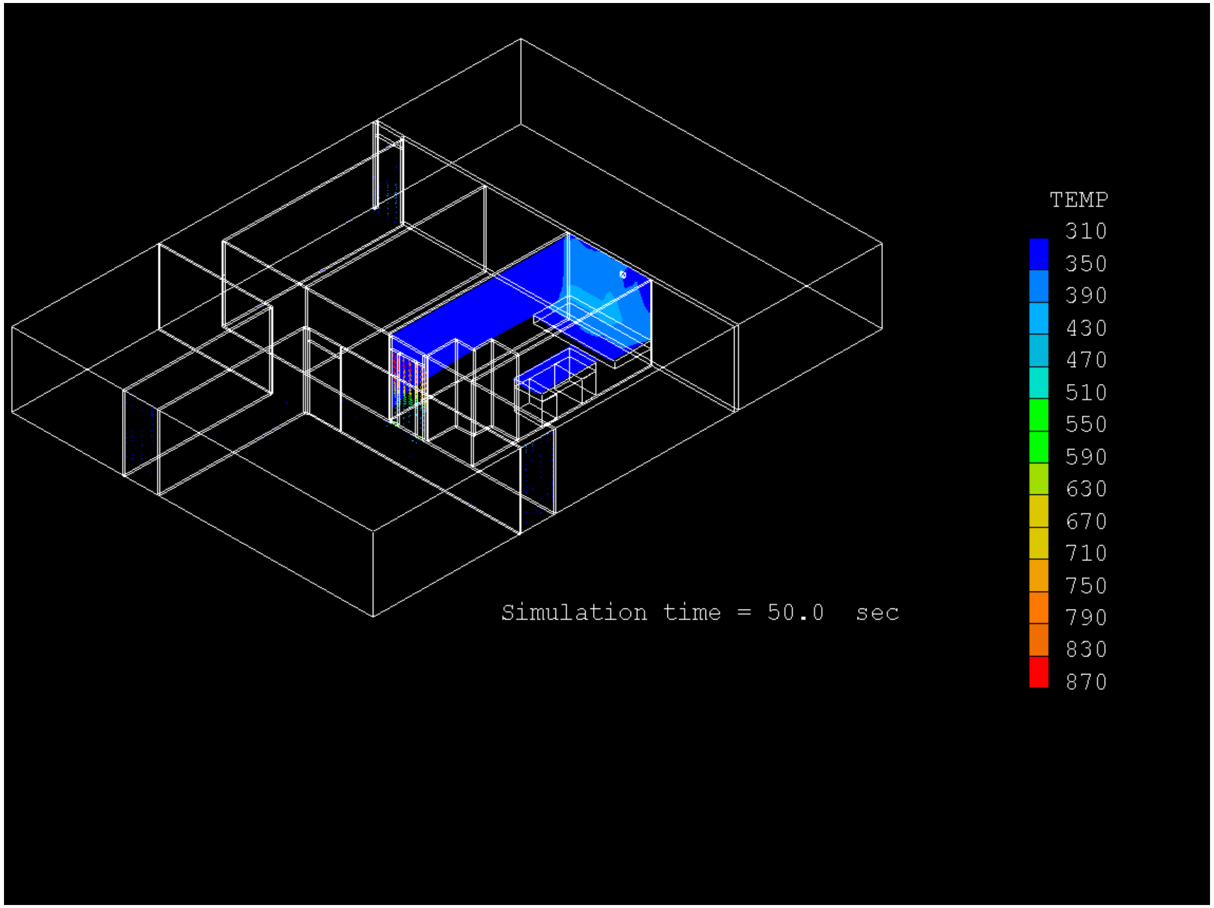


(a) Cenário - perspectiva

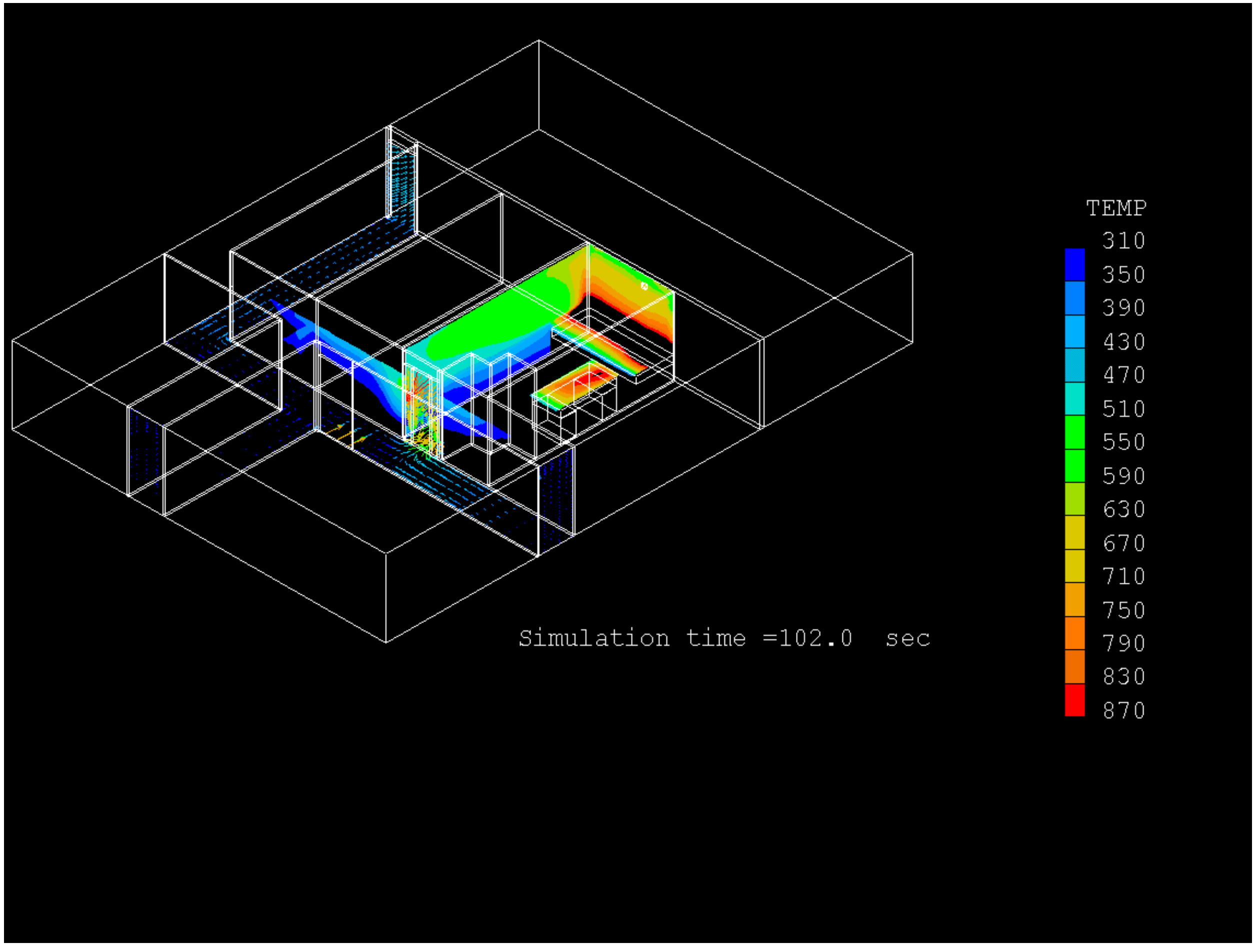


(b) Visão interna

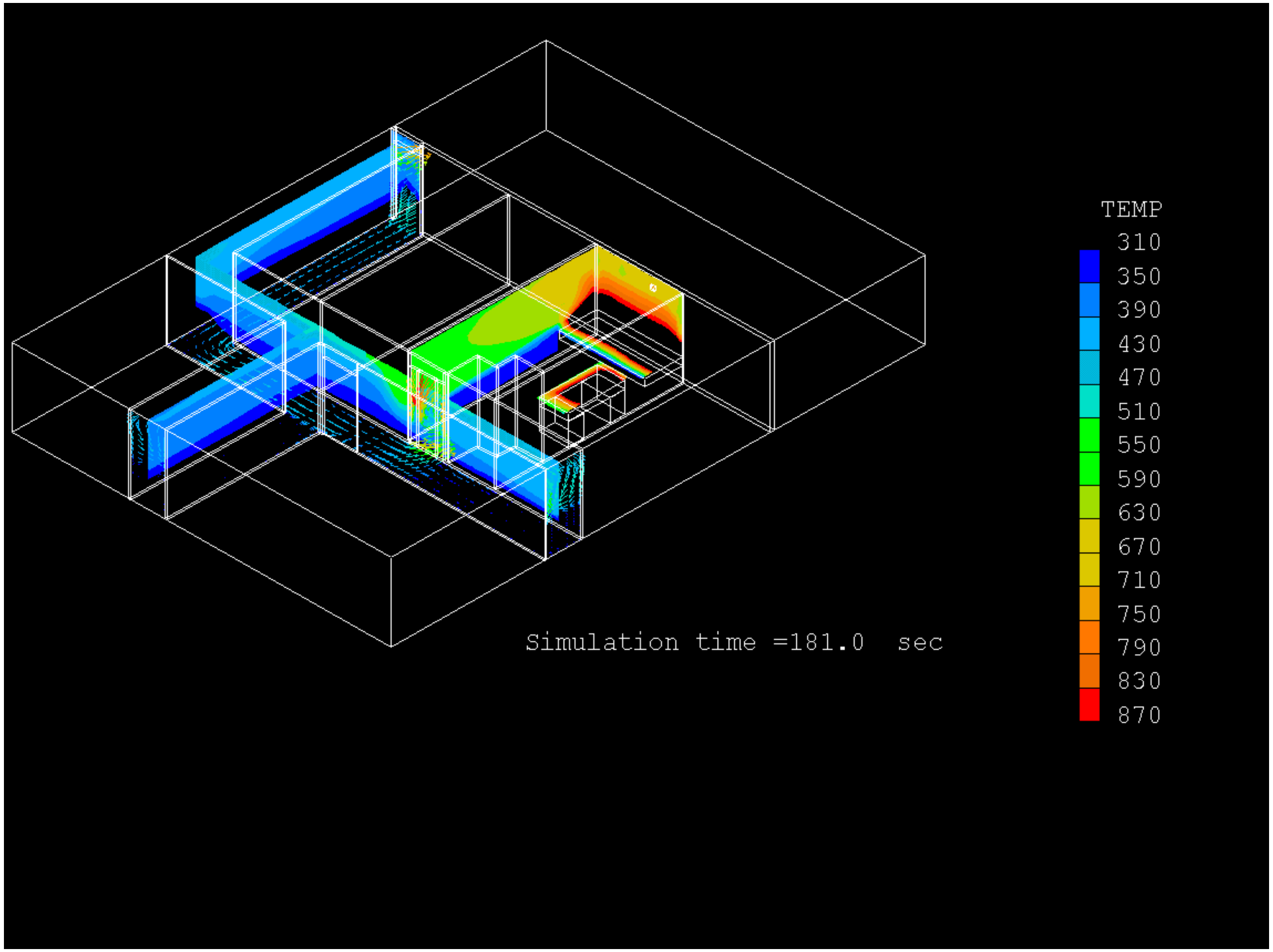
Pequeno exemplo



4) SMARTFIRE


TEMP
310
350
390
430
470
510
550
590
630
670
710
750
790
830
870
Simulation time =102.0 sec

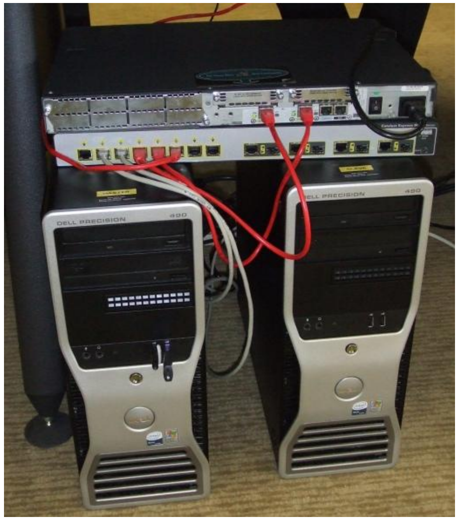
4) SMARTFIRE

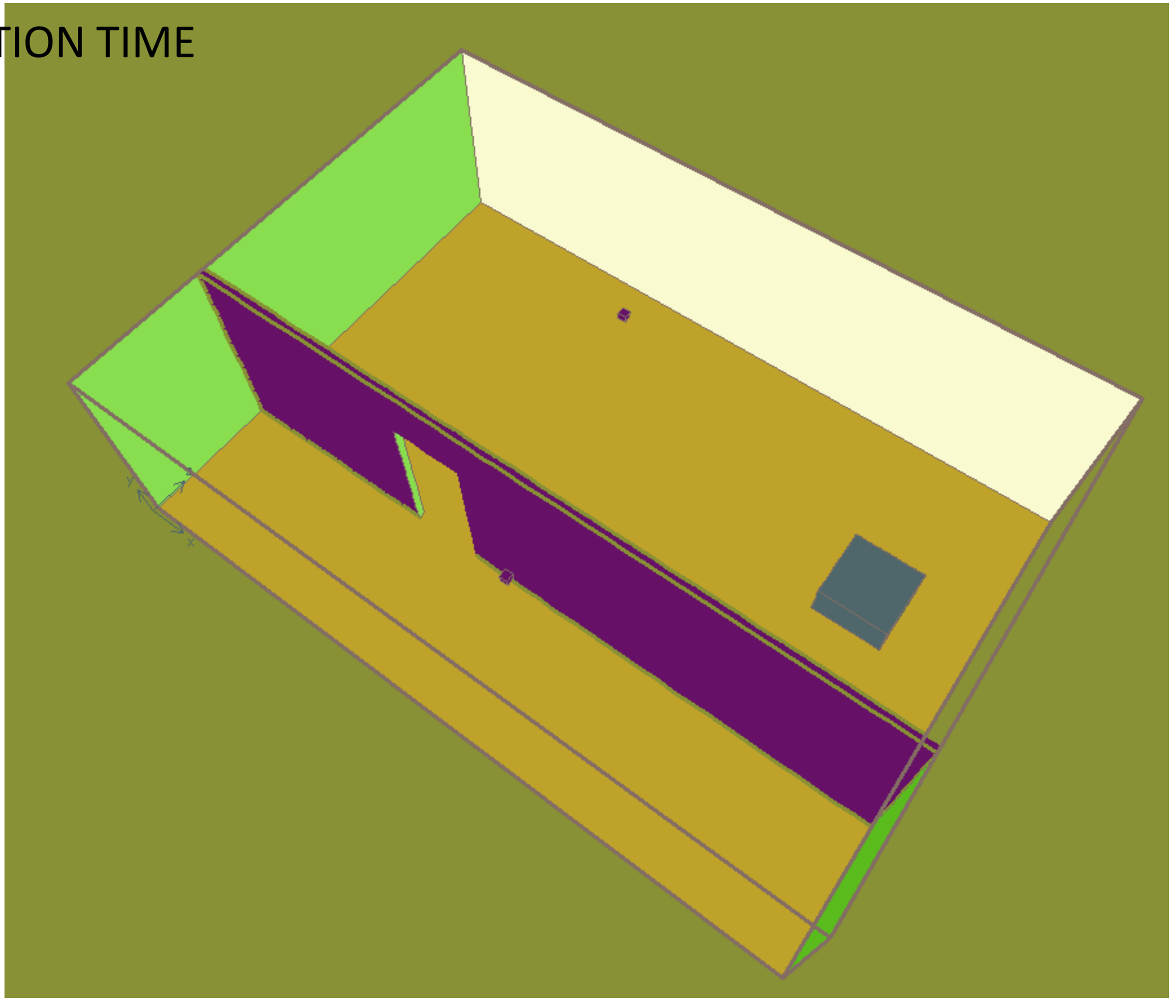

TEMP
310
350
390
430
470
510
550
590
630
670
710
750
790
830
870
Simulation time =181.0 sec

Algumas aplicações

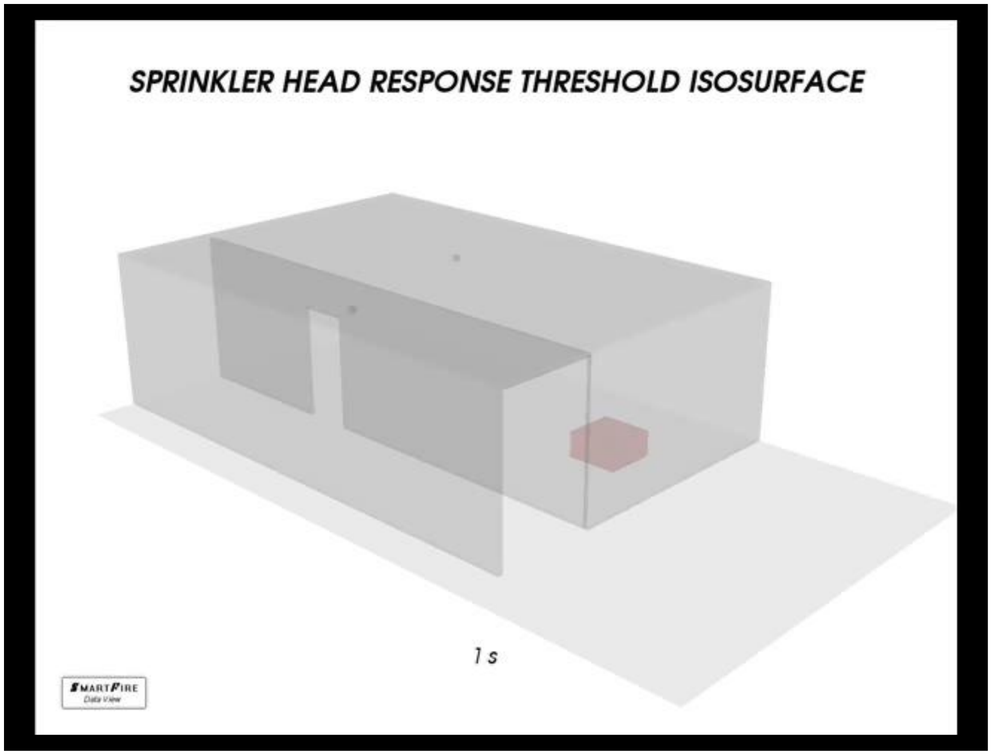
EXAMPLE 1
FIRE IN A SMALL SERVER ROOM

- SPRINKLER ACTIVATION TIME
- SMOKE DETECTOR ACTIVATION TIME
- COINCIDENCE DETECTION

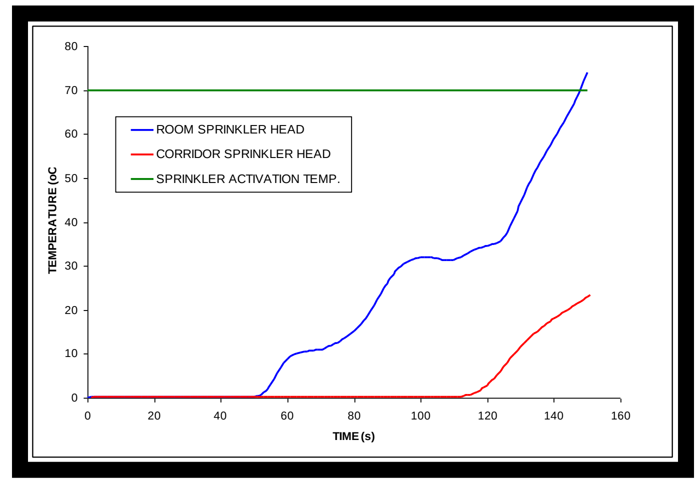




SPRINKLER ACTIVATION TIME

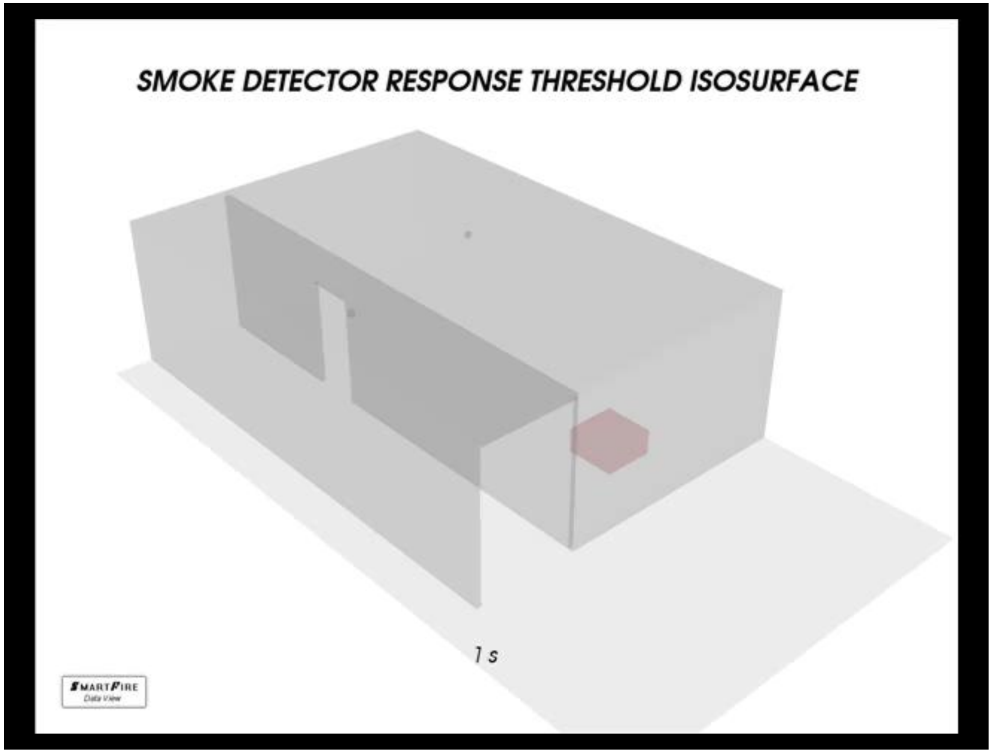


VIDEO TO SHOW 70 ^{o}C TEMPERATURE SPREAD

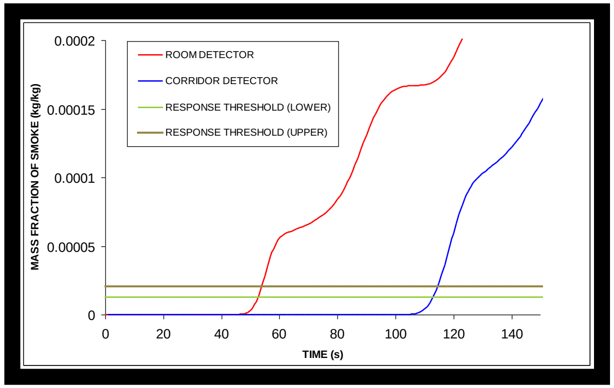


GRAPH TO SHOW TEMPERATURE AT THE SPRINKLER HEADS

SMOKE DETECTOR ACTIVATION TIME

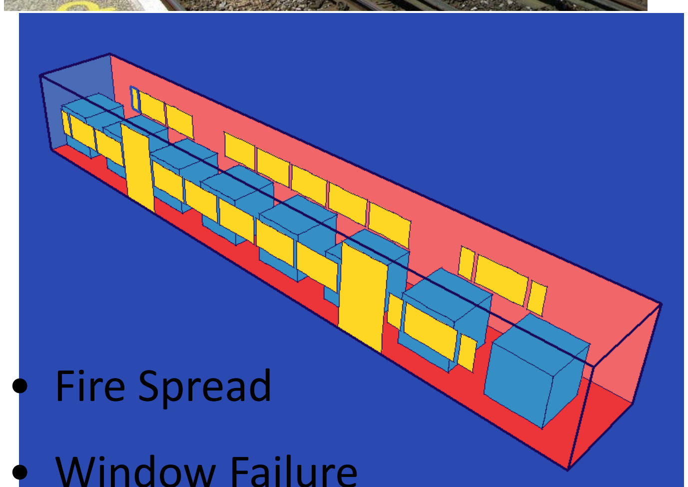


VIDEO TO SHOW SPREAD OF SMOKE WITH DENSITY EQUAL TO THE DETECTOR RESPONSE THRESHOLD

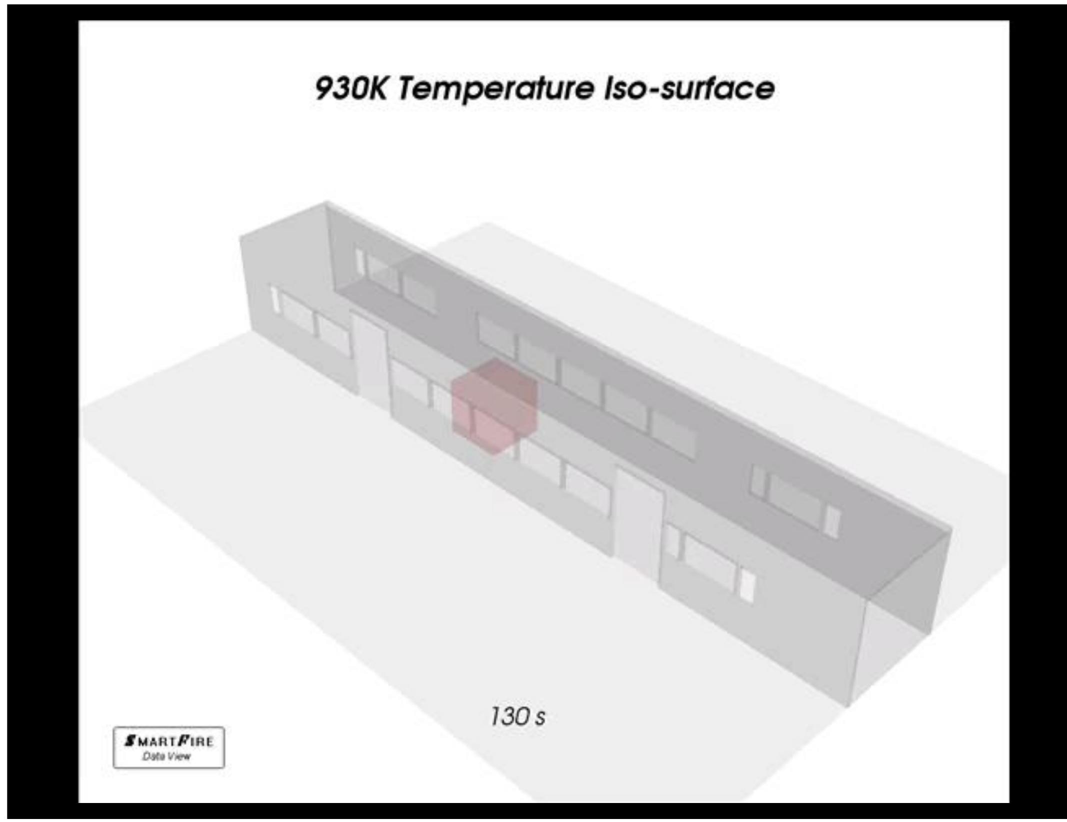


GRAPH TO SHOW SMOKE DENSITY AT THE DETECTOR HEADS

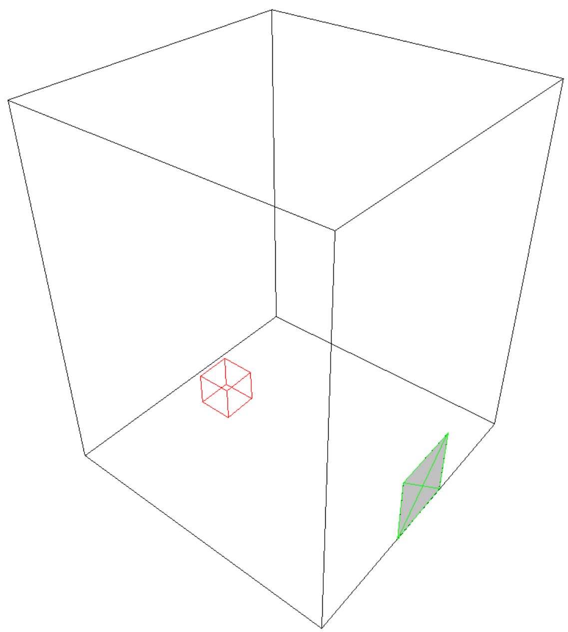
EXAMPLE 2
TRAIN CARRIAGE FIRE



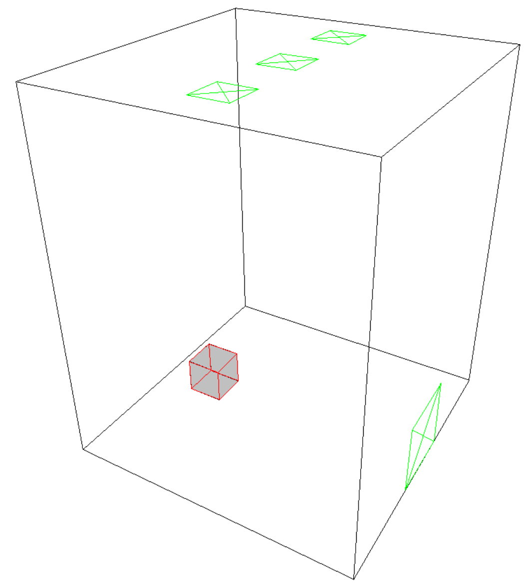
- Fire Spread
- Window Failure



EXAMPLE 3
FIRE IN ATRIA

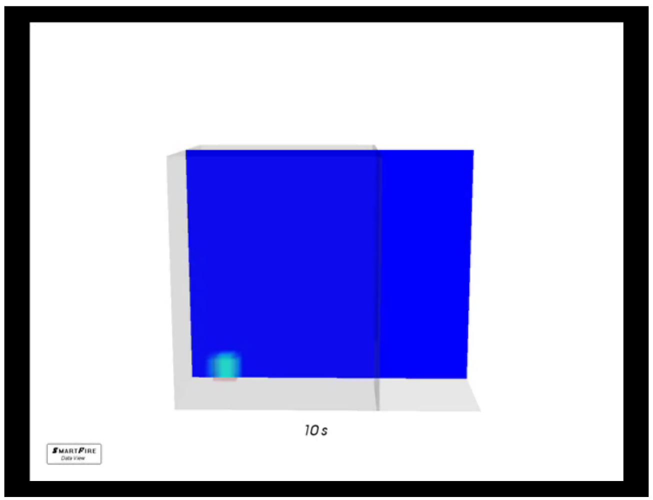


Geometry 1

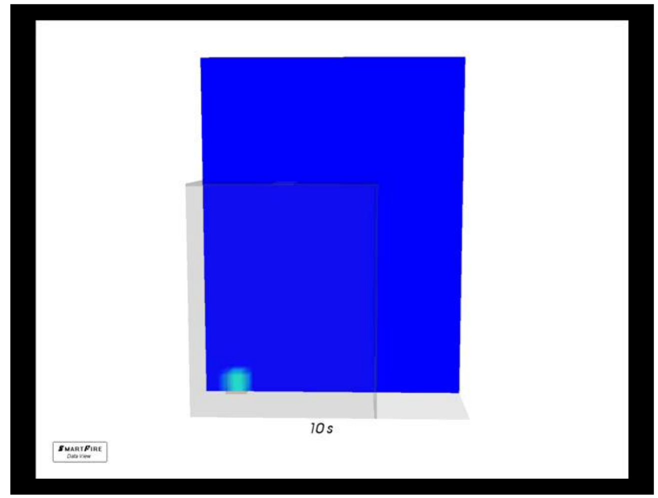


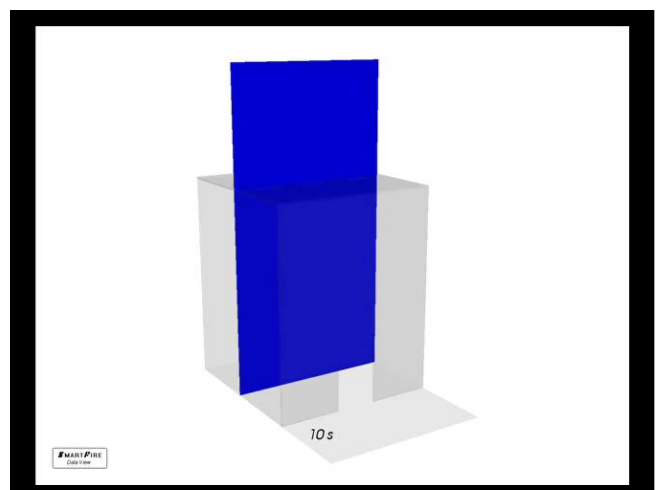
Geometry 2 – with natural ventilation

SMOKE CUT PLANES



Geometry 1- Results



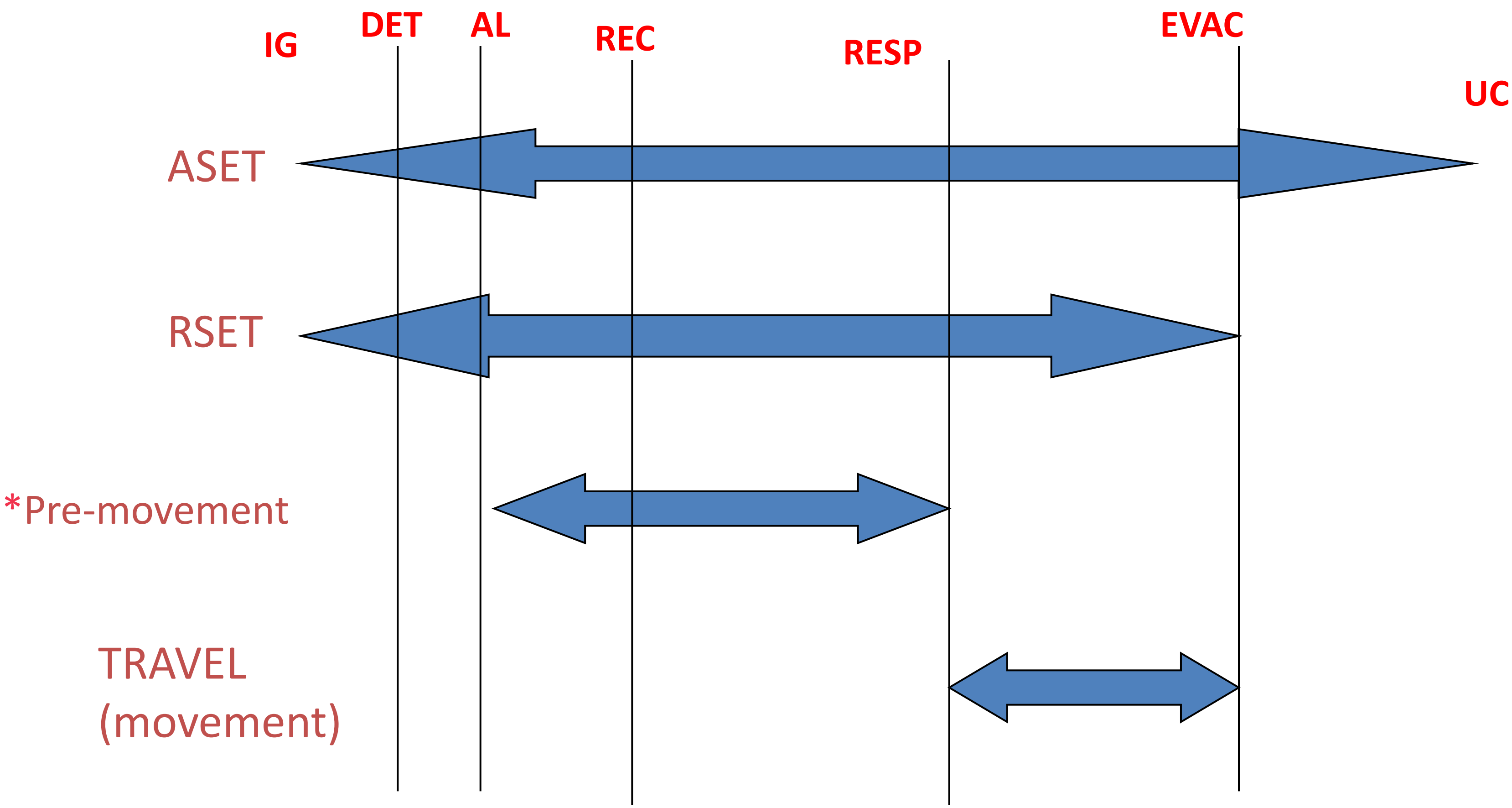


Geometry 2- Results

BENEFITS OF FIRE MODELLING USING CFD

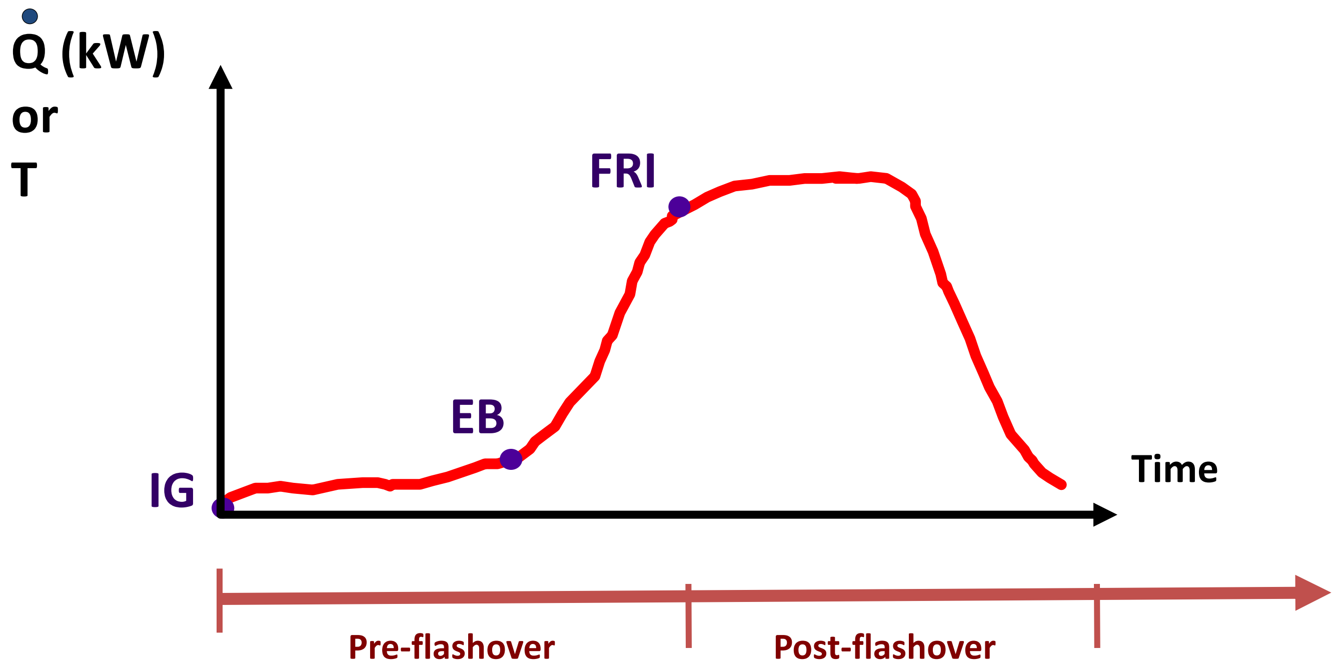
- Representative results possible for complex geometries and scenarios
- Helps reduce the need for over engineering inherent in many prescriptive codes
- Can provide cost effective solutions to smoke control problems, especially in unusual or complicated geometries. i.e. Atria, Transport Terminals etc.
- Can be used to assess the necessity and/or effectiveness of existing smoke control systems
- Calculate detection and sprinkler activation times
- Analyse the impact of fire on structural elements
- Can be used in conjunction with Evacuation Modelling to ensure RSET < ASET

ASET and RSET



*Pre-movement = Pre-evacuation

Typical Fire Behaviour in an Enclosure



(adaptation from Kawagoe, K.[1])

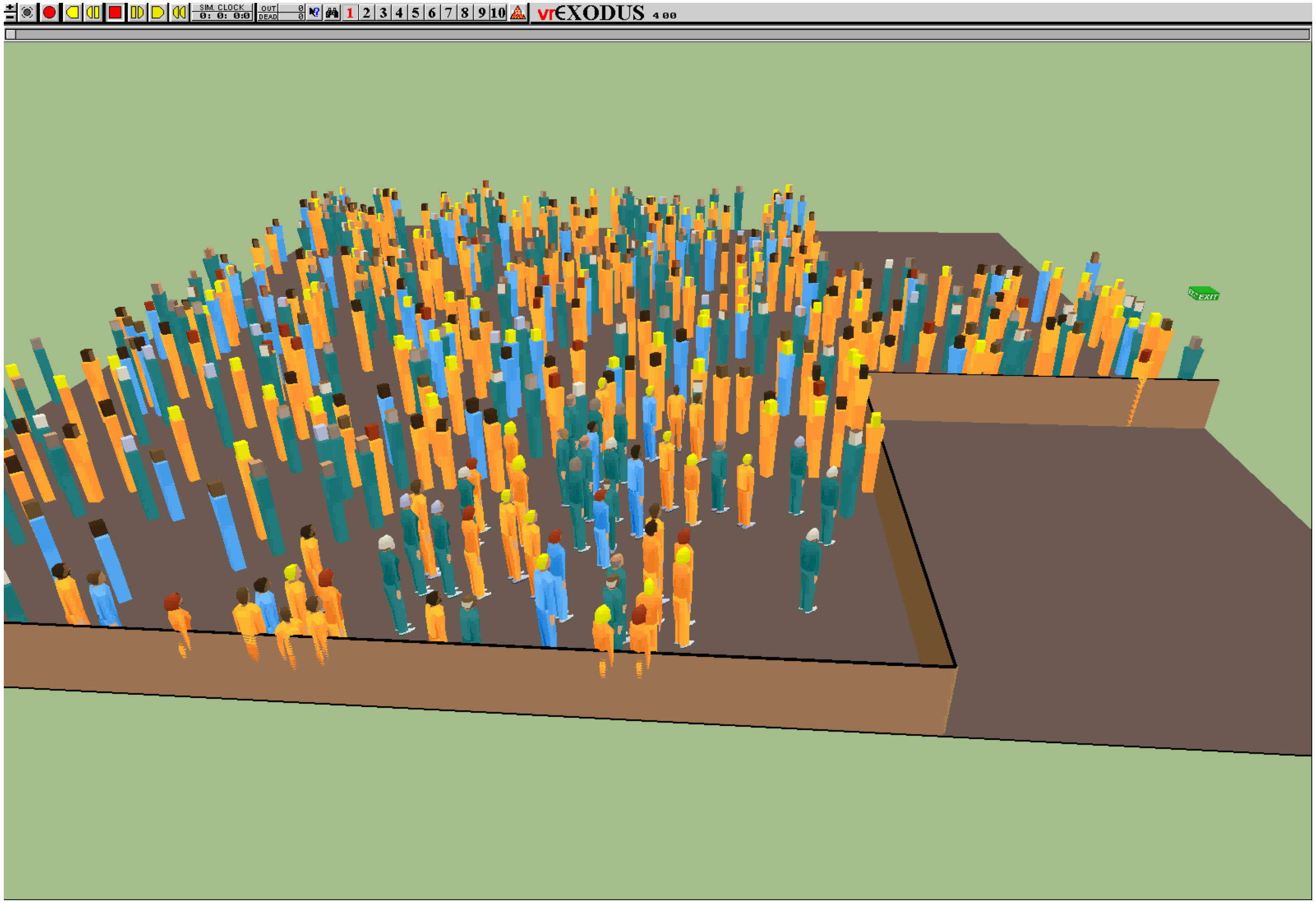
IG – Ignition

EB – Establishment of the Burning

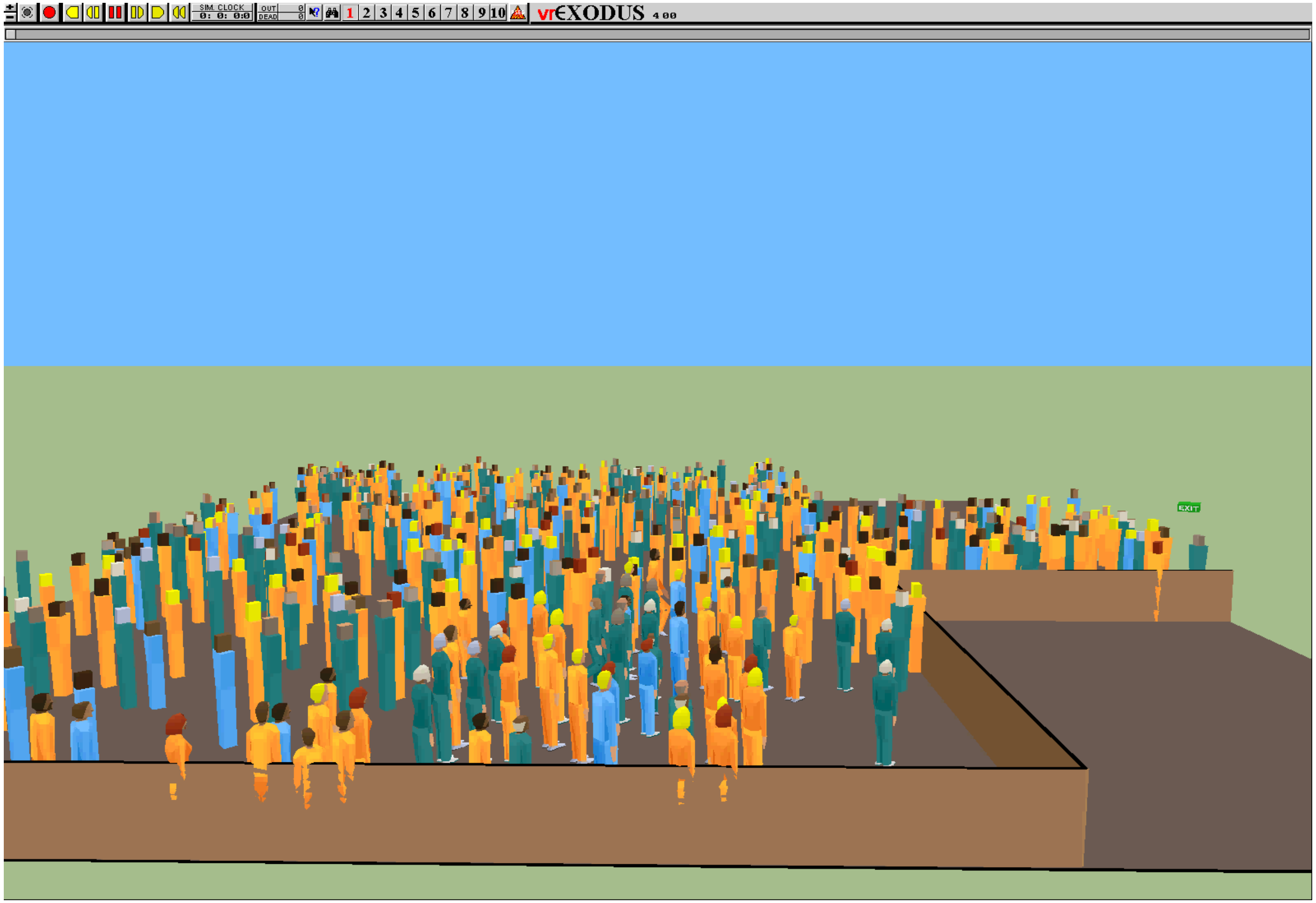
FRI – Full Room Involvement

1. "Fire Behaviour in Rooms", Report No. 27, Building Research Institute, Tokyo, 1958

FIRE IN AN ATRIUM
(without vents)



FIRE IN AN ATRIUM
(with vents)



The Benefits of Combined Modelling

- More realistic results:

Safe Design = RSET $<$ ASET

Specific design

Hand Calculations:

RSET $<$ ASET

(20 sec) $<$ (25 sec)

Combined Analysis:

RSET $>$ ASET

(28 sec) $>$ (25 sec)

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The development of a real performance-based solution through the use of People Movement Modelling Analysis (PeMMA) combined with fire modelling analysis

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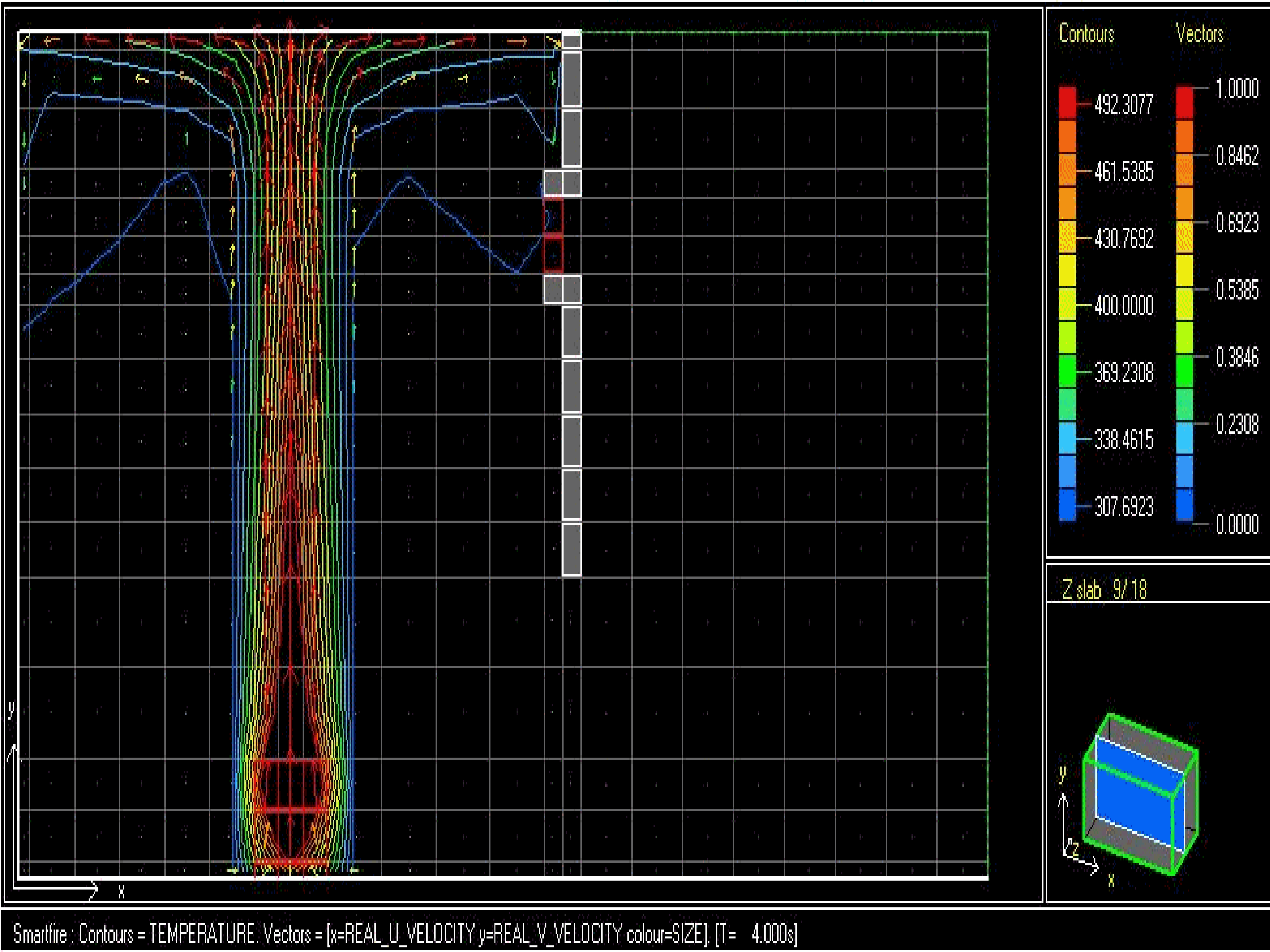
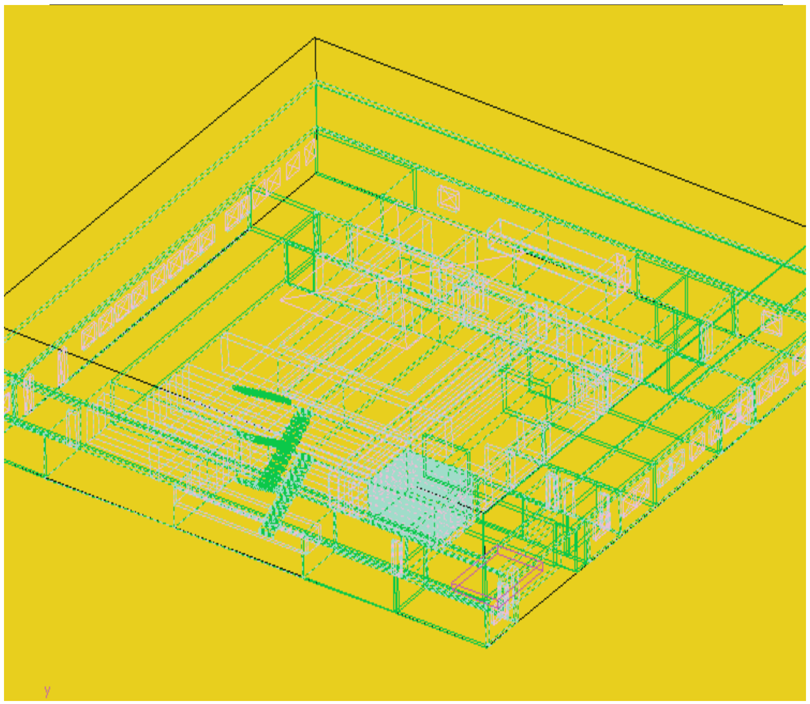
[a] IPT – Instituto de Pesquisas Tecnológicas (Institute of Technological Research), Laboratório de Segurança ao Fogo – LSF (Laboratory of Fire Safety), Av. Prof. Almeida Prado 532 Cid. Universitária., 05508-901 São Paulo, Brazil

[b] CAPITA SYMONDS Fire Engineering Team, United Kingdom[12]



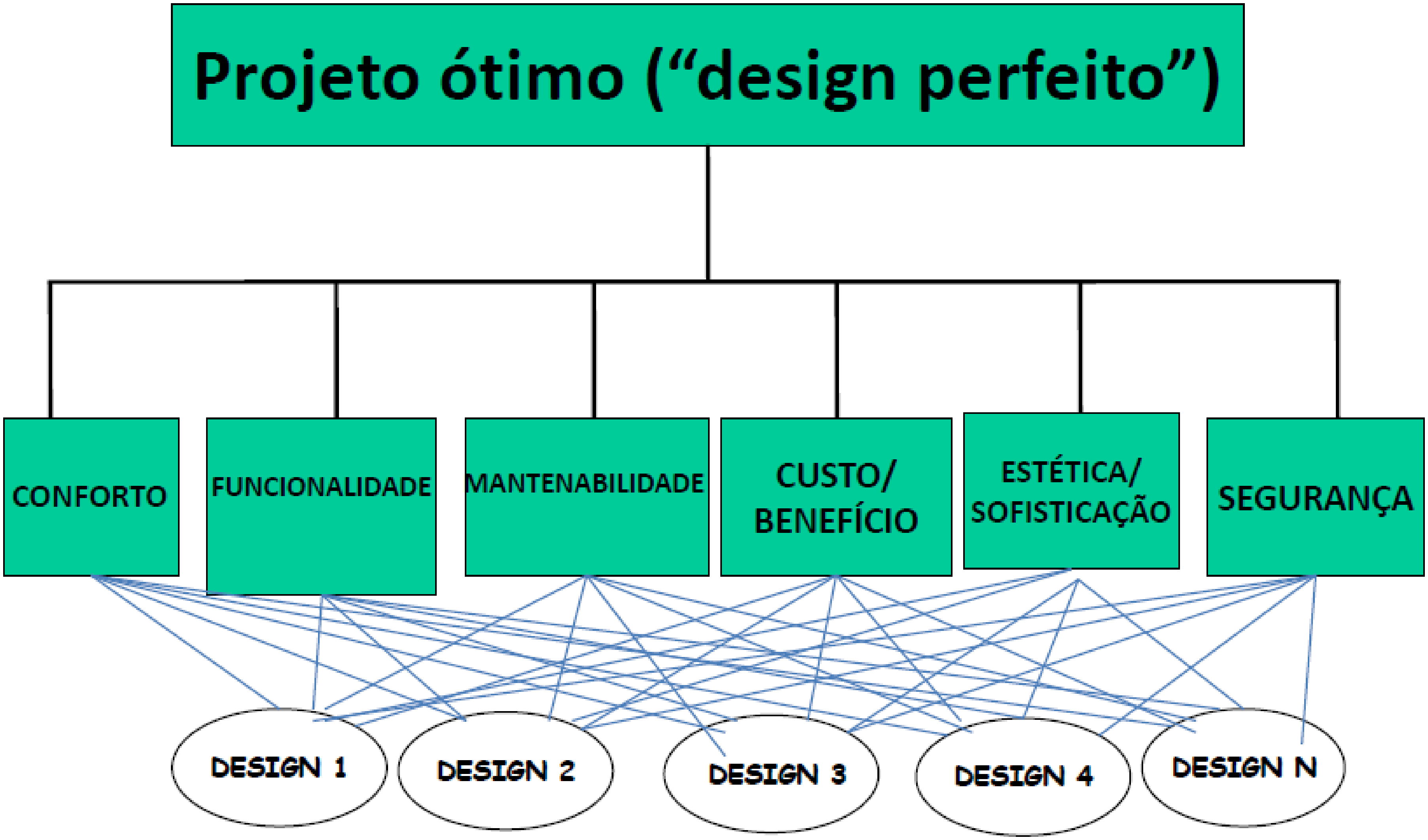
Contours
Vectors
492.3077
461.5385
430.7692
400.0000
369.2308
338.4615
307.6923
1.0000
0.8462
0.6923
0.5385
0.3846
0.2308
0.0000
Z slab 9/ 18
y
x
z
Smartfire : Contours = TEMPERATURE. Vectors = [x=REAL_U_VELOCITY y=REAL_V_VELOCITY colour=SIZE]. [T= 4.000s]

1. Why model?



Design = Information System

time = f (x,y,z,...)



Rodrigo Machado Tavares

2) Contexto da Arquitetura no cenário internacional

PROJETOS ARQUITETÔNICOS

- CONFORTO
- FUNCIONALIDADE
- MANENTABILIDADE
- ESTÉTICA
- CUSTO/BENEFÍCIO;
- **SEGURANÇA**

PROJETO ARQUITETÔNICO ÓTIMO: É AQUELE QUE OFERECE TRÊS ASPECTOS FUNDAMENTAIS AOS USUÁRIOS

Rodrigo Machado Tavares

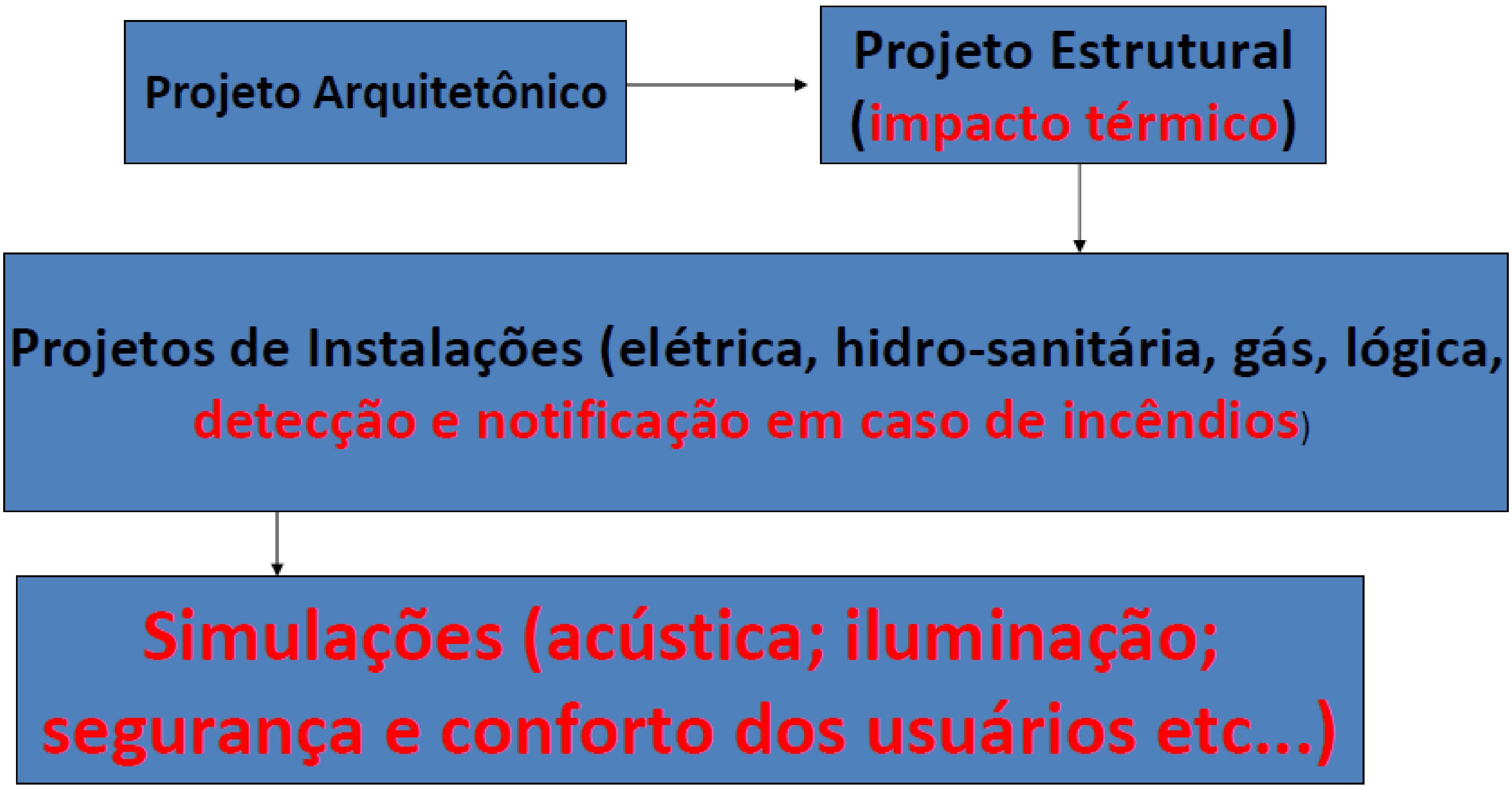
2) Contexto da Arquitetura no cenário internacional

Rodrigo Machado Tavares

2) Contexto da Arquitetura no cenário internacional

UNIÃO entre os "designers": arquitetos + engenheiros (de cálculo estrutural; instalações hidro-sanitárias; ambiental; de segurança contra incêndios; de iluminação; de acústica etc...).

2) Contexto da Arquitetura no cenário internacional



Rodrigo Machado Tavares