CFD Modelling for Smoke Movement

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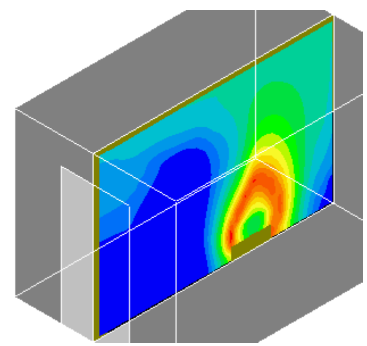

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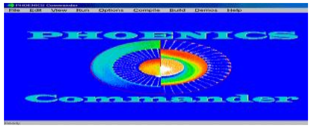
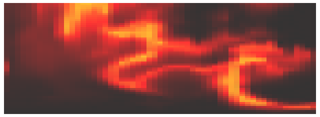
1. CFD Information

Common CFD software packages

- PHOENICS: CHAM



- FLUENT: ANSYS
- STAR-CD(CCM+): CD-ADAPCO
- FLOW-3D: Flow Science
- FLOVENT: Mentor Graphics
- Fire Dynamics Simulator (FDS): NIST



CFD: >> Computational Fluid Dynamics

- CFD is not only for general computational fluid dynamics, but also numerical heat transfer (NHT), etc.
- A discipline that predicts fluid flow, heat and mass transfer, chemical reactions, and other wide range phenomena.
- CFD simulation is to solve the mathematical equation sets which describing the real phenomena with reasonable simplifications.
- To predict the distribution and change of the related parameters (e.g. temperature, velocity, pressure, concentration, etc.).

CFD: >> Computational Fluid Dynamics

- CFD is a numerical simulation that describes the basic equations governing conservation of mass, conservation of momentum and conservation of energy. Numerical methods are used to describe the mathematical equations of fluid flow, numerical solutions are obtained at discrete positions in time and space, and the laws of flow and physical properties of flow are revealed.
- Discrete regions are solved for many small time intervals. During these small time intervals, the approximate differential equations are represented by a series of algebraic equations that can be solved by computer.
- The accuracy of the solution depends on the various computational tools and discrete methods used
- Verification & Validation

CFD Components

- Mathematical and physical models (turbulence, radiation, combustion and chemical reactions, etc.)
- Discrete methods: finite volume method, finite element method, finite difference method, boundary element method
- Computational Grids: Structured Grids, Multiple Grids, Adaptive Grids, and Unstructured Grids (Meshless: Lattice Boltzmann, etc.)
- Solution: non-stick Euler equation, viscous NS equation, turbulence n equation model, Reynolds stress model, direct numerical simulation and large eddy simulation, etc.
- Simulation steps: Preprocessing model, solving process and post-processing results

CFD development stages

- Initial Stage (1960-1970s): To solve the basic theoretical problems of CFD, such as the model equations (turbulence, rheology, heat transfer, radiation, gas particles, chemical reactions, combustion, etc.), numerical methods (differential format, algebraic equations, etc.), meshing, Preparation and implementation.
- Industrial applications (1970-1980s): To discuss the feasibility, reliability and popularization and application of CFD in solving various practical engineering problems. Professional research team, the software is not interchangeable. Spalding / CHAM Company: PHOENICS.
- Rapid development (1980s-1990s): Has been fully recognized in academia. Promoted by CHAM company (Spalding), Partaker promotion in the United States.
- Widely used since 2000s

2. Why CFD Modelling for Smoke Control ?

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Why Study Smoke Movement

- There are always smoke produced in the fire
- Smoke moves more fast than flame spread
- Smoke is the major killer in the building fire
- Criteria on fire safety is closely related with smoke
- Smoke control is critical for the fire safety design

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Why Study Smoke Movement by CFD

- Impossible to solve more complicated problems by simple formula
- Too much cost or inconvenient for real test
- Smoke movement (especially for static system) is highly influenced by the building configuration/shape, smoke extraction performance might be greatly reduced if only considering volume/height as in most code/standard (e.g. 8 ACH)
- CFD has the capability to deal with complex design challenges
  - Quite accurate results with technique developed
  - Flexible to adjust the design by the computer model
  - Fast & convenient by the personal computers
  - More detailed information predicted on the environment described by the velocity vector, temperature and smoke concentrations are useful for deriving the relevant macroscopic parameters for engineering purposes

CFD for Smoke Movement

- Comprehensive information will be generated with 3D simulation reflecting the real scenario.
- To predict more parameters: combustion products and toxic gases concentration and distribution, the amount of smoke production and flow distribution, visibility of air, air temperature, thermal radiation intensity distribution, etc.
- To assess the capacity and effectiveness of mechanical or static smoke extraction system, rationality of smoke outlet distribution, in complex building such as large atriums or irregular building spaces
- Graphical output of the geometry, temperature and other parameters from the CFD results is desirable

3. How CFD Modelling for Smoke Control

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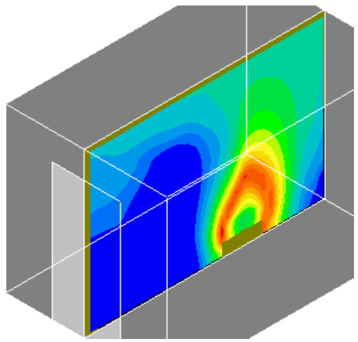
CFD for Smoke Movement

- Identify the practical problem and objective
- Parameters (temperature distribution, smoke layer, etc.) to be predicted
- Geometry (including building , equipment, adjacent structures) and environment information (weather, direction, wind, etc.)

- CFD Model (FDS is capable or not) and support software (pre & post processing software required?)
- To prepare relevant information (smoke extraction rate and grilles distribution) or basic calculation following handbook/standard/code



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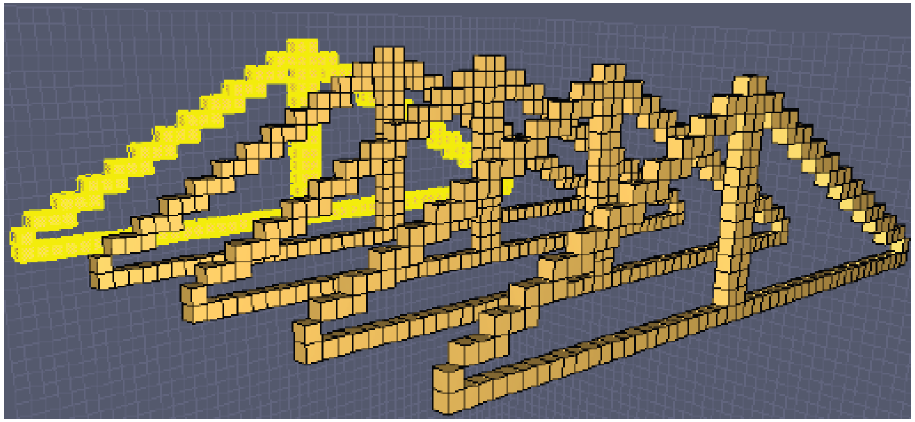
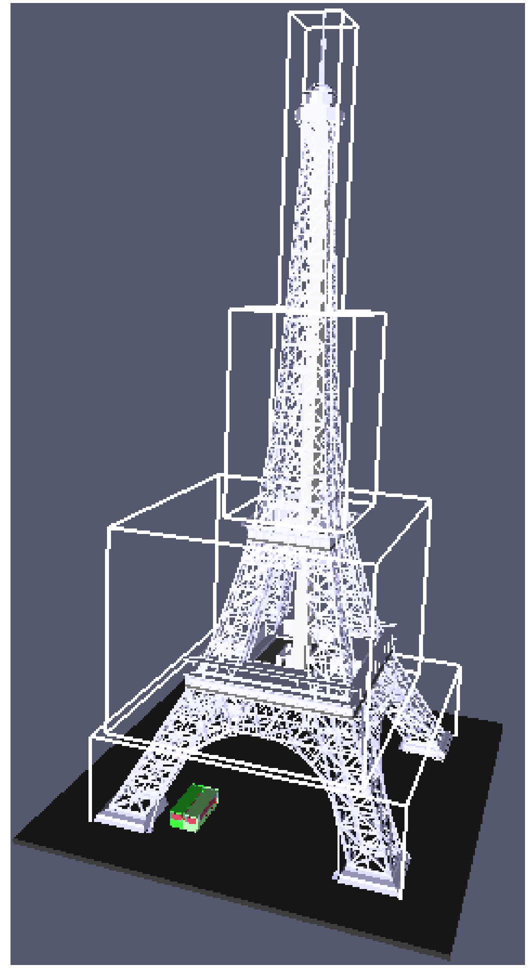
CFD for Smoke Movement

- Less simplifications on the geometric models
  - Simplification has to be required for complex model
  - Preprocessing software to improve the model



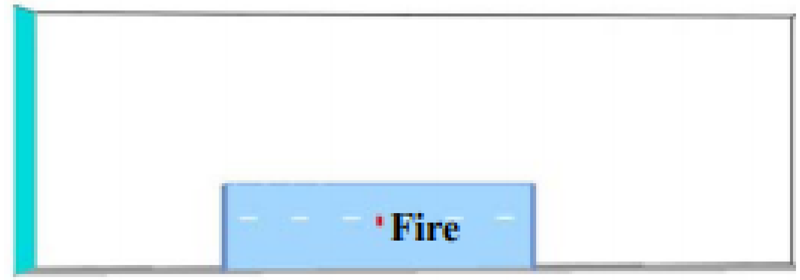
- Identify the system design
  - Position of fan, grille (type, size, rate, etc) and duct
  - Smoke control system (detector type, etc.)
  - Sprinkler and others

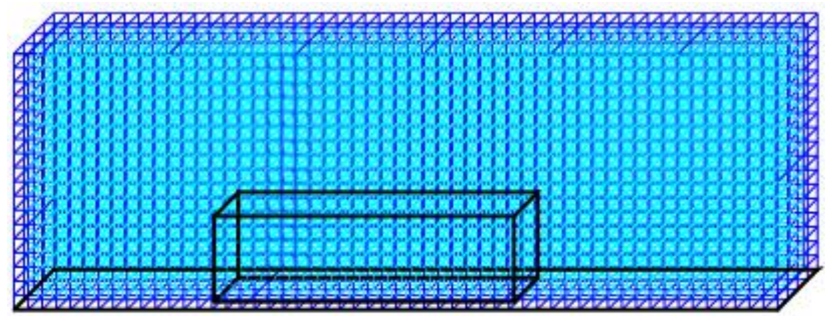


CFD for Smoke Movement

- Boundary conditions
  - Enclosed building
  - Half open building
  - Mechanical or static system

- Reasonable fire scenario:
  - Fuel, location, design fire
  - Smoke extraction type
  - Wind conditions, etc.





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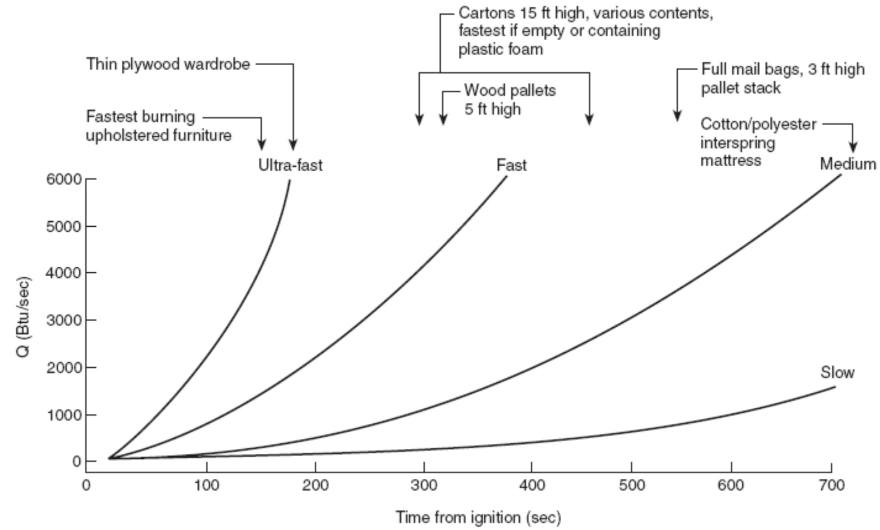
CFD for Smoke Movement

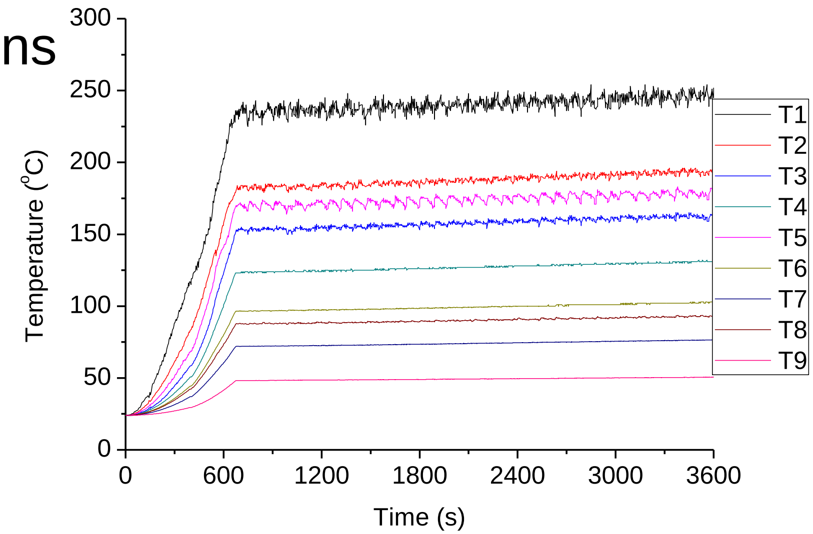
- Design fire
  - Materials for fuel
  - FSI system: sprinkler control or not
  - Fire growth rate: slow to ultra-fast
  - Burning duration etc.

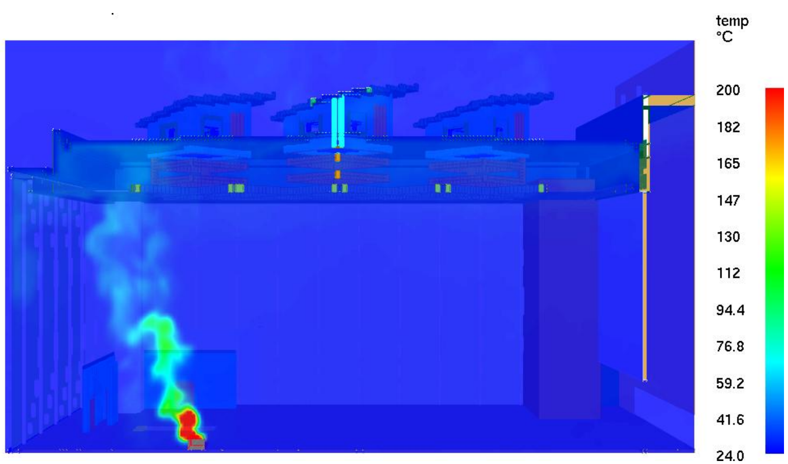


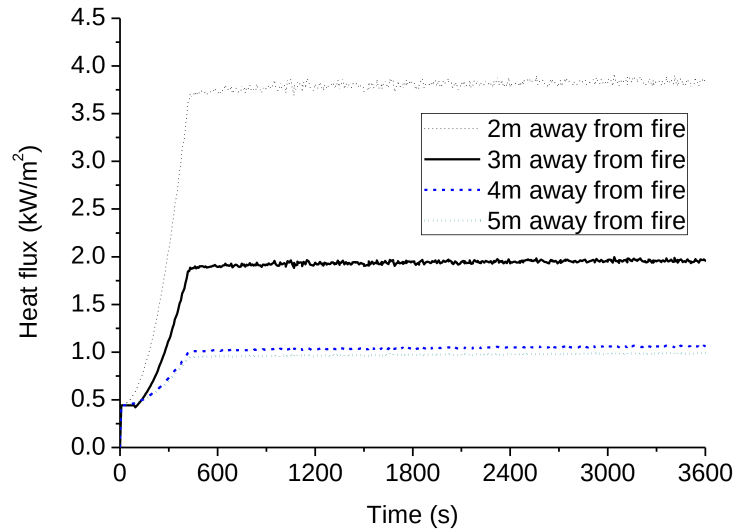
- Soot yield: different values for same combustibles under different conditions
- CO yield: model used in CFD, combustible and environment
- Visibility: background light, exit
- Literature reference (high quality data from handbooks, journal papers)

Simulation Results

- Temperature/Visibility/Gas concentrations
- Temperature from thermocouple
- Different heat fluxes
- Velocity/ vectors?
- Others required







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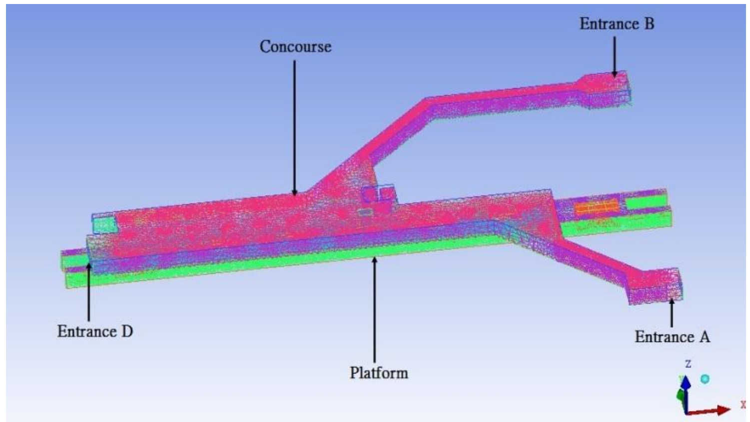
Simulation Results

- ➢ Model to check
  - ✓ Smoke flow reasonable (e.g. no leakage)
  - ✓ Values reasonable? (no strange peak value, e.g. too high temperature)
  - ✓ Vector direction
  - ✓ Results at key area (vent, boundary, fire)

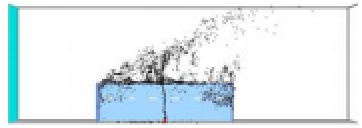


- ➢ Design criteria or performance
  - ✓ Correct simulation may be not complete
  - ✓ Design criteria

- ➢ Working duration of smoke system and simulation time
- ➢ Effects of grid size/meshing/time on accuracy

Key Points to Note

- Treatment of the boundary conditions is very important, try to extend the computing domains far away from the opening area
- Wind condition and stack effect



- Improved meshing scheme and increased grid resolution to offsets the negative effects (e.g. irregular boundary)
- Interaction between various systems
- Experimental data for verifying the results, tuning the parameters concerned in the physical equations and deriving new solution methods
- Results should be compared and be consistent with those derived from simple theory

4. Discussions on CFD Modelling

CFD Limitations – model

- Model dependence, still needs improvement
- How much simplification and accuracy
- Numerical Solution Technical Development: discrete approximation solution (reduced discrepancy error/iteration error/rounding error)
- Multidisciplinary intercourse
- Validation and verification

CFD Limitations – FDS model

- Less models with less functions compared with general commercial CFD packages (e.g. PHOENICS, FLUENT)
- Rectilinear geometry for grid/ cuboid cells

  Many geometric features do not conform to the rectangular grid, quality of simulation results will be reduced by the boundary layer effects, although there are techniques in FDS to reduce the effect of “sawtooth” obstructions
- Combustion model

  The combustion model should be adjusted when the fire is under-ventilatited condition or water spray condition as the simple mixture fraction-based combustion model is used for most conditions.
- Radiation model

  Radiation heat might be unevenly distributed for the far away area from the fire source as the radiation transfer is discretized by limited solid angles
- Combustion model

  Many geometric features do not conform to the rectangular grid, quality of simulation results will be
- Others (low speed assumptions, etc.)

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CFD Limitations – not too easy to user

- Requires a high level of expertise
- Many considerations, easier to wrong results with careless application or insufficient considerations
- With default or constant parameters might be problems in simulating a complicated physical system for most cases
- Multidisciplinary intercourse capacity
- How much understanding vs CFD acceptance
- Time cost is critical

What should improve – the more the better

- The physical principles behind the turbulence, fine tuning parameters
- Chemical reaction and combustion
- How about the thermal radiation model
- The schemes for discretizing the equation set and the algorithms in solving the system have to be considered carefully
- Experienced skill with multiple discipline knowledge
- Good cooperation

Key Points to Note - to improve

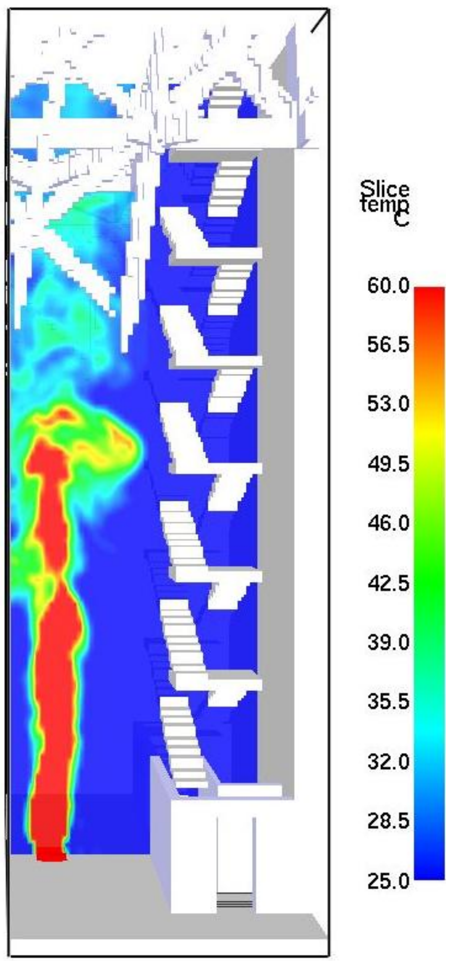
- Reliable CFD model
- Correct input parameters
- Less but reasonable assumptions

- Fire physics/ Fire chemistry/ Turbulence/ Numerical schemes
- Research Vs Development
- Interaction with other disciplines

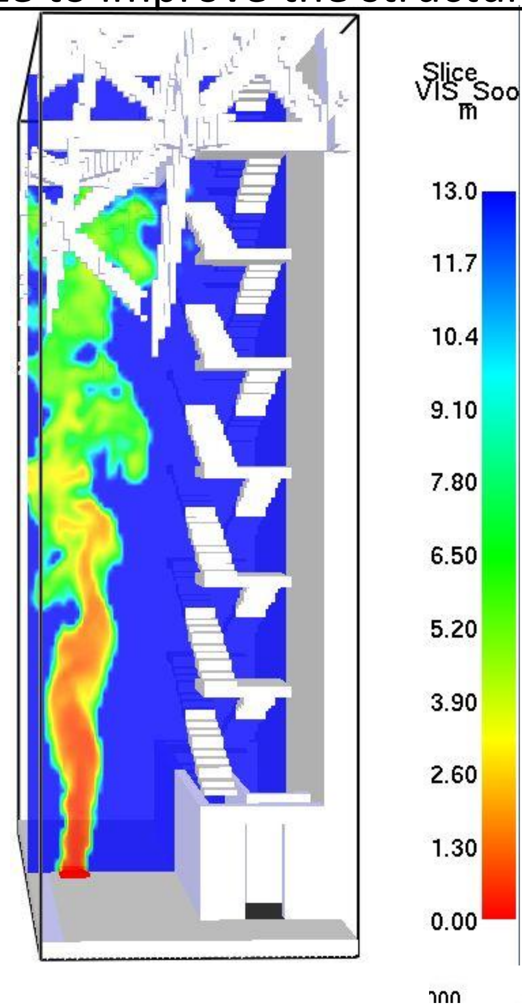
5. CFD modelling examples

Key Parameters from CFD simulation for a high shaft

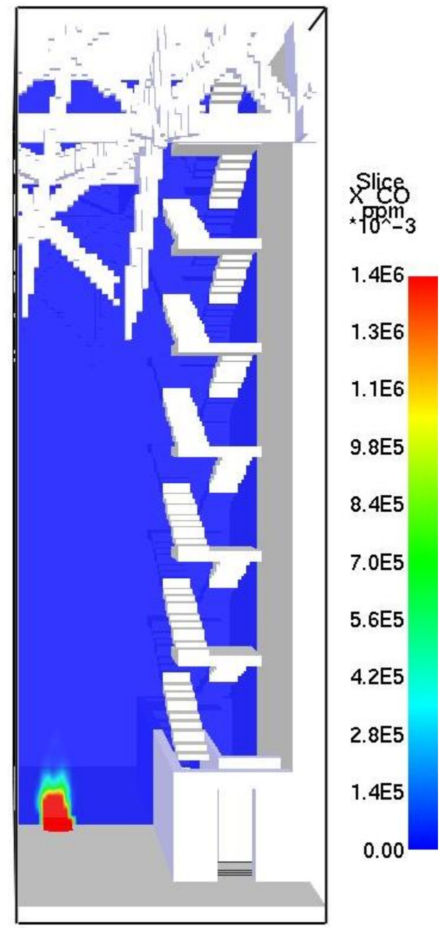
- <u>Try to reduce the grid size to improve the structures covering the smoke flow path</u>



Temperature



Visibility



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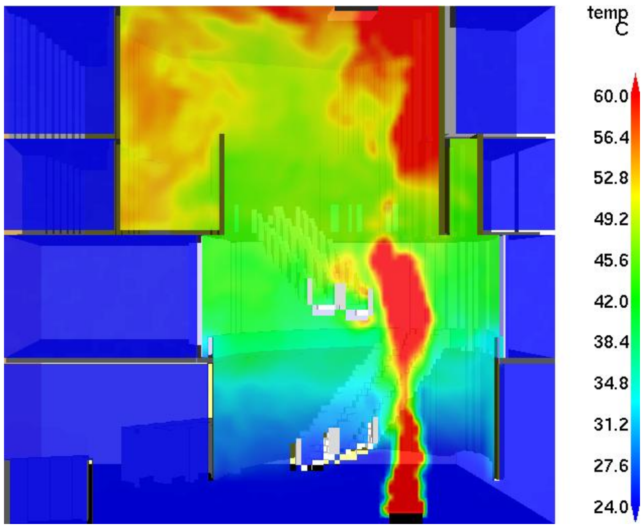
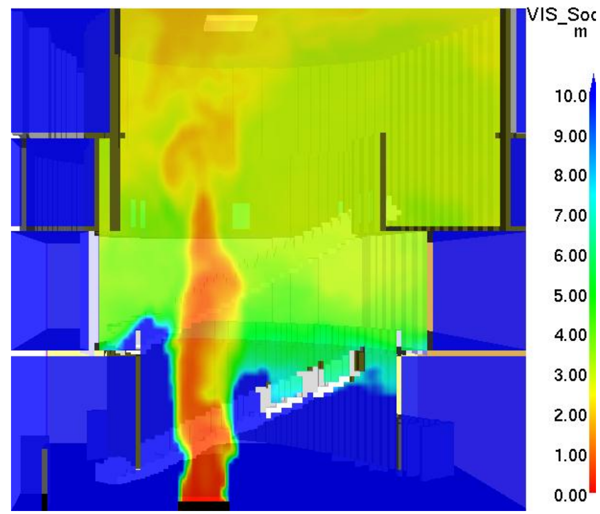
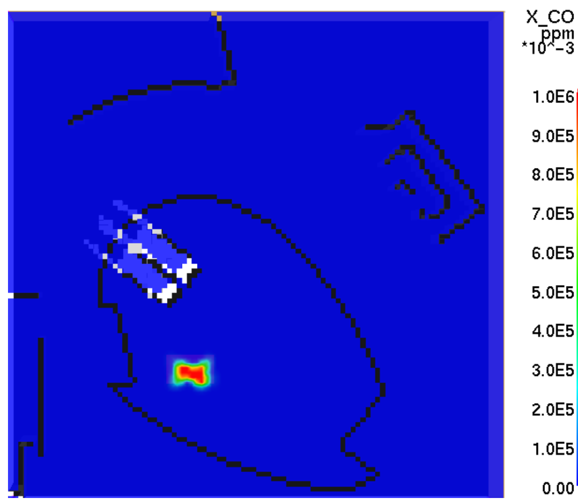
CFD simulation for a atrium fire

- <u>Smoke barriers and curtains (fine grids) have great effects on the smoke flow</u>

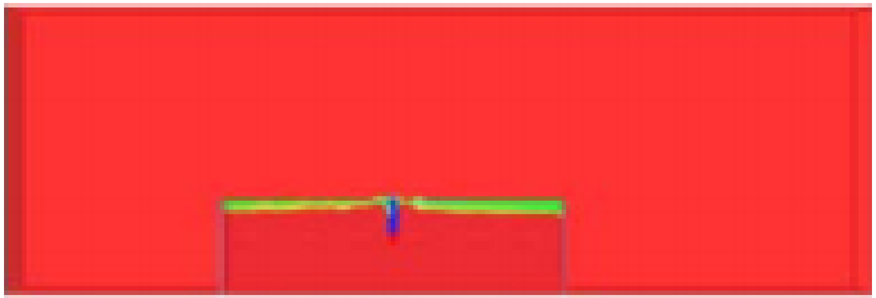


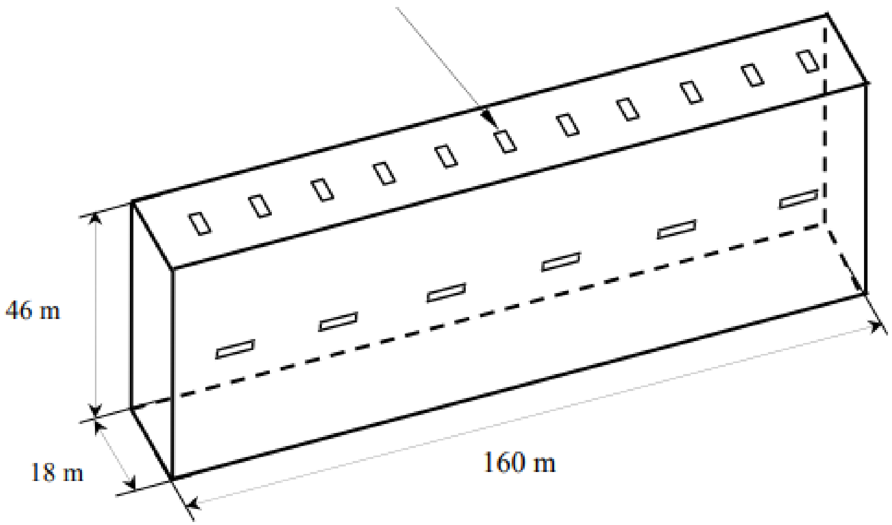


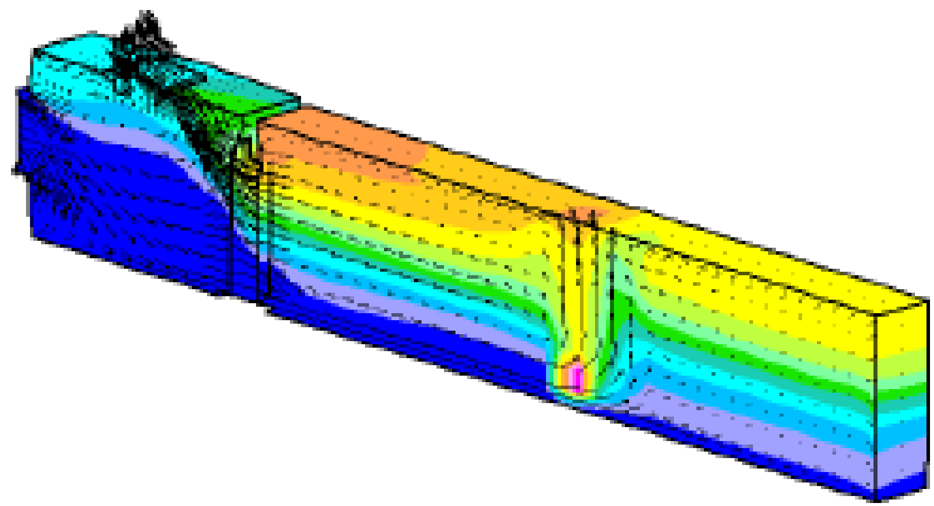


CFD simulation for a cargo

- <u>Try to extend the boundary of domain to reduce the boundary effect</u>



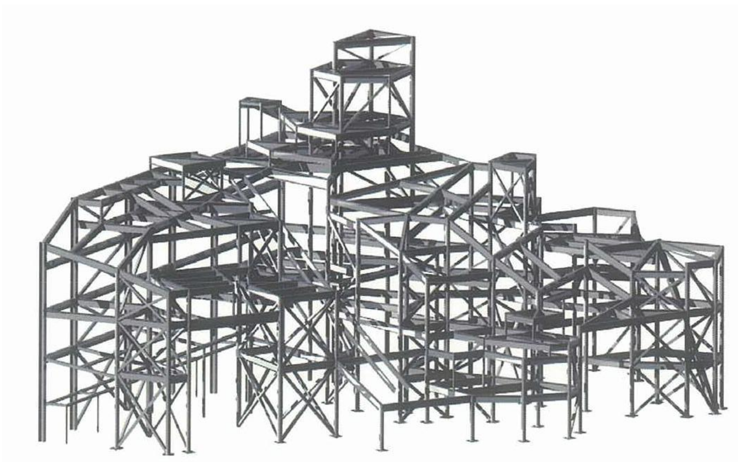


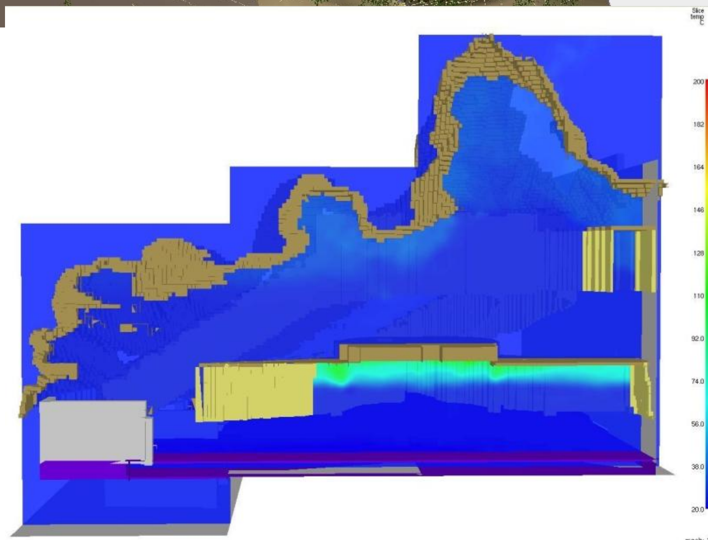


CFD Simulation for Disney Park

- Other software (e.g pyrosim) has to be adopted to build the complex model

➢ Unusual built-up structure, i.e. rockwork mountain, with the complicated steel structure for HK Disney Park





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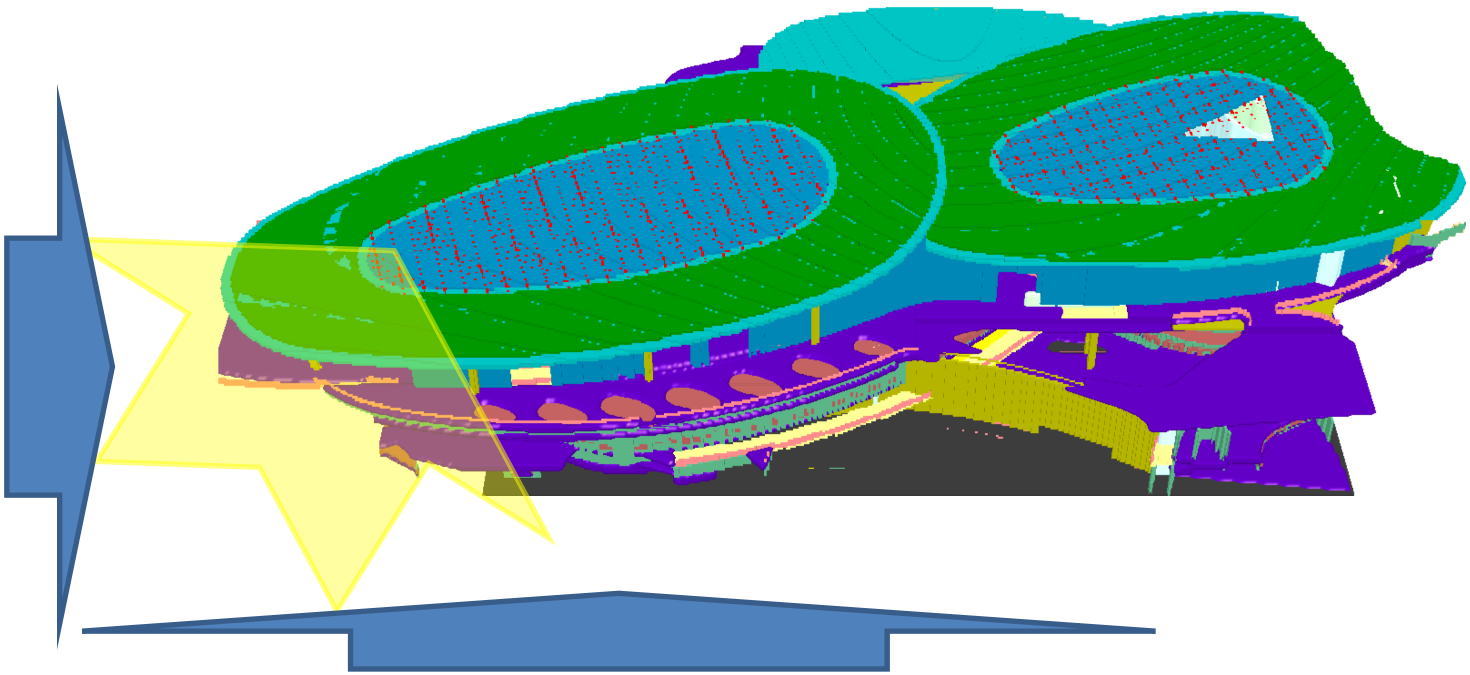
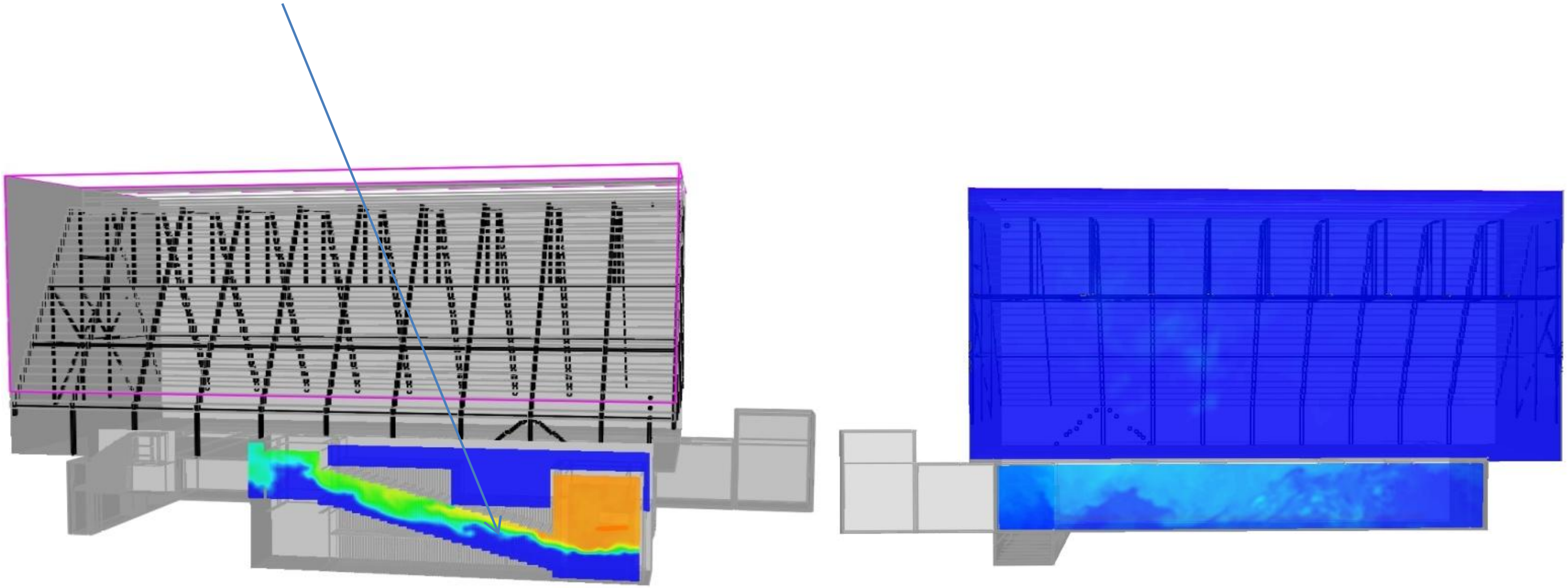
CFD Simulation for Water Park

- Wind effects (feasible directions with sufficient domain) for the irregular model



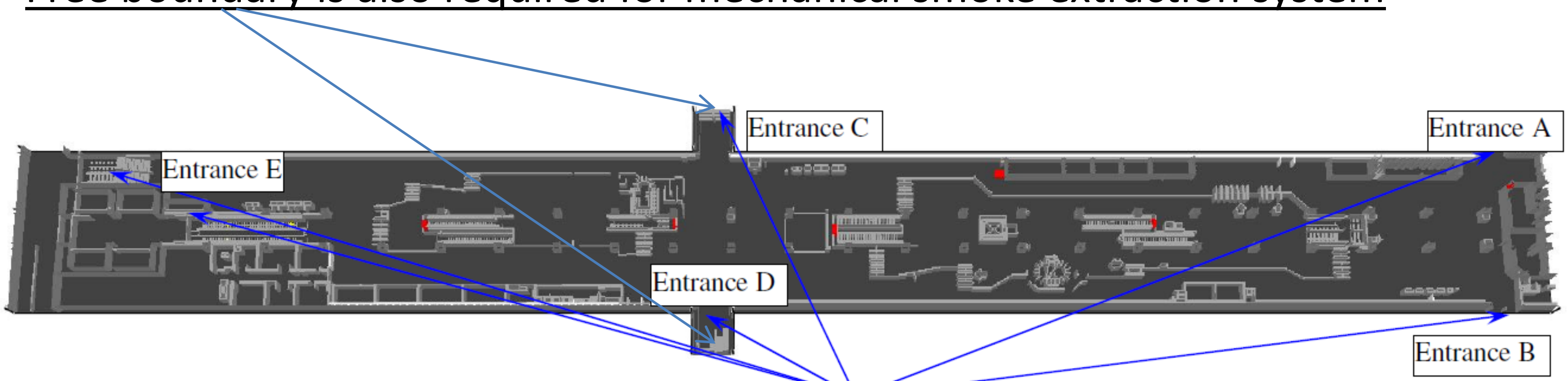
CFD Simulation for a power station

- <u>Boundary and initial conditions are critical important for this complex building with underground space</u>

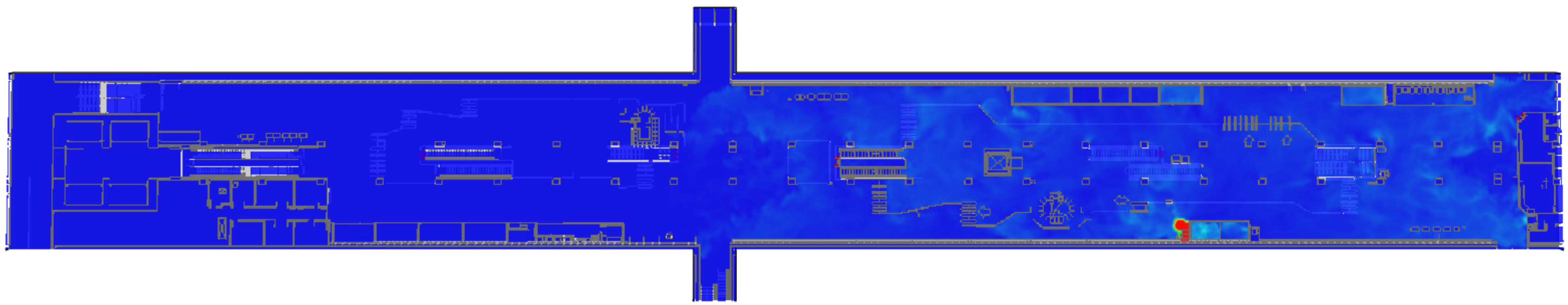


CFD simulation for a platform

- Free boundary is also required for mechanical smoke extraction system

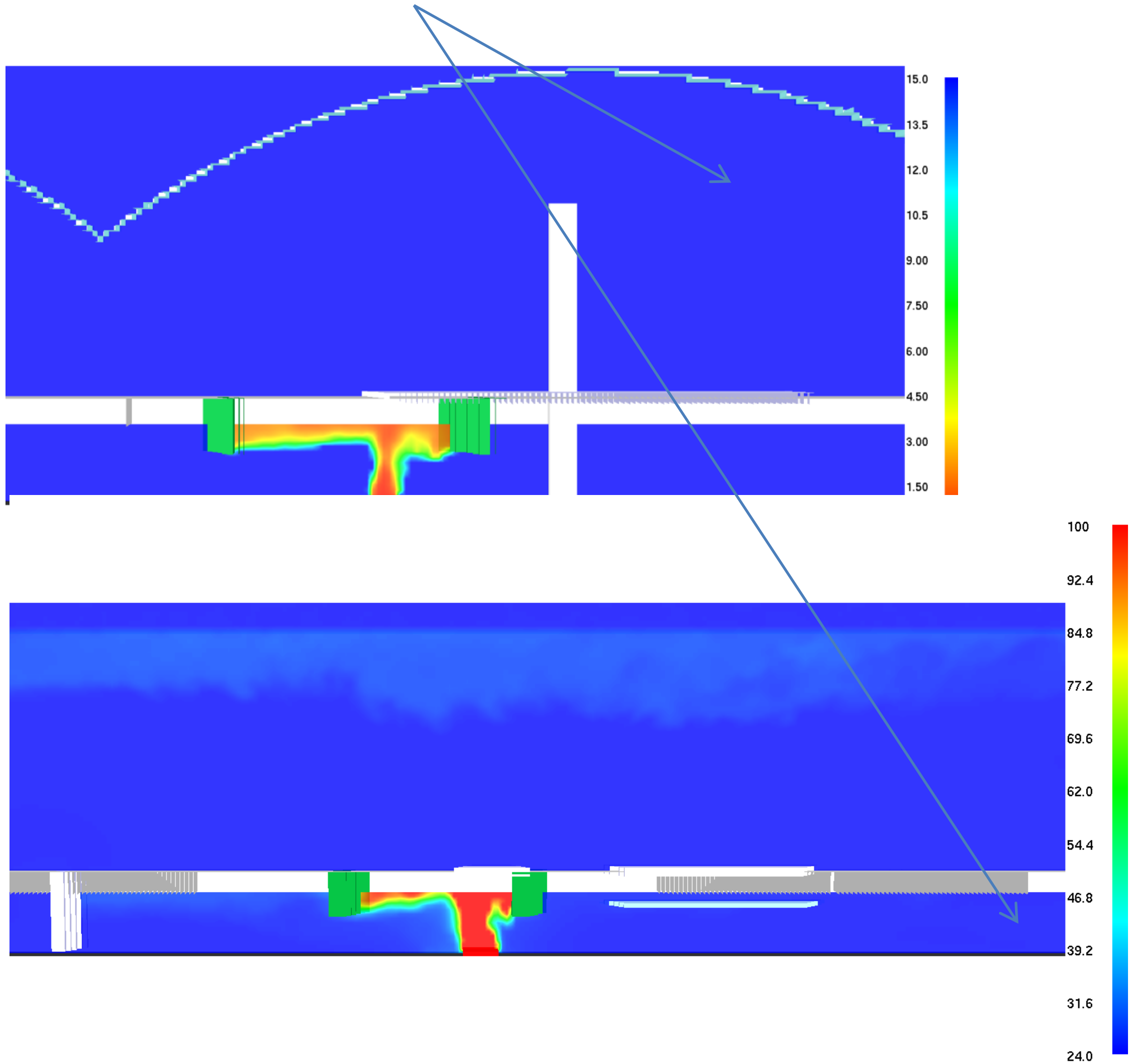


Makeup air from the staircases (also for smoke extraction) for the concourse (grid: 0.2m*0.2m*0.2m, No.:2700000)



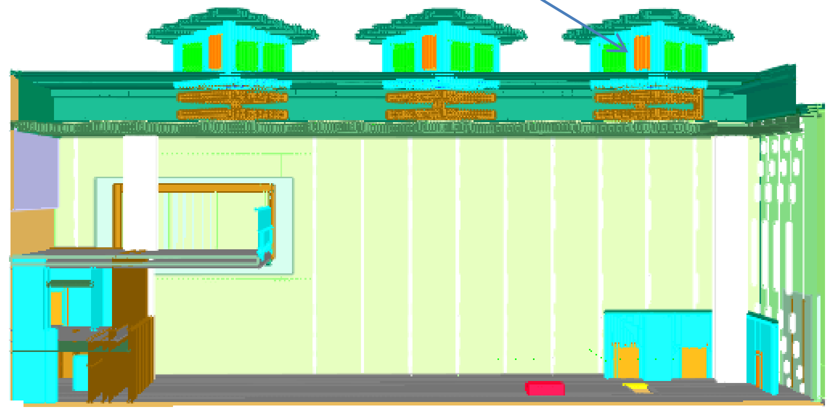
CFD simulation for smoke movement under a large hall

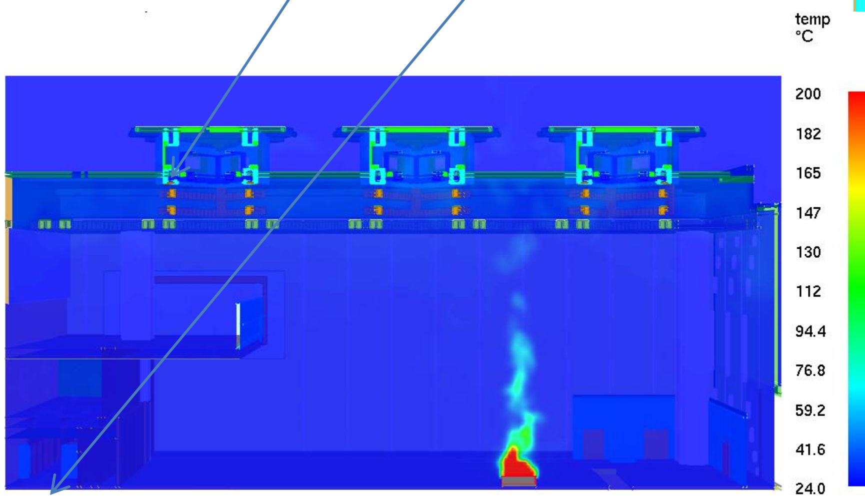
- Keep sufficient space to maintain free flow for the smoke



CFD simulation for static smoke system at airport

- Leave sufficient space for smoke vent and makeup area, fine grids for the vents





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