# Sensitivity studies OD-1D/3D of thermo aeraulic models of industrial premises

# Assistance in the identification of influential phenomena

# Preparation of experimental protocols for the Zephyr test platform

OpenTURNS Days – June 10th 2021

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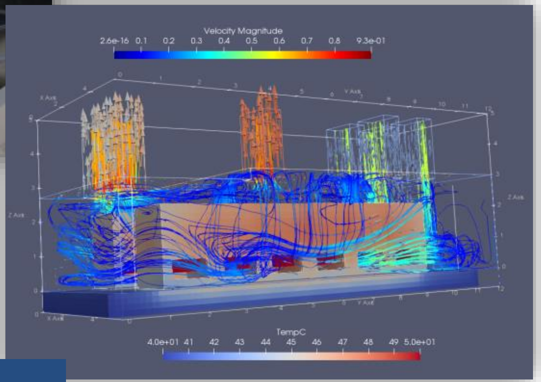
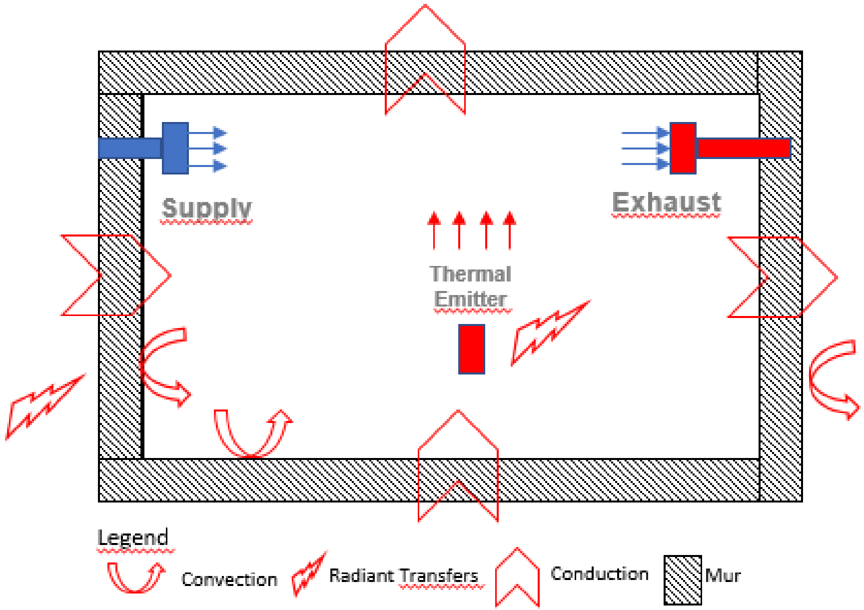


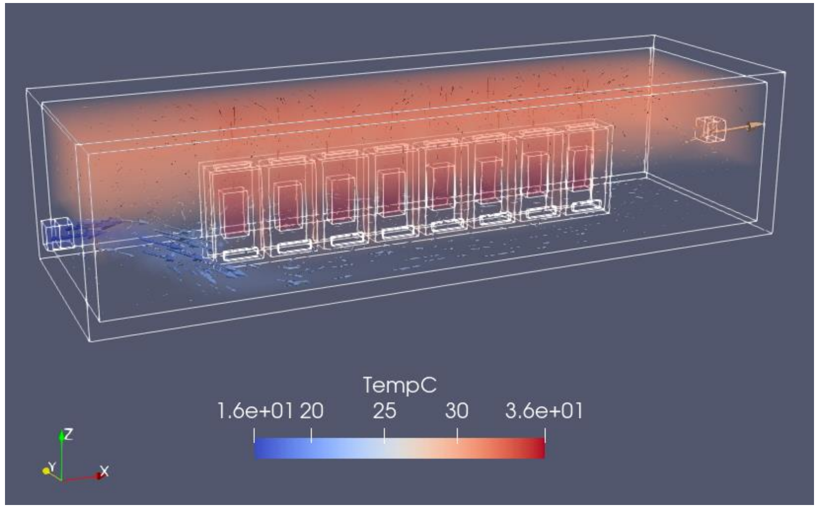

# Proposed Agenda

1. **Context of industrial thermo-aeraulic studies**
2. **Setup of numerical study experiment of Zephyr laboratory**
   a. Presentation of Zephyr laboratory
   b. Numerical methodology
   c. Salome Workflow
   d. Variables of interest
   e. Uncertain parameters
3. **Results and Perspective**
   a. Experience plan results analysis: distribution and dependency
   b. Metamodeling : sensitivity studies

# Context of industrial thermo-aeraulic studies

- **Context – Objectives of industrial thermal studies**
  - Assess operability of electrical and I&C cabinet in industrials premises in various situation (consistency with thermal qualification)
    - Thermal transient : steady state, thermal transient with partial or total loss of HVAC
    - Premises configuration : geometry, thermal loads, thermal conditioning
- **Industrial practices**
  - Use of 0D/1D codes with a unique thermal potential for the whole cavity :
    - no access to heterogeneity indicators.
    - Some rooms can appear as critic with low margin between predicted temperature and materiel qualification temperature
- **Numerical Study objectives**
  - Preliminary identification of **influent phenomena** on **temperature distribution**
  - **Compare 0D/1D-3D** code predicted temperatures / thermal power balances (convective / radiative heat flow)
  - Focused on geometry of **Zephyr laboratory** test room (building in progress on EDF R&D Chatou site)



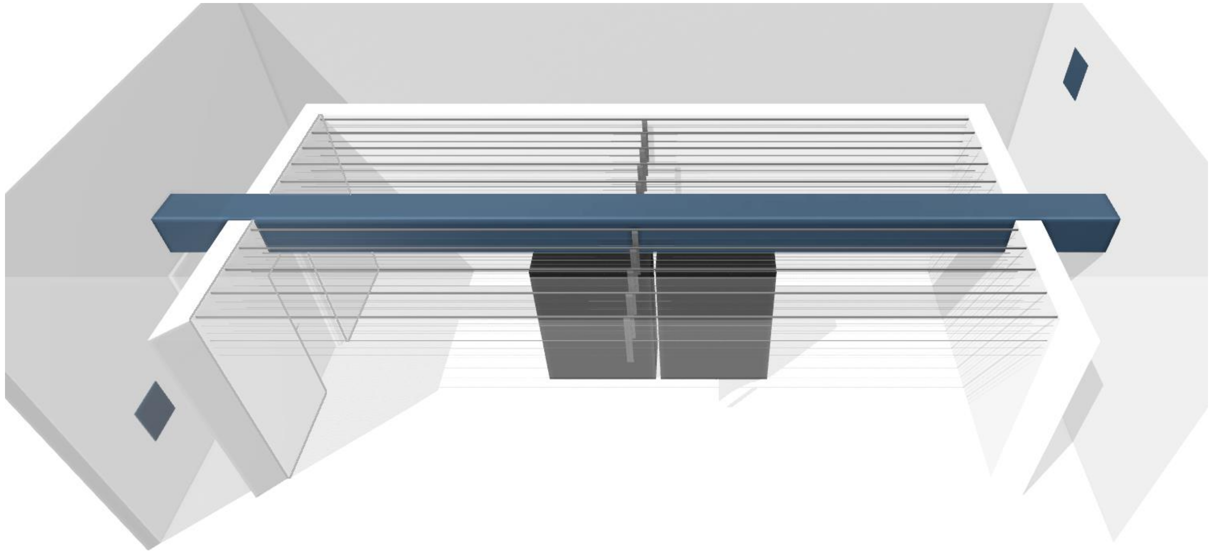
# Modular laboratory ZEPHYR - Generalities

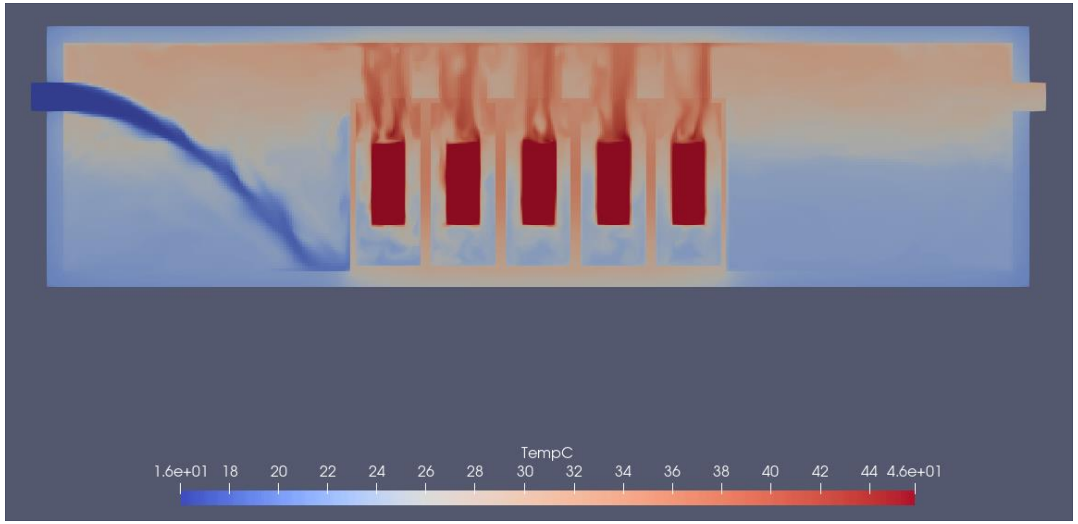

**Assets**
- Existing and future nuclear configurations
- Scale 1
- Modularity of the installation
- Multi-client

## Main technical objectives

- Experimental evaluation of the metrological performance of innovative measurement systems
- Consolidation of numerical calculation codes used in ventilation
- Support for the design and commissioning of ventilation installations
- Optimisation in deconstruction (filtration, air locks)

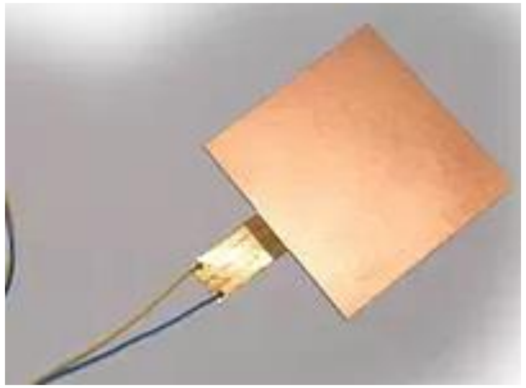
# Representative concrete room



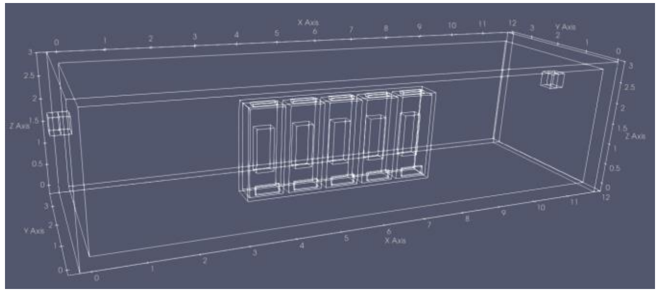



Rij / user wall function – size : 0,033m

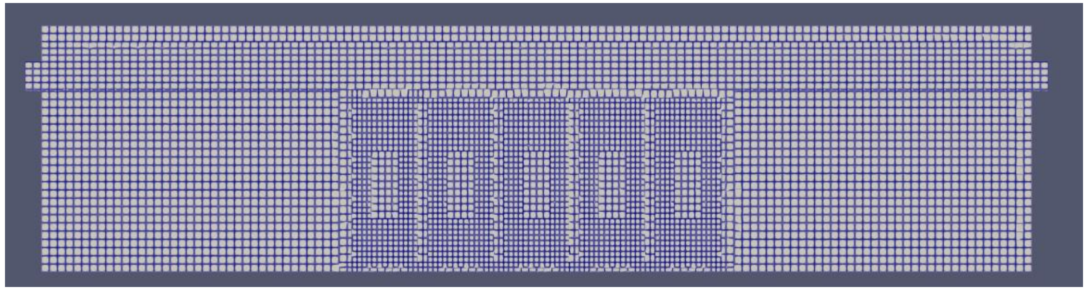
- Double enclosure (control of initial conditions in the external skin)
- Representative internal walls (thickness and reinforcement)
- Measurement of all the main thermo-aerodynamic variables:
  - Air flow
  - Flux at the walls
  - Temperature distributed by optical fiber (Raman)
  - Pressure and hygrometry



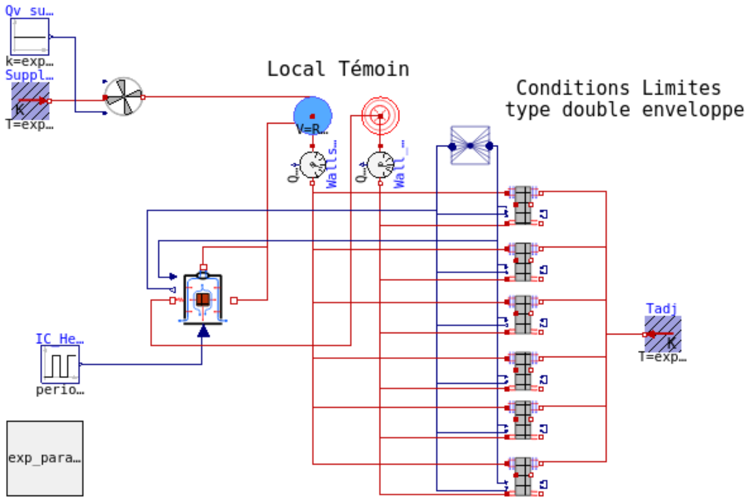
# 3D numerical experiments – Cases setup



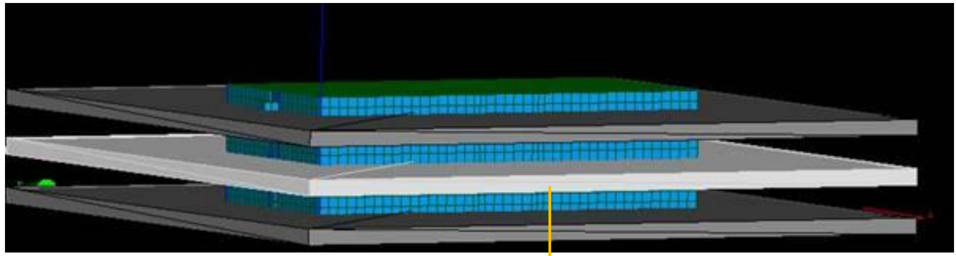
- **Phenomena modelled (3D and 0D)**
  - Fluid flow
  - Heat transfers / Conjugate heat transfer
    - Conduction / Convection /Radiant transfers



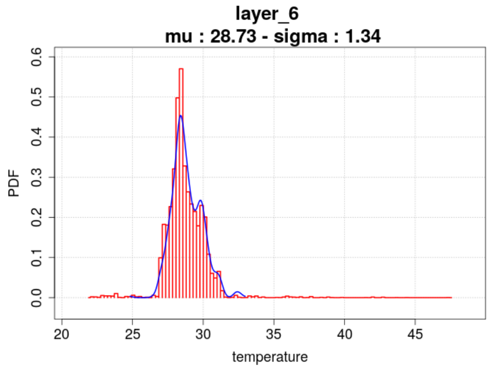
- **Mesh**
  - Air, Walls and Electrical Cabinet Modelled
  - Elementary size : 0,1m
  - Wall functions : integral correlation used for heat flow
- **Main numerical parameters**
  - Unsteady solver
  - Turbulence : $k - \omega\ SST$
  - Schemes : upwind for turbulence, centered (with sloped test) for other variables
  - Unsteady solver with 0,1 s reference time step
    - Between 3000 and 6000 iterations required
      - Around 10 – 20 h Cpus cumulated time (0,5 – 1h with 20 cores)

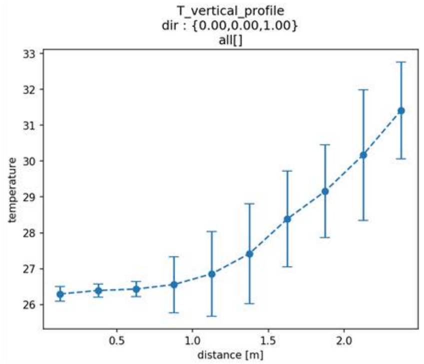


# 3D numerical experiments – Case WorkFlow



- **Cases step**
  - Generate mesh (Salome : geom/smesh)
  - 3D simulation of air flow and solid conduction (Code Saturne)
  - 0D/1D Simulation (TAeZoSyPro with OpenModelica)
  - Postprocess Results (Specific Python library)
    - Mean profiles (Specific Code Saturne User functions)
    - Integrate local 3D results
- **Experiences plans**
  - Generate Plans (Persalys)
  - Wrap case in _exec function (Specific Python Library)
    - Enables case restart and results saving
  - Evaluate plans until convergency is reached for each case
  - Results analysis as a new Data model
    - Dependencies
    - Sensitivity analyses metamodel based



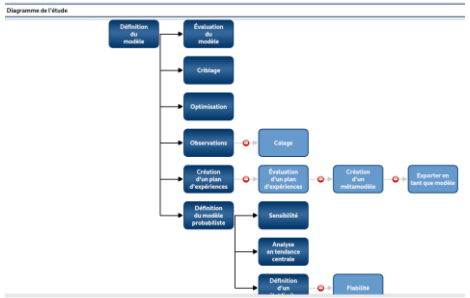



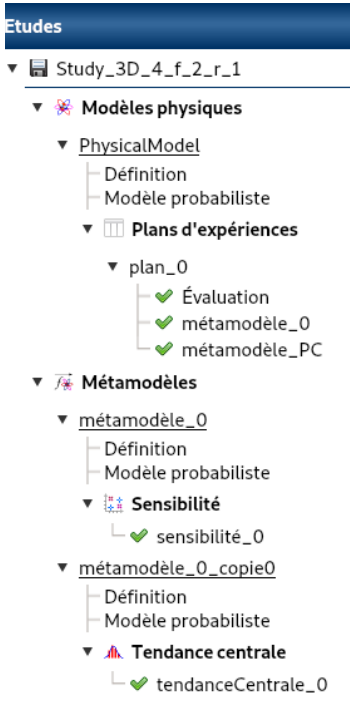
# 3D numerical experiments – Persalys WorkFlow

- **Persalys _exec function**
  - Define as a YACS model
  - Evaluation of the plan with dumped code modification

```
import salome_ot
import os
study,ModèleYACS_0=salome_ot.getYacsPyStudy(code)
import pydefx
pydefx_path = os.path.dirname(pydefx.__file__)
light_executor_path = os.path.join(pydefx_path, "plugins", "lightexecutor.py")
mybuilder = pydefx.slurmbuilder.SlurmBuilder(executor=light_executor_path)
myModel = pydefx.SlurmStudy(schemaBuilder=mybuilder)
ModèleYACS_0.setJobModel(myModel)
```

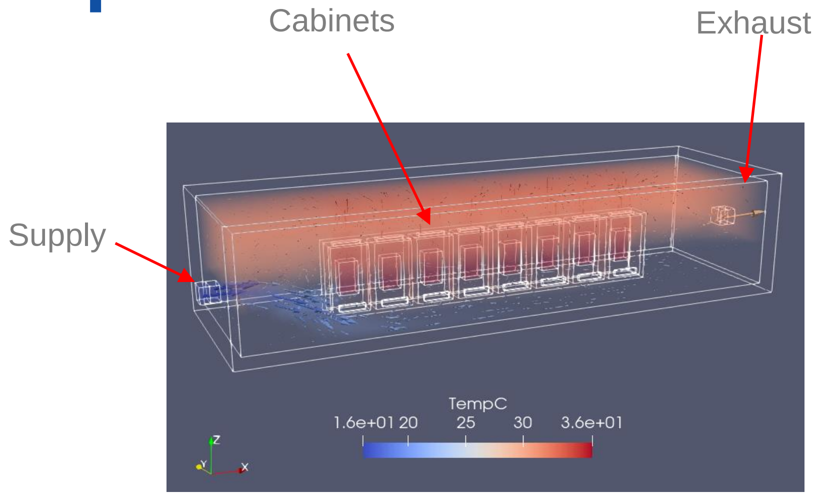
  - Use ‘slurm study’ feature to evaluate point by block (10 for instance)
  - Use of default YACS model does not allow executables to be launched with *srun* command
  - Executable to be launched with : *srun –exclusive –n X ./my_mpi_program*
    - *--exclusive* options allow slurm to use all allocated resources
    - *Waste some resources when block size increases : reason not identified*
      - *Example : block size of 10 with 204 cpus allocated on 6 nodes allow evaluations 10 by 10*
      - *Block size of 50 with 1020 cpus on 30 nodes allows evaluations 37 by 37 instead of expected 50*

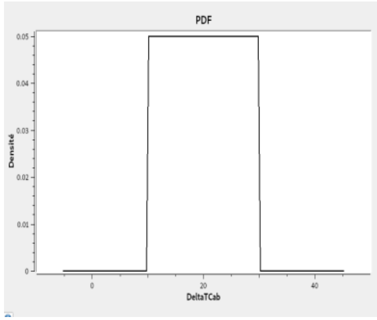


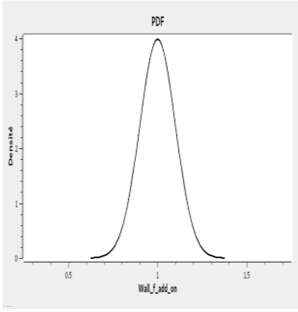


# 3D numerical experiments – Uncertain parameters

| | Parameter | Marginal | description |
|---|---|---|---|
| Geometrical parameters | **Inlet_Z/Y_percent [-]** | Uniform [0,1 – 0,9] | Supply position |
| Geometrical parameters | **Outlet_Z/Y_percent [-]** | Uniform [0,1 – 0,9] | Exhaust position |
| Geometrical parameters | **Cab_Em_per [-]** | Uniform [0.4,0.7] | Emitter volume percentage of cabinet |
| Geometrical parameters | **Cab_X/Y_Percent [-]** | Uniform [0.1,0.9] | Position of cabinet row in the room |
| Geometrical parameters | **HL_W_Cab** $[W]$ | Uniform [300,1000] | Heat Loads per cabinet (round to inf int) |
| Geometrical parameters | **Cabinet_H** $[m]$ | Uniform [1.5,2] | Cabinet height |
| Geometrical parameters | **Room_H** $[m]$ | Uniform [2.4,2.8] | Room height |
| Limit conditions | **Renewal_Rate** $[vol.h^{-1}]$ | Uniform [1,10] | Air change rate |
| Limit conditions | **Inlet_Speed** $[m.s^{-1}]$ | Uniform [1,5] | Supply air speed |
| Limit conditions | **HL_density** $[W.m^{-2}]$ | Uniform [50,150] | Heat Loads density |
| Limit conditions | **T_supply** $[degC]$ | Uniform [16,20] | HVAC supply temperature |
| Limit conditions | **T_adj** $[degC]$ | Uniform [20,30] | Adjacent room temperature |
| Model param | **Wall_f_add_on [-]** | Normal $[\mu = 1.0\ , \sigma = 0.1]$ | Modificator of predicted wall heat exchange coefficient with integral correlation |
| Model param | **KsiCab [-]** | Uniform [6-50] | Number of dynamic pressure losses (at inlet speed) of Cabinet |




- **Methodology**
  - Study equiprobable situations
  - Investigate generic model sensitivity
- **Dependency**
  - Independent Copula

# 3D numerical experiments – Variables of interest

**Power balance**

- Radiant/convective heat flow for surface
- HVAC power
  - $P_{HVAC} = \dot{m}c_p(T_{supply} - T_{Room})$
- Convergency at final time step
  - $cvg = \frac{P_{instationnaire}}{Heatloads}$

**Temperatures**

- $T_{moy}$ 3D / $T_{0D}$ / $T_{outlet\ 3D}$
- $T_{inlet}$ / $T_{outlet}$ cabinets
- Vertical mean profile temperature:
  - 10 layers : $\mu^*_{layer\_id} = \frac{\sum_{c\_id=0}^{n\_cells-1} w_{c\_id} \times x_{c\_id}}{\sum_{c\_id=0}^{n\_cells-1} w_{c\_id}}$
    - With : $w_{c\_id}$ weight of cell for layer id

**Scales**

- Power : $P_{heatloads}$
- Dimensionless power : $\frac{P}{P_{heatload}}$
- Temperature $\begin{cases} \frac{1}{2}\xi\rho_0 V^2 = \Delta\rho g h = \rho_0 \beta \Delta T_{ref} g h \\ \dot{m}c_p \Delta \mathrm{T}_{\mathrm{ref}} = P_{th} \end{cases} \Rightarrow \begin{cases} V = \left[\frac{2\beta P_{th} g h}{S_{cab} c_p \xi \rho}\right]^{\frac{1}{3}} \\ \Delta \mathrm{T}_{\mathrm{ref}} = \frac{P_{th}}{\rho V S_{ar} c_p} \end{cases}$

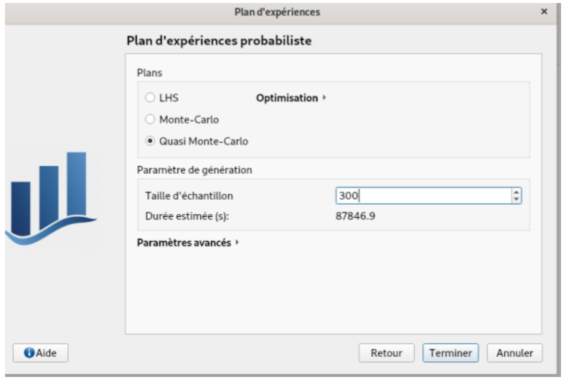
  with $\xi = 1$ / $S_{cab} = 0.07$ : $cabinet\ inlet\ surface$
- Dimensionless temperature : $T_n = \frac{T - T_{mean\ 3D}}{\Delta T_{ref}}$ / $\Delta T_n = \frac{\Delta T}{\Delta T_{ref}}$

**Methodology**

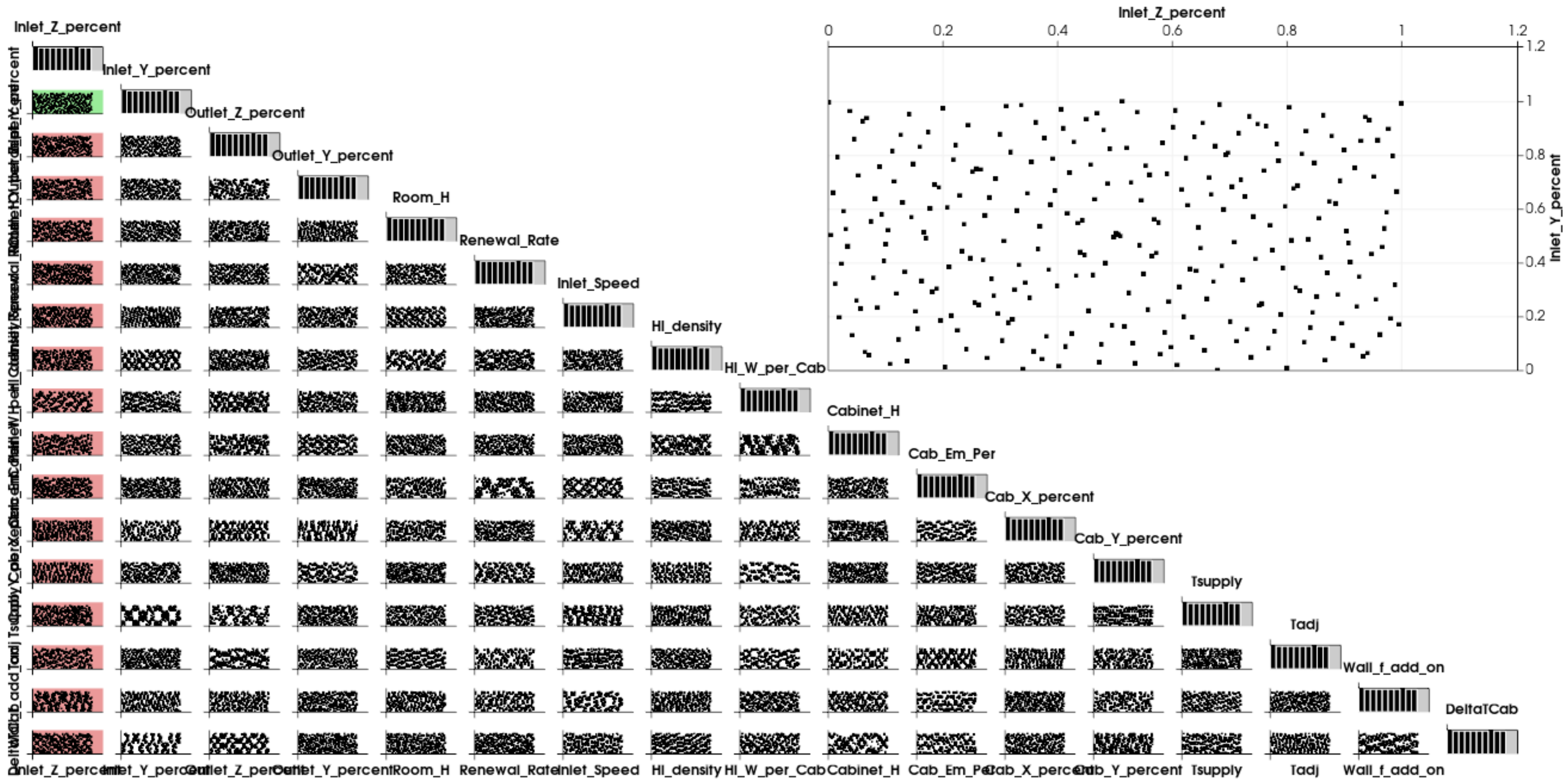
- **Numerical integration** of local 3D variables
- **Project 3D field** on **a fixed 1D field** (mean profile)
- Get **similar** variables of interest between **0D** and **3D** codes
- **Dimensionless** variables to help **comparison** between cases

EDF

# 3D numerical experiments – generated experience plan




- Probabilistic experience plan : Low discrepancy experience plans (Quasi Monte Carlo)
    - 300 points
    - 17 uncertain parameters
    - Sensible filling rank space given the use of uniform and independent marginal law
    - Try to fill optimize space filling (distance between two points)
- Point number : Compromise between computing time and number of points



# 3D numerical experiments – Results

Point Values

Catalyst View

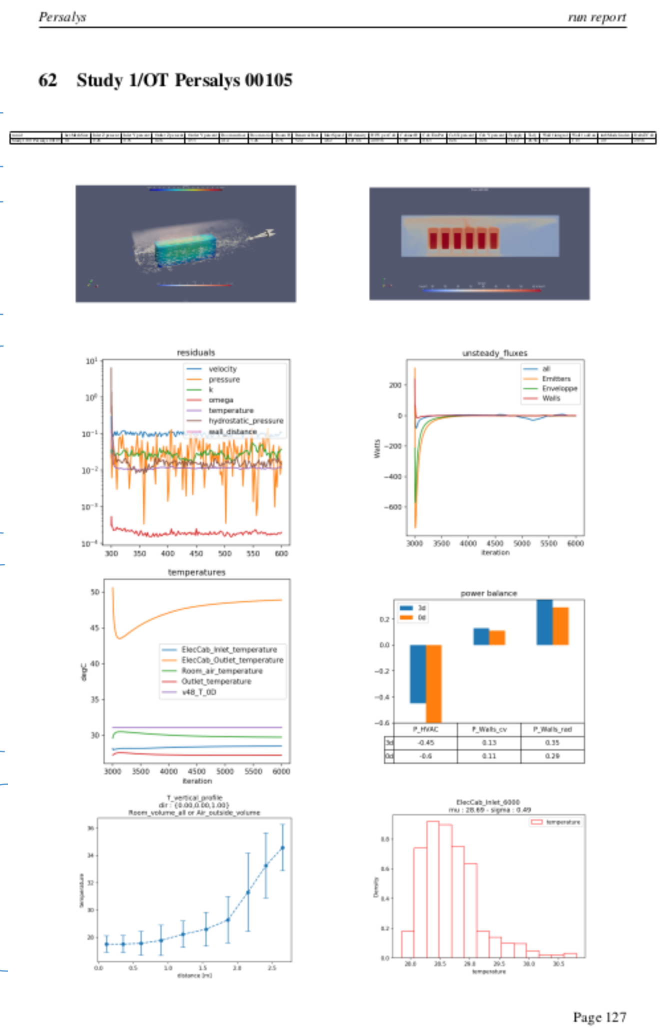
Convergence

HVAC balances Temperature – Power Balance

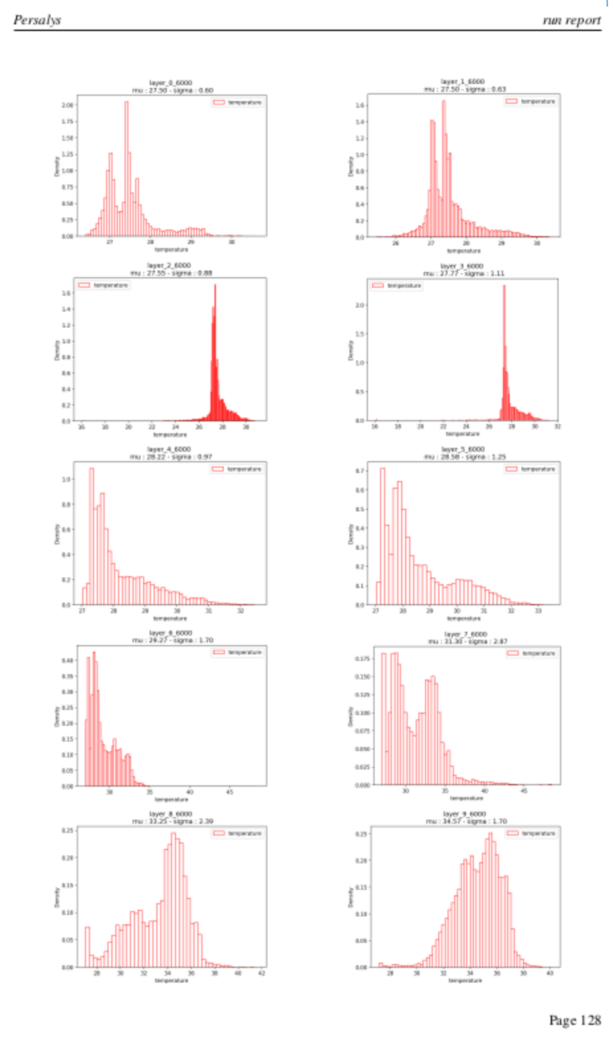
(0d/3d)

Mean TempC profile

TempC distribution at cabinet Inlet

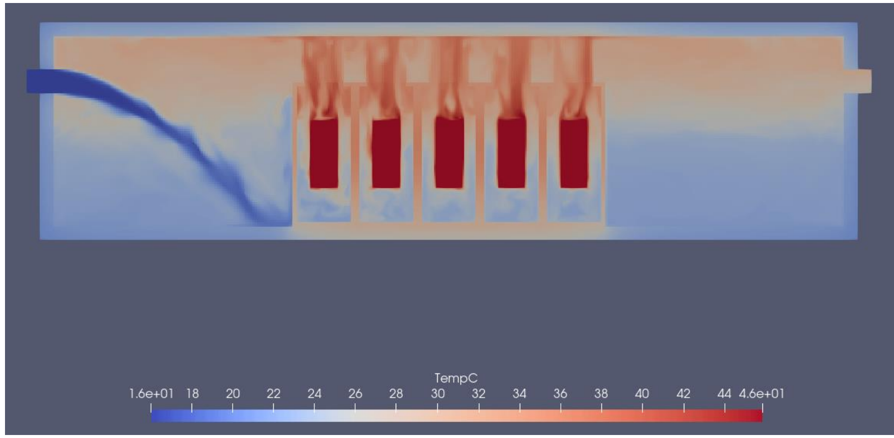



TempC distribution for each profile layer




- **Total evaluations**
  - First experience plan of 16 cases with different numerical setups : 10 000 Cpus days
  - Determine sensible compromises between precision and cpu cost of each point evaluation
- **Evaluations**
  - 18 points failed due to 3D convergence issues
  - Cpus Time : 140 cumulated days – 1.5 day (user) on GAIA
- **Report**
  - LaTeX PDF report
  - Run_id exported as variable of interest to make the link between Persalys experience plan table and detailed run results

# 3D numerical experiments – Results



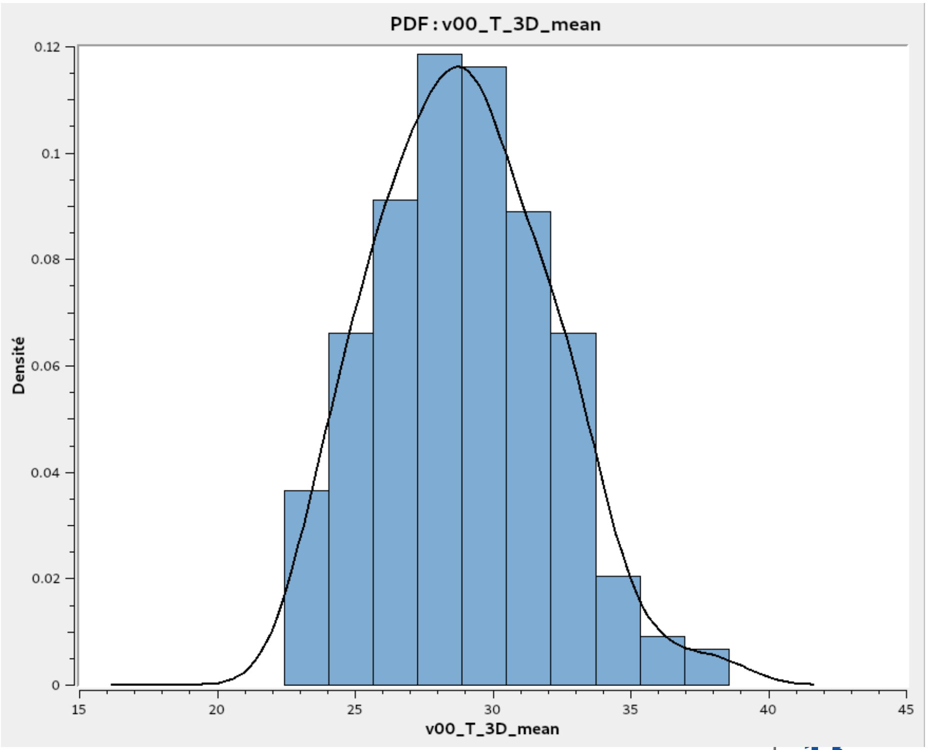

- **Reminder : implication of 0D approach**

$$\sum_{i}^{supply}\left(\dot{m}_i c_{p_i} T_i\right) - \dot{m}_{exhaust} c_{p_{room}} T_{air} + \sum_{i}^{walls} h_{total} S_{wall}(T_{wall} - T_{air}) + W = 0$$

  - Local energy equation integrated on the whole room volume
    - $\frac{\partial \hat{T}}{\partial \hat{t}} + \hat{\rho}\underline{\hat{V}}\,.\underline{\hat{\nabla}}\hat{T} = \frac{1}{\sqrt{RaPr}}\underline{\hat{\nabla}}\hat{\lambda}\underline{\hat{\nabla}}\hat{T}$
  - No reason, given expected heterogeneity that $T_{air}$ is the relevant potential in the first equation, $T_{air} = \frac{1}{m_{air}}\iiint_v \rho T dV$

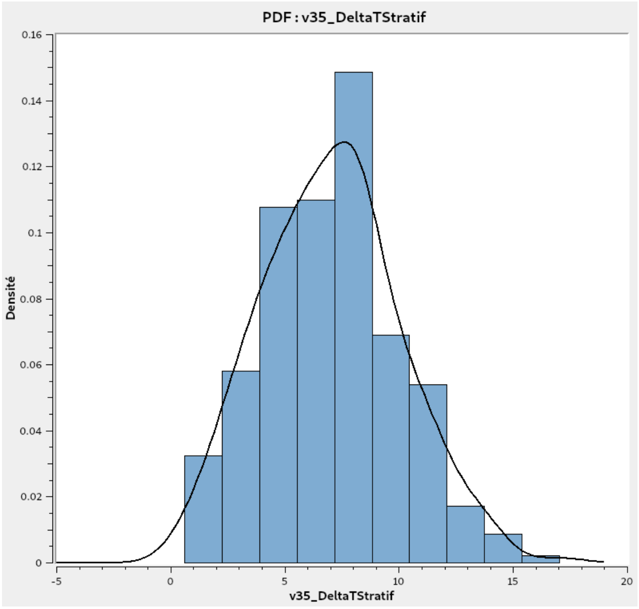
- **Analysis focused :**
  - Stratification phenomena (given by the 3D code)
  - Consistency between predictions of 3D and 0D code

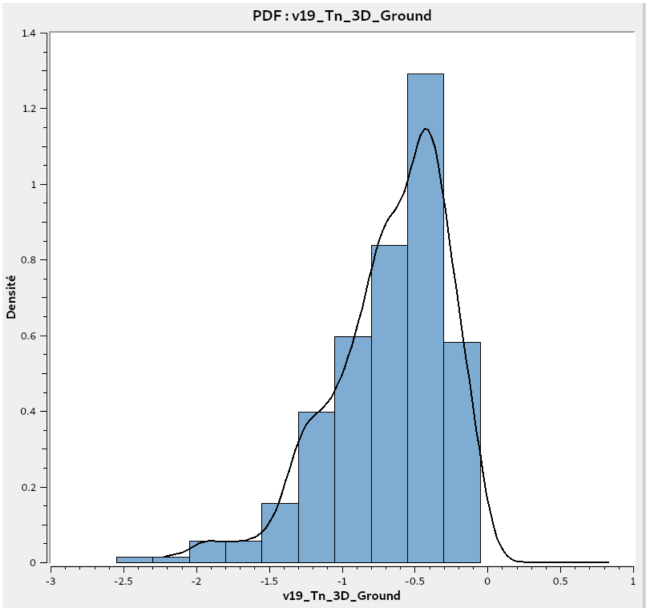
- **Global results**
  - Sensible global mean room temperature distribution given the range of the uncertain parameters

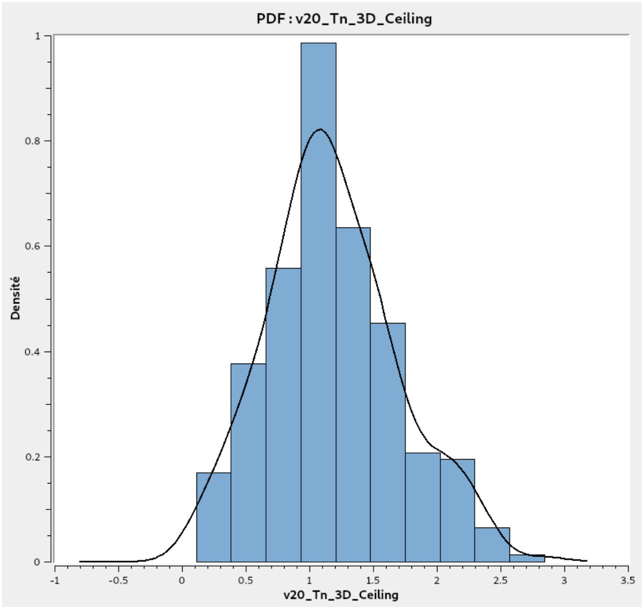


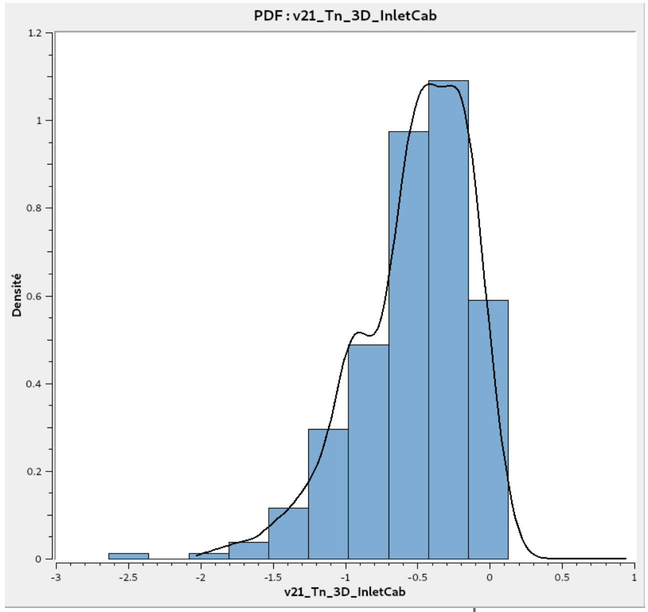
# 3D numerical experiments – Results

- **Main dependencies (Spearman indices)**
  - $\Delta T_{stratification}$: -0,48 Inlet_Z_percent / -0.469 : Inlet_speed / 0,428 : HL_density / 0,179 HL_W_per_Cab / 0,2 Tadj /
  - $Tn_{sol}$ :0.483 Inlet_Z_percent / 0.214 Renewal_Rate / 0.42 Inlet Speed / -0.434 HL_density / 0.334 HL_W_Per_Cab
- **Analysis**
  - Stratification tends to be mainly linked to supply parameter (geometry and way of supply) combined with the need of a certain amount of heat loads
  - Emitters parameters are less influent once heat loads density fixed
  - Emitter inlet temperature always below mean air temperature
    - Cabinets act as an active devices with air inlet on the bottom part and blowing air in upper part of the room



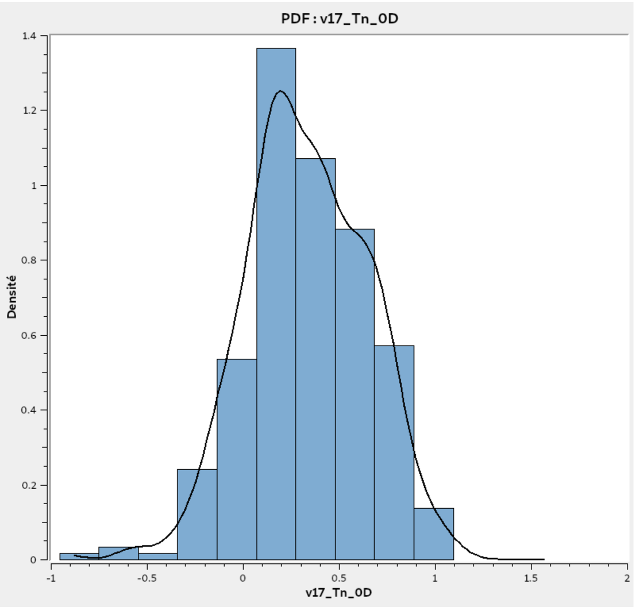



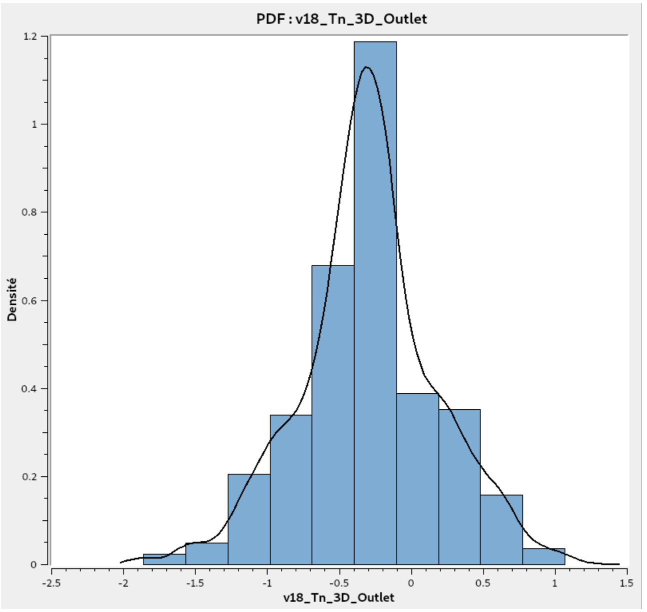



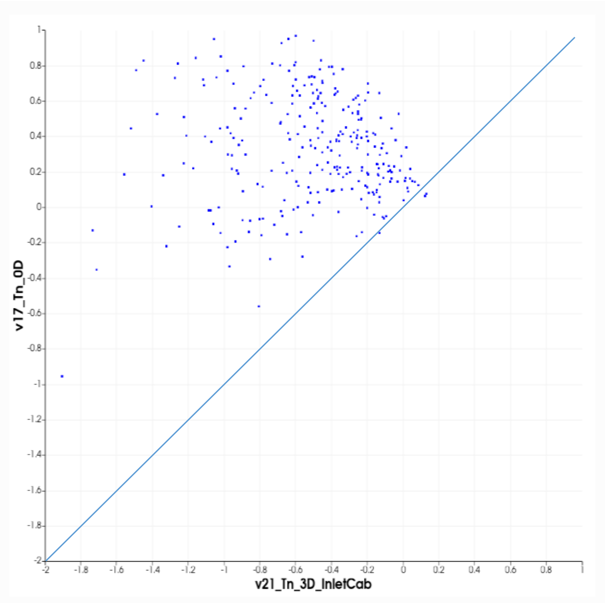
# 3D numerical experiments – Results

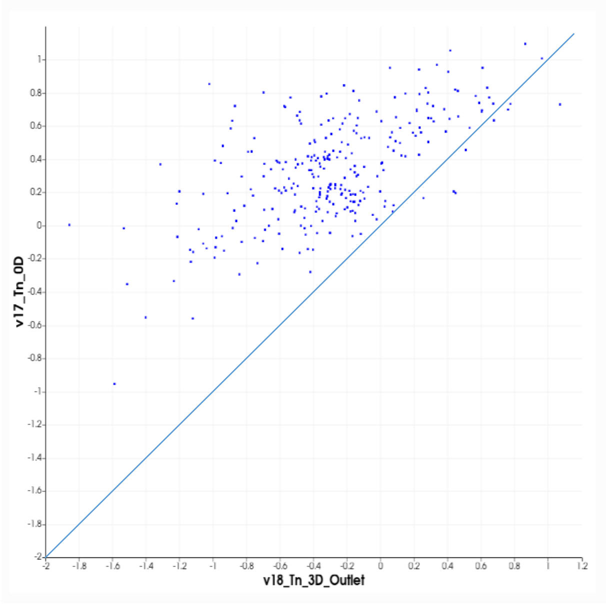
## Temperatures : 0D – 3D

- **Analysis**
  - $T_{0D}$ globally above $T_{CabInlet}$
    - Case or both are close are linked to case with low absolute temperature stratification
  - Over estimation of HVAC power with 0D approach (link to poor ceiling heat transfer estimation)
  - Cases with $T_{0D}$ lower than $T_{3D\ Mean}$ combined stratification and exhaust in lower part of the room



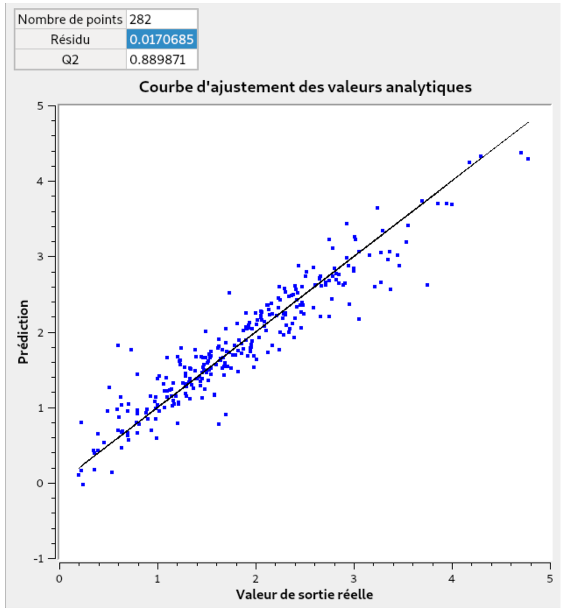
# 3D numerical experiments – Results

# MetaModels

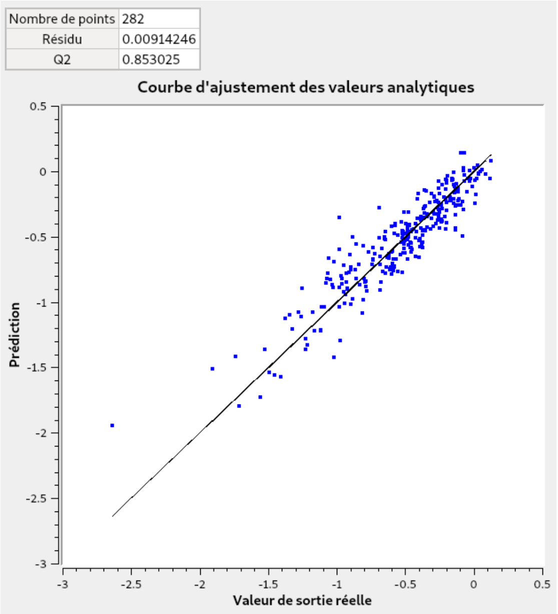
- **Objectives**
  - Learn dimensionless temperature to
    - Perform quantified sensitivity analysis (Sobol')
    - Perform partial quantified sensitivity analysis (with some influent parameters set as constant)
    - Allow metamodel export for improve 0D modelling of electrical premises
- **Technics used**
  - Polynomial chaos
  - Kriging
- **Validation criteria**
  - $Q^2 = 1 - \frac{\sum_{j=1}^{n_t} \left(Y_j - \hat{Y}_j\right)^2}{\sum_{j=1}^{n_t} \left(Y_j - \bar{Y}\right)^2}$ / Compute with test sample, analytic method and K-Fold
  - Qualitive Analysis of residuals distribution
    - Aim is to have a metamodel averagely accurate

# 3D numerical experiments – MetaModels - Kriging

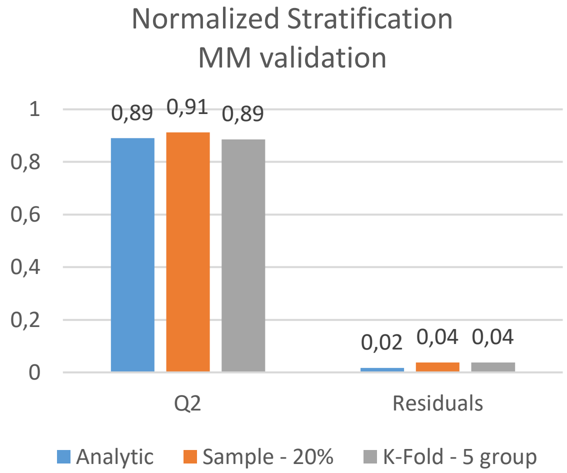
- **Parameters**
  - Covariance kernel : squared exponential
  - Constant tendency with optimize hyper parameters $\Delta T_n$
- **Results**
  - All scales within bounds except Wall_f_add_onn (less influent parameter)
    - Scales for normalized parameter $\dfrac{x-\bar{x}}{sd(x)}$
  - Acceptable Q2 for 3D based variables
- **Validation**

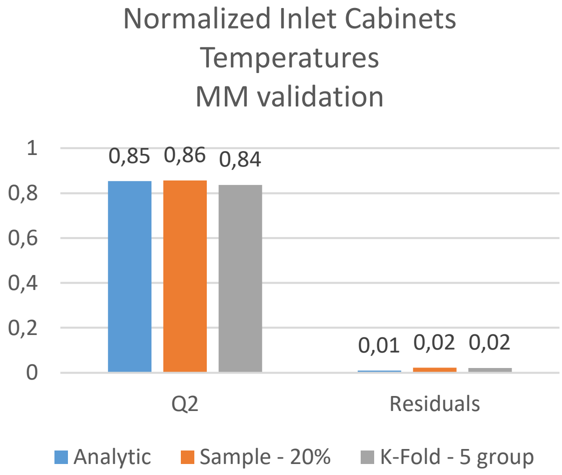


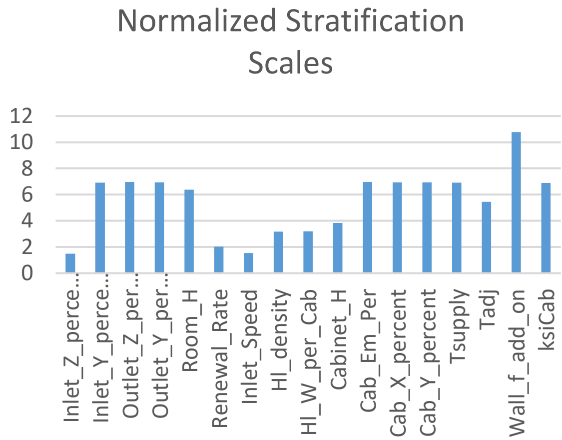

$\Delta T_n$ – Stratification

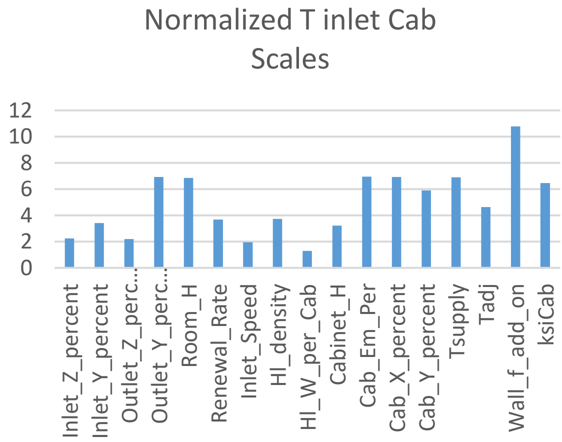



$T_n$ – Inlet Cabinet



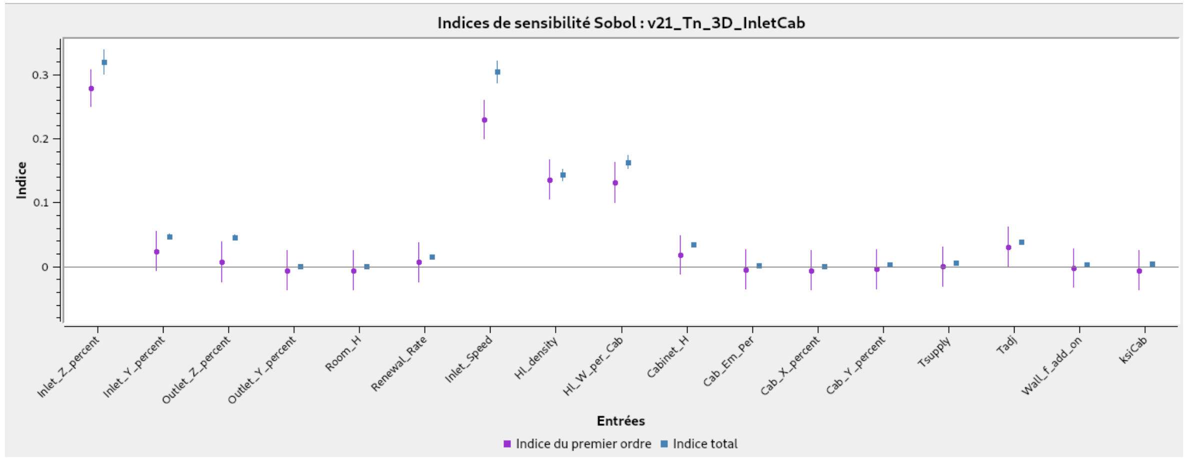
# 3D numerical experiments – MetaModels – Kriging Sensitivity

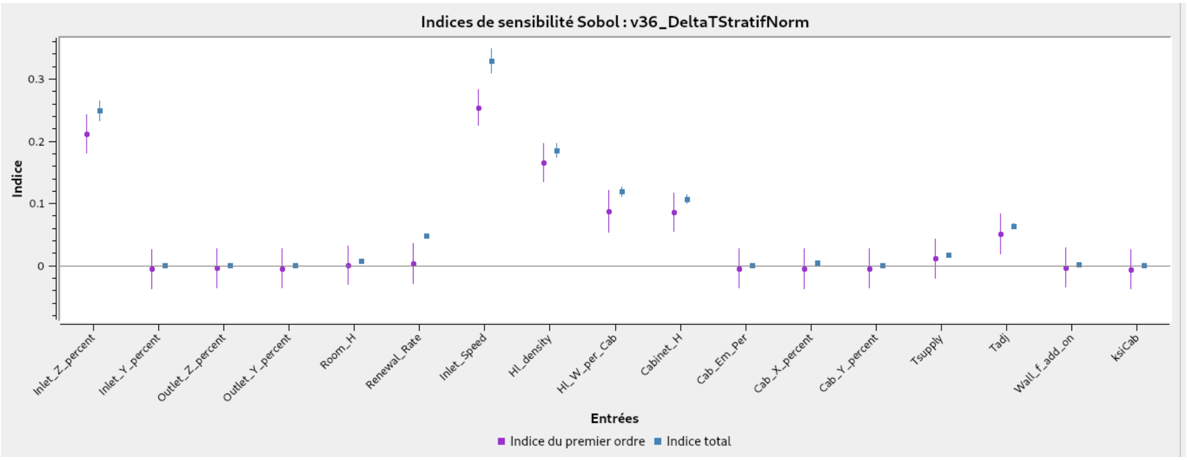
- **Method**
  - Use generated MetaModel to estimate Sobol' indices

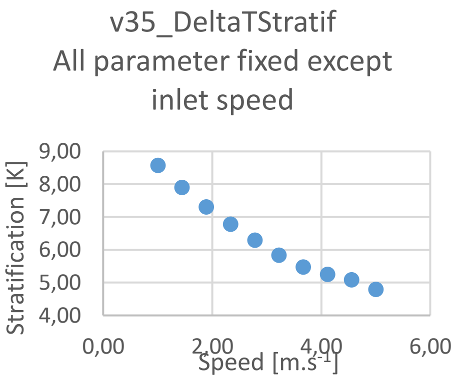
$$S_i = \frac{Var\left[E[Y|X_i]\right]}{Var[Y]}$$

$$ST_i = 1 - \frac{Var\left[E[Y|X_{\sim i}]\right]}{Var[Y]}$$

- **Analysis**
  - Results consistent with Spearman indices and computed kriging scales
  - Significant role of interactions
    - Supply geometry and inlet speed and air change rate
    - Deeper investigation of supply geometry and parameters to be done on next experience plans (supply angle, jet turbulence, inlet grid roles …)
  - Can be used to generate experience plan of lower dimension
    - Projected 1D (all parameters fixed except 1) often tends to have a kriging variance nearly equal to amplitude parameter
    - Number of points for model training is low given the input dimension

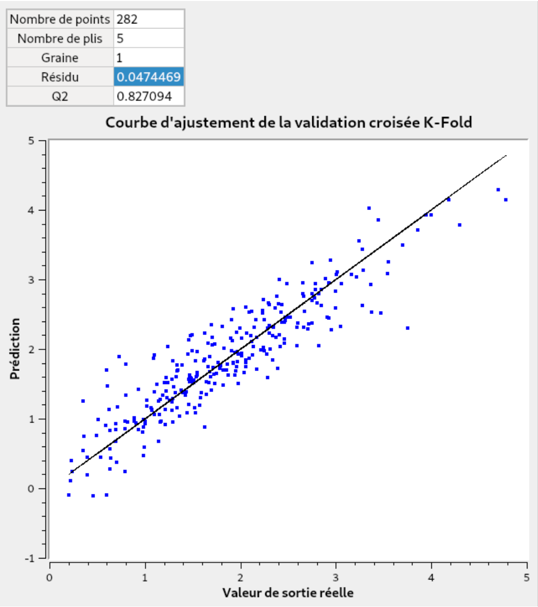


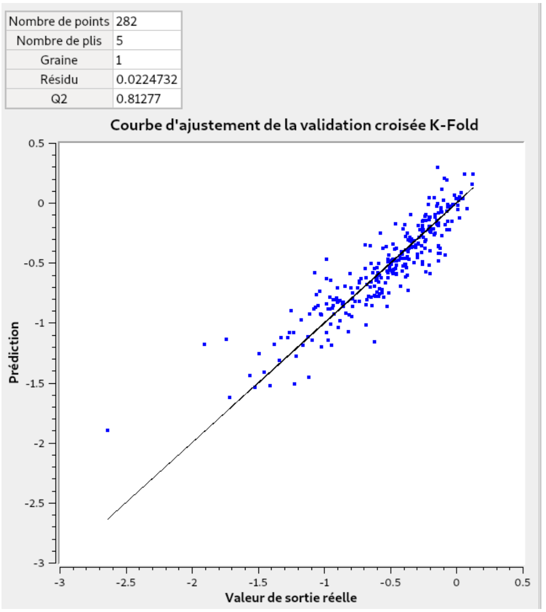



# 3D numerical experiments – MetaModels – Polynomial Chaos

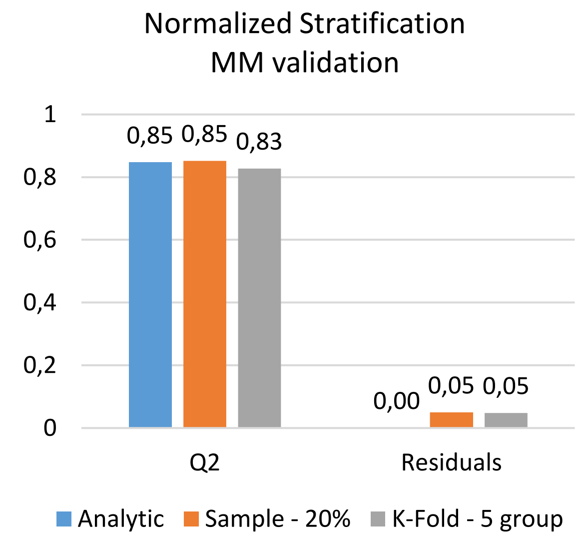
- **Parameters**
  - Max degree : 2 / Sparse basis
- **Results**
  - Slightly lower Q2 than kriging method
  - Lower maximum degree based on explained part of variance
  - Specify marginal of input samples improve significantly Q2
- **Validation**

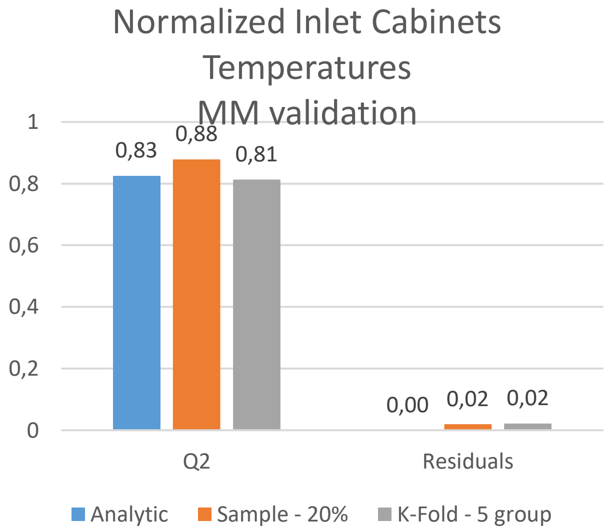



$\Delta T_n$ – Stratification




$T_n$ – Inlet Cabinet



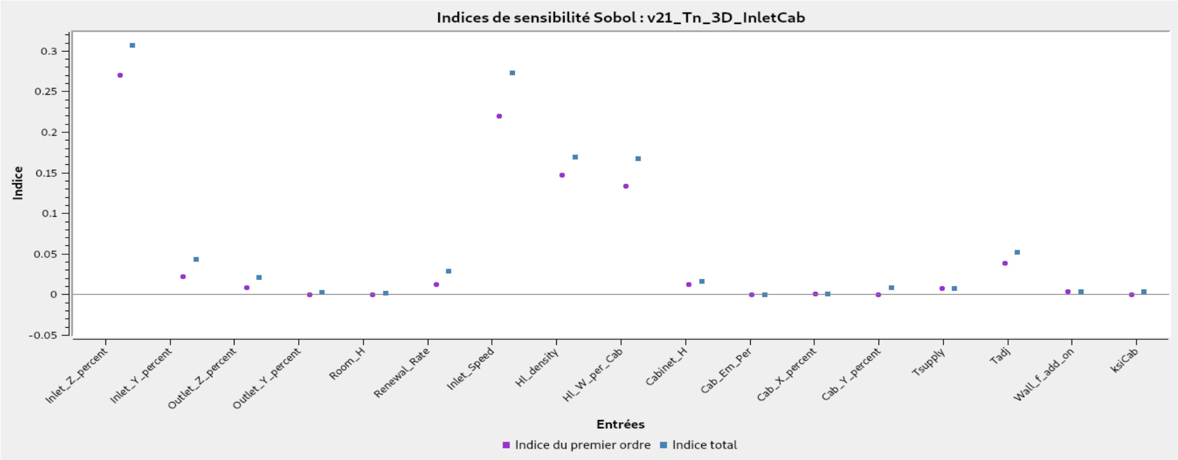
# 3D numerical experiments – MetaModels – Kriging

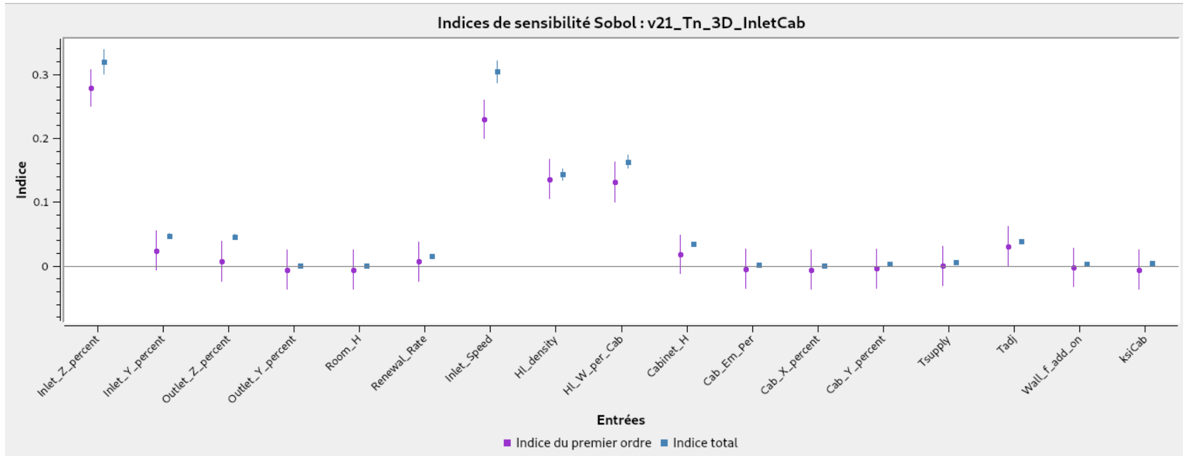
# Sensitivity

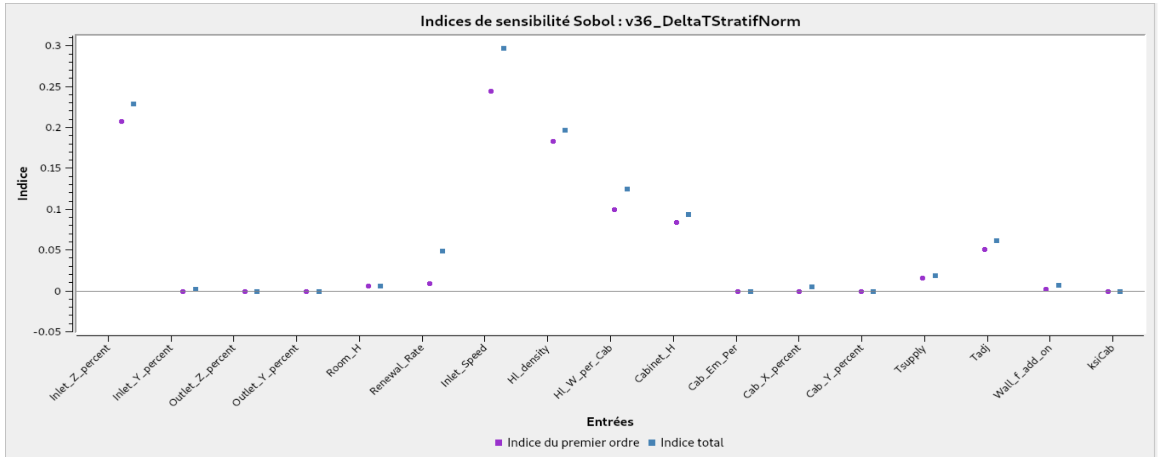
- **Analysis**
  - Consistent Sobol indices between the two models

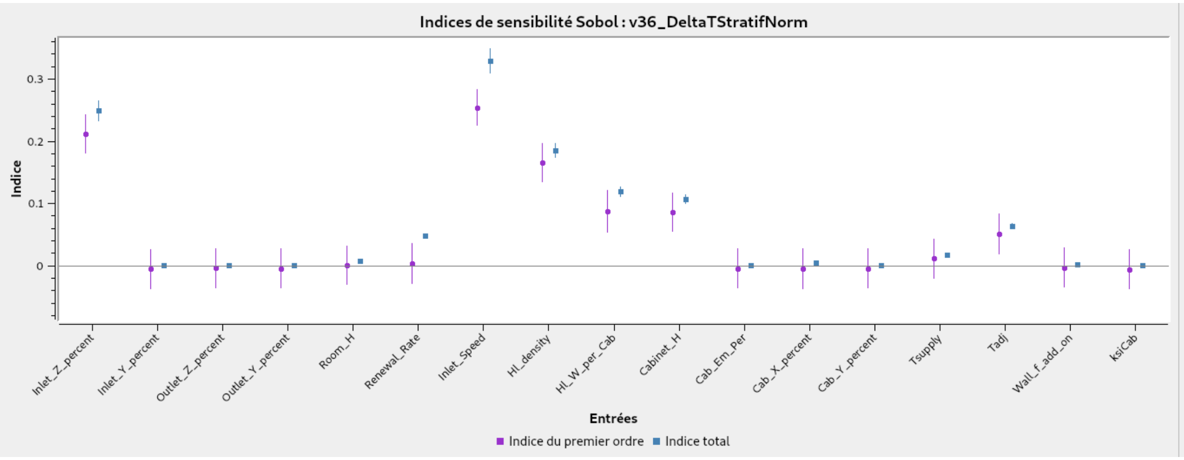
$$S_i = \frac{Var\left[E[Y|X_i]\right]}{Var[Y]}$$

$$ST_i = 1 - \frac{Var\left[E[Y|X_{\sim i}]\right]}{Var[Y]}$$



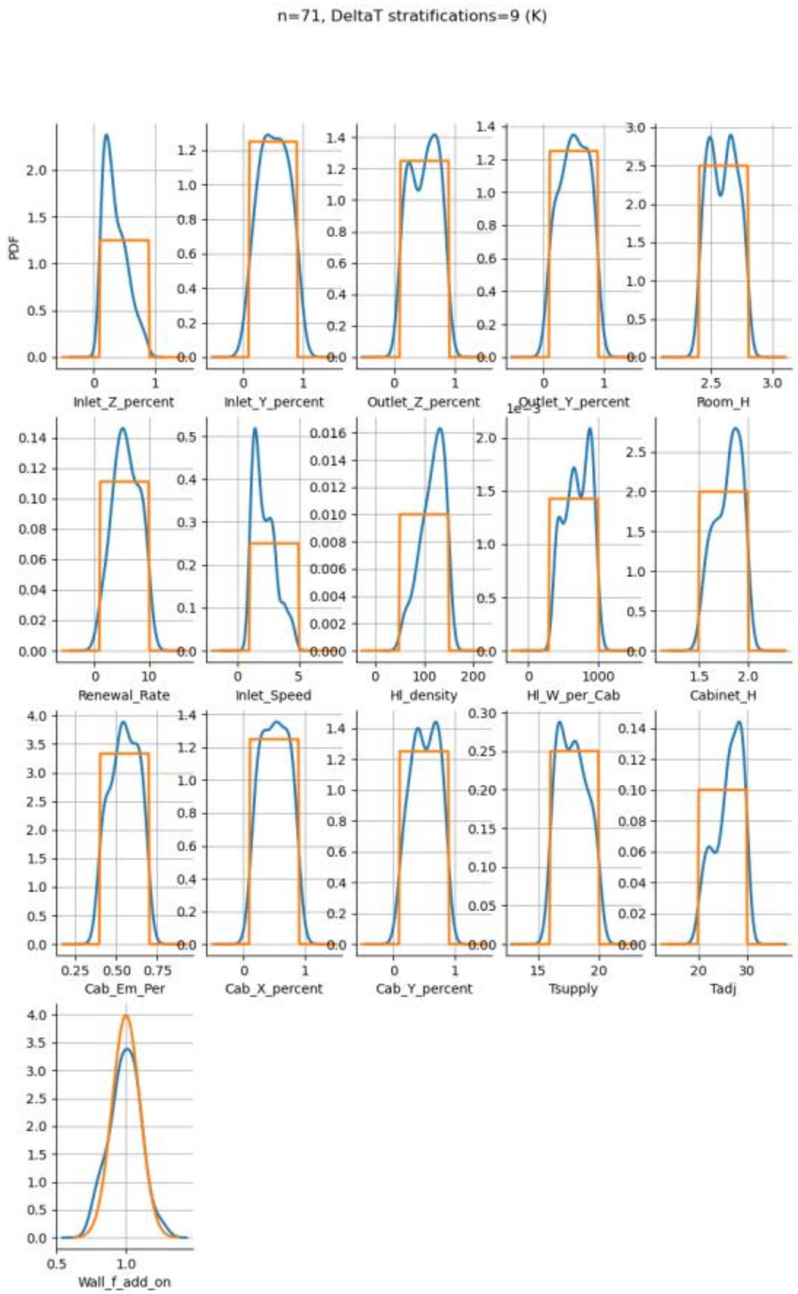



# 3D numerical experiments – Estimate conditional marginal law[1]

- **Method**
  - Select a sample from the evaluated experience plan based on quantile of a variable of interest
  - Let $Y_s$ be a threshold on the output, e.g. computed from a quantile of $Y$. Plot the unconditional distribution of each marginal input $X_i$ and the conditional distribution $X_i \mid Y > Y_s$, where If the variable $X_i$ is independent from the event $X_i \mid Y > Y_s$, then the two distributions are equal. Otherwise, there is a dependency
  - Chosen variable of interest : $\Delta T_{statification}$
- **Analysis**
  - A significant stratification modify the input parameter distribution for the most influent parameters
  - These parameters are the same than the ones previously identified (with Spearman indices and then Sobol' indices estimation with MetaModel)




1. Joint work with M. Baudin

# Conclusions and perspectives

- **Conclusion**
  - **Tool chain operational** for thermo aeraulic sensitivity studies : Based on Salome plateforrm
  - **First quantification** of influent parameters leading to air mix in industrial premises
    - **Significant** role of **supply** : need further investigation on its modelling
  - **MetaModelling** of integrated local 3D variable with reasonable accuracy
    - CFD with y+ =1 : 5000 cpus days -> 3D with integral correlation : 20 h cpus -> MetaModel : 0,001 s
  - **0D** model generally **overestimate** temperature of interest due to the perfect air mix hypothesis
- **Perspectives**
  - Select **group of influent** parameters (optimal size base on first or total Sobol' indices) and re-evaluate experience plan with a lower input dimension
  - **Implement MetaModel** of stratification in **0D** tool by export it and re import in Modelica Model (work in progress with Phimeca – python.h based for wrapping python object in C function)
    - Quantify error propagation in 0D model based on MetaModel residuals distribution
  - Perform dimensional analysis (Vaschy-Buckingham theorem) and try to calibrate traditional $\pi$ functions


- **Acknowledgments:**
  - Sofiane Benhamadouche / Martin Ferrand / Thomas Fonty / Chai Koren / Yvan Fournier : for their CFD expertise and help for advanced use of Code Saturne
  - Michael Baudin / Ovidiu Mirescu : For their advice in the use of Persalys/OpenTURNS and their uncertainties expertise


Persalys

code_saturne

SALOME

OM

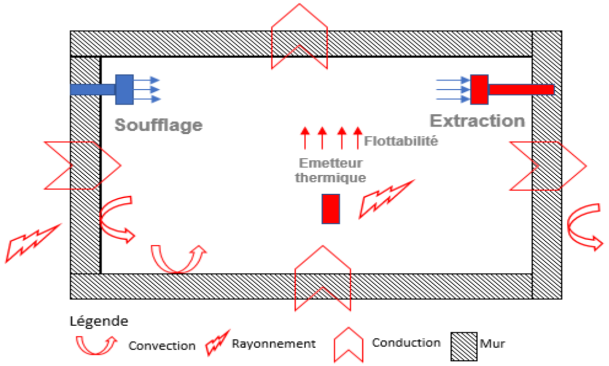
# Thank you for your attention

?

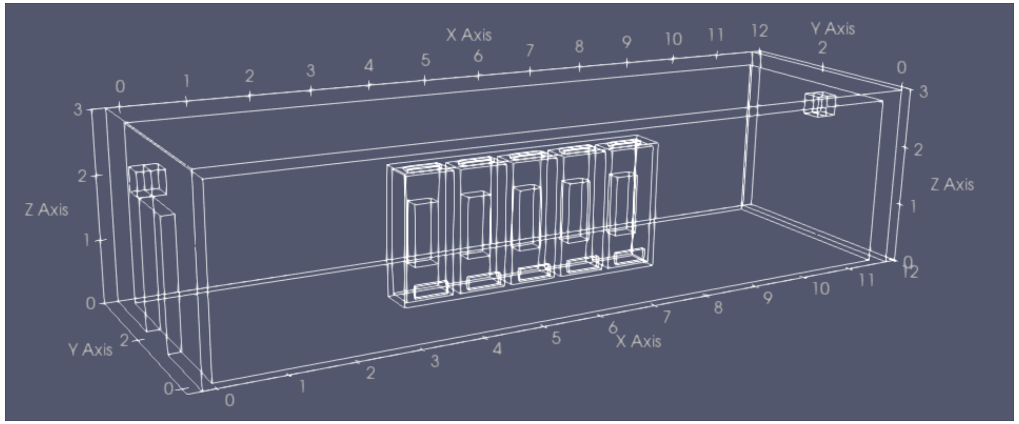
# ANNEXE

# Rappels de la méthode TIPPI (PIRT)

- **L1.01 d:**
  - Proposer une identification à priori des phénomènes influents sur la base d'une approche théorique
  - Réaliser une première quantification sur la base d'expériences numériques s'inspirant de la géométrie du local Zephyr
  - Approche itérative
- **Périmètre**
  - Problématique vaste et multiphysique
  - Les situations thermo aérauliques de locaux industriels nécessiteraient plusieurs PIRT
  - Focus on steady state with Zephyr test room laboratory configuration

# Order of magnitude of the studied case




- Pour le cas de locaux industriels, les ordre de grandeurs sont:
  - $V_0 = 1 m.s^{-1}$ / $L = 1\ m$ / $\rho_0 = 1\ kg.m^{-3}$ / $\delta p_0 = 1\ Pa$
  - $\Delta T = 10\ degC$ / $\lambda_{metal} = 50\ W.m^{-1}.K^{-1}$ / $\lambda_{beton} = 2.3\ W.m^{-1}.K^{-1}$
  - $h_{cv} = 3\ W.m^{-1}.K^{-1}$ / $\mathrm{e_{metal}} = 0{,}05\ \mathrm{m}$ / $\mathrm{e_{beton}} = 0{,}3\ \mathrm{m}$
- Ce qui conduit
  - Pour les parois : $Ra \approx 1e9 - 1e10$
  - $Ri \approx 1$ loin de singularité
  - $Re \approx 1e5$ : écoulement turbulent, notamment au niveau des jets
  - $\mathrm{Pr} \approx 0{,}7$
  - $Bi_{metal} \approx 3e^{-3}$ / $Bi_{beton} \approx 3e^{-1}$
- Ces nombres seront à réévaluer de manière plus précises selon les cas étudiés ; les valeurs mentionnées sont utiles pour situer le problème

$$\underline{\nabla} \cdot \rho \underline{V} = 0$$

$$\frac{\partial \hat{\rho} \underline{\hat{V}}}{\partial \hat{t}} + \underline{\hat{\nabla}}\left(\hat{\rho} \underline{\hat{V}} \underline{\hat{V}}\right) = -Eu \underline{\hat{\nabla}} \hat{p} + \frac{1}{Re} \underline{\hat{\nabla}}\, \underline{\underline{\widehat{\sigma'}}} - Ri\, \underline{e_z}$$

$$\frac{\partial \hat{T}}{\partial \hat{t}} + \hat{\rho} \underline{\hat{V}} \,.\, \underline{\hat{\nabla}} \hat{T} = \frac{1}{\sqrt{RaPr}} \underline{\hat{\nabla}} \hat{\lambda} \underline{\hat{\nabla}} \hat{T}$$

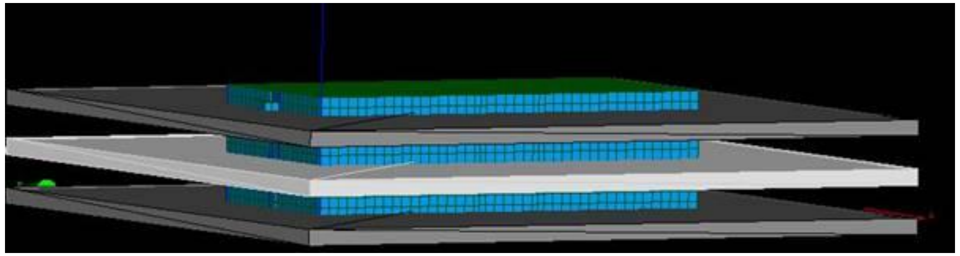
$$\hat{p} = \frac{p - \rho_0 \underline{g}.\underline{x}}{\delta p_0} \ / \ \hat{\rho} = \frac{\rho}{\rho_0} \ / \ \hat{t} = \frac{V_0}{L} t \ / \ \underline{\hat{x}} = \frac{\underline{x}}{L} \ / \ \underline{\hat{V}} = \frac{\underline{V}}{V_0} \ / \ \underline{\hat{\nabla}} = L \underline{\nabla}$$

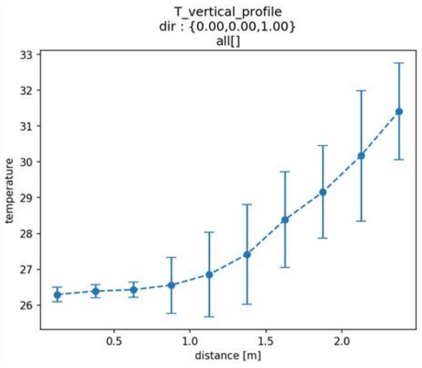
$$Eu = \frac{\delta p}{\rho_0 V_0^2} \ / \ Re = \frac{\rho_0 V_0 L}{\mu_0} \ / \ Ri = \frac{g \beta \Delta T L}{V_0^2}$$

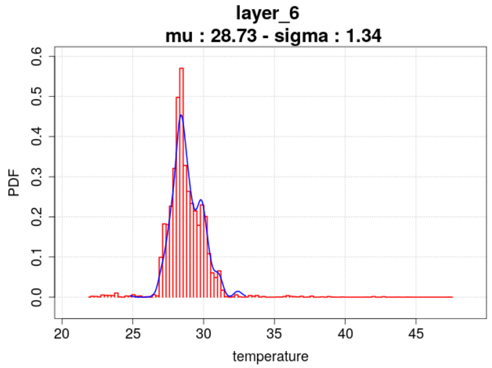
$$: Pr = \frac{\mu_0 c_p}{\lambda_0} \ / \ Ra = GrPr = \frac{\rho c_p g \beta \Delta T L^3}{\lambda \nu} \ / \ Gr = \frac{\rho g \beta \Delta T L^3}{\mu} \propto Re^2$$

# 3D numerical experiments – tools used

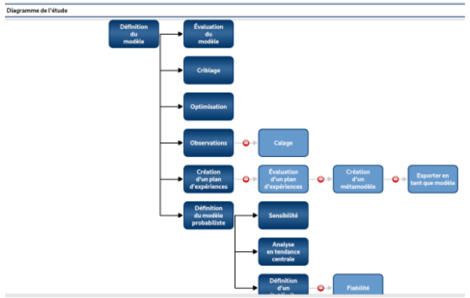
- **Numerical tools used**
  - Code Saturne (CFD)
  - Salome platform
    - Geom/Smesh Modules(CAO/meshing)
    - Persalys Module (YACS model)
  - OpenModelica with TAeZoSysPro library
    - Use of ModelicaScripting library to wrap OpenModelica Model in Persalys _exec function
- **Specific development for this study**
  - Python library to drive global model within Persalys _exec (3600 lines)
    - Automatic meshing generation (to account uncertain geometric parameter)
    - Run Cases (Saturne and TAeZoSypro) in parallel
      - ❑ Handle RESU directory unique name
      - ❑ Possibility to restart 3D model if convergency not reached
      - ❑ Possibility to only read already run case to extract other variable of interest
    - Post processing tools (matplotlib graph generation)
  - Features to monitor global quantities for code saturne
    - Mean Profiles on all or part of the mesh (MEDCoupling or CS STL) by layer (c++ 3800 lines)
    - Balance by zone (surfaces/volumes) to monitor radiant/convective thermal exchanges and hvac power (3000 c lines)
  - Various Python UNIX tools to handle amount of data generated (1 To of data generated for a total of 12 000 cpus day)
  - _exec function  writing for models drive (5800 lines)
  - Python meshing function



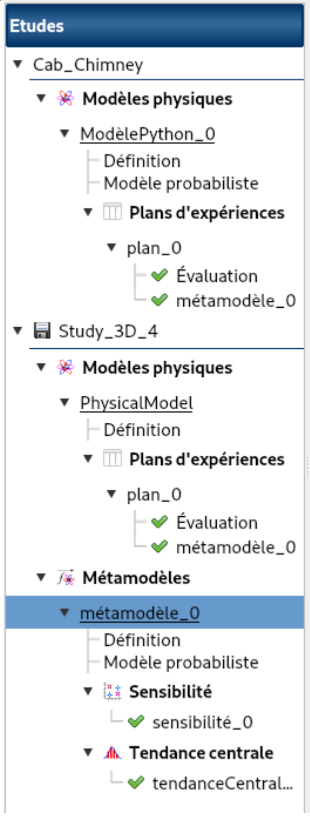


# 3D numerical experiments – Workflow



- **Setup meshing script (uncertain geometrical parameter parts)**
- **Setup Code Saturne (uncertain parmeter : physical properties / limite conditions)**
- **Setup equivalent 0D/1D TAeZoSysPro model (with accounted uncertain parameters)**
- **Setup persalys function _exec and test (if __name__==‘__main__’:)**
- **Generate Persalys study with several decoupled steps**
  - Use of Persalys YACS model modified with the use of slurm study feature : enable executables launch with *srun* command within an allocated batch on cluster (default YACS model launched branches with *srun* command, preventing other use of *srun* command)
    - Example : evaluate 300 point, each point require 20 Cpus, by block of 10 (total of 6 GAIA nodes with 204 Cpus requested)
  - Generate probabilistic experience plan based on uncertain parameters probabilistic model and csv export
  - Create another study with the same YACS model and create and imported csv experience plan
    - Run the experience plan as many time as required for all points to reach convergency
  - Create other YACS model, same uncertain parameters but with other variables of interest
    - _exec function will only read already run point
    - 1 for power balance / 1 for temperatures / 1 for dimensionless number




- **Result analysis within Persalys**
  - Experience plan result analyse
  - Use experience plan as data model to generate MetaModel
    - Perform sensivity/central tendency analyses
    - Export MetaModel to improve 0D/1D models

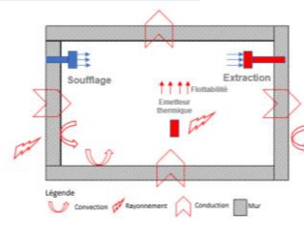
```
import salome_ot
import os
study,ModèleYACS_0=salome_ot.getYacsPyStudy(code)
import pydefx
pydefx_path = os.path.dirname(pydefx.__file__)
light_executor_path = os.path.join(pydefx_path, "plugins", "lightexecutor.py")
mybuilder = pydefx.slurmbuilder.SlurmBuilder(executor=light_executor_path)
myModel = pydefx.SlurmStudy(schemaBuilder=mybuilder)
ModèleYACS_0.setJobModel(myModel)
```

- https://gitlab.pleiade.edf.fr/hvac_numerical_tools/vn24/L1.01d_PIRT_3D (internal EDF access)

# Phénomènes physiques identifiés

- **Les principaux phénomènes physique identifiés à l'échelle du local industriel sont:**

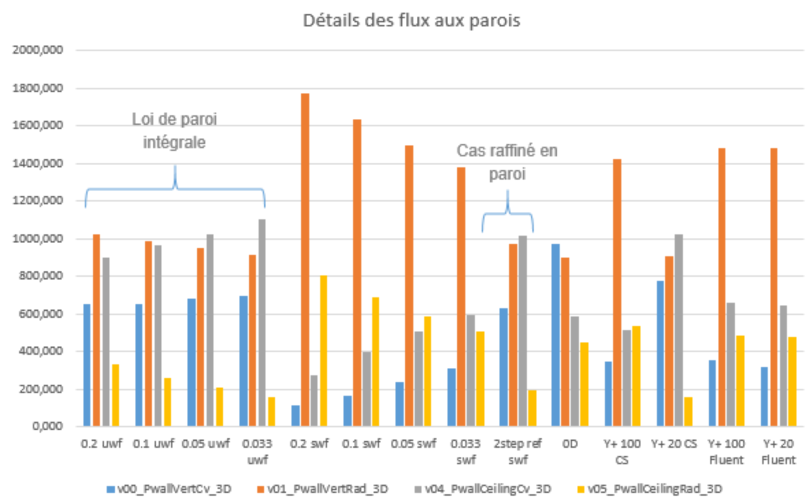
| Phénomènes physiques | Paramètres géométriques | Paramètres matériaux | Conditions aux limites | Nombre adimensionnel |
|---|---|---|---|---|
| **Conduction thermique dans les solides**<br>**Béton - Emetteur** | Epaisseur des parois<br>Surface des parois | Conductivité thermique<br>$c_p$ et $\rho$ | Température adjacente<br>Flux adjacent | Biot |
| **Convection naturelle murs** | Surface,<br>Longueur caractéristique | Viscosité<br>$\rho, \lambda_{fluide}$ | Température adjacente<br>Flux adjacent | Rayleigh<br>Prandtl |
| **Rayonnement**<br>**Mur – Mur**<br>**Emetteur – Enveloppe**<br>**Enveloppe -Mur** | Surface<br>Angles solides entre surfaces | Emissivité | Flux solaire<br>Température ciel | - |
| **Inertie thermique** | Géométrie des masses<br>Surface d'échange | $\rho, c_p, V, \lambda$ | - | Fourrier |
| **Transferts enthalpiques** | Géométrie du local<br>Position des bouches de soufflages/extraction | $\beta, \rho, c_p, \mu, \lambda$ | Débit ventilation<br>Localisation entrée/sorties<br>Température de soufflage<br>Charge thermique | - |
| **Stratification thermique** | Géométrie du local<br>Géométrie source thermiques (incluant leurs freins aérauliques) | $\beta, \rho, c_p, \mu, \lambda$ | Température de soufflage<br>Vitesse de soufflage<br>Charge thermique | Richardson |
| **Effets de jets** | Géométrie des obstacles | $\beta, \rho, c_p, \mu, \lambda$ | Vitesse de soufflage | Reynolds<br>Richardson |
| **Panaches thermiques** | Géométrie du local<br>Géométrie des sources | $\beta, \rho, c_p, \mu, \lambda$ | Charge thermique | Rayleigh<br>Reynolds |
| **Configuration Rayleigh Bénard** | Géométrie du local | $\beta, \rho, c_p, \mu, \lambda$ | Température adjacente | Rayleigh |
| **Mélange turbulent** | Géométrie de la pièce<br>Nature des obstacles | $\beta, \rho, c_p, \mu, \lambda$ | Vitesse soufflage<br>Charge thermique | Reynolds<br>Rayleigh |



# Expérience numériques 3D

## Configuration

- Utilisation de loi de paroi thermique intégrale pour une estimation correcte des flux thermiques (précision l'ordre de 10-20 %)
- Couplage de l'ensemble des phénomènes (conduction thermique solide, échanges conducto/convectifs, échanges radiatifs) étant donné l'importance de chacun d'entre eux sur la distribution du champs de température
- Utilisation de maillages hexaédriques par bloc avec une taille de cellule élémentaire de 0,01 m
- Modèle de turbulence : $k - \omega\ SST$ (faible sensibilité au modèle de turbulence vis-à-vis des grandeurs d'intérêt intégrales identifiées)
- Approche 3D zonale ou CFD macroscopique : La résolution de la structure local fine de l'écoulement n'est pas réalisée.




## Configuration numérique

- Schémas numériques
  - Upwind pour la turbulence
  - SOLU pour les autres variables
- Précision solver : 10e-5 sauf la température 10e-6
- Paramètres temps
  - Variable en temps (IDTVAR=1)
    - Ref time step : 0,1 s
    - Time step maximal variation : 0,01
  - CDTVAR :
    - 20 pour la température pendant 1000-1500 itérations
    - Passage à 1 via cs_user_extra_operations.c au bout de 1000-1500 itérations, calcul poursuivi jusqu'à 3000- 4000 itérations
- A affiner selon les cas

## Post Traitement

- Export de tous les bilans et profils en csv
- Export vtk de l'état final
- Export Catalyst : Vue globale, coupe en température et en vitesse
- Génération d'un rapport LaTeX globale : 2 pages par cas d''évaluation