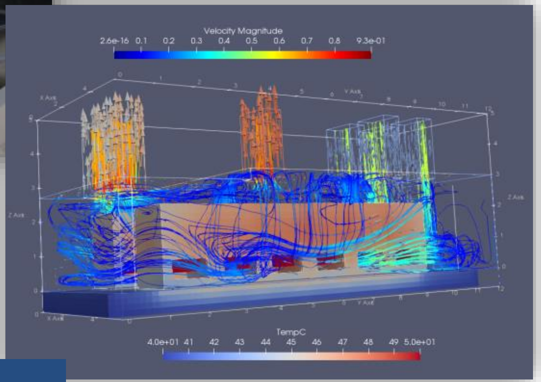
Sensitivity studies OD-1D/3D of thermo aeraulic models

Persalys User's Day – November 7th 2024

Pascal Borel (R&D/PRISME)



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 and sensitivity studies

Context of industrial thermo-aeraulic studies

Objectives of industrial thermal studies

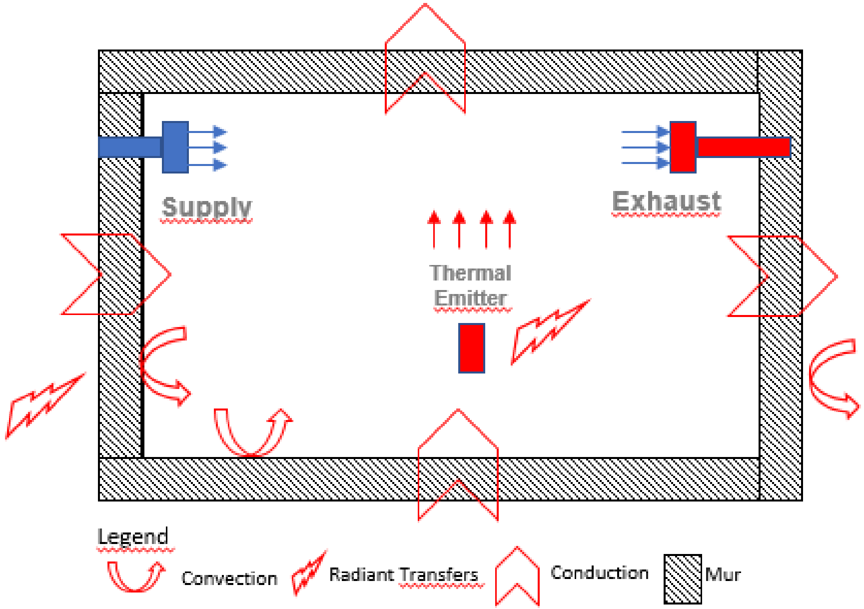
- Assess operability of electrical and I&C cabinet in industrials premises in various situation (consistency with thermal qualification)
- Thermal transient : steady state, thermal transient with partial or total loss of HVAC
- Premises configuration : geometry, thermal loads, thermal conditioning

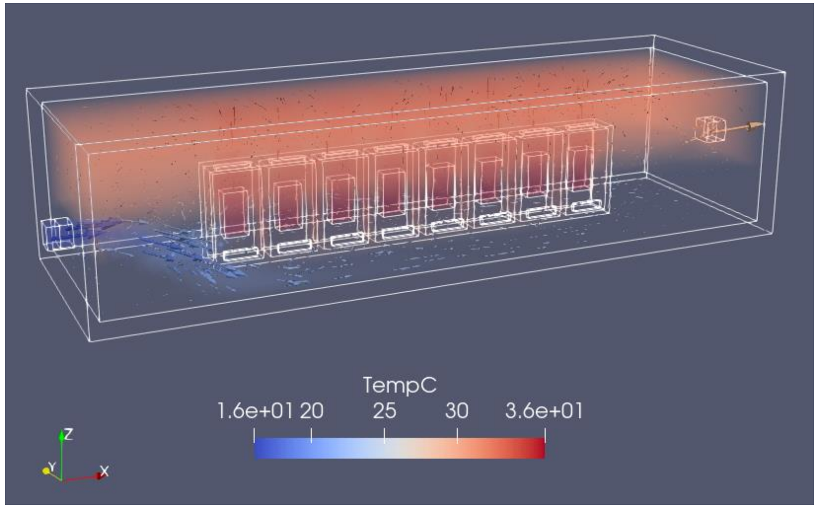
Industrial practices

- 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 on EDF R&D Chatou site





Modular laboratory ZEPHYR - Generalities

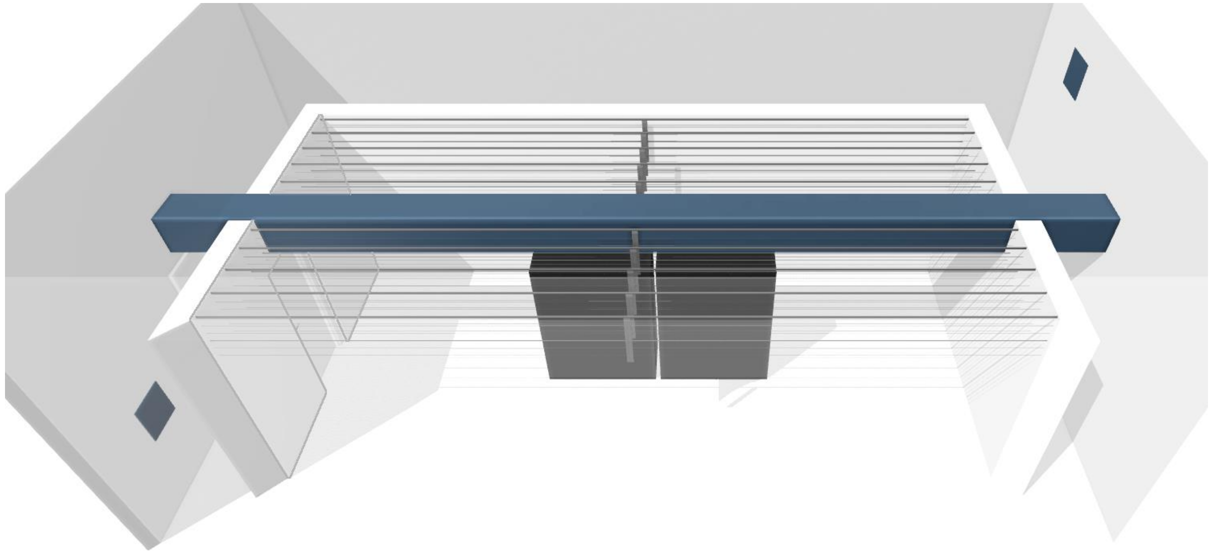
Assets

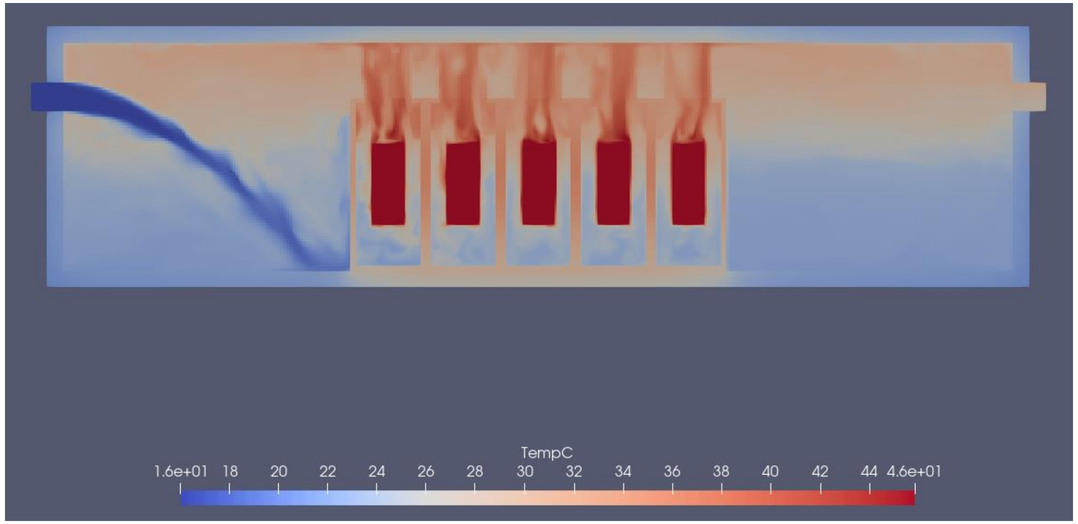
- Existing and future nuclear configurations
- Scale 1
- Modularity of the installation
- Multi-client

Main technical objectives

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

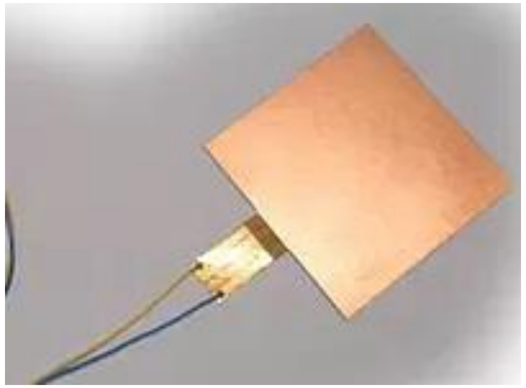
Representative concrete room



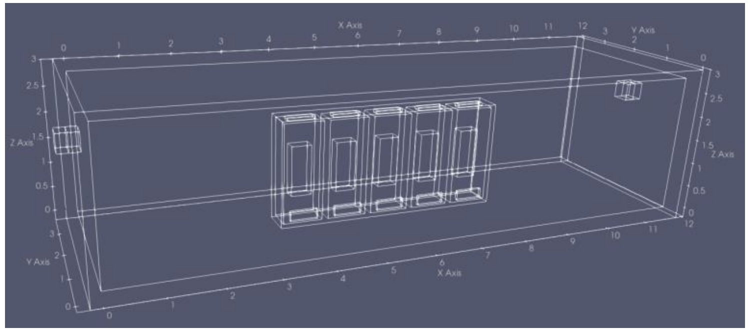


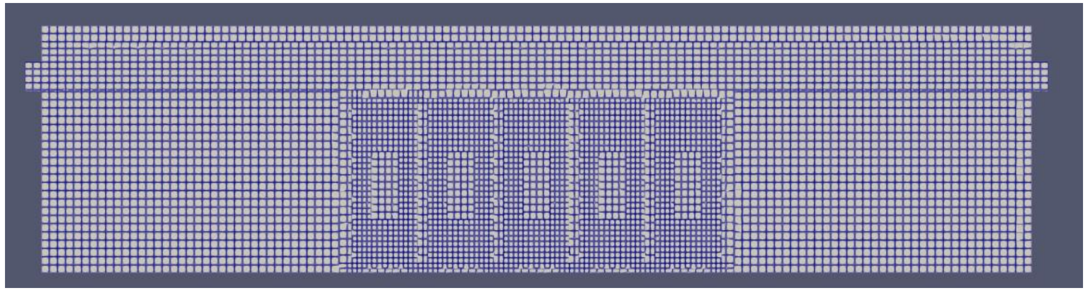
Rij / user wall function – size : 0,033m

- 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)

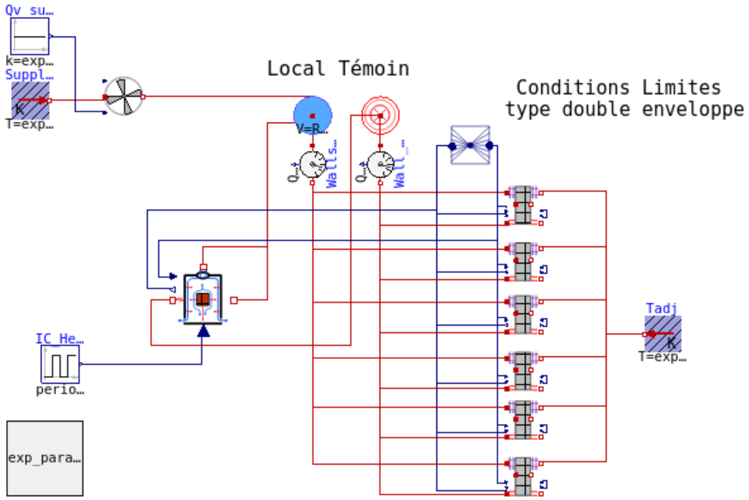
- Fluid flow
- Heat transfers / Conjugate heat transfer
- Conduction / Convection /Radiant transfers

Mesh

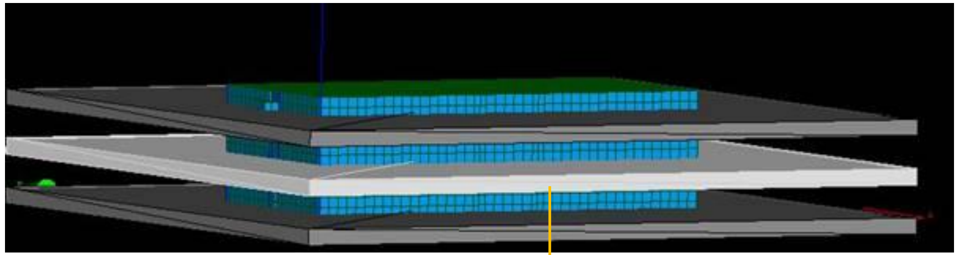
- Air, Walls and Electrical Cabinet Modelled
- Elementary size : 0,1m
- Wall functions : integral correlation used for heat flow

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)

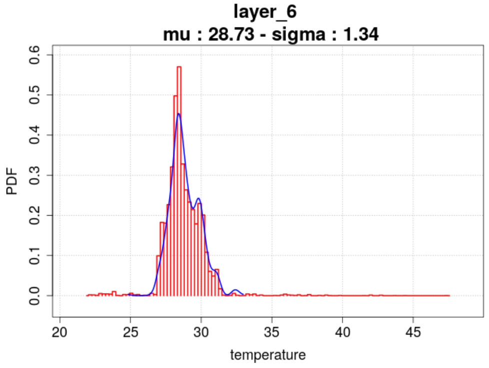


3D numerical experiments – Case workflow



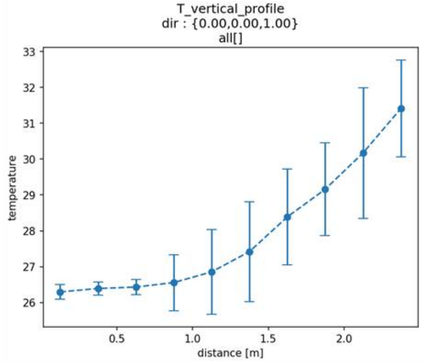
Cases step

- 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



Experimental plan

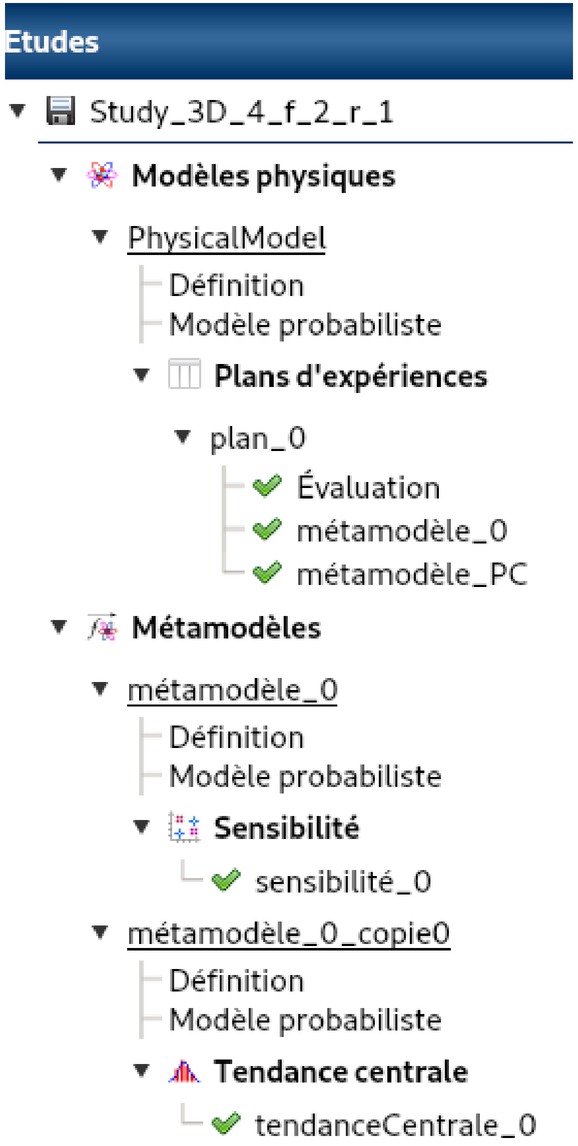
- Generate design of experiments (Persalys)
- Wrap case in _exec function (Specific Python library)
- Enables case restart and results saving
- Evaluate experimental plans until convergency is reached for each case
- Results analysis as a new Data model
  - Dependencies
  - Sensitivity analyses metamodel based



3D numerical experiments – Persalys workflow

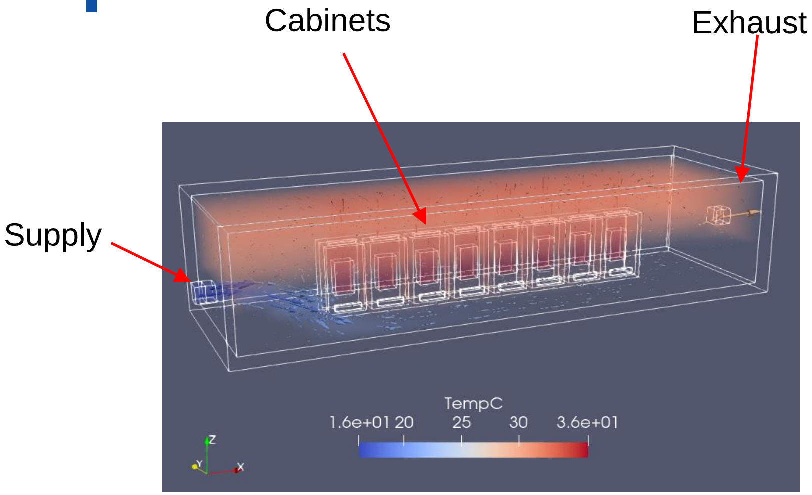
Persalys `_exec()` **function**

- Define as a YACS model
- Evaluation of the plan with code modification



3D numerical experiments – Uncertain parameters

	Parameter	Marginal	Description
Geometrical parameters	Inlet_Z/Y_percent [-]	Uniform [0,1 – 0,9]	Supply position
	Outlet_Z/Y_percent [-]	Uniform [0,1 – 0,9]	Exhaust position
	Cab_Em_per [-]	Uniform [0.4,0.7]	Emitter volume percentage of cabinet
	Cab_X/Y_Percent [-]	Uniform [0.1,0.9]	Position of cabinet row in the room
	HL_W_Per_Cab $[W]$	Uniform [300,1000]	Heat loads per cabinet (round to inf int)
	Cabinet_H $[m]$	Uniform [1.5,2]	Cabinet height
	Room_H $[m]$	Uniform [2.4,2.8]	Room height
Limit conditions	Renewal_Rate $[vol.h^{-1}]$	Uniform [1,10]	Air change rate
	Inlet_Speed $[m.s^{-1}]$	Uniform [1,5]	Supply air speed
	HL_density $[W.m^{-2}]$	Uniform [50,150]	Heat Loads density
	T_supply $[degC]$	Uniform [16,20]	HVAC supply temperature
	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
	KsiCab [-]	Uniform [6-50]	Number of dynamic pressure losses (at inlet speed) of Cabinet

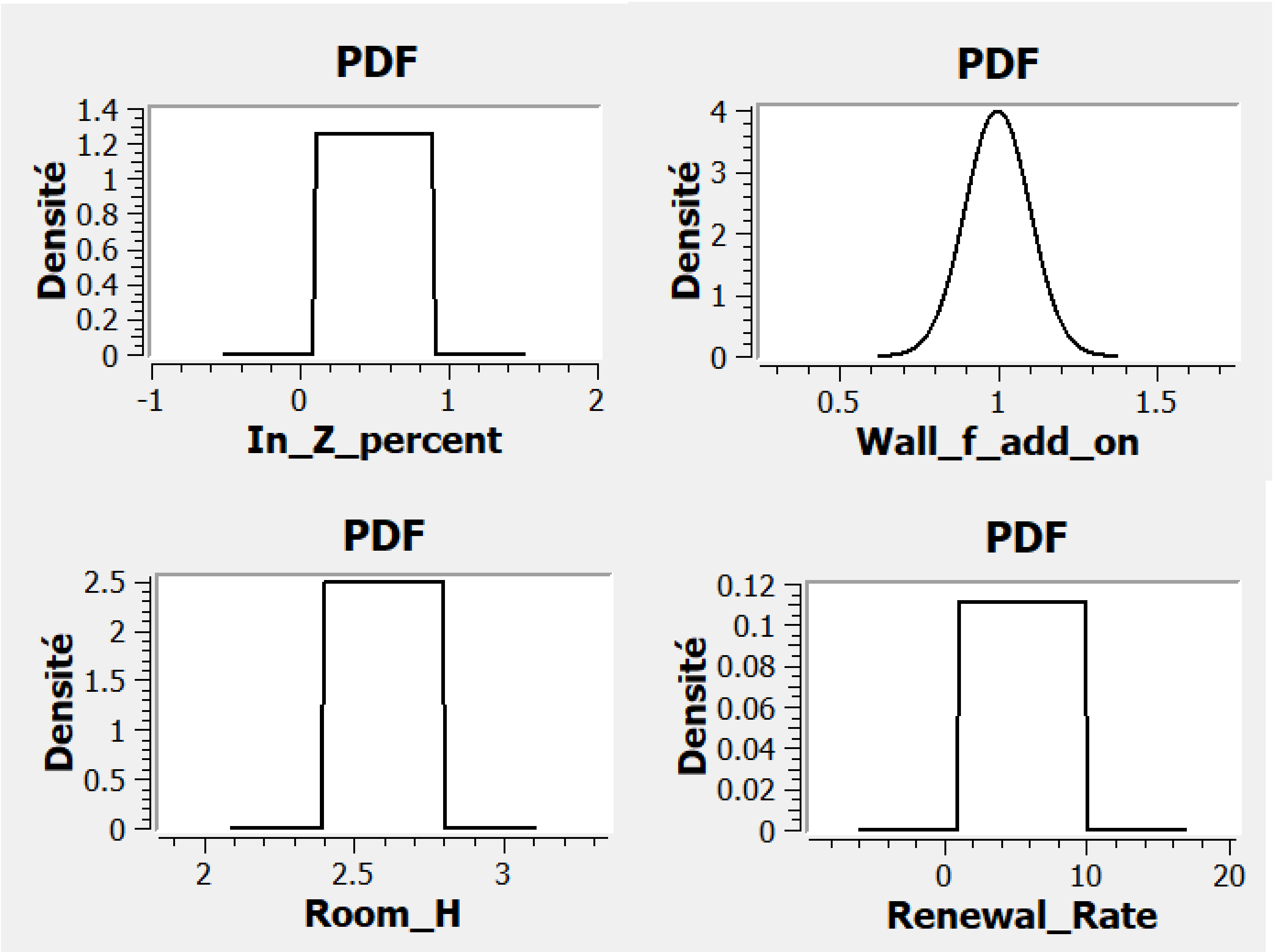


3D numerical experiments – Uncertain parameters

Methodology

- Study equiprobable situations
- Investigate generic model sensitivity

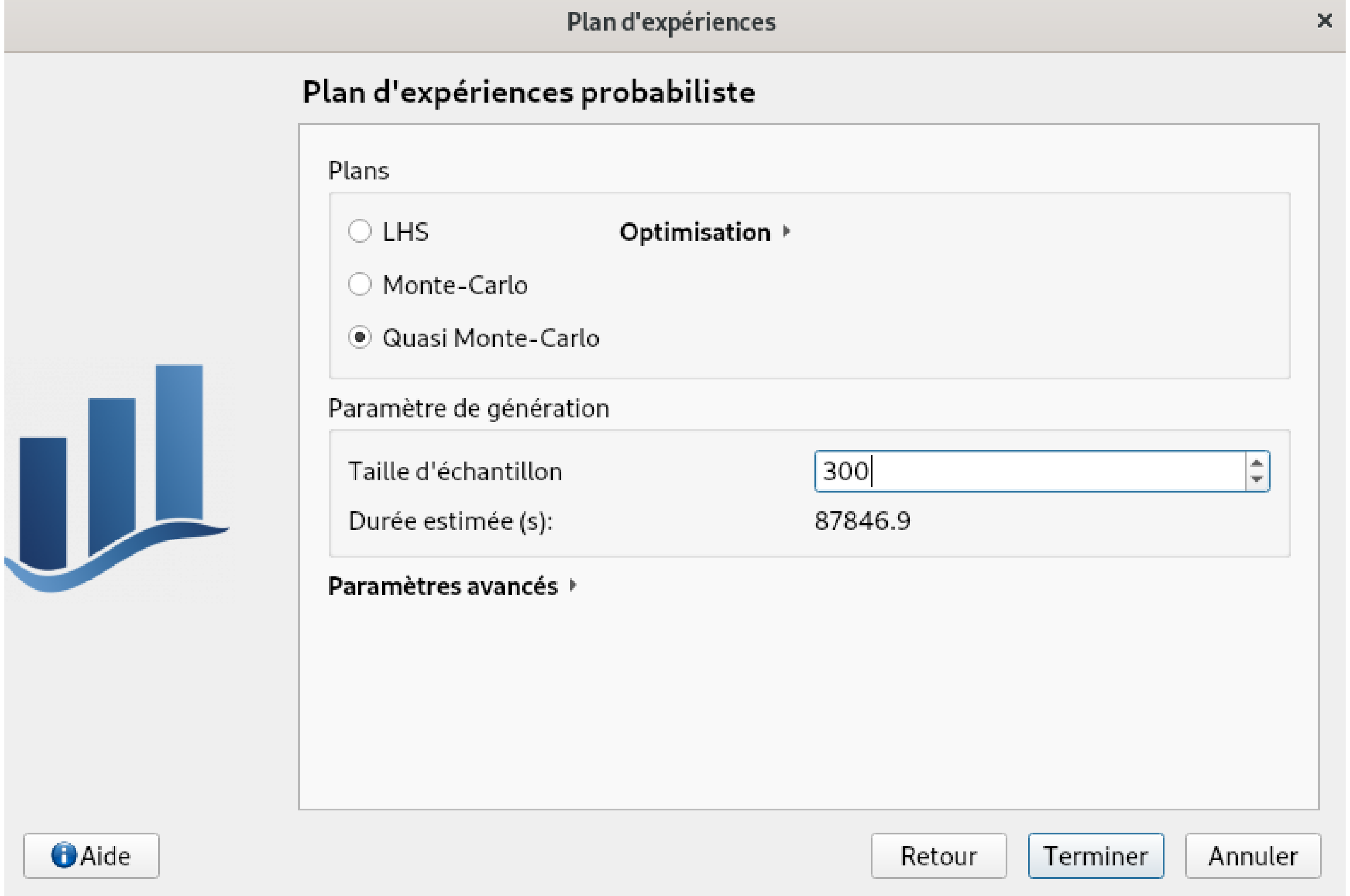
Dependency : independent copula



3D numerical experiments – Experimental plan

Probabilistic experimental plan

- 17 uncertain parameters
- Low discrepancy sequence (Quasi Monte Carlo): fills the space to minimize the discrepancy
- 300 points
- Sample size: trade-off between computing time and number of points



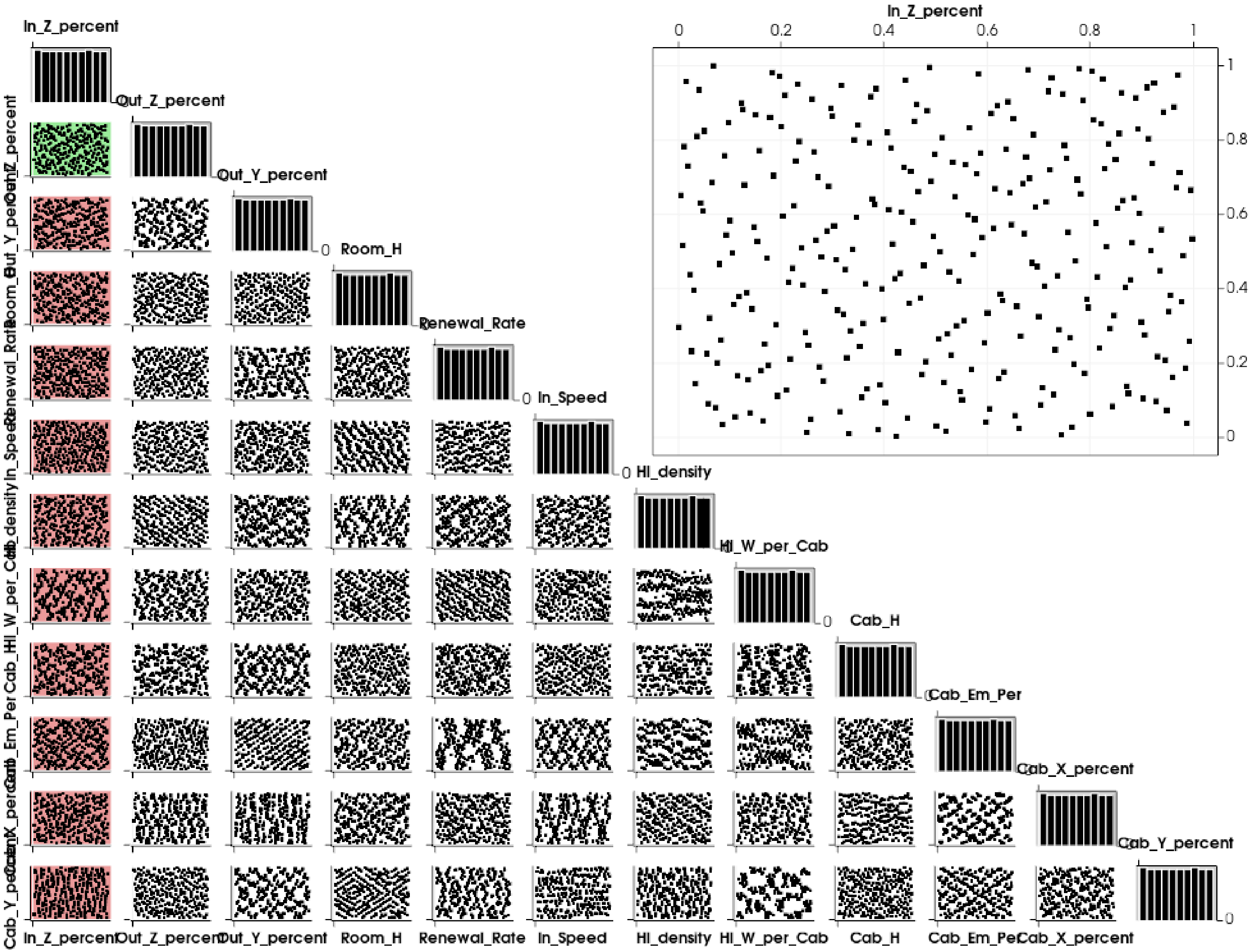
3D numerical experiments – Results

Total evaluations

- First experimental plan of 16 cases with different numerical setups : 10 000 CPUs days
- Determine sensible trade-offs 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



3D numerical experiments – Variables of interest

Analysis focus

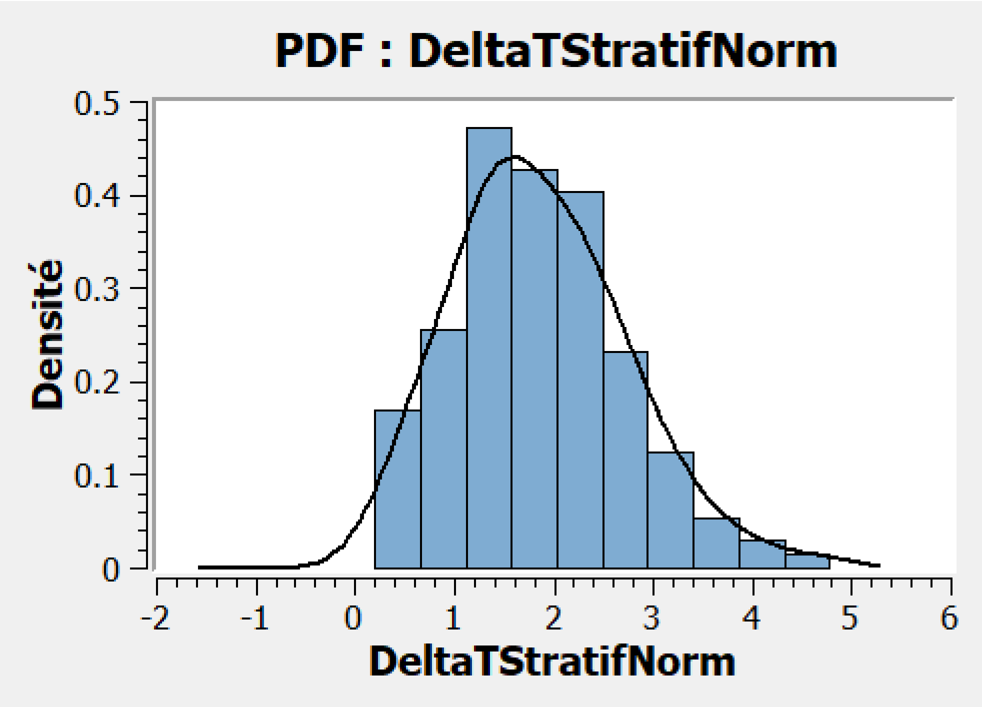
- Stratification phenomena (given by the 3D code)
- Consistency between predictions of 3D and 0D code

Stratification: dimensionless temperature difference between ceiling mean and floor mean:

$$\Delta T_n = \frac{\overline{T_{ceiling}} - \overline{T_{floor}}}{\Delta T_{ref}}$$

Result:

95% of the normalized stratifications are in the interval [0.38, 3.80]



Variable	Value	95% confidence interval
Mean	1.86	[1.76, 1.96]
Standard deviation	0.86	[0.80, 0.94]

3D numerical experiments – Results

Main dependencies (Spearman indices)

$\Delta T_{stratification}$ is mainly influenced by:

- Inlet Z percent
- Renewal rate
- Inlet speed
- HI density
- Cabinet H
- T adj.

Conclusion

- 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 influential

Estimation de la matrice de Spearman

	DeltaT_Strat
In_Z_percent	-0.431
In_Y_percent	0.0188
Out_Z_percent	-0.0288
Out_Y_percent	-0.00838
Room_H	-0.0826
Renewal_Rate	-0.0988
Inlet_Speed	-0.412
HI_density	0.403
HI_W_per_Cab	-0.263
Cabinet_H	0.347
Cab_Em_Per	0.00565
Cab_X_percent	-0.0326
Cab_Y_percent	-0.0143
Tsupply	-0.0974
Tadj	0.204
Wall_f_add_on	-0.0364
ksiCab	-0.0079
DeltaT_Strat	

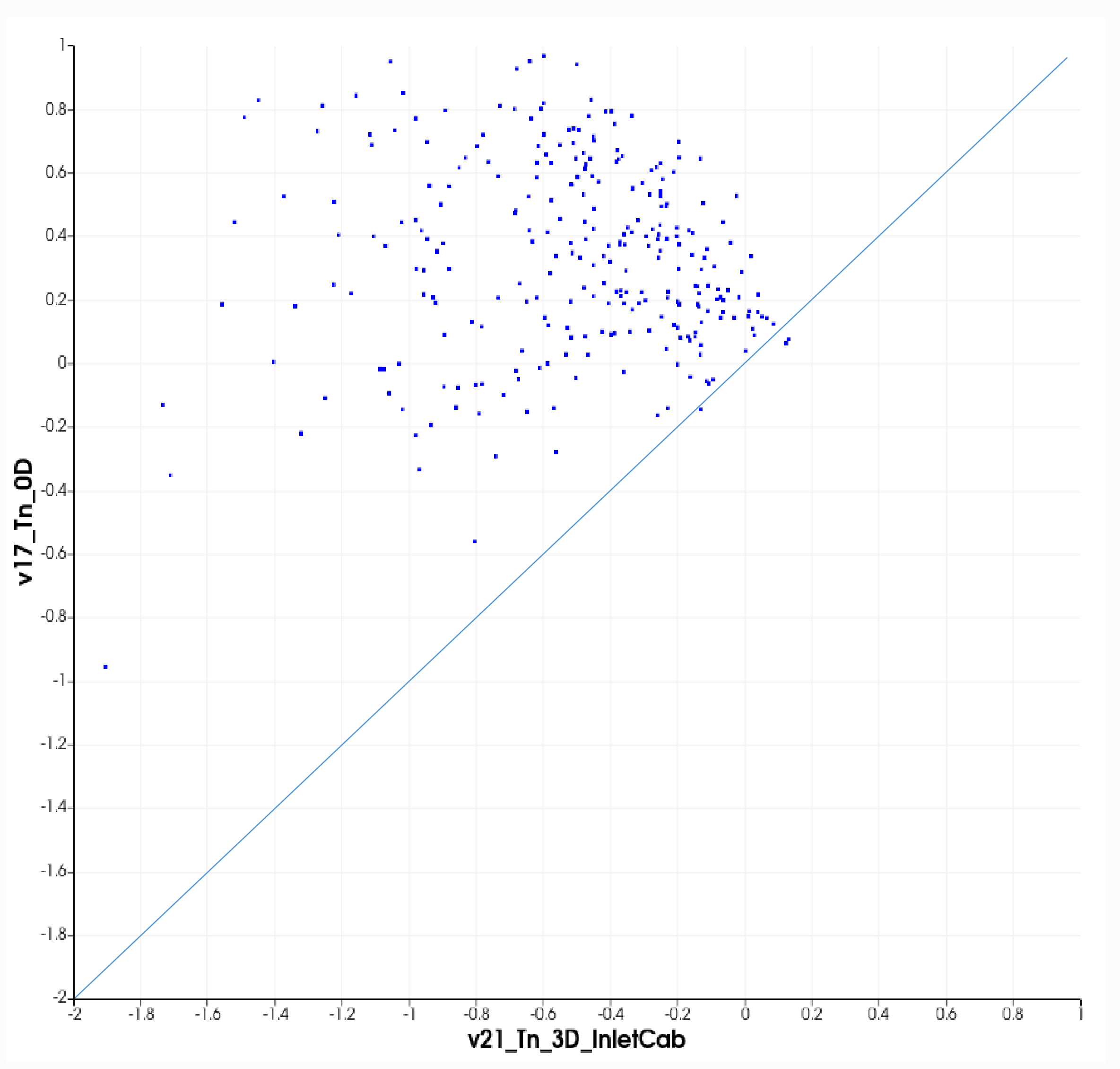
Coefficient de Spearman
ρ > 0.7
0.3 < ρ ≤ 0.7
ε < ρ ≤ 0.3
-ε ≤ ρ ≤ ε
-0.3 ≤ ρ < -ε
-0.7 ≤ ρ < -0.3
ρ < -0.7

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 sensitivity analysis (Sobol')
  - Perform partial sensitivity analysis (with some influential parameters set as constant)
  - Allow metamodel export for improve 0D modelling of electrical premises

Methods

- 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

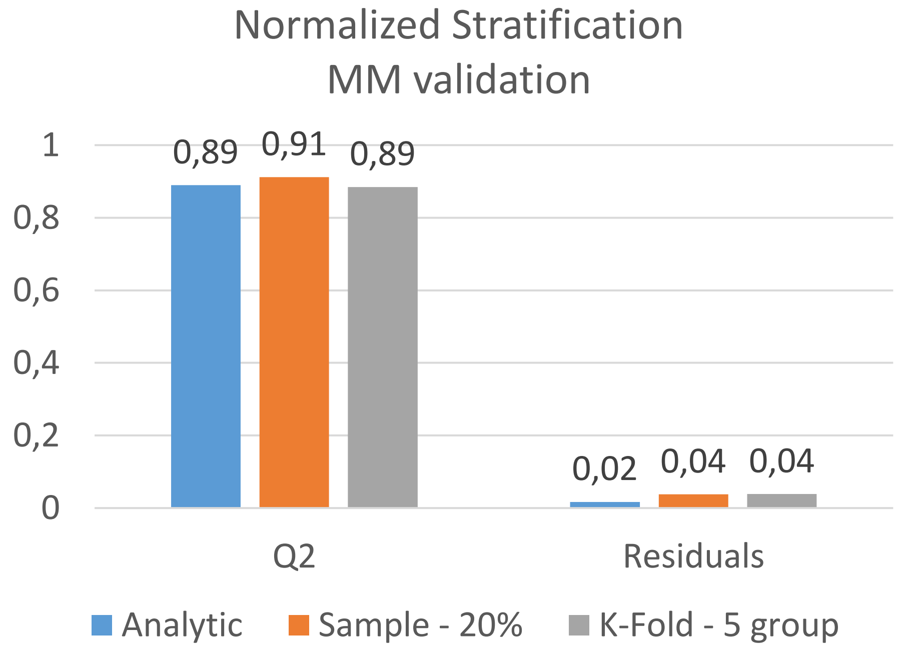
3D numerical experiments – MetaModels - Kriging

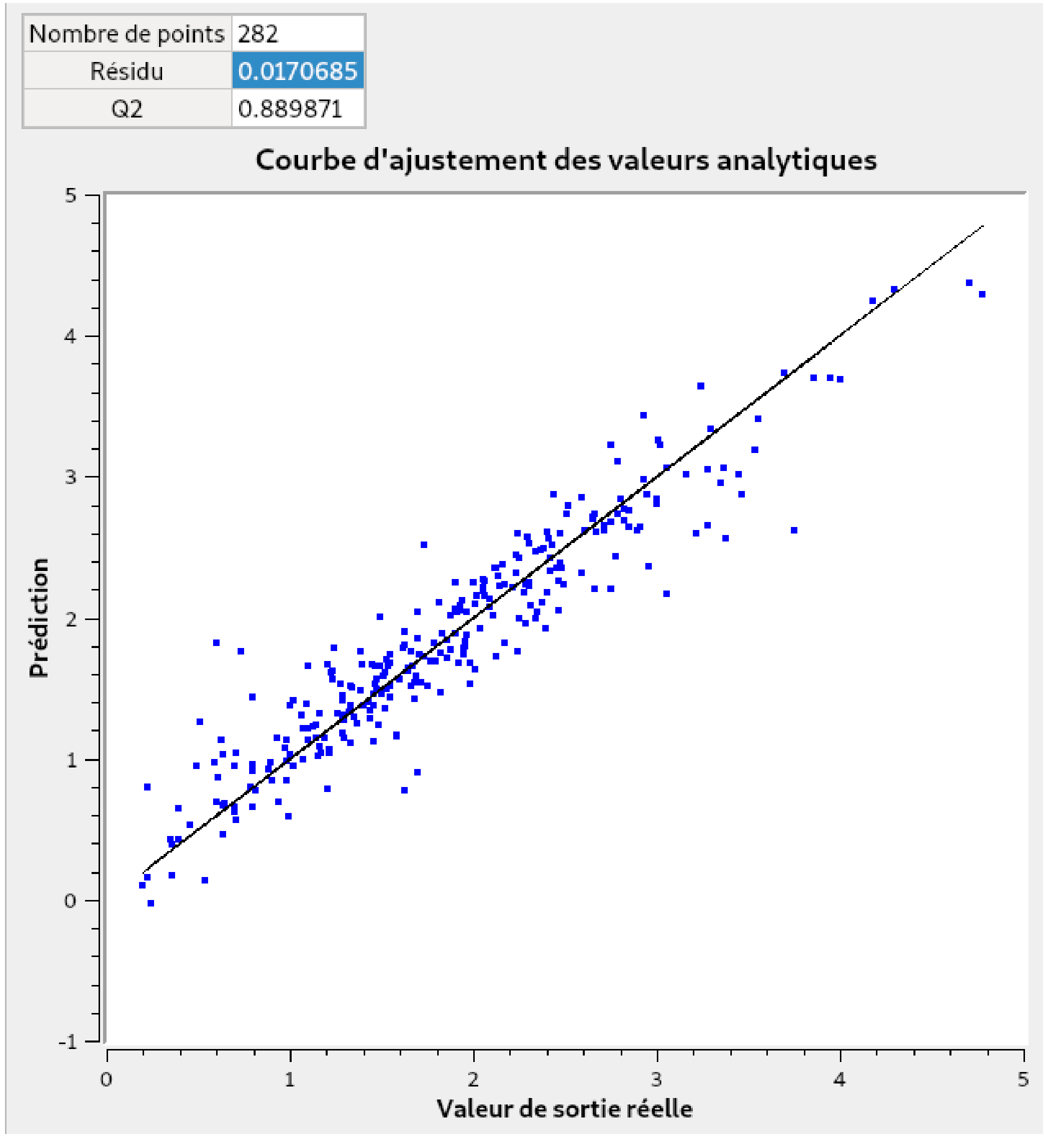
Parameters

- Covariance kernel : squared exponential
- Constant tendency with optimized hyper parameters

Results

- All correlation lengths within bounds except Wall_f_add_on (less influential parameter)
- Acceptable Q2 for 3D based variables





ΔT_n – Stratification

3D numerical experiments – MetaModels – Kriging Sensitivity

Method

- Use generated metamodel to estimate Sobol' indices

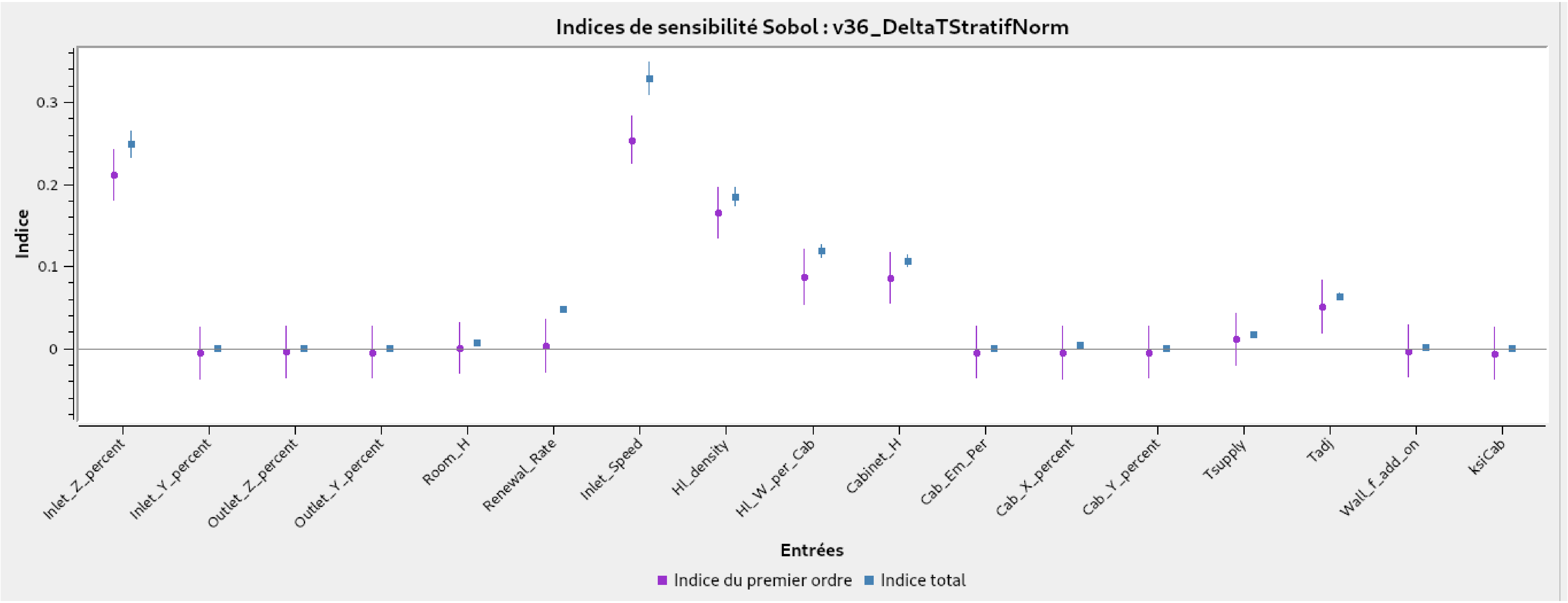
$$S_i = \frac{Var\left[E\left[Y|X_i\right]\right]}{Var[Y]}$$

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

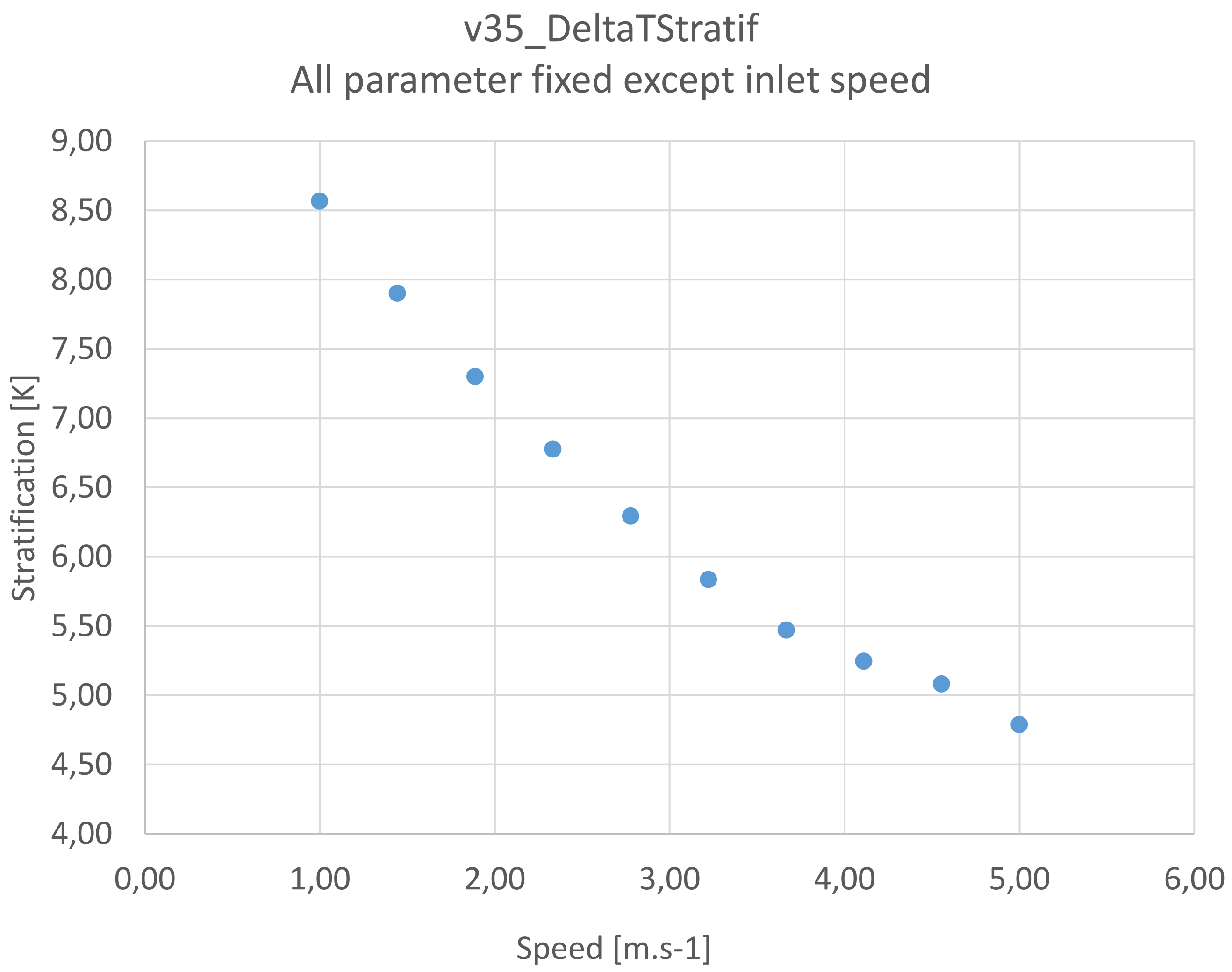
Analysis

- Results consistent with Spearman indices and computed kriging scales
- Significant role of interactions : supply geometry, inlet speed and air change rate
- Can be used to generate experimental 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 – Kriging
Sensitivity



3D numerical experiments – MetaModels – Kriging
Sensitivity



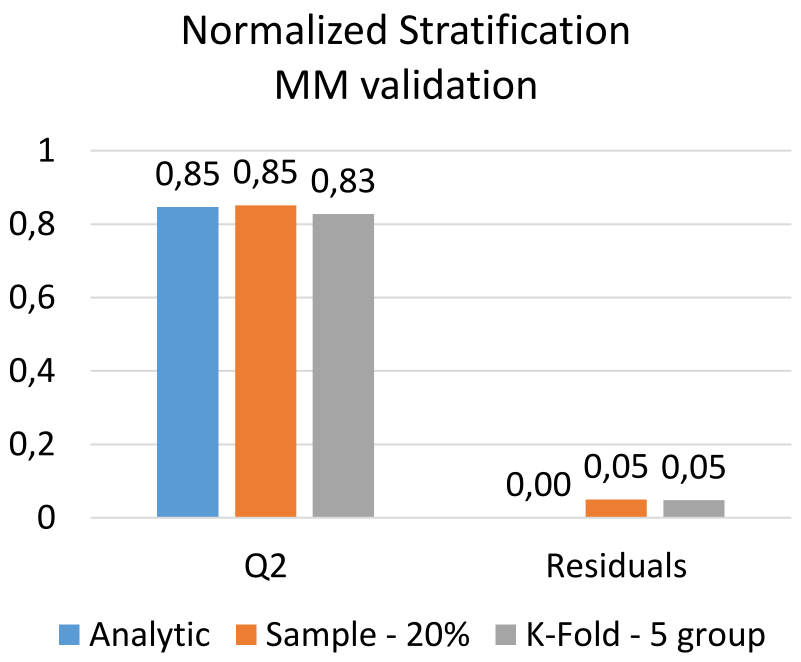
3D numerical experiments – MetaModels – Polynomial Chaos

Parameters

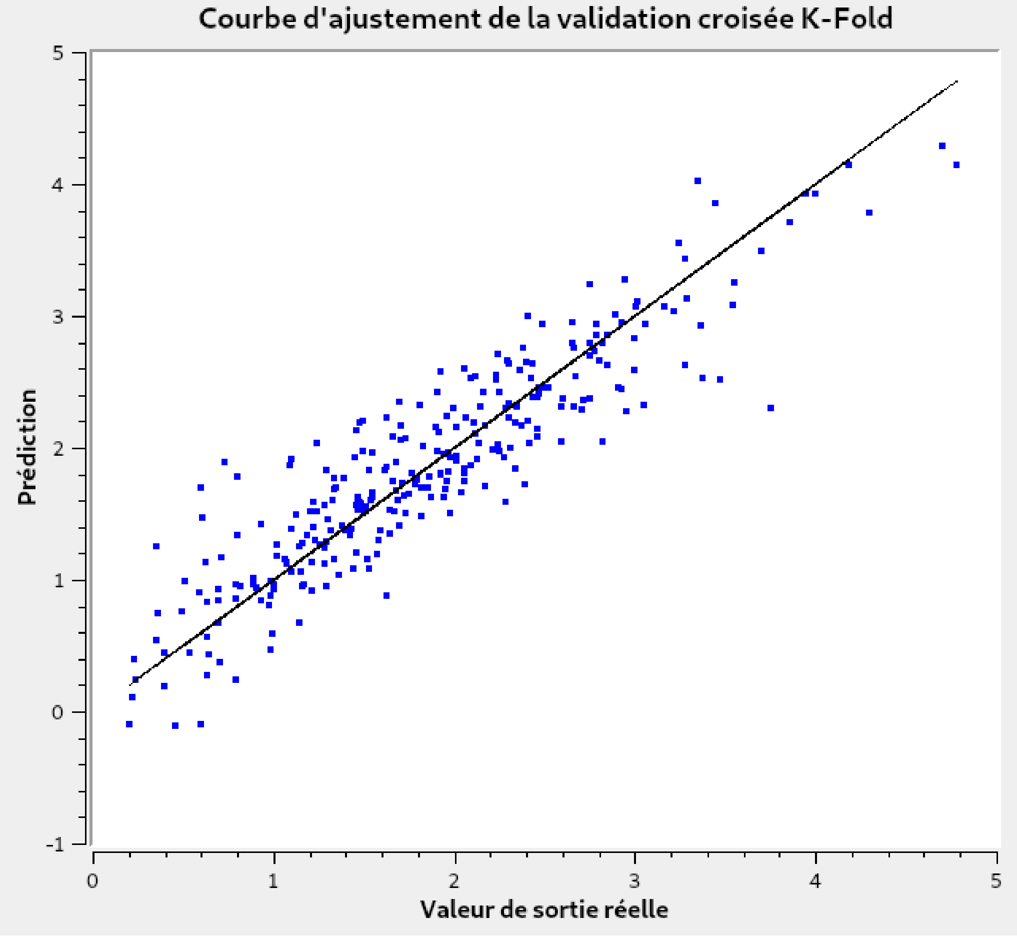
- Max degree : 2
- Sparse basis

Results

- Slightly lower Q2 than kriging method
- Lower maximum degree based on explained part of variance
- Specify marginal of input samples significantly improves Q2



Nombre de points	282
Nombre de plis	5
Graine	1
Résidu	0.0474469
Q2	0.827094

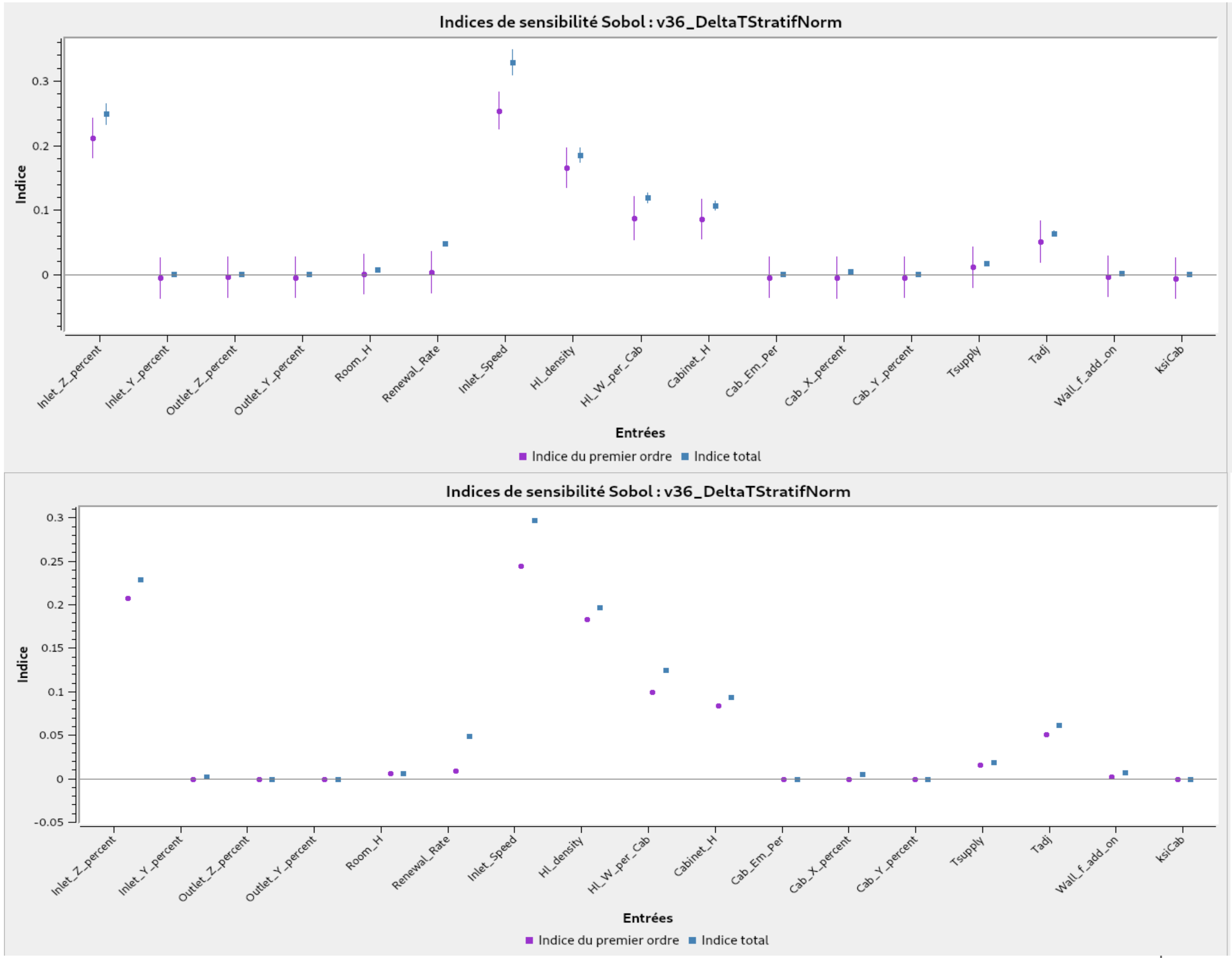


ΔT_n – Stratification

3D numerical experiments – MetaModels – Kriging

Sensitivity

Analysis : Consistent Sobol’ indices between the two metamodels



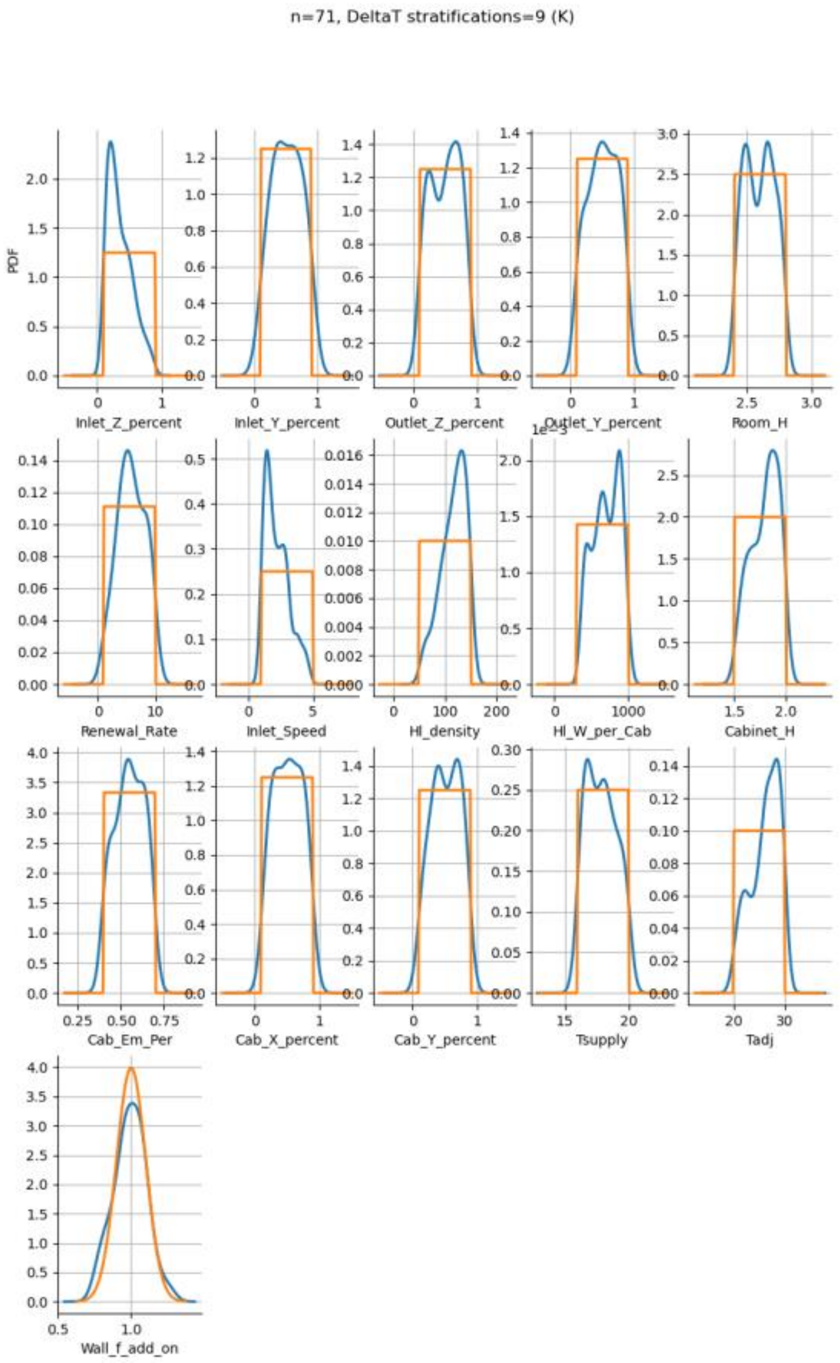
3D numerical experiments – Estimate conditional marginal law[1]

Method

- Select a sample from the experimental 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.
- We are interested by the event $Y > Y_s$.
- Plot the unconditional distribution of each marginal input X_i and the conditional distribution $X_i \mid Y > Y_s$.
- If the variable X_i has the same distribution as $X_i \mid Y > Y_s$, then the input X_i is not influential on the event.
- Otherwise, there is a dependency: X_i is influential.
- Chosen variable of interest : $\Delta T_{statification}$

Analysis

- A significant stratification modify the input parameter distribution for the most influential 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 platforrm
- **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 influential** 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)
- Quantify error propagation in 0D model based on metamodel residuals distribution

Acknowledgments:

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

Thank you for your attention

?

ANNEXE

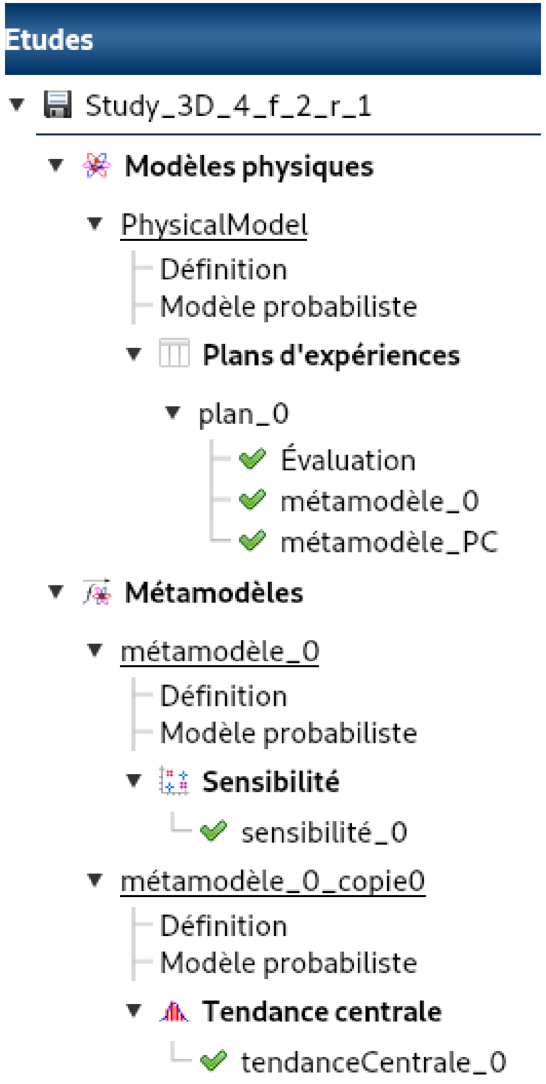
3D numerical experiments – Persalys workflow

Persalys `_exec()` **function**

- Define as a YACS model
- Evaluation of the plan with dumped code modification

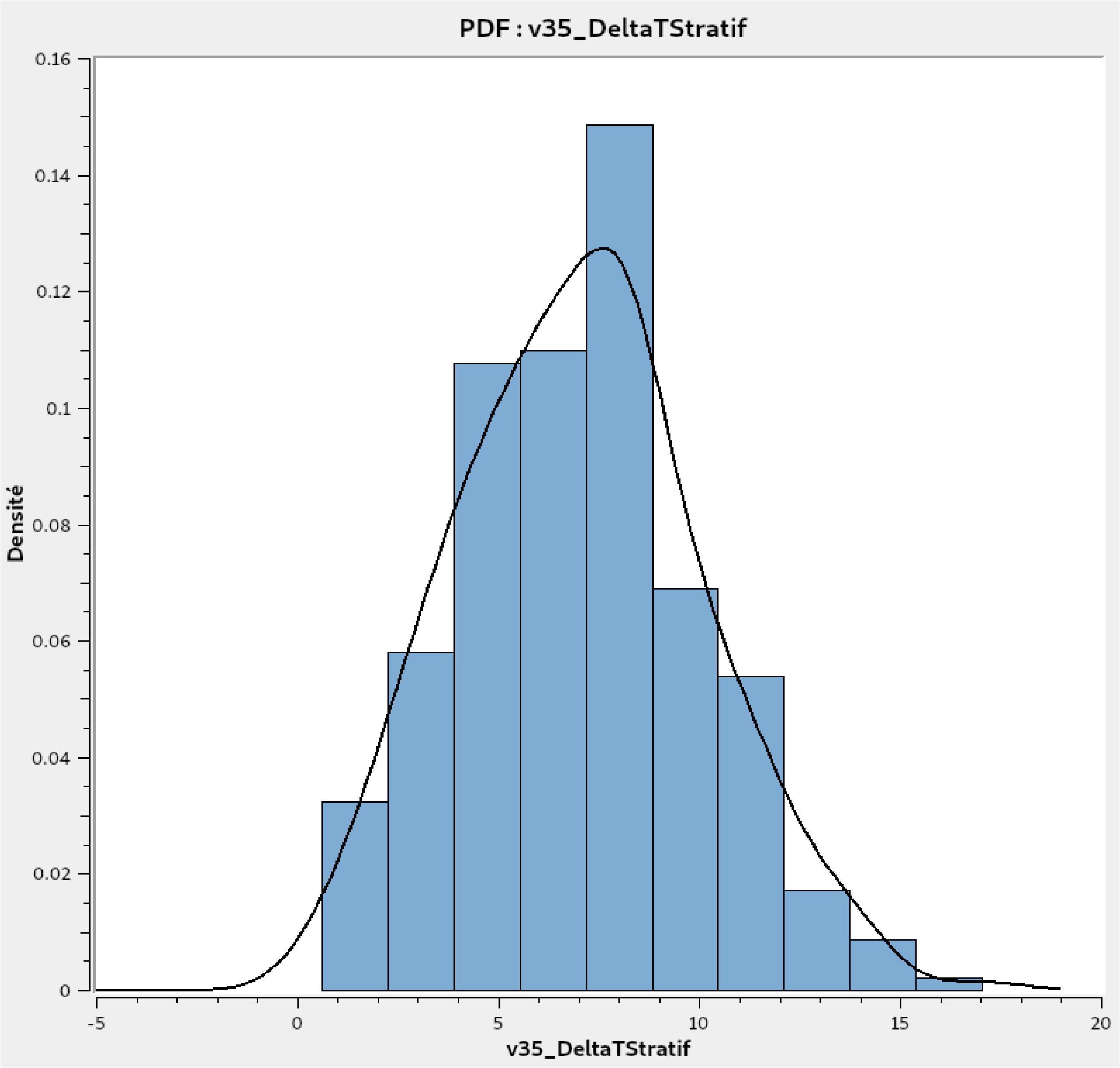
```
import salome_ot
import os
study,ModèleYACS_0=salome_ot.getYacsPyStudy(code)
import pydefx
pydefx_path = os.path.dirname(pydefx.__file__)
light_executor_path = os.path.join(pydefx_path, "plugins", "lightexecutor.py")
mybuilder = pydefx.slurmbuilder.SlurmBuilder(executor=light_executor_path)
myModel = 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 launched with: `srun -exclusive -n X ./my_mpi_program`
- `-exclusive` option allow Slurm to use all allocated resources

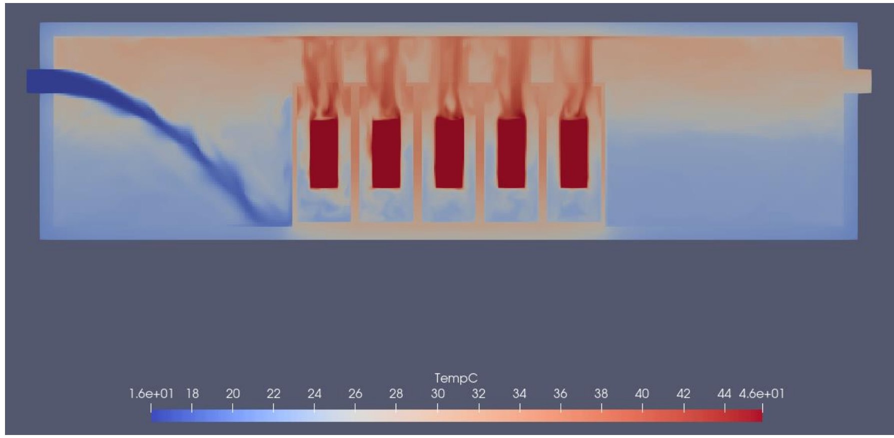


3D numerical experiments – Results

- **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 influential 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



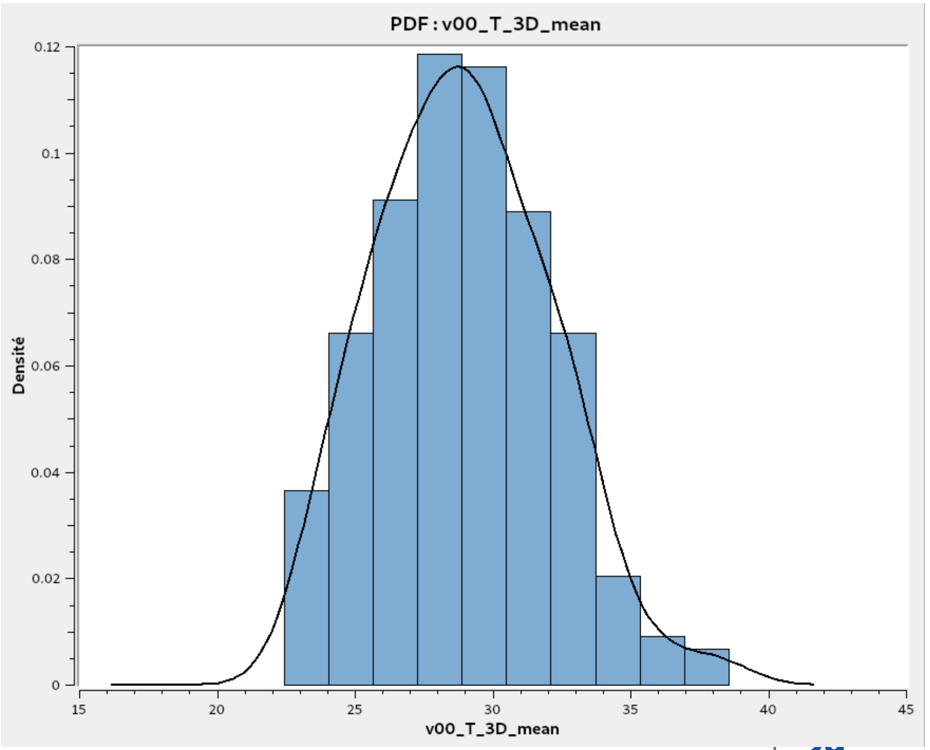
- Reminder : implication of 0D approach

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

- 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 focus :
  - 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

Point Values

Catalyst View

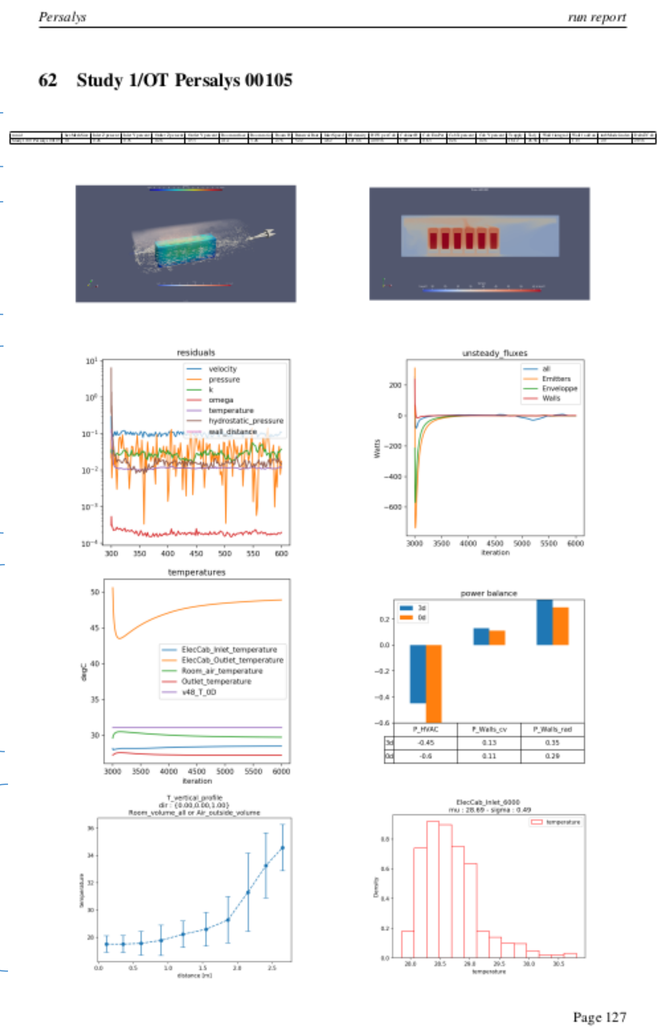
Convergence

HVAC balances Temperature – Power Balance

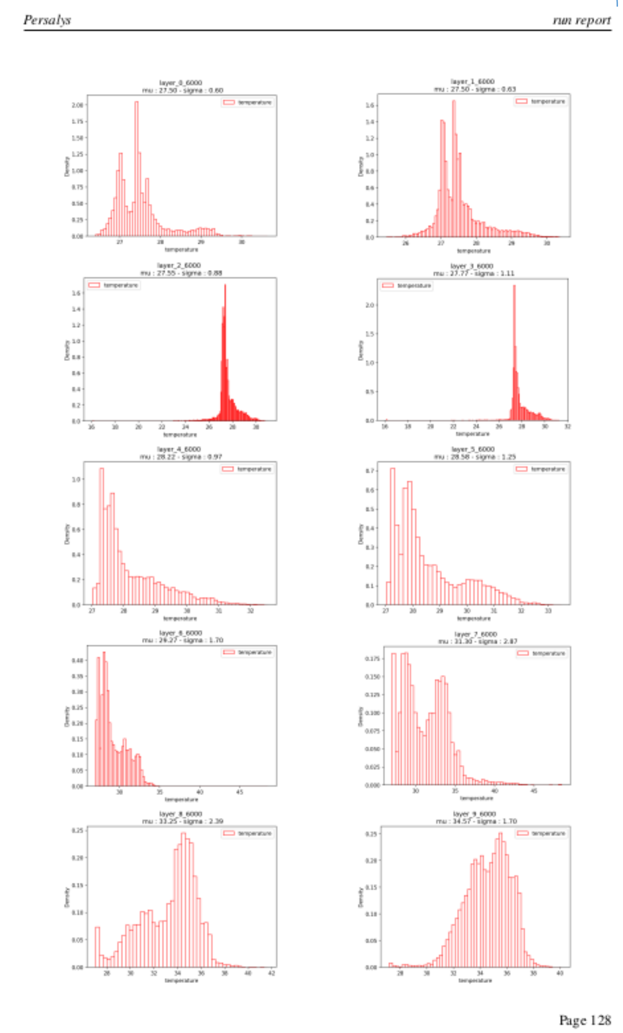
(0d/3d)

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 experimental plan table and detailed run results

3D numerical experiments – Variables of interest

Power balance

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

Scales

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

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

Temperatures

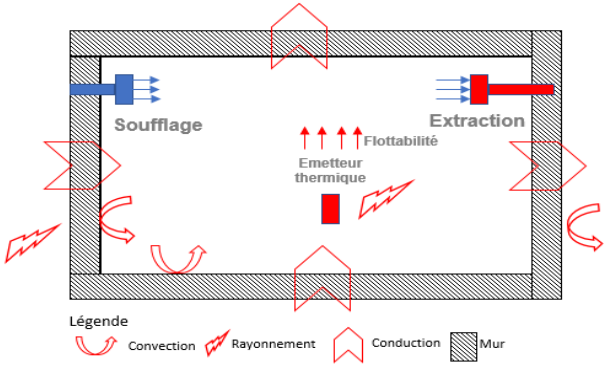
- T_{moy} 3D / T_{0D} / $T_{outlet\ 3D}$
- T_{inlet} / T_{outlet} cabinets
- Vertical mean profile temperature:
  - 10 layers : $\mu^*_{layer\_id} = \frac{\sum_{c\_id=0}^{n\_cells-1} w_{c\_id} \times x_{c\_id}}{\sum_{c\_id=0}^{n\_cells-1} w_{c\_id}}$
  - With : w_{c_id} weight of cell for layer id

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

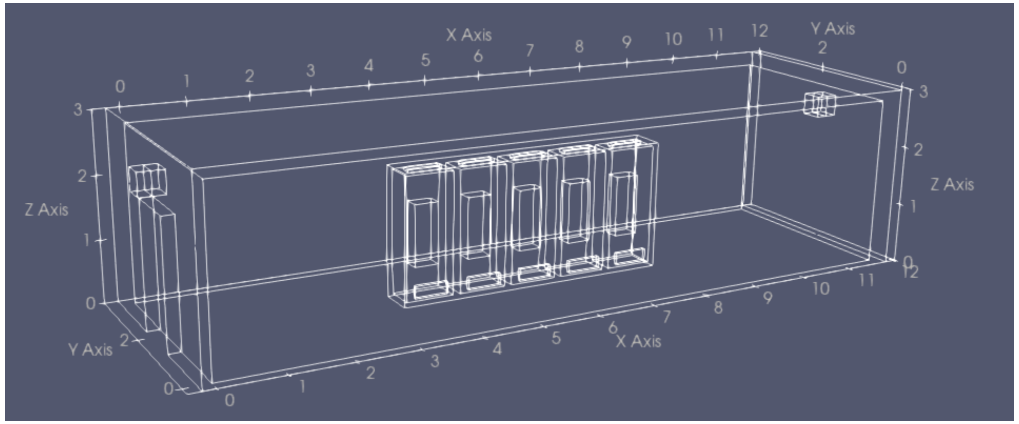
Rappels de la méthode TIPPI (PIRT)

- **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



1. Définition de l'étude et objectif du PIRT
2. Définition du transitoire et du domaine de simulation
3. Identifier les paramètres d'intérêt (Figures of Merit)
4. Identifier les principaux phénomènes physiques (schéma simple)
5. Lister les paramètres associés aux phénomènes physiques en jeu
6. Classer les paramètres par importance d' influence (sur FoM) et selon le niveau de connaissance :
Formalisation d'un tableau PIRT
7. Procédé itératif : reclasser après de nouveaux résultats

Order of magnitude of the studied case



- Pour le cas de locaux industriels, les ordre de grandeurs sont:
  - $V_0 = 1 m.s^{-1}$ / $L = 1\ m$ / $\rho_0 = 1\ kg.m^{-3}$ / $\delta p_0 = 1\ Pa$
  - $\Delta T = 10\ degC$ / $\lambda_{metal} = 50\ W.m^{-1}.K^{-1}$ / $\lambda_{beton} = 2.3\ W.m^{-1}.K^{-1}$
  - $h_{cv} = 3\ W.m^{-1}.K^{-1}$ / $\mathrm{e_{metal}} = 0{,}05$ m / $\mathrm{e_{beton}} = 0{,}3$ 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

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

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

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

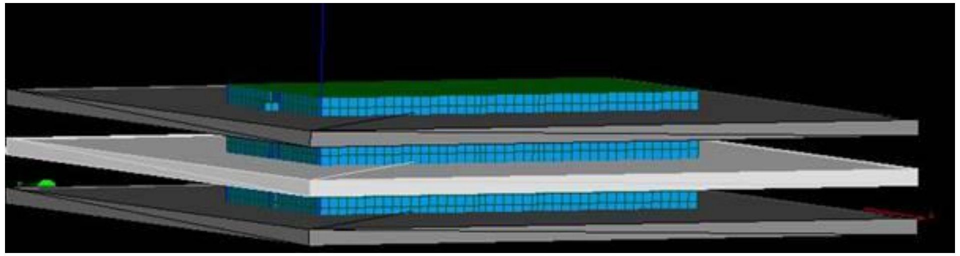
$$\hat{p} = \frac{p-\rho_0 \underline{g}.\underline{x}}{\delta p_0}\ /\ \hat{\rho} = \frac{\rho}{\rho_0}\ /\ \hat{t} = \frac{V_0}{L}t\ /\ \hat{\underline{x}} = \frac{\underline{x}}{L}\ /\ \hat{\underline{V}} = \frac{\underline{V}}{V_0}\ /\ \hat{\underline{\nabla}} = L\underline{\nabla}$$

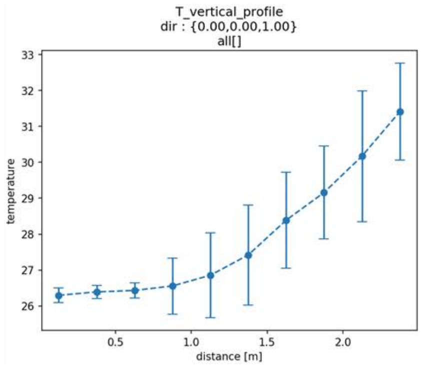
$$Eu = \frac{\delta p}{\rho_0\, V_0^2}\ /\ Re = \frac{\rho_0 V_0 L}{\mu_0}\ /\ Ri = \frac{g\beta\Delta T L}{V_0^2}$$

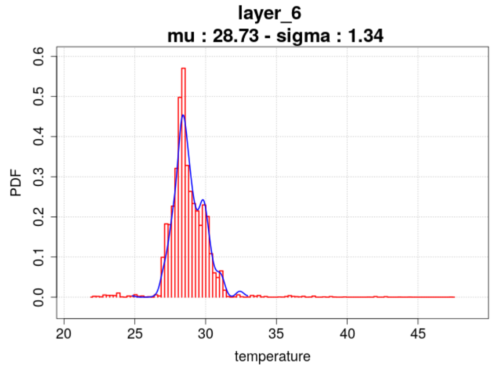
$$: Pr = \frac{\mu_0 c_p}{\lambda_0}\ /\ Ra = GrPr = \frac{\rho c_p g\beta\Delta T L^3}{\lambda\nu}\ /\ Gr = \frac{\rho g\beta\Delta T L^3}{\mu} \propto Re^2$$

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

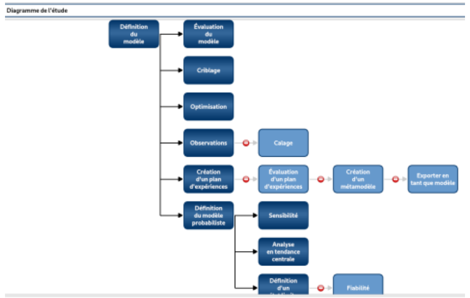




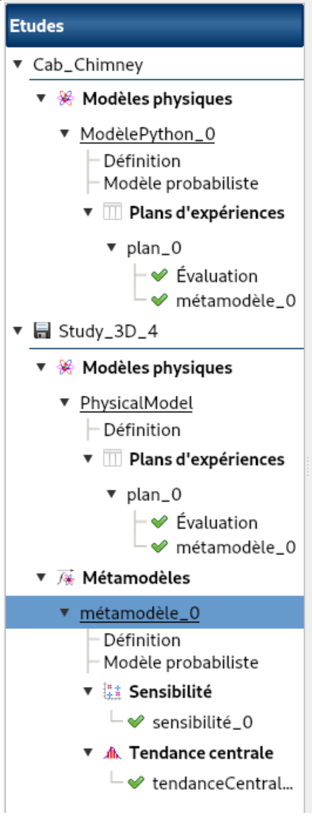


3D numerical experiments – Workflow

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



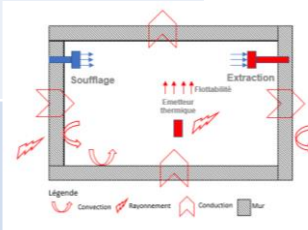
```
import salome_ot
import os
study,ModèleYACS_0=salome_ot.getYacsPyStudy(code)
import pydefx
pydefx_path = os.path.dirname(pydefx.__file__)
light_executor_path = os.path.join(pydefx_path, "plugins", "lightexecutor.py")
mybuilder = pydefx.slurmbuilder.SlurmBuilder(executor=light_executor_path)
myModel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



Phénomènes physiques identifiés

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

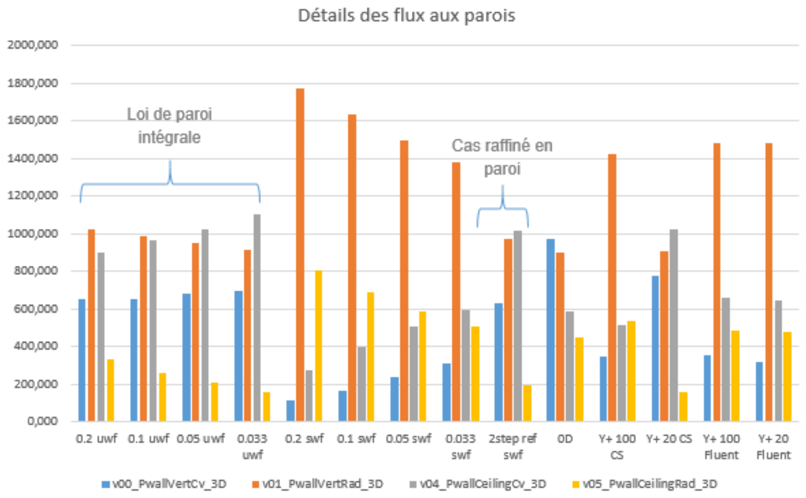
Phénomènes physiques	Paramètres géométriques	Paramètres matériaux	Conditions aux limites	Nombre adimensionnel
Conduction thermique dans les solides **Béton - Emetteur**	Epaisseur des parois Surface des parois	Conductivité thermique c_p et ρ	Température adjacente Flux adjacent	Biot
Convection naturelle murs	Surface, Longueur caractéristique	Viscosité ρ, λ_{fluide}	Température adjacente Flux adjacent	Rayleigh Prandtl
Rayonnement **Mur – Mur** **Emetteur – Enveloppe** **Enveloppe -Mur**	Surface Angles solides entre surfaces	Emissivité	Flux solaire Température ciel	-
Inertie thermique	Géométrie des masses Surface d’échange	ρ, c_p, V, λ	-	Fourrier
Transferts enthalpiques	Géométrie du local Position des bouches de soufflages/extraction	$\beta, \rho, c_p, \mu, \lambda$	Débit ventilation Localisation entrée/sorties Température de soufflage Charge thermique	-
Stratification thermique	Géométrie du local Géométrie source thermiques (incluant leurs freins aérauliques)	$\beta, \rho, c_p, \mu, \lambda$	Température de soufflage Vitesse de soufflage Charge thermique	Richardson
Effets de jets	Géométrie des obstacles	$\beta, \rho, c_p, \mu, \lambda$	Vitesse de soufflage	Reynolds Richardson
Panaches thermiques	Géométrie du local Géométrie des sources	$\beta, \rho, c_p, \mu, \lambda$	Charge thermique	Rayleigh Reynolds
Configuration Rayleigh Bénard	Géométrie du local	$\beta, \rho, c_p, \mu, \lambda$	Température adjacente	Rayleigh
Mélange turbulent	Géométrie de la pièce Nature des obstacles	$\beta, \rho, c_p, \mu, \lambda$	Vitesse soufflage Charge thermique	Reynolds 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 : 10^{e}-5 sauf la température 10^{e}-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 global : 2 pages par cas d''évaluation