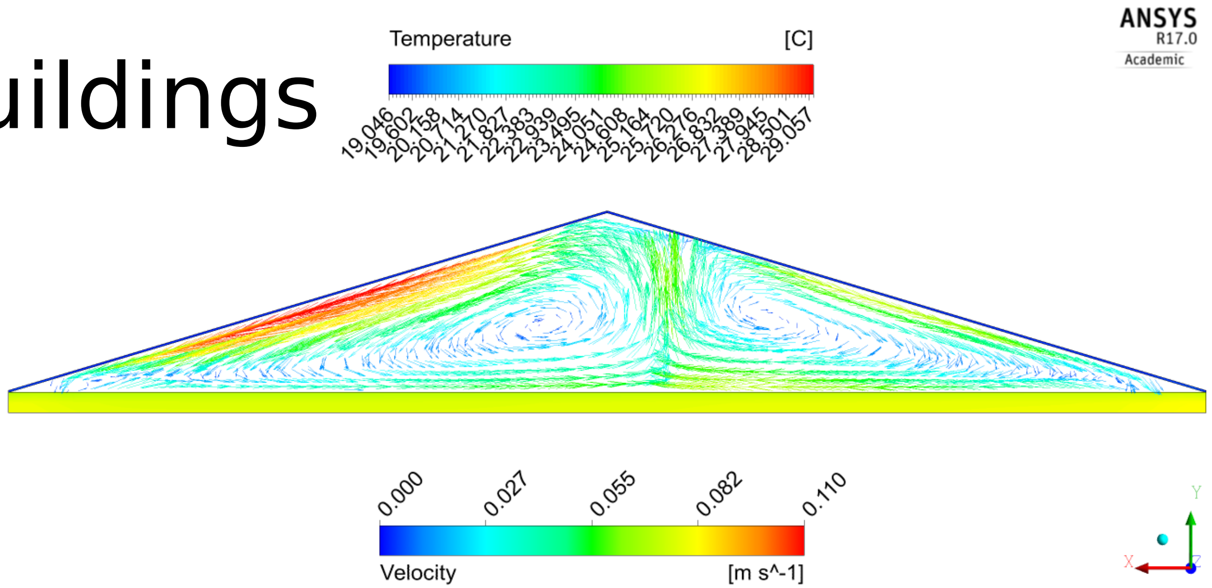
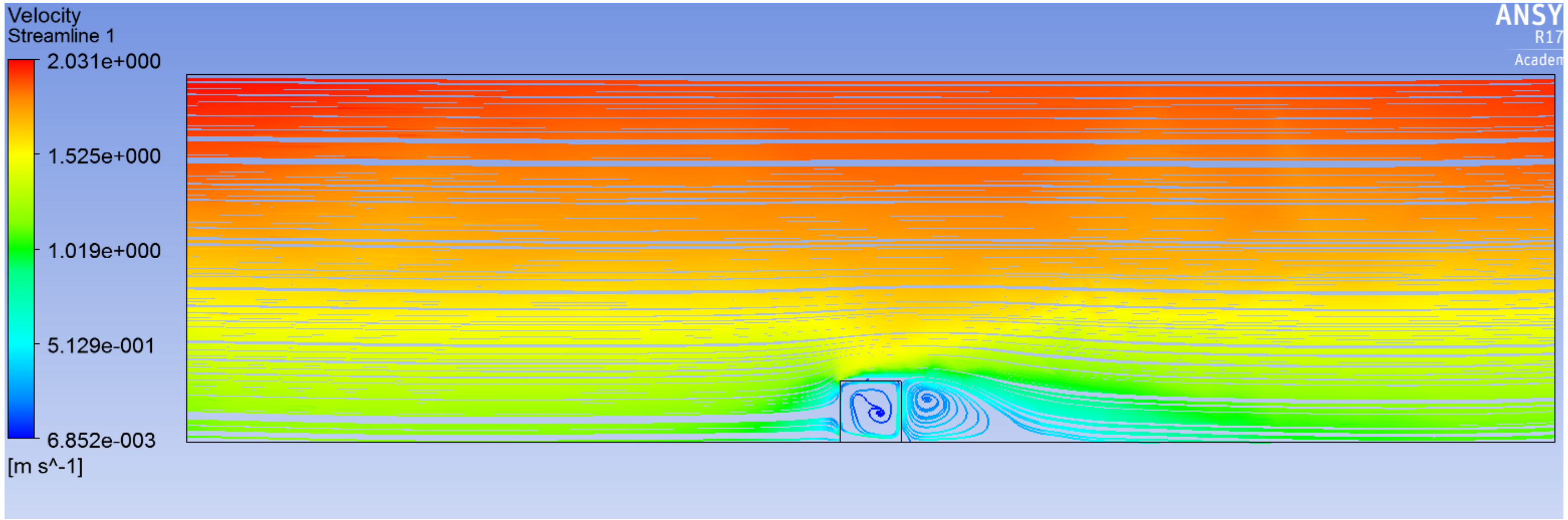
(Intelligent) Co-simulation to bring advanced physics to BPS tools

Mazuroski W., Intelligent co-simulation: a strategy to solve complex building energy simulation problems. PhD Thesis, PUCPR, 2018.

Advanced physics in buildings

- Unsteady Navier-Stokes based airflow

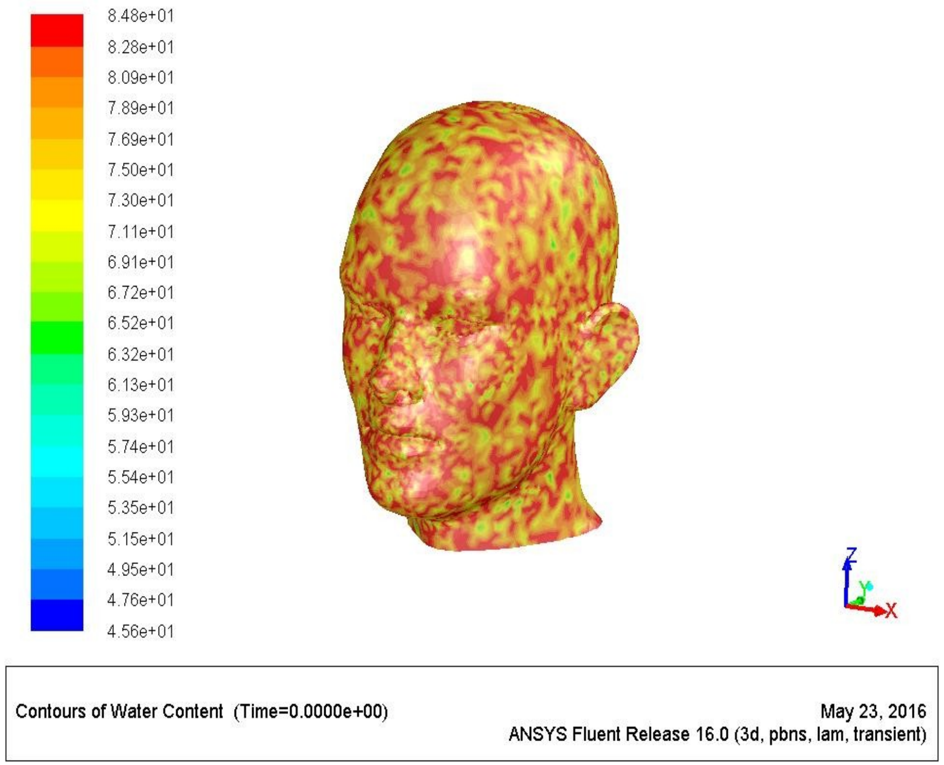




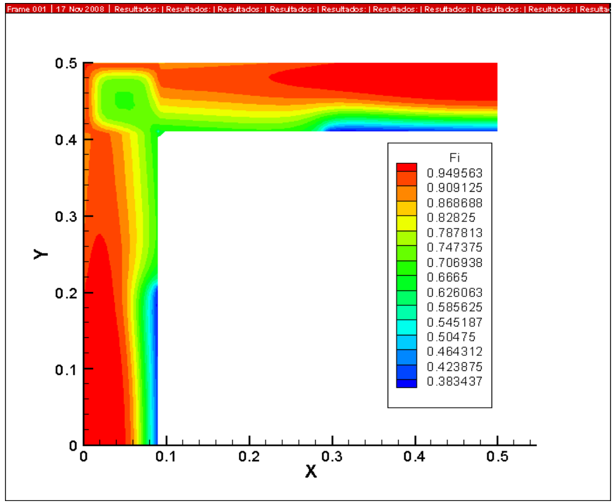
Source: Adrien Gros' post-doc work

Advanced physics in buildings

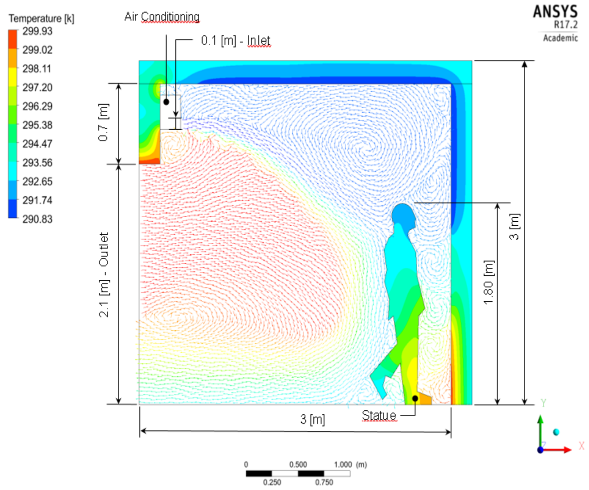
- Multidimensional heat and moisture transfer



Source: Luciano Melo's Ph.D. Thesis



Source: Gerson Santos' Ph.D. Thesis



Source: Luciano Melo's Ph.D. Thesis

Co-Simulation

Co-simulation

A type of simulation where at least two simulation tools jointly solve systems of equations and exchange data during the time the coupling is performed.

Several approaches such:

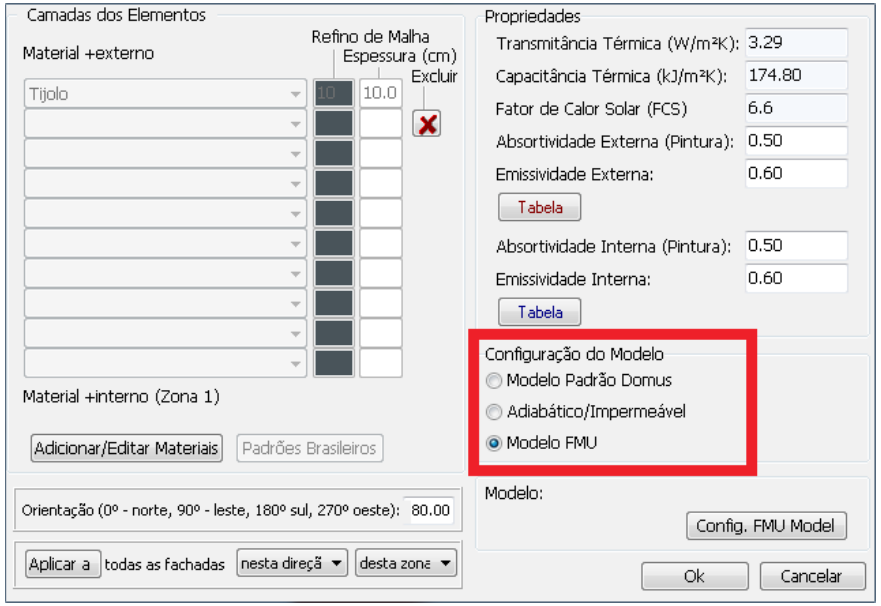
- one-to-one
- middleware
- direct coupling - standard interface

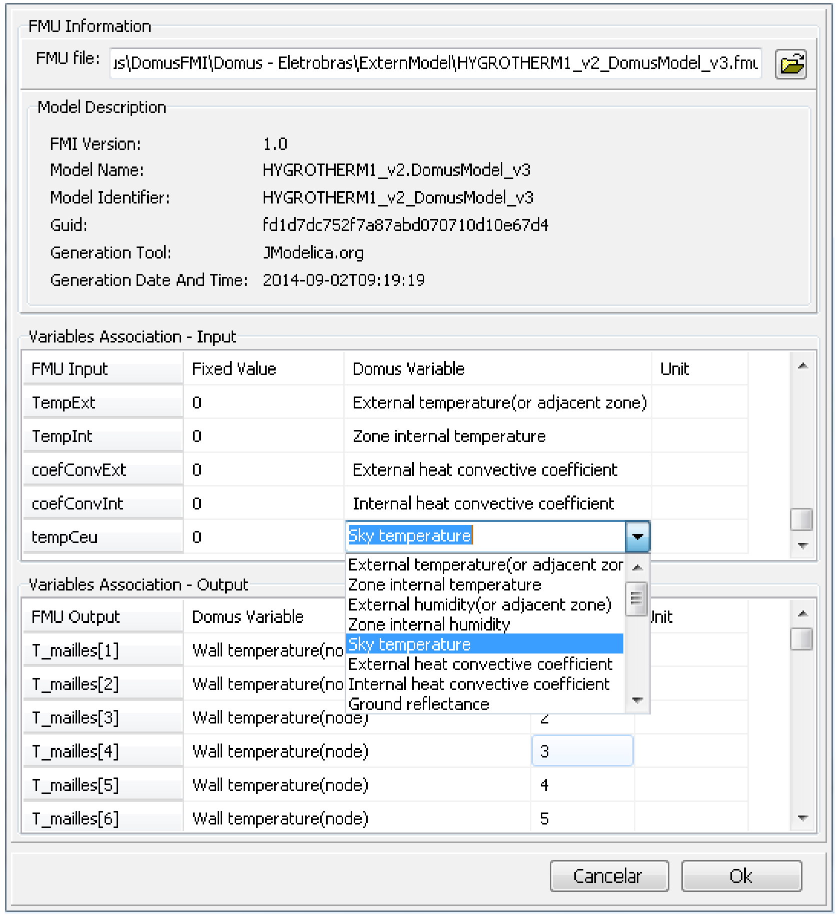
Example:

Standard Interface: Functional Mock-up Interface (FMI)

Domus and IEA Annex 60 Activity 1.2

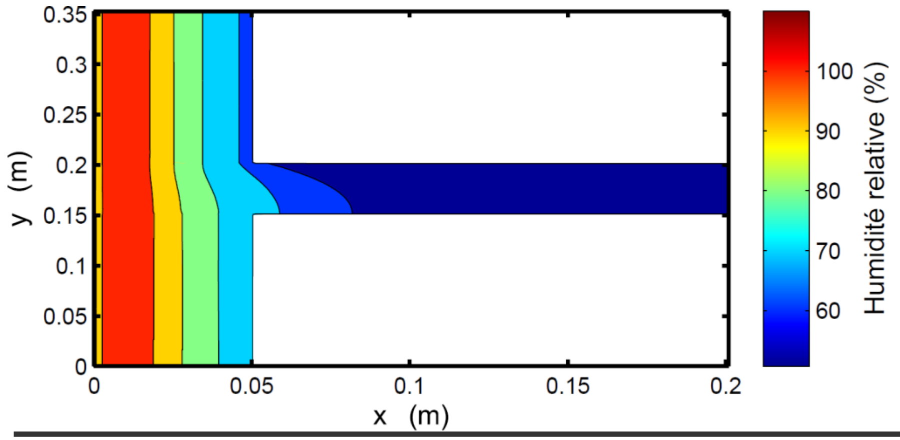
- Simple use of FMU interface
- FMU Model as an option

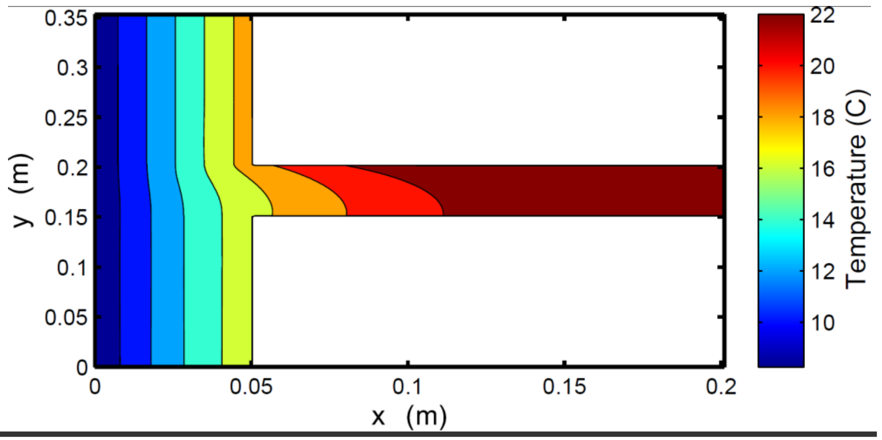




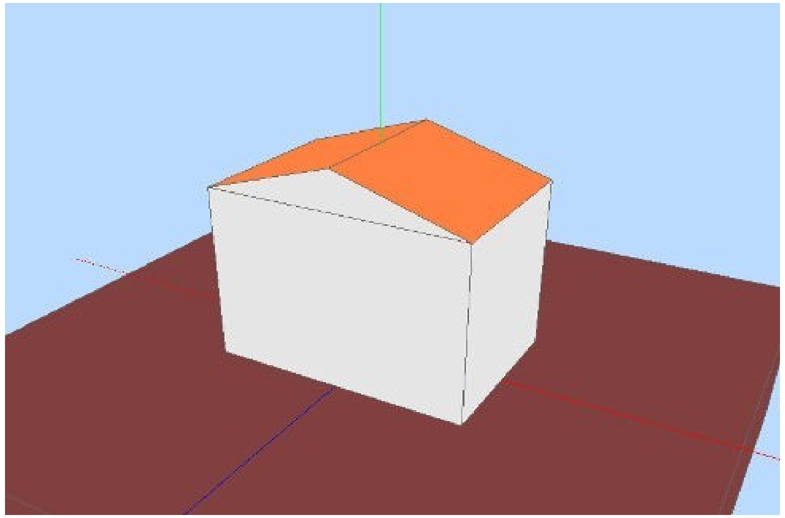
HM-PGD - Domus results

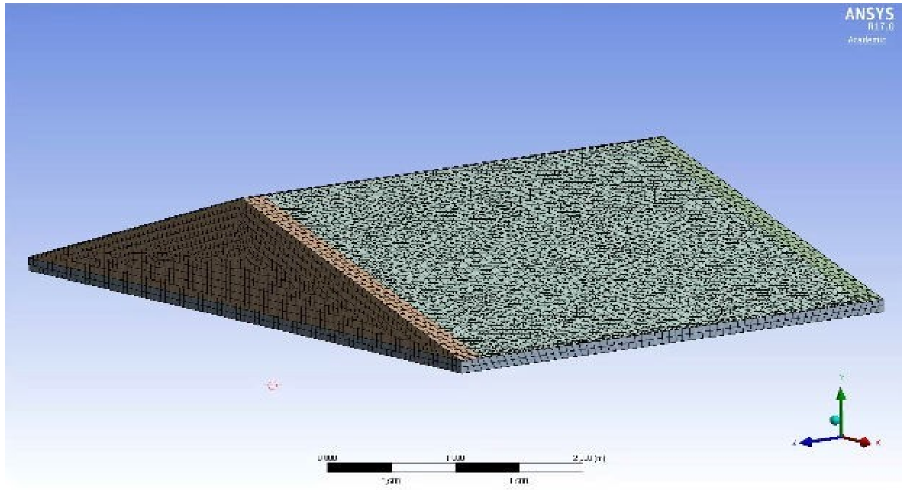
- *Validation of the coupling method on the benchmark ex1 of IEA Annex 41*
- *Simulation of 2D wall assemblies*
- *Simulation of parametric problems, considering domain of variation of material properties*





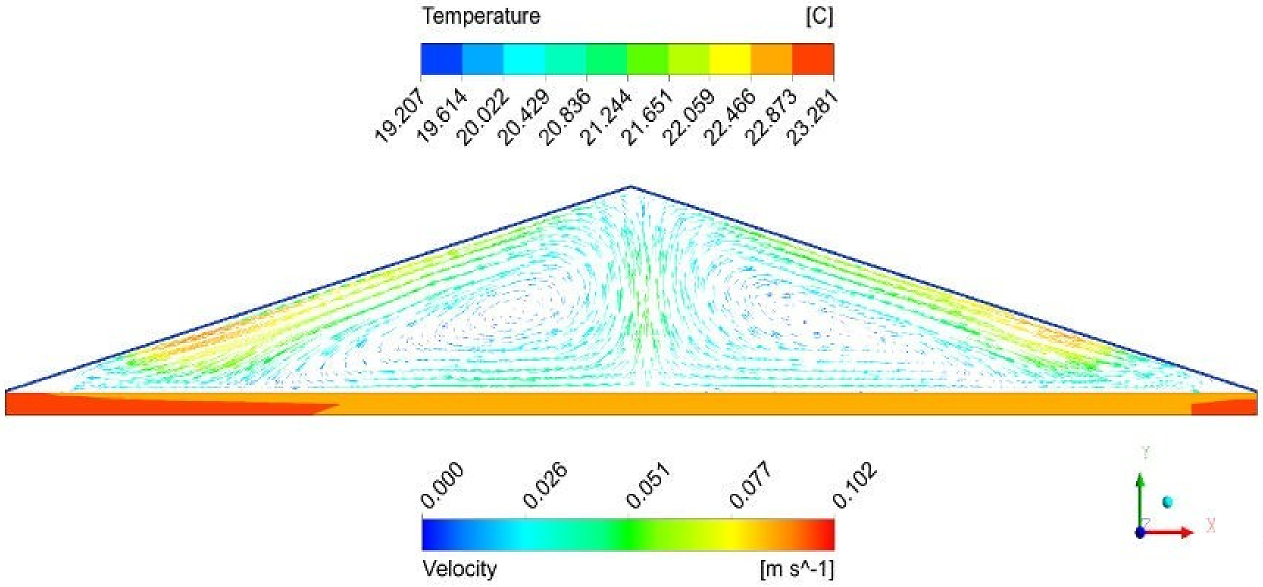
Co-simulation Case Study 2

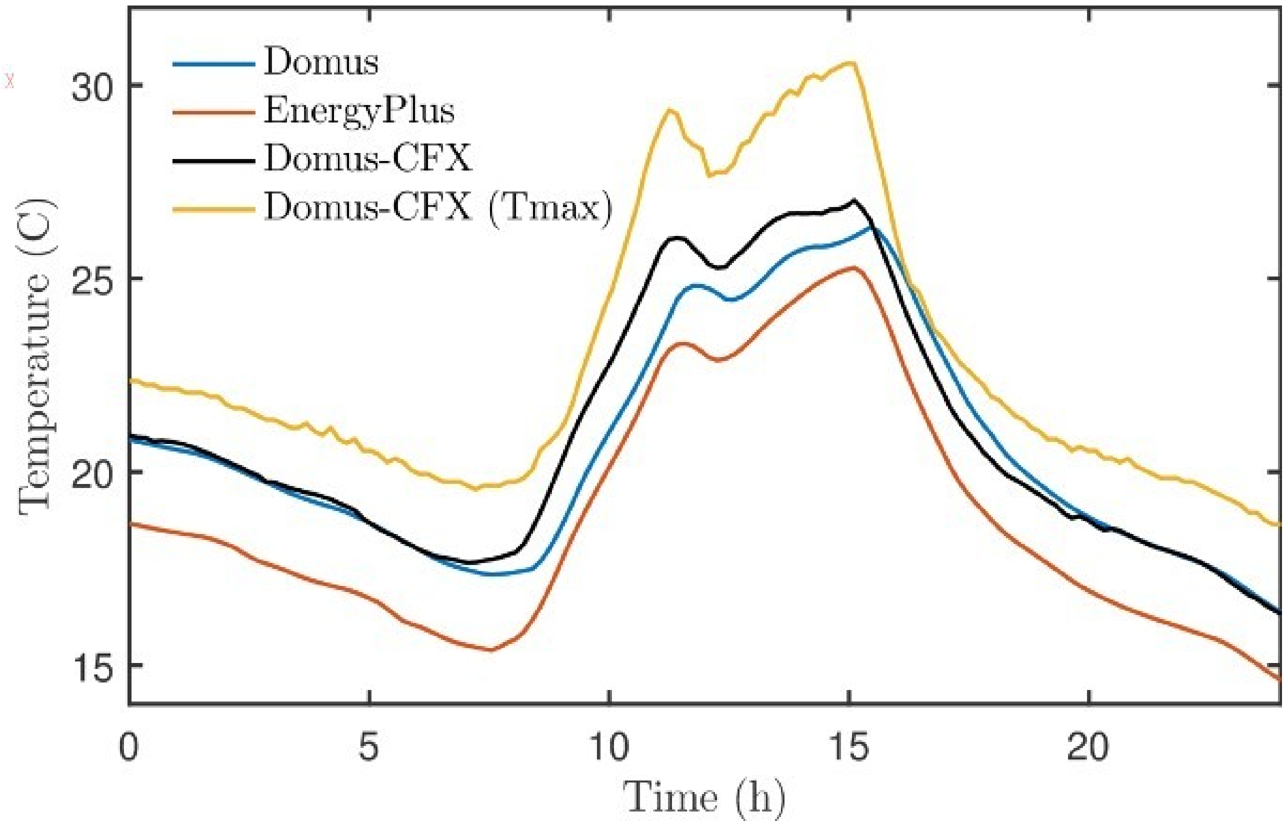




- Two thermal zones
- 96-m^3 room
- 13-m^3 attic
- co-simulated attic
- 10 min Domus time-step
- 1 min CFX time-step

Co-simulation Case Study 2

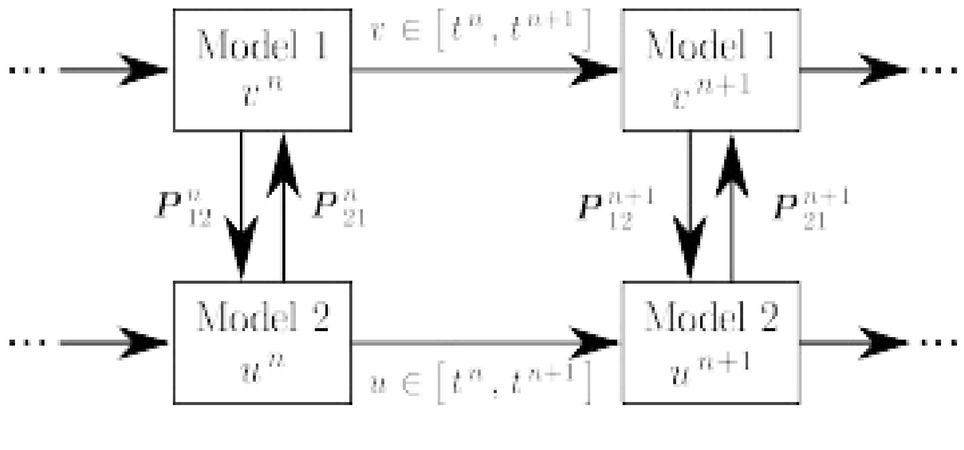




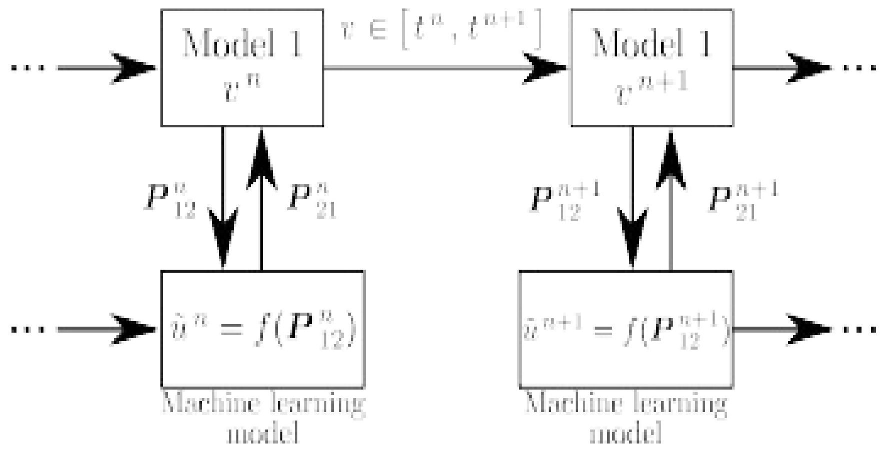
Intelligent co-simulation strategy

General statement

- Significant reduction of the high computational cost.



(a) Classic co-simulation



(b) Intelligent co-simulation

Intelligent co-simulation strategy

Training phase

- performing the co-simulation in its standard setup,
- a short period of co-simulation - training period,
- trains a neural network model → prediction model,

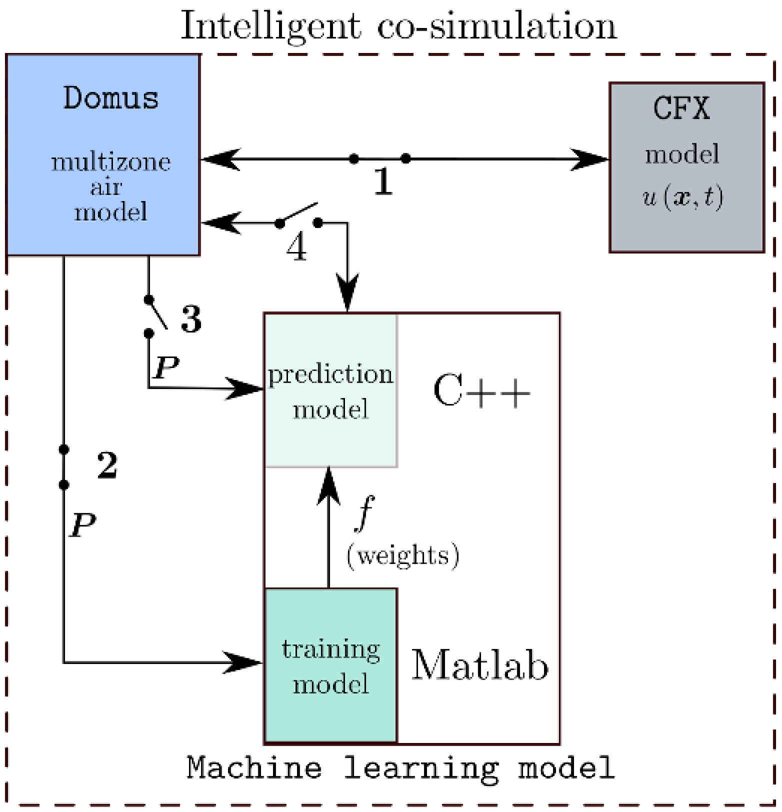
Prediction phase

- disconnect the co-simulated tool,
- now using the prediction model,
- faster and more accurate.

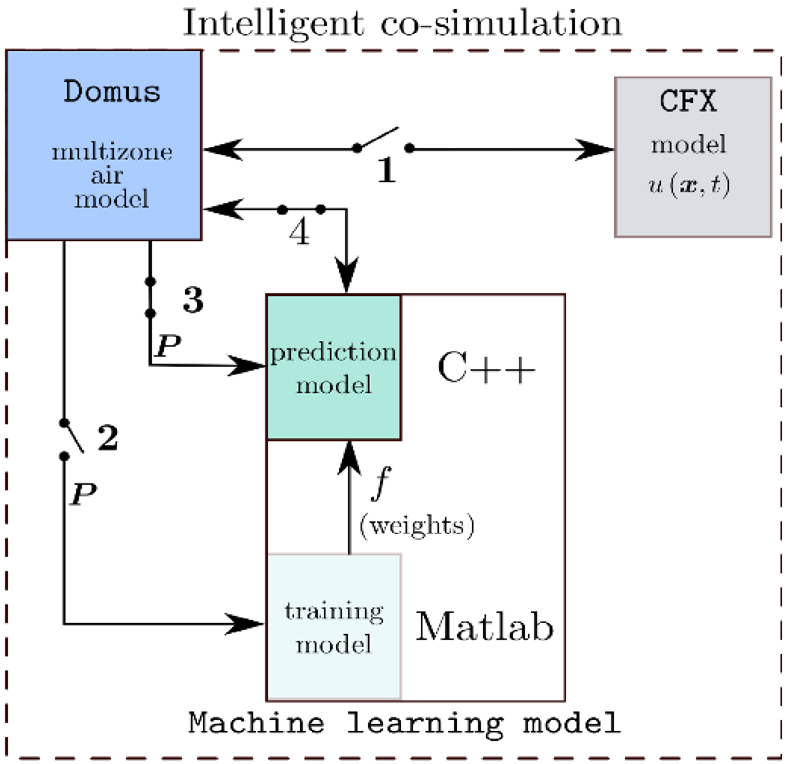
Other highlights

- all in a single BPS tool,
- transparent to the user.

Co-simulation training a RNN



(c) Training phase



(d) Prediction phase

	Training phase	Prediction phase
1	ON	OFF
2	ON	OFF
3	OFF	ON
4	OFF	ON

Intelligent co-simulation case study 2(Attic)

- Attic case study,
- 2 materials in ceiling.

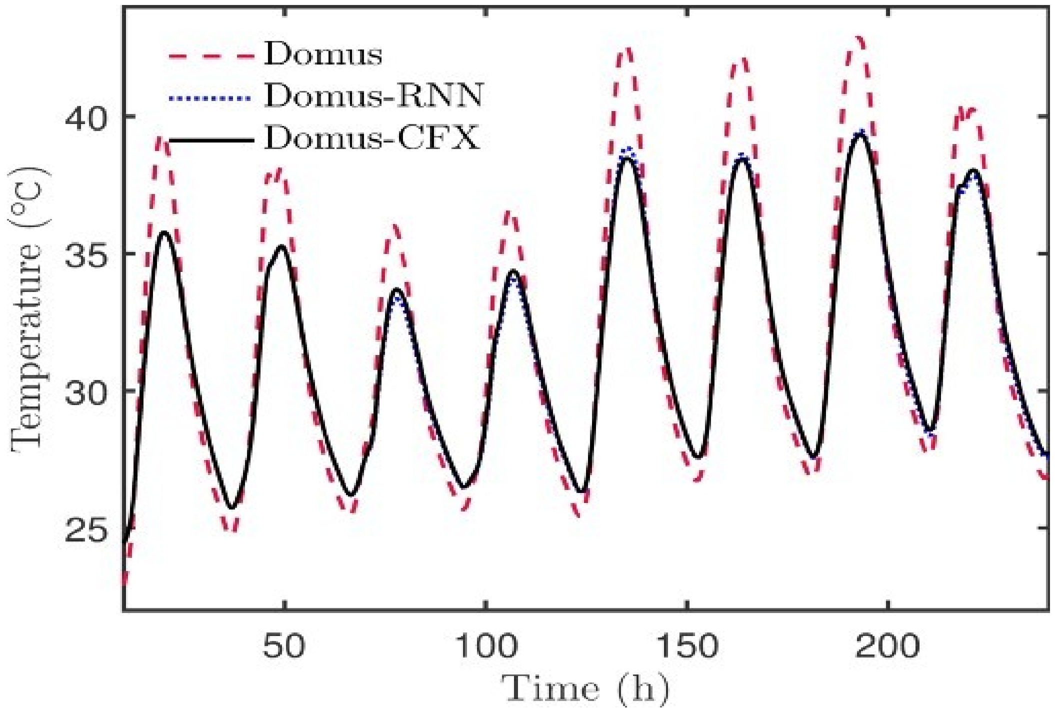
Training Phase

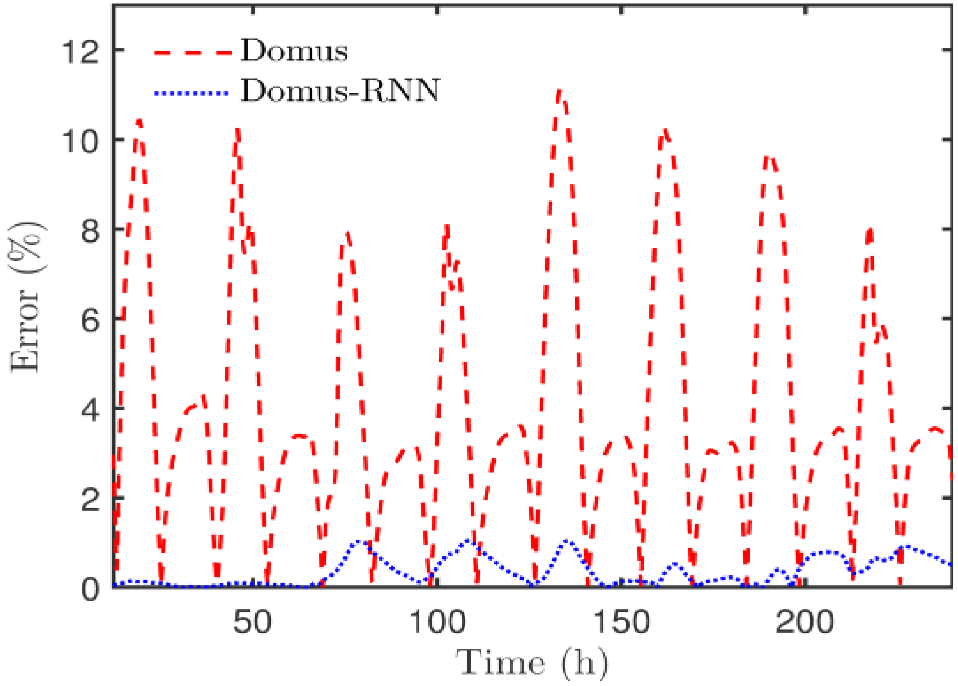
- first 432 time-steps (72h) as training period,
- 8 inputs,
- 2 targets.

Prediction phase

- Domus RNN model replaces the attic object in the simulation,
- no new access to CFX is performed

Some Results





- standalone model provides a maximum difference of 4.2 $^\circ$ C
- RNN model presents a 10 times lower error
- maximum difference of only 0.4° C

Computer run time for a 10 days period

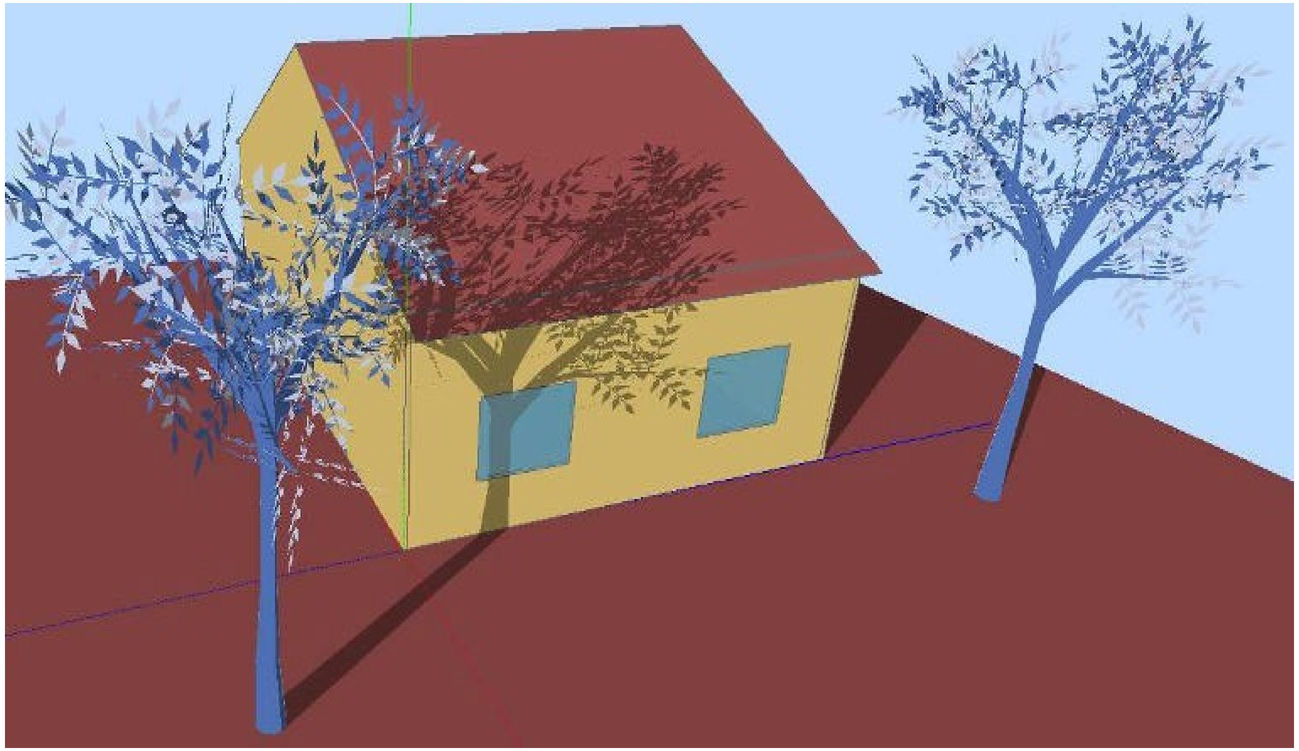
Approach	Total time		CFX		Prediction Model
	(h)	(min)	(h)	(min)	(min)
Domus lumped model	0.01	< 1	$--$	$--$	$--$
Classical co-simulation	656	39360	656	39360	$--$
Intelligent co-simulation	101.71	6103	101.68	6101	< 1

Computer run time for a one-year period.

Approach	Total time	CFX	Domus	Prediction Model
	(sec)	(sec)	(sec)	(sec)
Domus lumped model	11	$--$	11	$--$
RNN-based prediction model	10	0	6	4

Complex Boundary Conditions

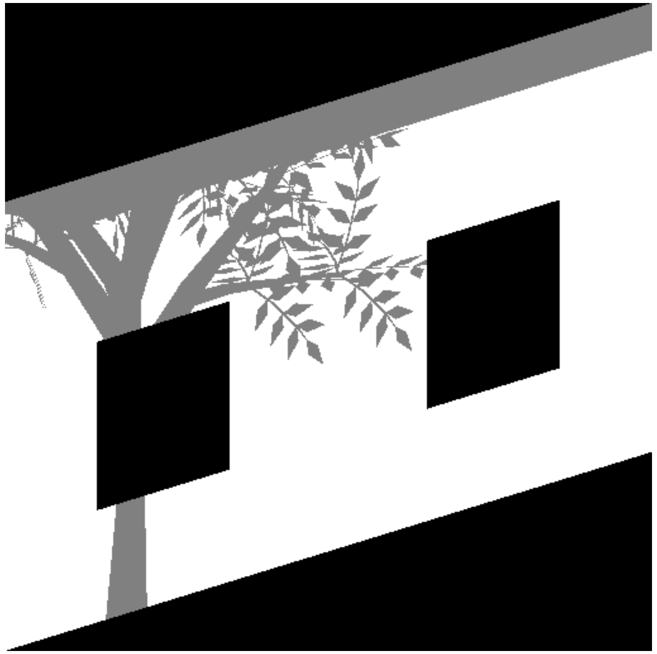
- Co-simulation to provide direct, diffuse and reflected radiation fluxes, and the sunlit contour,
- internal and external surfaces,
- considering precisely complex shadings by means of the Pixel-Counting technique.



Shadowing pattern example in the Domus interface.

Domus PxC → CFD simulation

1 - Domus export sunlit pixels as world coordinate points.



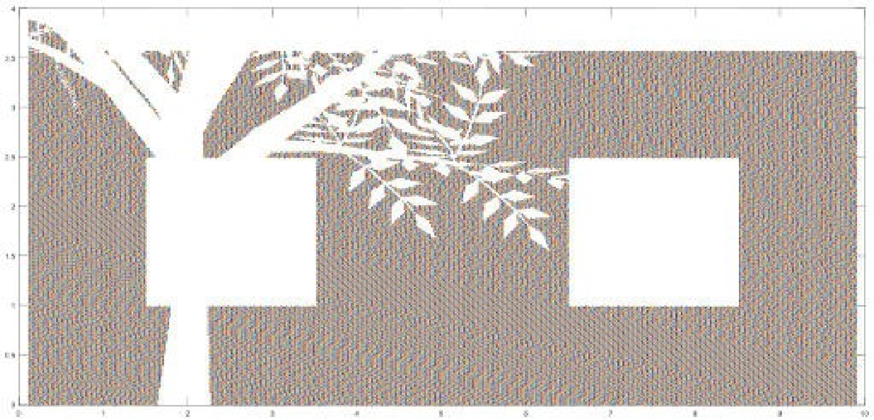
(a)

(b)

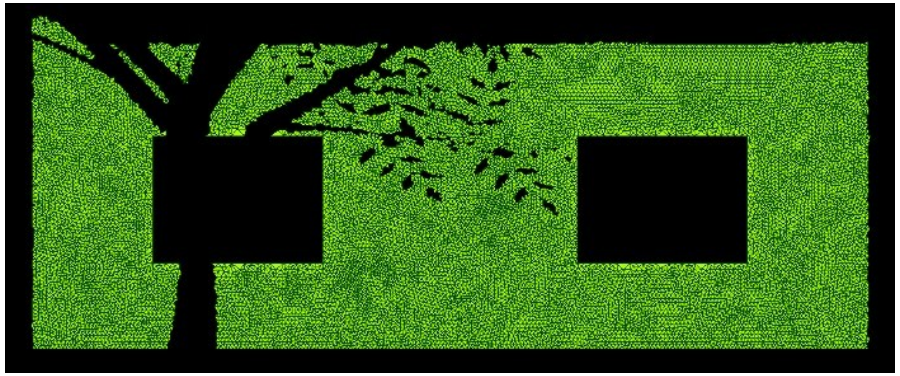
Domus projected shadowing over the facade (a) and plot of the matrix with deprojected points (world coordinates) (b).

Domus PxC → CFD simulation

2 - Auxiliary software (Salome) to generate a sunlit area mesh.



(a)

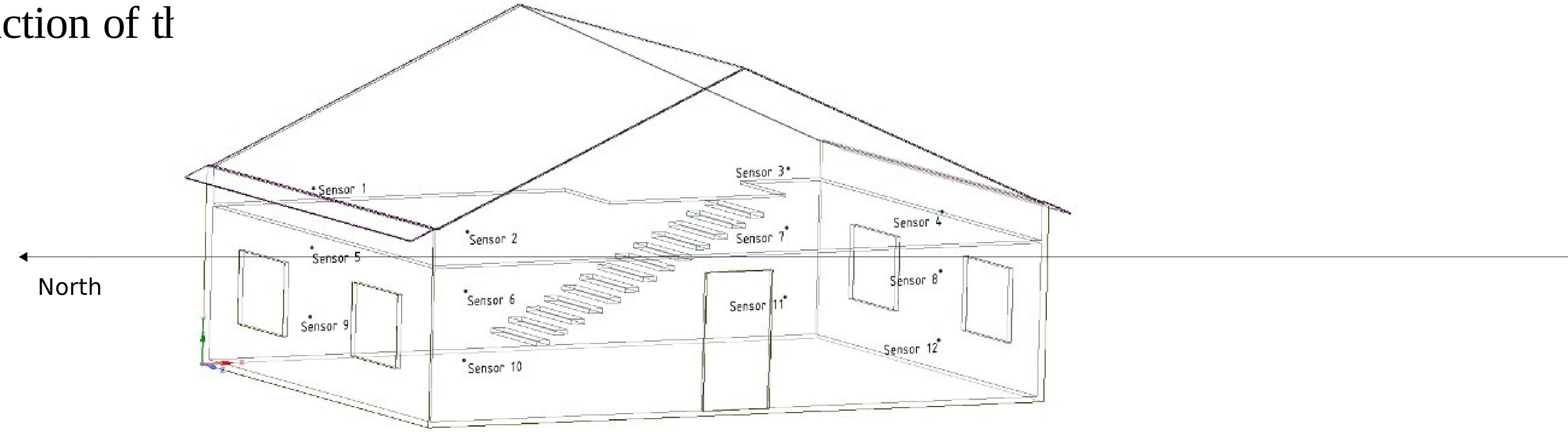


(b)

Coordinate points provided by Domus (a) and Salome locating mesh faces
(b).

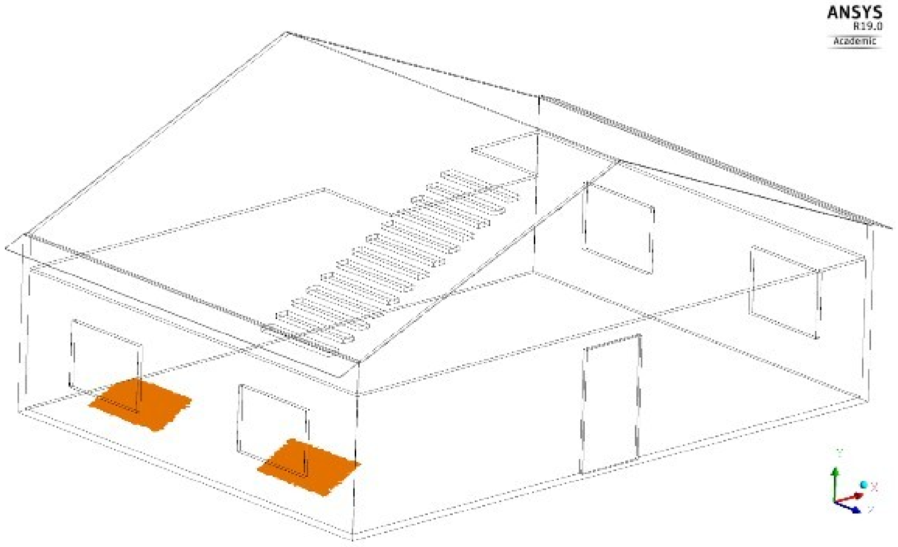
Complex case study - Intelligent co-simulation

- two storey building with 3D sunlit boundary condition,
- 6 training days,
- two training approaches - training climate and first simulation days,
- prediction of tl

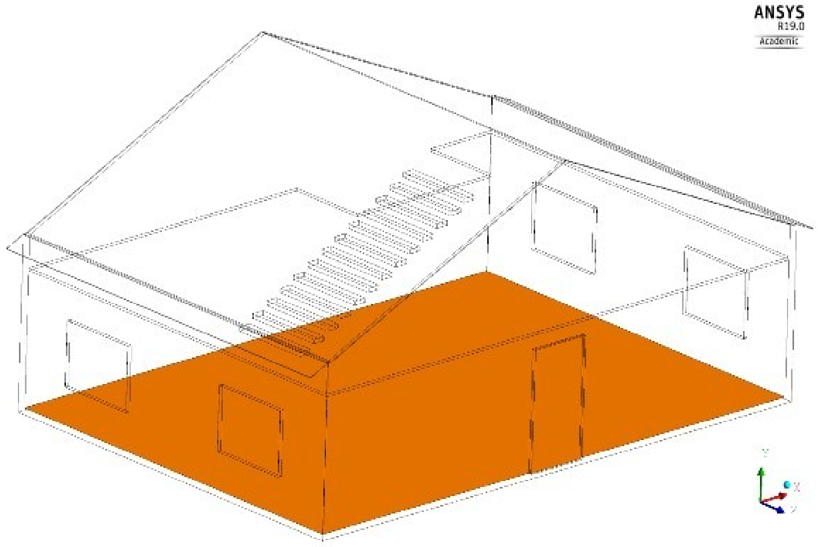


Sensors position within the building model.

Domus PxC → CFD simulation



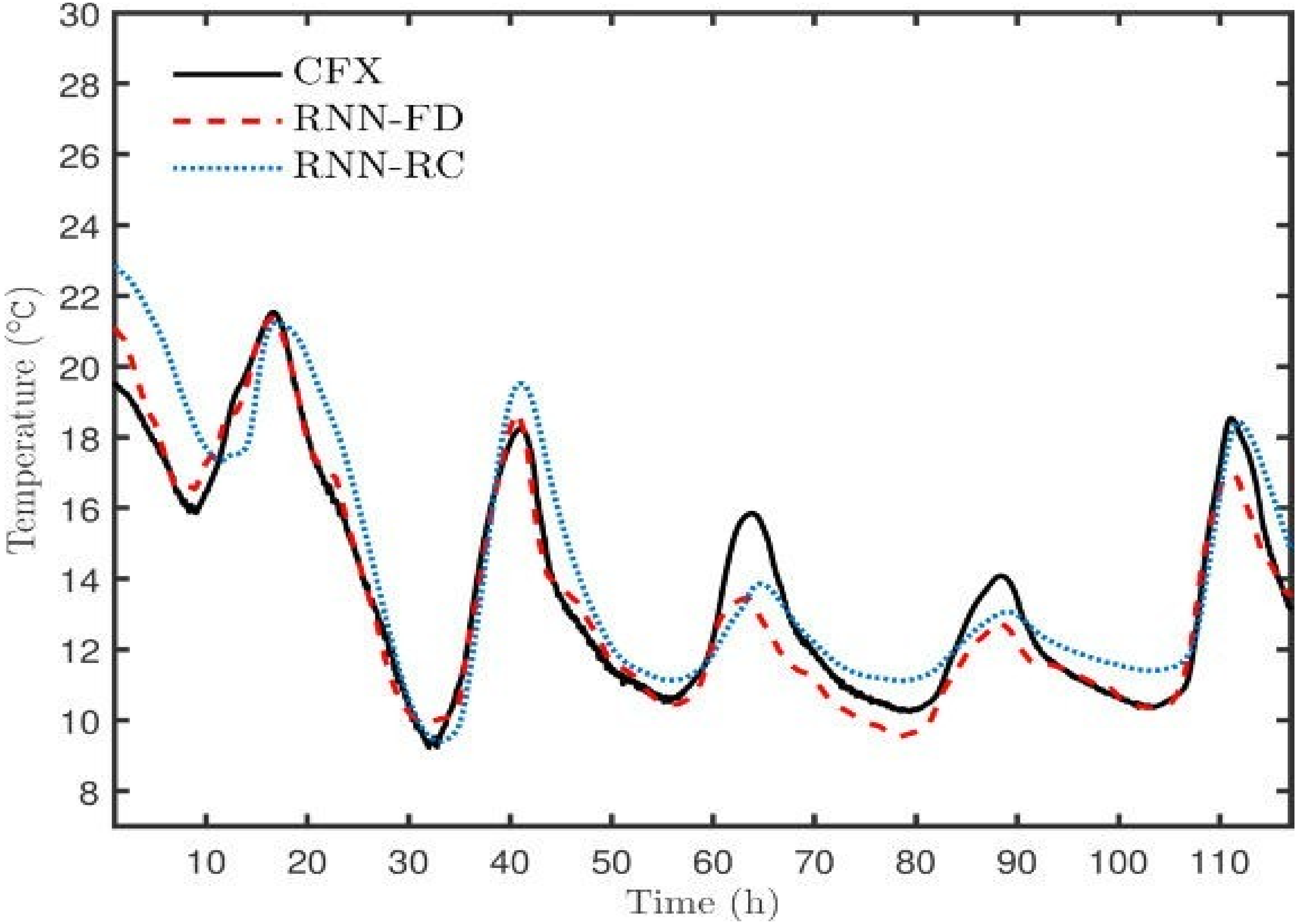
(a)



(b)

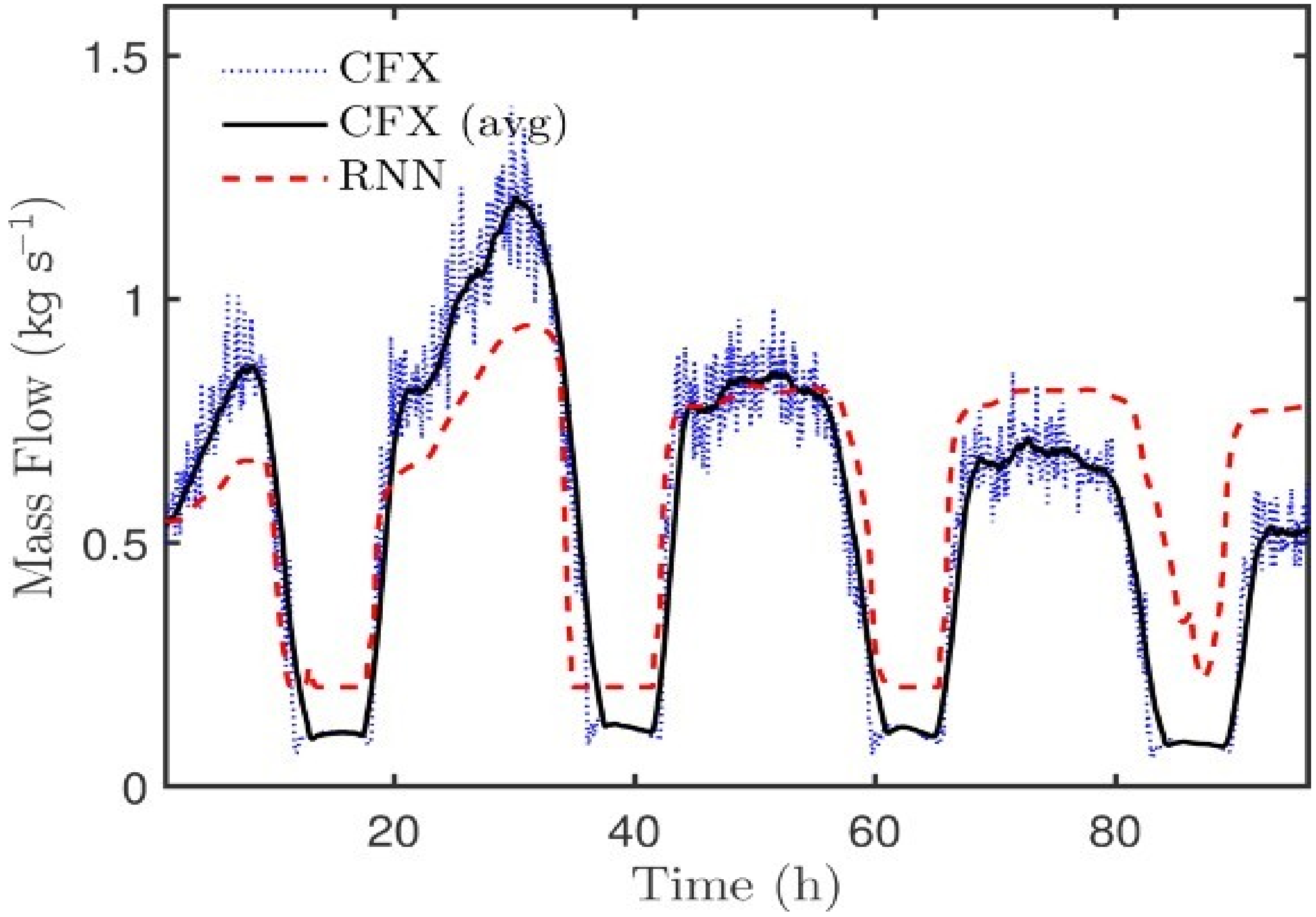
- (a) - 100W/m² on 7.8 m²
- (b) - 5.7W/m² on 135.3 m²

Complex case study - Intelligent co-simulation



Temperature and RNN prediction for sensor 1 in the winter period.

Complex case study - Intelligent co-simulation



Mass airflow at the opening between the two zones in the winter period

Final Remarks

- A new co-simulation method to bring advanced physics to building simulation tools:

- The prediction model is capable to provide results, as close as possible to the ones provided by the complete model, with a much lower computer run time

- Once the model is trained, the model can be used for yearly simulation, running even faster than the simplified purely lumped model

- Therefore, we believe this innovative strategy is promising to accurately bring advanced physics to building simulation tools.

Next Challenges

- Conduct research on the use of other neural network structures and new training models to reduce the training time period;

- Conduct research on multidimensional heat, air and moisture (HAM) transfer intelligent co-simulation