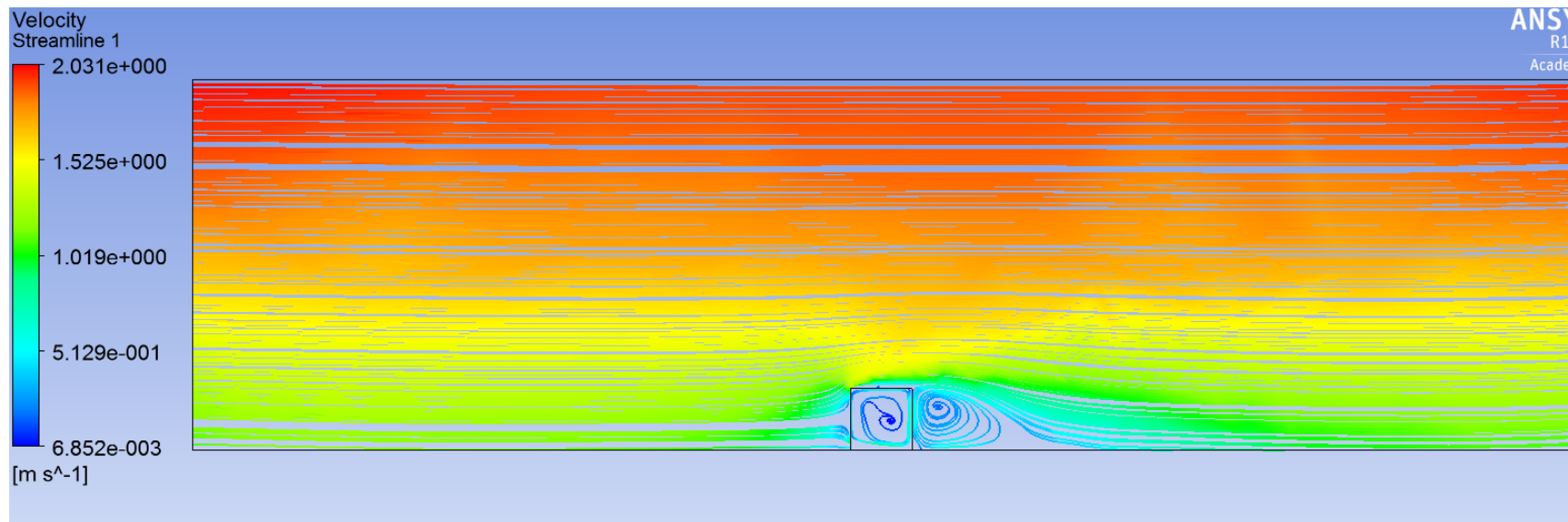
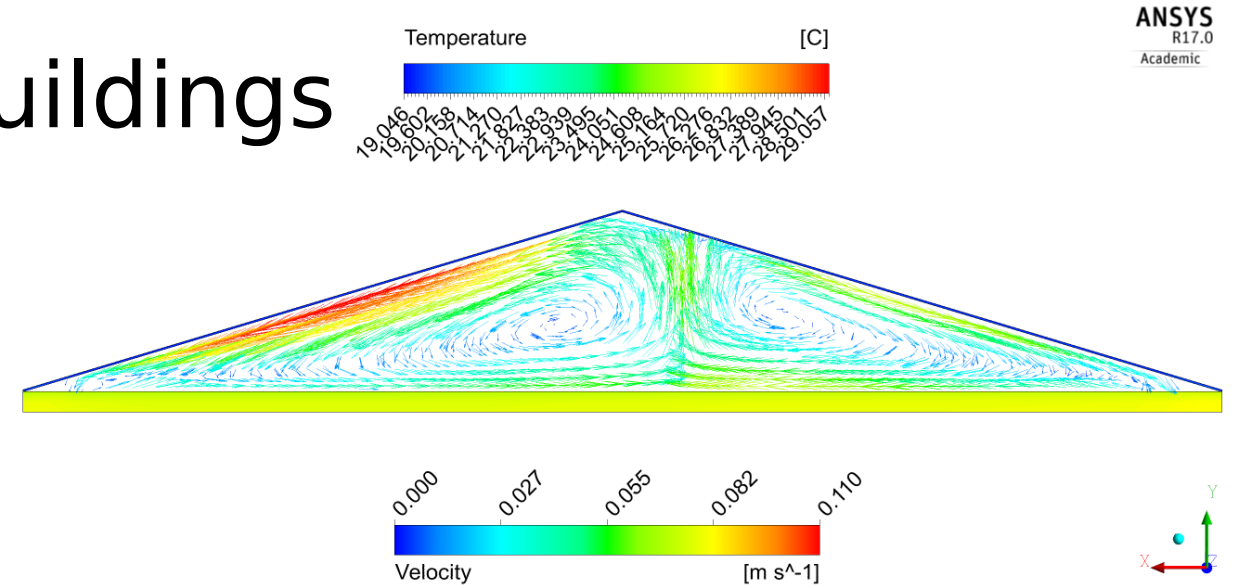


(Intelligent) Co-simulation to bring advanced physics to BPS tools

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

Advanced physics in buildings

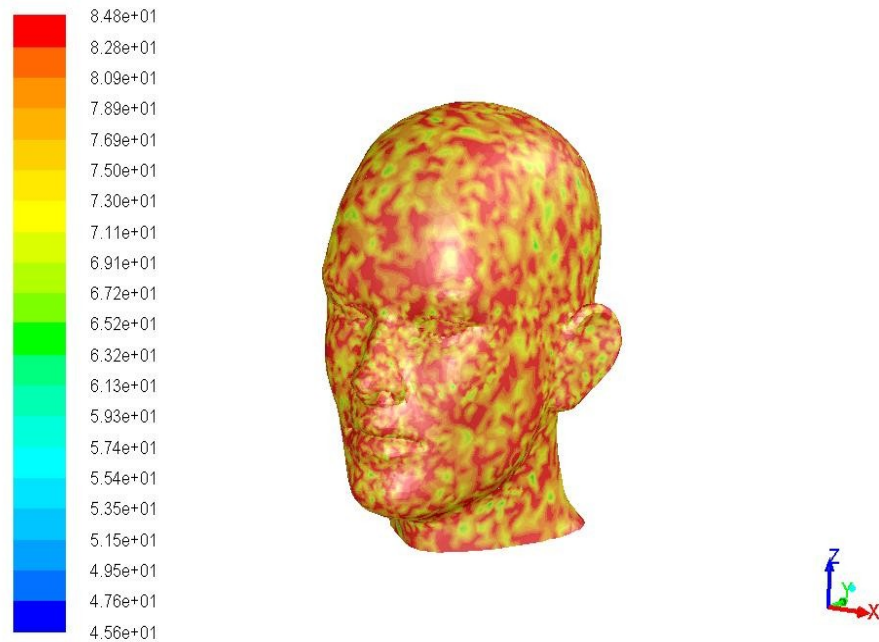
- Unsteady Navier-Stokes based airflow



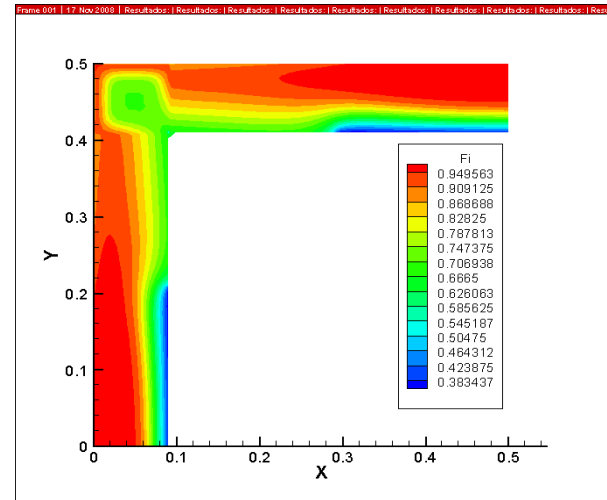
Source: Adrien Gros' post-doc work

Advanced physics in buildings

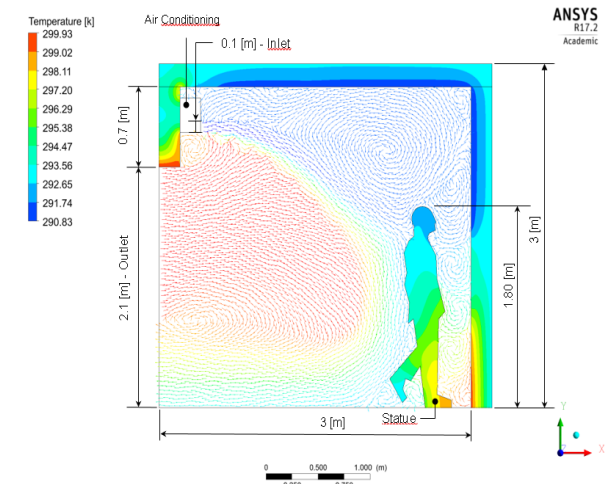
- Multidimensional heat and moisture transfer



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

Camadas dos Elementos

Material +externo

Material	Refino de Malha	Espessura (cm)	Excluir
Tijolo	10	10.0	<input checked="" type="checkbox"/>

Material +interno (Zona 1)

Orientação (0° - norte, 90° - leste, 180° sul, 270° oeste): 80.00

todas as fachadas

Propriedades

Transmitância Térmica (W/m²K): 3.29

Capacitância Térmica (kJ/m²K): 174.80

Fator de Calor Solar (FCS): 6.6

Absortividade Externa (Pintura): 0.50

Emissividade Externa: 0.60

Absortividade Interna (Pintura): 0.50

Emissividade Interna: 0.60

Configuração do Modelo

☐ Modelo Padrão Domus

☐ Adiabático/Impermeável

☒ Modelo FMU

Modelo:

FMU Information

FMU File: js\DomusFMI\Domus - Eletrobras\ExternModel\HYGROTHERM1_v2_DomusModel_v3.fmu

Model Description

FMI Version: 1.0

Model Name: HYGROTHERM1_v2.DomusModel_v3

Model Identifier: HYGROTHERM1_v2_DomusModel_v3

Guid: fd1d7dc752f7a87abd070710d10e67d4

Generation Tool: JModelica.org

Generation Date And Time: 2014-09-02T09:19:19

Variables Association - Input

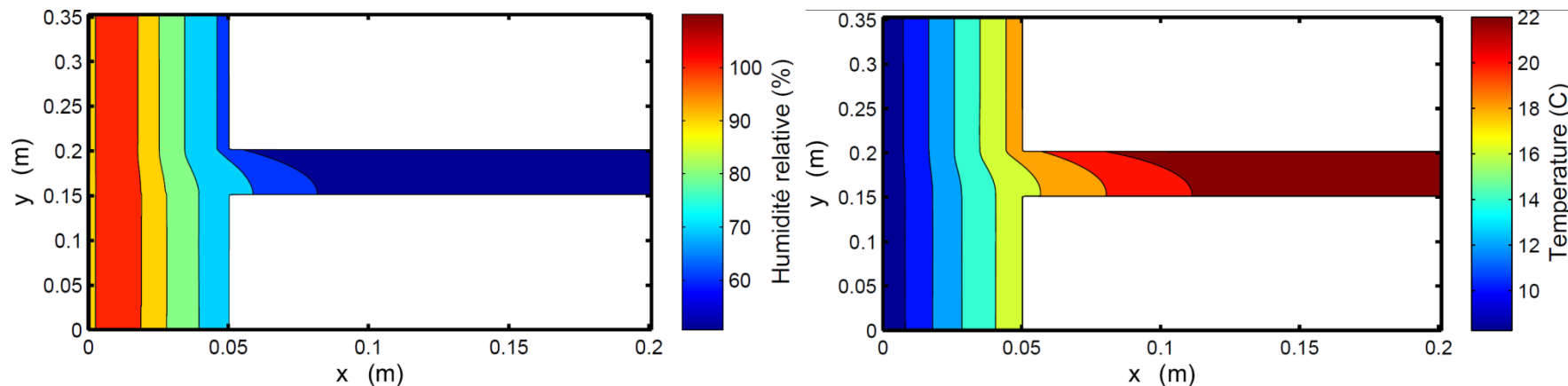
FMU Input	Fixed Value	Domus Variable	Unit
TempExt	0	External temperature(or adjacent zone)	
TempInt	0	Zone internal temperature	
coefConvExt	0	External heat convective coefficient	
coefConvInt	0	Internal heat convective coefficient	
tempCeu	0	Sky temperature	

Variables Association - Output

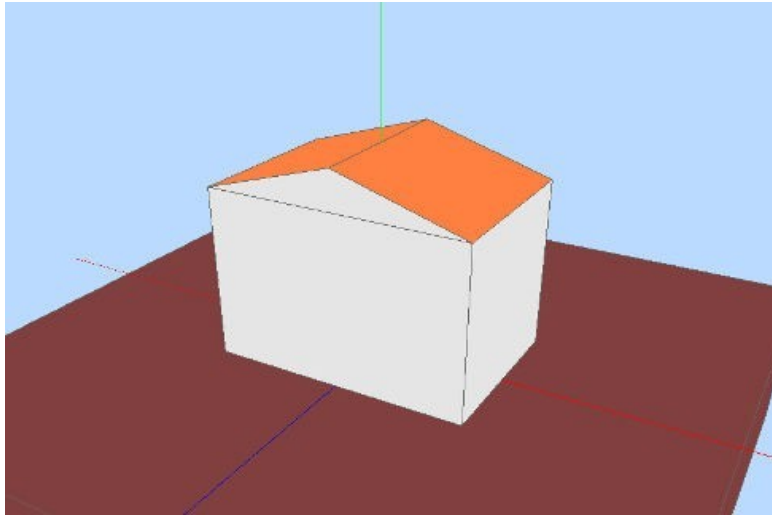
FMU Output	Domus Variable	Unit
T_maill[1]	Wall temperature(node)	
T_maill[2]	Wall temperature(node)	
T_maill[3]	Wall temperature(node)	
T_maill[4]	Wall temperature(node)	3
T_maill[5]	Wall temperature(node)	4
T_maill[6]	Wall temperature(node)	5

HM-PGD - Domus results

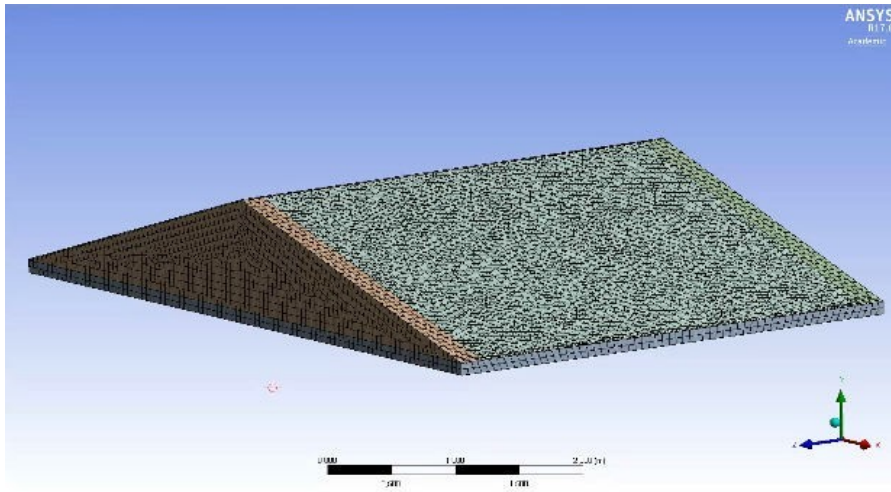
- *Validation of the coupling method on the benchmark ex1 of IEA Annex 41*
- *Simulation of 2D wall assemblies*
- *Simulation of parametric problems, considering domain of variation of material properties*



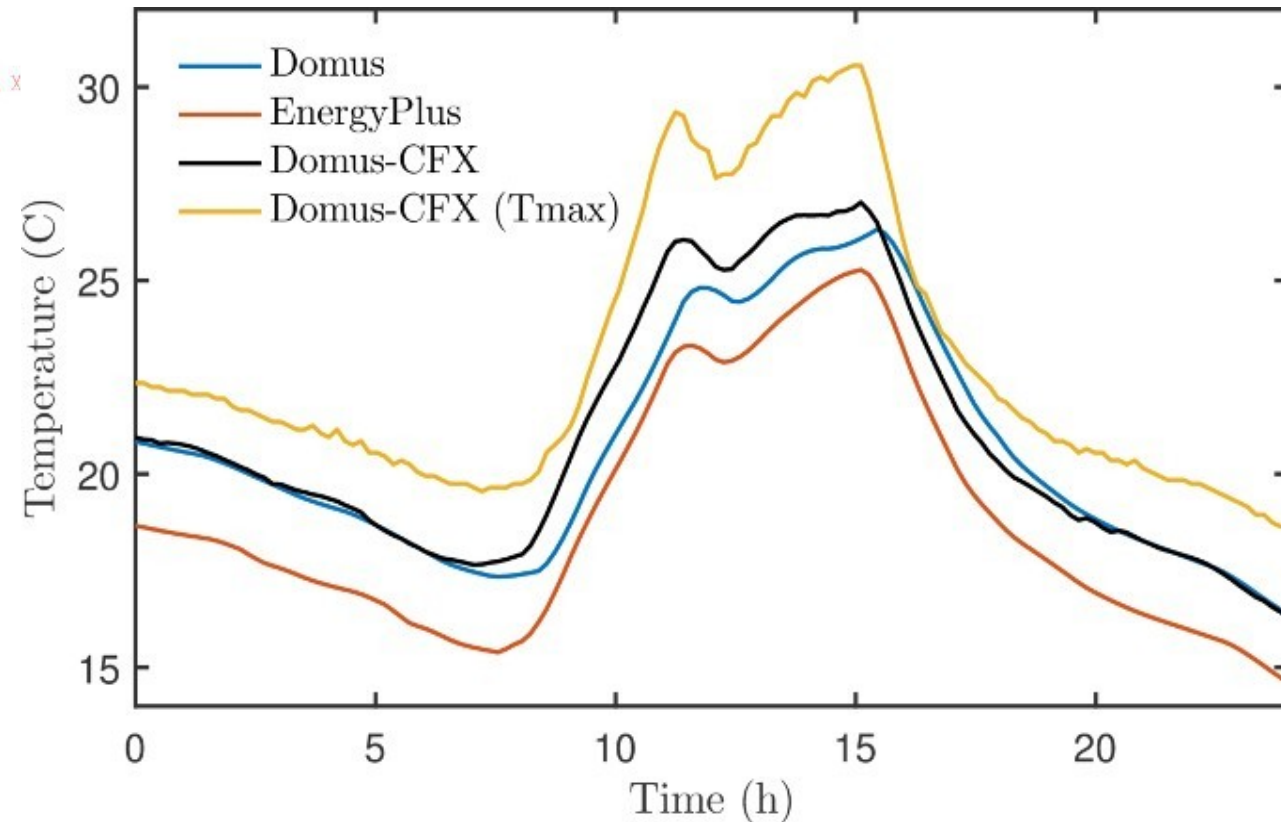
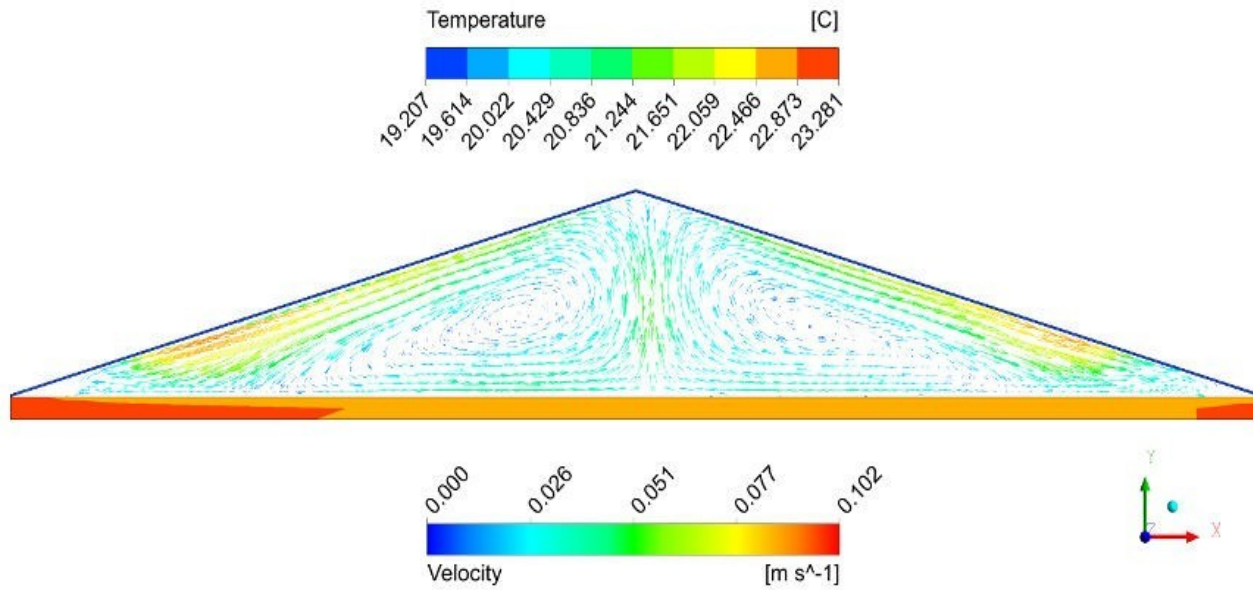
Co-simulation Case Study 2



- Two thermal zones
- 96-m³ room
- 13-m³ attic
- co-simulated attic
- 10 min Domus time-step
- 1 min CFX time-step



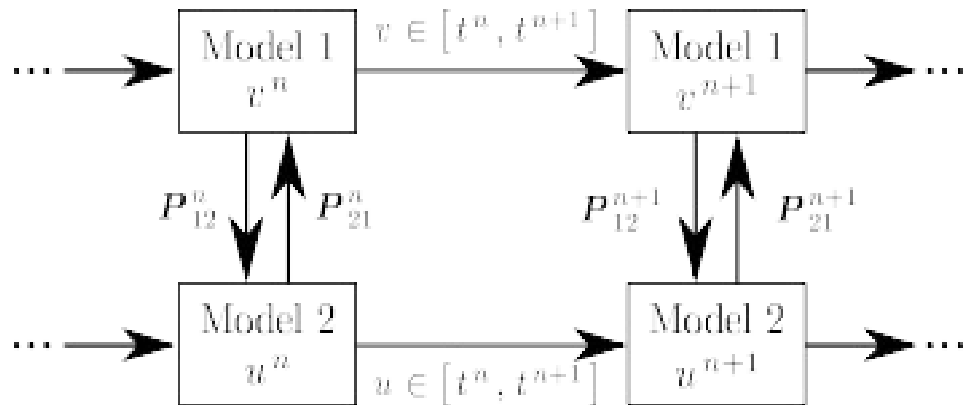
Co-simulation Case Study 2



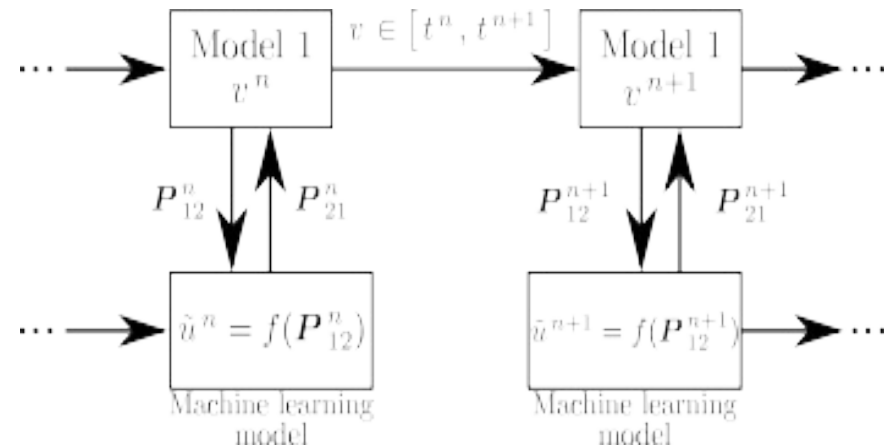
Intelligent co-simulation strategy

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,

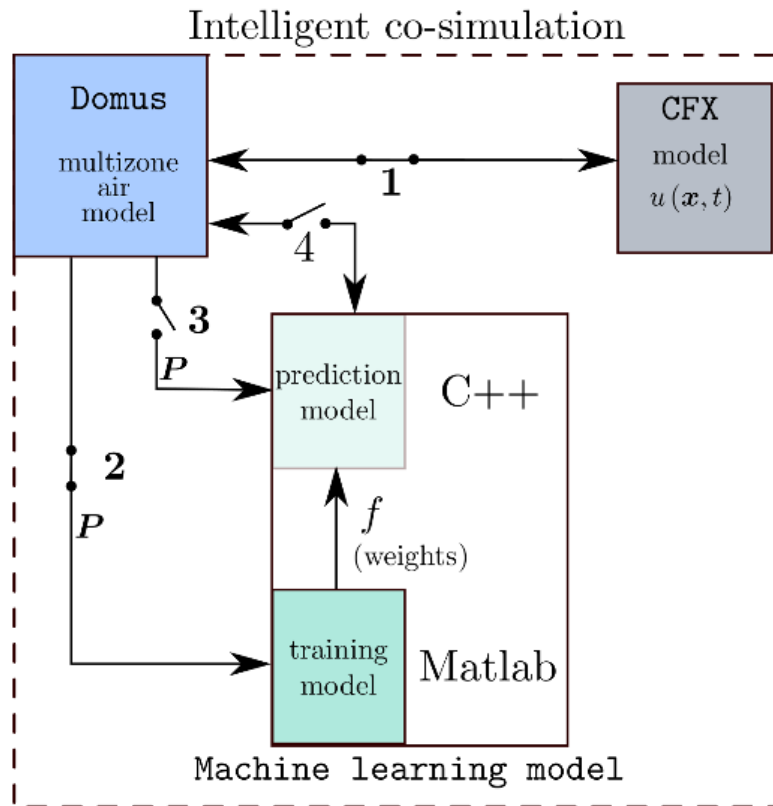
Prediction phase

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

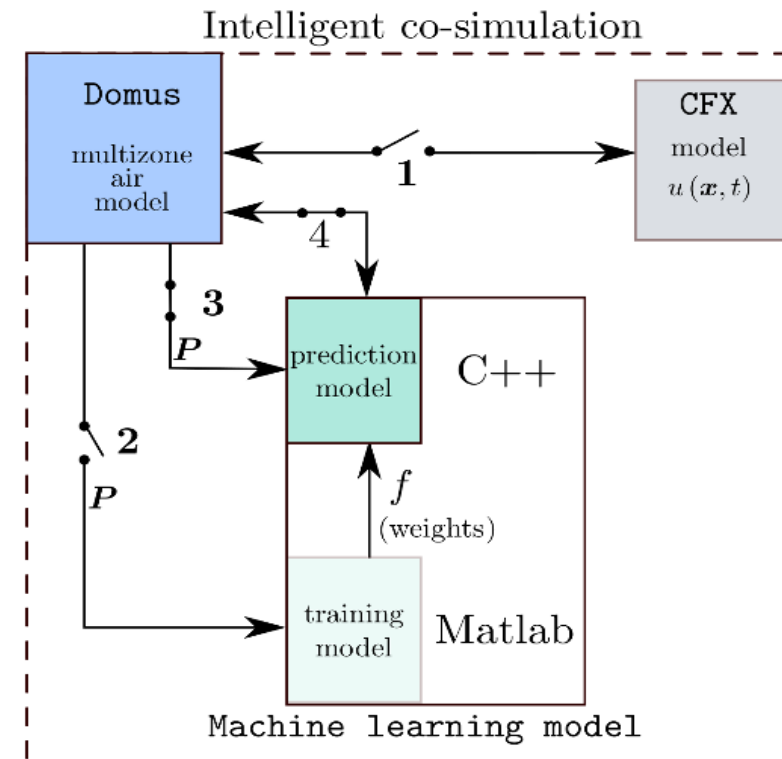
Other highlights

- 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.

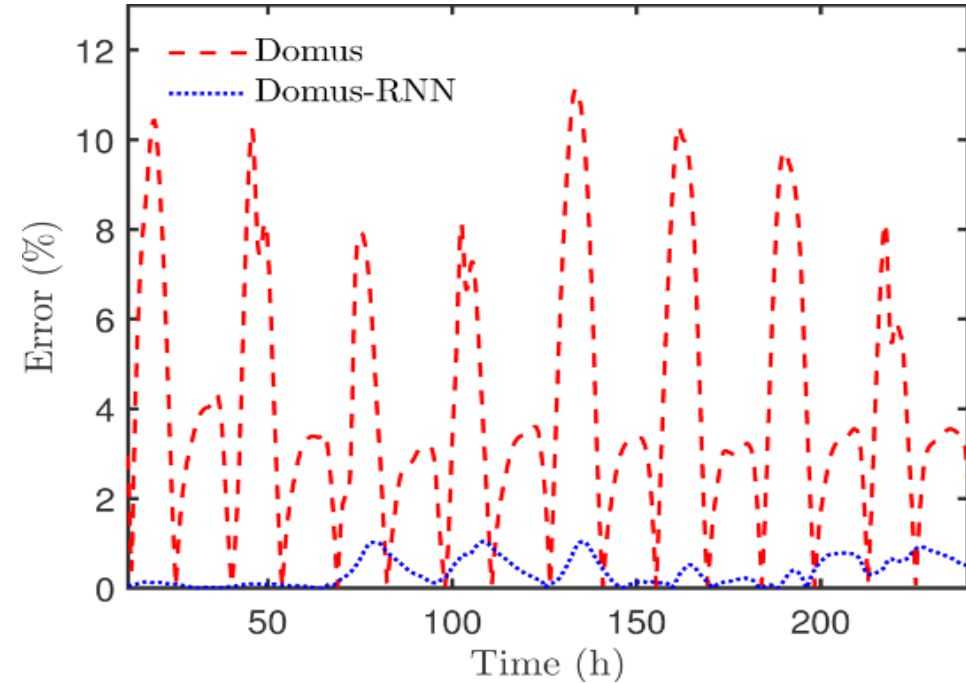
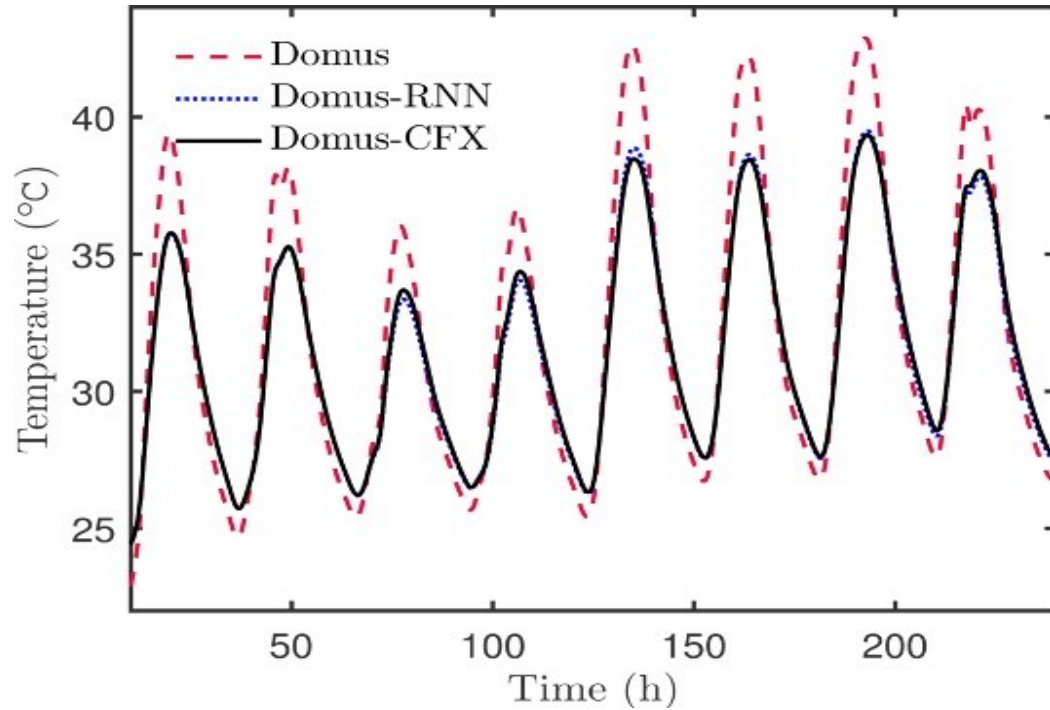
Training Phase

- 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 °C
- RNN model presents a 10 times lower error
- maximum difference of only 0.4° C

Computer run time for a 10 days period

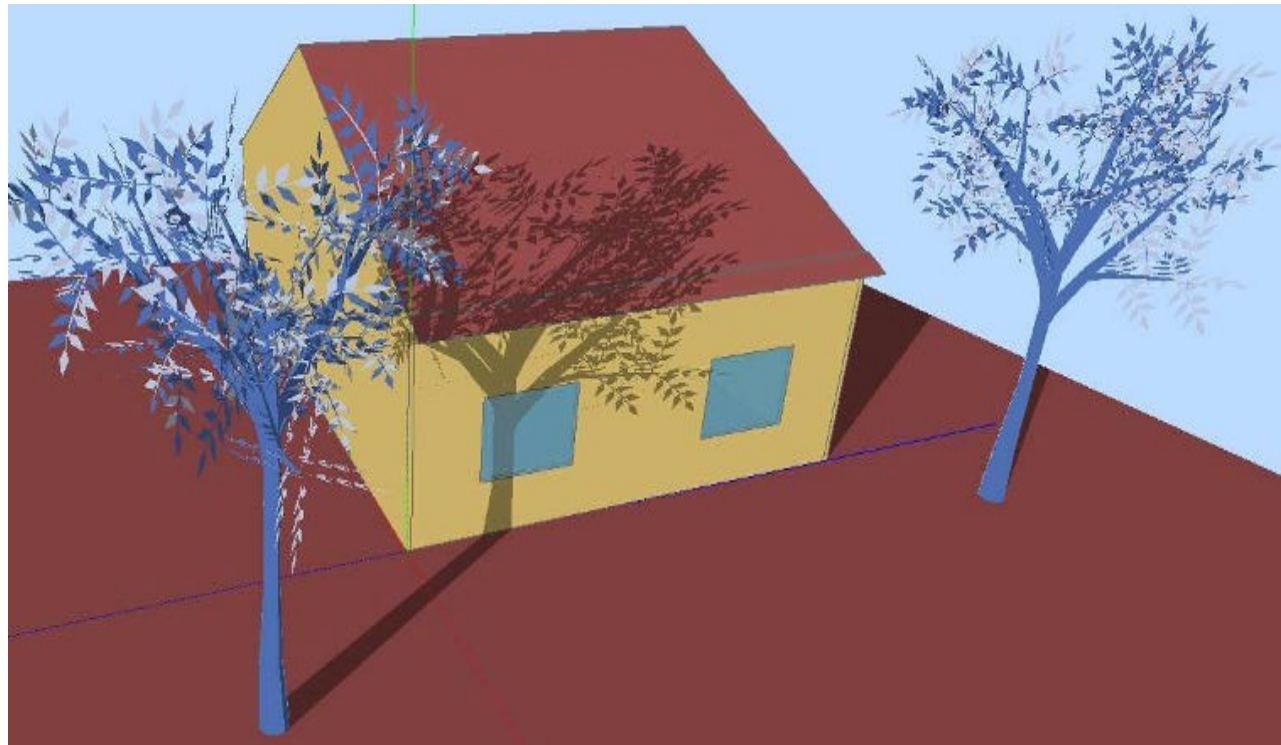
Approach	Total time		CFX		Prediction Model
	(h)	(min)	(h)	(min)	(min)
Domus lumped model	0.01	< 1	—	—	—
Classical co-simulation	656	39360	656	39360	—
Intelligent co-simulation	101.71	6103	101.68	6101	< 1

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

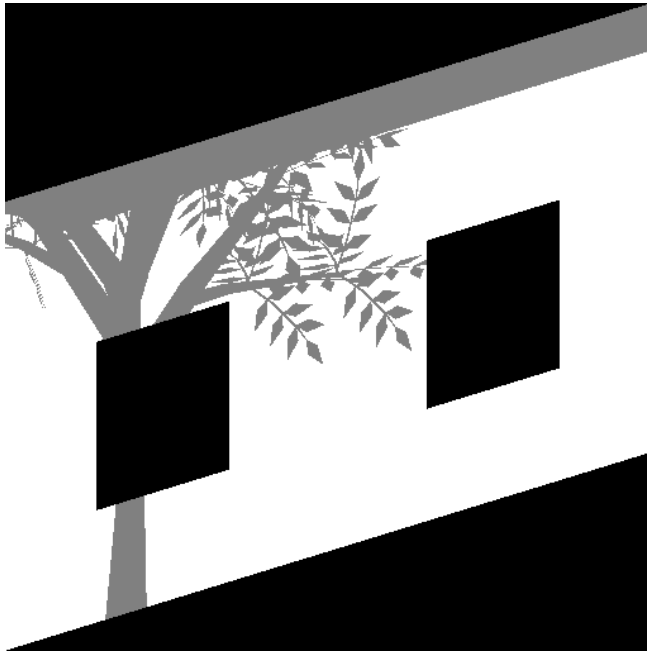
- Co-simulation to provide direct, diffuse and reflected radiation fluxes, and the sunlit contour,
- internal and external surfaces,
- considering precisely complex shadings by means of the Pixel-Counting technique.



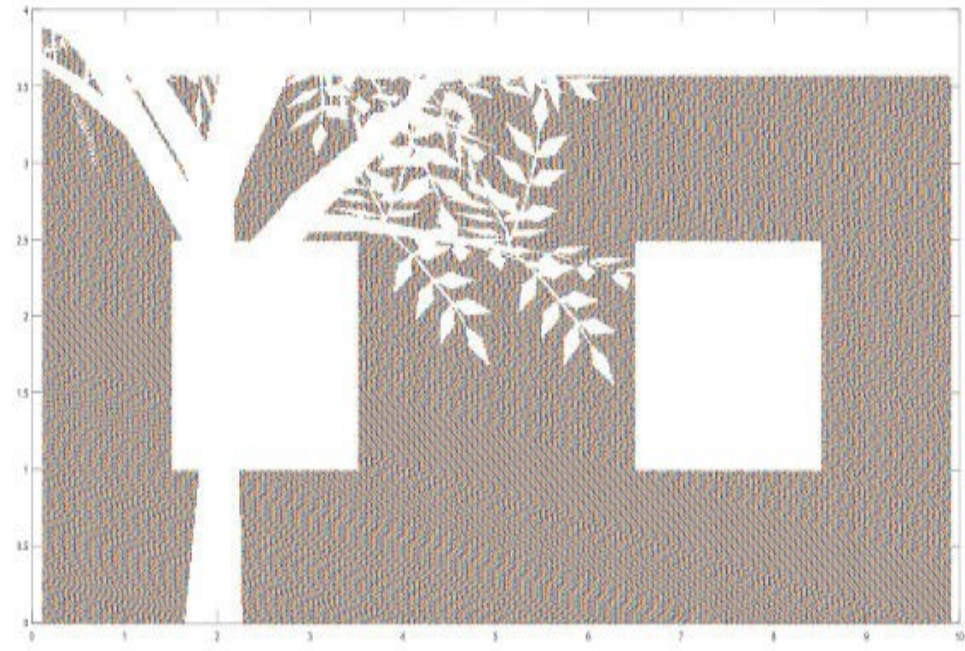
Shadowing pattern example in the Domus interface.

Domus PxC → CFD simulation

1 - Domus export sunlit pixels as world coordinate points.



(a)

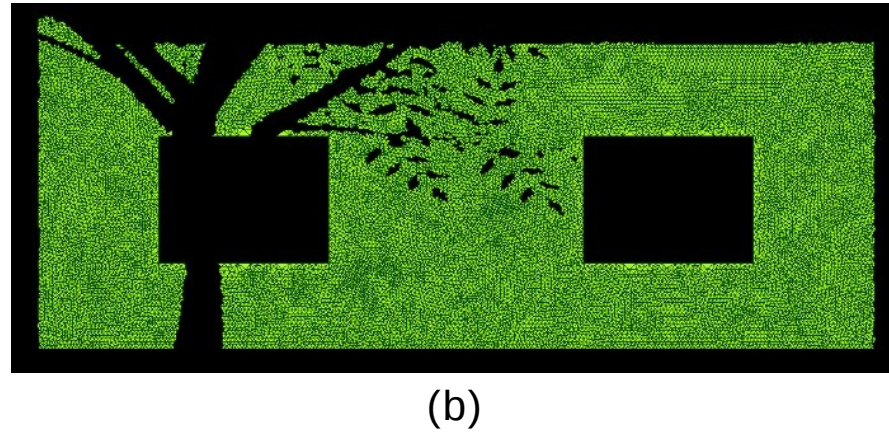
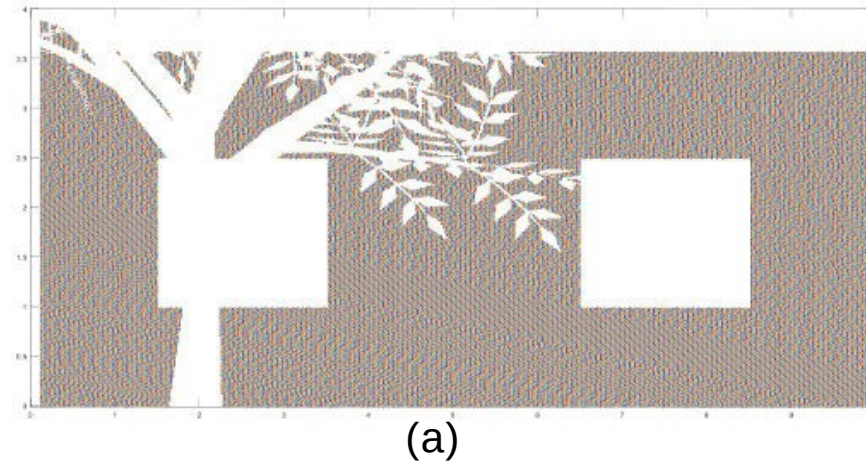


(b)

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

Domus PxC → CFD simulation

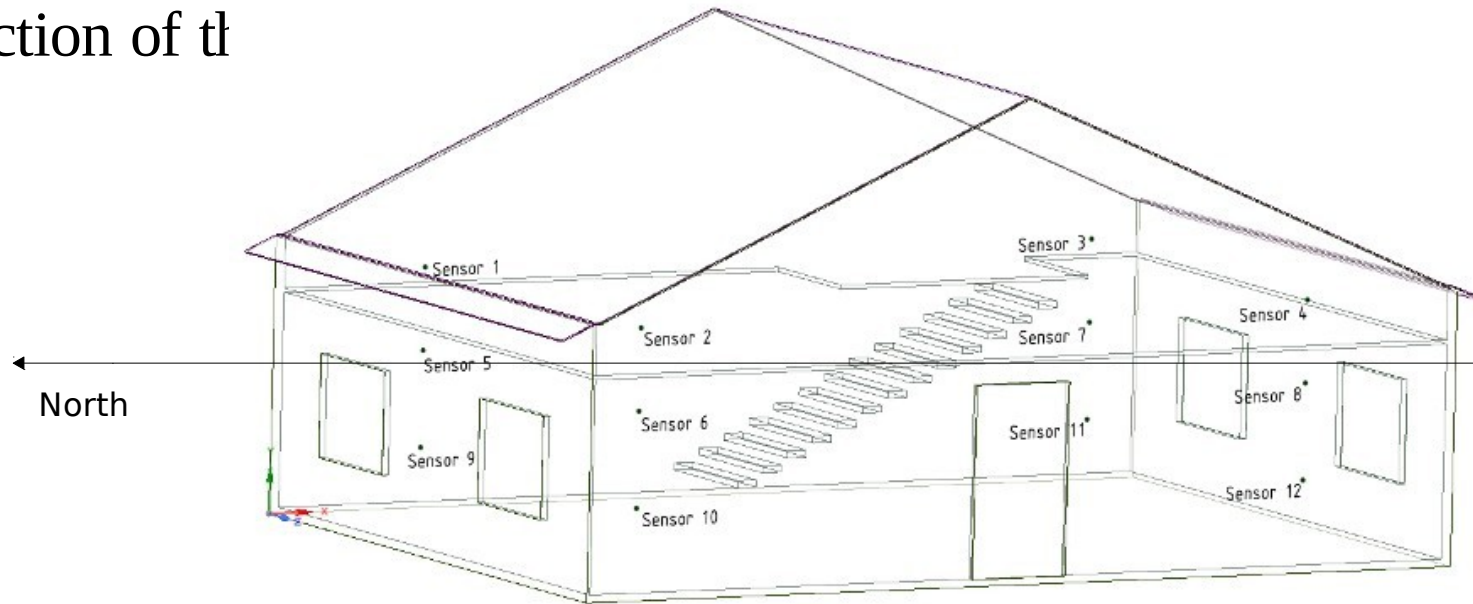
2 - Auxiliary software (Salome) to generate a sunlit area mesh.



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

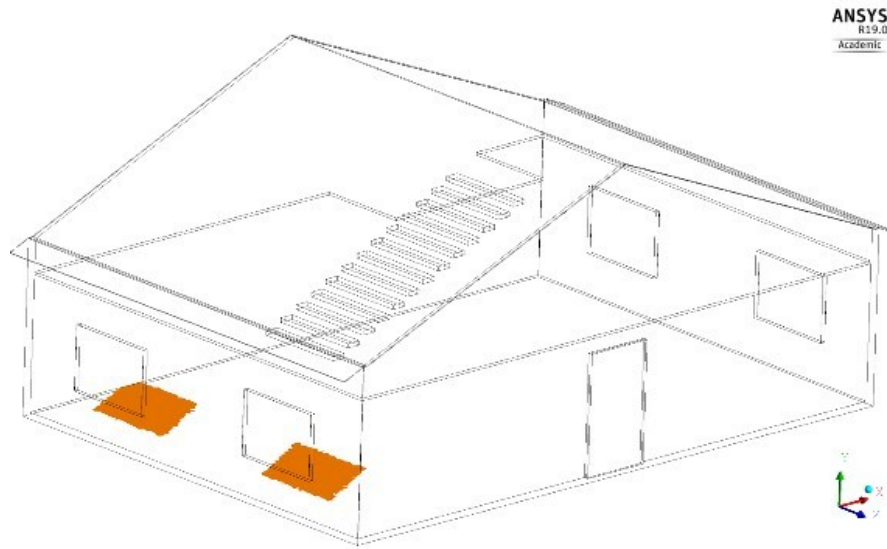
Complex case study - Intelligent co-simulation

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



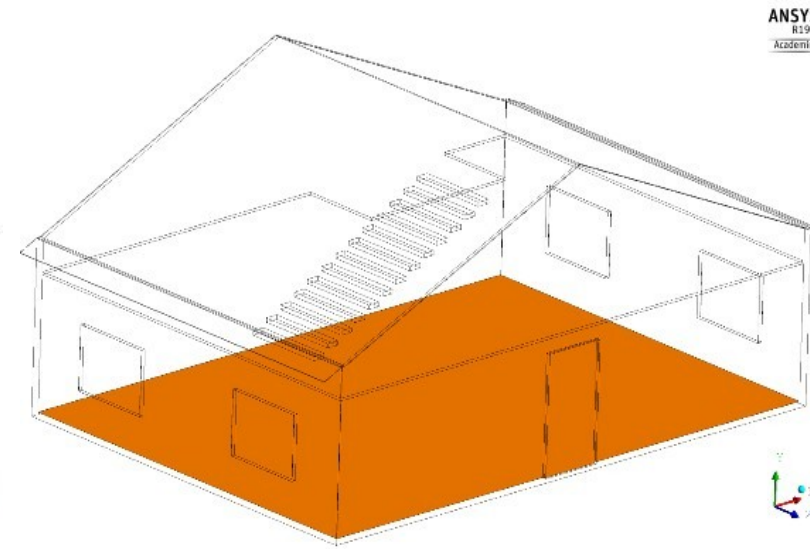
Sensors position within the building model.

Domus PxC → CFD simulation



(a)

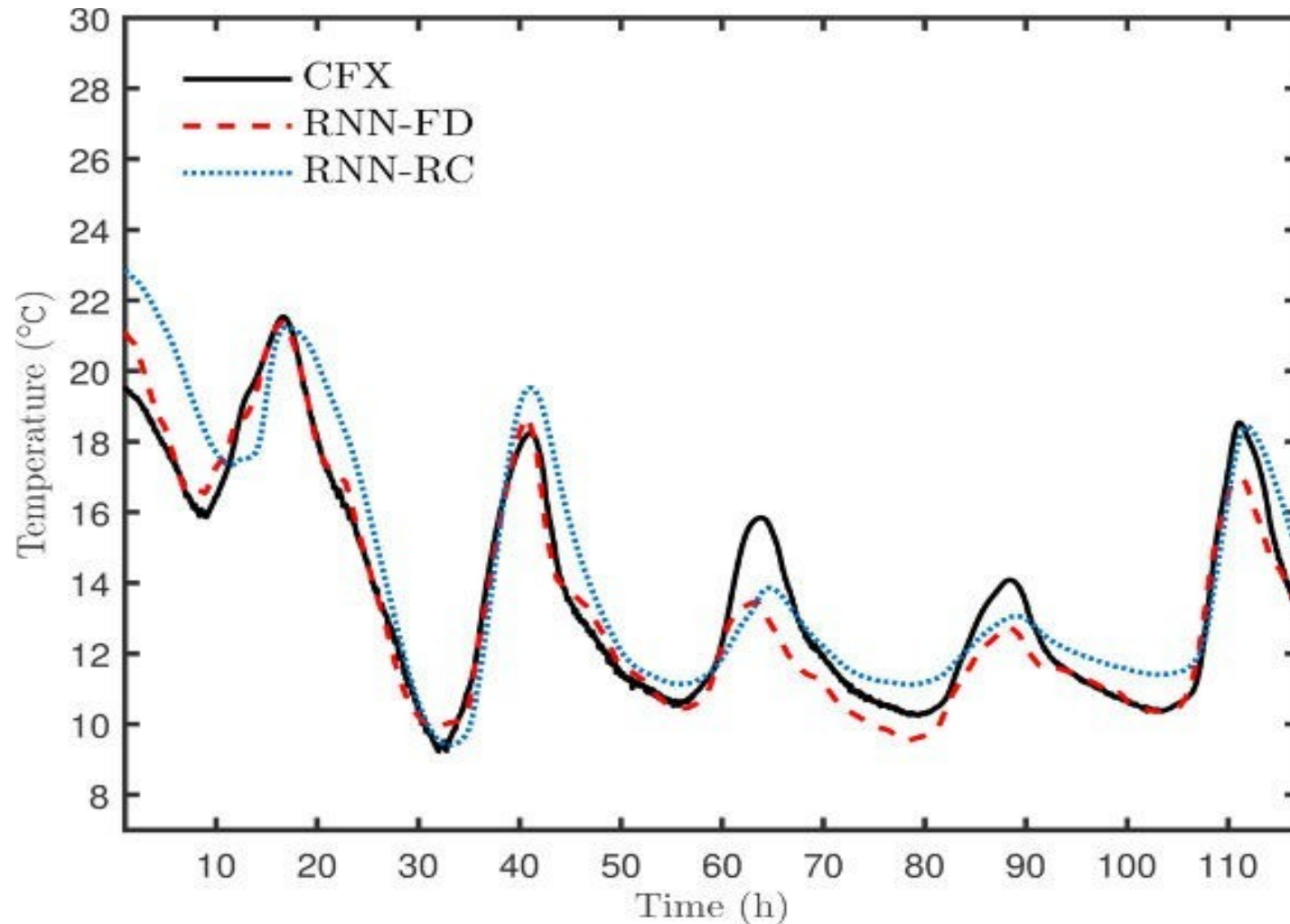
- (a) - 100W/m^2 on 7.8 m^2



(b)

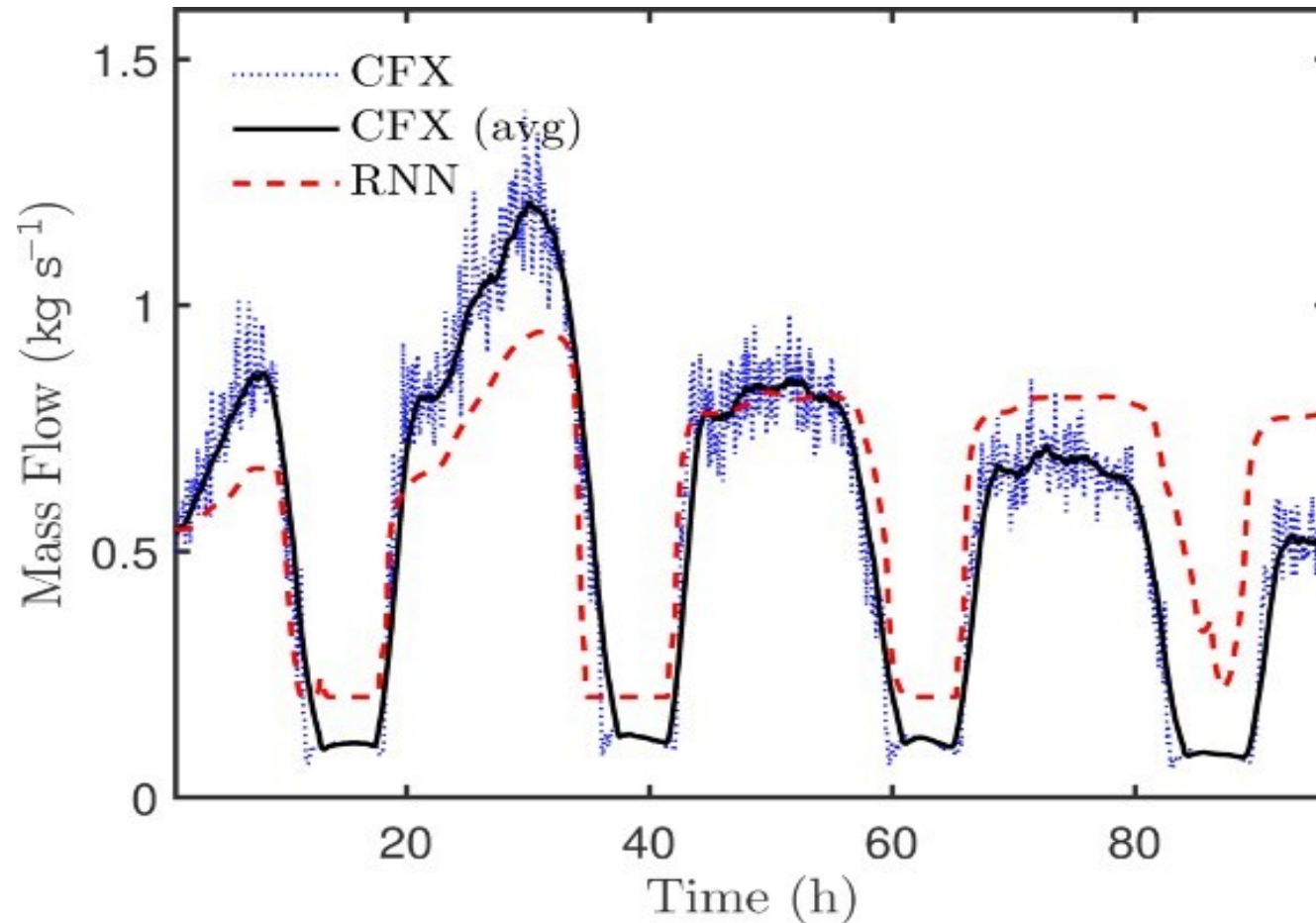
- (b) - 5.7W/m^2 on 135.3 m^2

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

