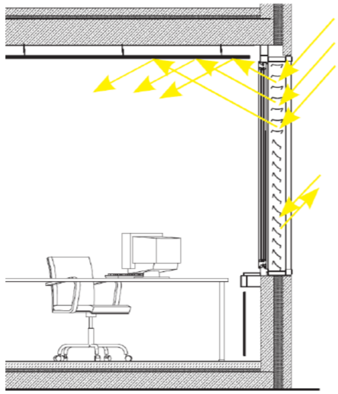
Coupling Radiance and Computational Fluid Dynamic simulation for a detailed characterization of façades with integrated shading device

Ingrid Demanega, Giuseppe De Michele

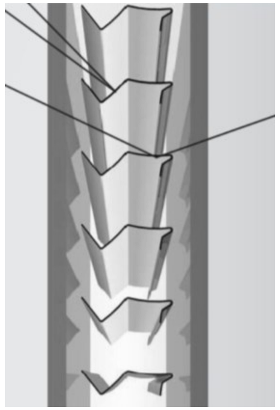
Radiance Workshop, 29.08.2023

Complex Fenestration Systems (CFS)

Optical and thermal properties characterized by a complex dependence on the ***angle of incidence*** *and* ***wavelength*** *of* ***solar radiation***



Source: Bartenbach GmbH



Source: RETROLux Therm

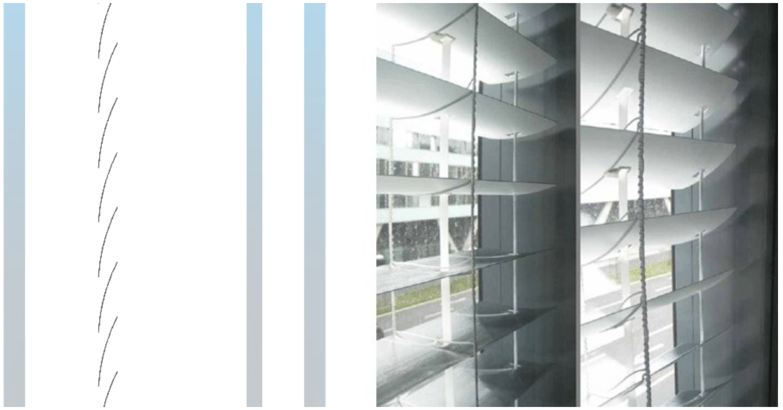
Complexity of the **shading system**

\+

Interaction with **fluid flow** in the window cavity

⇩

Accurate modelling and simulation techniques to assess the thermal and optical behaviour

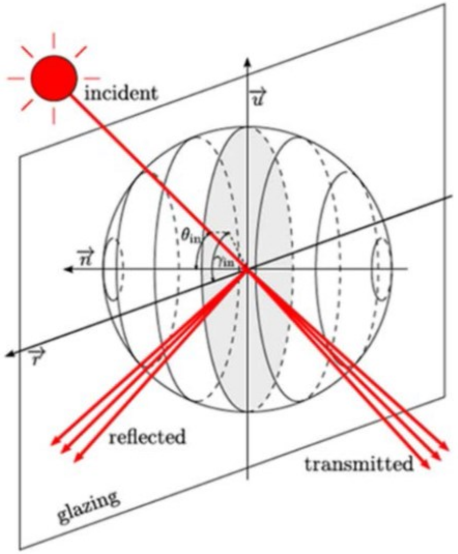


Source: RETROFlex Therm

Complex Fenestration Systems (CFS)

Optical modelling:

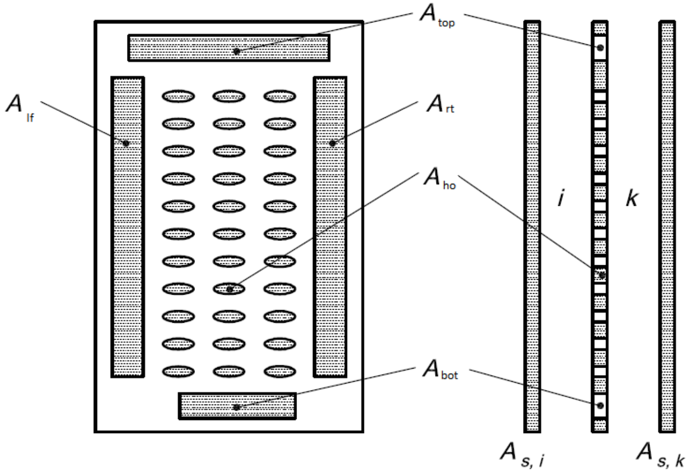
- Models (based on BSDF) with high level of accuracy, used to perform daylight/optical simulations



Source: Hiller and Schöttl (2014)

Thermal modelling:

- Modelling approach in main BES tools based on ISO 15099
- Restrictions in the applicability to CFS:
  - Interaction between shading system and window cavity
  - Ventilated cavities additional complexity (not properly treated in the BPS tools)
  - Neglection of thermal inertia



Source: ISO 15099:2003

Aim of the work

Definition and **experimental validation** of a novel **modelling approach** for the thermal characterization of **Complex Fenestration Systems** with integrated venetian blinds at different tilt angles and under **dynamic conditions**

Modelling approach

1. Detailed optical model for solar radiation

based on ray tracing

- Calculation of absorbed fraction of solar radiation

RADIANCE + WINDOW 7

2. Fluid flow and heat transfer (CFD simulation)

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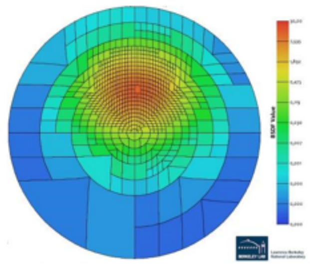
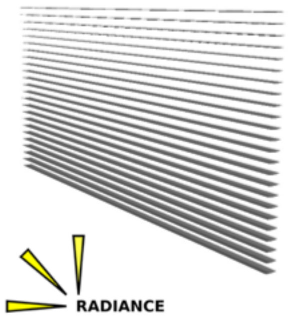
Modelling approach

Detailed optical model for solar radiation – step 1

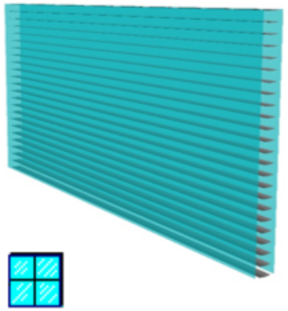
Measure
shading material BRDF



Model
shading system BSDF



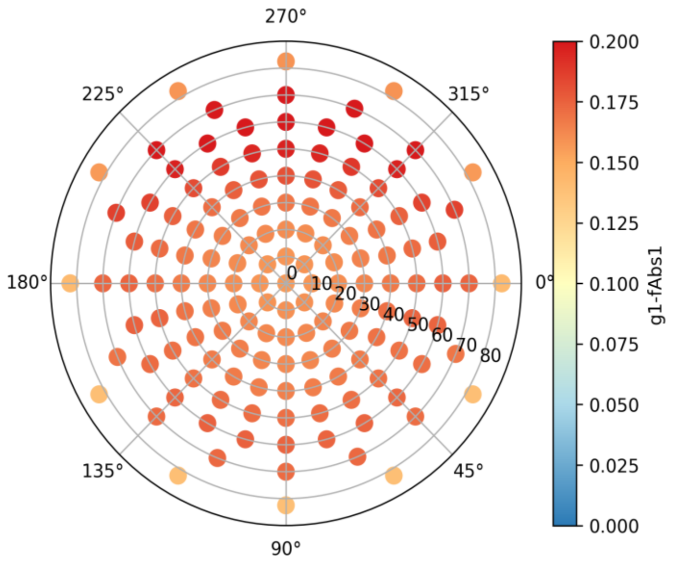
Combine shading
system and glazings



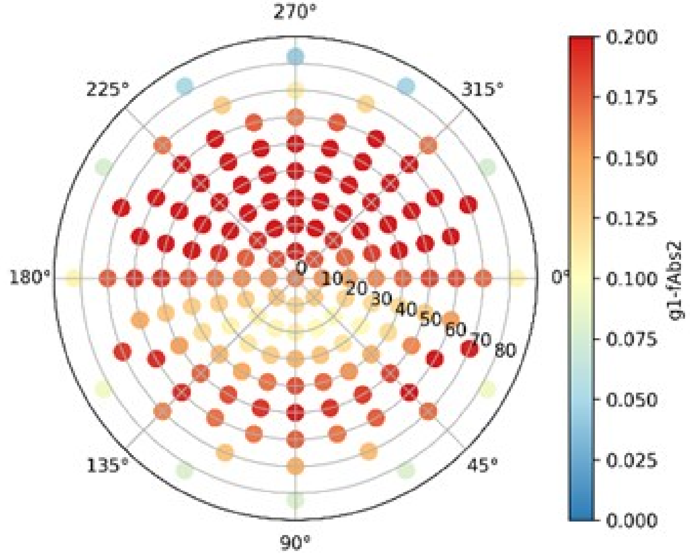
Measurement → genBSDF → WINDOW 7.6

Shading modelling in Radiance

→ Absorption vectors



Glazing layer



Shading layer – venetian blinds

De Michele, G., Loonen, R., Saini, H., Favoino, F., Avesani, S., Papaiz, L., & Gasparella, A. (2018). Opportunities and challenges for performance prediction of dynamic Complex Fenestration Systems (CFS). Journal of Facade Design and Engineering, 6(3), 101-115.

Modelling approach

Detailed optical model for solar radiation – step 2

$$Abs(t)_i = S\ D\ A_i$$

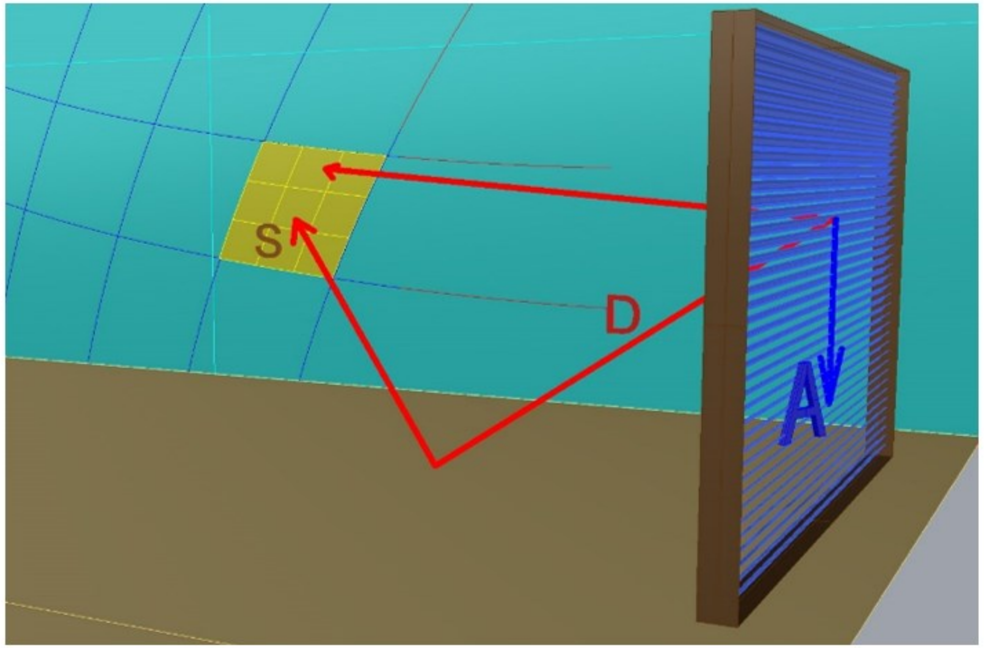
S: Sky Matrix *

D: Daylight Matrix

Ai: Absorbtion coefficients' vector of layer *i*

Abs(t)i: time- dependent heat flow rate of radiation absorbed by layer i

*
```
# Sky matrix
gendaymtx –m 1 -O1 location.wea > location.smx
```

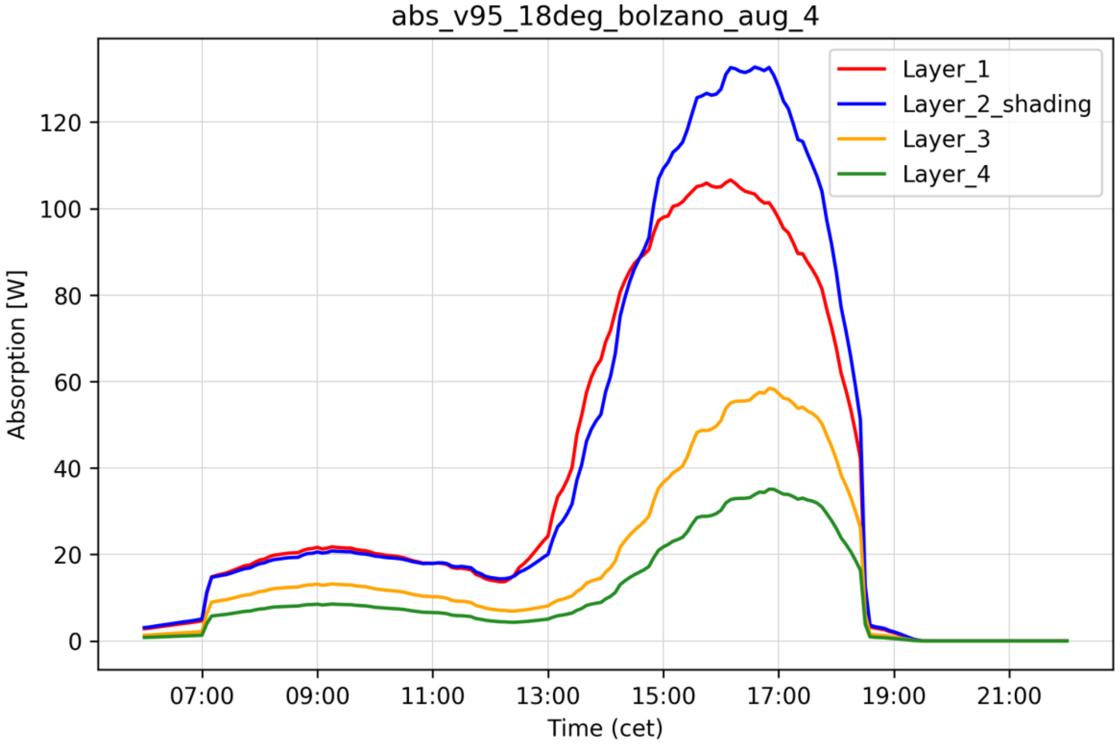


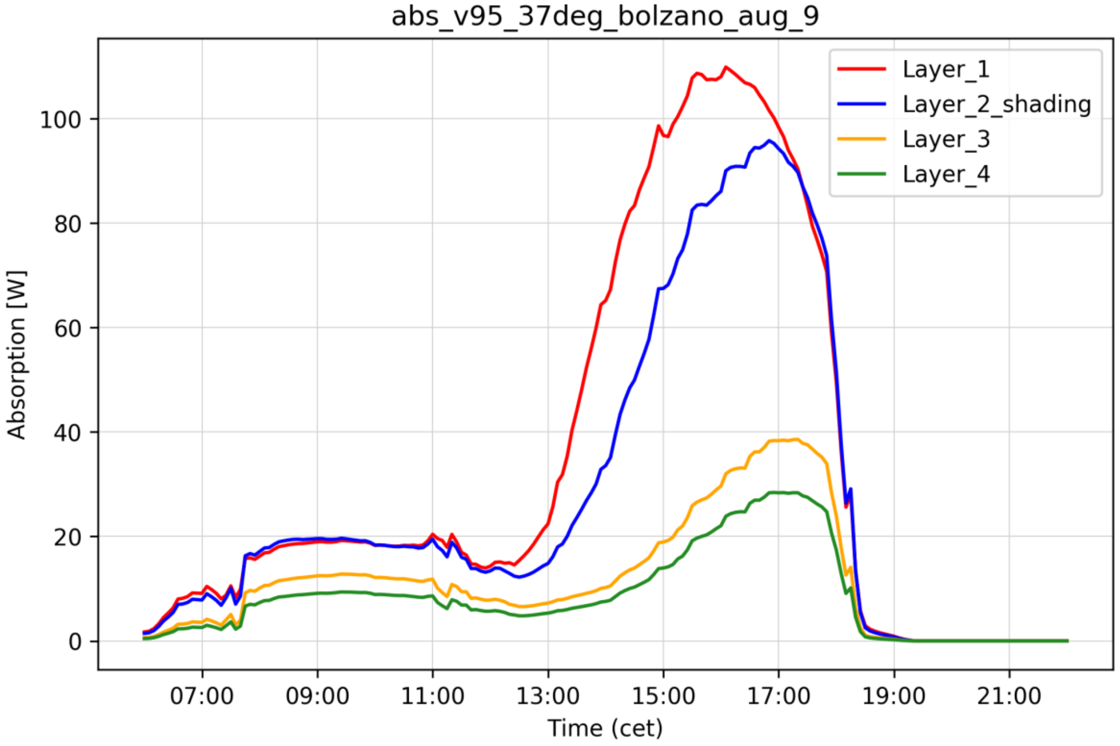
Modified Three-Phase Method

Andy McNeil, Using Radiance to produce lighting and solar optical schedules for Energy Plus simulations, Radiance workshop 2011

Modelling approach

Detailed optical model for solar radiation – step 1 - output





Modelling approach

Fluid flow and heat transfer (CFD simulation)

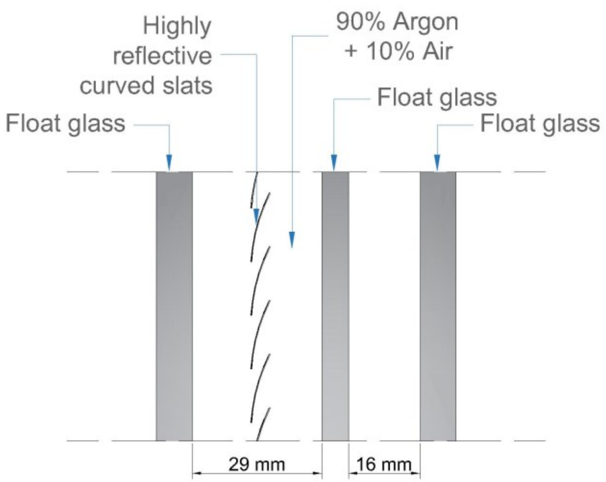
- FEM-based software COMSOL Multiphysics
- Pre-calculated solar absorption is assigned as heat source
- Assumptions:
  - 2D calculation domain
  - Long wave radiation exchange computed with radiosity method
  - Laminar flow regime

COMSOL MULTIPHYSICS®

Window typology

Complex Fenestration System with integrated venetian blinds
at different tilt angles:

- Open position: 18° from horizontal
- Intermediate position: 37° from horizontal



CFS at the Living Lab of the Free University of Bozen-Bolzano, Measurement setup

In-situ measurements

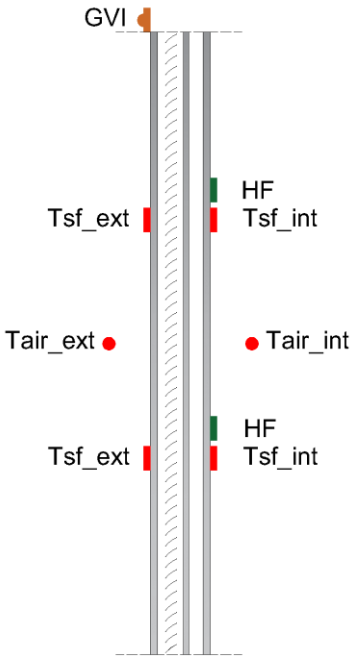
- Continuous measurements for ten days during three periods: April, July and August

Measured parameters

Parameter	**Symbol (drawing)**
Internal air temperature (°C)	T_{air_int}
External air temperature (°C)	T_{air_ext}
Internal glazing surface temperature (°C)	T_{sf_int}
External glazing surface temperature (°C)	T_{sf_ext}
Internal heat flux (W m^{-2})	*HF*
External global vertical irradiance (W m^{-2})	*GVI*
External global and diffuse horizontal irradiance (W m^{-2})	-

Input: Boundary conditions

Output: Simulation result



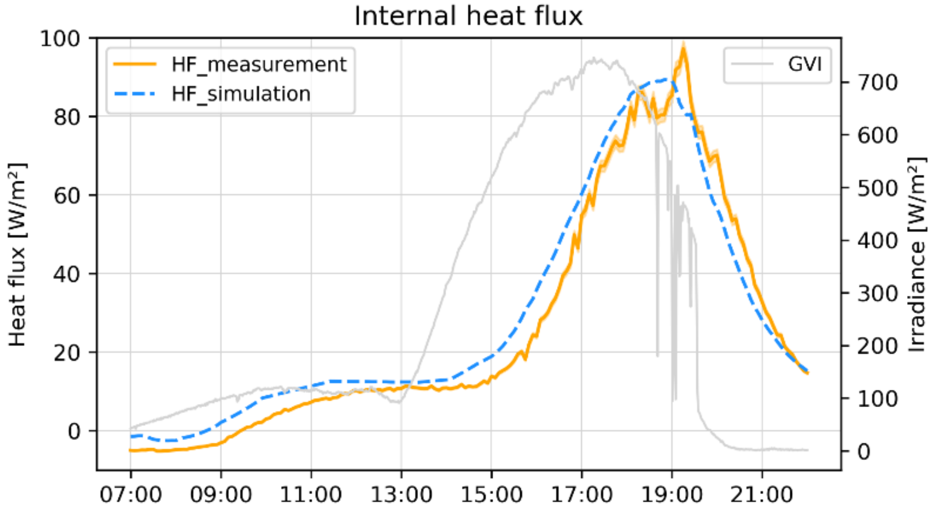
Model calibration

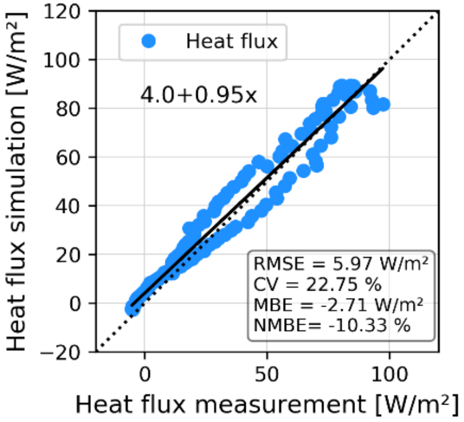
- 1-2 measurement days for each period
- Most relevant calibration parameter:

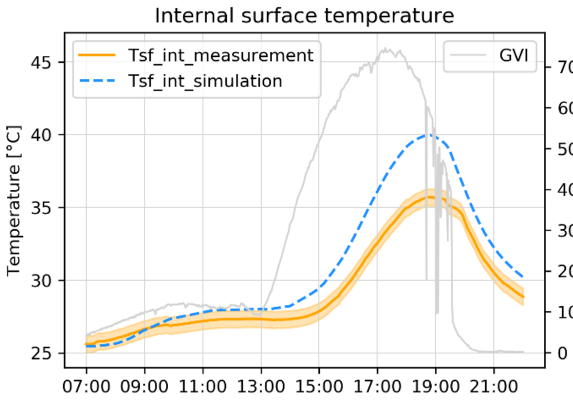
  Convective heat transfer coefficient (internal/external)
- Several models from literature were evaluated and the most suitable ones implemented in the model:
  - **Internal convective heat transfer coefficient:**
    - Khalifa and Marshall model
    - Alamdari and Hammond model
  - **External convective heat transfer coefficient:**
    - Building Loads Analysis and System Thermodynamics (BLAST) model
    - McAdams model

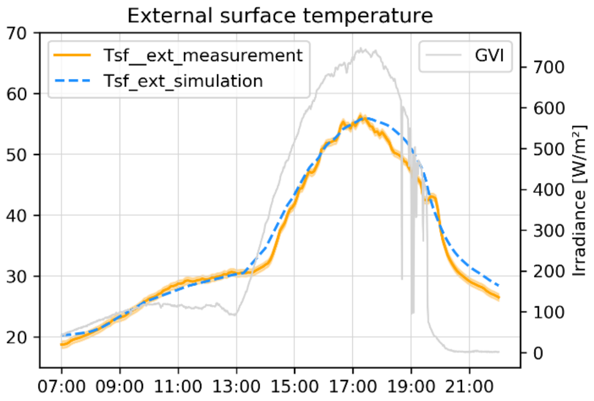
Most suitable h_c models:
Minimized the analyzed statistical indicators for the majority of days

Results – Blinds at 18°



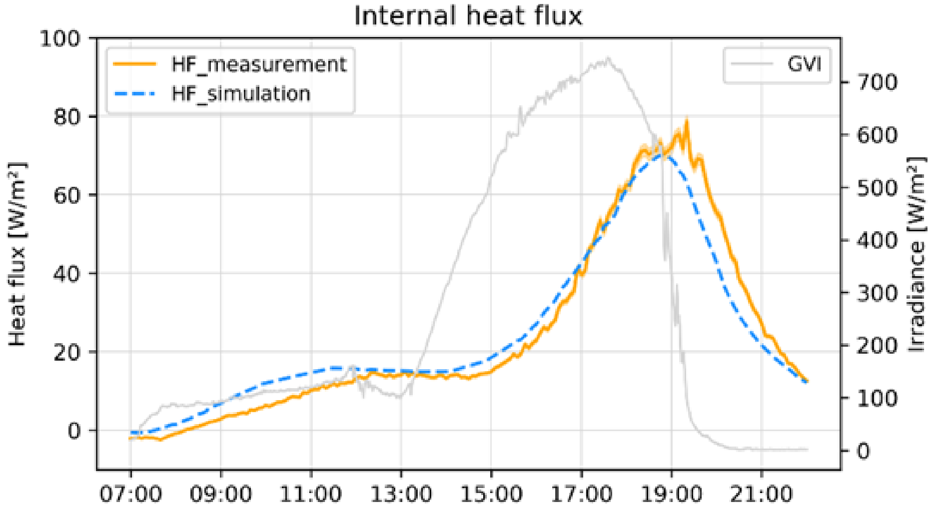


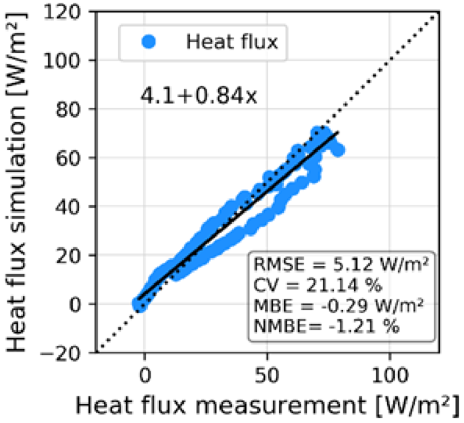


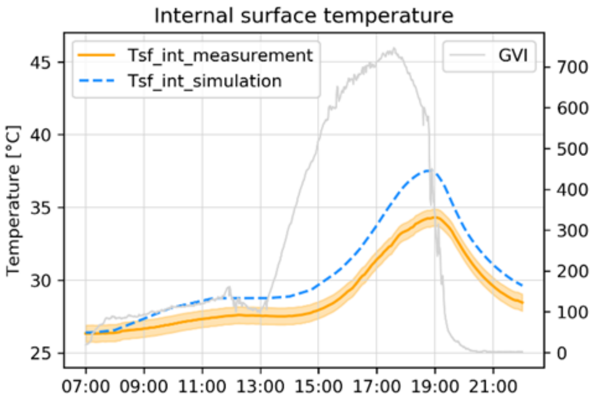


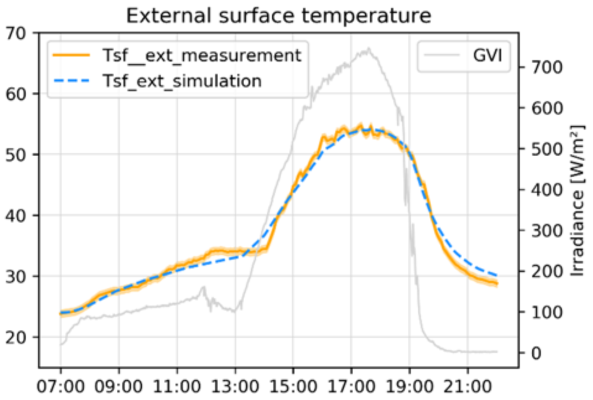
- Overall a **good performance** of the model, especially for heat flux and external surface temperature
- Overestimated heat flux in the first part of the day (+3.5W/m²); underestimated HF in the second part of the day (-6.9W/m²)
- **Poorer accuracy** for the **internal surface temperature**; model overreports the temperature (RMSE = 2.14°C) -> T_{sf_int} very sensitive to **convective heat transfer** coefficent (could be improved)
- Dynamic behaviour is well represented by the model (time lag of more than 2 hours between irradiance and heat flux) -> **thermal inertia** of the fenestration system

Results – Blinds at 37°



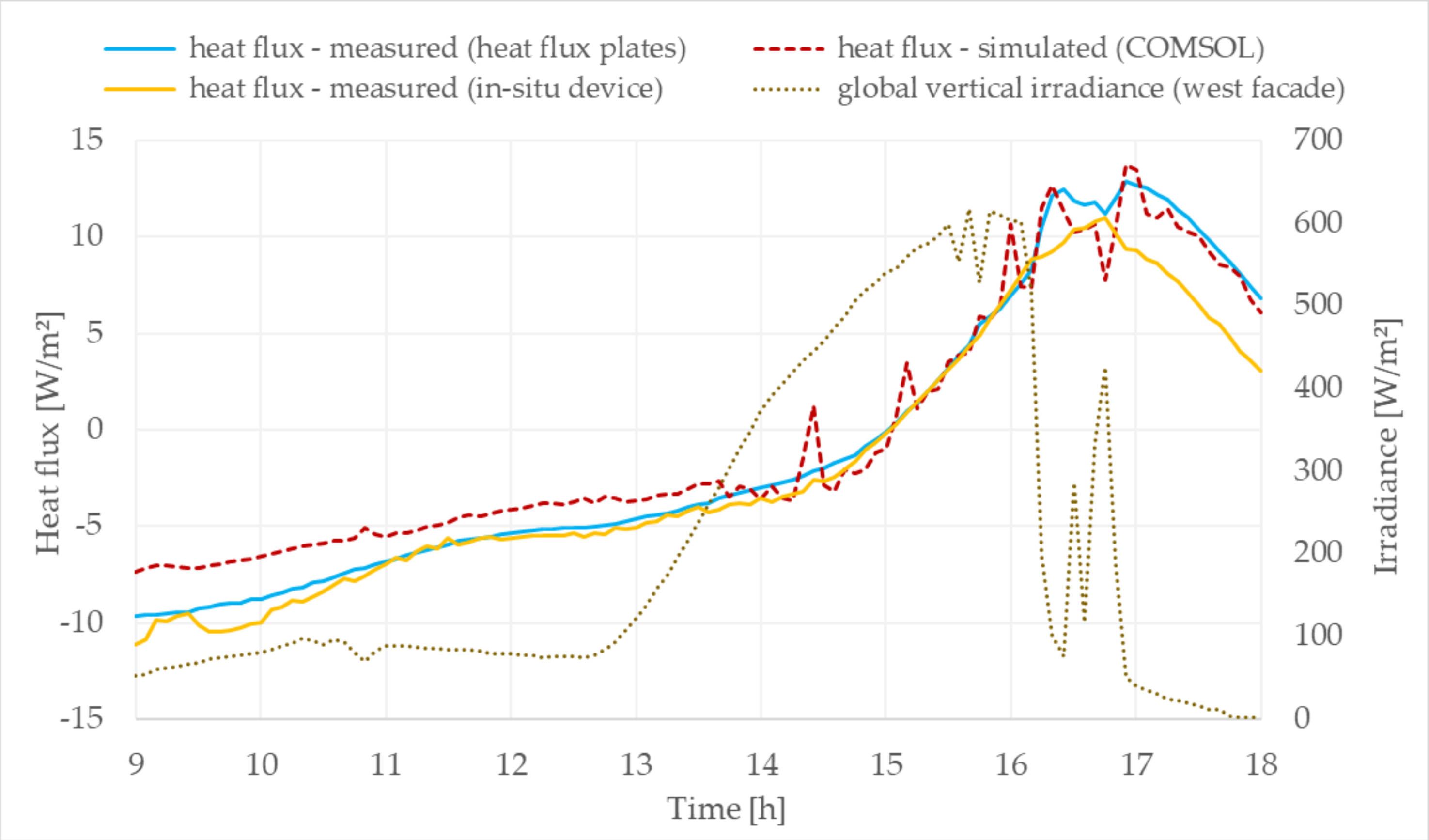






- Overall a **good performance** of the model, especially for heat flux and external surface temperature
- Overestimated **heat flux** in the first part of the day (+3.0W/m²); underestimated HF in the second part of the day (-5.1W/m²)
- **Poorer accuracy** for the **internal surface temperature**; model overreports the temperature (RMSE = 1.75°C) -> T_{sf_int} very sensitive to **convective heat transfer** coefficent (could be improved)
- Dynamic behaviour is well represented by the model (time lag 2.5 hours between irradiance and heat flux) -> **thermal inertia** of the fenestration system

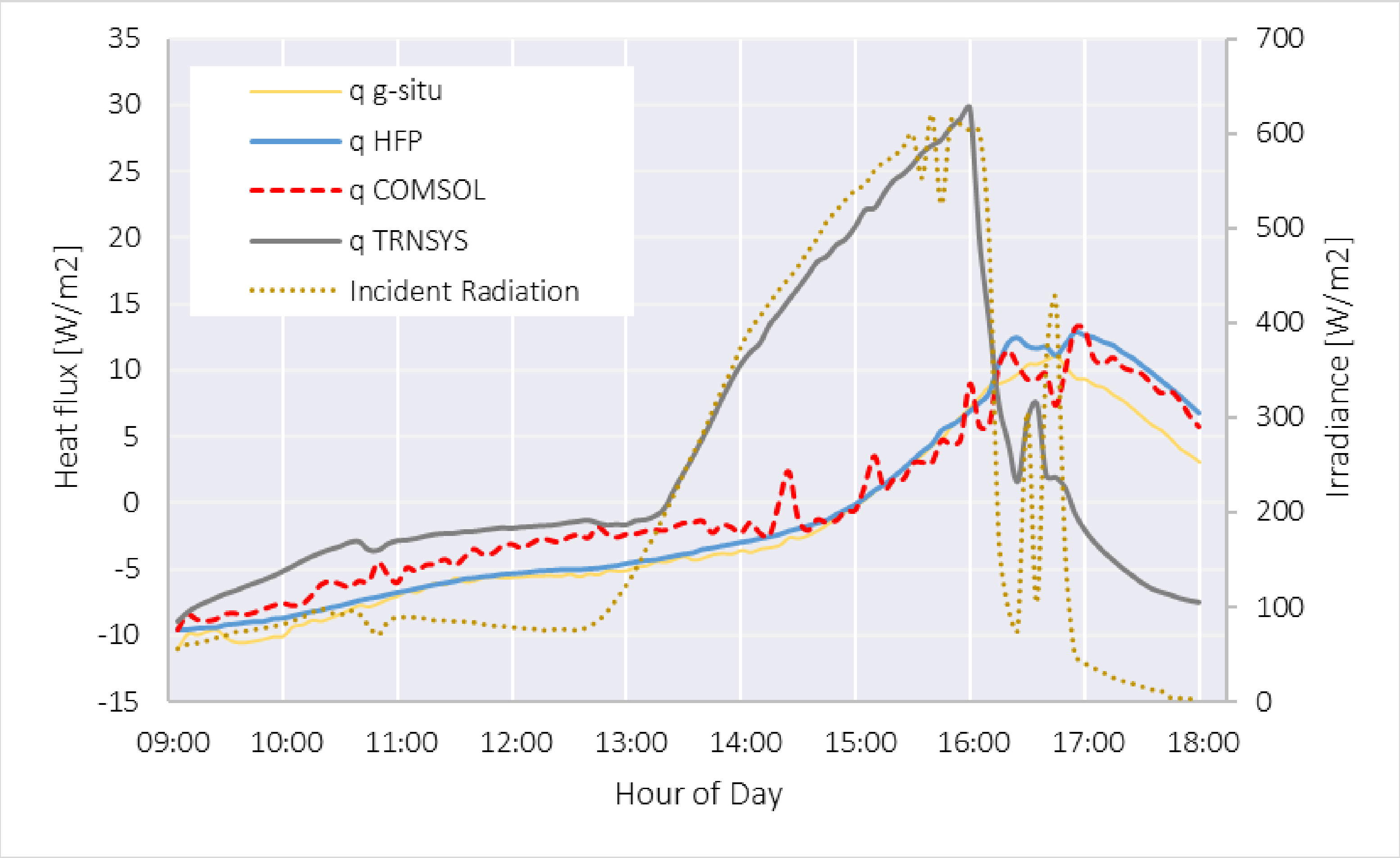
Results – Blinds at 75°



- Results from a previous study [1]
- Overall a **good performance** of the model, also for the closed blind configuration (very low solar transmission)
- RMSE = 1.45 W/m² (for heat flux measured with heat flux plates)
- Dynamic behaviour is well represented by the model (time lag 2.5 hours between irradiance and heat flux) -> **thermal inertia** of the fenestration system

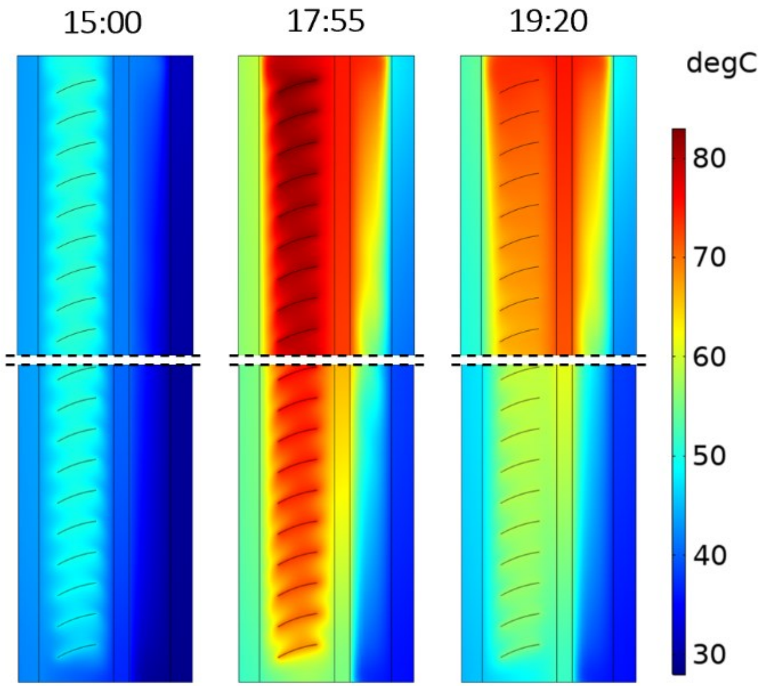
[1] I. Demanega, G. De Michele, M. Hauer, S. Avesani, G. Pernigotto, A. Gasparella, Numerical and experimental characterization of the thermal behavior of complex fenestrations systems under dynamic conditions, Build. Simulat. Appl. (2020) 109–116, 2020-June.

Results – Blinds at 75° - Comparison with TRNSYS

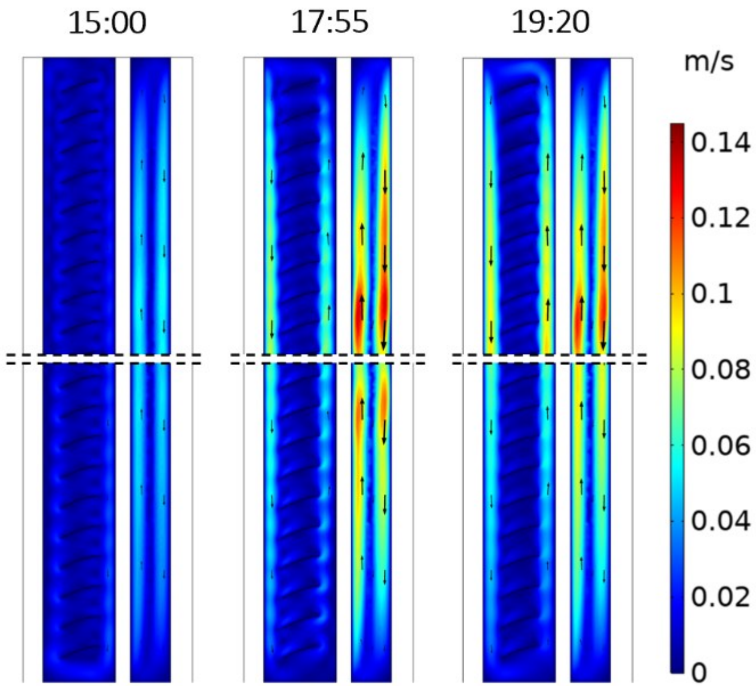


While TRNSYS (based on ISO15099) is not able to properly chatch the trend of the secondary heat fluxes, this dynamic behaviour is well represented by the COMSOL+RADIANCE model.

Results – Temperature and velocity distribution



Temperature distribution
CFS with blinds 18° - 04/08



Velocity distribution
CFS with blinds 18° - 04/08

- Peak temperatures of **more than 80°C** in the upper part of the external window cavity
- High temperatures maintained for **several hours**
- **Air circulation** inside cavities: upwards flow along the central glass pane (warmest part) and downwards flow along the external and internal glass pane (coldest part)

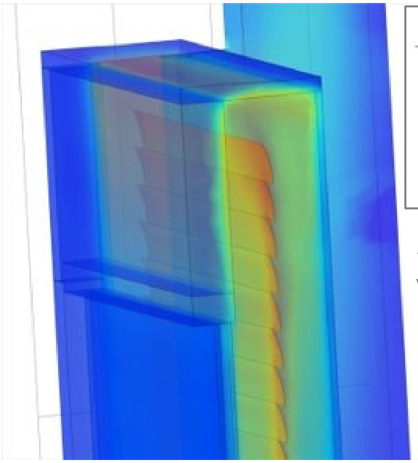
Conclusions

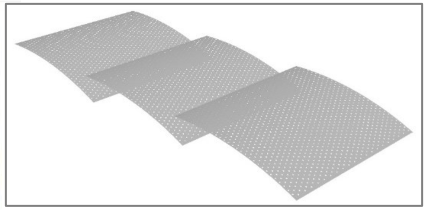
- The **decoupled modelling** approach for the **optical calculation** and **thermo-fluiddynamics** is a valid modelling approach for CFS. It allows to combine a detailed optical calculation with a detailed heat transfer and fluid flow simulation in an **efficient** and **accurate** way.

- This modelling approach is relevant, because it allows to assess the **spatial temperature and velocity** distribution and quantify **extreme temperature values** (crucial for some kinds of fenestration systems, especially with integrated shading systems, to **adequately design** the involved materials, such as sealing materials, glass inter-layer PVB and electronic components).

- It allows to appraise the **dynamic behaviour** of fenestration systems: important for a correct design of the HVAC system.

Application of the methodology





3D geometry of the perforated venetian blinds

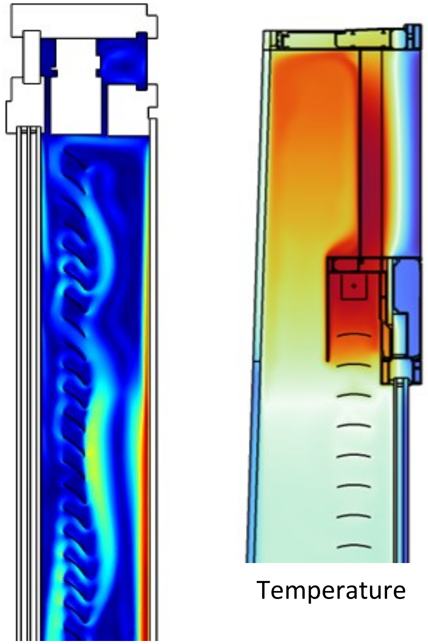
CFD + **optical modelling** of a naturally ventilated Double Skin Façade with integrated perforated venetian blinds

Condensation risk analysis in a naturally ventilated cavity of a Double Skin Façade through coupled **CFD**, **heat** and **moisture** transfer simulation

Relative humidity

Liquid water concentration

https://www.focchi.it/it/progetti/paddington-square



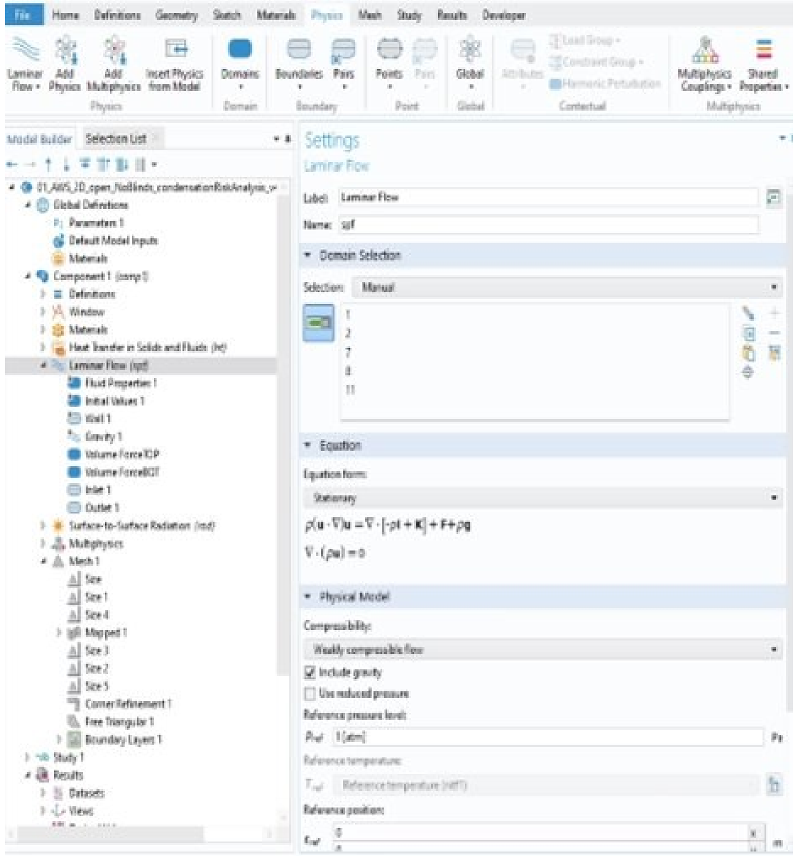
Air velocity

Temperature

CFD + **optical modelling** of different kinds of open and closed DSF

Application of the methodology

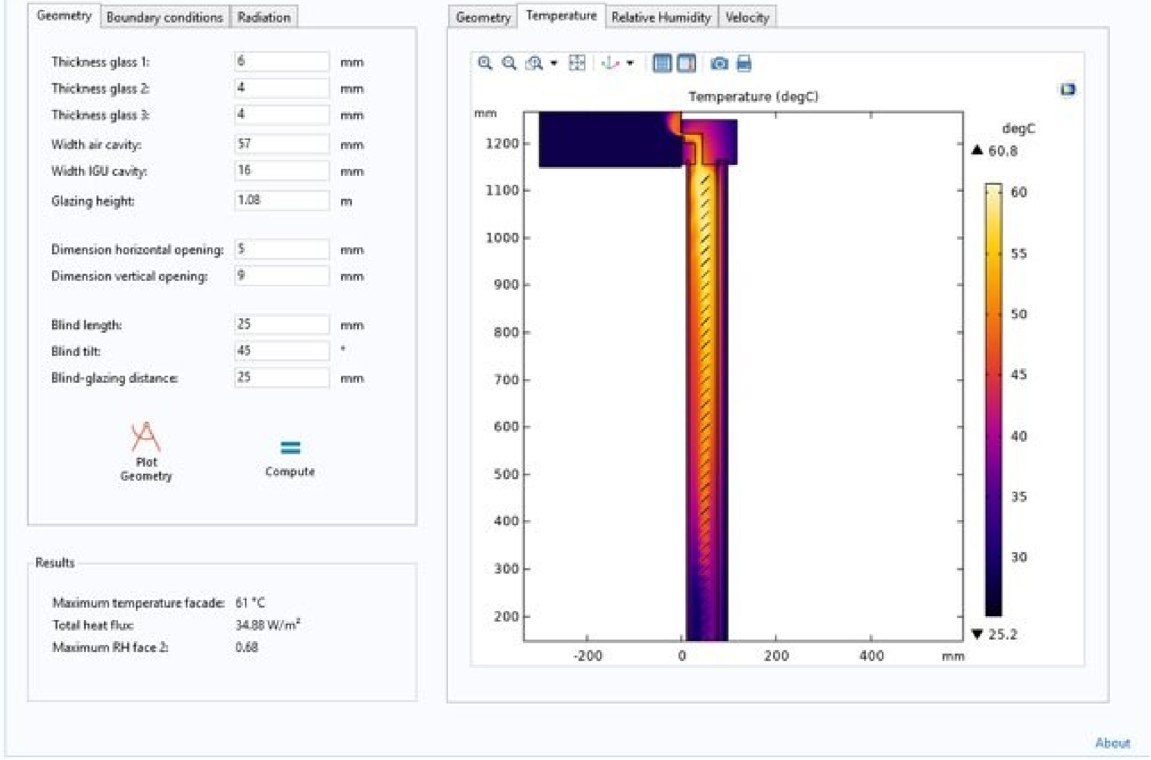
TOOL WITH SIMPLIFIED USER INTERFACE FOR CFD MODELING OF DOUBLE SKIN FACADES



Standard CFD setup interface

Simplified input mask
Parametric geometry

Detailed results



Tool with simplified user interface

Thank you for your attention

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Development and experimental validation of a CFD model for the thermal behaviour assessment of Complex Fenestration Systems

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