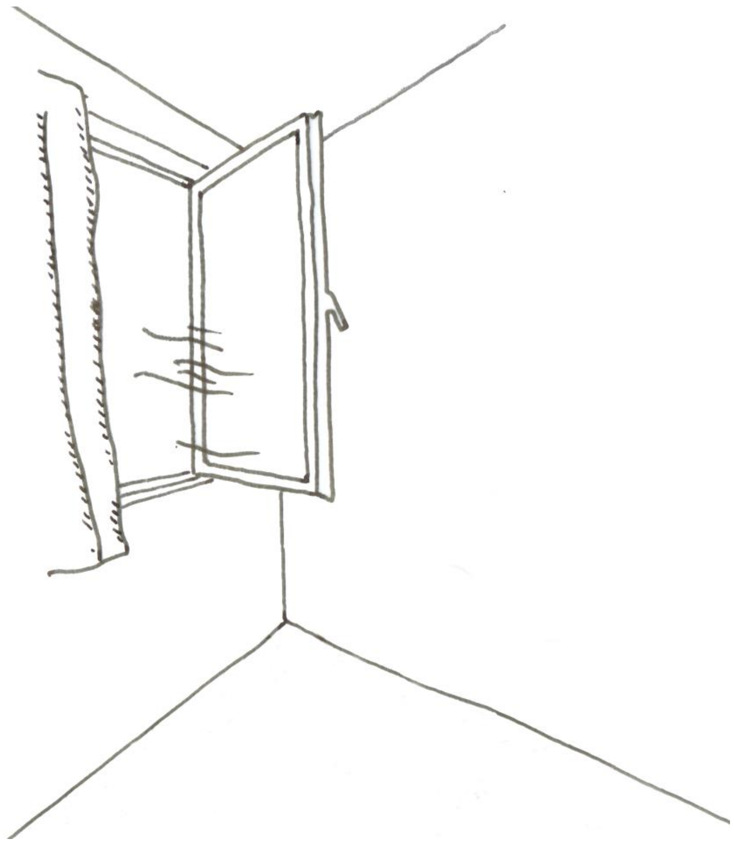
SENSITIVITY OF NIGHT COOLING PERFORMANCE TO ROOM/SYSTEM DESIGN: SURROGATE MODELS BASED ON CFD

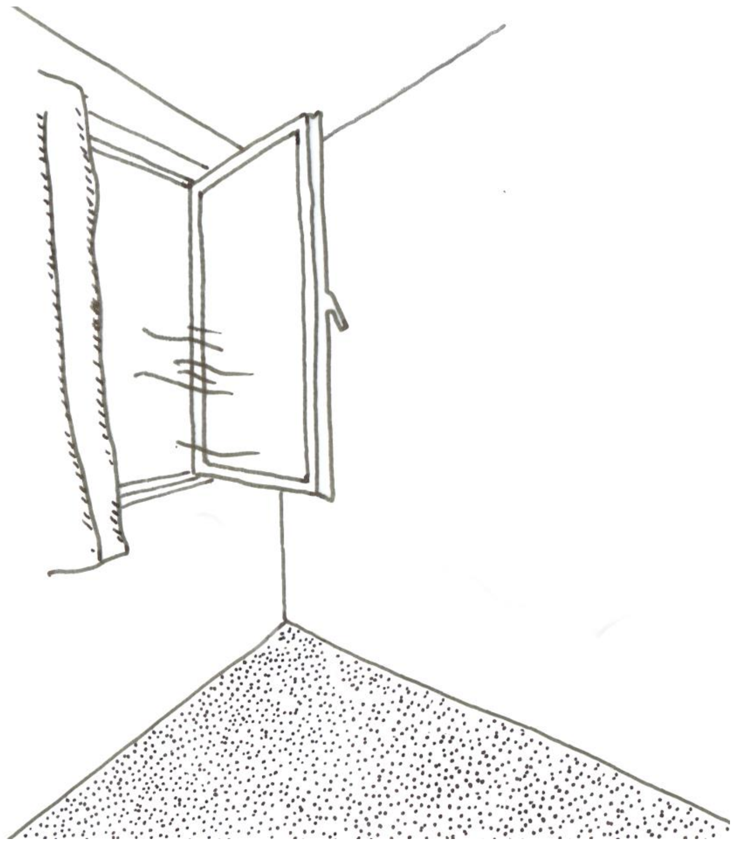
Kim Goethals and Arnold Janssens
Laboratory of Building Physics, Construction and Services

Three basic elements of night cooling

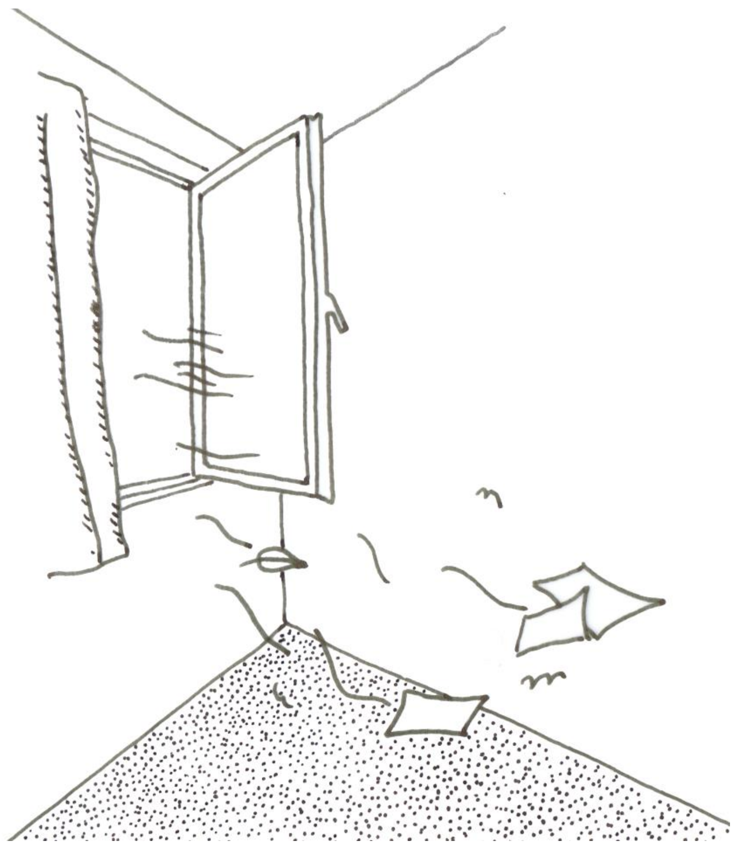


Supply of cool air

Three basic elements of night cooling



Three basic elements of night cooling



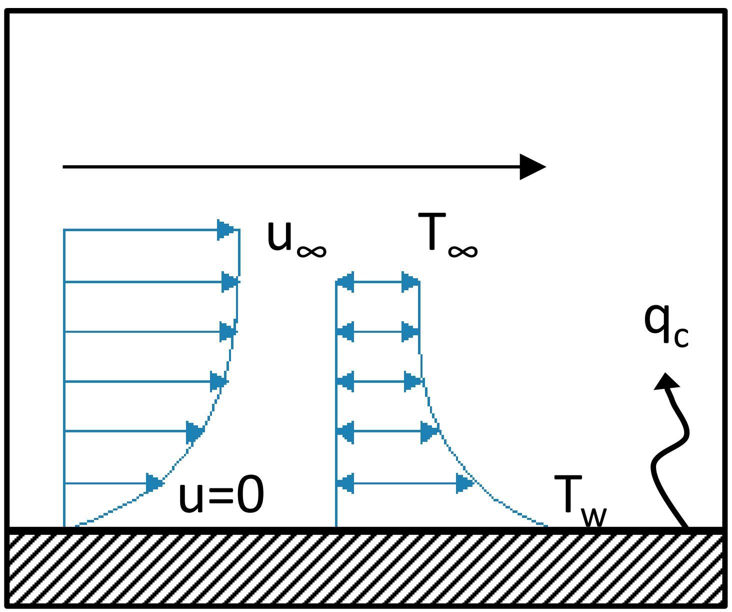
Supply of cool air

Heat transfer

Heat storage

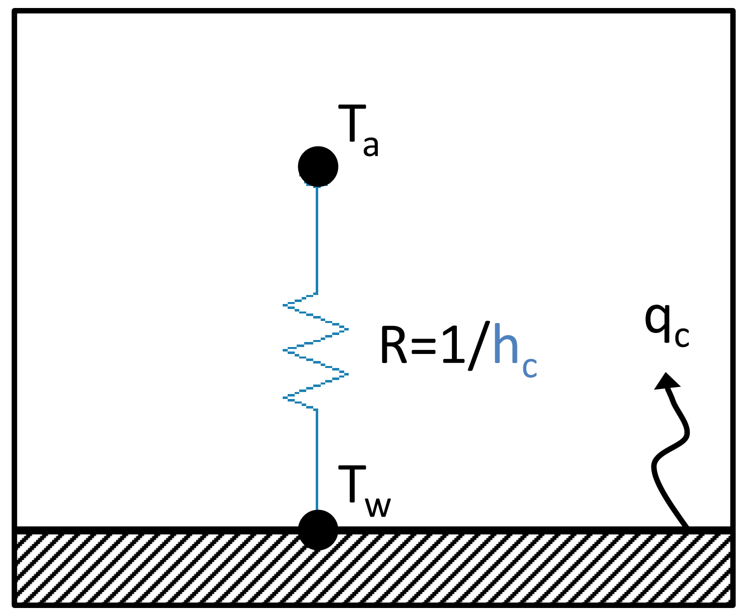
Convective heat transfer in…

… reality



$q_c = \ldots$

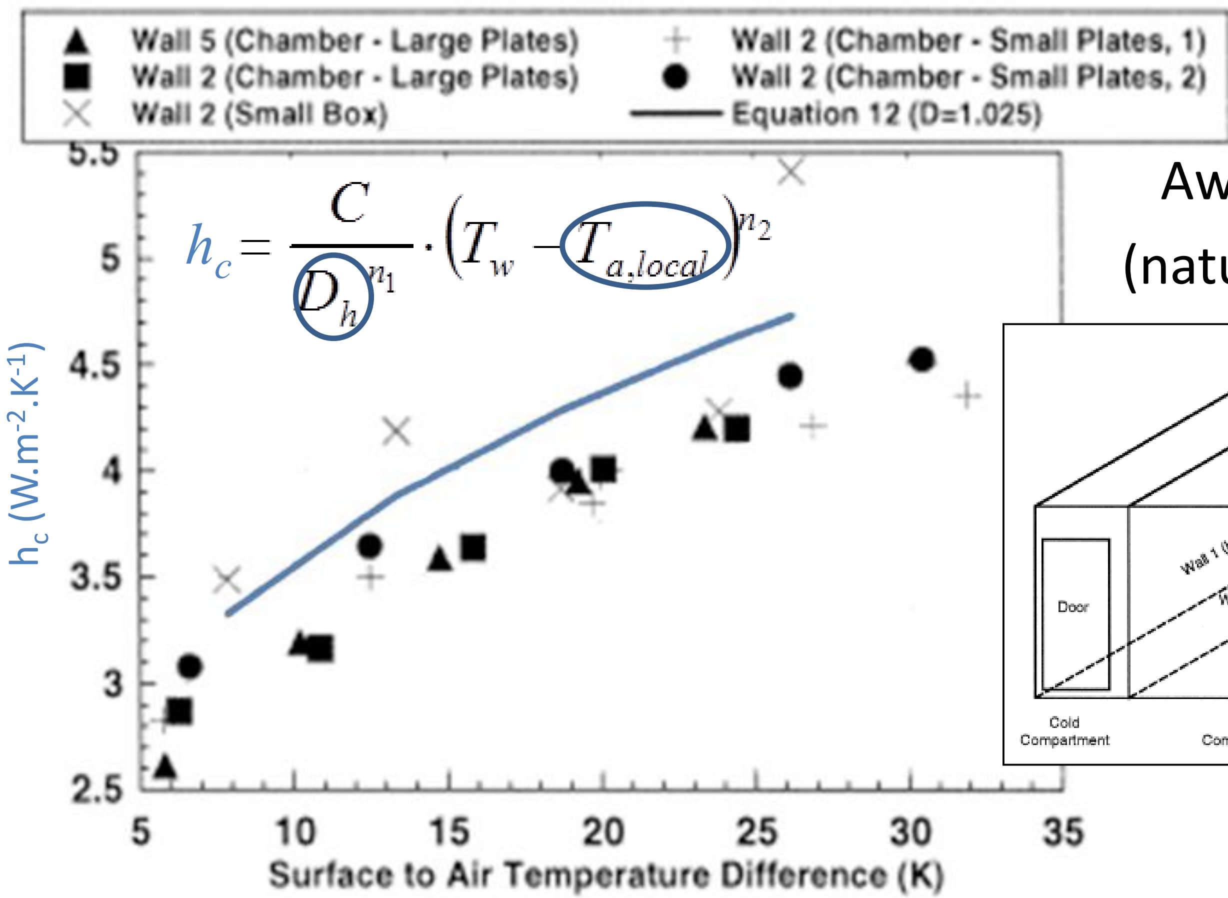
… Building Energy Simulation (BES)



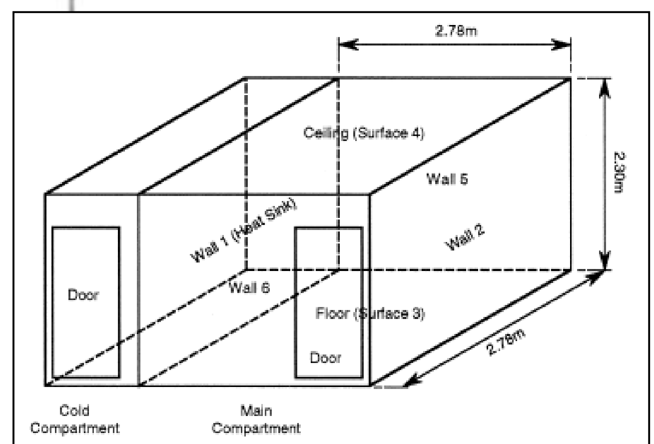
$q_c = h_c \cdot (T_w - T_a)$ (correlations)

natural/forced/mixed • laminar/turbulent • surface location, surface orientation…

Correlations are case-specific



Awbi and Hatton
(natural convection)



Is the current BES approach sufficient to model night cooling? No!

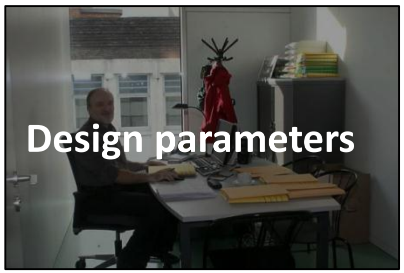
Part 1: Importance of the choice of correlation (BES)

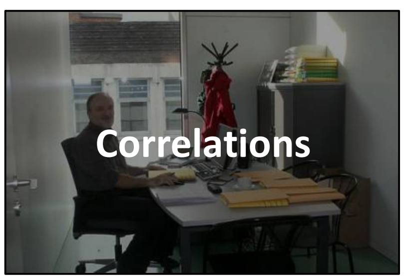
Part 2: Applicability of current correlations (experiments)

What possibly is a proper way? BES + CFD-based surrogate models!

Part 3: Methodology to derive CFD-based surrogate models

Importance of choice of correlations?





BES

Overheating risk

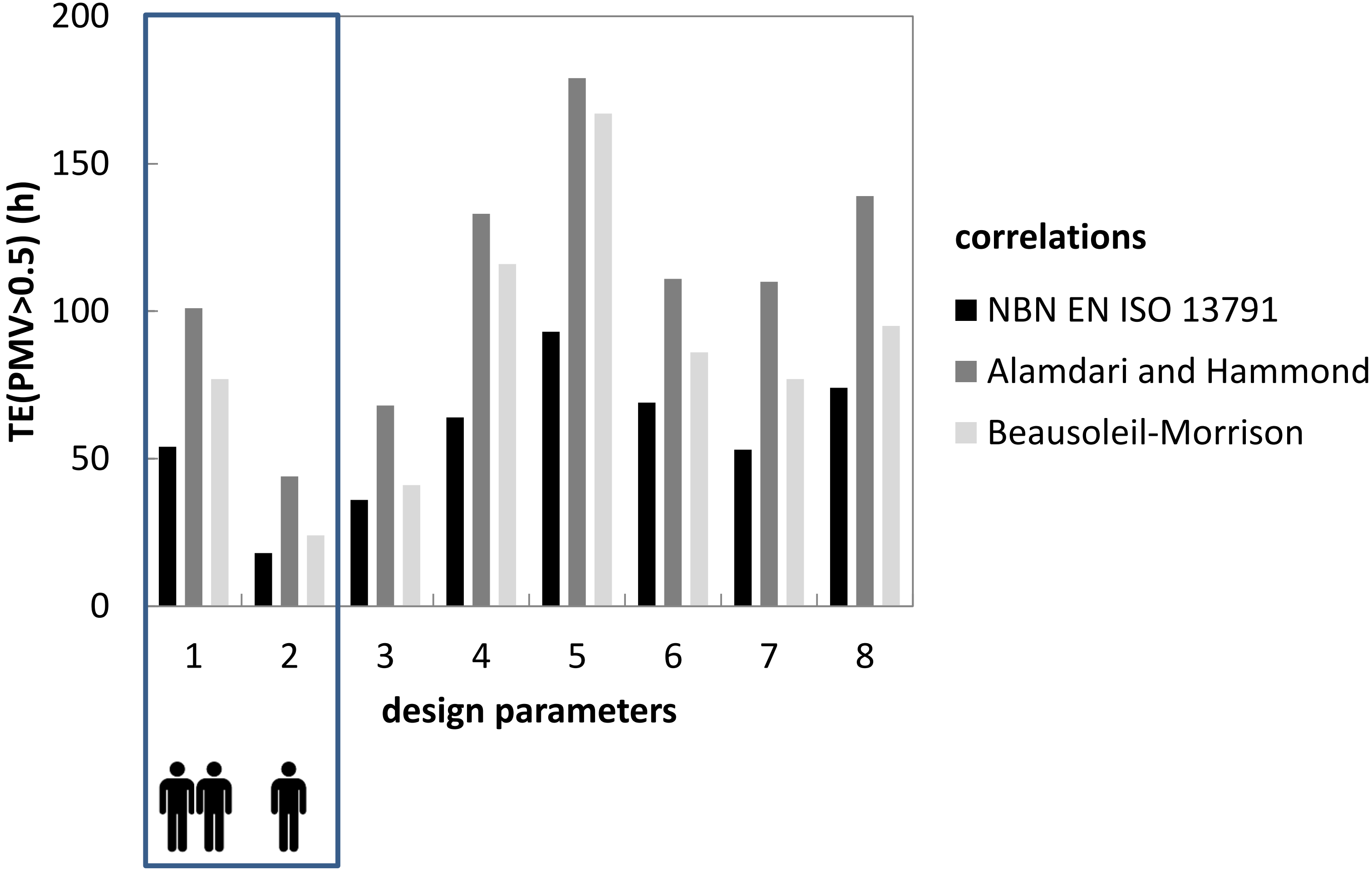
Saved cooling demand

Operation time

(Part 1)

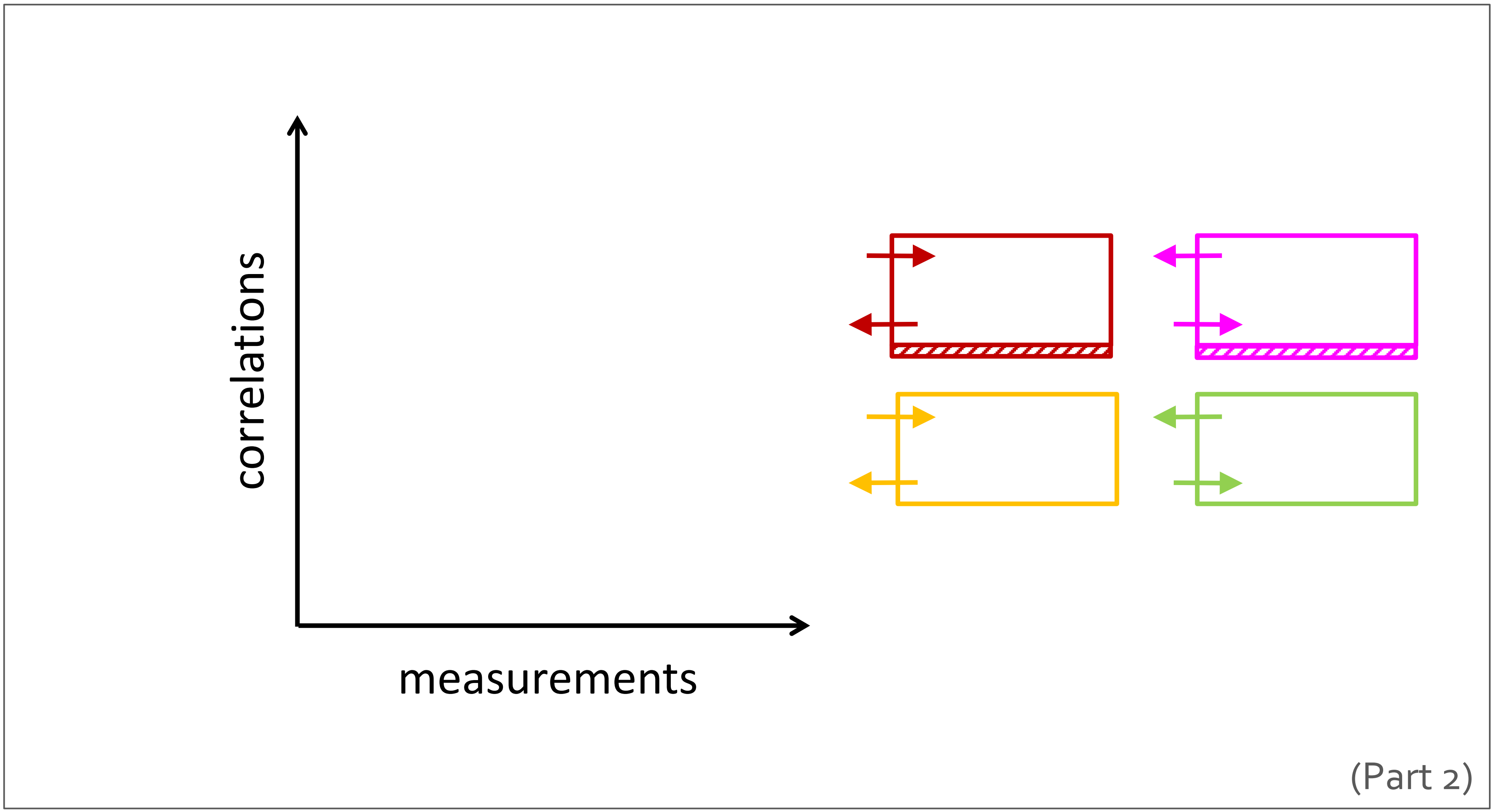
Ufo (Ghent, Belgium)

Impact of the choice of correlation



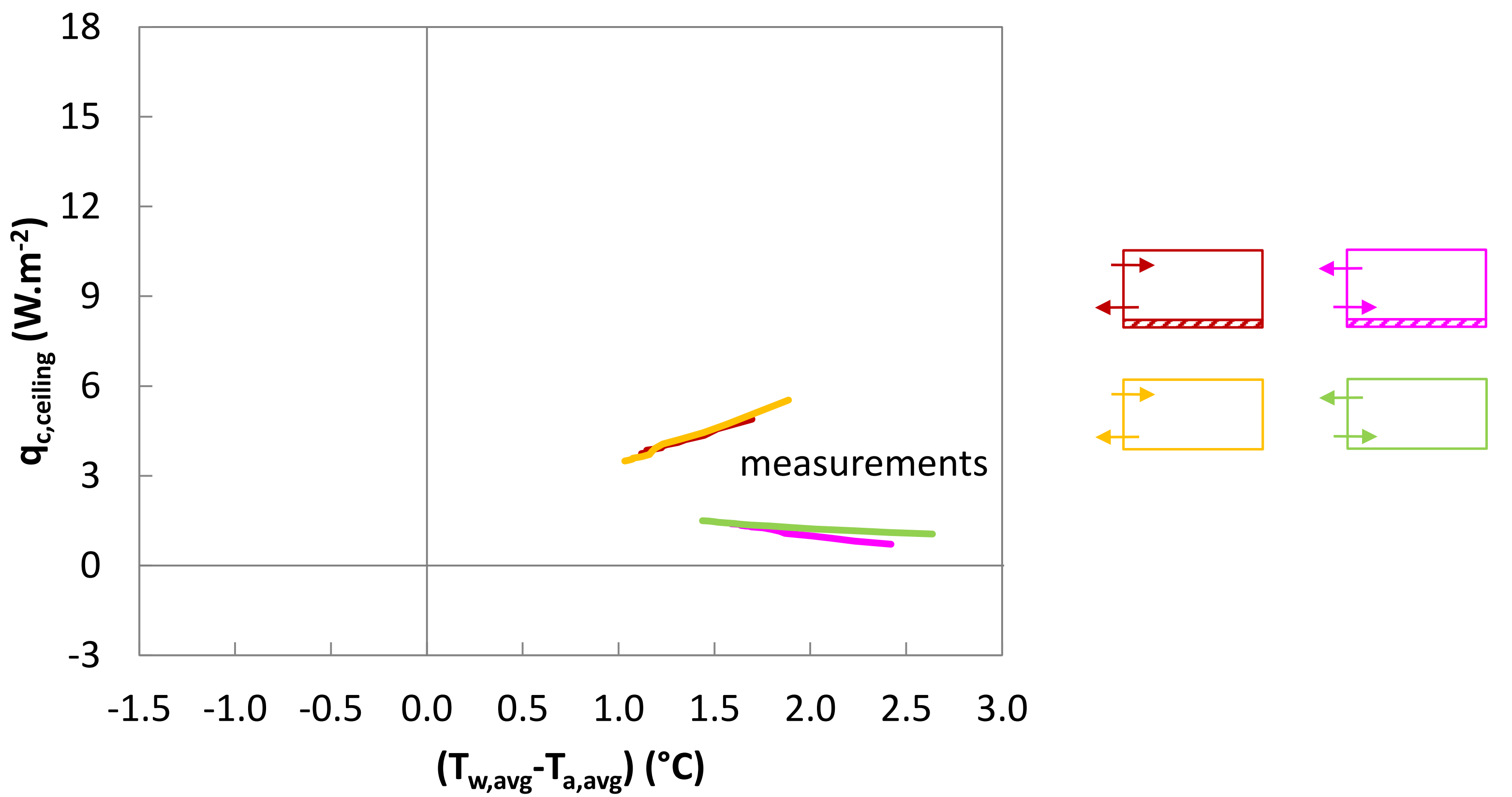
Is convective heat transfer modelling of minor importance? No!

Applicability of current correlations?

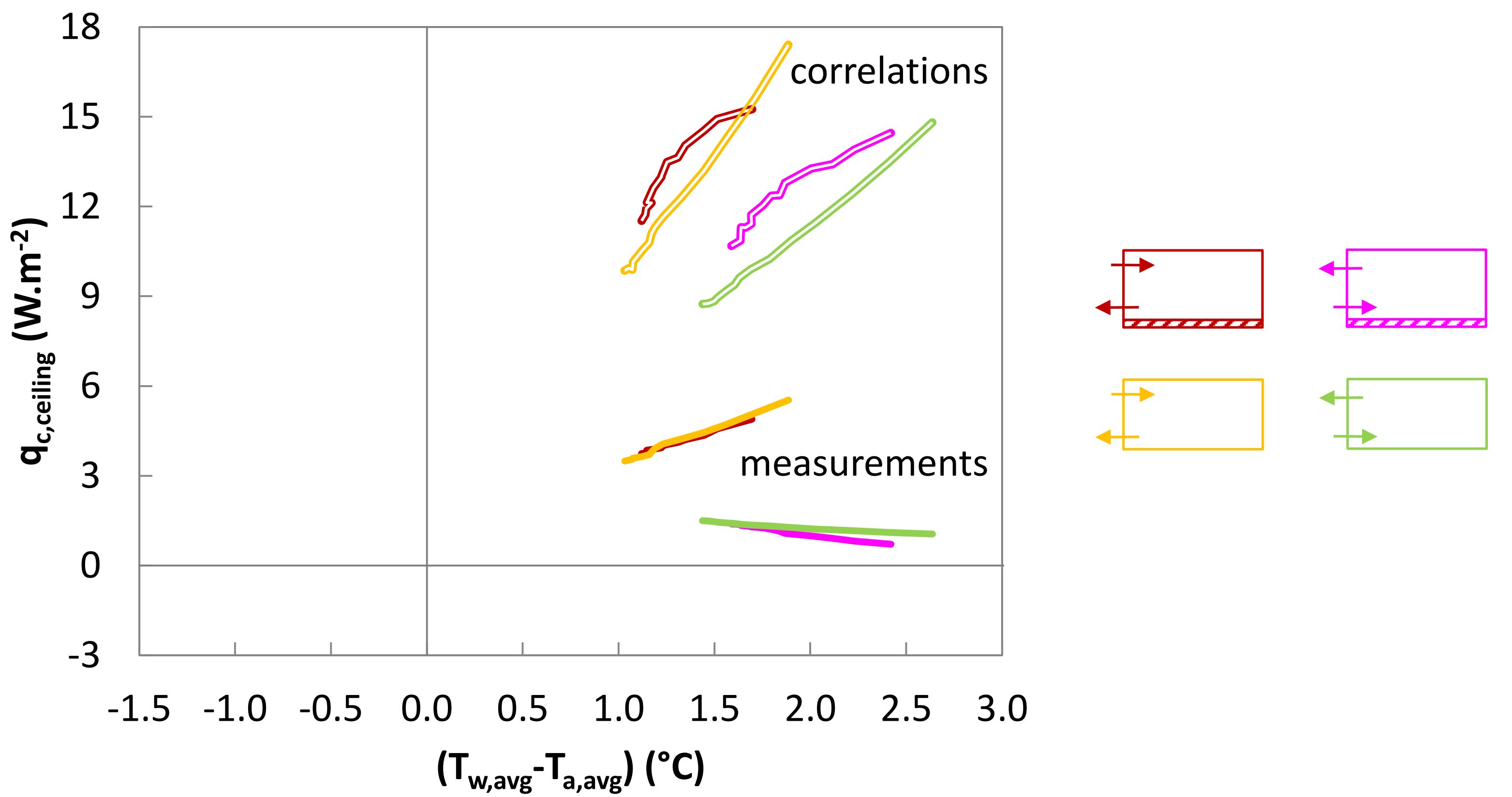


PASLINK (Limelette, Belgium)

Comparison to correlations



Comparison to correlations



Are the currently available convection correlations always usable? No!

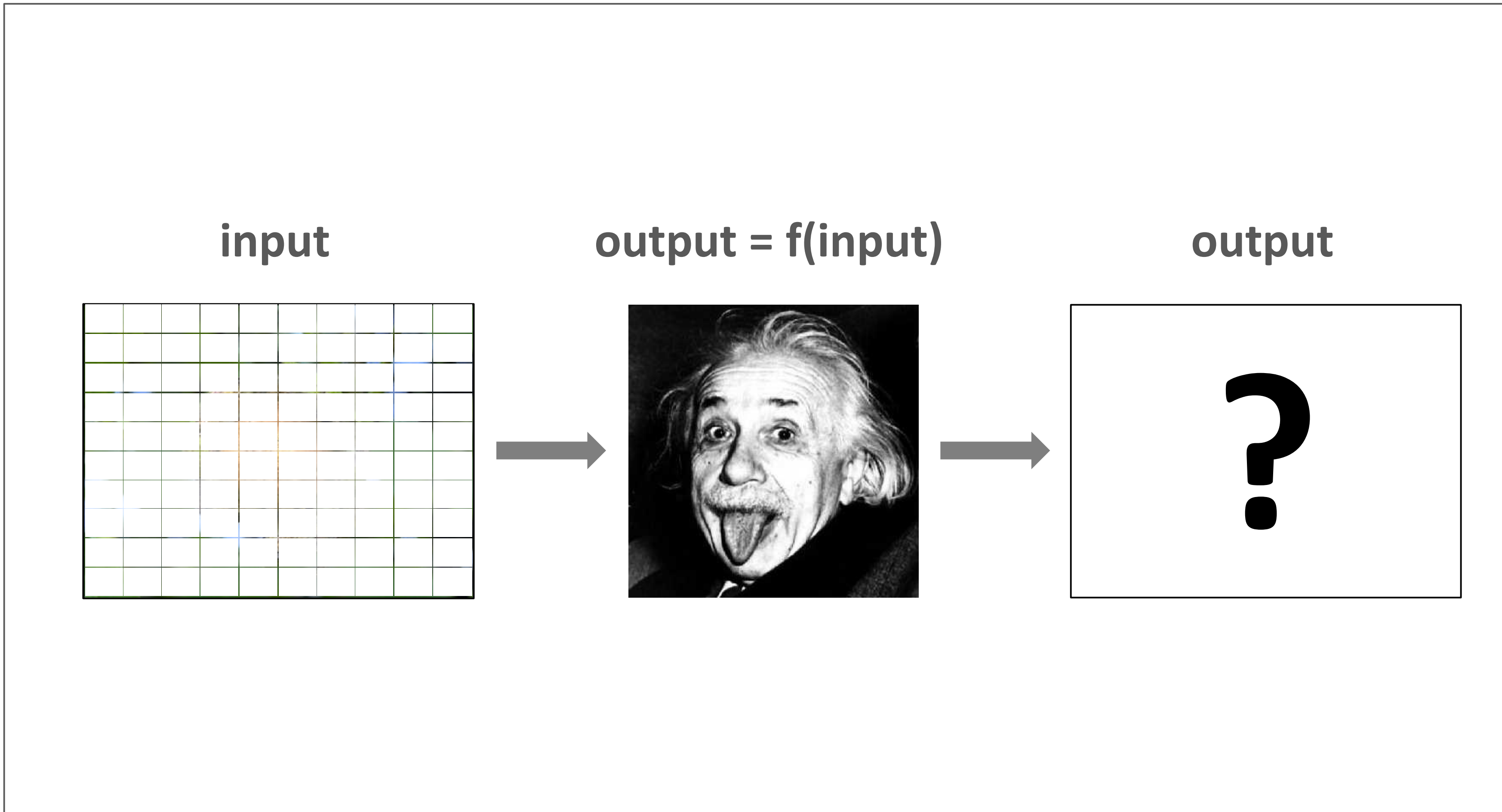
- BES + more empirical correlations

- [ ] BES + more empirical correlations

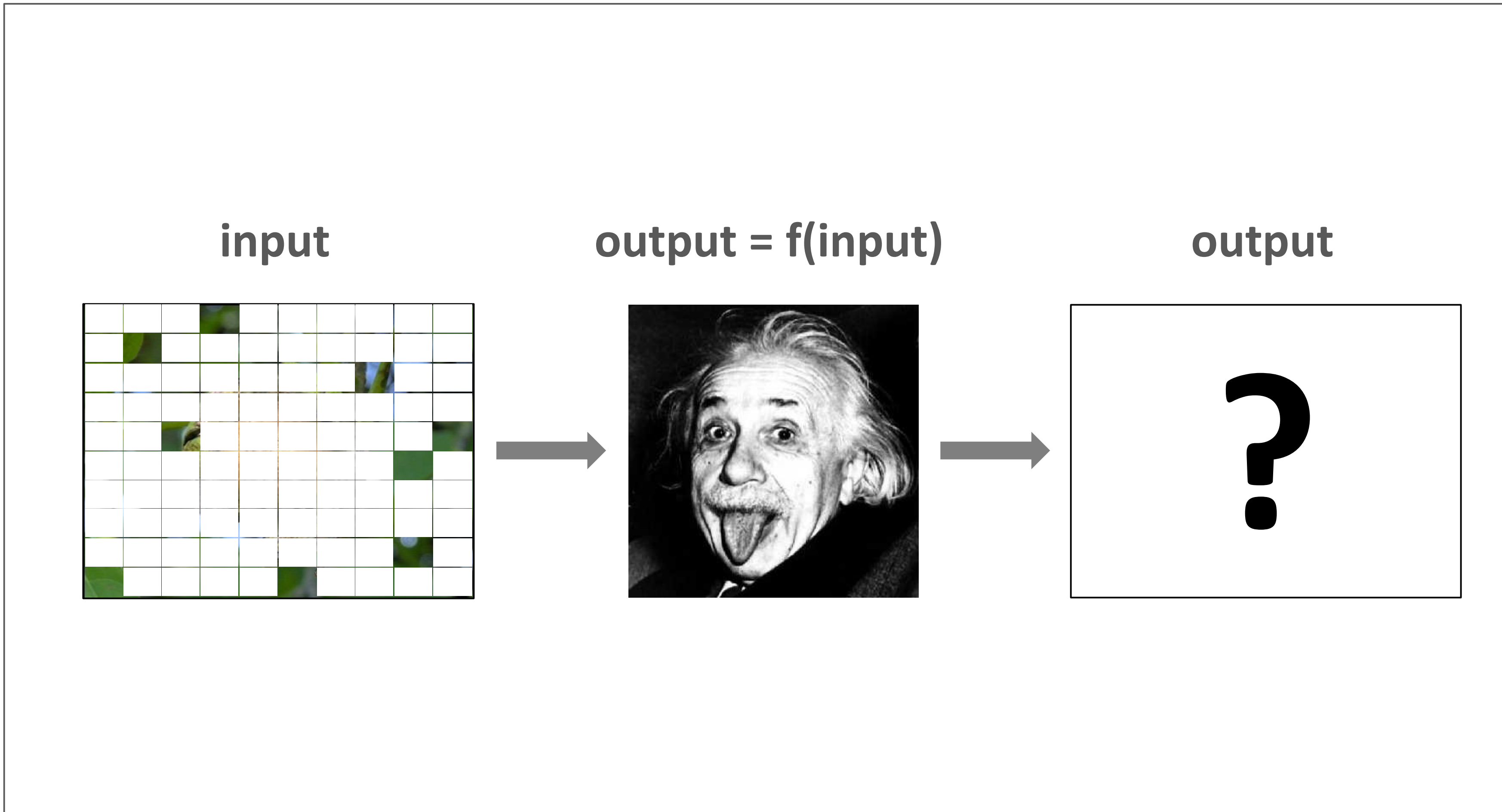
- [ ] BES + CFD

- [ ] BES + more empirical correlations
- [ ] BES + CFD
- [x] BES + CFD-based surrogate models

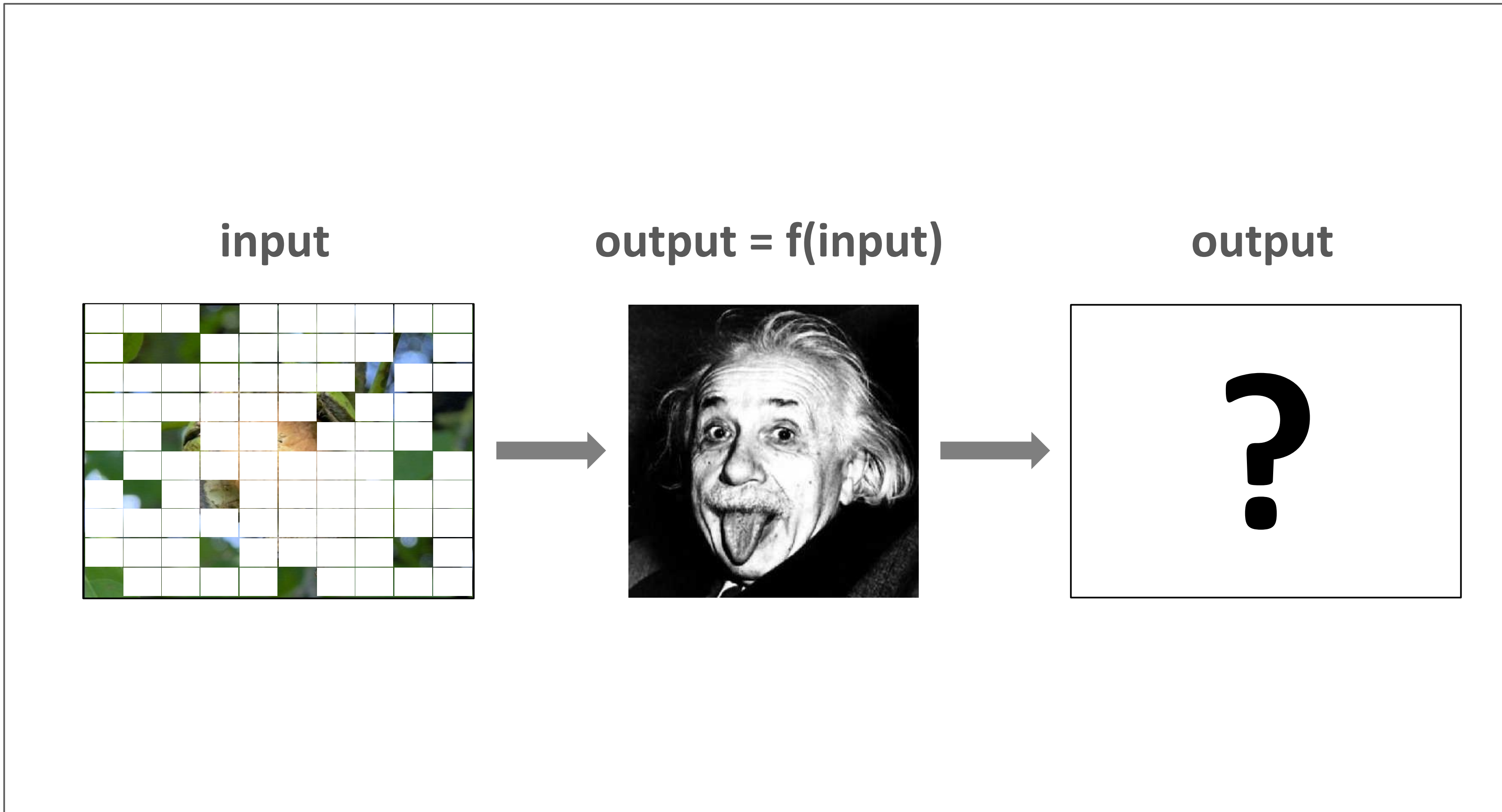
Methodology to derive
CFD-based surrogate models?



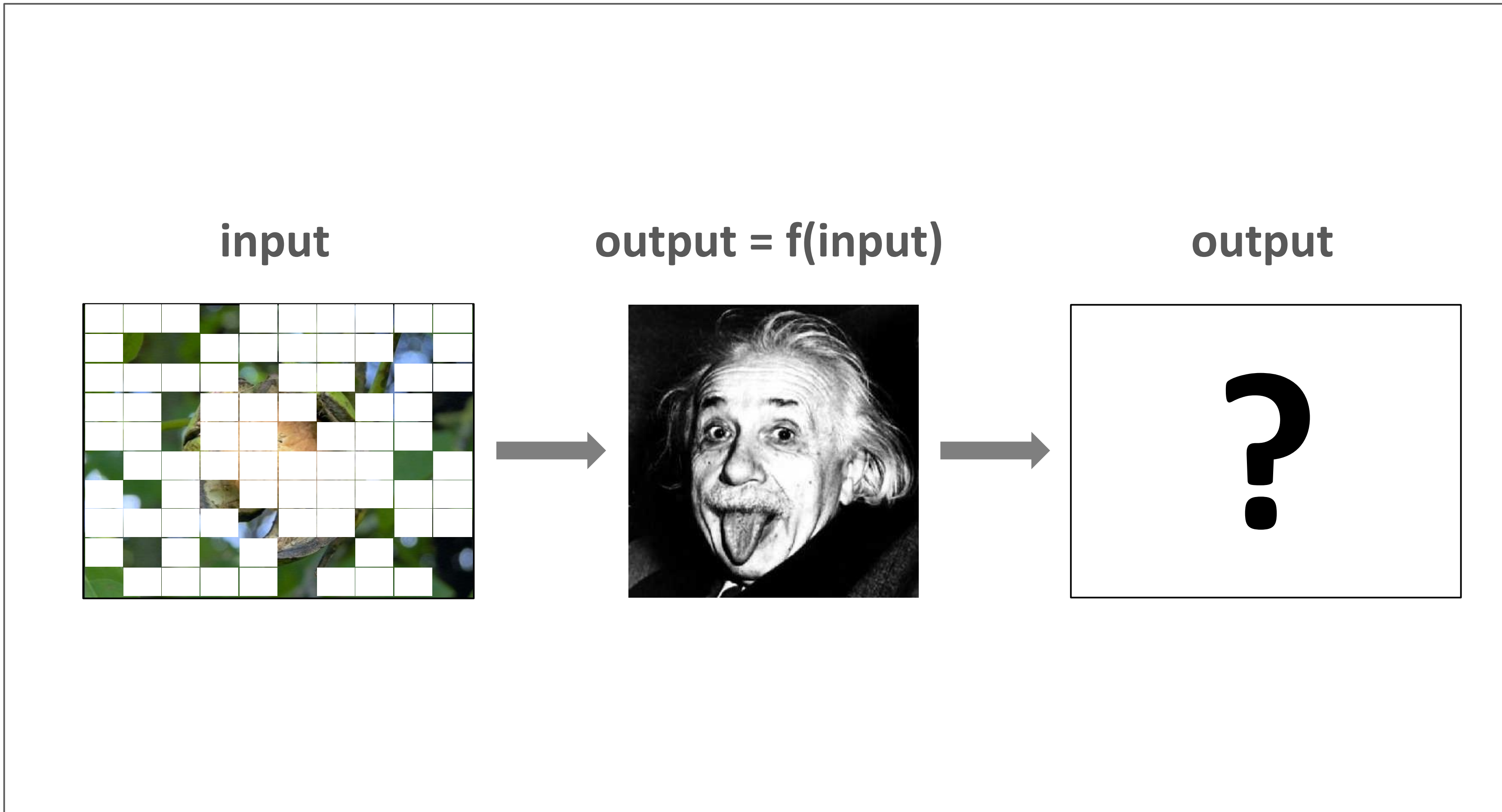
Methodology to derive CFD-based surrogate models?



Methodology to derive CFD-based surrogate models?

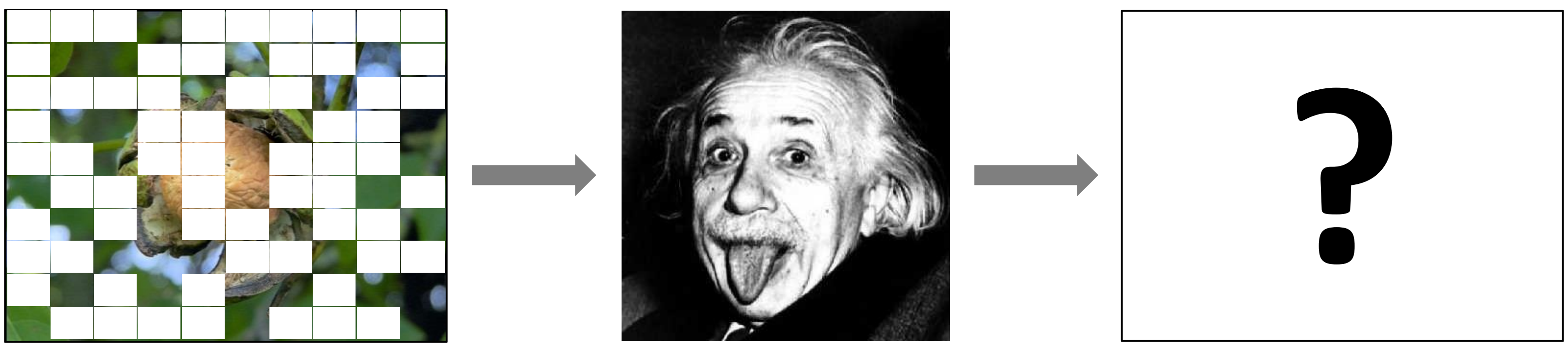


Methodology to derive CFD-based surrogate models?

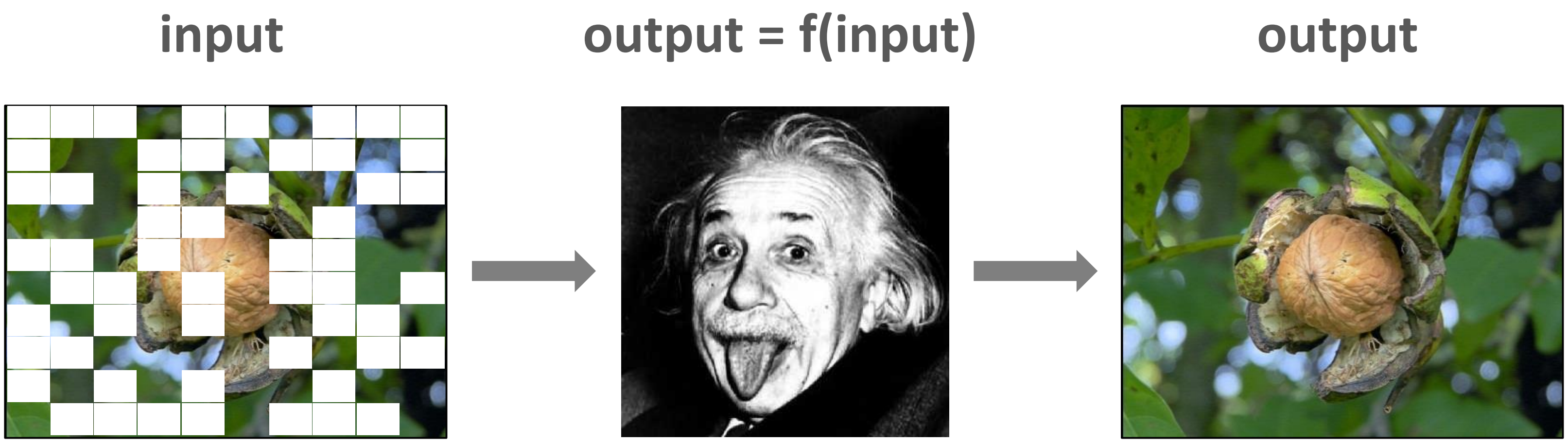


Methodology to derive CFD-based surrogate models?

input | output = f(input) | output



Methodology to derive CFD-based surrogate models?

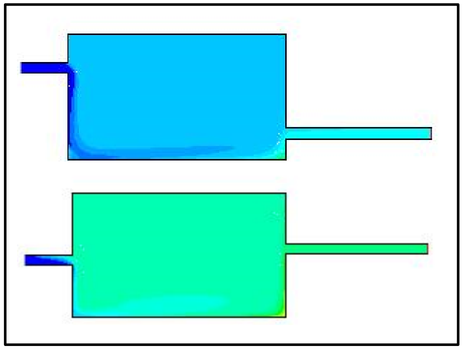


Methodology to derive CFD-based surrogate models?

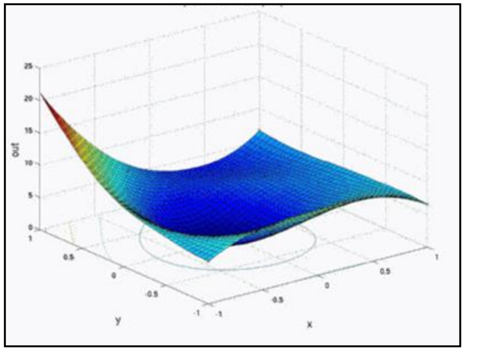
input

output = f(input)

output



SUMO



(Part 3)

Pilot study on night cooled landscape office

Night cooling in offices	Usually in oblong landscape offices Often line-shaped diffusers/band windows So, roughly speaking, 2-D airflow
Design parameters	Ventilation concept Mass distribution Geometry Driving force for convective heat transfer

Stirring up the Annex 20 2-D case

cfd-benchmarks.com

Two-dimensional benchmark test | Computer simulated person air quality | Computer simulated person thermal comfort | Computer simulated person Personalized ventilation

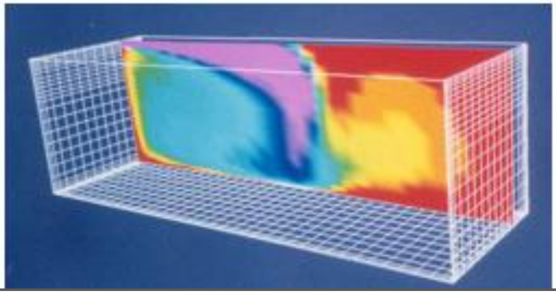
Links

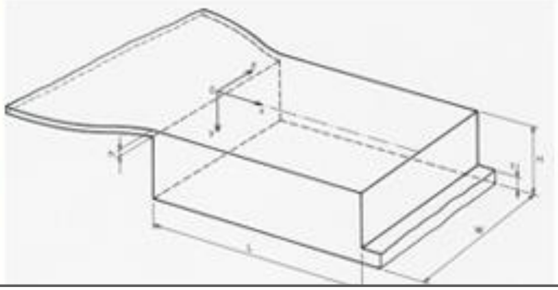
- The benchmark test
- Selected literature

Two-dimensional benchmark test

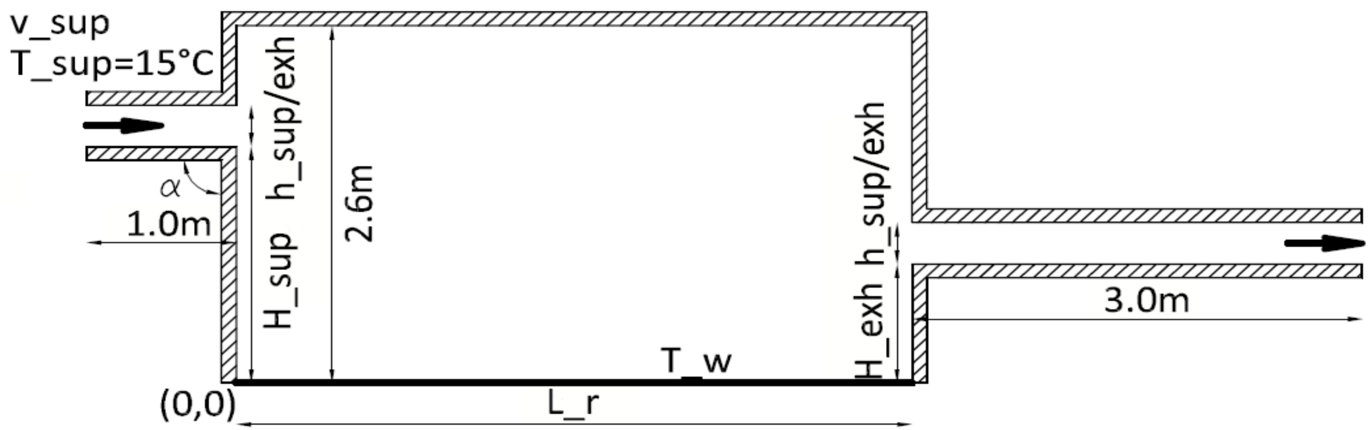
The two-dimensional benchmark test, also called the "IEA 2D test case" was defined in 1990 to be used in the IEA Annex 20 work, but there have been a very large number of papers that use this geometry in other CFD work.

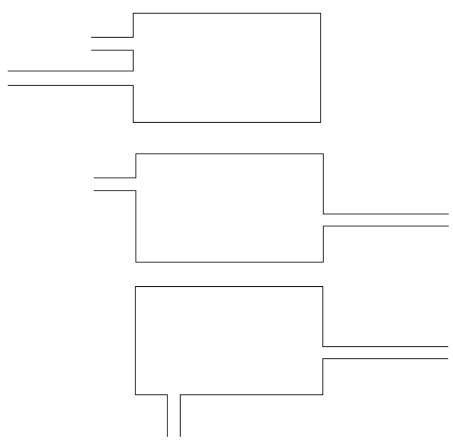
We believe that it is attractive to a new user to stick to a geometry used by a number of other researchers. It is possible to compare the results with other authors' results (other turbulence models, other numerical schemes, etc.). The basic knowledge behind the benchmark test has thus expanded during the years and made the test case more useful.





Parameterizing Annex 20 2-D case

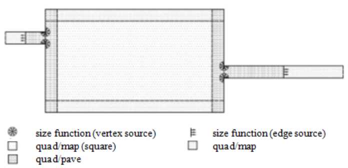




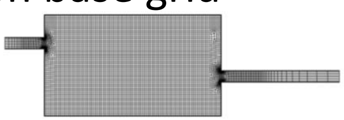
Parameter	Type	Min	Max
-	Ventilation concept	Single-sided/cross/under floor	
-	Mass distribution	Floor/ceiling	
L_r (m)	Geometry	4.5	9
H_{sup} (m)		0+BL	2.6-BL (L_r-0.5m)
H_{exh} (m)		0+BL	2.6-BL
$h_{sup/exh}$ (m)		0.1	0.5
α (°)		60	120
n (h^{-1})	Driving force	1.5	10
T_w (°C)		16	25

Gambit + Fluent + SUMO = surrogate model

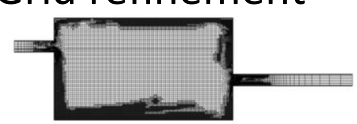
Controlled by Matlab (fully automated)



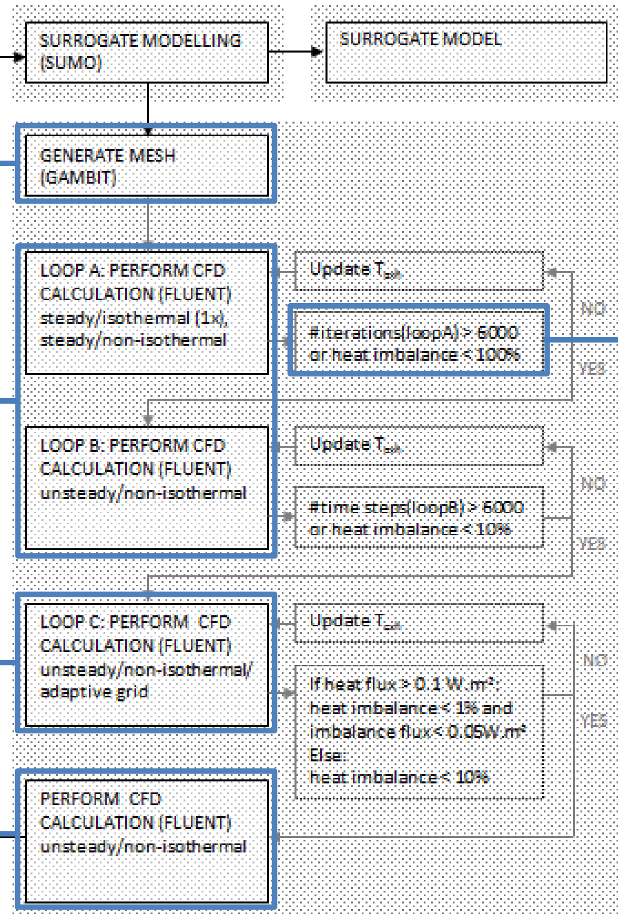
Estimate airflow on base grid

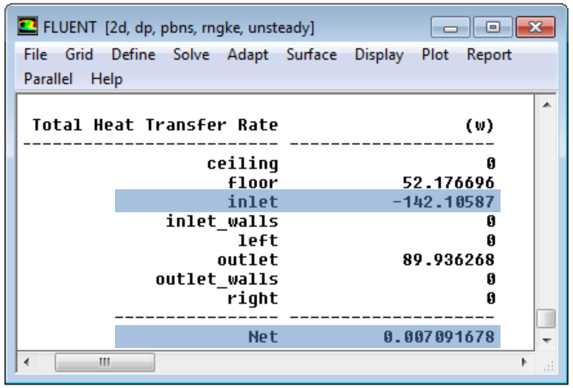


Grid refinement



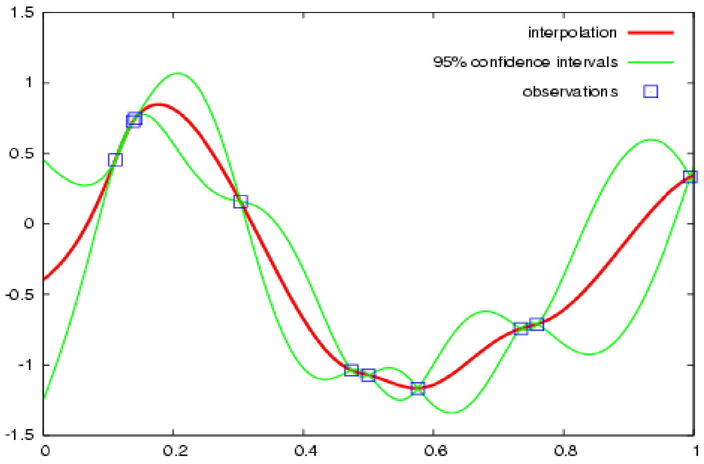
Calculate average convective heat flux



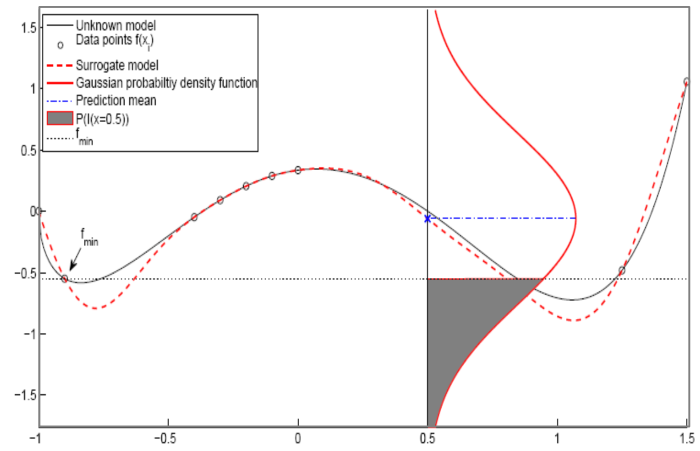


! Monitoring residuals and quantities is contestable

SUMO: global Surrogate-Based Optimization

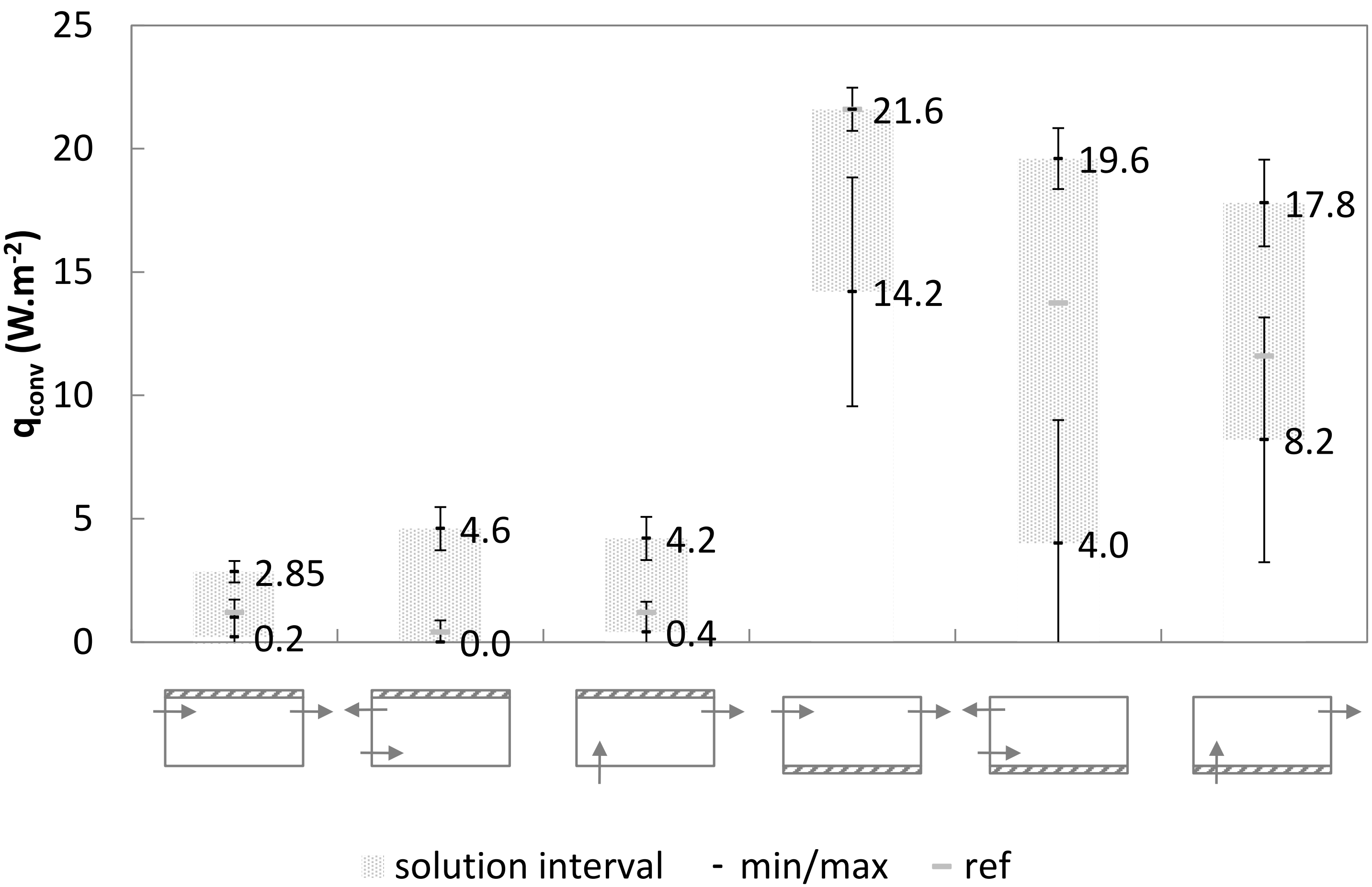


Interpolation modelling (kriging)



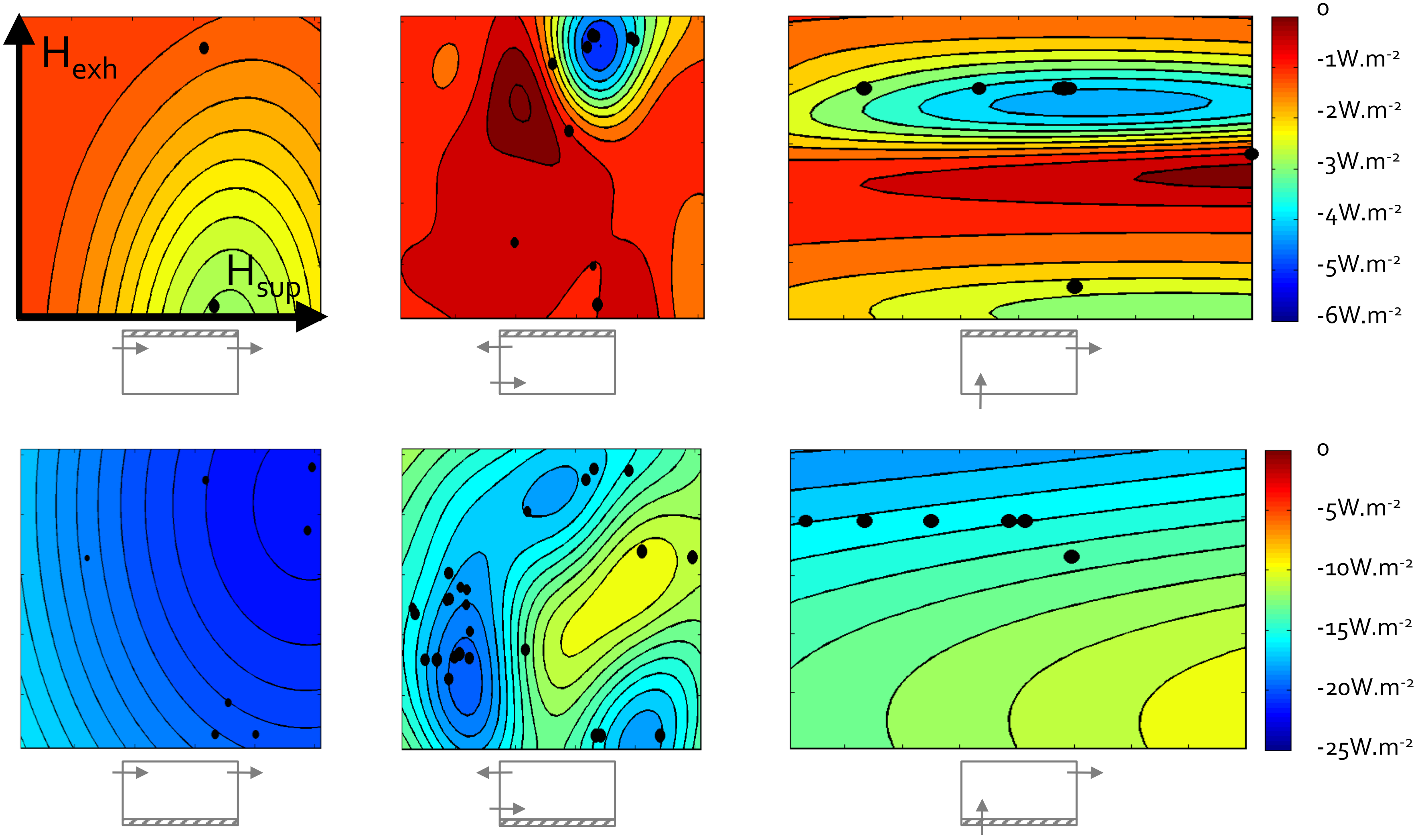
Adaptive sampling (expected improvement)

Sensitivity: position of thermal mass more important than ventilation concept



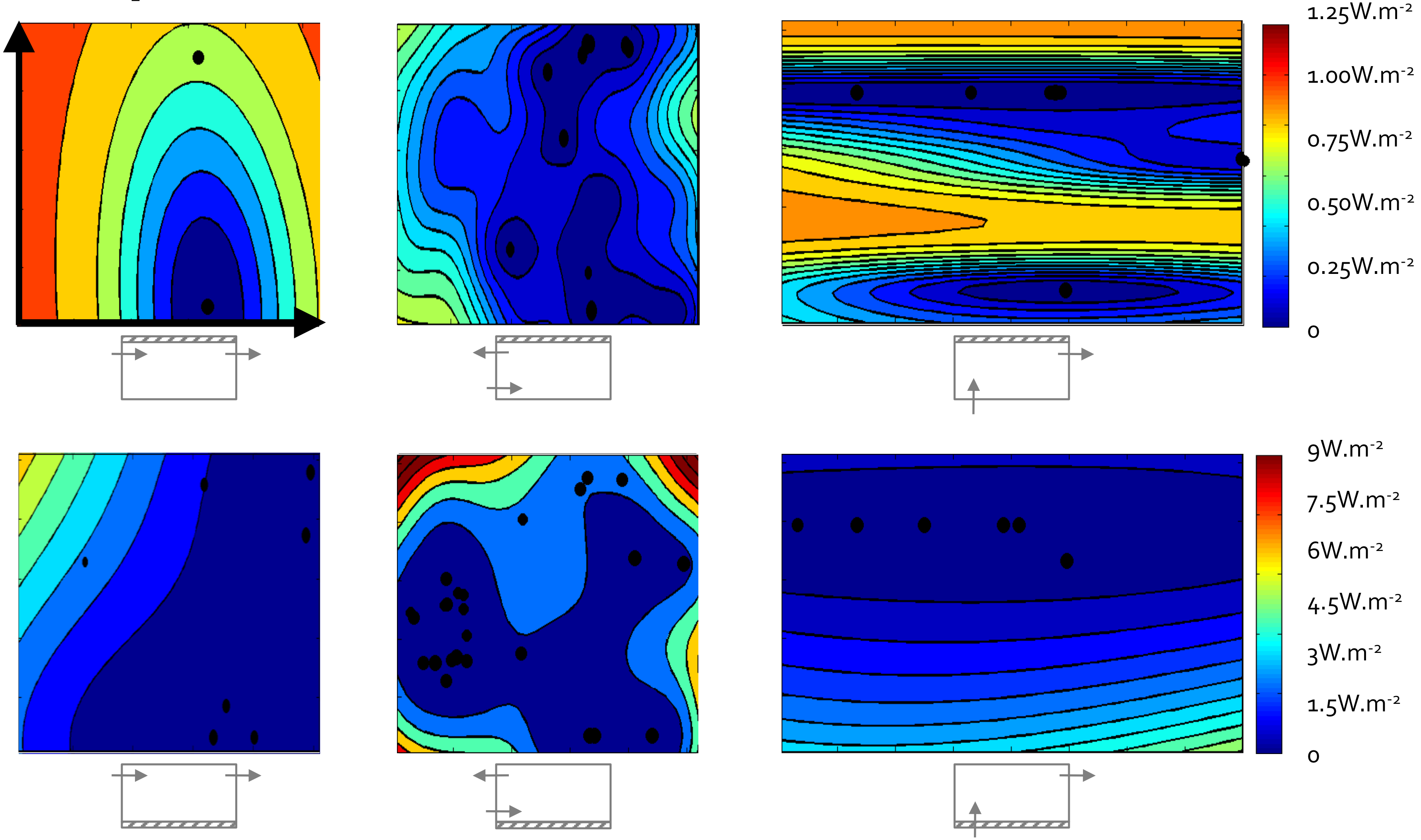
(L_r=4.5m, (T_w-T_{sup})=10°C and n=10h^{-1})

Typical contour plots of the convective heat flux q_c



(L_r=4.5m, α=90°, $h_{sup/exh}$=0.10m, (T_w-T_{sup})=10°C and n=10h^{-1})

Typical contour plots of the prediction variance $\hat{s}^2$



(L_r=4.5m, α=90°, $h_{sup/exh}$=0.10m, (T_w-T_{sup})=10°C and n=10h^{-1})

These CFD-based surrogate models can provide insight (now)
advance BES-modelling (later)

Advancement of BES modelling

Surrogate models

Indicate optimal solutions for which new correlations can be derived empirically

Make a basis for more globally accurate surrogate models

Framework (in Matlab)

Can be used to derive more surrogate models for different sets of room/system design parameters

Can be extended to enable co-kriging (few high-res simulations and many low-res simulations)

SENSITIVITY OF NIGHT COOLING PERFORMANCE TO ROOM/SYSTEM DESIGN: SURROGATE MODELS BASED ON CFD

UNIVERSITEIT GENT

Kim Goethals and Arnold Janssens

Laboratory of Building Physics, Construction and Services

Further reading:

K. Goethals, H. Breesch et al., Sensitivity analysis of predicted night cooling performance to internal convective heat transfer modelling. Energy and Buildings, 43(9) (2011) 2429-2441

K. Goethals, M. Delghust et al., Experimental investigation of the impact of room/system design on mixed convection heat transfer. Energy and Buildings, 49 (2012) 542-551

K. Goethals, I. Couckuyt et. al., Sensitivity of night cooling performance to room/system design: surrogate models based on CFD, Building and Environment, 58 (2012) 23-36

K. Goethals, Convective heat transfer modelling in offices with night cooling (Ph.D.), Ghent University, 2012