Ventilative Cooling: Modeling + Simulation Challenges

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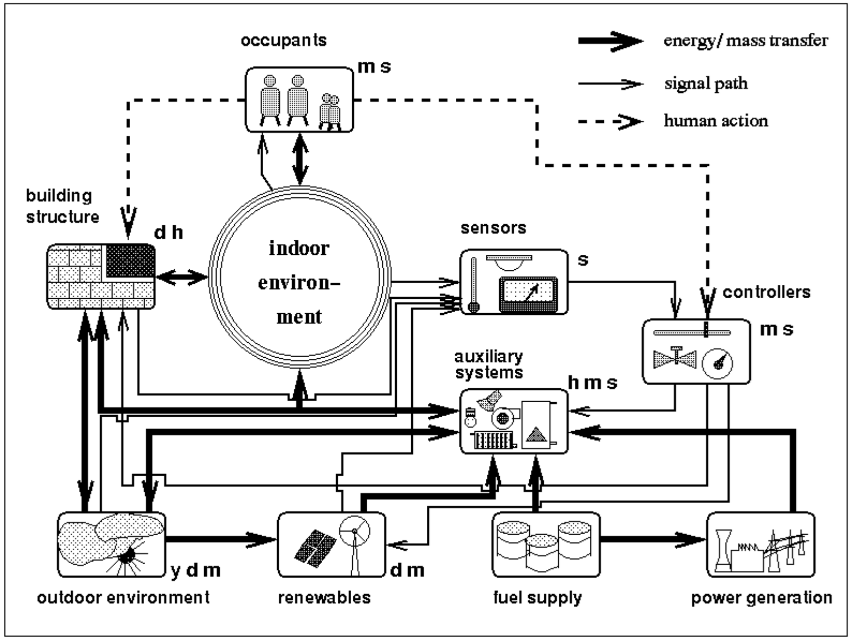
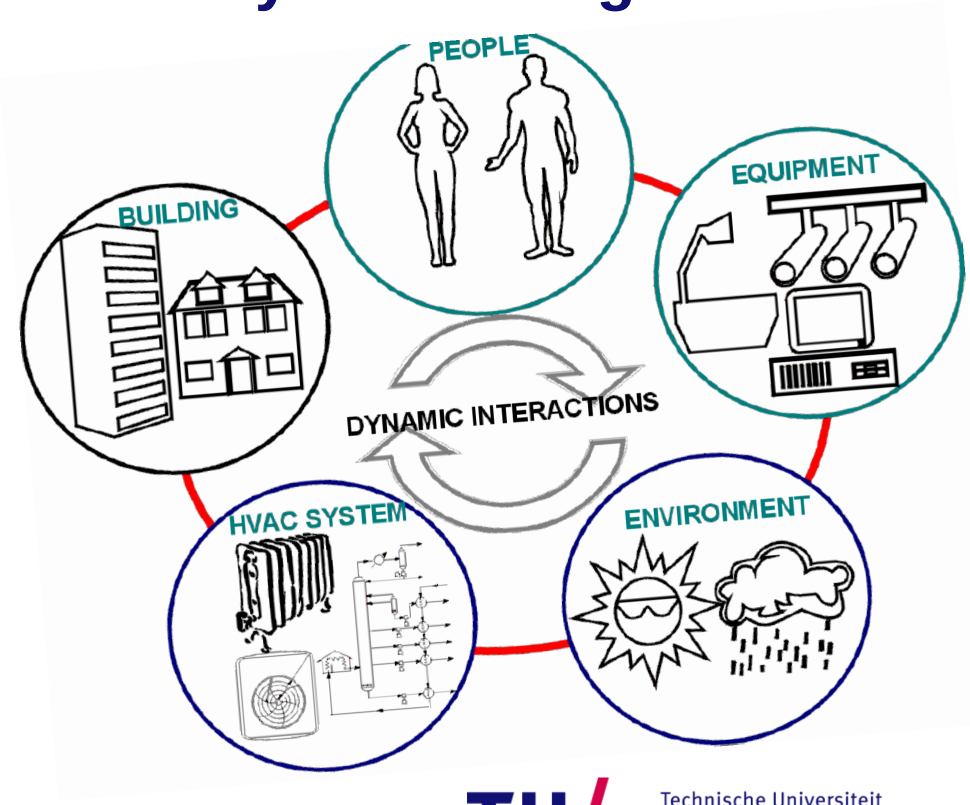
Where innovation starts

Ventilative cooling

Depends on air flow and temperature/ enthalpy differences affected by dynamically interacting complex sub-systems





Air flow modeling methods

- **“Simplified” expressions**
- **Mass flow balance network method**
- **Computational fluid dynamics (CFD)**

Can be used separately or combined with building energy modeling (BEM)

Air flow modeling - simplified

- n = .7 ACH
- Q = Q50 / K

  (K ~ 20 for heating season urban NL)
- LBL-method

$$Q = L(A\Delta t + B\upsilon^2)^{0.5}$$

where Q = air flow rate (L/s)
L = effective leakage area (cm^2)
A = 'stack' coefficient
Δt = average outside/inside temperature difference (K)
B = wind coefficient
υ = average wind speed, measured at a local weather station.

- Etc ....

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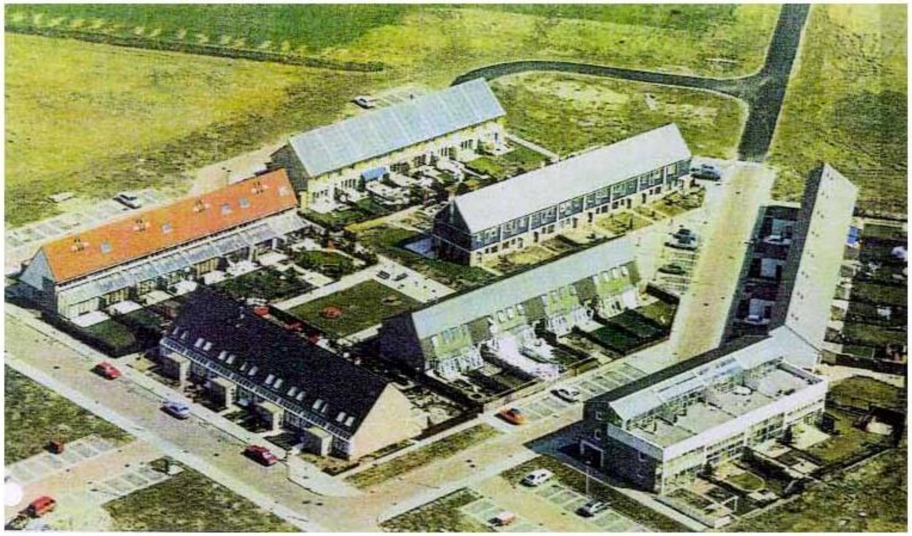
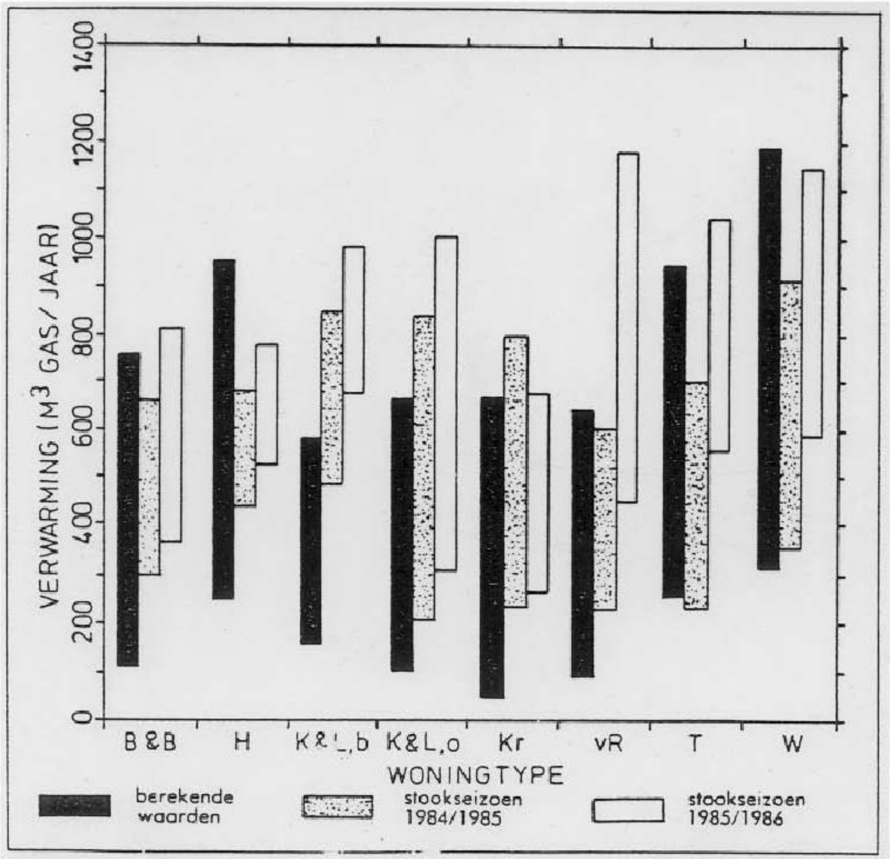
Air flow modeling – simplified + BEM





Uncertainty analysis (1984 style): variability in heating energy demand of low-energy houses due to (stochastic) occupant behaviour in terms of Tset, Qint, ACR

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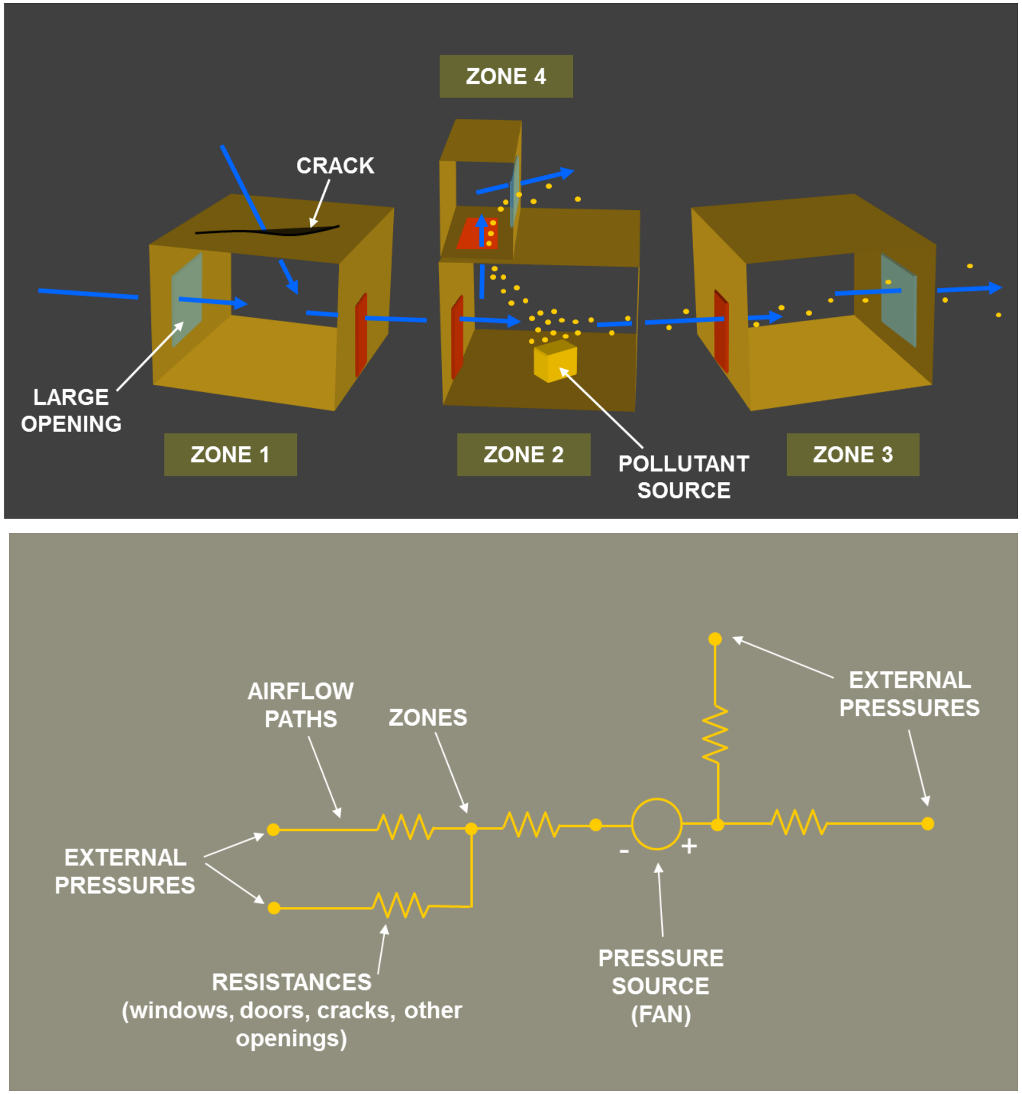
Air flow modeling – mass balance network



Source: IBPSA-USA

- **for each branch**

$$\dot{m} = \rho C_i \left(p_i - p_j\right)^n \left[kg / s\right]$$

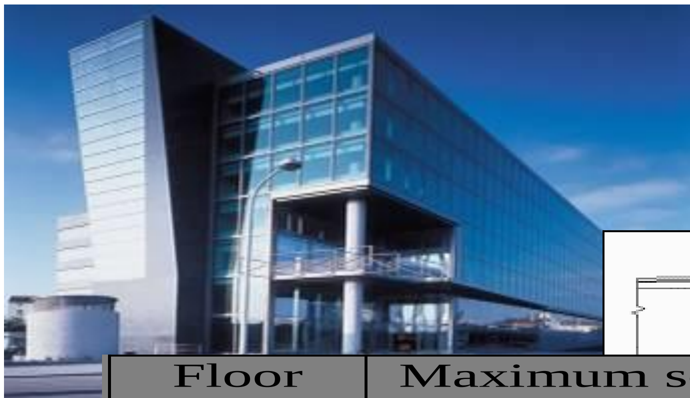
- **for each non-boundary node**

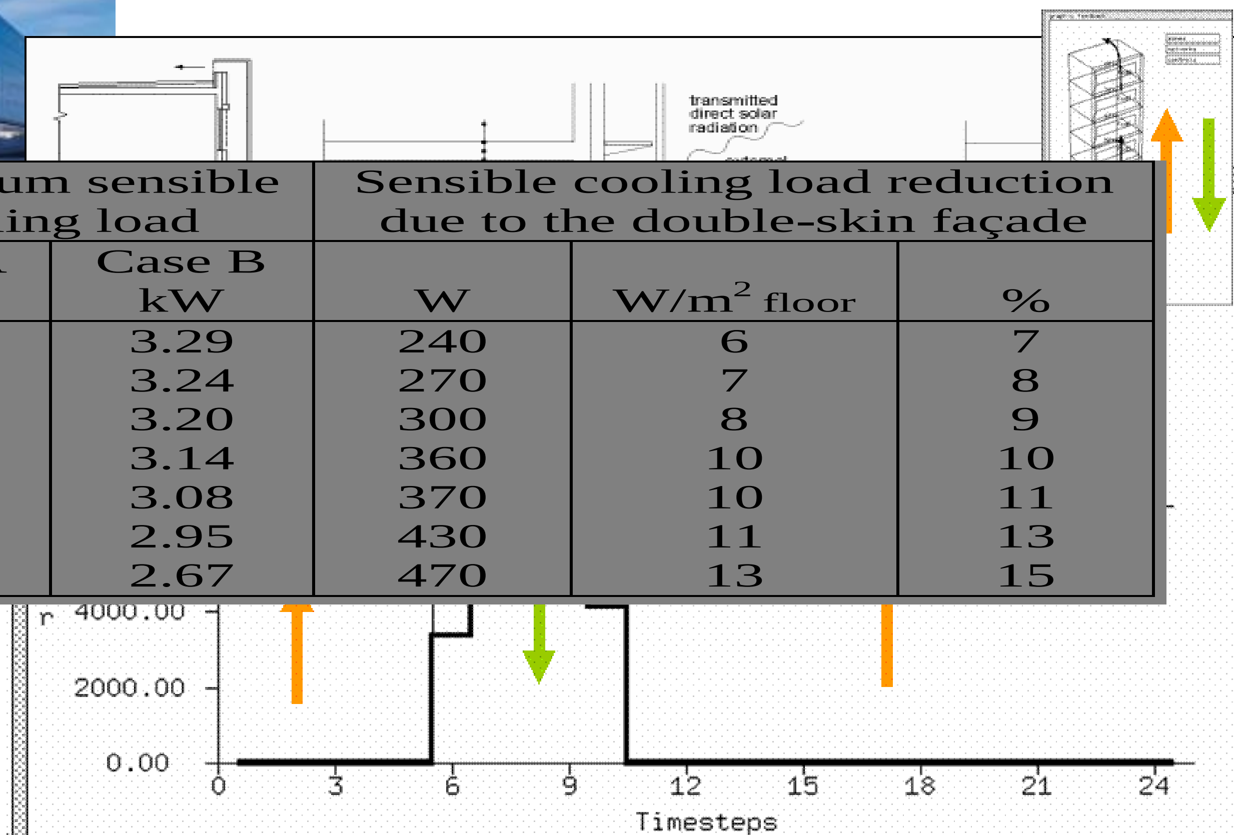
$$\sum \dot{m} = 0 \left[kg / s\right]$$

- **for each boundary node**

$$p = "known" \left[Pa\right]$$

Air flow modeling – flow network + BEM





Floor level	Maximum sensible cooling load		Sensible cooling load reduction due to the double-skin façade		
	Case A kW	Case B kW	W	W/m^2 floor	%
8th	3.53	3.29	240	6	7
7th	3.51	3.24	270	7	8
6th	3.50	3.20	300	8	9
5th	3.50	3.14	360	10	10
4th	3.45	3.08	370	10	11
3rd	3.38	2.95	430	11	13
2nd	3.14	2.67	470	13	15

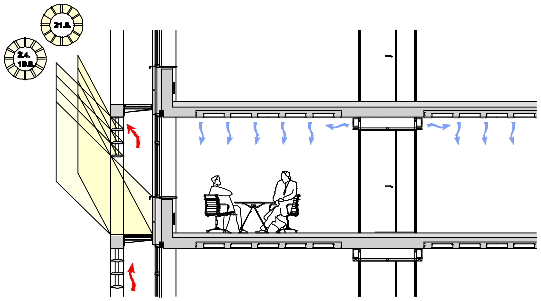
Air flow modeling – flow network + BEM

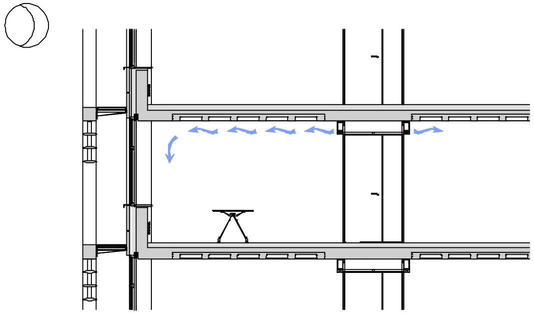
Passive cooling

- External shading
- High thermal mass
  (exposed floor / ceiling, ribs)

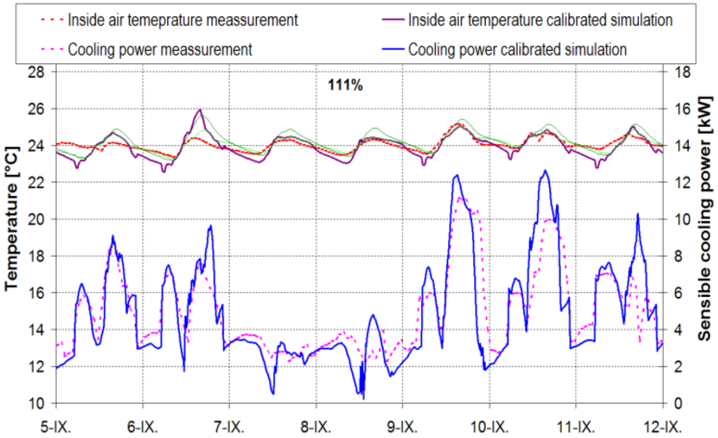
Low energy cooling

- All air system
- Night ventilation
- Top cooling
- Heat recovery

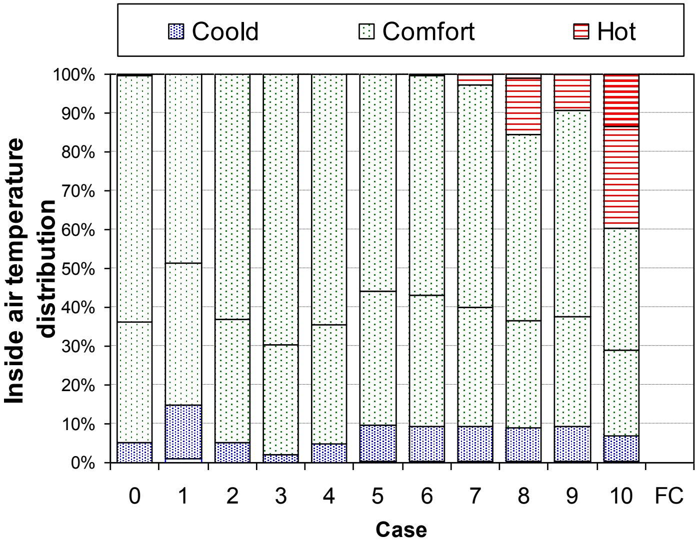


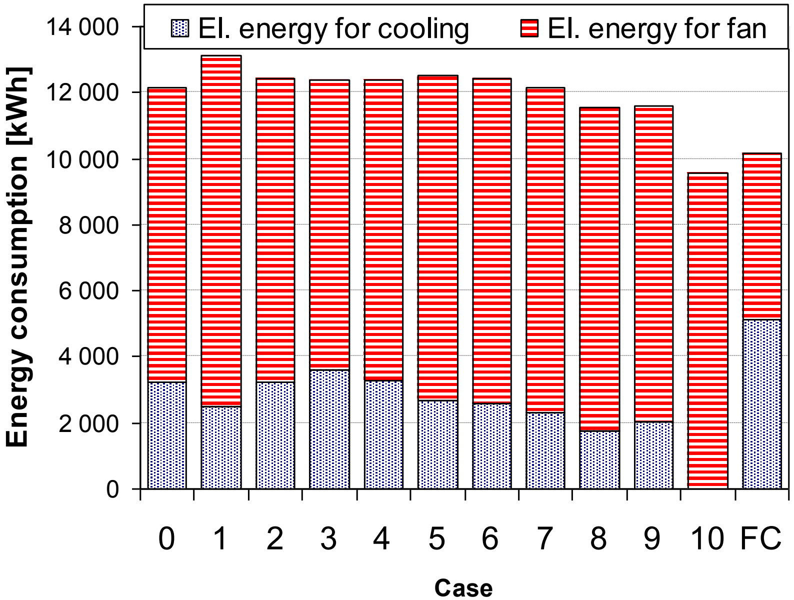


Air flow modeling – flow network + BEM



- Using calibrated building + systems model, 10 operation scenarios were simulated: 6 scenarios with various combinations of flow rates and control periods, 5 scenarios with reduced cooling coil capacity





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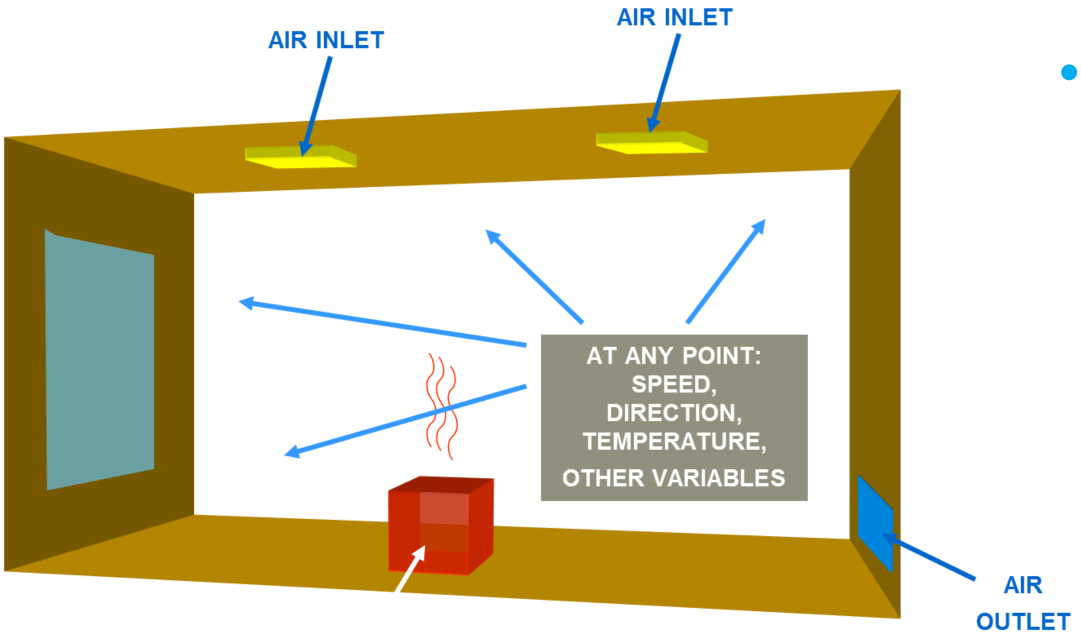
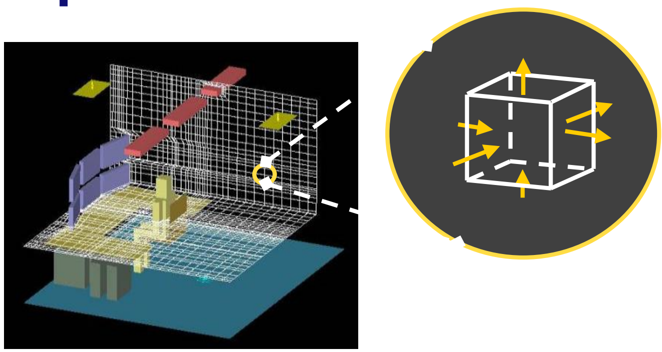
source: Milos Lain

Air flow modeling – CFD

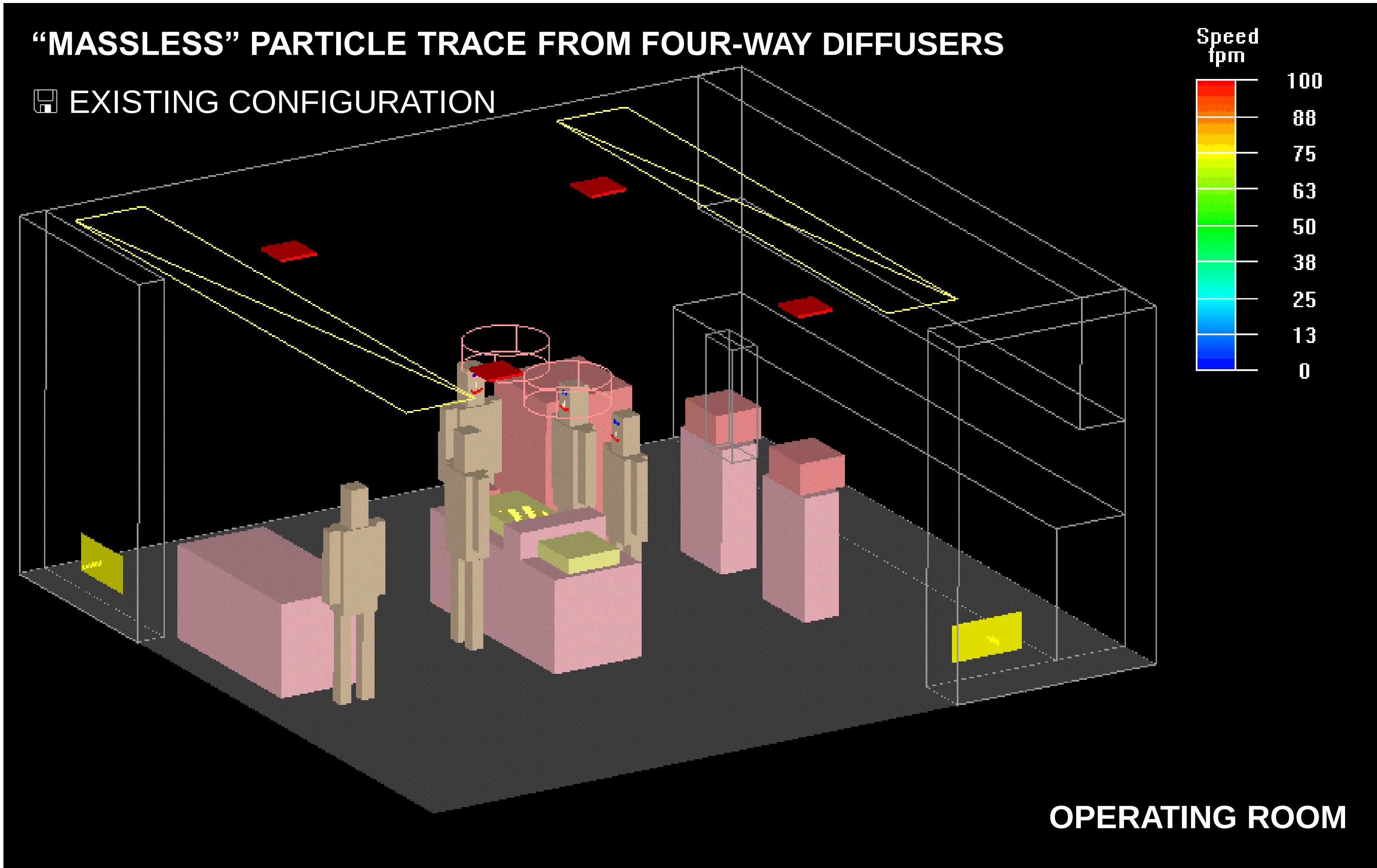


Source: IBPSA-USA

- **Conservation of**
  - **Mass**
  - **Momentum**
  - **Energy**
  - **Species**



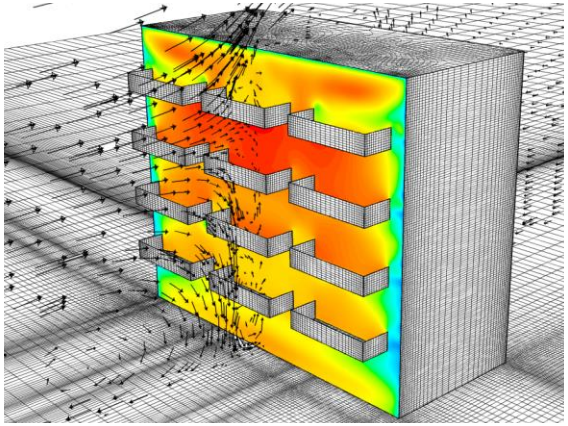
Air flow modeling – CFD



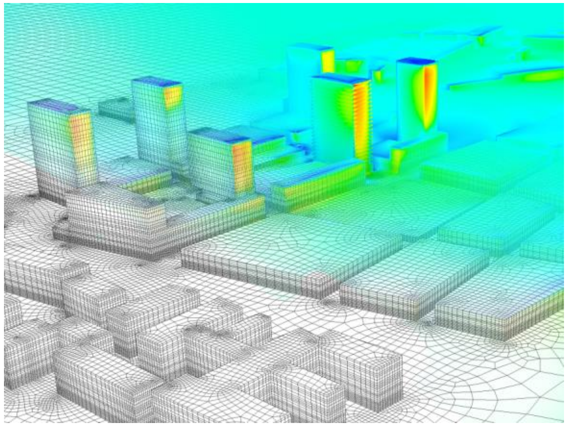
Source: IBPSA-USA

Air flow modeling – CFD

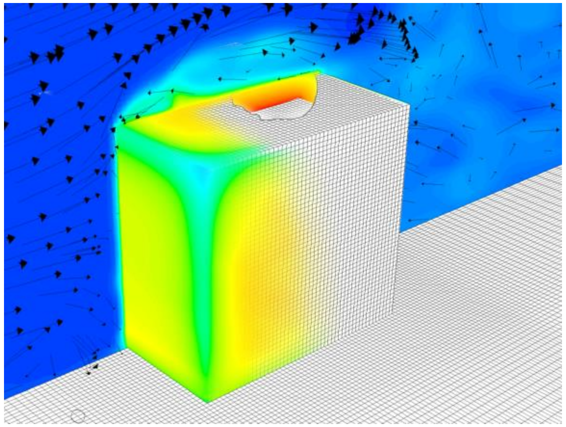
- Building components, such as balconies, can lead to very strong changes in wind pressure distribution on building facades



CFD modeling of air flow around a building



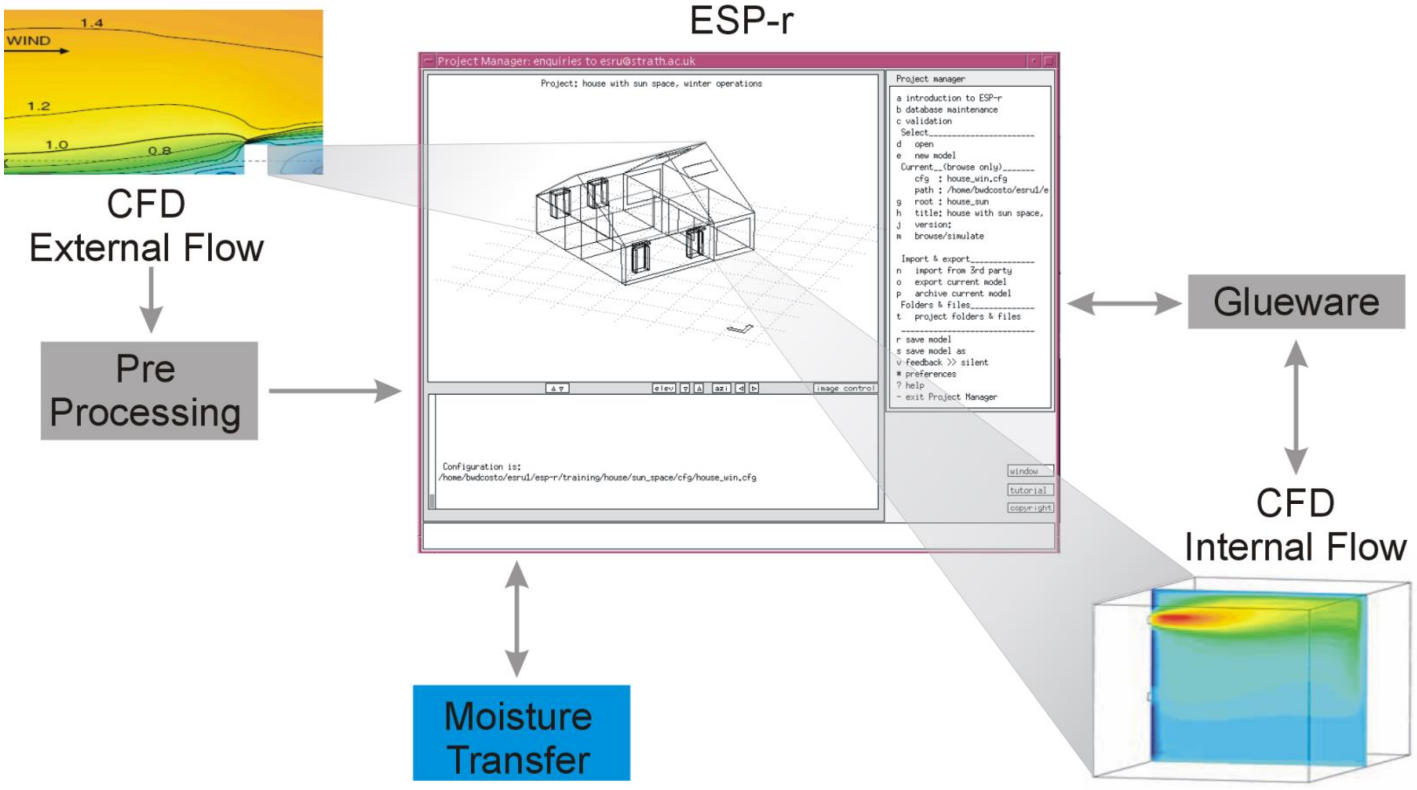
Computational modeling of air flow in an urban area*



LES simulation of heat transfer around a building

***Montazeri, H., Blocken, B., Janssen, W.D., van Hooff, T. CFD evaluation of wind comfort on high-rise building balconies: validation and application. The Seventh International Colloquium on Bluff Body Aerodynamics and Applications Shanghai, China; September 2-6, 2012.**

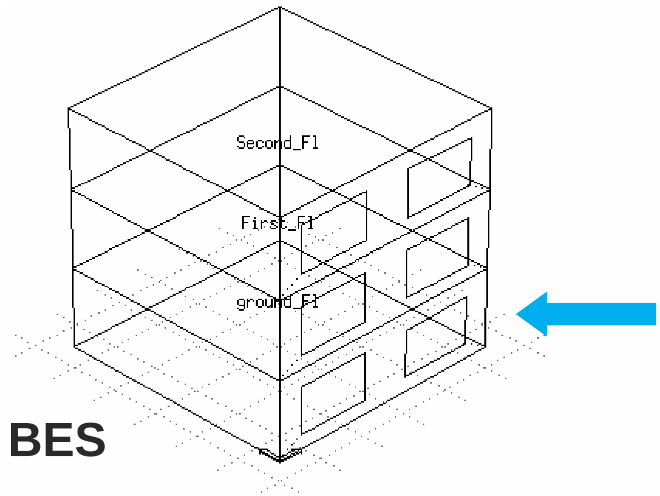
Air flow modeling – CFD + BEM



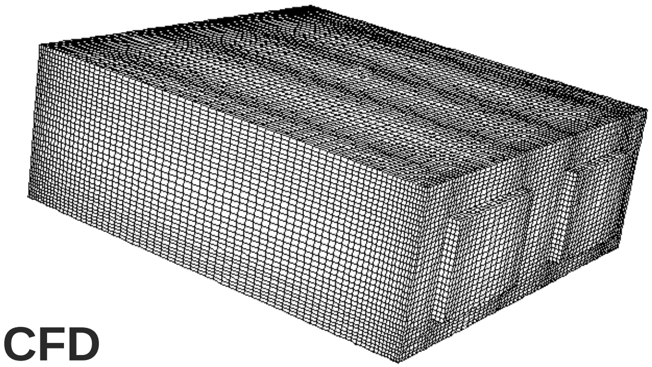
deliverables:
- prototype software
- coupling procedure
- coupling validation

Air flow modeling – CFD + BEM

- ➢Volume: 10 (m) *10 (m) * 3.33 (m)
- ➢12 surfaces
- ➢Duration = 1 day (31st of March)
- ➢2 time steps per hour
- ➢Location: Brussels
- ➢Free floating temperature



BES



CFD

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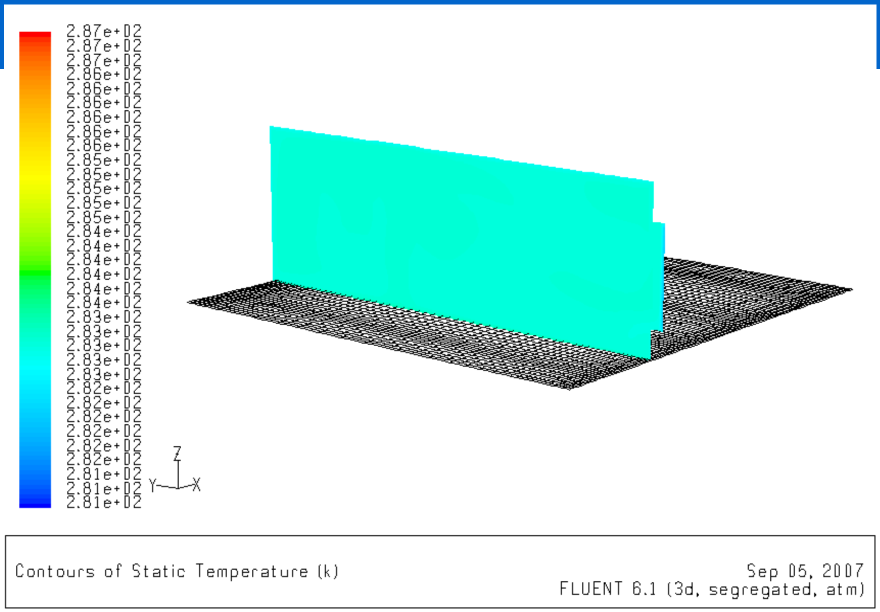
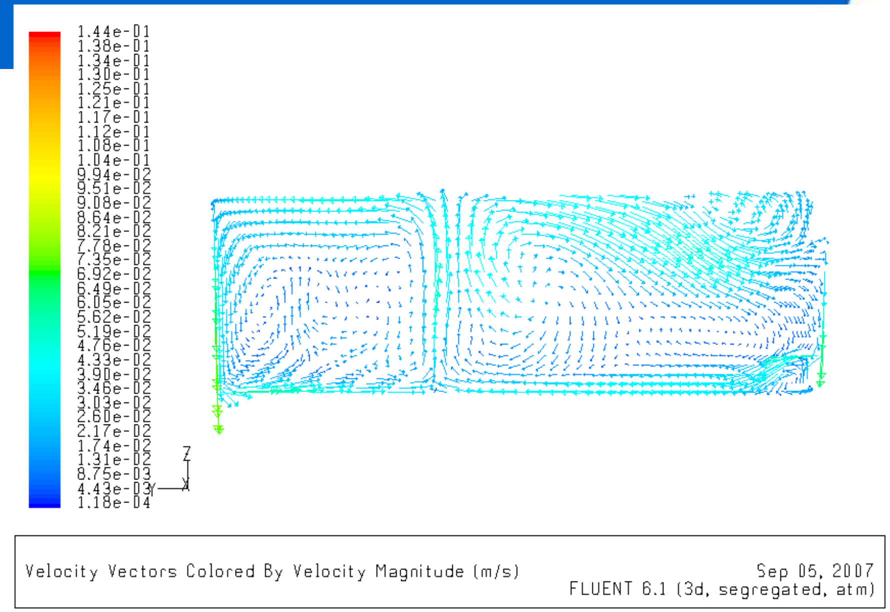
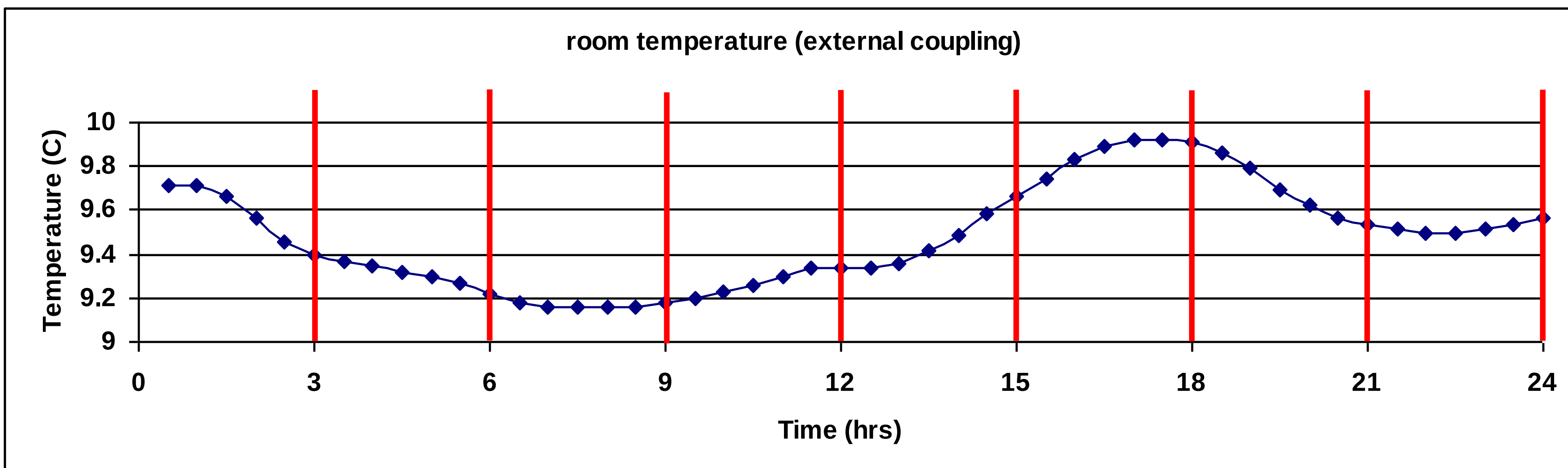
Air flow modeling – CFD + BEM







Source: Daniel Costola + Mohammad Mirsadeghi

Best modeling approach?

Case: displacement ventilation

Performance indicator	A	B	C
cooling energy	--	++	--
fan electricity	++	++	--
whole body thermal comfort	+	++	+
local discomfort, gradient	--	+	++
local discomfort, turbulence intensity	--	--	++
ventilation efficiency	--	0	++
contaminant distribution	-	-	++
whole building integration	++	++	--
integration over time	++	++	--

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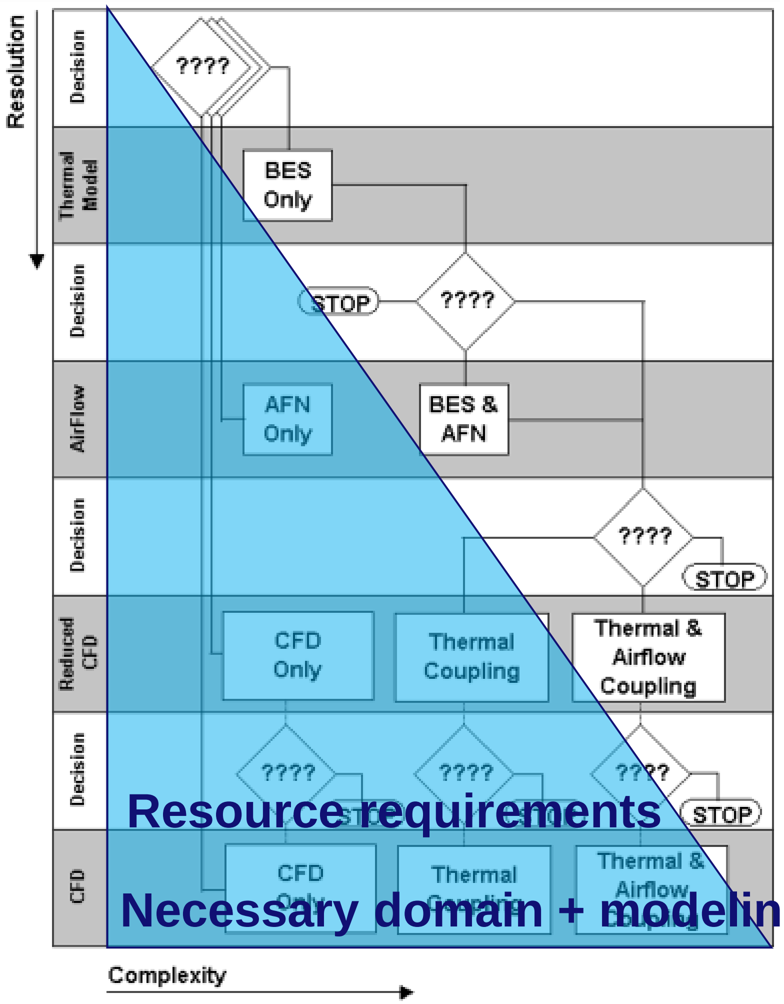
Quality Assurance (QA)

- **Ensuring that our model or simulation reproduces the state and behavior of the real world object, feature or condition. (= fidelity)**

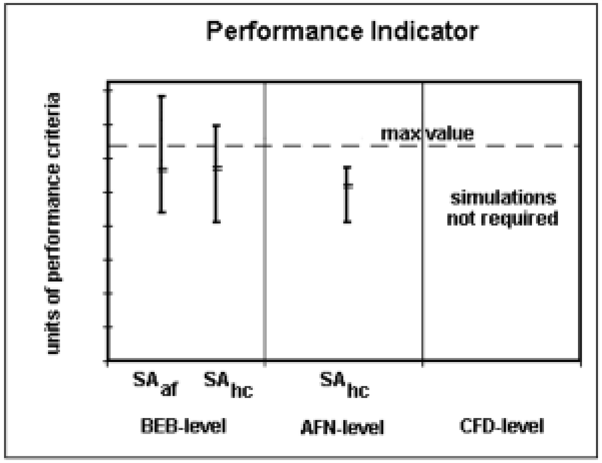
- **Ensuring that our simulation has meaning for the real world question being asked (= usefulness)**

QA: best modeling approach?



Resource requirements

Necessary domain + modeling knowledge



QA: data uncertainty / model complexity

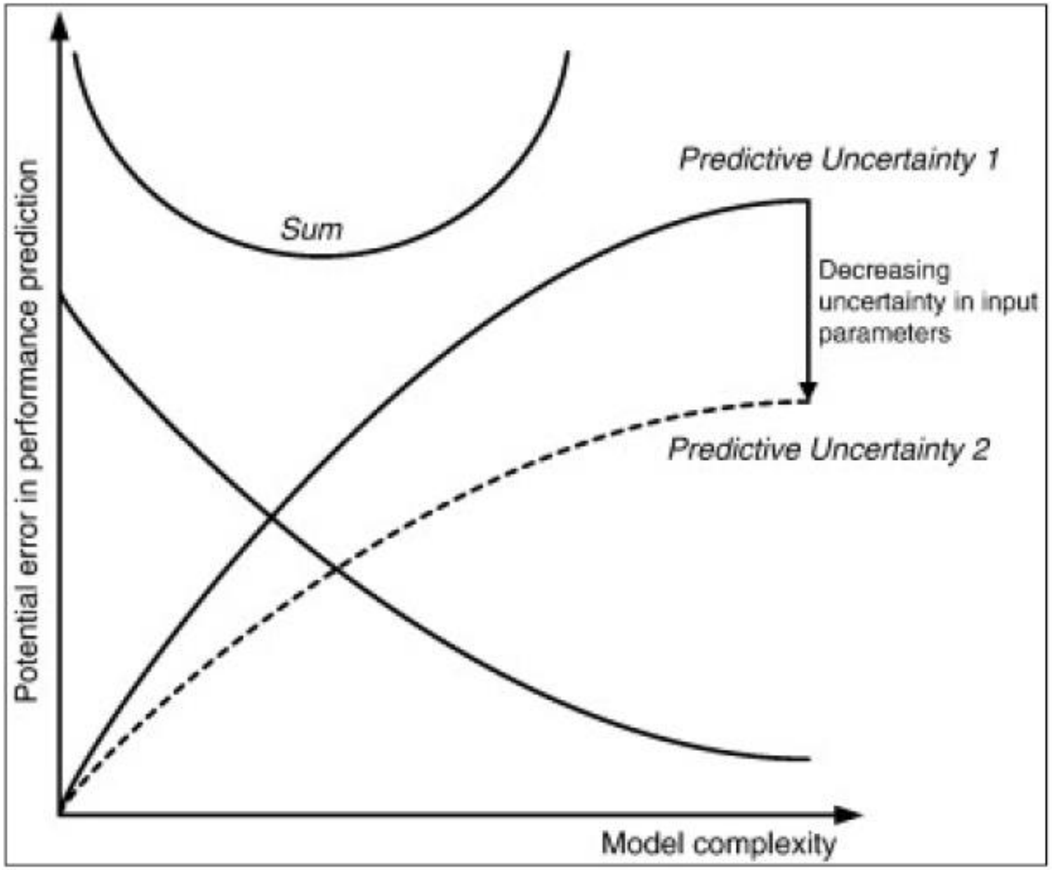
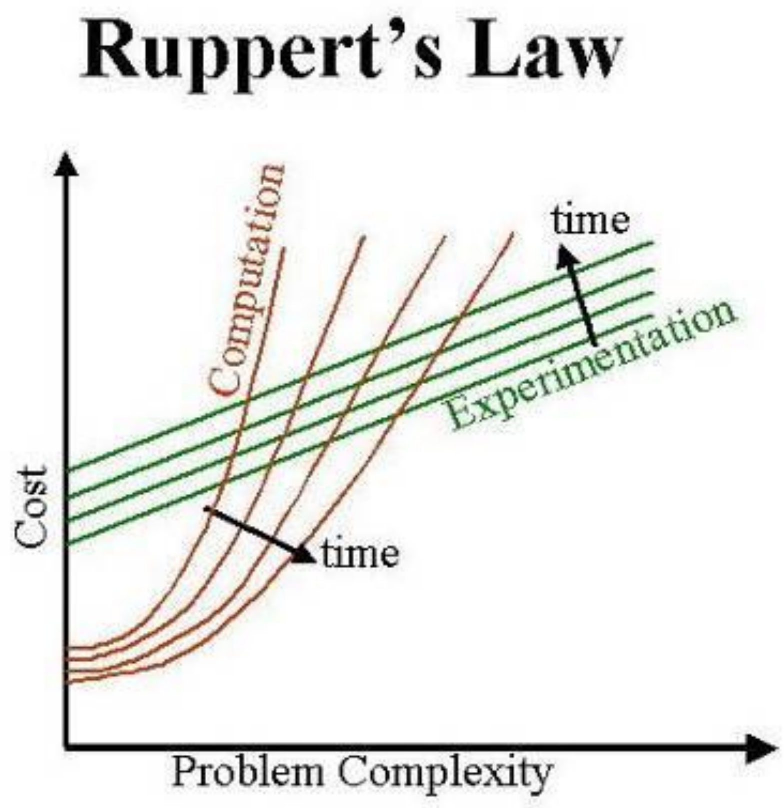


Figure 6 Potential errors in performance prediction vs. model complexity/ level of detail [11]

QA: measurements vs. simulation



Measurements essential for verification, validation and calibration !

QA: don’t simulate when

1. the problem can be solved using "common sense analysis“
2. the problem can be solved analytically (using a closed form)
3. it's easier to change or perform direct experiments on the real
4. the cost of the simulation exceeds possible savings
5. there aren't proper resources available for the project
6. there isn't enough time for the model results to be useful
7. there is no data – not even estimates
8. the model can't be verified or validated
9. project expectations can't be met
10. system behavior is too complex, or can't be defined

Banks & Gibson, 1997

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QA: do simulate but

Black Belt Energy Modeling Matrix

Belt		Capabilities
Trainee	White	• Collect modeling input data
	Yellow	• Perform input data calculations
	Orange	• Develop building geometry and zoning
Tech-nician	Green	• Create building input file using software wizard
	Blue	• Build minimally-code compliant building model
Core Analyst	Purple	• Review results for reasonableness • Complete calibrations
	Brown	• Perform complex modeling • Complete detailed QC • Complete system level calibration
Master	Red	• Understand the algorithms • Use supplemental analysis
	Black	• Balance modeling level of detail against accuracy of results needed to support decision making

E Franconi, RMI, 2011

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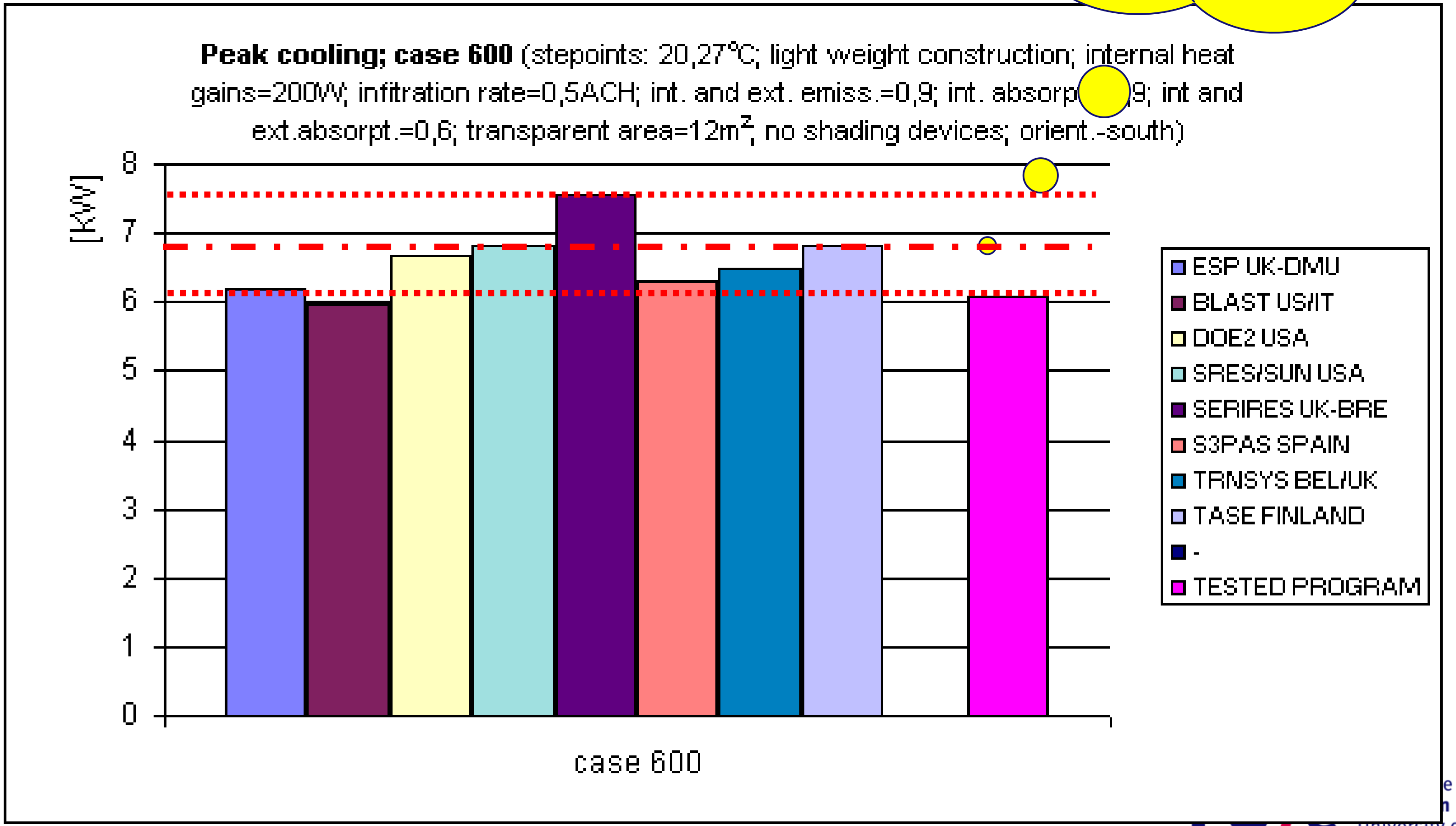
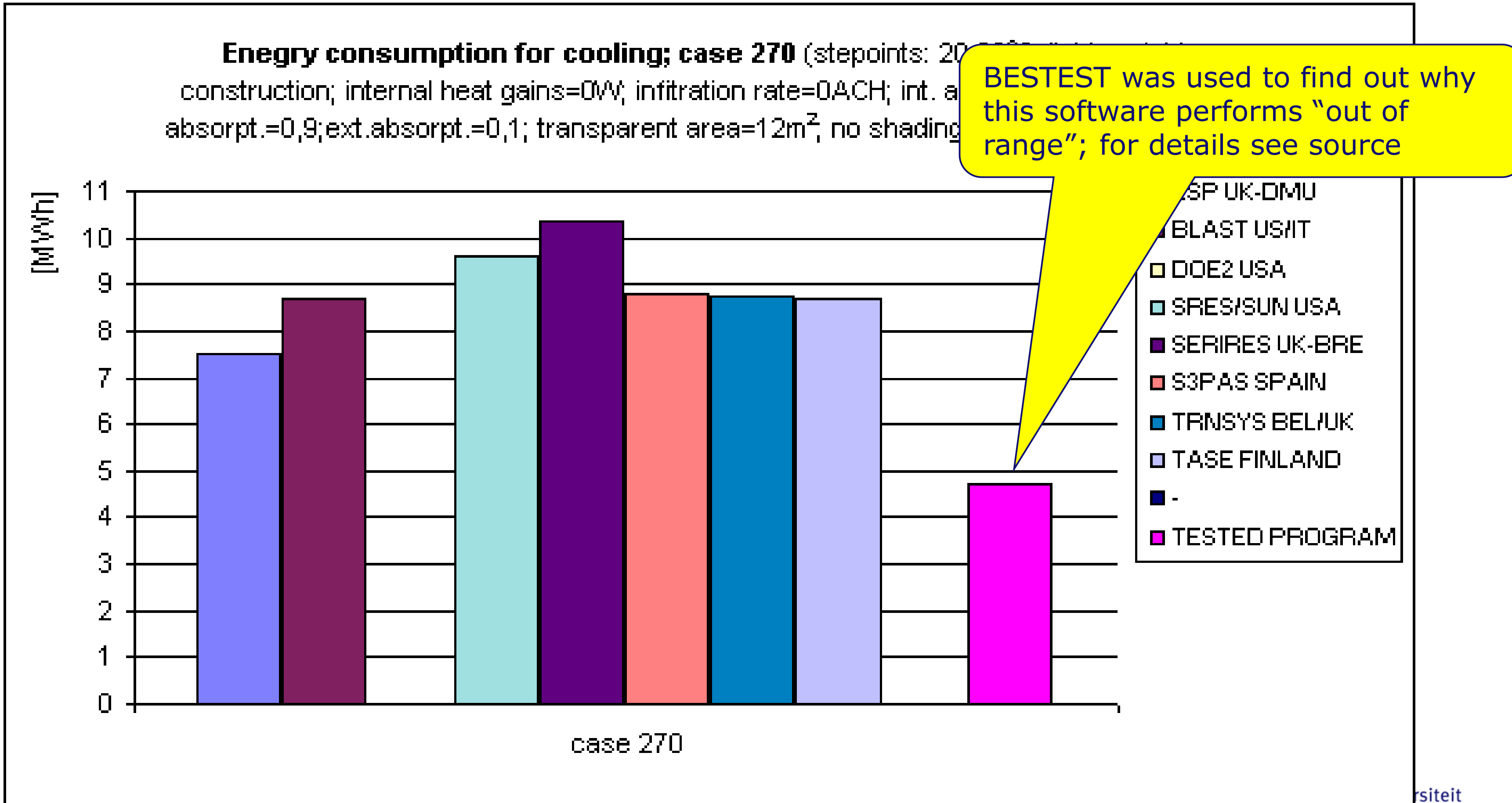
QA: how accurate are predictions

The range 6.9 +/- 10% gives you some idea of "normal" uncertainty – and this is for a really very simple building, with no definition uncertainty



QA: how accurate are predictions



Tested program = Ecotect

Source: Hensen and Radosevic 2004

QA: and in case of uncertainty in

- Weather (frequency, missing variables, local micro climate, climate change, ….)
- Wind pressure distribution (due to shape and surroundings)
- Pressure – flow characteristics of “openings”
- Occupant behavior (operable building elements, set points, …..)
- Organizational changes (company, family make-up, …)
- Behavioral changes (rebound effects, societal changes, …)
- …

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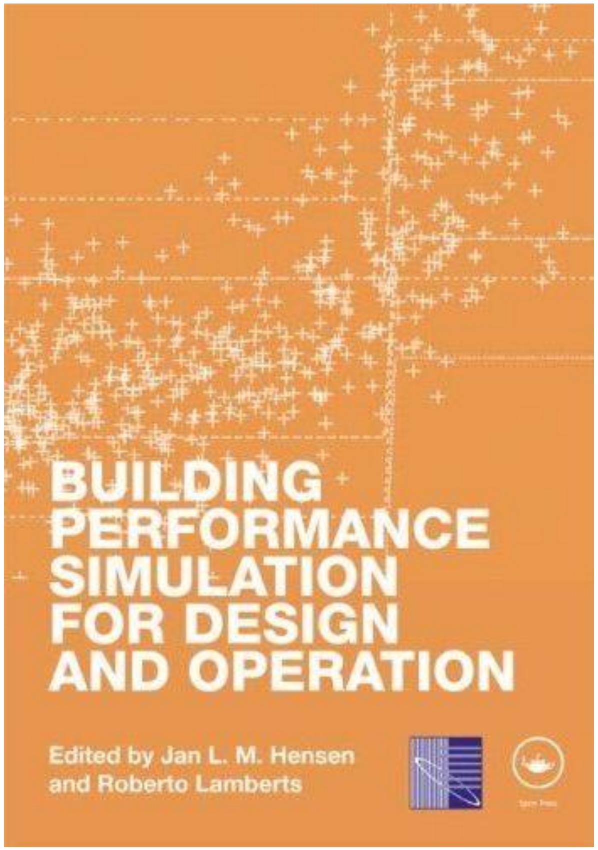
Conclusions

Assuming correct and appropriate use, building performance simulation:

- **Can be pretty good for relative comparisons including contrasting design solutions, sensitivity analysis, robustness analysis, (multi objective) design optimization, scenario studies, etc., but**
- **Is generally quite poor in absolute predictions, such as future real world energy consumption**



Thank you !

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