Conception optimisée du bâtiment par la SIMUlation et le Retour d'EXpérience, 00007 (2012)
DOI:10.1051/iesc/2012simurex00007

Building energy simulation: challenges and opportunities

Jan Hensen

Building energy simulation: challenges and opportunities

Jan Hensen

- context
- building simulation
- quality assurance
- conclusions

Technische Universiteit Eindhoven
University of Technology

Where innovation starts

Context – building energy use

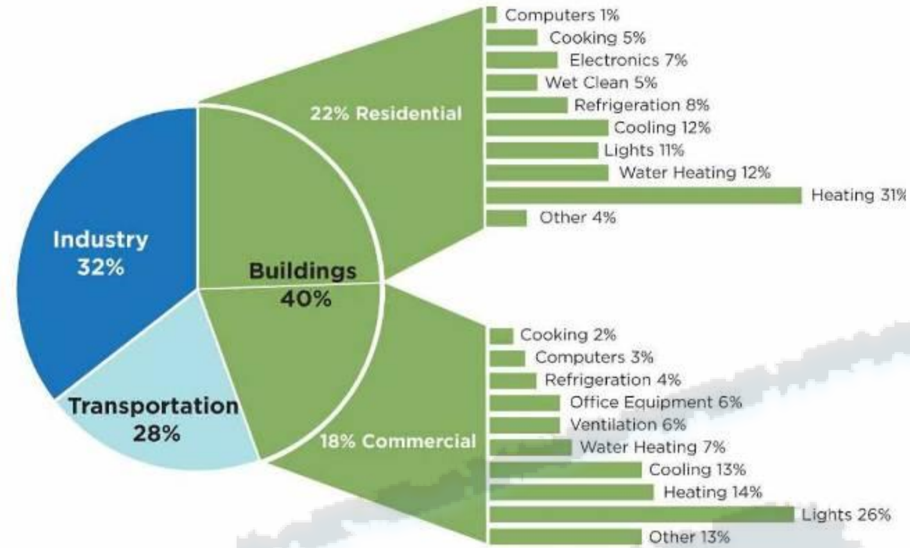


Figure 1. Energy Consumption in the United States
Source: 2007 DOE Buildings Energy Data Book, Tables 1.1.3, 1.2.3, 1.3.3

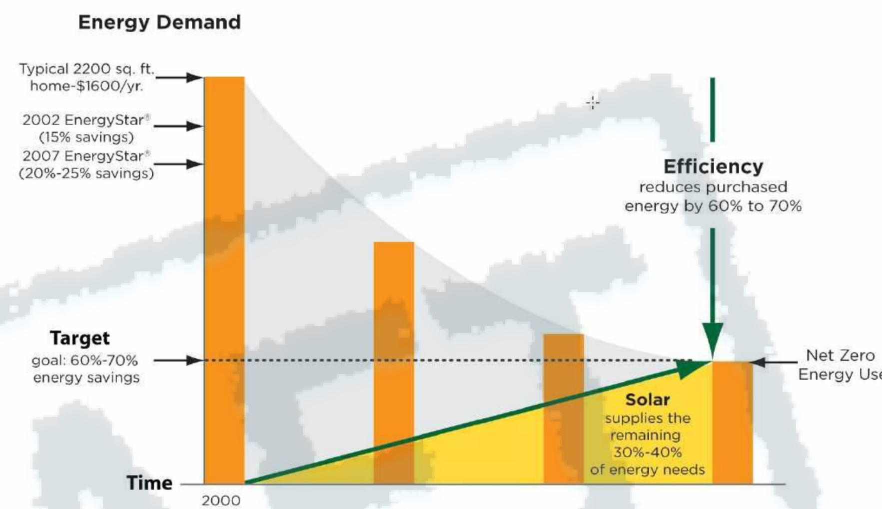


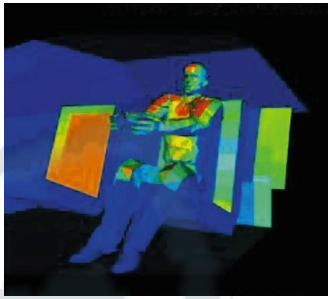
Figure 3. Approach for Achieving Net-Zero Energy Buildings
Federal R&D Agenda for Net-Zero Energy, High-Performance Green Buildings Report

currently buildings:

- consume ~ 37% world energy
- exploit ~ 40% of world resources
- produce ~ 40% of world waste

Context – indoor environment quality

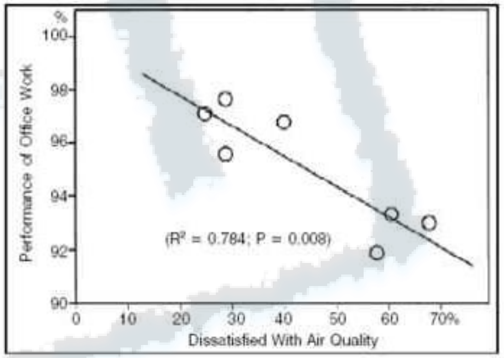
- **Increasing comfort demands**



www.automotiveworld.com

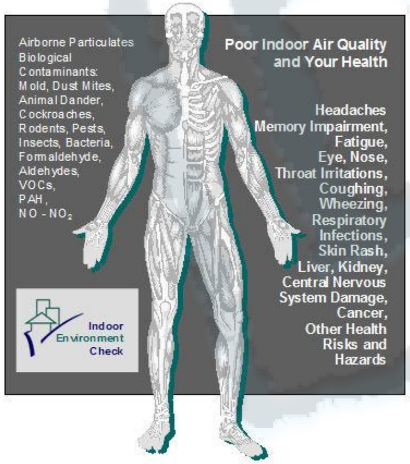
- **IEQ <> productivity (growing awareness)**

Energy costs only a small portion of total costs. Personnel costs are dominant.



Wargocki, P 2002 "Making the Case For IAQ", ASHRAE IAQ Applications

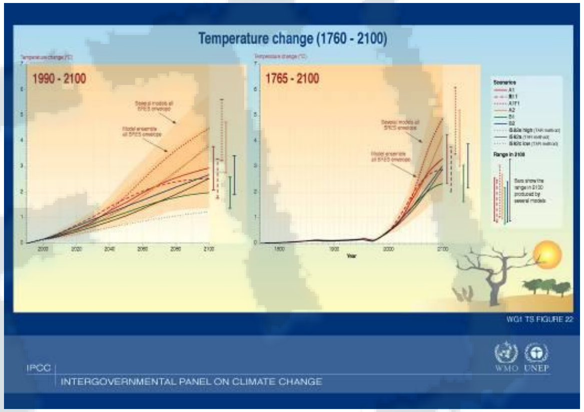
- **IEQ <> health (research)**



Economic impact:
€ energy
€ € productivity
€ € € health

Context – general building "issues"

- **Buildings need to be flexible (organizations change)**
- **Building systems need to be robust**
- **Buildings are complex**



Virginia Tech
Lumenhaus
Solar Decathlon 2009

Green design guidance / regulation

performance

Voluntary "best green" performance of some buildings

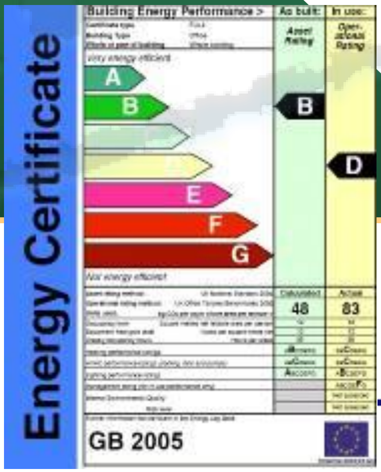
More complex tools are acceptable

LEED, BREEAM, CASBEE, ……

Mandatory minimum energy performance of every building

Tools must be as simple as possible

EPBD



LEED buildings perform better than other buildings *on average*

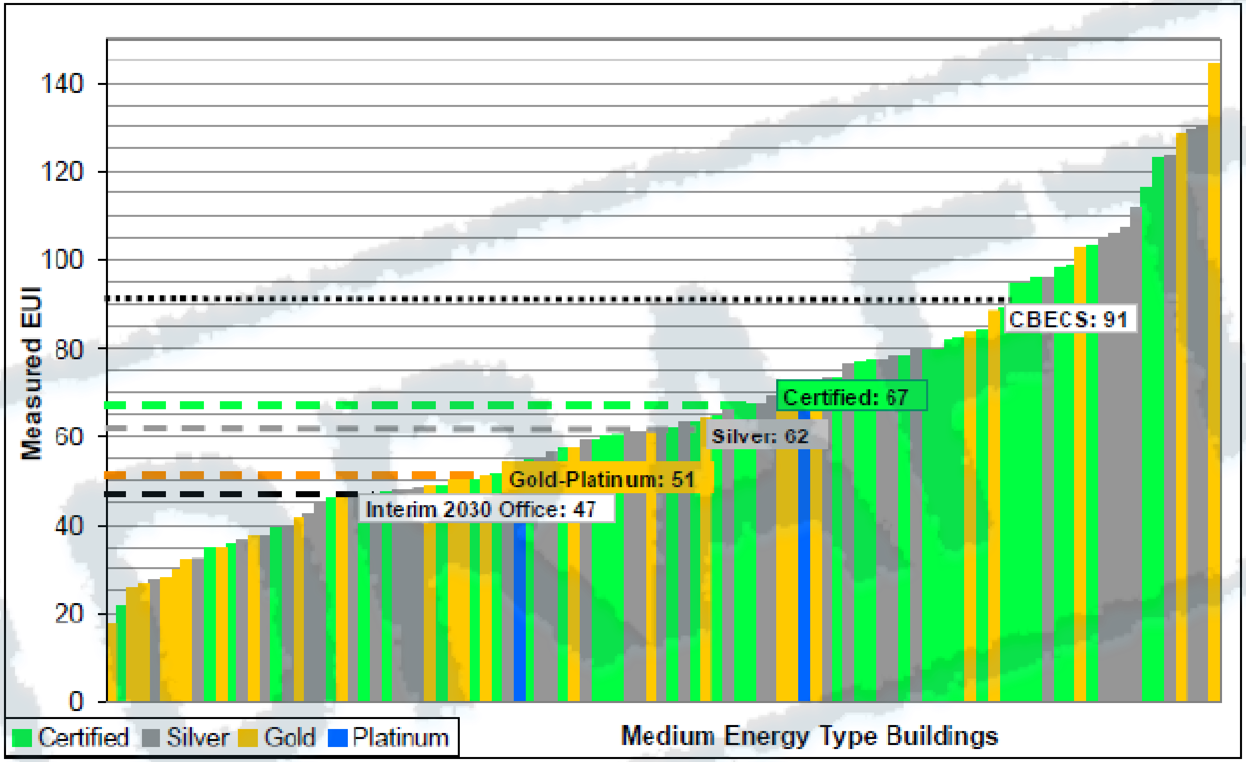


Figure 9: EUIs (kBtu/sf) for Medium Energy Buildings, with Medians by RatingLevel

Turner, C. and M. Frankel. 2008. Energy Performance of LEED® for New Construction Buildings. New Buildings Institute

…but many perform much worse than predicted

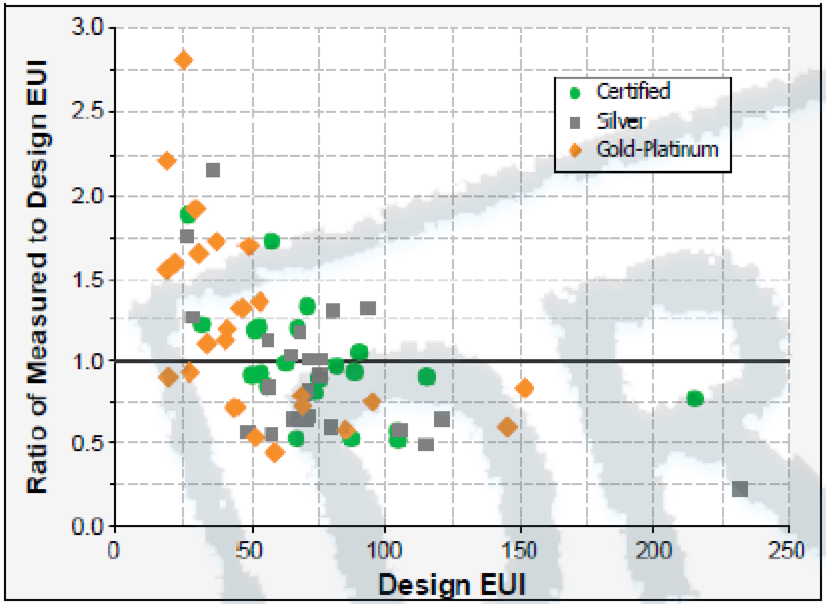


Figure 19: Measured/Design Ratios Relative to Design EUI

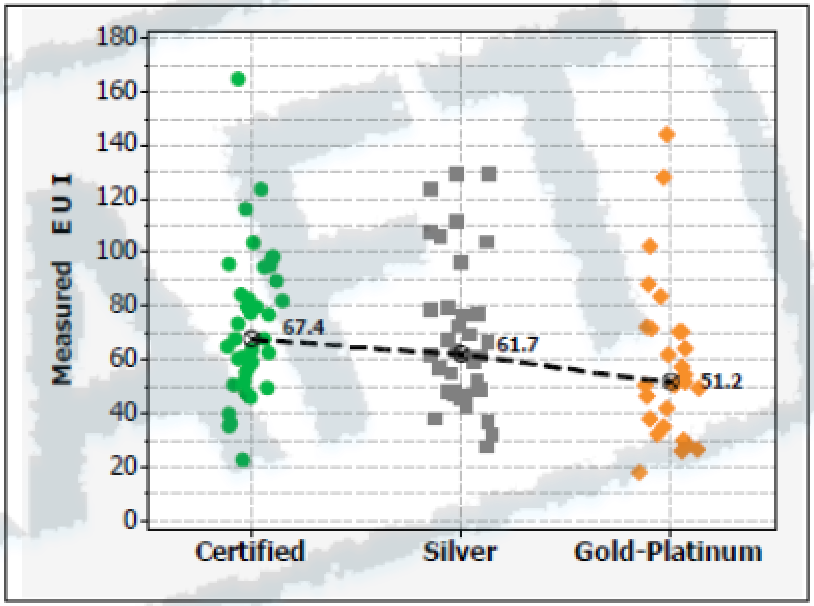


Figure 11: Measured EUIs (kBtu/sf) by LEED-NC Rating Level

Turner, C. and M. Frankel. 2008. Energy Performance of LEED® for New Construction Buildings. New Buildings Institute

...and some perform worse than code minimum

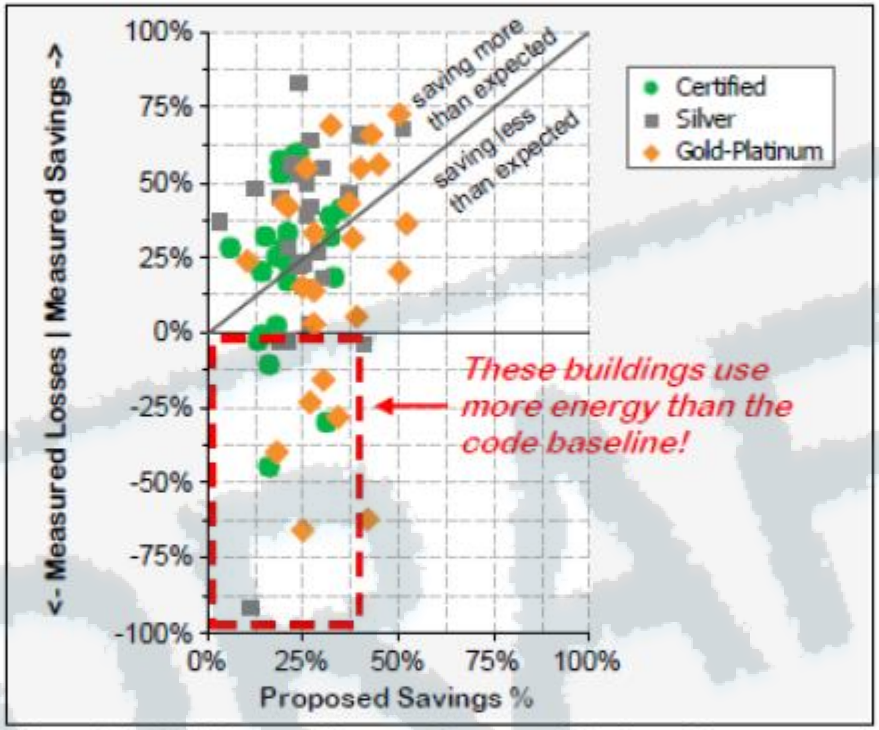
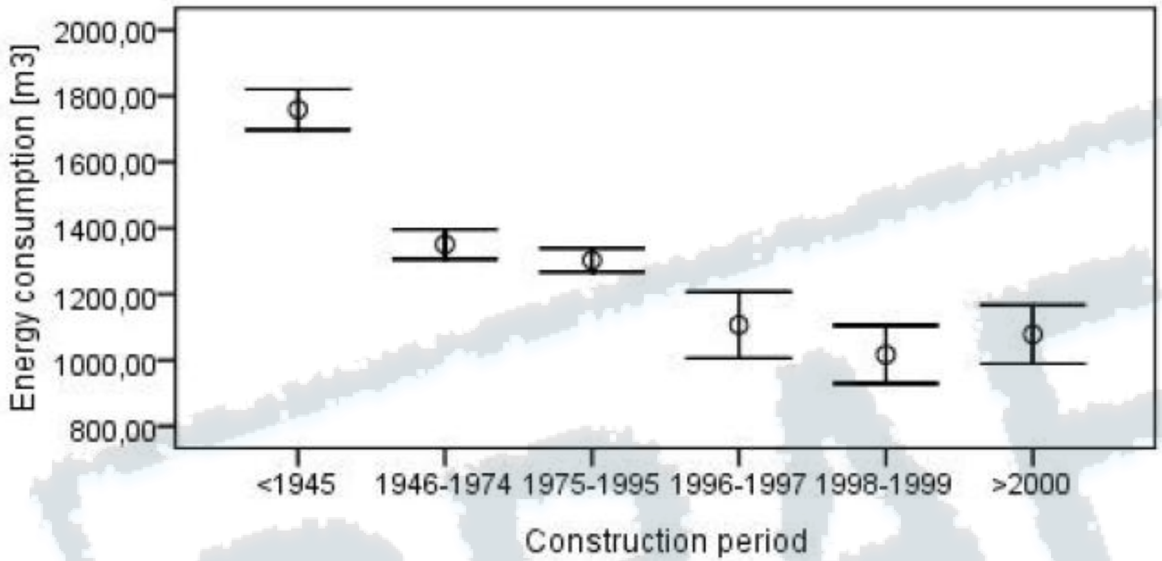


Figure ES- 5: Measured versus Proposed Savings Percentages

Turner, C. and M. Frankel. 2008. Energy Performance of LEED® for New Construction Buildings. New Buildings Institute

Design standards, codes, and rating systems may be *necessary*, but they are not sufficient

Issue – real energy use change



(Source, WoON database, www.VROM.nl)
Figure 4: Mean and 95% confidence interval for energy consumption per construction period

source: Guerra-Santin 2010

Issues – real energy use prediction

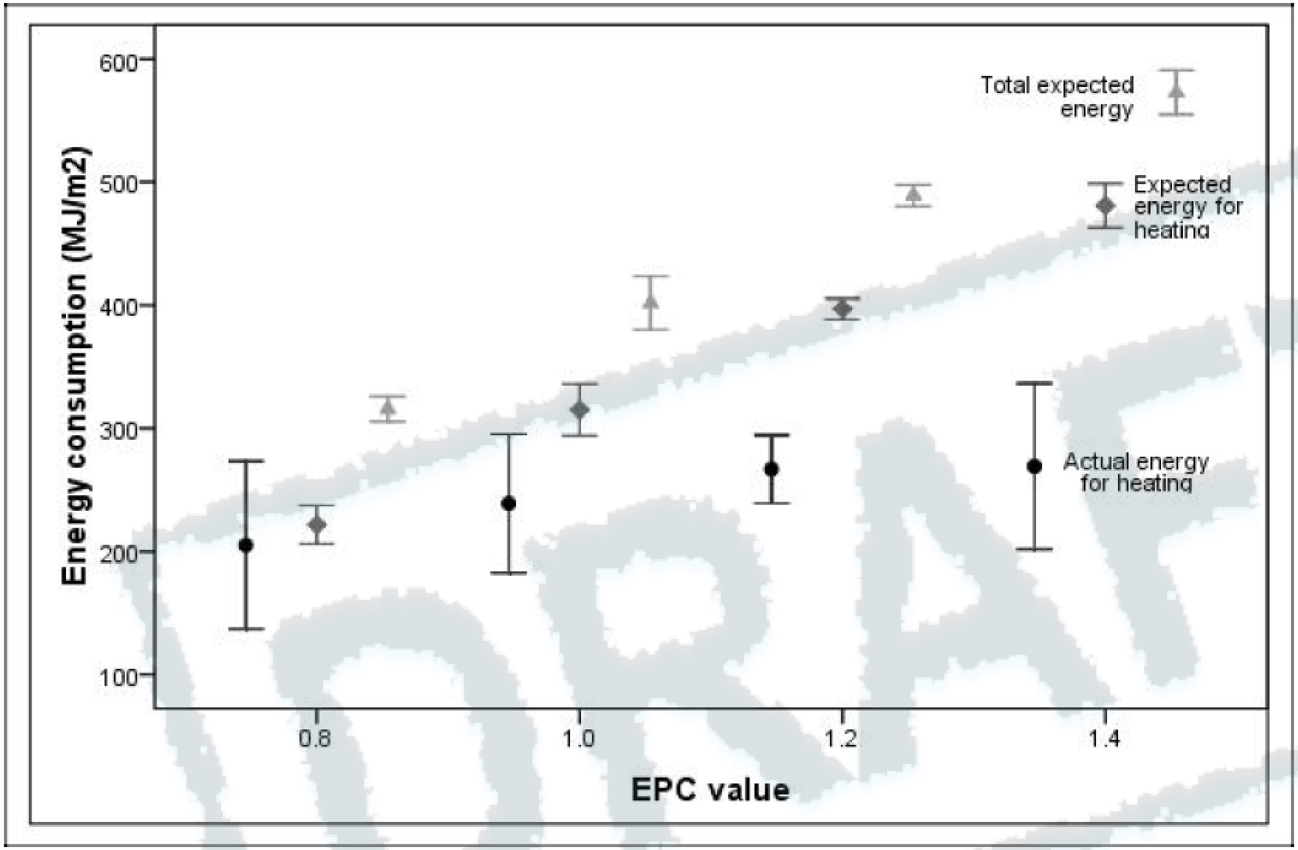
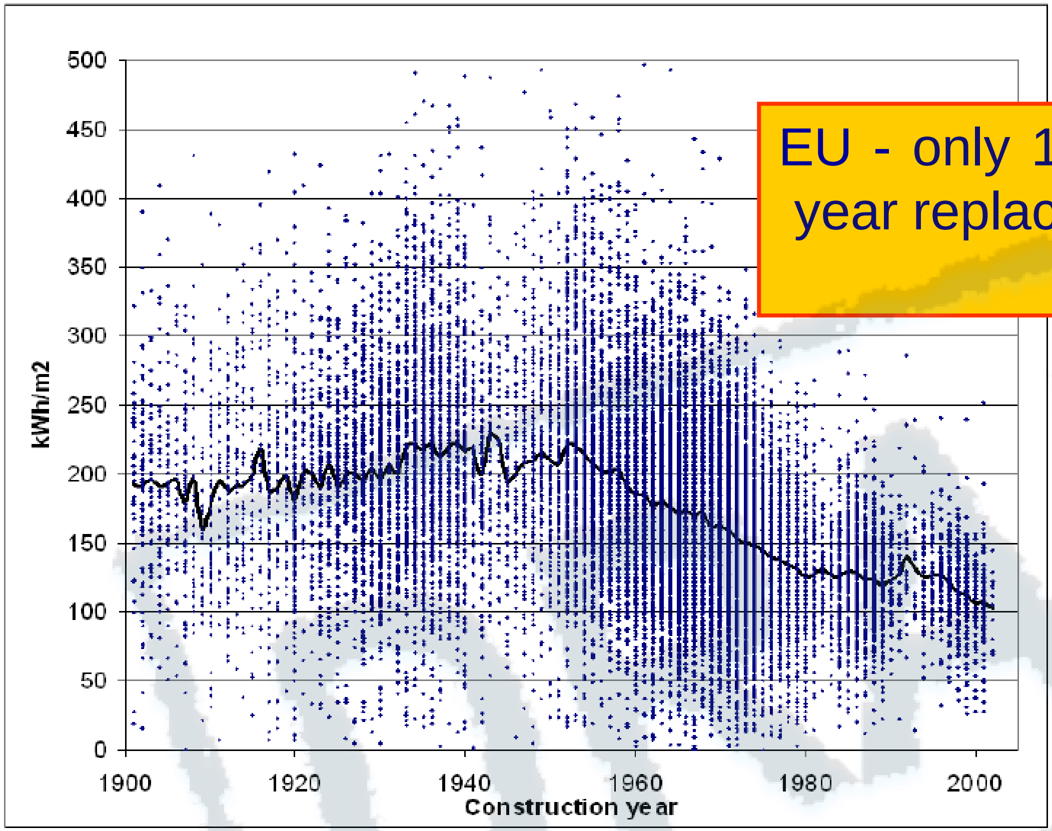


Figure 5 Mean and 95% confidence interval for the actual energy consumption (MJ/m2), total expected energy (MJ/m2) and expected energy for heating (MJ/m2) per EPC value

source: Guerra-Santin 2010

Issue – many existing buildings



EU - only 1% (heated floor area) per year replaced by new construction

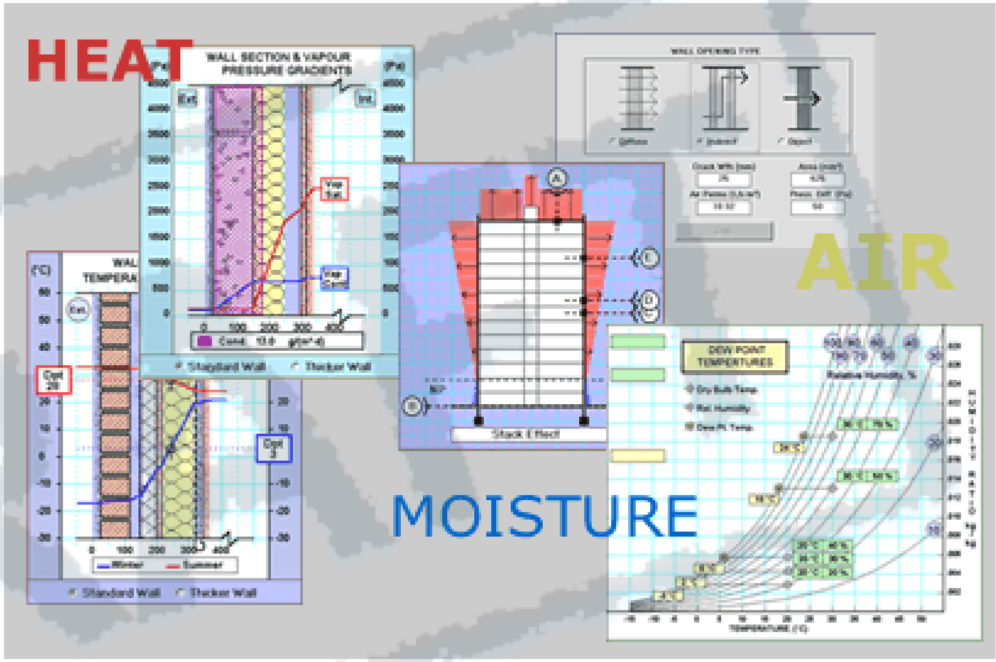
2020 2050

Figure 2 Yearly natural gas consumption kWh/m² in 2003 for Danish single-family houses related to construction year and the median. The solid line is the locus of the medians of all the individual observations for each year and the dots are the individual observations

source: Kjaerby ea 2010

Traditional tools

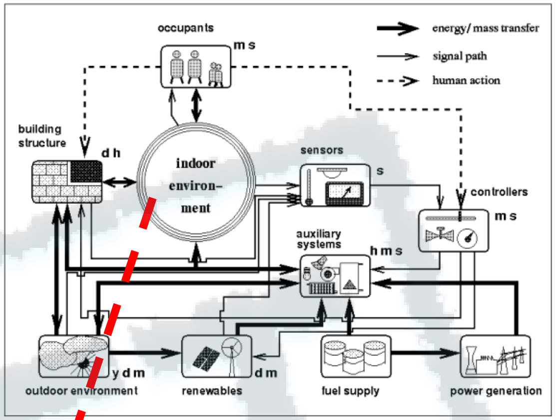
- **mono-disciplinary**
- **solution oriented**
- **narrow scope**
- **static**
- **extreme conditions**
- **analytical methods (exact solution of very simplified model of reality)**

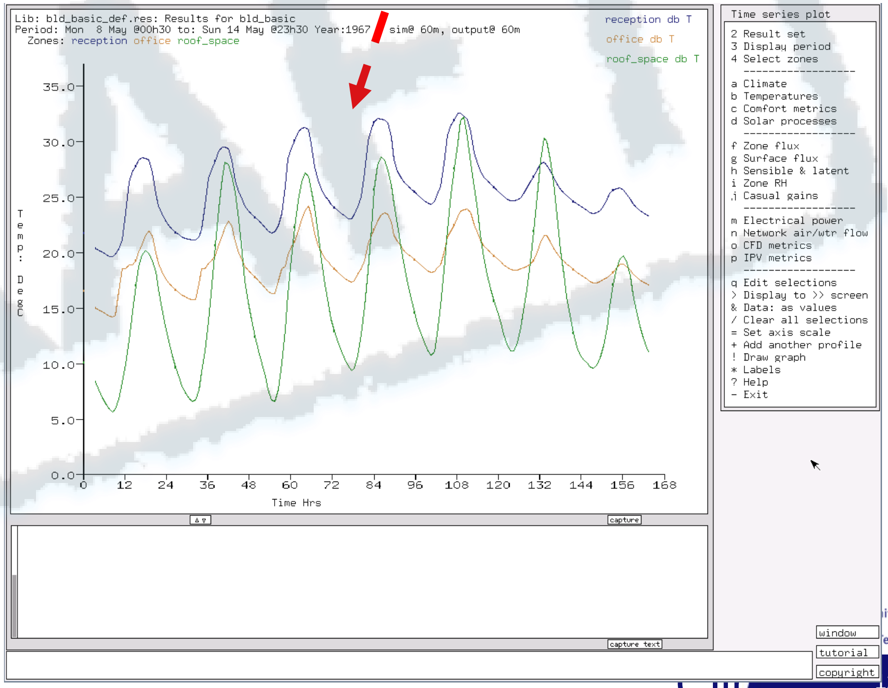


source: www.virtual-north.com

Simulation tools

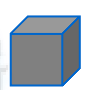
- **multi-disciplinary**
- **problem oriented**
- **wide(r) scope**
- **dynamic**
- **all conditions**
- **numerical methods (approximate solution of realistic model of reality)**



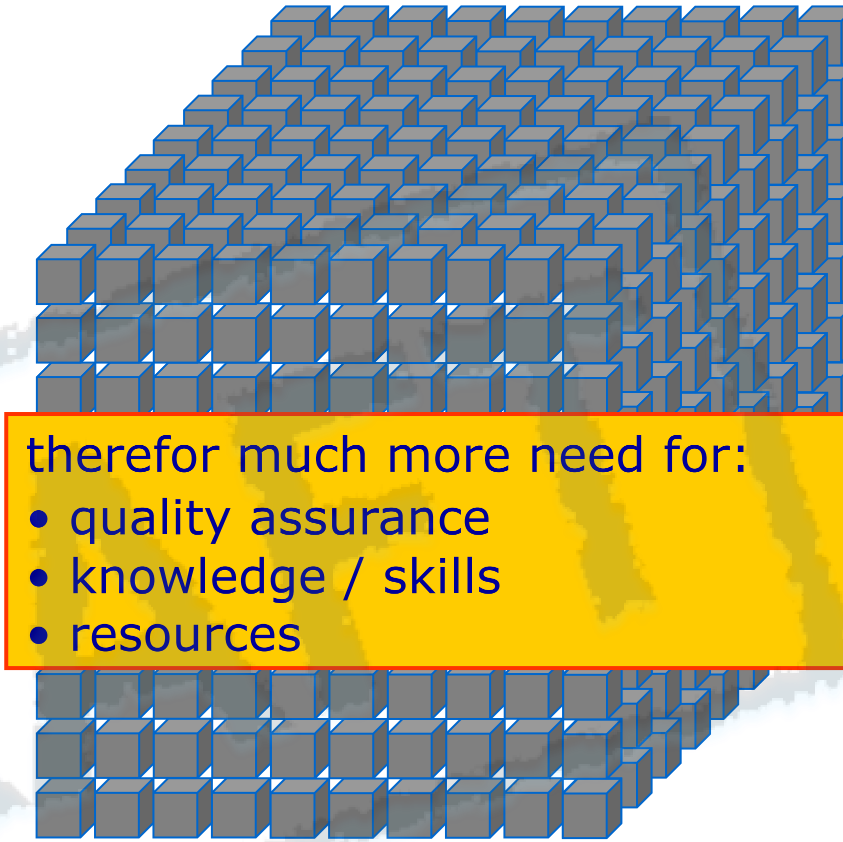


What is the difference ?

fundamental difference between traditional and simulation tools is in the **complexity**



traditional models
– perhaps 10 variables

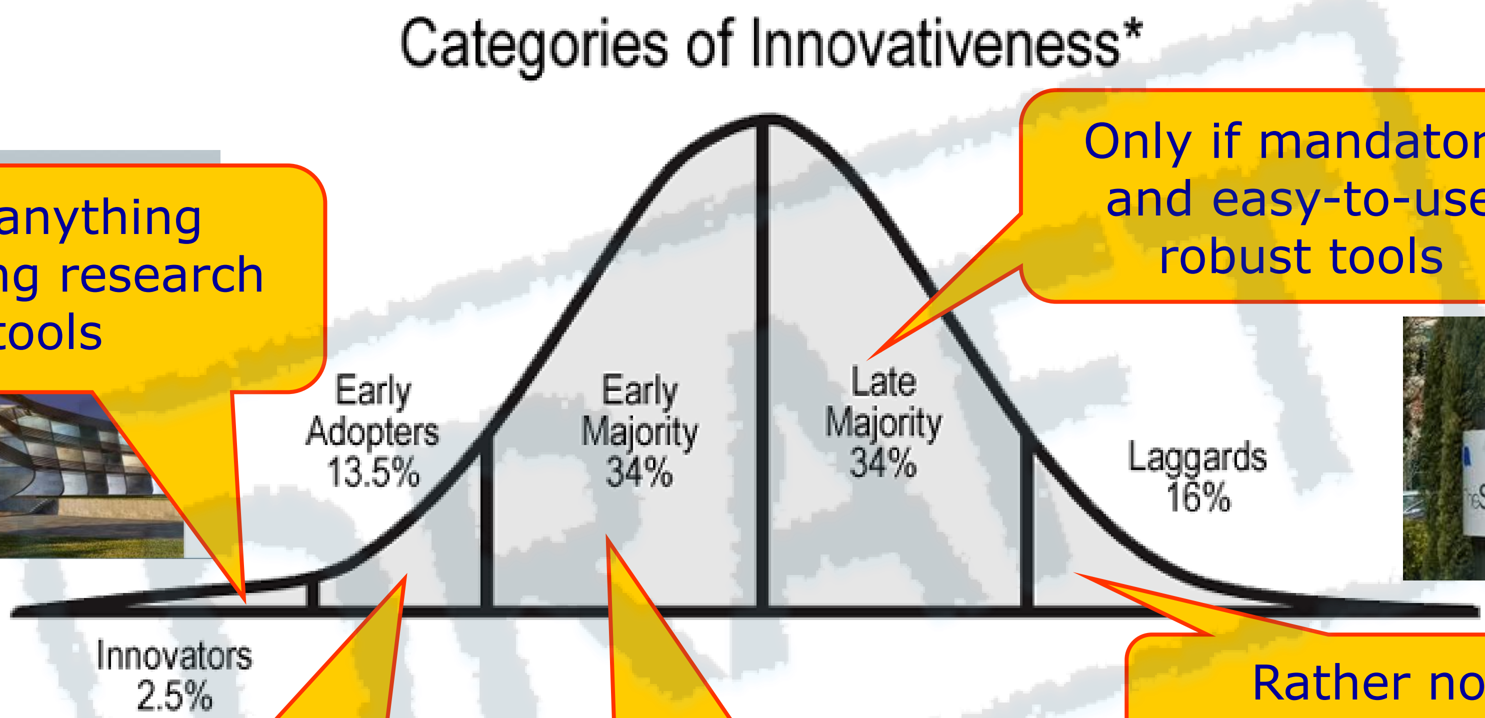


therefor much more need for:
- quality assurance
- knowledge / skills
- resources

computer simulation
– often > 10,000 variables

source: IBPSA-USA

Building simulation user types



Use anything including research tools

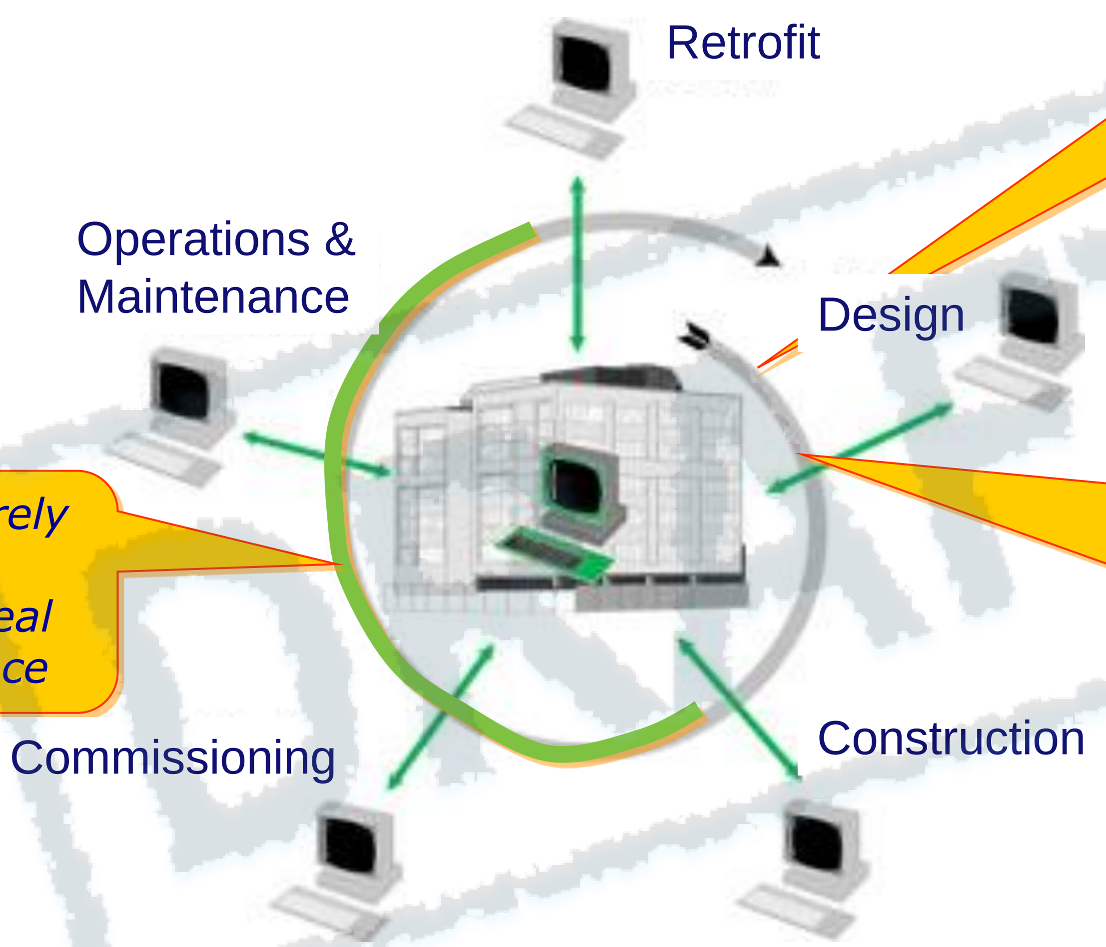
Only if mandatory and easy-to-use robust tools

Eager for flexible / expandable tools

Want easy-to-use and robust tools

Rather no simulation at all

Simulation in the building life-cycle



while early design decisions have much more impact

it is mainly used for design development + code compliance

and it is rarely used to optimize real performance

source: eetdnews.lbl.gov

Building simulation challenges

- Quality assurance
  - Educate and certify users
  - Develop application procedures
  - Increase physical validity of tools
- Provide better design support
  - Early phase design support
  - Multi-scale (construction detail … district level)
  - Uncertainty and sensitivity analysis
  - Robustness analysis (use/ environmental scenarios, …)
  - Optimization under uncertainty
  - Inverse approach (what if => how to)
  - Multi-physics (power flow modeling, …)
  - Integrate in design process (BIM, process modeling, …)
- Building operation and management support
  - Accurate in-use energy consumption prediction
  - Model predictive (supervisory mimo) control

More complex is not always better…..

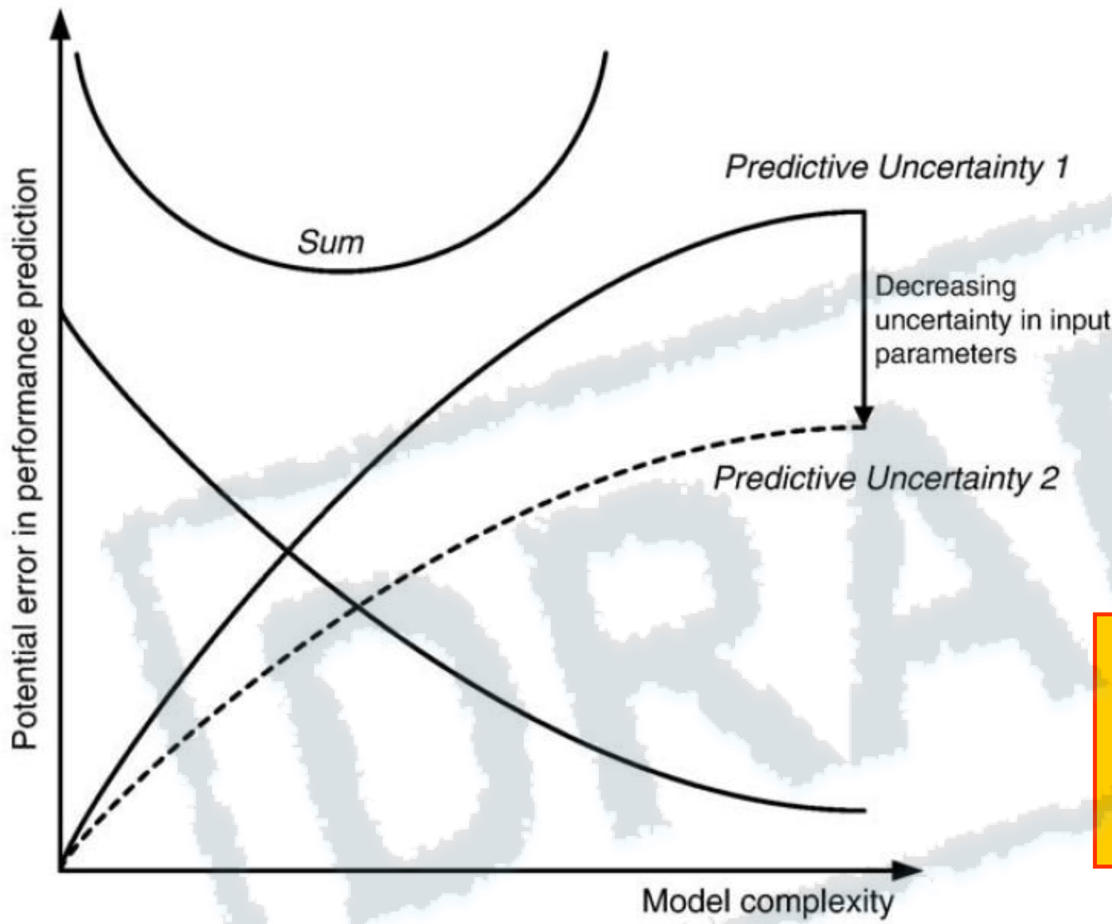


Fig. 3. Model uncertainty vs. complexity.

source: Trcka & Hensen 2010

"Einstein's principle":
a model should be
as simple as possible,
but not simpler

Simulation approach - issues

- Consistency (person to person, program to program)
- Time & cost (hard- + software, training, project hours)
- Accuracy (but simpler methods have bigger issues)
- Enforcement when “mandatory”
- Maintenance
  - Changes in standards
  - Bug fixes
    - User interface
    - Simulation engine

Quality Assurance (QA)?

- QA is all about developing confidence in the predictions of simulation tools
- we need to be confident that our models are providing an "accurate" representation of how a building or system will behave in reality
- this is important as we are basing design decisions on the results from simulations
- one of the main mechanisms to improve the quality of a simulation tool is to undertake rigorous validation
- however as we will see later validation is only part of the quality picture

Validation in Building Simulation

- **the validation of building simulation programs is a challenging field that has existed almost as long as building simulation itself**
- **extensive validation efforts have been conducted under the auspices of:**
  - **the International Energy Agency (IEA)**
  - **the American Society for Heating Refrigeration and Air-Conditioning Engineers (ASHRAE)**
  - **the European Committee for Standardization (CEN)**
- **the aim of these efforts was to create methodologies, tests, and standards to verify the accuracy and reliability of building simulation programs**

Validation

- **validation is a means to diagnose *internal sources of error* in simulation codes**
- **Judkoff et al. [1983] classify these errors in three groups:**
  - **differences between the actual thermal transfer mechanisms taking place in reality and the simplified model of those physical processes;**
  - **errors or inaccuracies in the mathematical solution of the models; and**
  - **coding errors**

R. Judkoff, D. Wortman, B. O'Doherty, and J. Burch. A methodology for validating building energy analysis simulations. Technical Report TR-254-1508, Solar Energy Research Institute, Golden USA, 1983.

Validation

- **Judkoff and Neymark [1995] proposed three primary validation approaches to check for internal errors:**
  - **analytical verification;**
  - **empirical validation; and**
  - **comparative testing**

R. Judkoff and J. Neymark. International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method. IEA/ECBCS Annex 21 Subtask C and IEA/SHC Task 12 Subtask B Report, 1995.

Analytical Verification

- in analytical verification, the program output is compared to a well known analytical solution for a problem that isolates a single heat transfer mechanism
- typically this necessitates very simple boundary conditions
- although analytical verification is limited to simple cases for which analytic solutions are known, it provides an exact standard for comparison

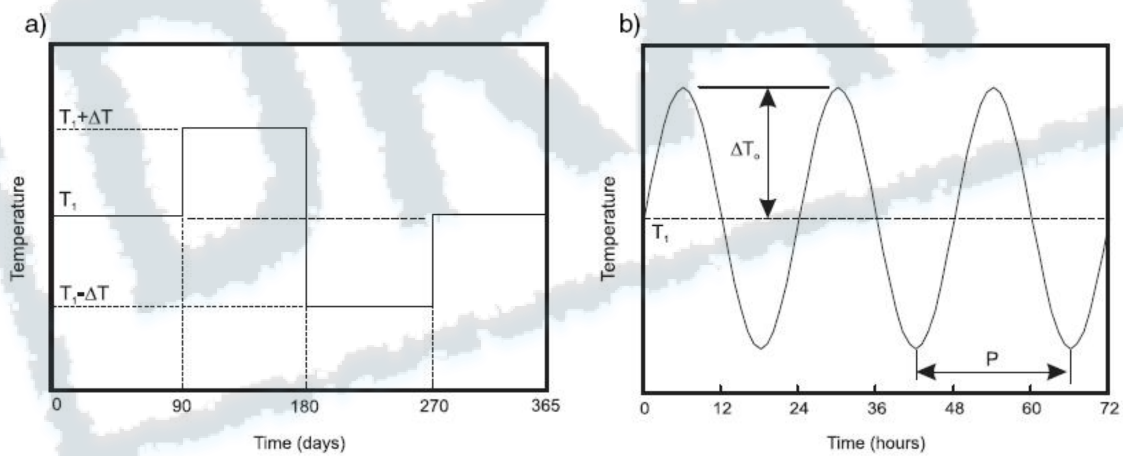
Analytical Test – example

from Xiao et al. Transient conduction analytical solutions for testing of building energy simulation programs, Building Serv. Eng. Res. Technol. 26,3 (2005) pp. 229/247

- **ESP-r and Blast were compared against solutions of the governing thermal diffusivity equation – modelling transient conduction through fabric**

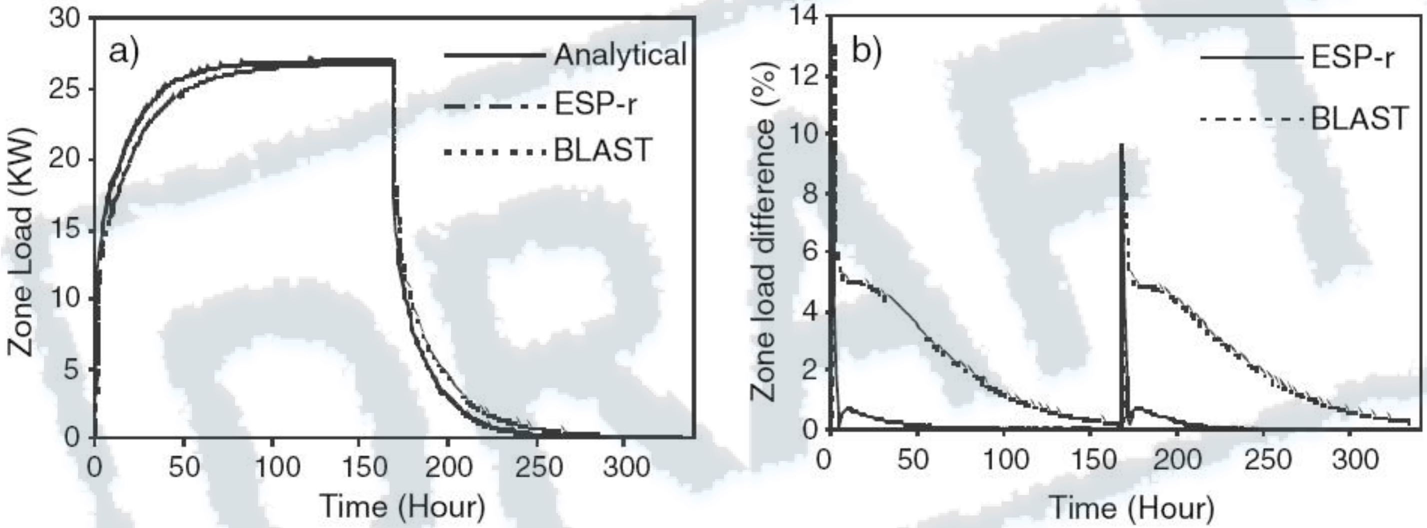
$$\frac{\partial^2 T(x,t)}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T(x,t)}{\partial t}$$

- **tests involved simplified boundary conditions**



Analytical Tests

- **results from simulation models compared to analytical solutions**



- **simulation models used are simple boxes with basic constructions**

Analytical Tests

- **by their nature analytical tests only exercise a small part of a building simulation model**
- **the situations modelled need to be simple enough for manual analysis and calculation**
- **provides a useful indication if the program captures the basic physics of a situation correctly**

Empirical Validation

- program outputs are compared to monitored data during empirical validation
- the measurements can be made in real buildings, controlled test cells, or in a laboratory
- the design and operation of experiments leading to high-quality data sets is complex and expensive, thus restricting this approach to a limited number of cases
- the characterization of some of the more complex physical processes treated by building simulation programs (such as heat transfer with the ground, infiltration, indoor air motion, and convection) is often excluded due to measurement difficulties and uncertainty

Empirical Validation - example

Just testing two
of the many
component models
in a simulation
software:
dynamics of a radiator
represented by
a 2 node or
an 8 node model

Source: Hensen 1991

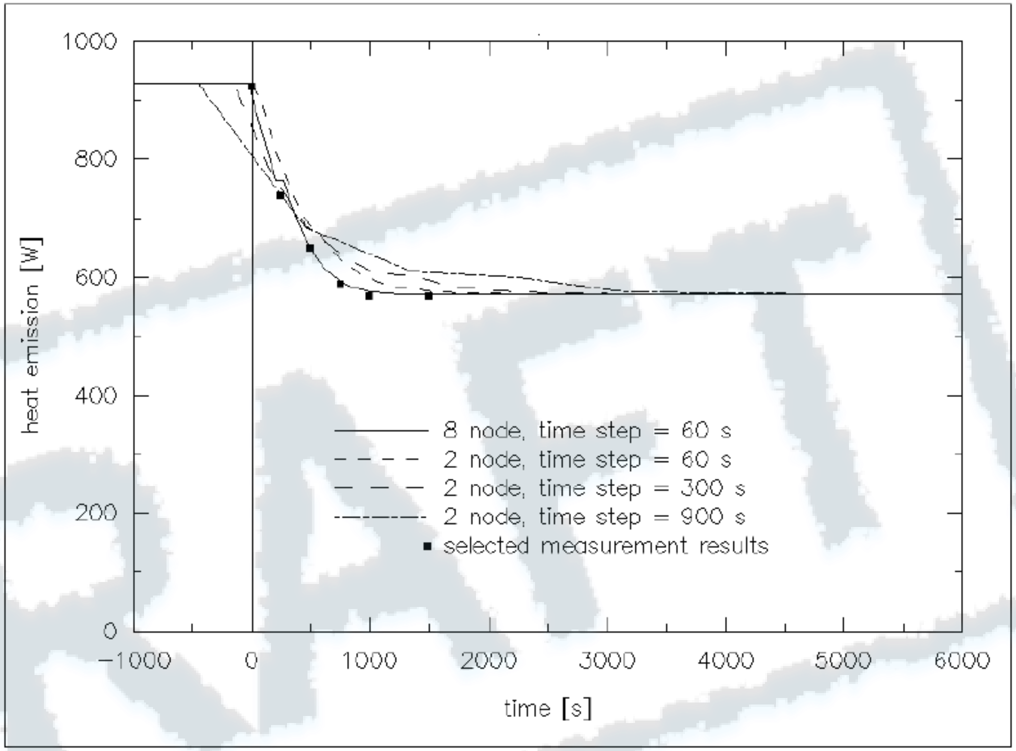


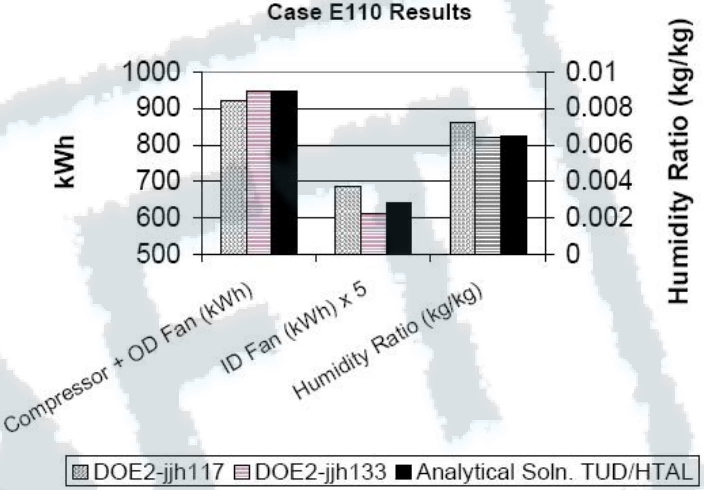
Figure 6.4 Radiator heat emission following a step change in inlet water temperature (91.0 -> $70.4°C$), as computed by *bps* with the two radiator models using different simulation time-steps. To the right are measured (dots) and computed (+) results as presented by Crommelin and Ham (1982). Some measurement results were copied to the left graph.

Empirical Validation

- provides a rigorous test of performance
- however experiments need to be designed and undertaken specifically for the purposes of collection of validation data
- ….otherwise data is often not useful for validation
- expensive and very time consuming process

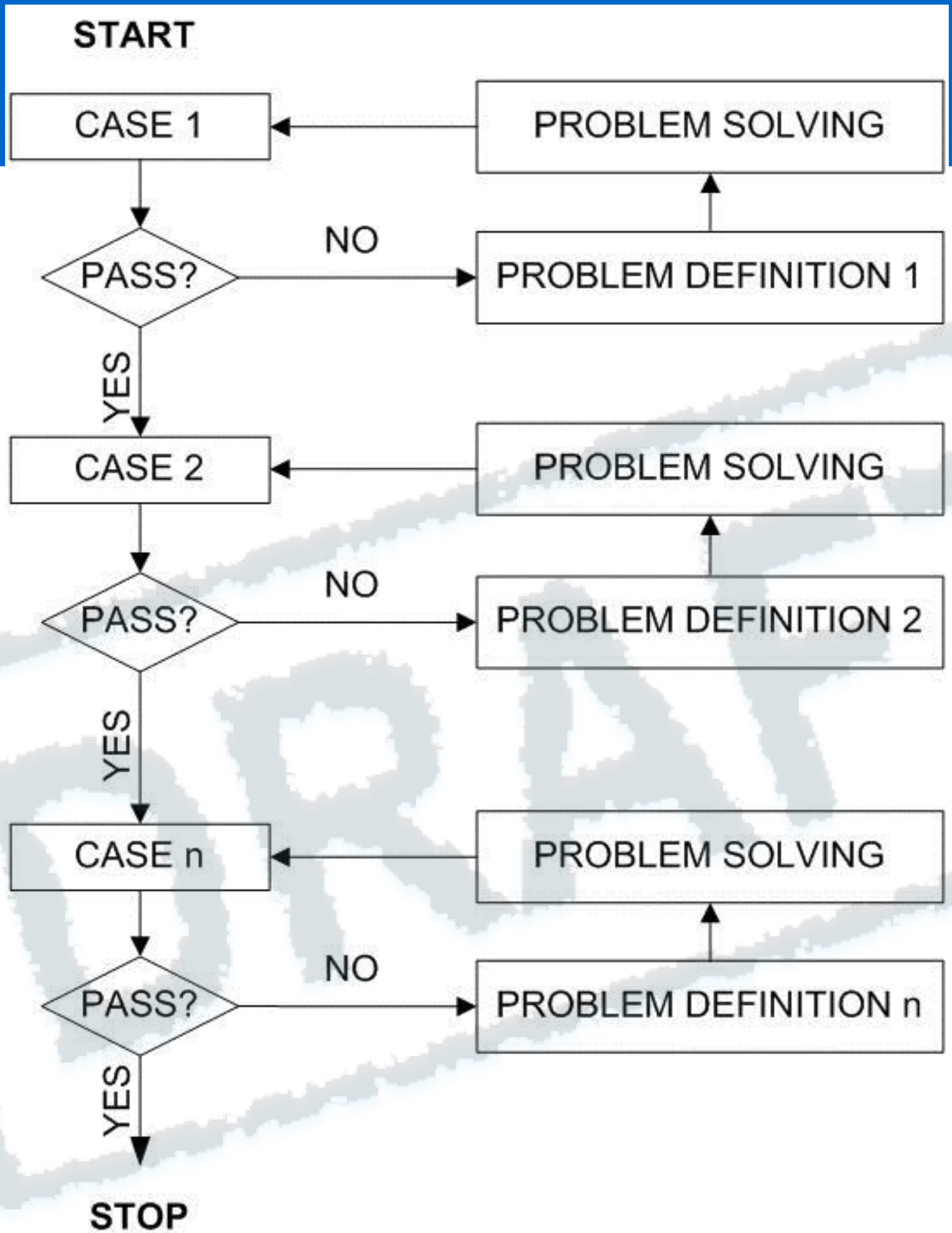
Inter-Model Comparison

- a program is compared to itself or other programs during comparative testing
- this includes both sensitivity testing and inter-model comparisons
- this approach enables inexpensive comparisons at many levels of complexity
- however, in practice the difficulties in equivalencing program inputs and outputs can lead to significant uncertainty in performing inter-model comparisons
- comparative testing also provides no absolute measurement of program accuracy; while different programs may make similar predictions, all of these predictions may be incorrect

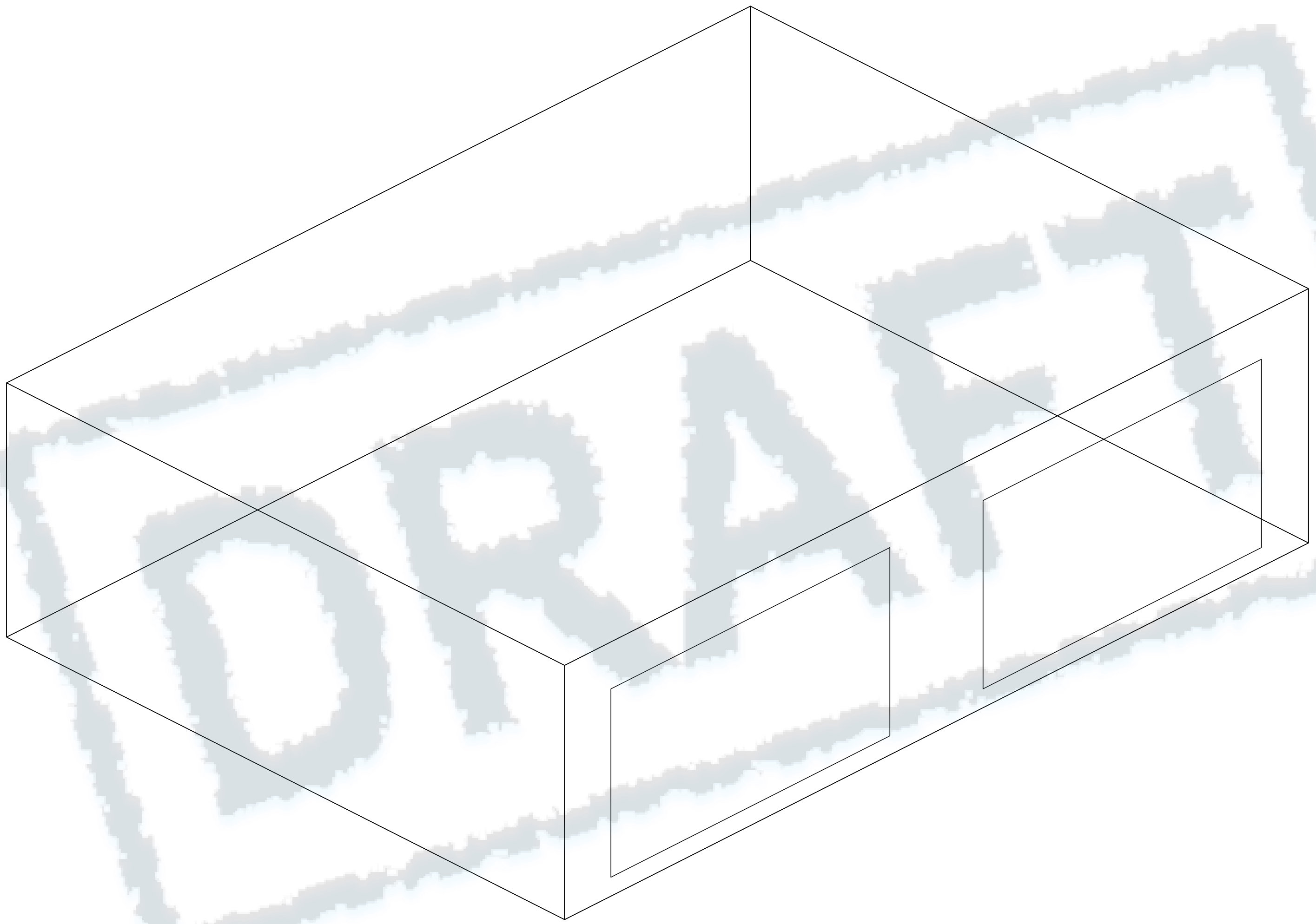


BESTEST => ASHRAE SMOT 140

- **Intermodel comparative test**
  - **Comparison with several other tools which are usually better familiar to the validators (ESP-r, TRNSYS, BLAST, DOE2…)**
- **Well defined cases**
  - **Cases progress systematically from the extreme simple to the relatively realistic**
- **Specific problem detection - diagnosis**

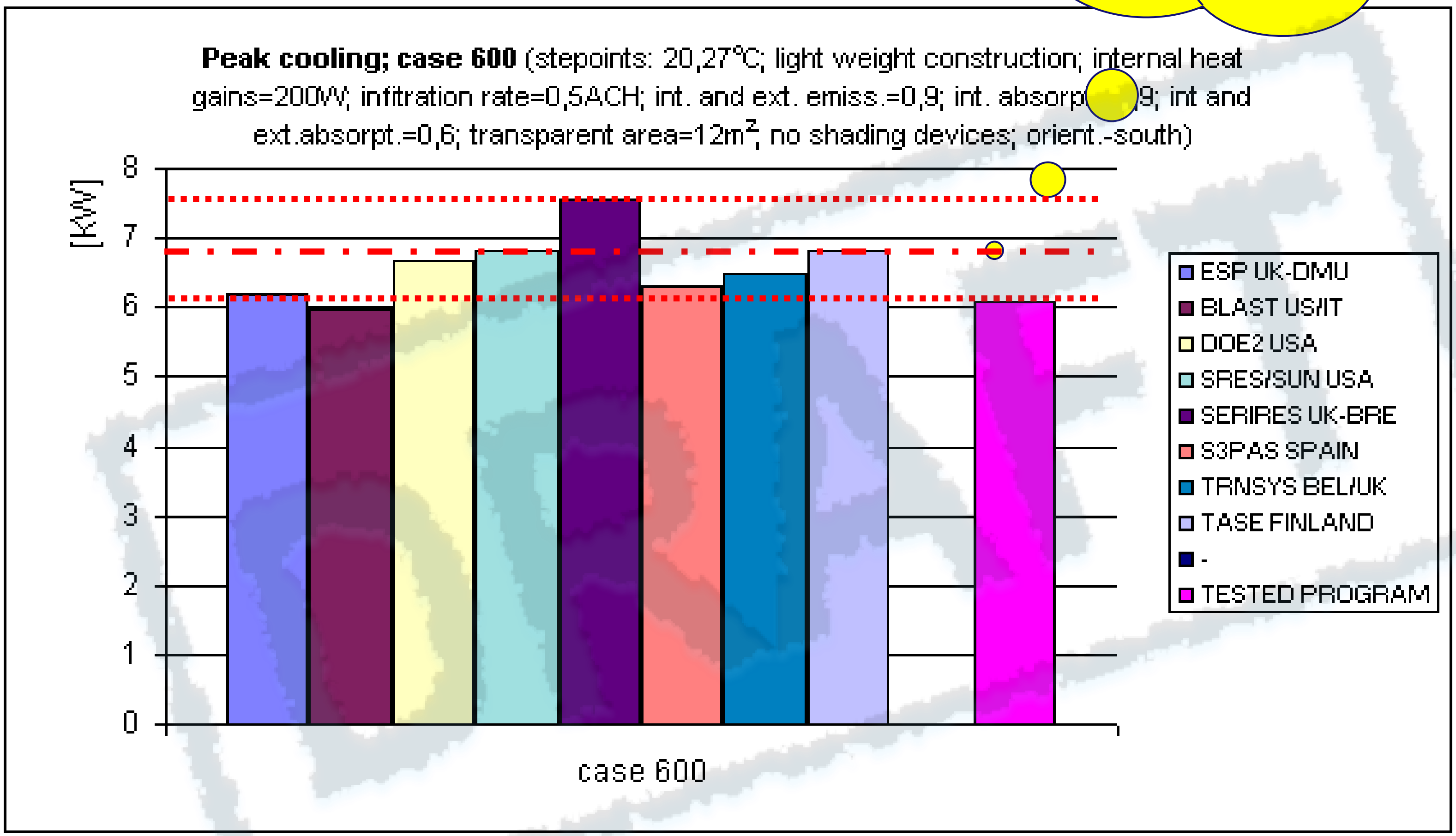

START
CASE 1
PROBLEM SOLVING
PASS?
NO
PROBLEM DEFINITION 1
YES
CASE 2
PROBLEM SOLVING
PASS?
NO
PROBLEM DEFINITION 2
YES
CASE n
PROBLEM SOLVING
PASS?
NO
PROBLEM DEFINITION n
YES
STOP

Example - Case 600

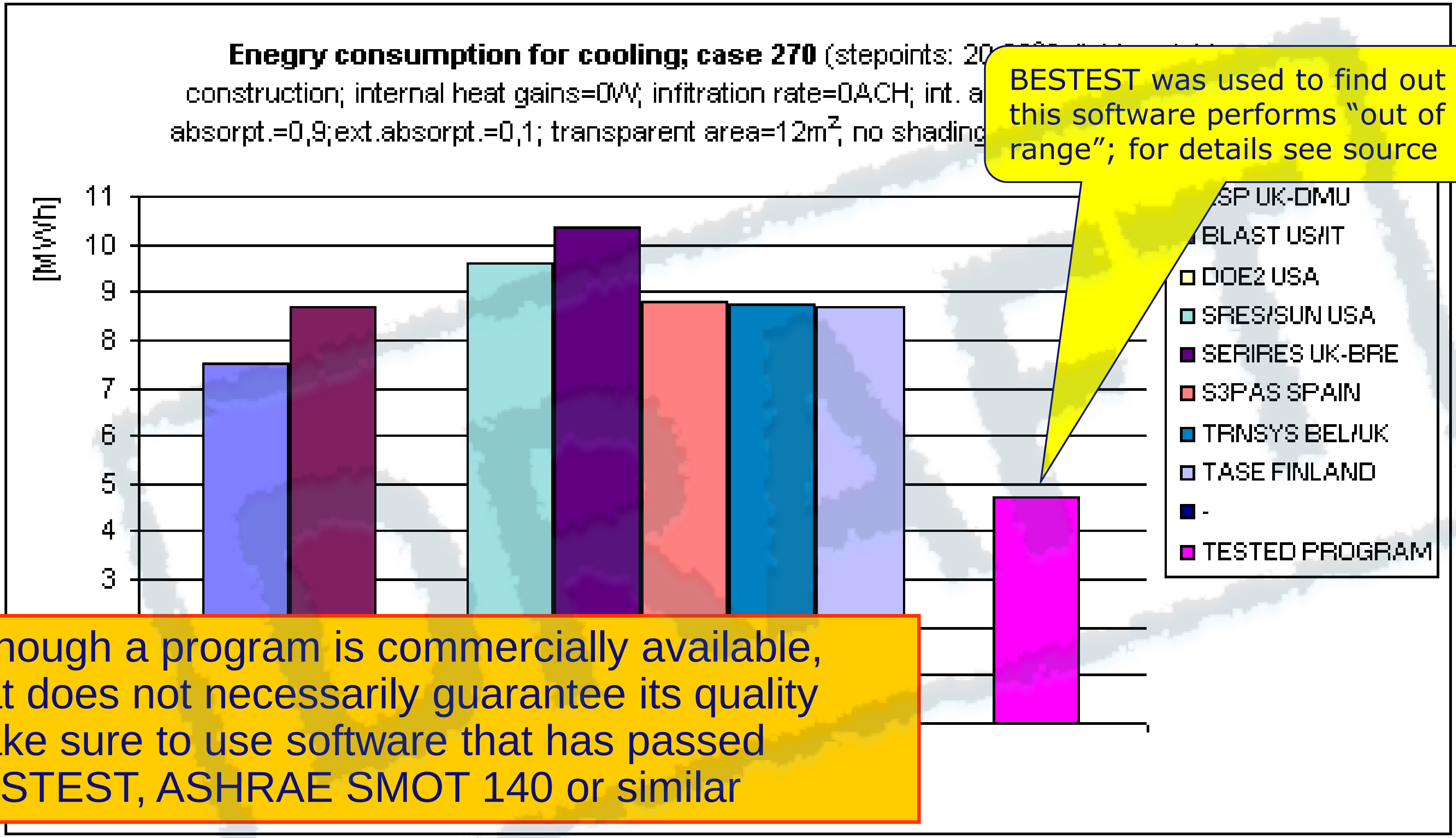


Results – peak cooling dema…

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



Results – annual cooling [MWh]



BESTEST was used to find out why this software performs "out of range"; for details see source

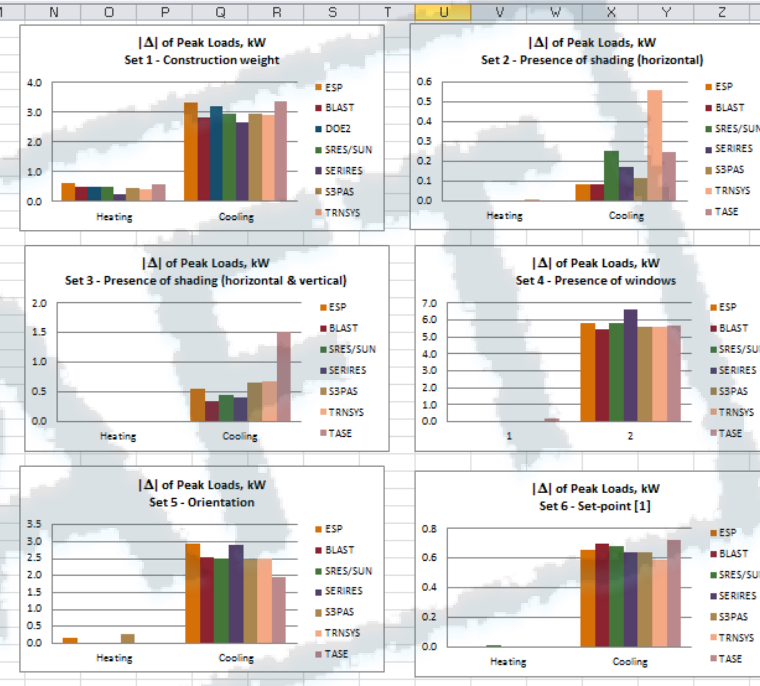
Although a program is commercially available, that does not necessarily guarantee its quality
Make sure to use software that has passed BESTEST, ASHRAE SMOT 140 or similar

Tested program = Ecotect

Source: Hensen and Radosevic 2004

Relative differences – better?

	Set		Case	ESP	BLAST	DOE2	RES/SU	SERIRES	S3PAS	TRNSYS	TASE	Comment
1	Set		Case	Simulation tools								Comment
2				ESP	BLAST	DOE2	RES/SU	SERIRES	S3PAS	TRNSYS	TASE	
3	1 – Construction weight	Peak Heating Load, kW	600	3.437	3.940	4.045	4.258	4.307	4.037	3.931	4.354	Light
4			900	2.850	3.453	3.557	3.760	4.081	3.608	3.517	3.797	Heavy
5			|Δ|	**0.587**	**0.487**	**0.488**	**0.498**	**0.226**	**0.429**	**0.414**	**0.557**	
6		Peak Cooling Load, kW	600	6.194	5.965	6.656	6.827	7.551	6.286	6.486	6.812	Light
7			900	2.888	3.155	3.458	3.871	4.901	3.334	3.567	3.457	Heavy
8			|Δ|	**3.306**	**2.810**	**3.198**	**2.956**	**2.650**	**2.952**	**2.919**	**3.355**	
9												
10	2 – Presence of Shading Device (Horizontal)	Peak Heating Load, kW	270	2.863	3.277		3.670	3.714	3.340	3.336	3.738	Absent
11			290	2.863	3.277		3.670	3.714	3.340	3.328	3.738	Present
12			|Δ|	**0.000**	**0.000**		**0.000**	**0.000**	**0.000**	**0.008**	**0.000**	
13		Peak Cooling Load, kW	270	6.356	6.641		7.163	7.967	6.819	6.764	6.867	Absent
14			290	6.269	6.555		6.910	7.793	6.700	6.203	6.621	Present
15			|Δ|	**0.087**	**0.086**		**0.253**	**0.174**	**0.119**	**0.561**	**0.246**	
16												
17	3 – Presence of Shading Device (Horizontal & Vertical)	Peak Heating Load, kW	300	3.014	3.276		3.685	3.714	3.599	3.328	3.770	Absent
18			310	3.015	3.277		3.672	3.714	3.599	3.328	3.771	Present
19			|Δ|	**0.001**	**0.001**		**0.013**	**0.000**	**0.000**	**0.000**	**0.001**	
20		Peak Cooling Load, kW	300	3.404	4.093		4.642	5.072	4.336	4.278	4.929	Absent
21			310	2.848	3.749		4.186	4.666	3.669	3.589	3.425	Present
22			|Δ|	**0.556**	**0.344**		**0.456**	**0.406**	**0.667**	**0.689**	**1.504**	
23												
24	4 – Presence of Windows	Peak Heating Load, kW	220	2.867	3.280	3.465	3.695	3.709	3.348	3.336	3.520	Absent
25			270	2.863	3.277		3.670	3.714	3.340	3.336	3.738	Present
26			|Δ|	**0.004**	**0.003**	–	**0.025**	**0.005**	**0.008**	**0.000**	**0.218**	
27		Peak Cooling Load, kW	220	0.560	1.166	0.937	1.340	1.342	1.215	1.179	1.213	Absent
28			270	6.356	6.641		7.163	7.967	6.819	6.764	6.867	Present
29			|Δ|	**5.796**	**5.475**	–	**5.823**	**6.625**	**5.604**	**5.585**	**5.654**	
30												
31	5 – Orientation	Peak Heating Load, kW	270	2.863	3.277		3.670	3.714	3.340	3.336	3.738	S
32			300	3.014	3.276		3.685	3.714	3.599	3.328	3.770	E/W
33			|Δ|	**0.151**	**0.001**		**0.015**	**0.000**	**0.259**	**0.008**	**0.032**	
34		Peak Cooling Load, kW	270	6.356	6.641		7.163	7.967	6.819	6.764	6.867	S
35			300	3.404	4.093		4.642	5.072	4.336	4.278	4.929	E/W
36			|Δ|	**2.952**	**2.548**		**2.521**	**2.895**	**2.483**	**2.486**	**1.938**	
37												
38		Peak Heating Load, kW	270	2.863	3.277		3.670	3.714	3.340	3.336	3.738	20, 20
39			320	2.861	3.275		3.661	3.714	3.340	3.336	3.735	20, 27



Validation & Verification - summary

Method	Pros	Cons
Comparative	No input problem Any level of complexity Inexpensive & quick	No truth standard
Analytical	No input uncertainty Exact truth standard Inexpensive	No test of model Limitedno. cases
Empirical	Approximate "truth" Any level of complexity	Data uncertainty Expensive & time-consuming Limited number of cases

External Sources of Error

- finally …. the major sources of error in modelling ….
- the user
  - setting up the model, model abstraction, interpretation of data, data input, results interpretation, etc
- Guyon et al. (1997) showed variations of 40% in results from the same model but with different users
- quality can be improved by providing adequate training to the user
- and ensuring support, supervision and expertise are available

Guyon G, The role of the user in results obtained from simulation software program, in proc. BS'97 The International Building Simulation Conference, Prague, 1997

Quality Essentials – in summary

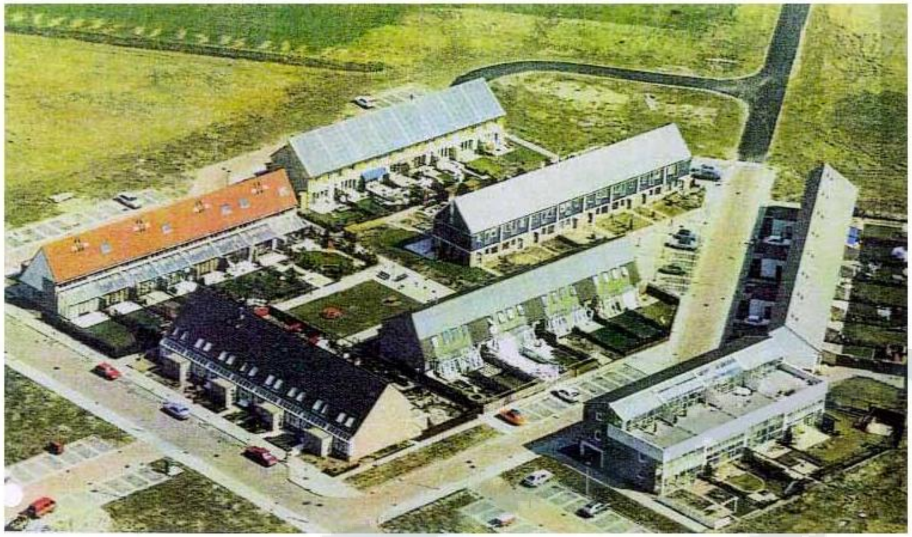
- Engineering essentials:
  - Knowledge and understanding of fundamentals and basic principles
  - Being able to creatively solve real world problems
  - By knowing which tools to use, when, why and how

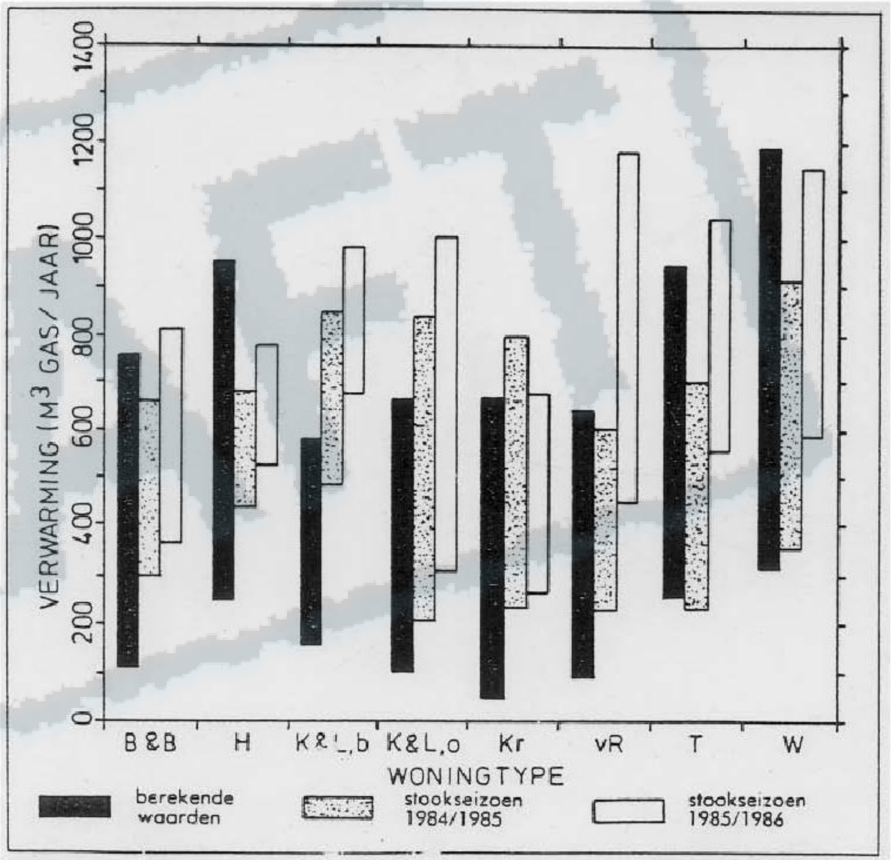
- Simulation = discipline (> s/w)
- Quality assurance through:
  - Appropriate level of resolution and complexity
  - Calibration of validated software
  - (Design) application methodology

Sources of uncertainty

- **Physical uncertainty**
- **Occupant behaviour**
- **Scenario uncertainty**
- **….**
- **….**

“Uncertainty analysis” (1984)

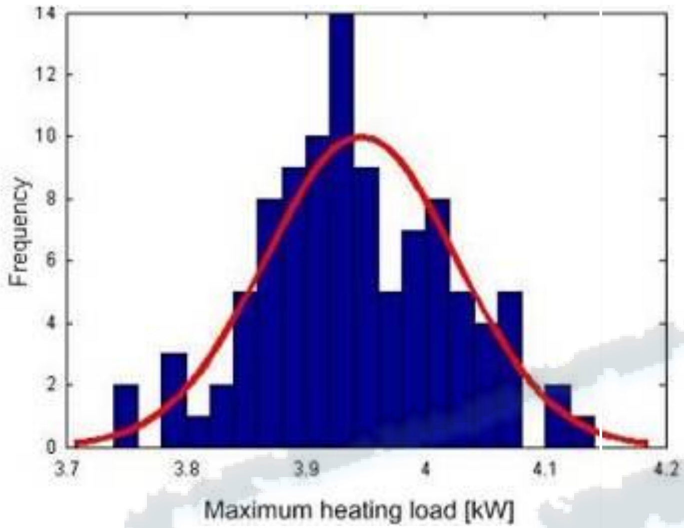


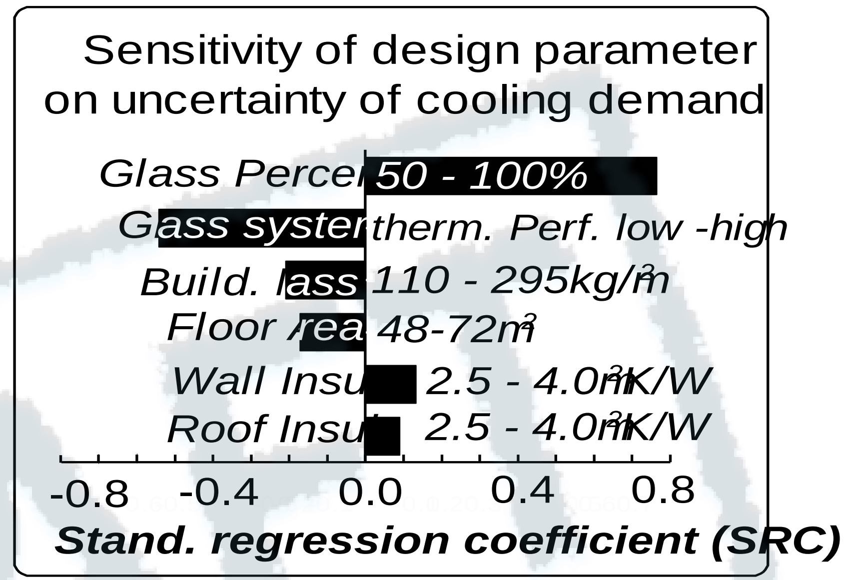


Variability due to (stochastic) occupant behaviour
in terms of Tset, Qint, ACR

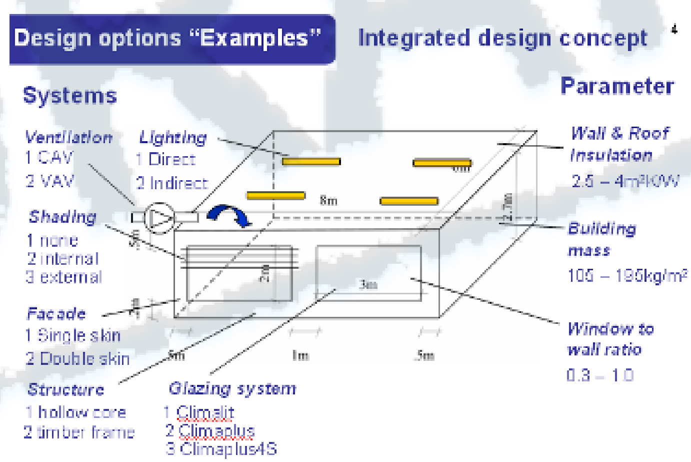
Uncertainty & sensitivity analysis

Variability due to physical parameter uncertainty

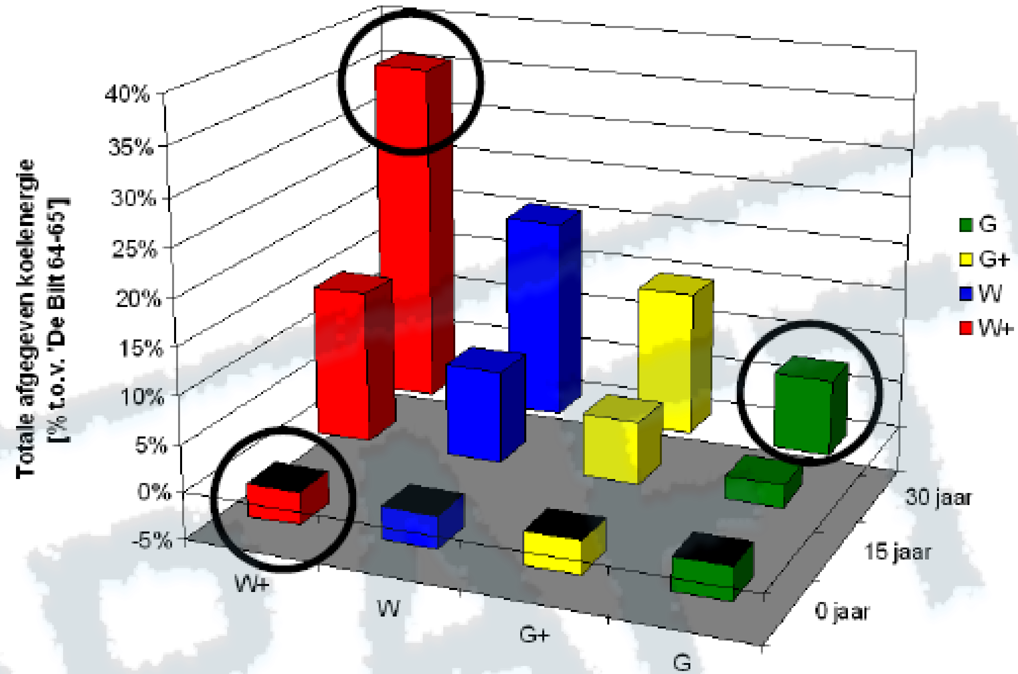


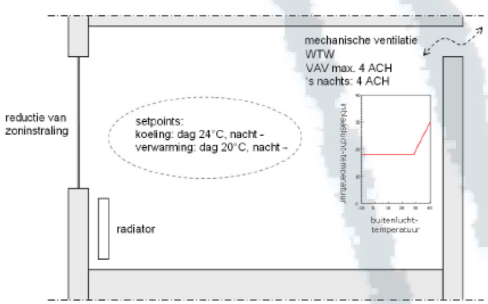


Source: Hopfe & Struck

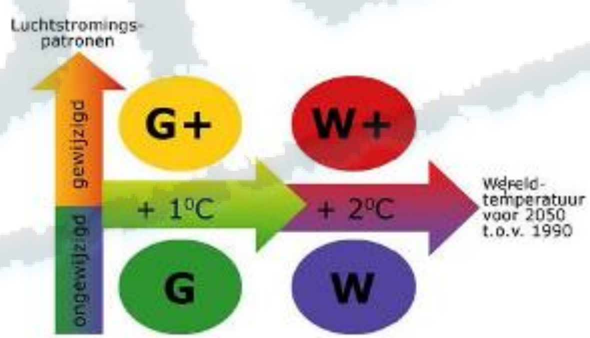


Uncertainty & robustness analysis





afgegeven koelenergie in % t.o.v. 'De Bilt 64-65', topkoeling-concept,



Source: Janneke Evers

Uncertainty & robustness analysis

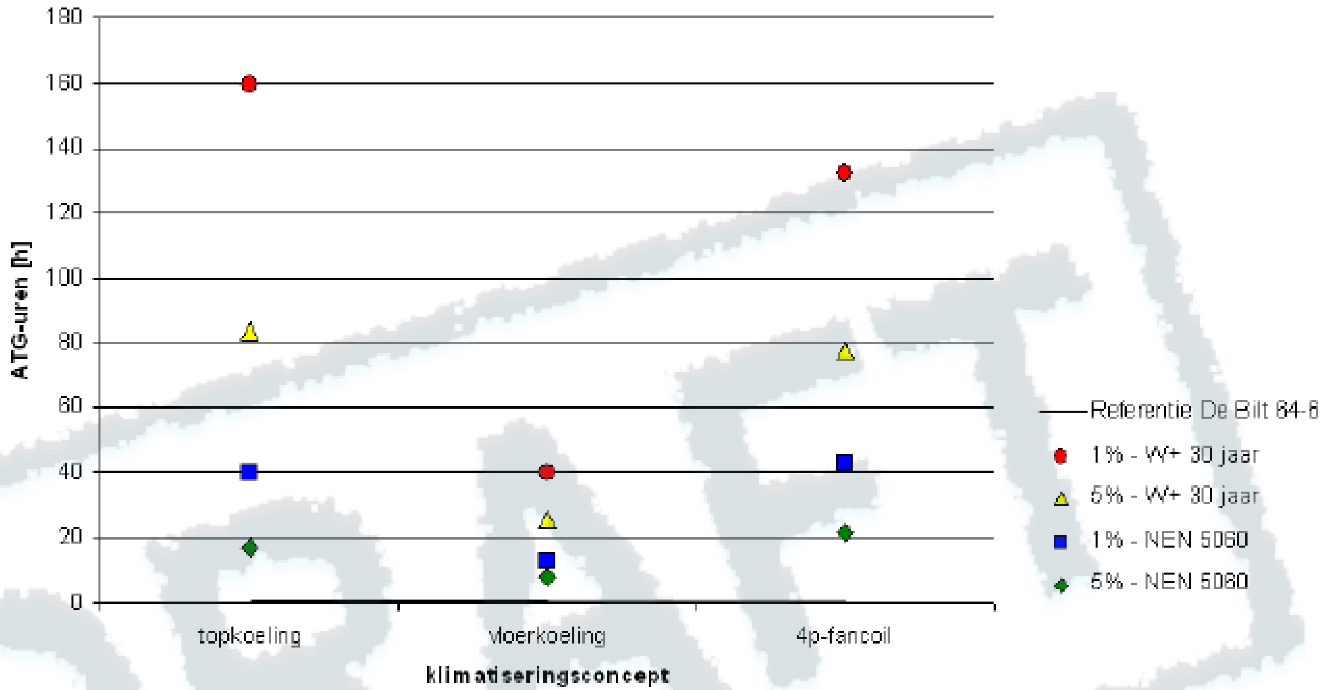
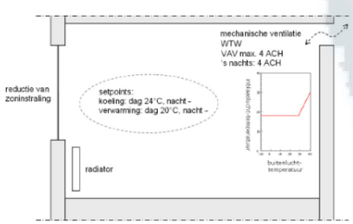
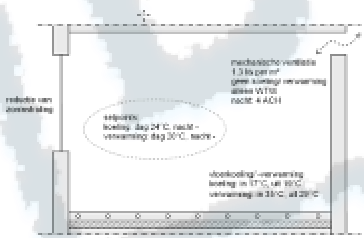
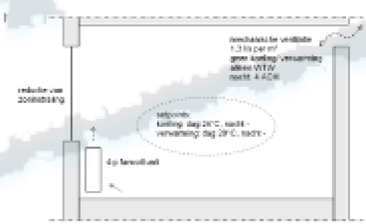


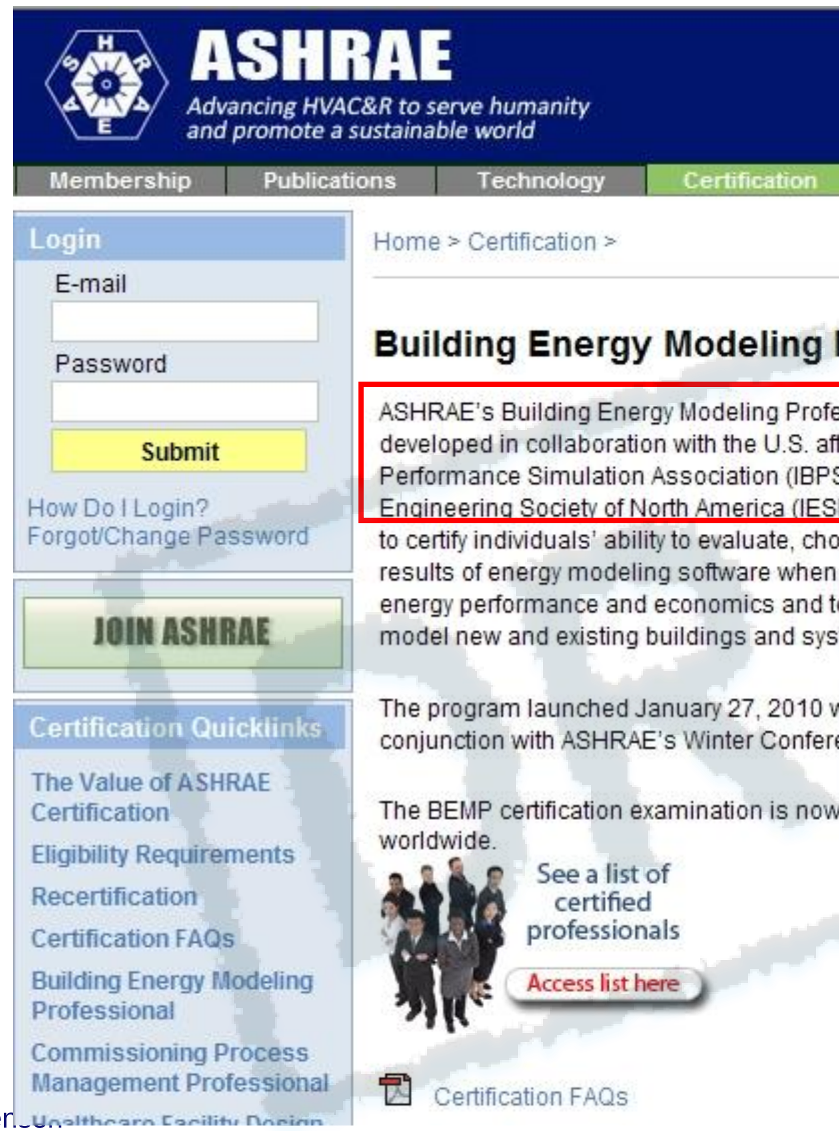
Fig. 6.4: Vergelijking van 3 klimatiseringsconcepten, ATG-uren, 'klimaatbestanden voor de toekomst', installatie gedimensioneerd op ATG-klasse B met 'De Bilt 64-65'

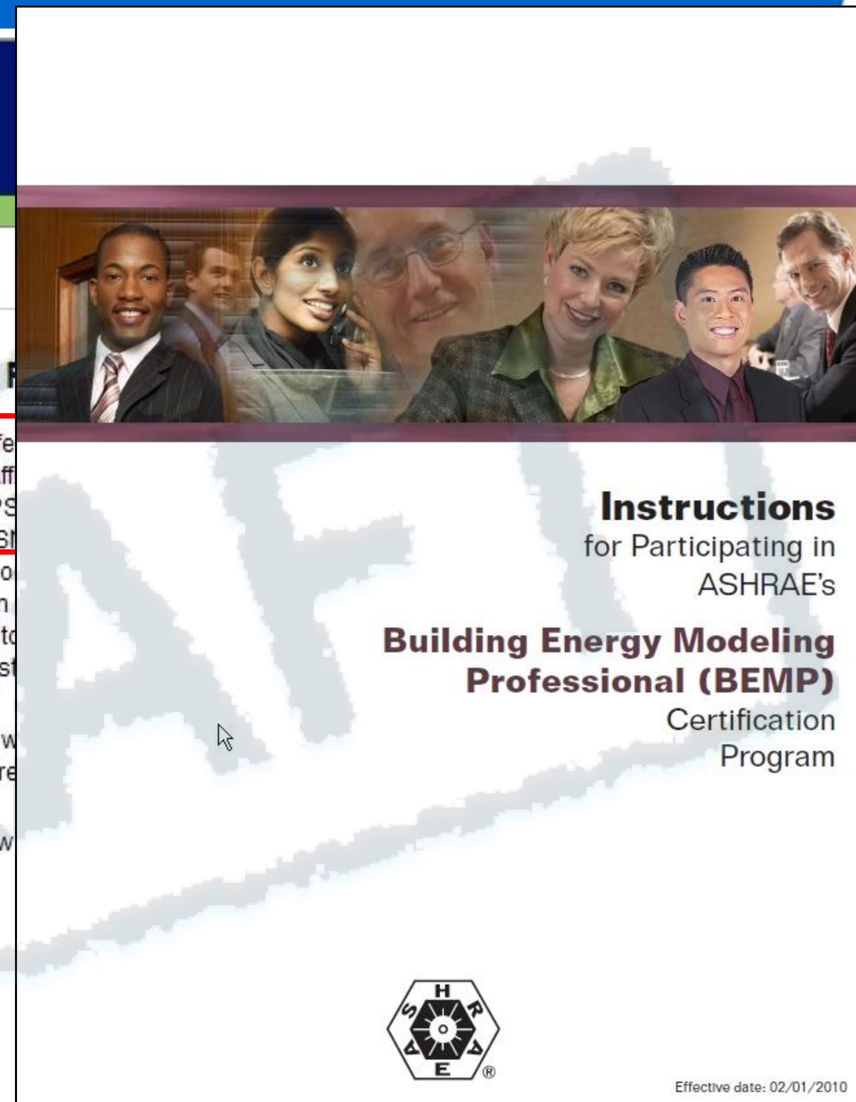






Simulation “user accuracy”





Quality assurance - summary

- Engineering essentials:
  - Knowledge and understanding of fundamentals and basic principles
  - Being able to creatively solve real world problems
  - By knowing which tools to use, when, why and how

- Simulation = discipline (> s/w)
- Quality assurance through:
  - Appropriate level of resolution and complexity
  - Calibration of validated software
  - (Design) application methodology

Conclusions

- **Main challenges: existing buildings, O&M, IEQ**
- **Simulation is a very promising technology for addressing major technical “sustainable building” challenges towards 2020 and beyond**
- **Simulation still needs many improvements, e.g.:**
  - **Quality assurance (tools, users & use)**
  - **Usefulness and integration in/ for performance based design and operation of buildings**
- **Opportunities for cooperation REHVA / IBPSA**
  - **R&D, Best Practice Examples, Guidebooks, Courses, Tool Accreditation, User Certification, …….**

www.IBPSA.or

Regional Affiliat
Home
About
Affiliates
IBPSA News
Events
Downloads/Links
Papers On-line
IBPSA Journal
References
Membership
Corporate Members
Mailing lists
IBPSA Awards
Contact
Sydney, Aus
For more info
IBPSA recent
SimBuild 20
website .
eSim Canad
information vis
Building Sir
papers look
Joe Clarke's
IBPSA Conference papers.
BUILDING PERFORMANCE SIMULATION FOR DESIGN AND OPERATION
Edited by Jan L. M. Hensen and Roberto Lamberts
ISSN: 1940-1493
nal of Building Performance Simulation
IBPSA
RNATIONAL BUILDING PERFORMANCE SIMULATION ASSOCIATION
Editors
Taylor & Francis
-Flanders, UAE and USA affiliates
gn and Operation, by Jan Hensen, Roberto
nd the contents list for JBPS vol 4 no 1
ISSN 1993-8586