The world needs building simulation : Are we ready ?

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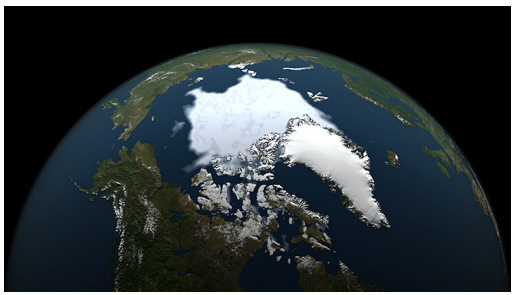
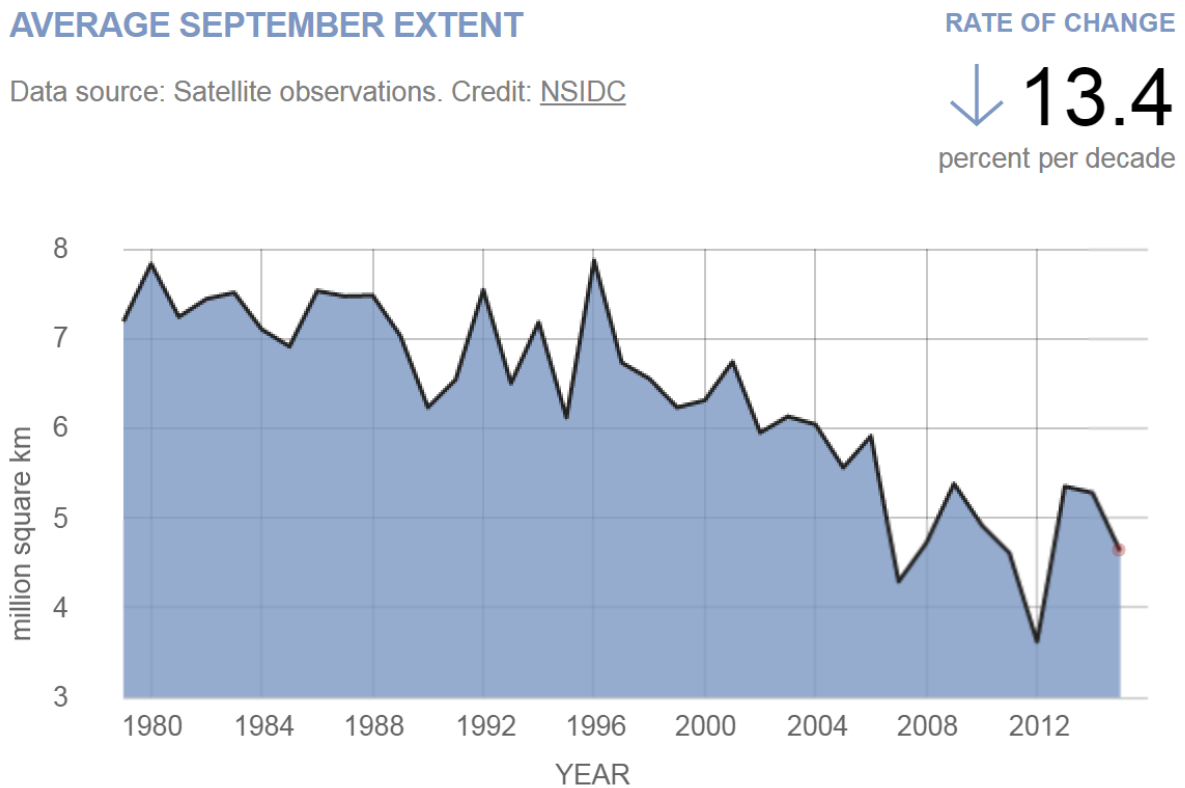
BSO 2016 BUILDING SIMULATION & OPTIMIZATION

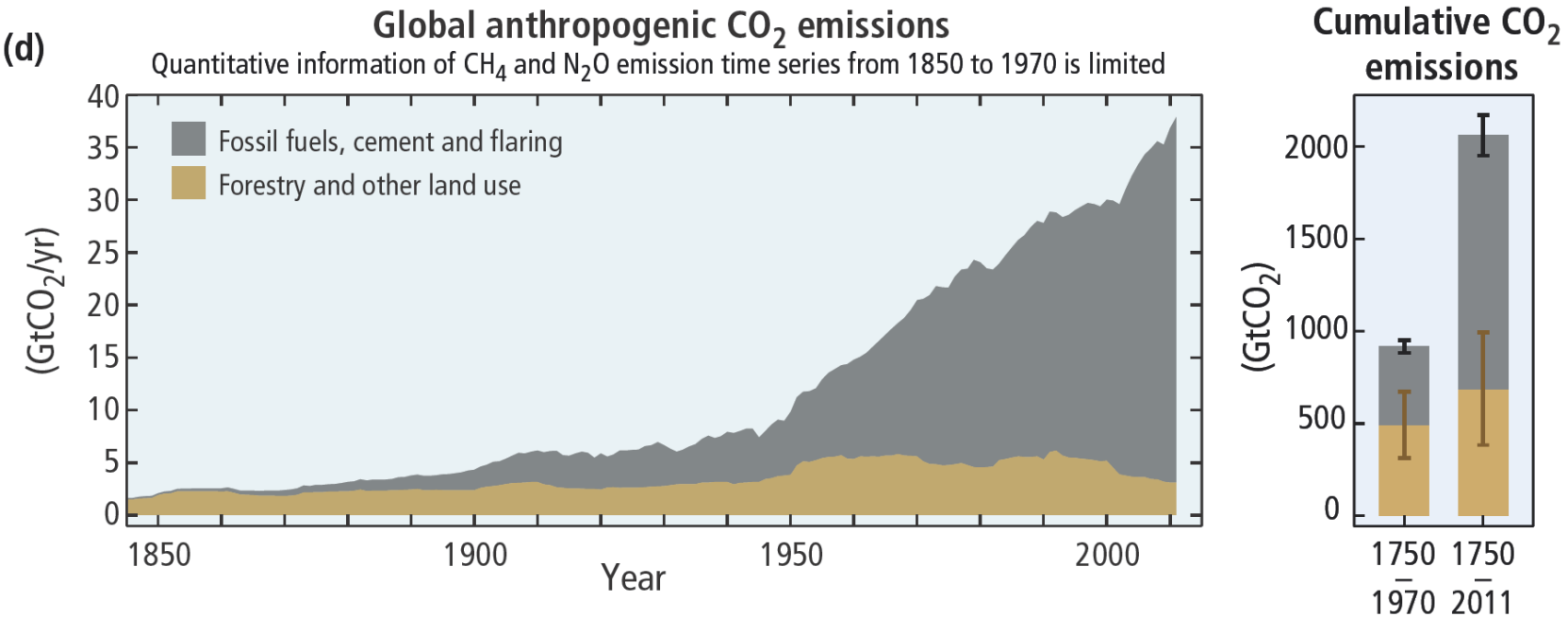
Climate change





Source : NASA.

Energy consumption is driving climate change



Source: Climate Change 2014: Synthesis Report, AR5, Intergovernmental Panel on Climate Change, 2015.

COP21 : The "Paris Agreement"

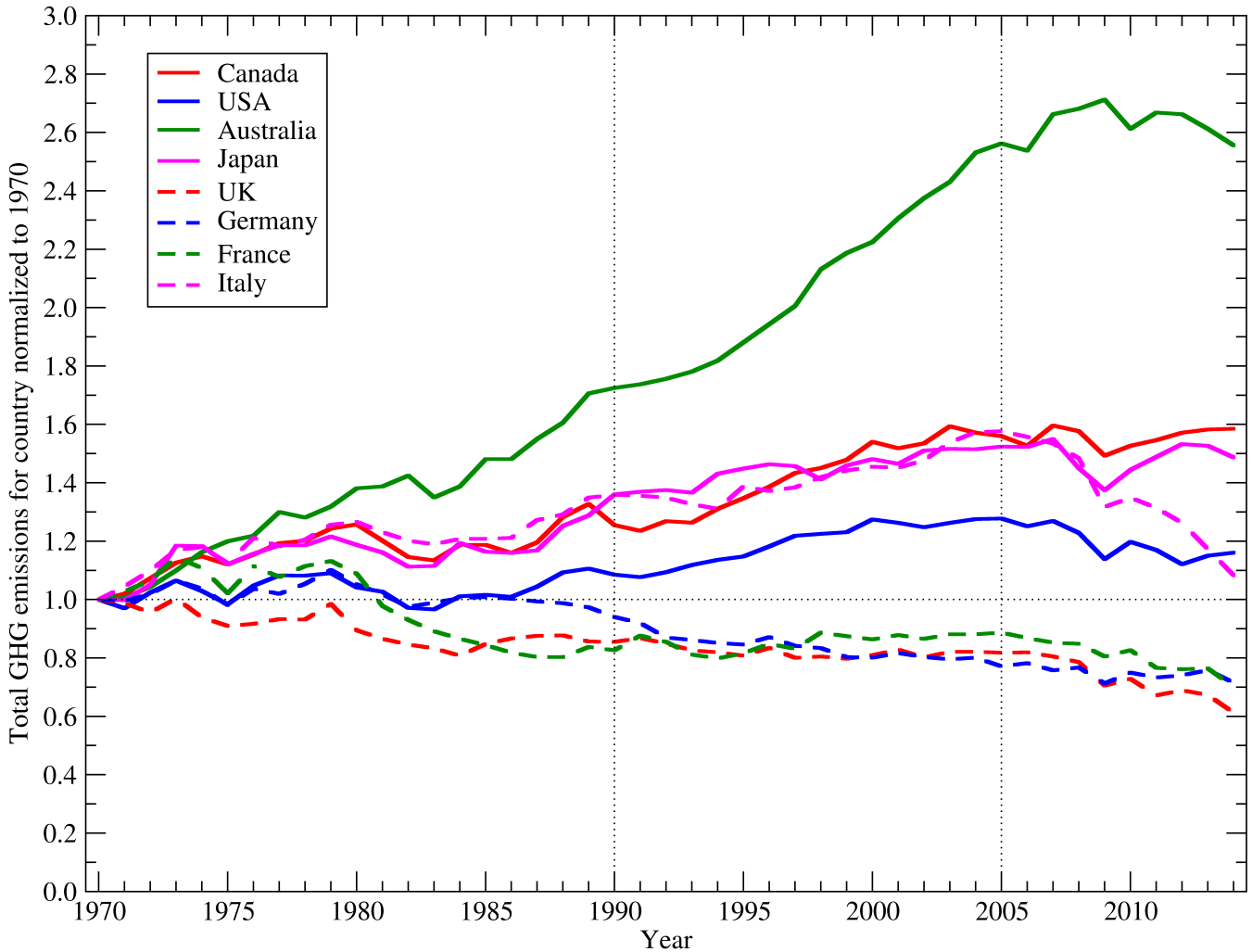
Goal

- Limit global warming to less than 2°C above pre-industrial levels.
- Pursue efforts to limit warming to 1.5°C.

Approach

- Each country commits to emissions reductions.
- Reach peak global GHG emissions as soon as possible.
- Balance sources by sinks by 2nd half of 21st century.

Past progress on reducing emissions



Data source : Trends in Global CO_2 Emissions, PBL Netherlands Environmental Assessment Agency, 2015.

On path to achieve Paris goal to limit warming to 2°C ?

- Many (most) countries not on trajectory to achieve targets.
- Targets set in current INDCs not sufficient[1].
- Realistic to count on balancing sources with sinks by 2nd half of 21st century ? (Article 4.1)

[1] Synthesis Report on the Aggregate Effect of the Intended Nationally Determined Contributions, UN FCCC/CP/2015/7.

On path to achieve Paris goal to limit warming to 2°C ?

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- More ambitious approaches required to achieve declared targets.
- And, targets must be enhanced.
- How are we going to achieve this ?

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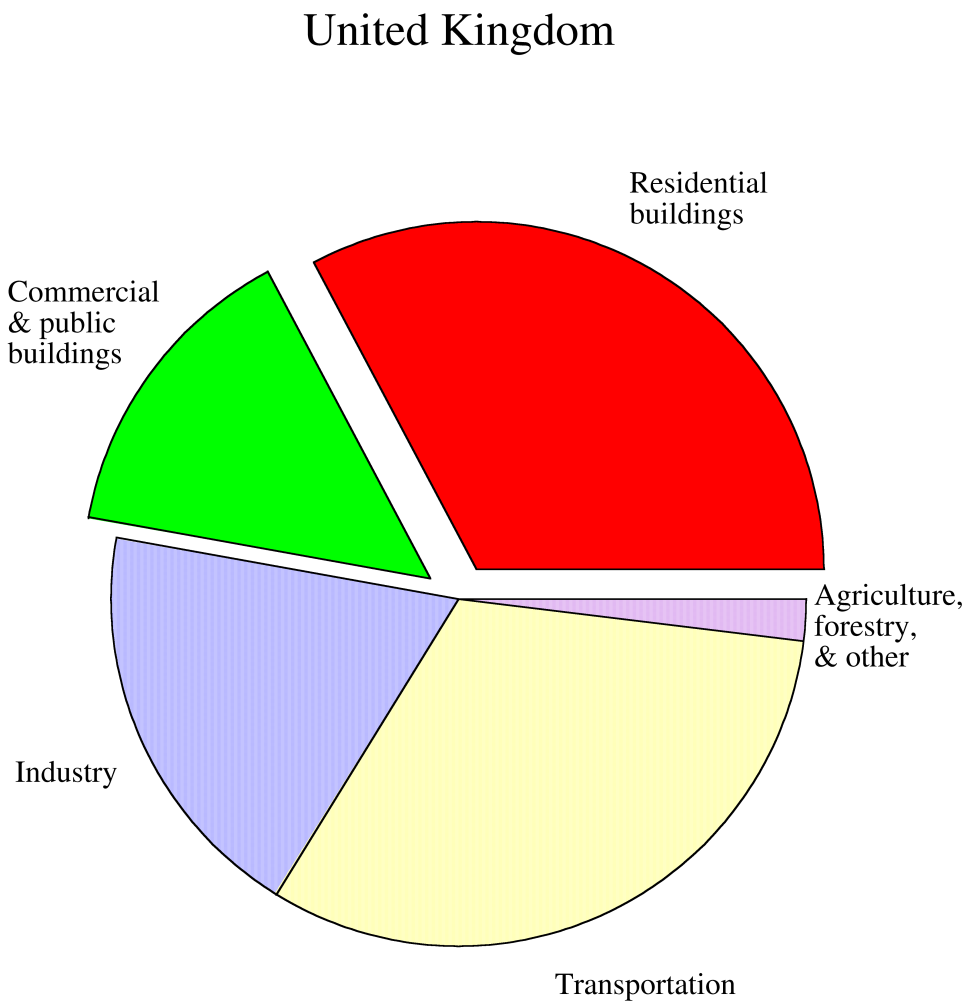
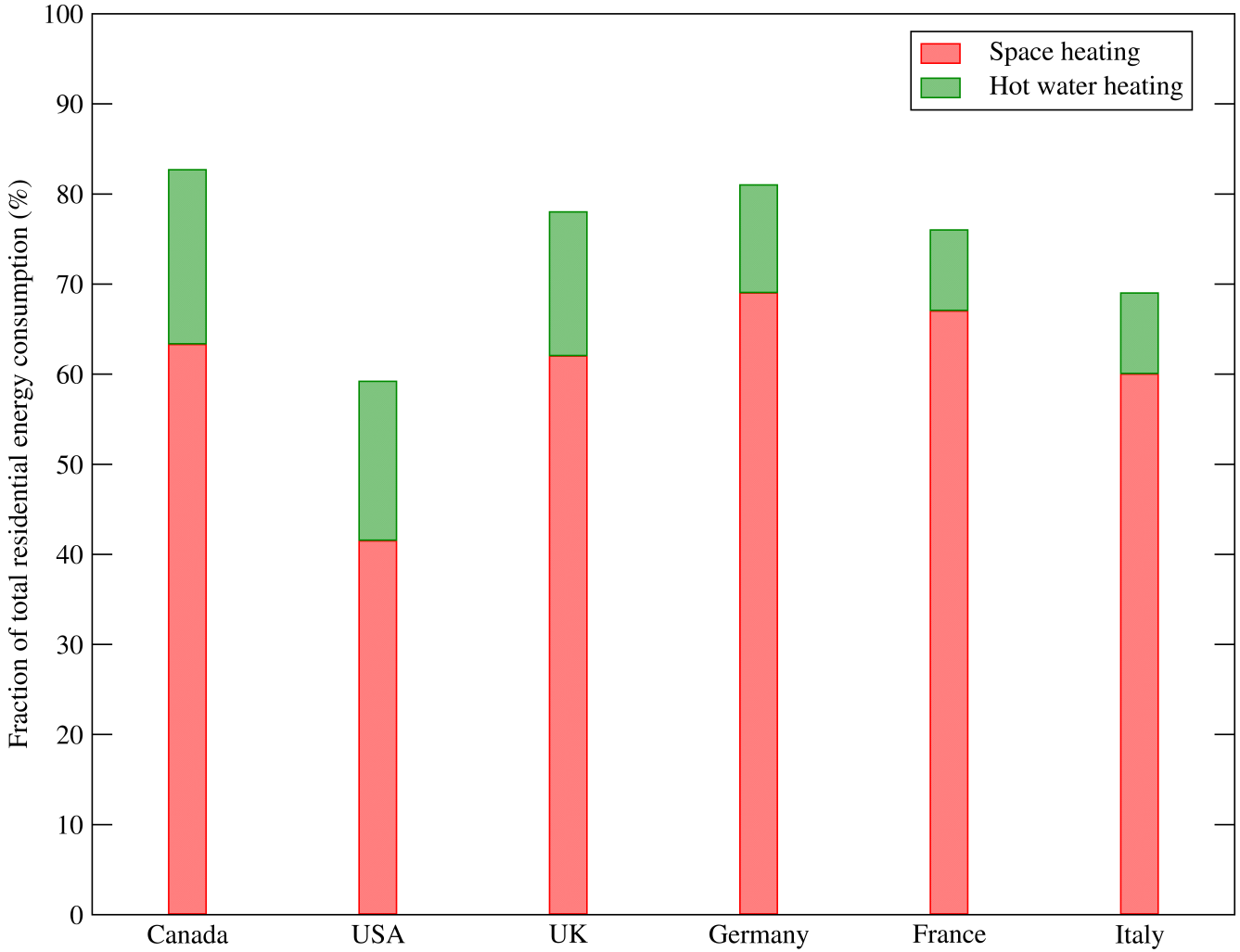
Total final consumption of energy



Data source : Energy Balances of OECD Countries, International Energy Agency, 2015.

Heat demands dominant in housing



Data source : National Energy Use Database, Natural Resources Canada; Residential Energy Consumption Survey, US Energy Information Administration; Enerdata, ENTRANZE.

Radical reduction in building energy consumption needed—Possibilities

- Enhanced efficiency :
  - More insulation, better windows, greater airtighness.
  - Improved combustion efficiencies.
  - Heat pumps to replace resistance heaters.
- Fuel switching :
  - Replace natural gas with electricity.
  - Only helpful if emissions-free generation added to grid.

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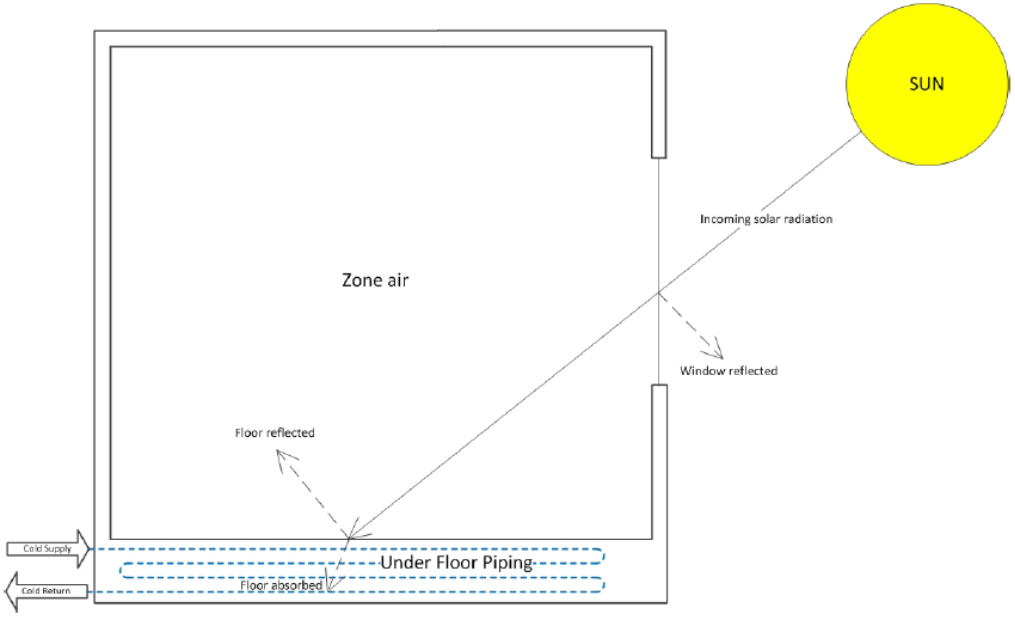
- Maximize capture and use of solar energy.

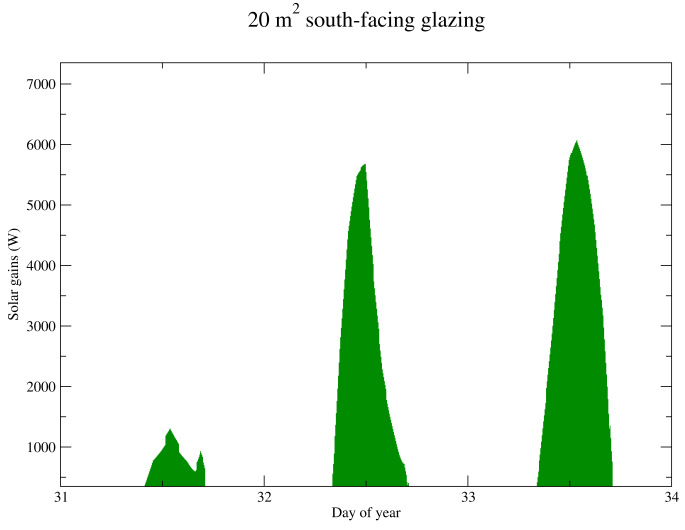
Solar options—Photovoltaics

NIST Net Zero Energy Residential Test Facility.

Supply-demand matching and grid assistance will be critical.

Solar options—Passive solar





- Go beyond passive storage (mass) and rejecting solar gains.
- Integration of passive and active components.

Solar options—Active solar

Long-term storage necessary for high solar fractions.

Future buildings

- Radical reduction in energy consumption required.
- More on-site solar needed. . . but this will add complexity :
  - Electrical storage.
  - Supply-demand matching.
  - Integration of passive solar gains with active systems.
  - Solar thermal with seasonal storage.
- Tighter integration of architecture, thermal, electrical systems.

How are we going to design and operate these buildings ?

Is the BPS field up to the challenge ?

Journal of Building Performance Simulation, 2015
Vol. 8, No. 2, 39–43, http://dx.doi.org/10.1080/19401493.2015.1007699

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Taylor & Francis Group

**A vision for building performance simulation:
a position paper prepared on behalf of the IBPSA Board**

Joe Clarke*

Energy Systems Research Unit, Department of Mechanical and Aerospace Engineering, University of Strathclyde, James Weir Building, Glasgow G1 1XJ, UK

This paper elaborates a future vision for building performance simulation and the contributions planned by IBPSA to enable it over time. The premise is that truly powerful support for the design and operation of the built environment can best be enabled by task sharing developments directed by an overarching vision of the ultimate goal.

Keywords: building performance simulation; modelling requirements; future vision

"BPS is a technology of considerable potential that provides the ability to quantify and compare the competing cost and performance attributes of a proposed design in a realistic manner and at relatively low effort and cost."

"Moreover, during the operational phase, simulation provides a means to compare measured performance versus design intent, to test systems for installation and operational faults, and to deduce effective control sequences."

Full potential of BPS is not being exploited

- Research into novel energy systems.
- Architectural design (pre-design and conceptual design).
- Engineering design (design development).
- Post-design to demonstrate code compliance or for labelling.
- Commissioning.
- Operation (building controls, fault detection).

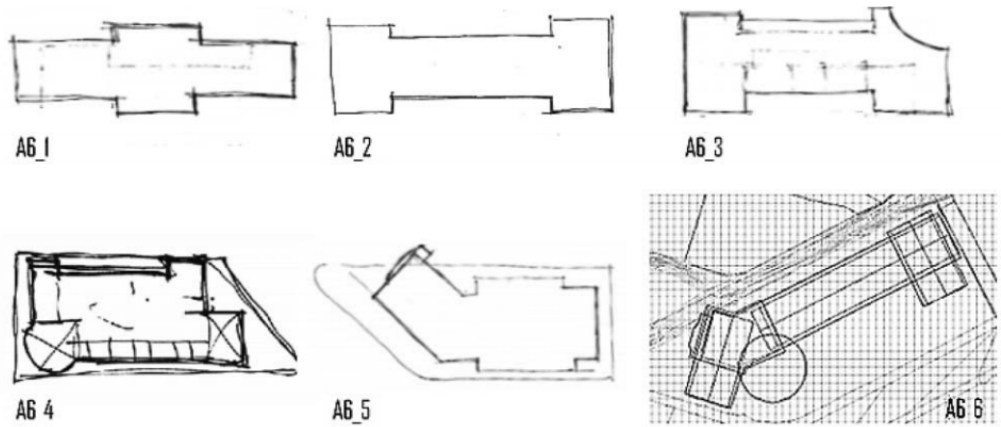

Figure from Akin and Moustapha (2004), Strategic use of representation in architectural massing, Design Studies.

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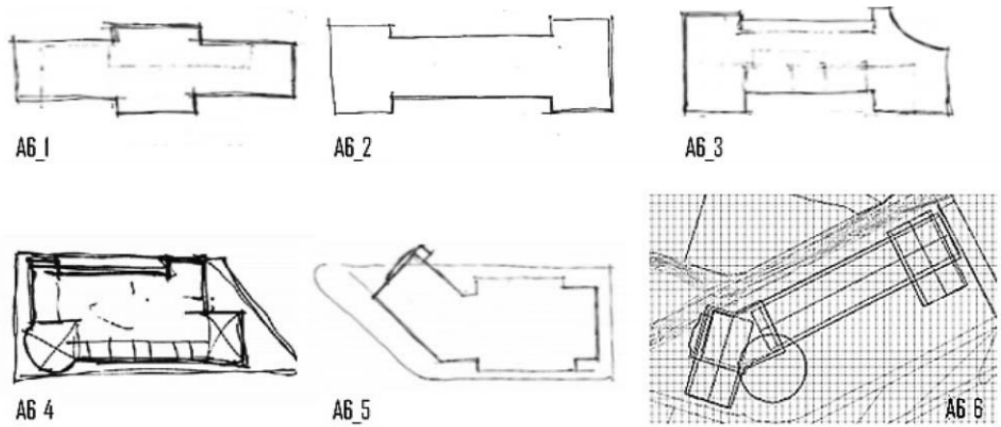

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Why ?

- Conservative industry focused on first cost.
- Split incentives between building developers, owners, tenants.
- Sequential rather than integrated design.
- Non-technical barriers:
  - Fee structures.
  - Professional liability.
  - Control over decision making.
  - Professional trust.

Energy Research & Social Science 19 (2016) 21–36

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Original research article

Of collaboration or condemnation? Exploring the promise and pitfalls of architect-consultant collaborations for building performance simulation

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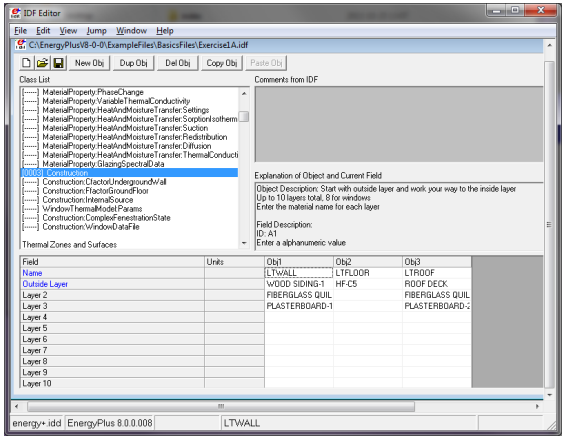
BPS suffers from a credibility gap :

- Tools—too many? too few? accurate?
- Users—who is qualified to operate the tools?

Are we lacking in BPS tools?



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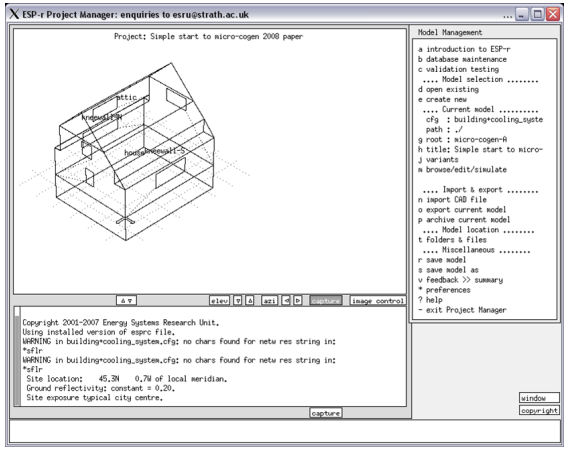

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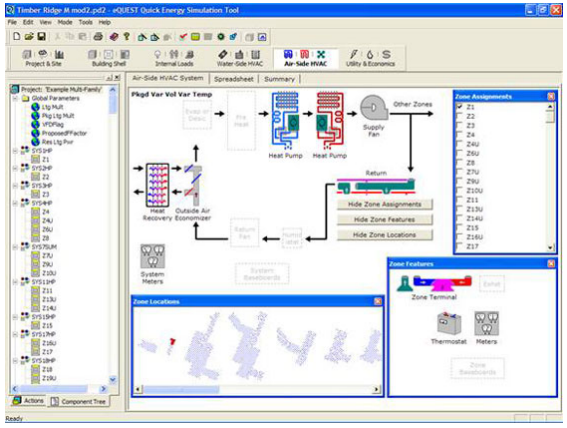

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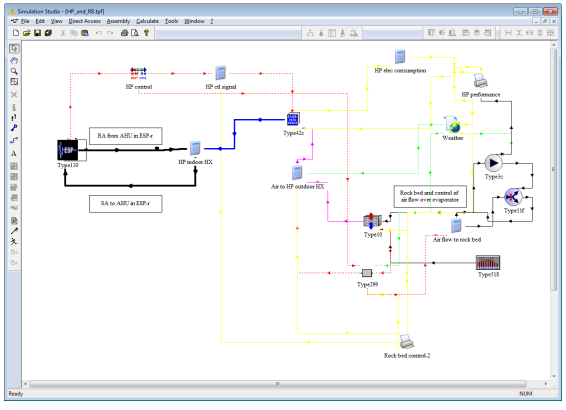

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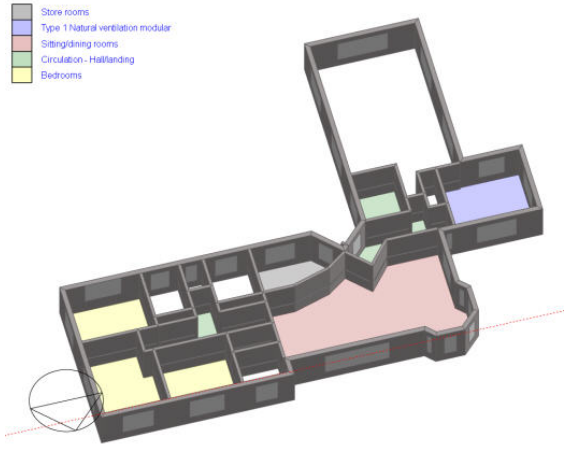
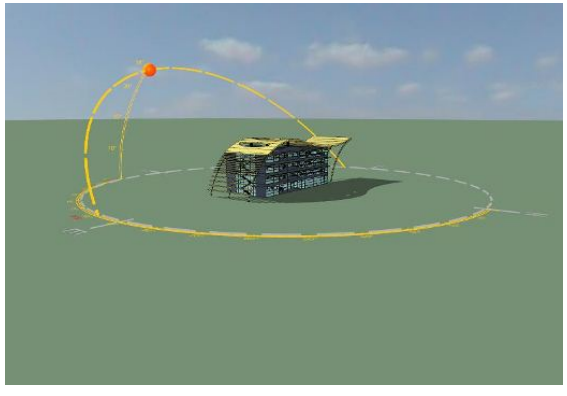
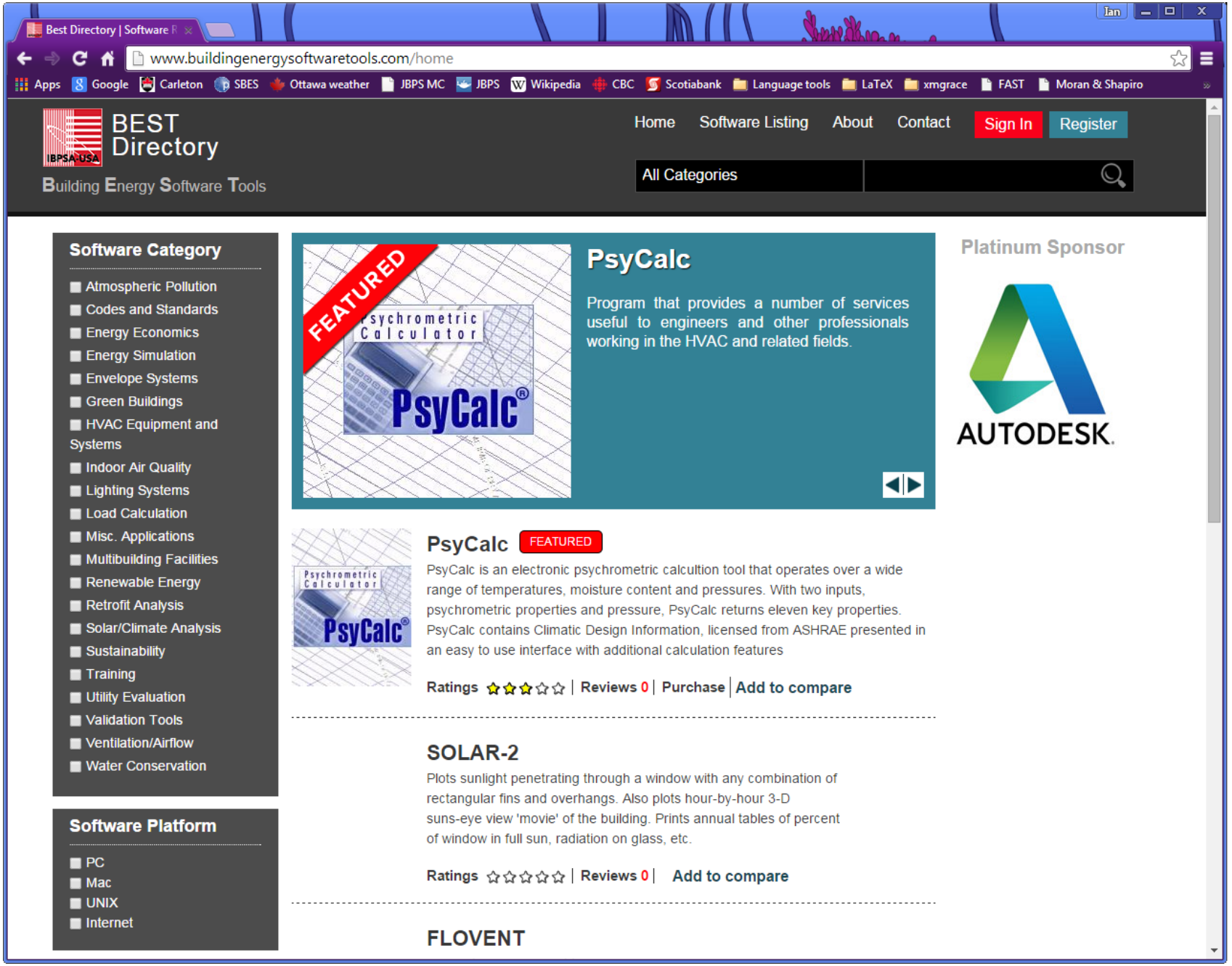


DesignBuilder



IES Virtual Environment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All Categories
Software Category
Atmospheric Pollution
Codes and Standards
Energy Economics
Energy Simulation
Envelope Systems
Green Buildings
HVAC Equipment and Systems
Indoor Air Quality
Lighting Systems
Load Calculation
Misc. Applications
Multibuilding Facilities
Renewable Energy
Retrofit Analysis
Solar/Climate Analysis
Sustainability
Training
Utility Evaluation
Validation Tools
Ventilation/Airflow
Water Conservation
Software Platform
PC
Mac
UNIX
Internet
FEATURED
PsyCalc
Program that provides a number of services useful to engineers and other professionals working in the HVAC and related fields.
Platinum Sponsor
AUTODESK.
PsyCalc FEATURED
PsyCalc is an electronic psychrometric calcultion tool that operates over a wide range of temperatures, moisture content and pressures. With two inputs, psychrometric properties and pressure, PsyCalc returns eleven key properties. PsyCalc contains Climatic Design Information, licensed from ASHRAE presented in an easy to use interface with additional calculation features
Ratings | Reviews 0 | Purchase | Add to compare
SOLAR-2
Plots sunlight penetrating through a window with any combination of rectangular fins and overhangs. Also plots hour-by-hour 3-D suns-eye view 'movie' of the building. Prints annual tables of percent of window in full sun, radiation on glass, etc.
Ratings | Reviews 0 | Add to compare
FLOVENT

Compare this to web search engines

The world's most popular search engines are:

Search engine	Market share in September 2015
Google	69.24%
Bing	12.26%
Yahoo!	9.19%
Baidu	6.48%
AOL	1.11%
Ask	0.24%
Lycos	0.00%

- Google processes 40 000 search queries every second.
- $\Rightarrow$ 3.5 billion per day / 1.2 trillion per year.
- How does this compare to the number of BPS simulations ?

- Why are there so many BPS tools ?
- Is this diversity a liability ?

The physics have been well understood for a long time

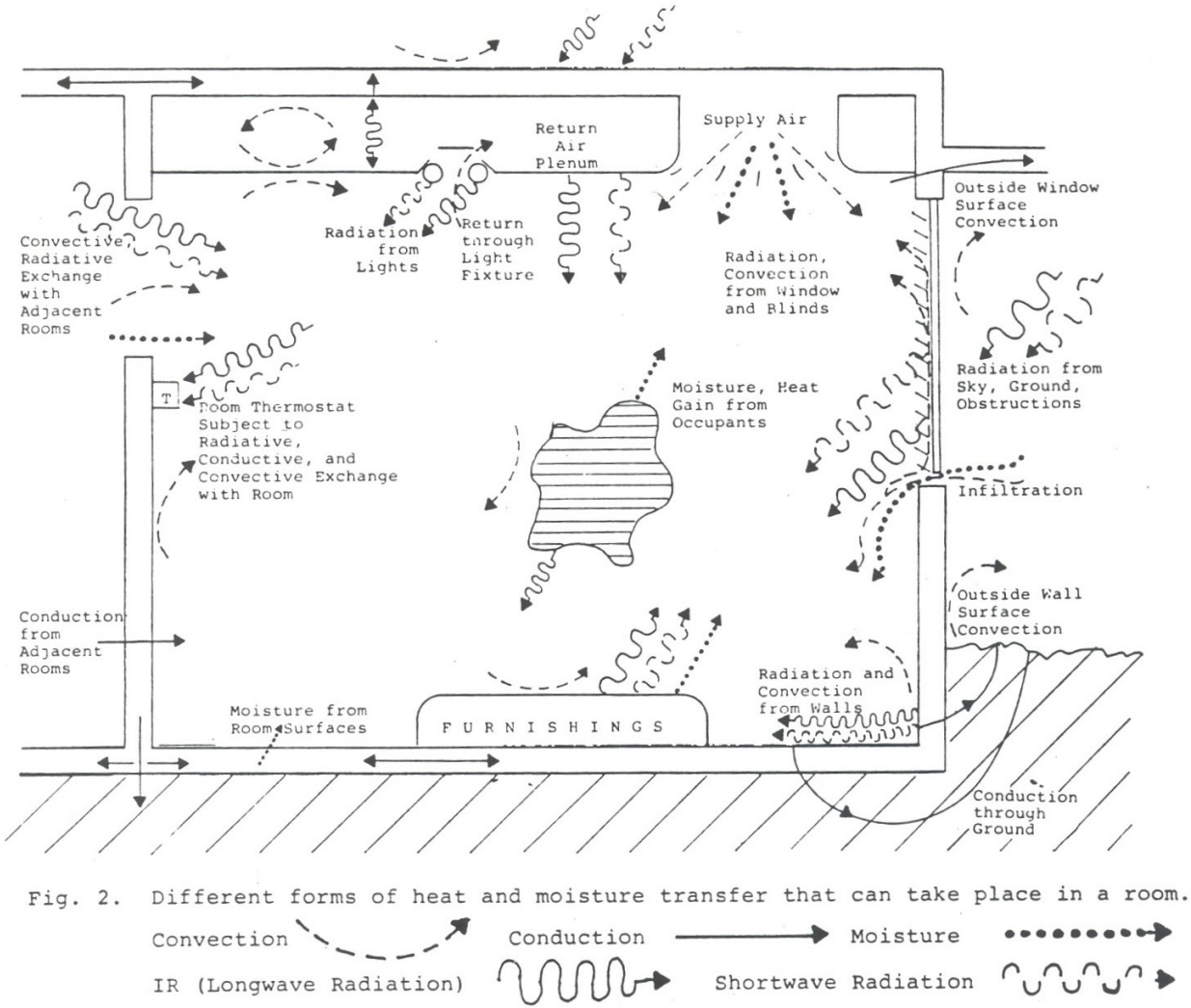


Figure from JJ Hirsch (1985), Plan for the Development of the Next-Generation Building Energy Analysis Computer Software, Proc. Building Simulation '85.

Transient conduction

$$\rho c_P \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right)$$

Internal surface convection

$$q_{conv} = h_c \cdot A \cdot (T_{surf} - T_{air})$$

Longwave radiation

$$q_{rad,1\to 2} = \epsilon_1 \epsilon_2 \sigma A_1 f_{1\to 2} T_1^4$$

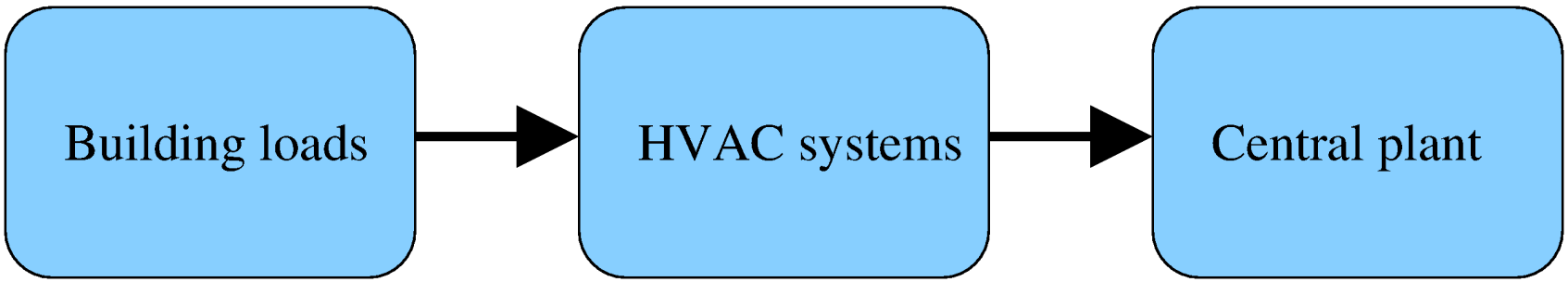
$$\begin{bmatrix} a_{1,1} & a_{1,2} & & & & & & & & & & & \\ a_{2,1} & a_{2,2} & a_{2,3} & & & & & & & & & & \\ & a_{3,2} & a_{3,3} & a_{3,4} & & & & & & & & & \\ & & a_{4,3} & a_{4,4} & a_{4,5} & & & & & & & & \\ & & & a_{5,4} & a_{5,5} & a_{5,6} & & & & & & & \\ & & & & a_{6,5} & a_{6,6} & a_{6,7} & & & & & & \\ & & & & & a_{7,6} & a_{7,7} & a_{7,8} & & & & & \\ & & & & & & a_{8,7} & a_{8,8} & a_{8,9} & & & & \\ & & & & & & & a_{9,8} & a_{9,9} & a_{9,10} & a_{9,11} & a_{9,12} & a_{9,13} \\ & & & & & & & & a_{10,9} & a_{10,10} & a_{10,11} & a_{10,12} & a_{10,13} \end{bmatrix} \times \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \\ T_7 \\ T_8 \\ T_9 \\ T_z \\ T_{s1} \\ T_{s2} \\ T_{s3} \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \\ b_6 \\ b_7 \\ b_8 \\ b_9 \\ b_z \end{bmatrix} \times \begin{bmatrix} q_{plant,1} \\ q_{plant,2} \\ q_{plant,3} \\ q_{plant,4} \\ q_{plant,5} \\ q_{plant,6} \\ q_{plant,7} \\ q_{plant,8} \\ q_{plant,9} \\ q_{plant,z} \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \\ z_6 \\ z_7 \\ z_8 \\ z_9 \\ z_{10} \end{bmatrix}$$

Image source: IBM Photo Archive.

First BPS programs

Mid 1960s

- Gas Application to Total Energy (GATE).
- ASHRAE Task Group on Energy Requirements (TGER).
- *Post Office Program* released in 1967.



Response factor method

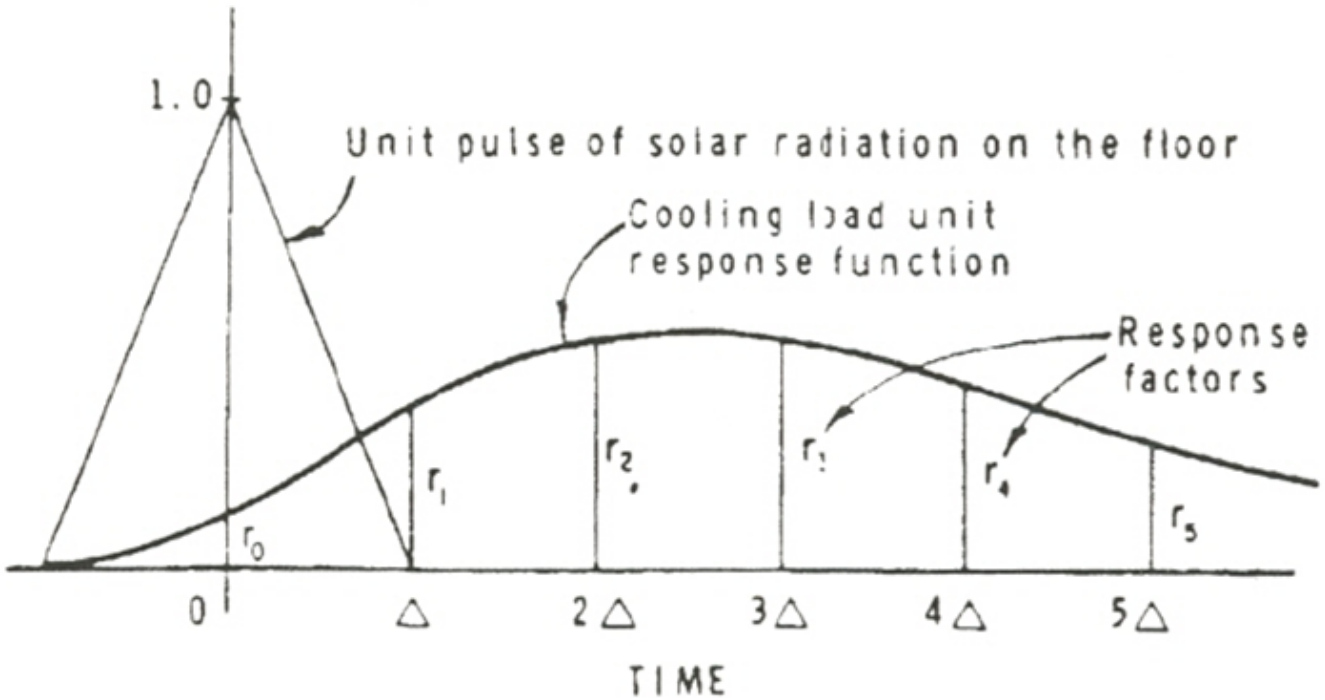
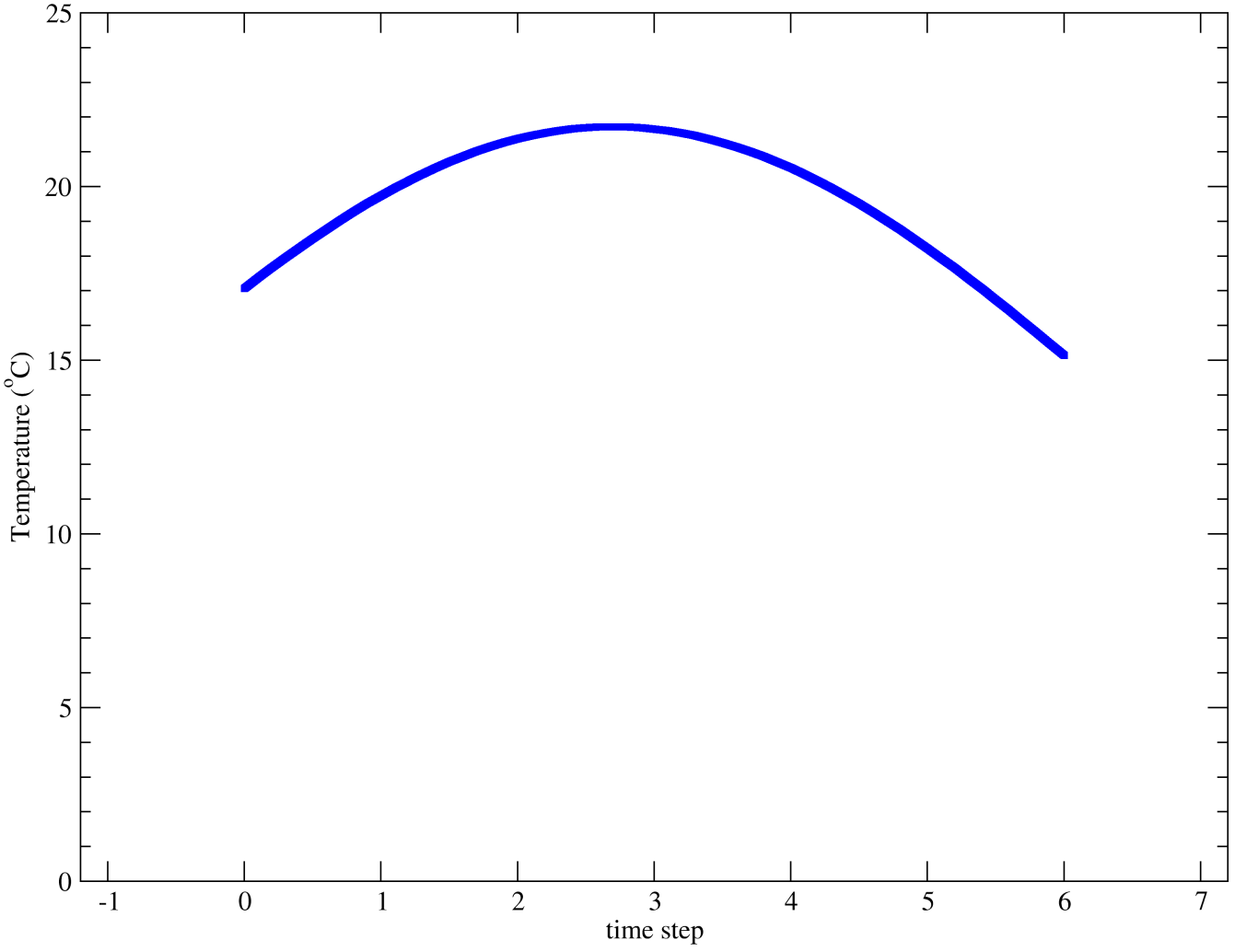


Figure from Stephenson and Mitalas (1967), Cooling load calculations by thermal response factor method, ASHRAE Transactions.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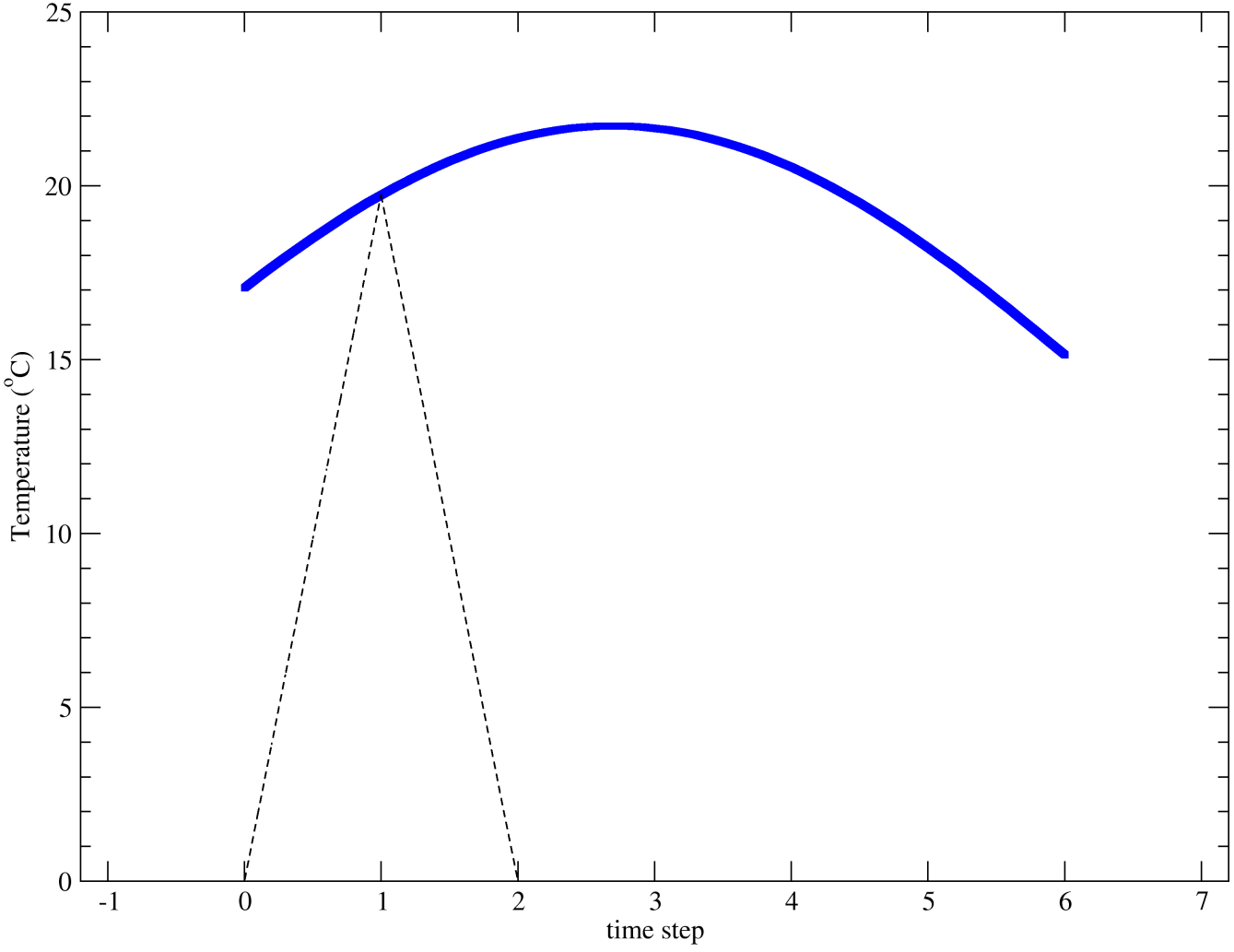
time step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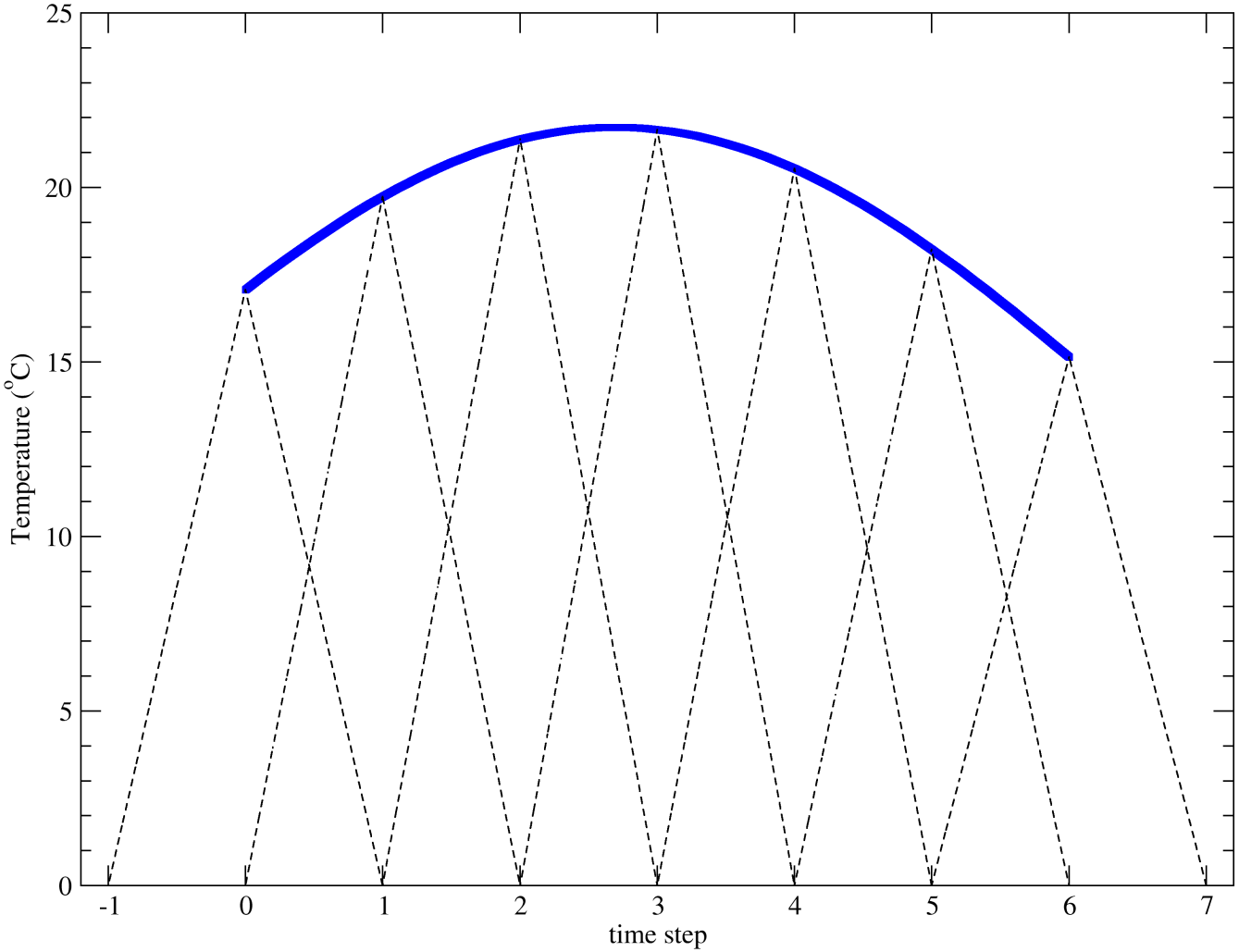
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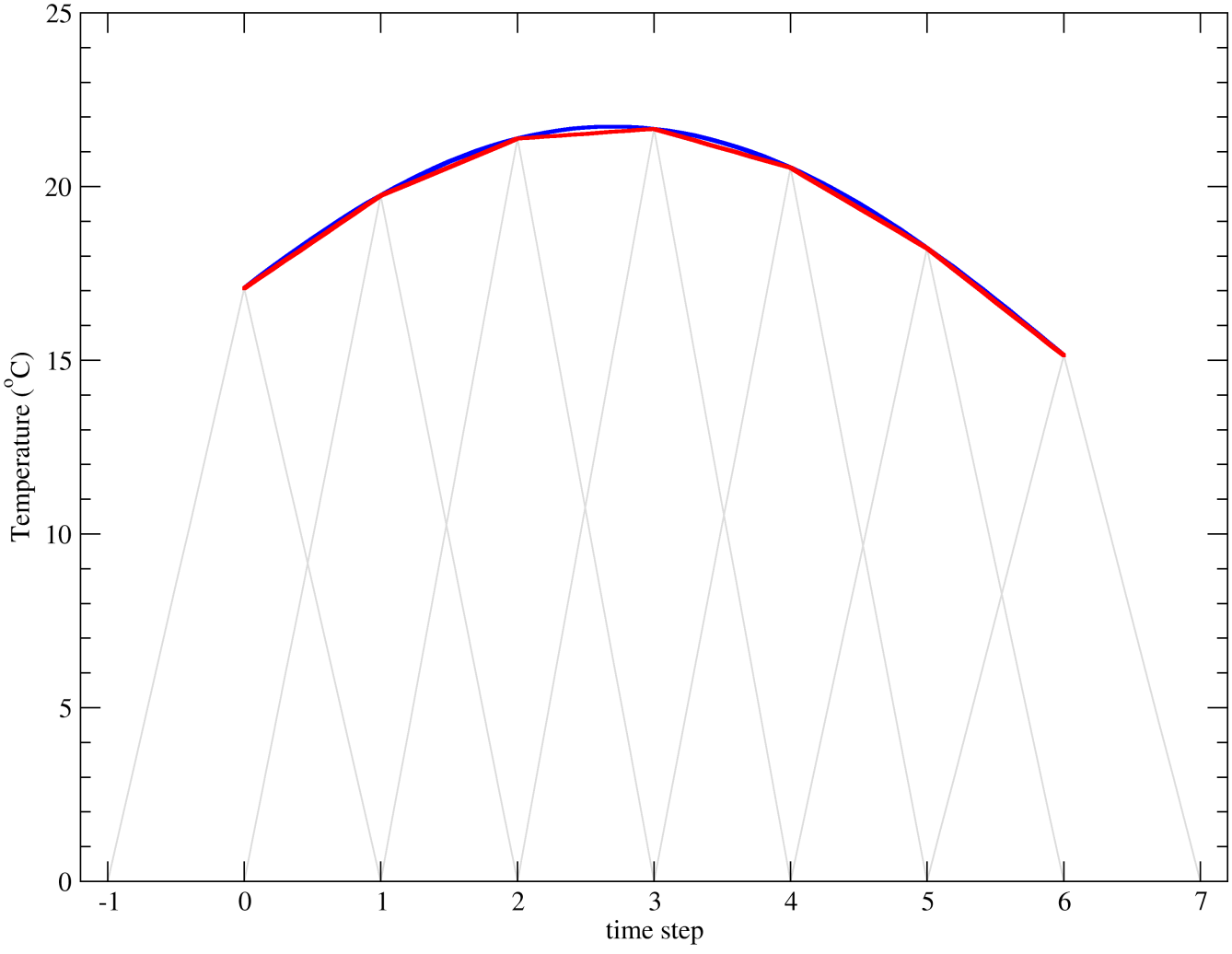


$$q(3) = r_0 \cdot T(3) + r_1 \cdot T(2) + r_2 \cdot T(1) + r_3 \cdot T(0) + ...$$

Principle of superpositioning

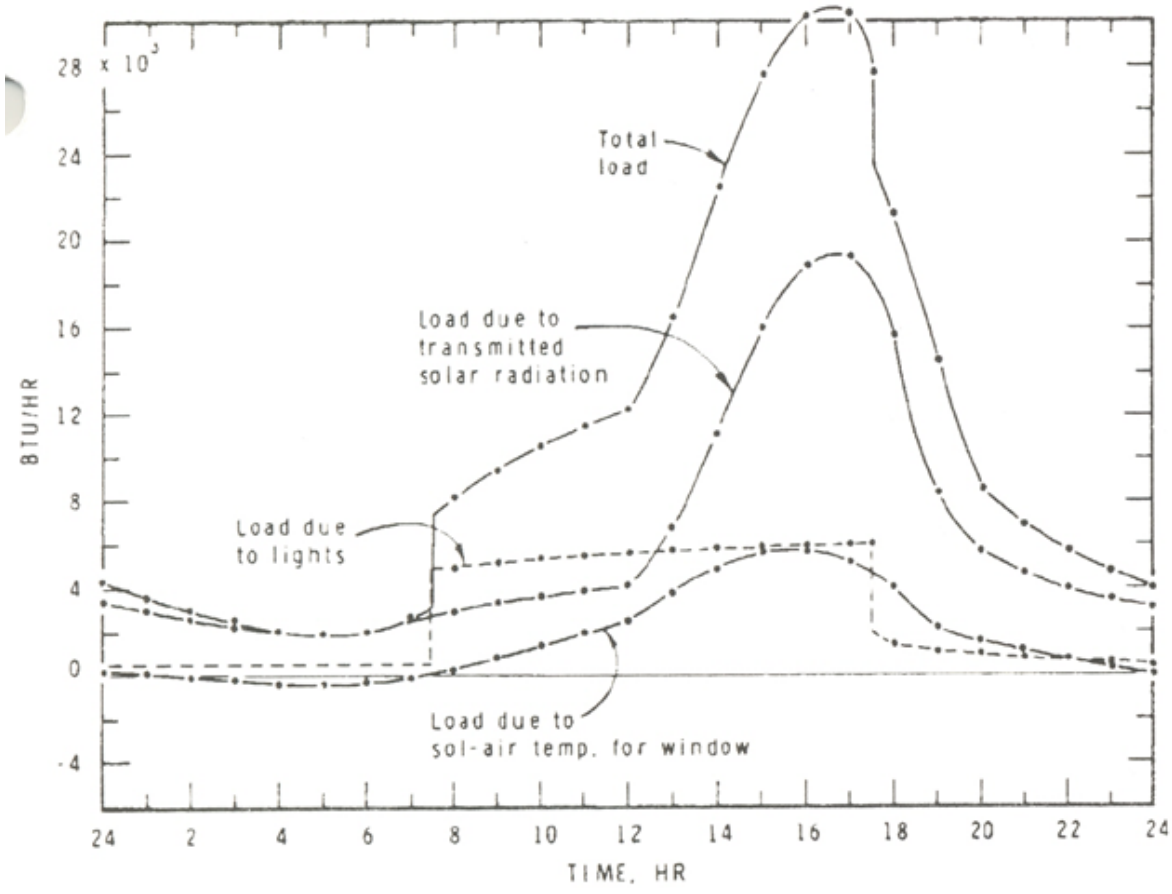


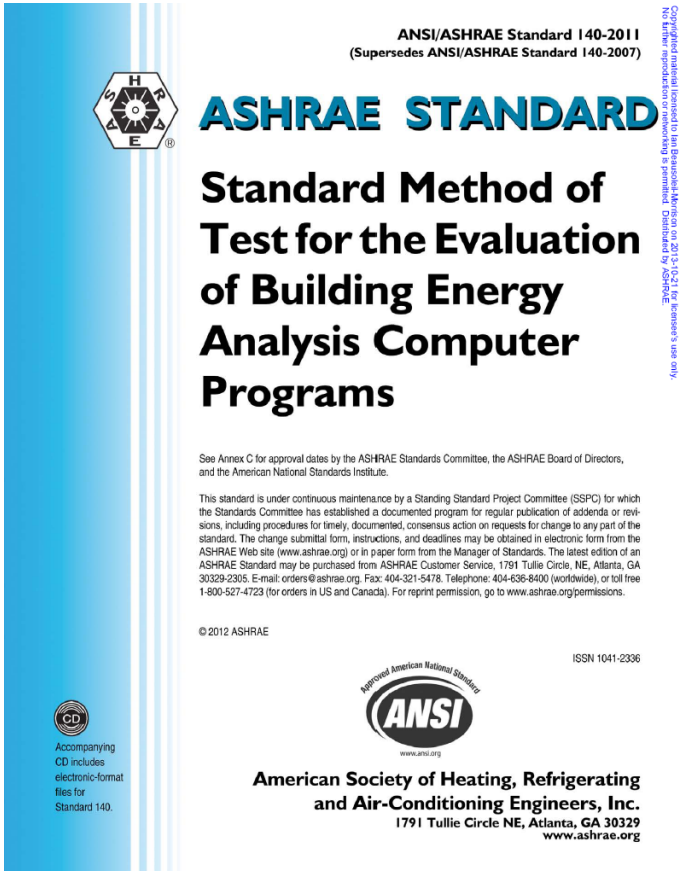
Figure from Stephenson and Mitalas (1967), Cooling load calculations by thermal response factor method, ASHRAE Transactions.

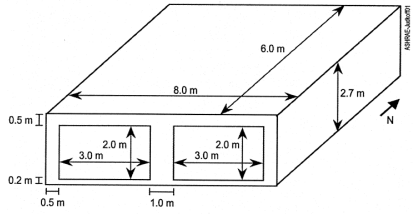
Myriad modelling approaches

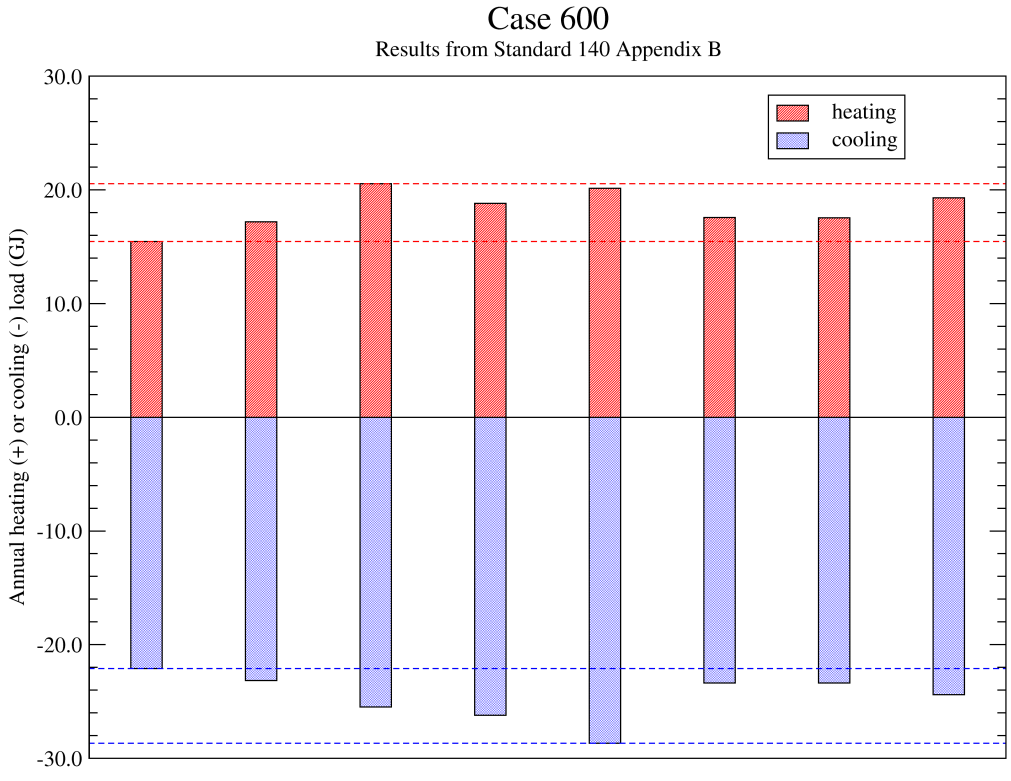
Zone energy balances	• Response factor methods • Heat balance methods
Transient conduction	• Numerical methods • Transfer functions
Internal surface convection	• Lumped with longwave radiation • Fixed coefficients • Dynamic calculations
Internal longwave radiation	• Fictitious surface temperatures • Approximate view factors • Ray-tracing
Solar transmission	• g-values • Multi-layered optical properties • Shades/blinds
Air infiltration	• User-prescribed • Single-zone methods • Nodal networks
HVAC	• Fixed efficiencies • System performance maps • Component-wise • Transient models

But do these differences matter ?

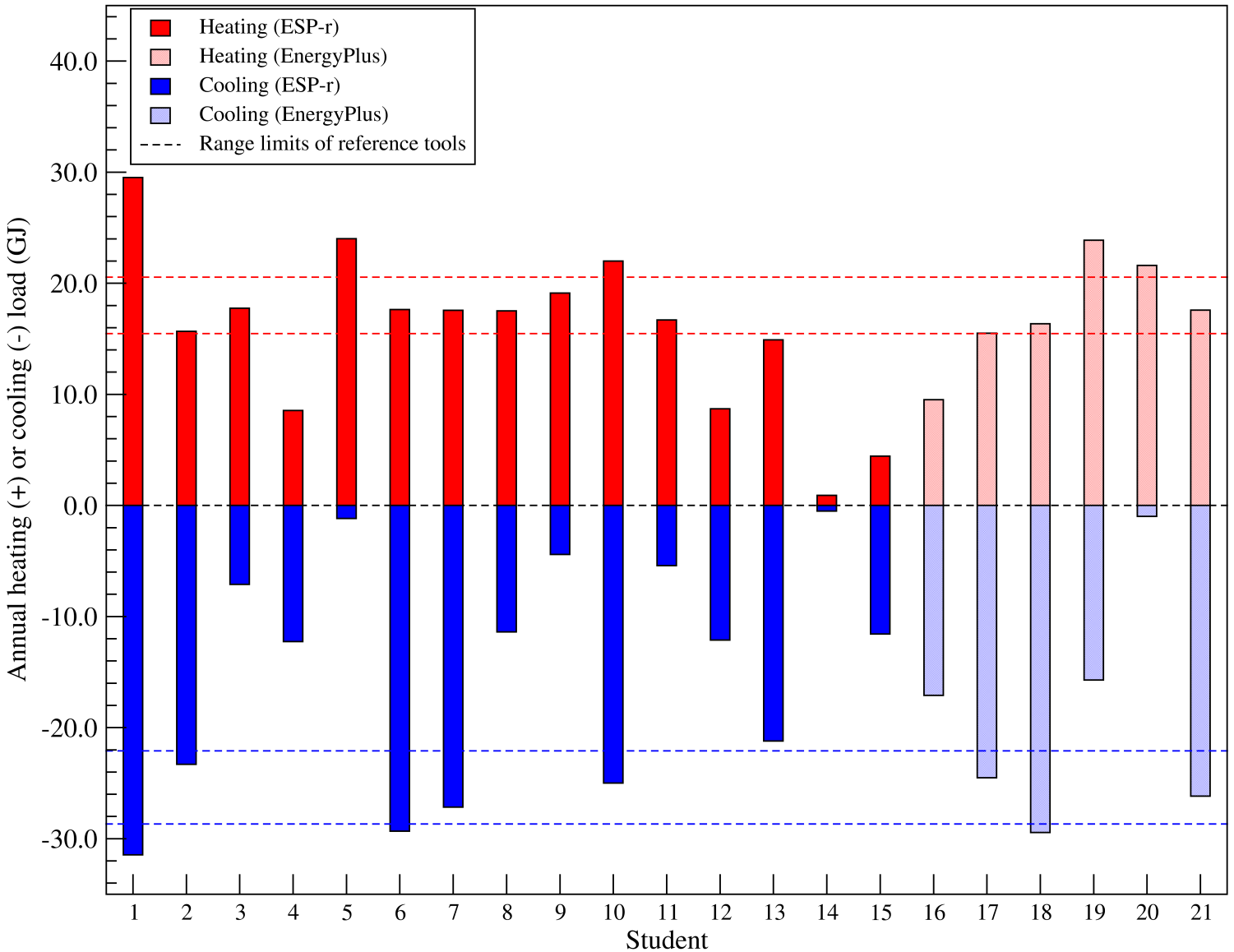
Do these algorithmic differences matter ?



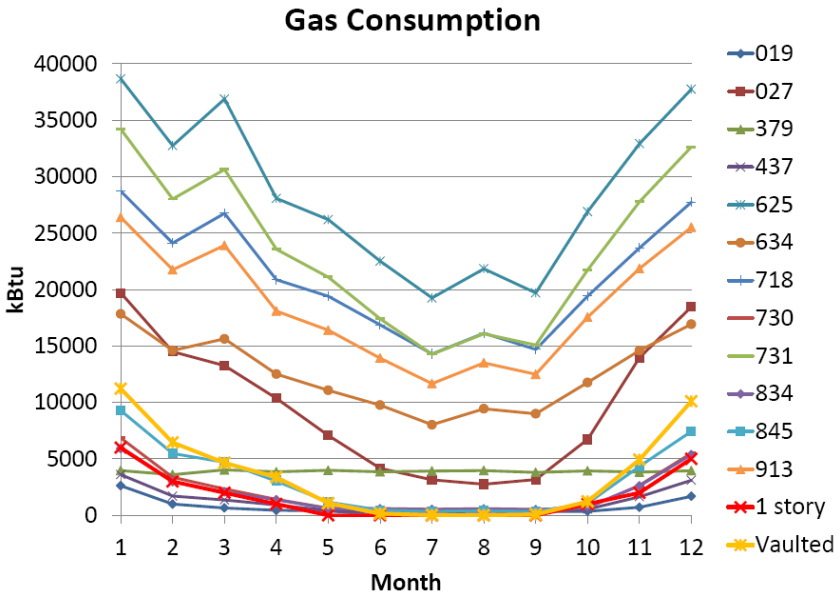


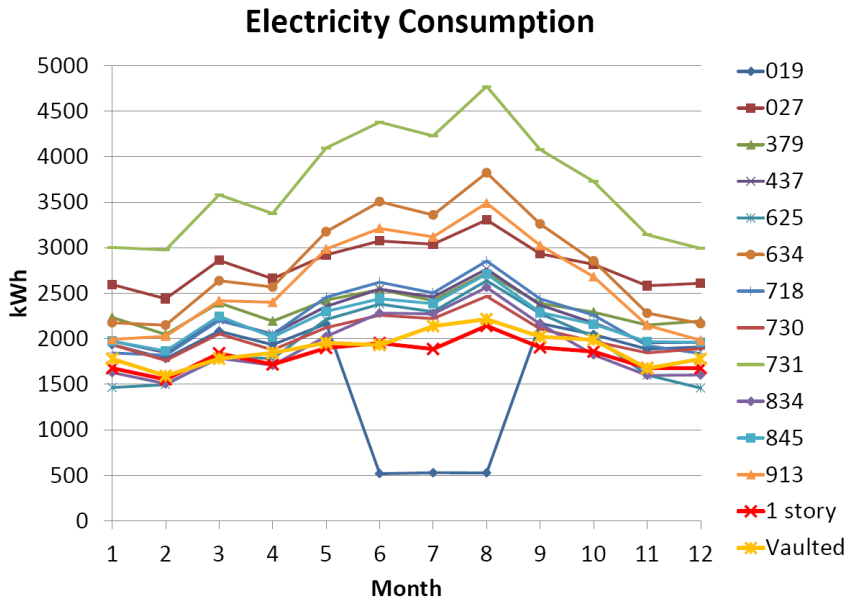


What about the user ?



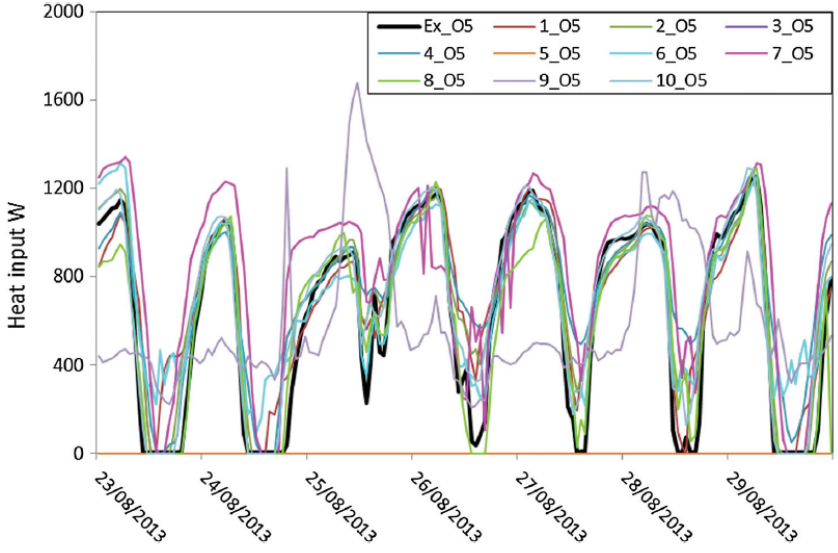
12 professional BPS practitioners using same tool

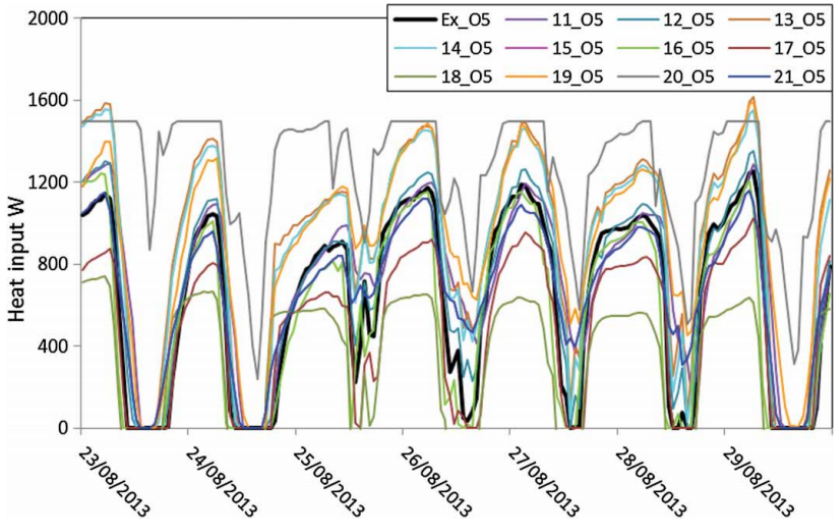




From Berkeley, Haves, and Kolderup (2014), Impact of modeler decisions on simulation predictions, ASHRAE/IBPSA-USA Building Simulation Conference.

21 teams from IEA/ECB Annex 58 analyzing a test house





From Strachan, Svehla, Heusler, and Kersken (2016), Whole model empirical validation on a full-scale building, Journal of Building Performance Simulation.

The user is the greatest source of uncertainty

Lawrie and Beranek (1985) [2]:

> *. . . the designer has been shown to be key to the calculated energy consumption. . . . Energy analysis remains an art but should be a science.*

[2] Linda Lawrie and Dwight Beranek (1985), Bringing order to the energy simulation process, Proc. Building Simulation '85.

Are we trying to make BPS too accessible ?

Tool developer claims

- Tool A: *"For wizard-based use, virtually no experience with energy analysis is necessary."*
- *(. . .)* *"an extremely powerful simulation engine, but . . . you don't have to be an expert to use it. Let Tool B do the hard work for you."*
- Tool C: *"Energy analysis made easy."*

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- Tool C: *"Energy analysis made easy."*

There are no shortcuts

- It is easy to train someone to operate a BPS tool.
- Producing accurate results is difficult.
- No substitute for knowledge of fundamentals.

Users must be able to cope with big questions

- Which models are applicable in which situations ?
- Physical phenomena considered/neglected ?
- Hidden default methods and inputs ?
- Which inputs matter most ?
- How do I scrutinize my results ?

Reform the way we teach BPS

- Need in-depth education of BPS fundamentals :
  - Engineers and architects.
  - Undergraduate / graduate.
  - Continuing professional development.
- Experiential learning is key :
  - Exposure to models and simulation methods.
  - Active experimentation using topic-specific exercises.
  - "Autopsies" to examine results.
- Tool-agnostic :
  - BPS specialists need proficiency with multiple tools.
- Critical to achieving credibility.

Keep improving models

Tamami Kusuda (1985) [3]:

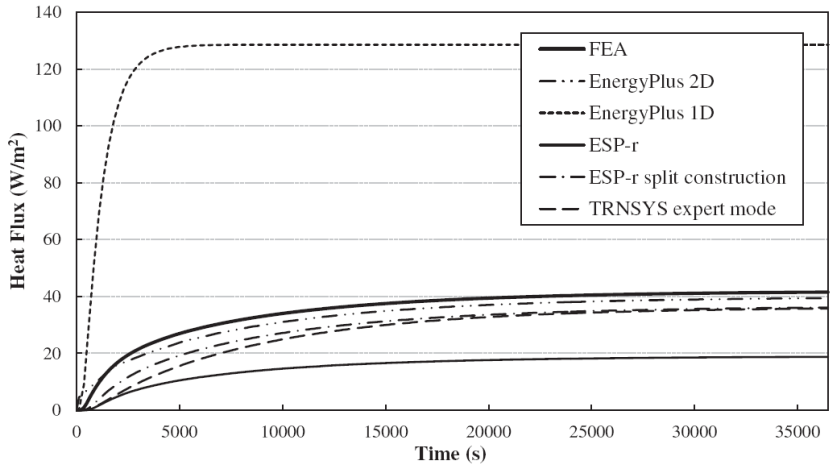
> *"One can not help wondering where all of this is leading to. How far do we go? When do we call it quits and say enough is enough?"*

- Air infiltration
- Occupant behaviour
- Ground heat transfer
- Thermal bridging
- Ground albedo
- Non-uniform material properties
- Coupled heat-air-moisture modelling
- Solar shadowing and distribution
- Distributed energy systems
- Inter- and intra-zone air flow
- Passive and hybrid ventilation
- HVAC dynamics
- Complex fenestration / blinds
- Local climate effects
- Phase-change materials
- Convective heat transfer
- Long-term thermal storage
- ...

[3] Tamami Kusuda (1985), Summary of recent activities on building energy simulation analysis in North America, Proc. Building Simulation '85.

Way more validation

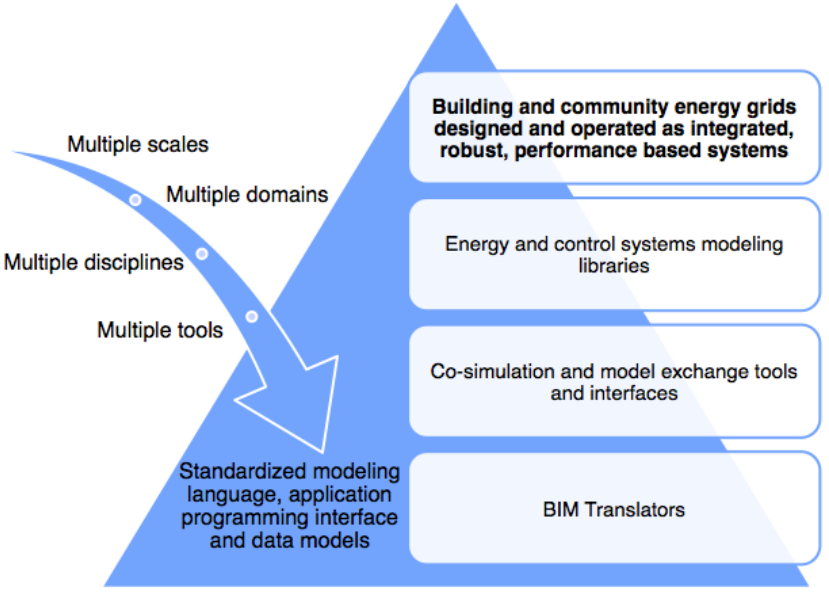
- Not sexy, but crucial.
- Analytical, inter-program comparative testing, empirical validation.
- Updated reference program results required.
- Lots of catching up required.



Source: Brideau, Beausoleil-Morrison, Kummert, and Wills (2016), Inter-model comparison of embedded-tube radiant floor models in BPS tools, Journal of Building Performance Simulation.

Build on the endowment

- Monolithic codes lack modularity . . . but contain decades of developments.
- New modelling languages and computational techniques.
- Co-simulation, inter-operability.
- Connecting BPS to wider domain: communities, energy grids, ...



Source: IEA / ECB Annex 60.

Summary

- Deep reductions in building energy use critical.
- Future buildings will be more complex.
- World needs BPS to design and operate these buildings.

Summary

- Deep reductions in building energy use critical.
- Future buildings will be more complex.
- World needs BPS to design and operate these buildings.

We've got a lot to do to get ready.

- Model R&D.
- Validation
- New computations methods.
- Focus on education.

Thank you !