# An Update on EnergyPlus:

## Current Developments, Applications, and the Road Ahead

**Tianzhen Hong, Walter Buhl, Philip Haves, Thierry Nouidui, Michael Wetter**
Simulation Research Group

**Simon Vidanovic**
Windows and Envelope Materials Group

**Amir Roth**
Building Technology Office, DOE

**Department of Building Technology and Urban Systems**
**Environmental Energy Technologies Division**
**May 30, 2014**

# Outline

- Simulation Research Group (Phil)
- EnergyPlus (Tianzhen)
- Building Energy Modeling - DOE’s View (Amir)
- Simergy – A GUI for EnergyPlus (Phil)
- Challenging Simulation Problems (Fred)
- Windows Modeling (Simon)
- Modelica, BCVTB and FMI (Michael and Thierry)
- Q & A

# Simulation Research Group

**Mission:**

•Develop computational methods to predict the energy performance of buildings and the urban environment.

•Implement software tools and deploy to practitioners, manufacturers, policy analysts, researchers, educators and other stakeholders.

•Contribute to both education and training in modeling and simulation

**History:**

•Cal-ERDA, DOE-1, DOE-2, SPARK, EnergyPlus

**Leadership:**

•IEA EBC: Co-Operating Agents of Annex 60 (Modelica) and 66 (Behavior)

•IBPSA, ASHRAE, BuildingSmart

**Personnel:**

•4 Scientists, 1 Faculty, 1 Fulbright, 1 DOE Fellow, 4 Postdocs,
6 Associates, 8 Guests

# Vision for Building Simulation

- Comprehensive support for ZNE and conventional buildings
- Used routinely in early design through operation
  - — inform all relevant design and operation decisions
  - — enable accountability for performance
- Integrated into primary work flows and used by architects, engineers and operators
- Seamless interoperability with other key tools – BIM, costing
- Control system design, implementation and testing
- Rapid prototyping by end users – practitioners and product developers
- Simulation uncertainties low and quantified and results accepted by financial decision-makers and by policy-makers

*All elements addressed by current and planned work*

# Simulation through the Life-cycle

- **Early stage design: nimble interface wrapping detailed model**
- (Schematic Design, Detailed Design, Construction Documents)
- **Controls design + automatic configuration**
- **Code compliance and rating system support**
- **Commissioning**
- **Operations:** integrated model-based approach to:
  - — Retro-commissioning
  - — Retrofit analysis
  - — Retrofit commissioning
  - — Routine operation – automated diagnostics

# EnergyPlus Background

- Started in 1998 to combine best capabilities of DOE-2.1E and BLAST, but added extensive new features.
- Simulation engine only, interfaces developed separately
- A national development team from multiple institutes, supported by DOE
- A large and powerful program
  - 230+ modules, 700,000+ lines of code
  - 3200+ active members in the E+ User Group
  - 500,000+ accumulative downloads
  - increasing adoption by practitioners
  - 5000+ pages of documentation
- Free, open source, runs on Windows, Linux, and Mac
- Web site: **energyplus.gov**
- R&D 100 Award in 2003

# EnergyPlus Team

Brent Griffith
Linda Lawrie

Kyle Benne
Eric Bonnema
Edwin Lee
Luigi Polese
Pablo Tabares

Fred Buhl
Tianzhen Hong
Philip Haves
Thierry Nouidui
Geof Sawaya
Simon Vidanovic
Michael Wetter
Fred Winkelmann
Ender Erdem

Krishnan Gowri
Daeho Kang

Mahabir Bandari
Brian Fricke
Piljae Im
Xiaobing Liu
Joshua New
Jibo Sanyal
Bo Shen

Lixing Gu
Richard Raustad
Bereket Nigusse

Amir Roth

Jason Glazer
Bob Henninger
Michael Witte

Dan Fisher
Matt Mitchell

Rick Strand

Chidambaram Nagappan
Larry Scheier
Jim Spielbauer

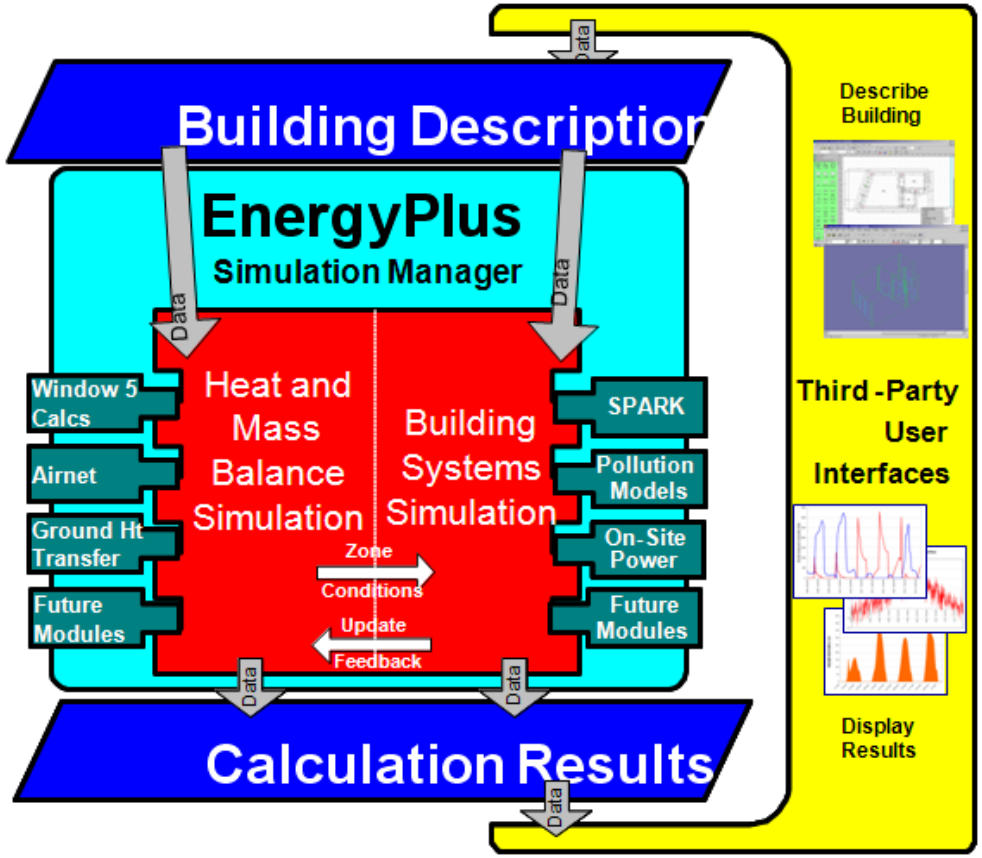
Stuart Mentzer

David Bosworth
Shannon Mackey

Peter Ellis
Neal Kruis

Vince Abeyta
John Kennedy
Barry Tsai

# EnergyPlus Structure and Features




## Key Features:

- Heat and moisture balance calculations
- Integrated building loads/systems solution
- Sub-hourly time steps, down to 1 minute
- Configurable HVAC systems
- No surface, zone or system limits
- Energy Management System
- Links to other tools via co-simulation: CFD, CONTAM, Radiance

***For EnergyPlus it is still a real challenge to model large and complex building systems.***

# What Can EnergyPlus Do?

**Simulate dynamics** of energy and environmental performance of buildings, considering the integration and interaction of major building components and systems – building envelope, lighting & daylighting, HVAC systems, service water systems, power generation, and renewable energy systems.

**Calculate:**

- Energy use and peak demand
- Energy/utility cost
- Water usage
- Air emissions ($CO_2$, NOx, etc)
- Indoor thermal comfort
- Indoor visual comfort
- Renewable energy
- Electricity generation
- Combined heat and power (CHP)
- Indoor $CO_2$

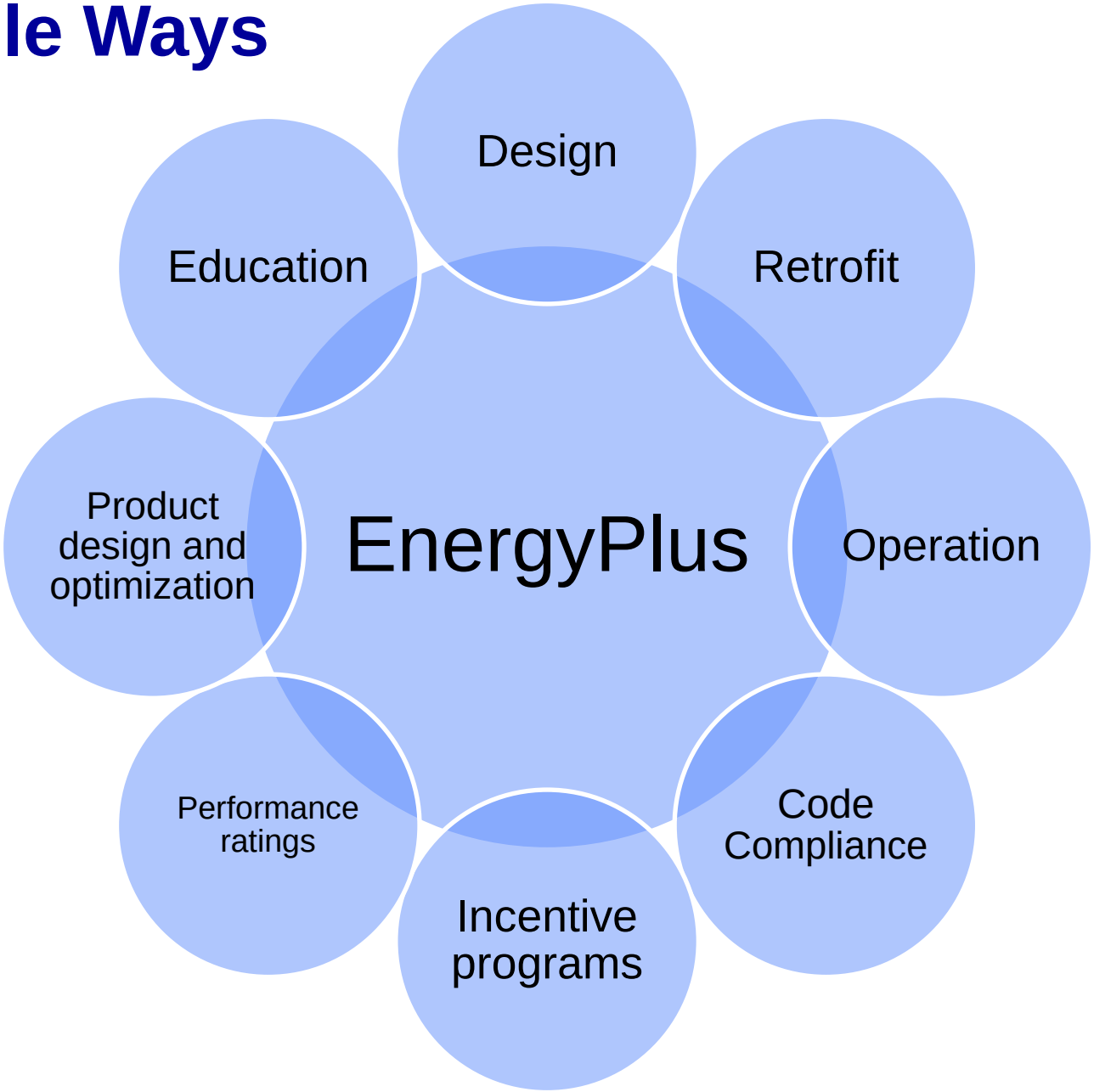
# What EnergyPlus Cannot Do?

- Outdoor micro or macro environment
- CFD (Computation Fluid Dynamics)
- Contaminate analysis
- Fluid network dynamics (air, water, refrigerant, etc)
- Detailed thermal/visual comfort analysis
- Noise analysis

# EnergyPlus Testing and Validation

- Analytical tests:
  - HVAC tests, based on ASHRAE Research Project 865
  - Building fabric tests, based on ASHRAE Research Project 1052
- Comparative tests:
  - ANSI/ASHRAE Standard 140-2007
  - International Energy Agency Solar Heating and Cooling Programme (IEA SHC) BESTest (Building Energy Simulation Test) methods not yet in Standard 140
  - EnergyPlus HVAC Component Comparative teststs
  - EnergyPlus Global Heat Balance tests
- Release and executable tests
- Empirical tests – a growing area

# EnergyPlus is Used by Different People in Multiple Ways

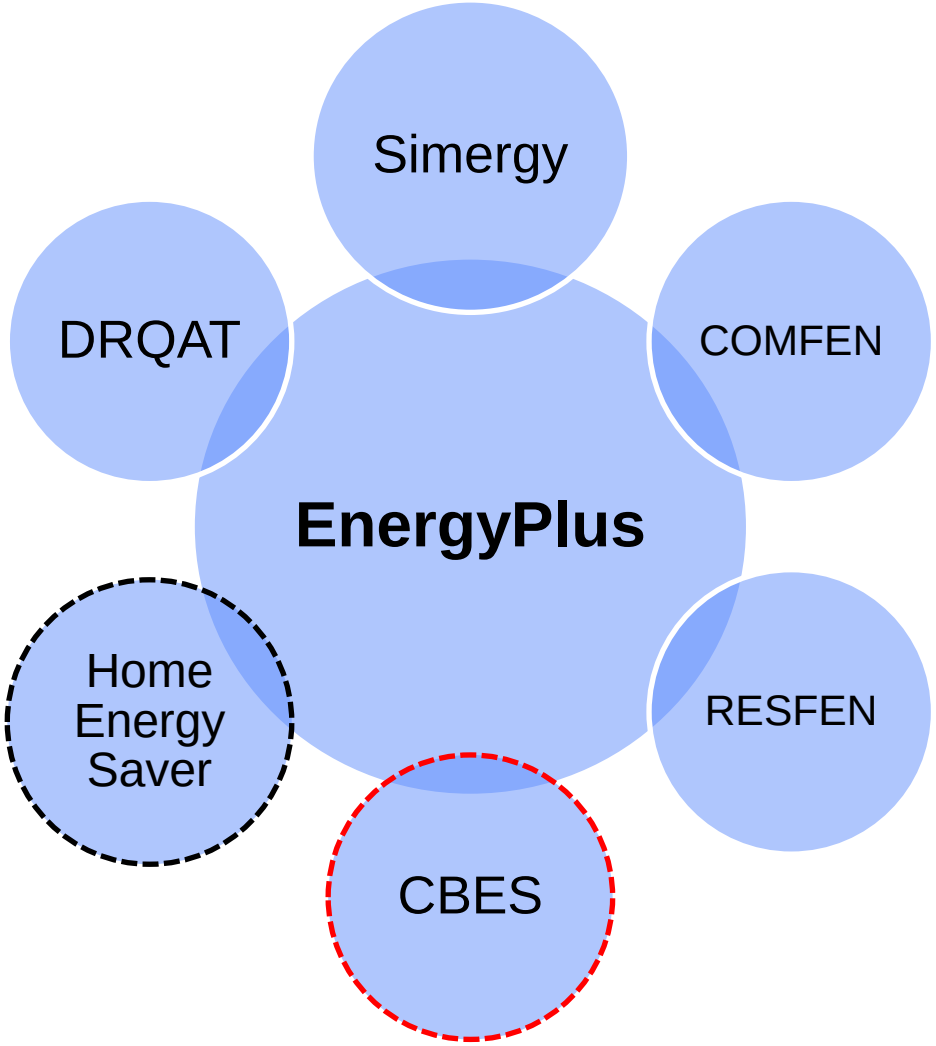


# EnergyPlus Development at LBNL

- **One of the founding developers in 1998**
- **To meet the needs of research, applications, and energy policy**
- **Traditional LBNL contributions**
  1. Air-side systems
  2. Autosizing of HVAC equipment
  3. Code compliance: California Title 24 and ASHRAE standards
  4. Window modeling
  5. Model innovative low energy systems
  6. Enable co-simulation with other tools
- **New areas of LBNL development**
  1. Improve product design: working with HVAC manufacturers
  2. Model building O&M issues/faults
  3. Improve run-time performance
  4. Enable real-time simulation
  5. Model occupant behavior

# EnergyPlus Related Tools

## LBNL Tools:




## Other Popular Tools:

1. OpenStudio, NREL
2. DesignBuilder, UK
3. AECOSim, Bentley Systems
4. GBS, Autodesk
5. Commercial Asset Scoring, PNNL
6. CBECC-COM, CEC
7. Simuwatt
8. Several under development

# New Features – Recent Releases
## (A complete list is available at EnergyPlus web site)

### V8.0 release: April, 2013

1. Support sub-hourly schedules
2. Export EnergyPlus as an FMU for co-simulation
3. Rename most report variables
4. Updated LEED performance reports
5. Report zone component loads
6. Improved HVAC component models
7. New BSDF window model

### V8.1 release: Nov, 2013

1. Improved cross- and natural- ventilation models
2. Comprehensive models for unitary HVAC systems
3. Many new HVAC templates including VRF, dual-duct, heat/cool VAV
4. HVAC “optimal start” control
5. Component model sizing diagnostics
6. Some models for equipment & operation faults including airside economizer
7. New zone daylight distribution model using the BSDF window model

# Several New Features - under Developments

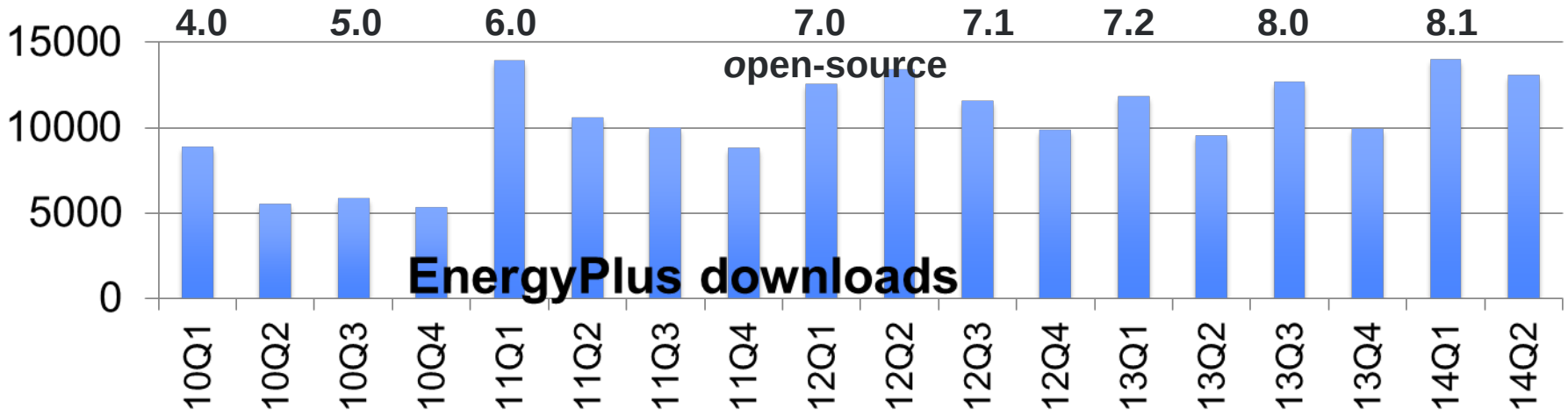
**V8.2 release: planned for Nov, 2014**

1. Unified, updated routines for equipment sizing
2. Unified model for room air and multi-zone air-flow network
3. Support concave spaces
4. Coolerado evaporative cooling systems
5. Models for servers & some datacenter HVAC equipment
6. Diagnostic simulation reports

**V9.0 release: planned for May, 2015**

1. XML schema for input & output
2. Models for servers & some datacenter HVAC equipment
3. Additional models for equipment & operation faults
4. New VRF model with advanced controls
5. New command-line interface for easier scripted analysis

# Progress & Accomplishments




**Downloads: ~20,000 downloads per version**

**Market Impact: new tools in past year (that we know of & can talk about)**

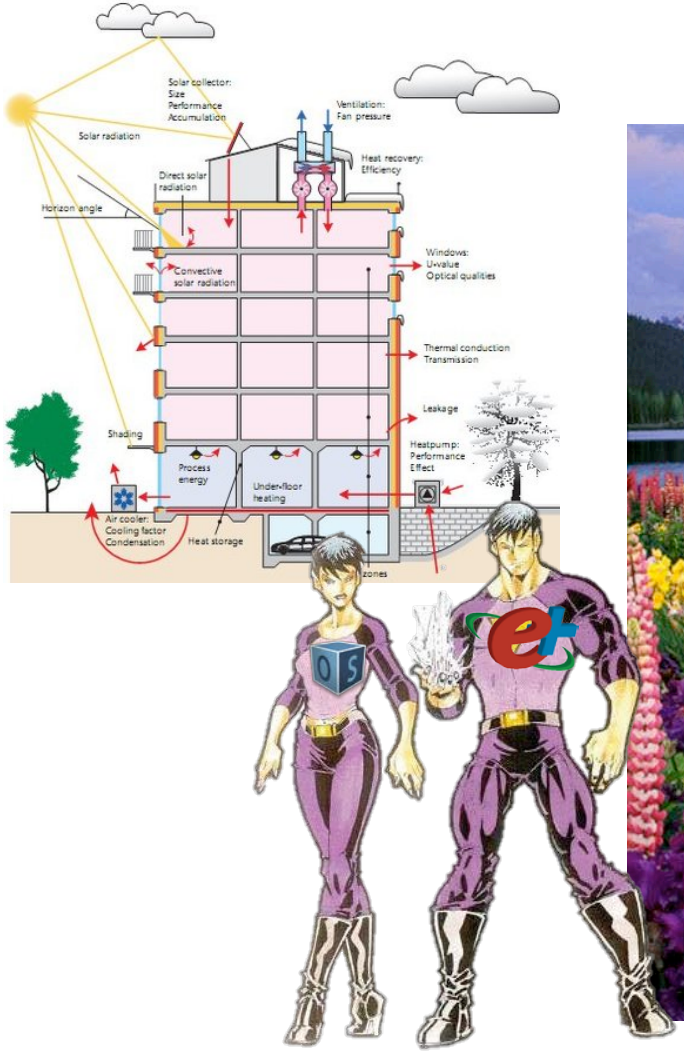
**•Interfaces: GreenSpaceLive gEnergy, ExpertApp N++, Sefaira Concept, ArchSim, Bentley AECOSim EnergySimulator V8i, DesignBuilder 3.4, LBNL/Digital Alchemy Simergy, OpenStudio application & Parametric tool***

**•Others: Xcel EDAPT*, CEC CBECC-Com*, BTO Asset Score*, Concept3D Simuwatt*, CEC CBES***

*** based on OpenStudio SDK—most new development will use this path**

*Slide courtesy Mike Witte and EnergyPlus Team*

# Building Energy Modeling (BEM) Overview



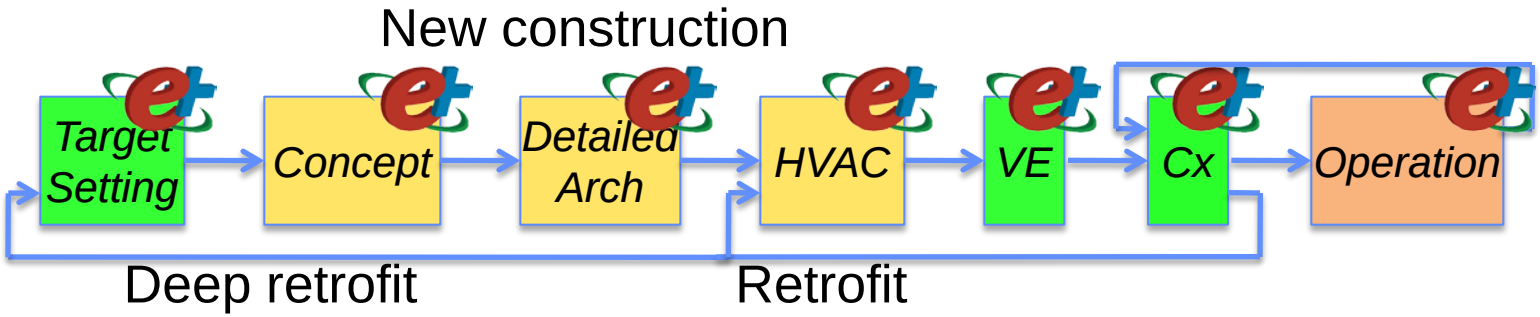
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

**Amir Roth, Ph.D.**
**amir.roth@ee.doe.gov**

# BEM is a Fundamental Energy-Efficiency Technology

**BEM calculates energy use from description of assets & operations**

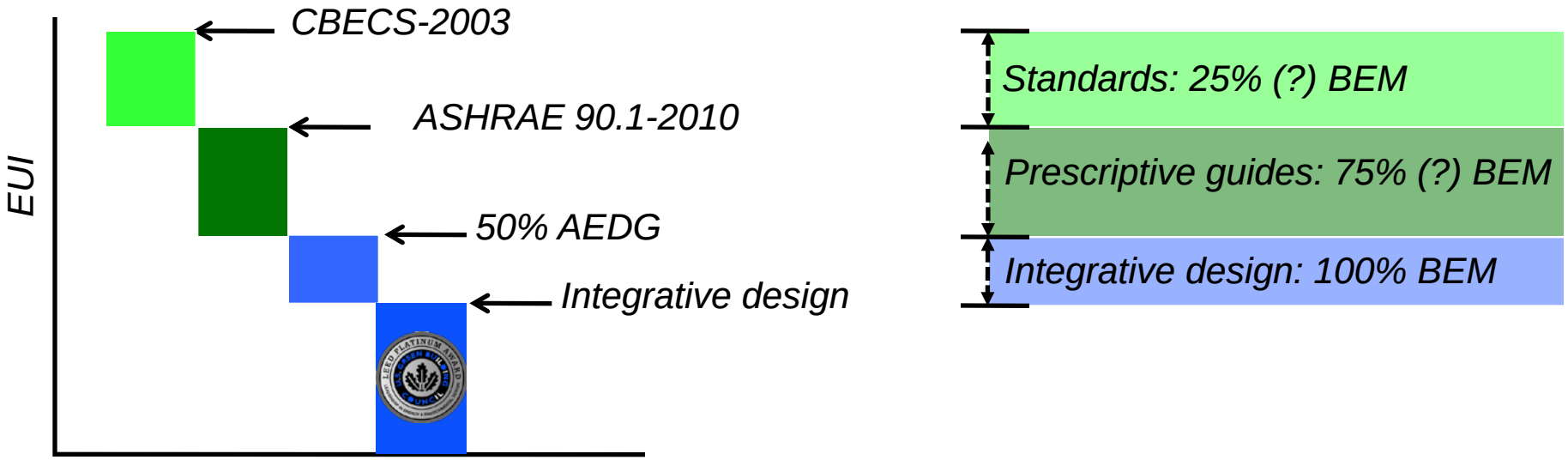
- **Predictive if all major inputs are certain; comparative when they are not**
- **Complements measured data: isolates effects, supports optimization & "what if"**



***BEM has multiple use cases, both established and emerging***

- ***Design**: architecture, HVAC system selection & sizing*
- ***Operations**: HVAC fault diagnosis, dynamic control & demand response*
- ***Market**: code development & compliance, ratings, incentives, M&V, policy, etc.*

# Measuring Impact—BEM on Buildings, BTO on BEM




## *Uber-metric: energy savings in actual buildings*

- *Easiest to attribute "integrative design" savings to BEM*
  - *Holistic optimization (30-50% savings) vs. individual ECMs (5-20% savings)*
  - *600 TBTU / year by 2030 [BTO p-tool] [Ed: this is a conservative estimate]*
  - *Will track integrative design & simulation use via AIA+2030 Commitment*
- *What about standards? And emerging operational use cases?*

## *Taxi-metric: number of third-party applications & services*

- *Slightly less meaningful than number of users & easier to get*

# Logic Model—BTO Role in BEM Ecosystem

## *BEM differs from windows, heat pumps & sensors*

- *Information technology with no "unit" cost ➔ DOE can build it*
- *An evaluation tool ➔ transparency & impartiality matter ➔ DOE should build it*

## *Ground rules for BTO (BEM) software*

- *State-of-the-art capabilities + commercial-friendly open-source licensing*
- *No end-user applications … except in special circumstances*
- ***"20 application vendors, not 20,000 end-users"***

# Emerging Technologies (ET) Projects

## *Best-in-class simulation engines*

- ***EnergyPlus whole-building energy simulation***
- *Radiance lighting*

## *Testing & validation*

- ***ASHRAE Standard 140:*** *"Method of test …"*
- ***FLEXLAB & Annex 58:*** *validation-grade experiments*

## *Targeted research & advanced development*

- *Modelica Buildings Library & IEA Annex 60*
  - *Modelica equation-based modeling*
    - *Ideal for HVAC & controls*
  - *Will form the basis of "Spawn-of-EnergyPlus"*
    - *More modularity, easier interface to other engines*
    - *Easier prototyping & sharing of component models*
    - *Control simulation, optimization & code generation*

# FORTRAN to C++ transition

## Background & context

- EnergyPlus originally in FORTRAN
- FORTRAN has limited access to modern hardware, software libraries & programmers
- DOE considered internal C++ transition several times, but difficult to pull off
  - Can't "stop the world" & little internal expertise

## Autodesk stepped up to fund & lead translation

- To facilitate uptake of EnergyPlus into their products
- Objexx performed 2-step translation: i) V8.0, ii) V8.2 "catch-up"
  - "Stopped the world" for 3 weeks rather than 9 months
- Currently removing C++ performance overhead (30% remaining)
- Will add object-orientation incrementally, automated translation gave FORTRAN-ic code

# Future—Inaccuracy/Validation & Uncertainty/Calibration

***Target problem:*** *perceived & real "inaccuracy" of energy simulation*

- *Some is "inherent" to physical approximation, most is "propagated" from uncertain inputs*
- *Limits use cases to comparative ("A is X% better than B"), not predictive ("A EUI is X")*
  - *Although you can actually do a lot this way*
- *Reduces confidence in all use cases, even comparative ones ☹*

***Approach I:*** *inaccuracy & algorithm validation*

- *Characterize & attribute (in)accuracy*
- *Use small well-characterized setups to remove input uncertainty*
  - *FLEXLAB, Annex 58 participants, maybe MAXLAB too*
  - *Currently working out initial set of experiments*
- *Formalize & publish test cases & results via ASHRAE standard 140*
- *Use 140 comparative testing to identify additional physical experiments*

***Approach II:*** *uncertainty & input calibration*

- *Outside of EnergyPlus, but complements end-uses*
- *Implementing two mechanisms in OpenStudio*
  - *Bayesian: fast & easy, includes uncertainty*
  - *Evolutionary (Autotune): more heavyweight but gets you closer*

# Future: Spawn-of-EnergyPlus

***Target problem:*** *monolithic structure with built-in imperative solvers*

- *Inhibits parallelization and co-simulation*
- *Barrier to prototyping of models for new technologies*
- *Poorly suited to operations-based use cases*

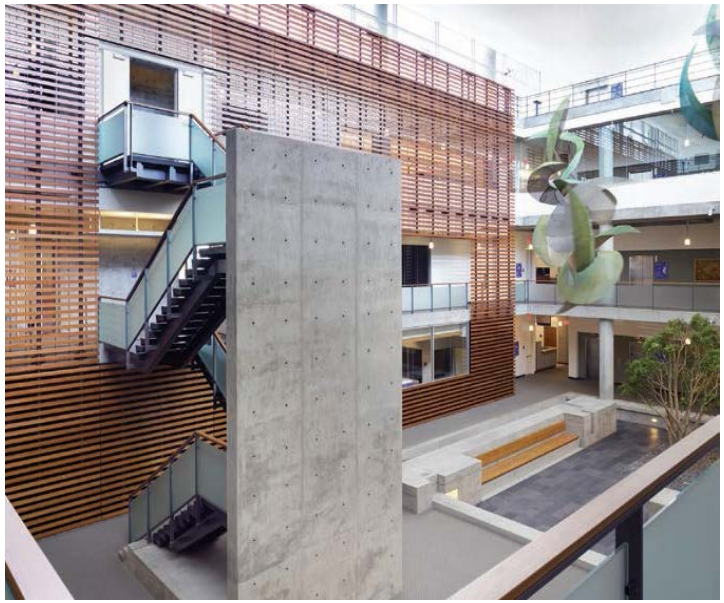
***Long term vision:*** *use Modelica for EnergyPlus HVAC&R/controls*

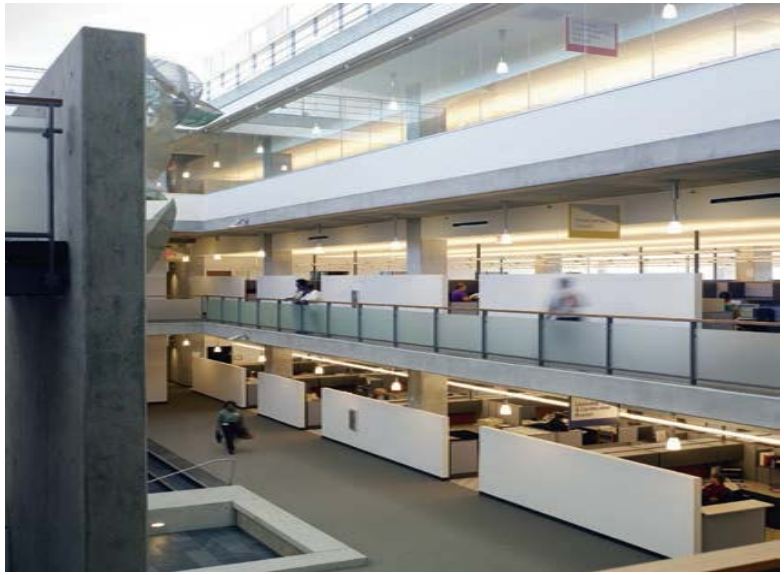
- *Modelica is a declarative modeling language*
  - *Decouples governing equations of the system from solver*
  - *Simplifies prototyping & sharing of models (no need to merge solvers)*
  - *Supports verification, optimization & direct implementation of control algorithms*
- *Developed & supported by international community (mostly EU)*
- *Born in automotive & aerospace world, but making headway in buildings*

***Approach:*** *Spawn-of-EnergyPlus*

- *Develop Modelica library for components & systems (LBNL & IEA Annex 60)—started FY13*
- *Develop & pilot prototype simulation master (LBNL, ORNL)—FY14*
- *Couple C++ EnergyPlus to solver (use RFP)—FY15-16*
  - *Will look like conventional EnergyPlus interface to existing users*
- *Incrementally replace existing C++ components with Modelica components over time*

# Challenging Simulation Problems
## (from Green-style Buildings)





- Large volumes with air stratification and daylight penetration
- Hybrid systems
- Zone based modeling
- Real world complexity

# Modeling Buildings of the Future

Gherkin Tower

Kingdom Tower

# Current Modeling Assumptions

All calculation procedures involve some kind of model; all models require simplifying assumptions and are therefore approximate. *(ASHRAE Handbook of Fundamentals, 2013)*

- Idealized Geometry
- Uniform Thermal Zones
- 1-D Heat Conduction
- Uniform Surfaces (Temperature, IR, SW)
- Steady State HVAC Systems
- Perimeter Daylighting

# Simergy

**Goal:** develop a free Graphical User Interface that enables EnergyPlus to be used easily and effectively by practitioners

**Public/private partnership:** collaborative development → free, public goods core + derivative works

**Contributors:** LBNL, Infosys, Digital Alchemy, Trane, Hydro-Quebec, Arup, HOK, SOM, Taylor Engineering

**Status:** V1.1 released April, 2014

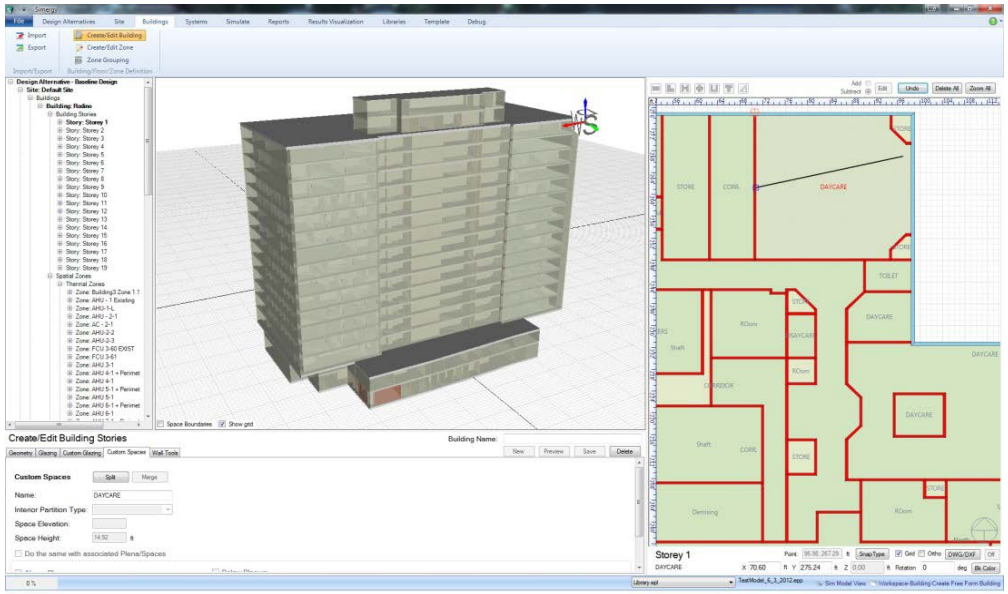
simergy.lbl.gov

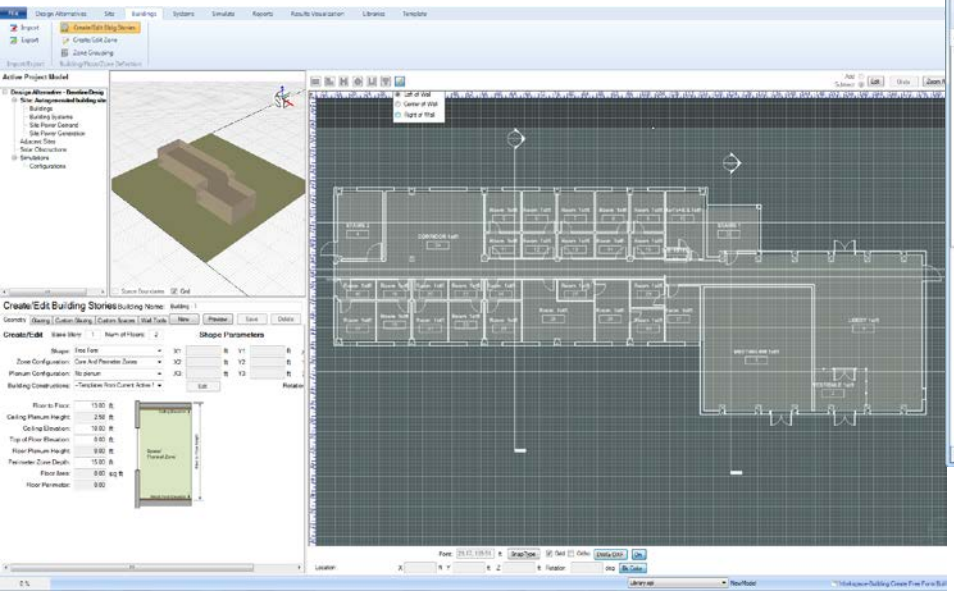
**Next Step:** Integration of rule-based compliance engine for Title 24

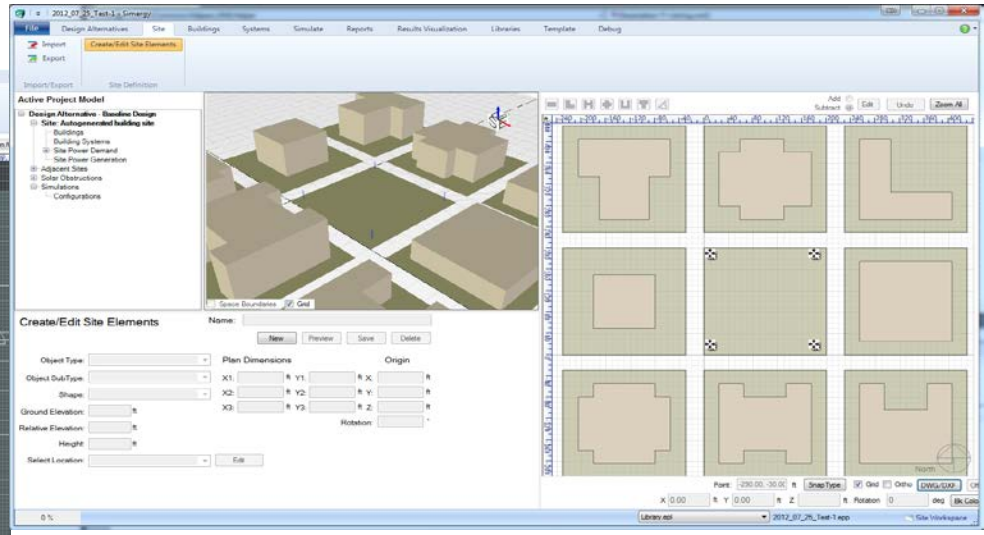
*Features defined in user requirements workshops by A&E's*

# Building Geometry

- Import from CAD/BIM:
  - IFC (ISO Standard, National BIM standard)
  - gbXML
  - trace over 2-D dxf or dwg
- Internal: stereotypical shapes

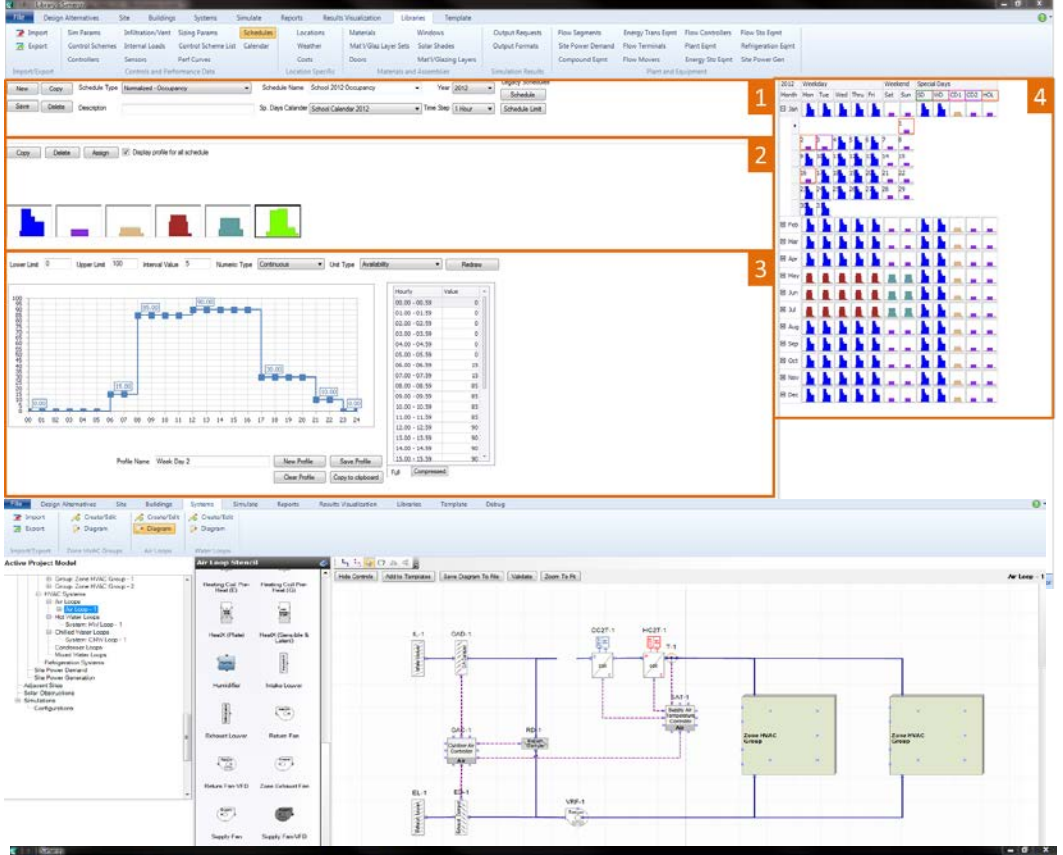


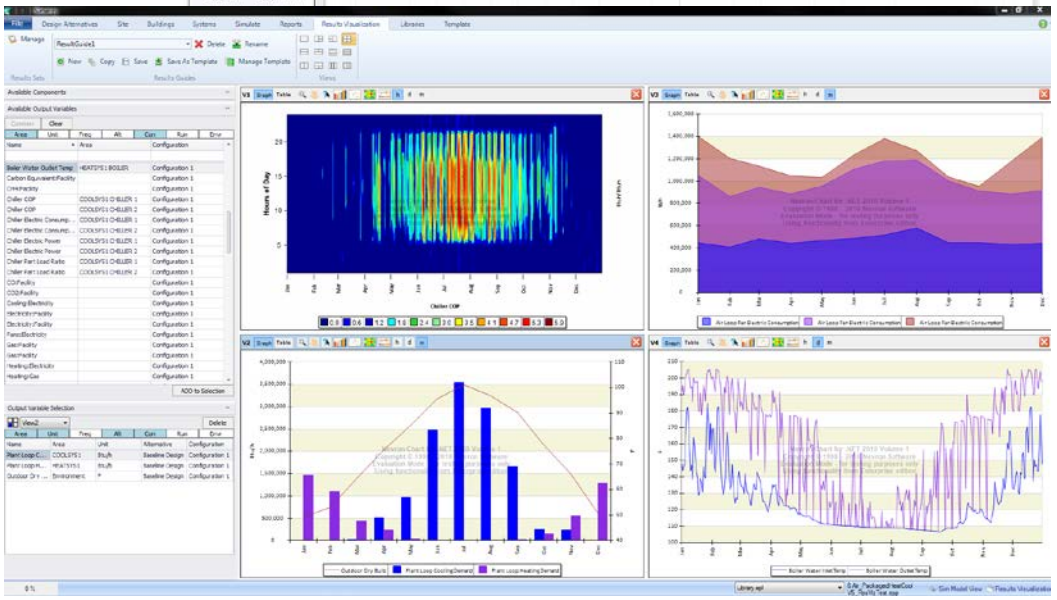



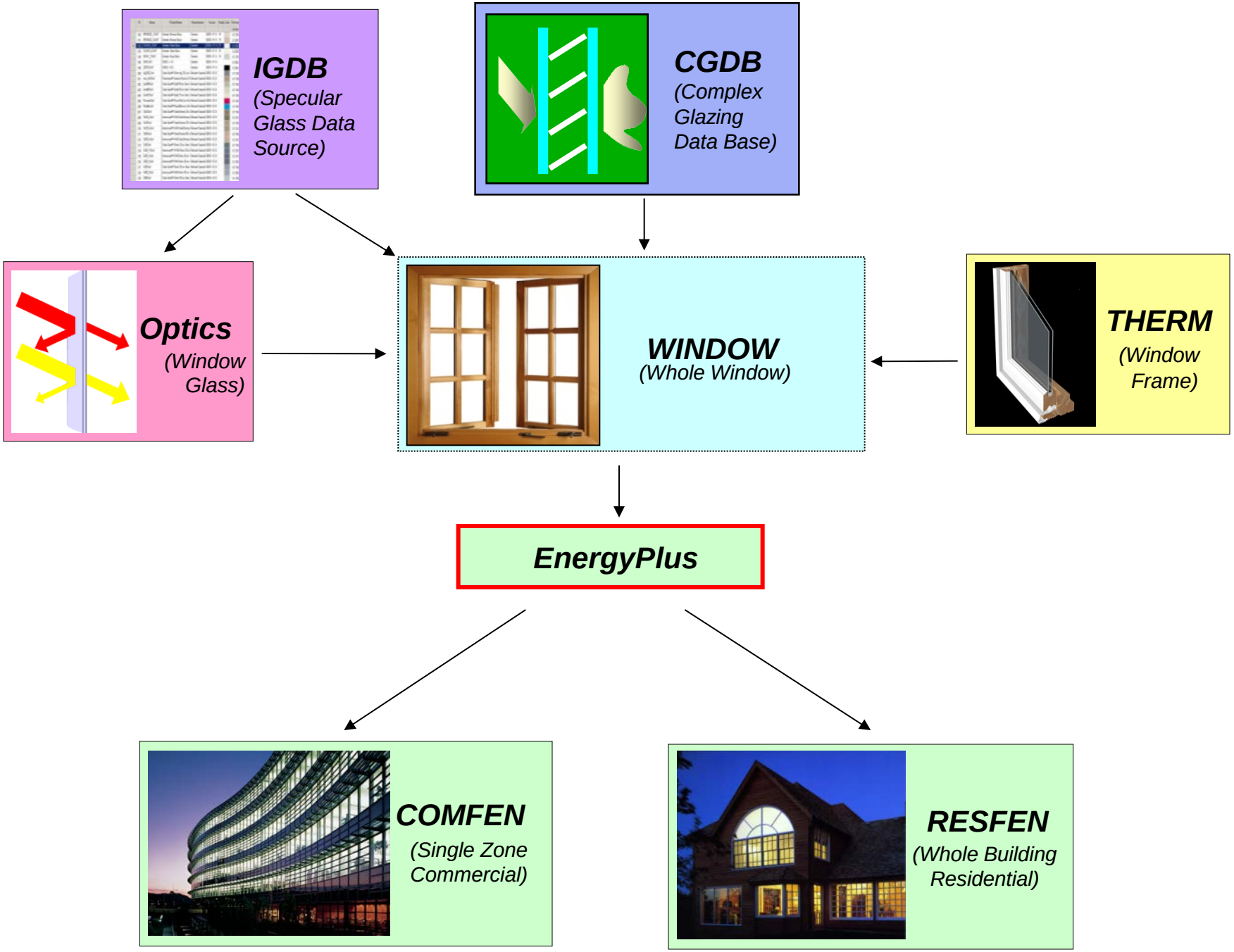



# Simergy Features

- Graphical schedule editor
- Drag and drop, component-based HVAC schematic editor
- Extensive templates and libraries – edit → innovative systems
- IP and SI units → international use
- Wide range of standard reports
- Interactive visualization of detailed output



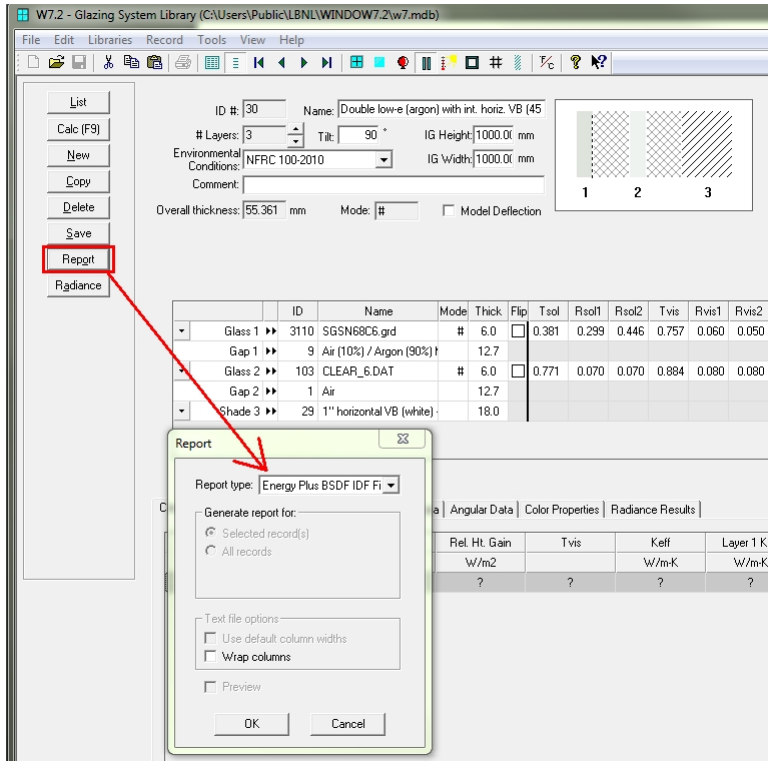




IGDB
(Specular Glass Data Source)
CGDB
(Complex Glazing Data Base)
Optics
(Window Glass)
WINDOW
(Whole Window)
THERM
(Window Frame)
EnergyPlus
COMFEN
(Single Zone Commercial)
RESFEN
(Whole Building Residential)

# EnergyPlus and WINDOW

*EnergyPlus and WINDOW now use same calculation engine in BSDF mode:*

- *Same governing equations for heat transfer (ISO 15099 and EN standards)*
- *Improvements, issues and new features can be implemented with minimum effort*
- *New type of shading devices can be easily used in EnergyPlus simulation*
- *Simple creation of window IDF*

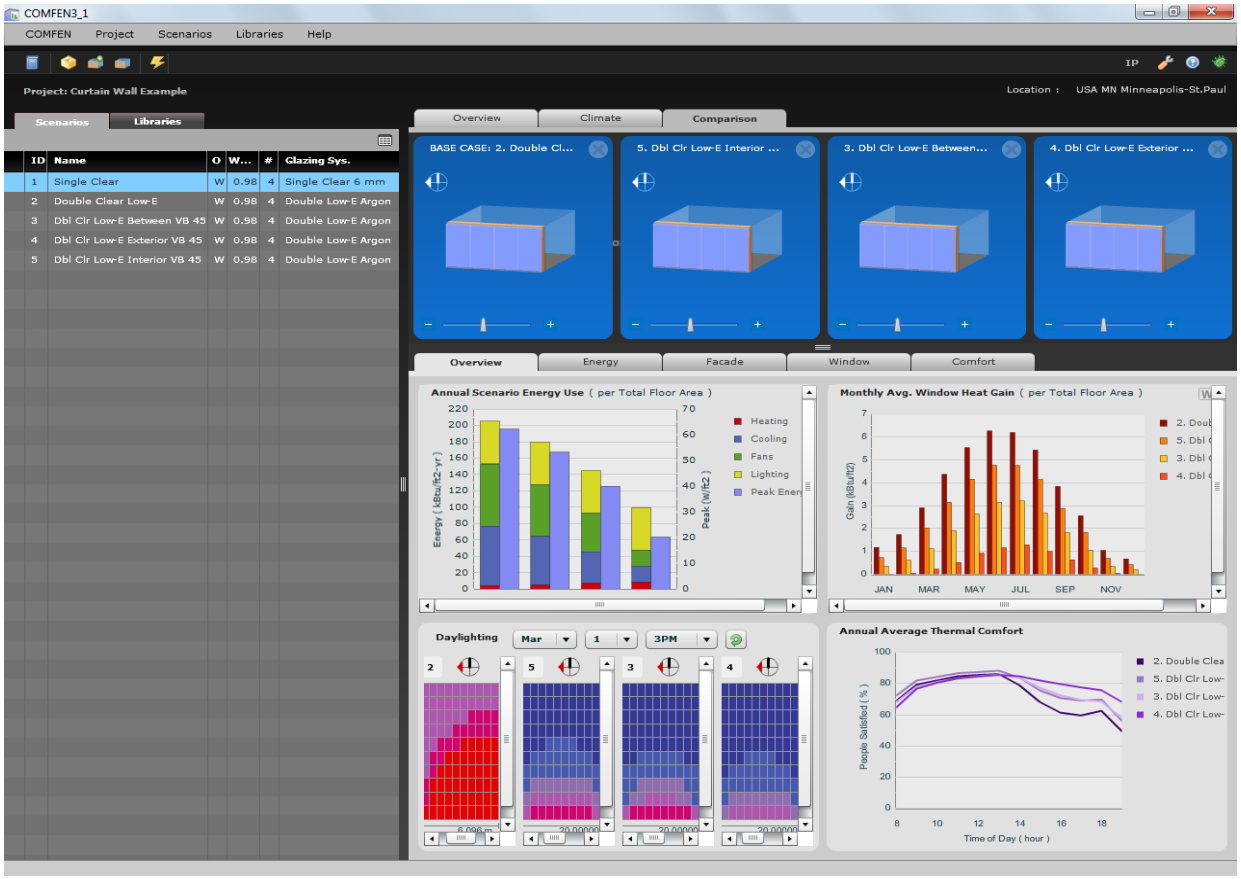



```
!================================
!         WindowConstruction
!================================

Construction:ComplexFenestrationState,
    ConWin0,            ! Frame/Divider Name
    LBNLWindow,         !- basis type
    None,               !- basis symmetry type
    ThermParam,         !- window thermal model
    CFS_Glz_Basis,      !- basis matrix name
    Tfsol_ConWin0,      !- Tfsol
    Rbsol_ConWin0,      !- Rbsol
    Tfvis_ConWin0,      !- Tfvis
    Tbvis_ConWin0,      !- Tbvis
    MatGlz0,            !- layer 1 name
    fAbs_ConWin0_Lay0,  !- fAbs
    bAbs_ConWin0_Lay0,  !- bAbs
    GapMatGas0,
    ,
    ,
    MatGlz1,
    fAbs_ConWin0_Lay1,  !- fAbs
    bAbs_ConWin0_Lay1,  !- bAbs
    GapMatGas0,
    ,
    ,
    MatGlz2,
    fAbs_ConWin0_Lay2,  !- fAbs
    bAbs_ConWin0_Lay2;  !- bAbs

Construction:ComplexFenestrationState,
    ConWin1,            ! Frame/Divider Name
```

# COMFEN

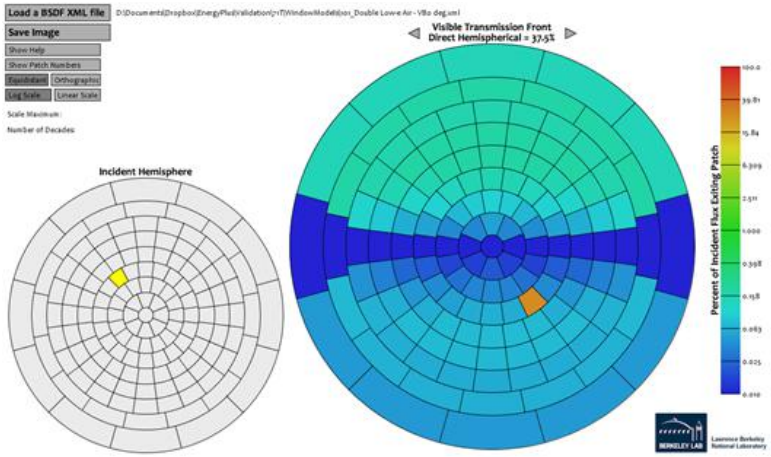
*COMFEN is user-friendly GUI for EnergyPlus:*

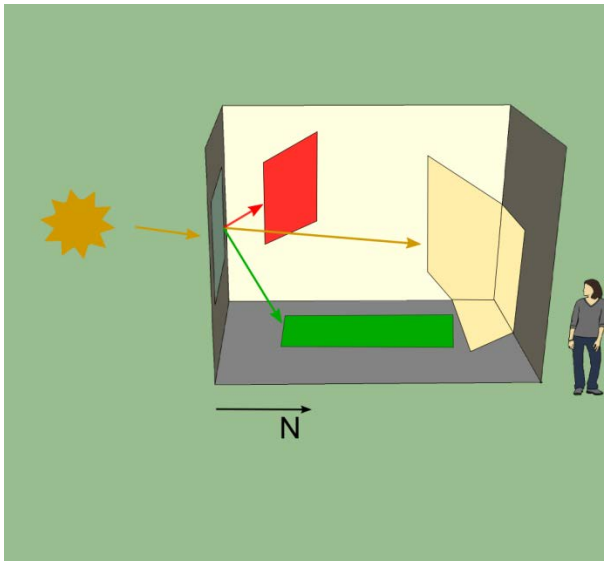
- *Automatic generation of BSDF window types*
- *Visual representation of results*
- *Quick comparison between different products (Energy + Peak Demand, CO2 Emissions, Daylighting + Thermal Comfort, etc)*



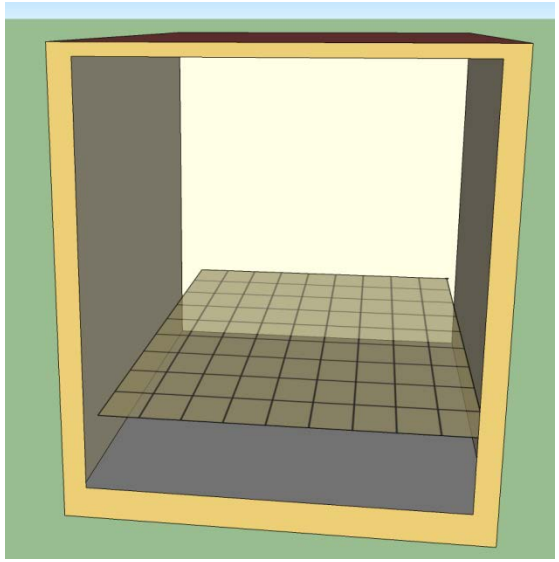
# *Bidirectional Scattering Distribution Function*

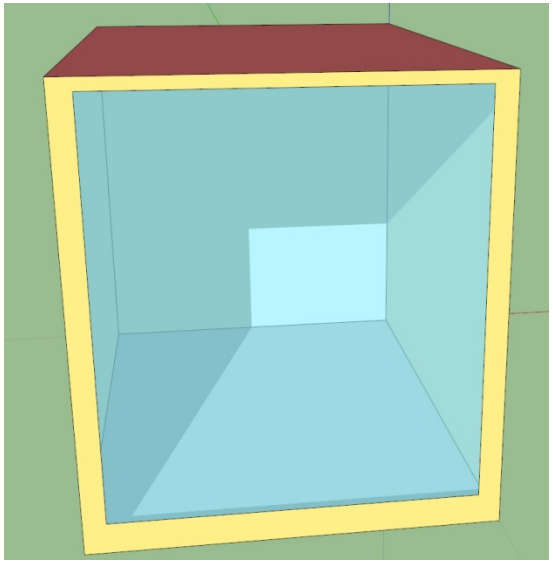
- *Describes the way the light is scattered by surface*
- *Generalized way to describe light scattering in window systems*
- *EnergyPlus and WINDOW use Klems basis 145 x 145 solid angles*
- *Window transmittance (BTDF) and reflectance (BRDF)*
- *More accurate daylighting calculation*
- *This approach provides improved accuracy for windows with shading devices*

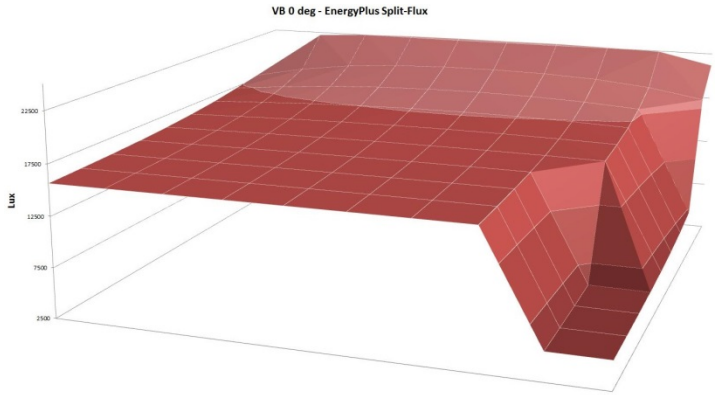


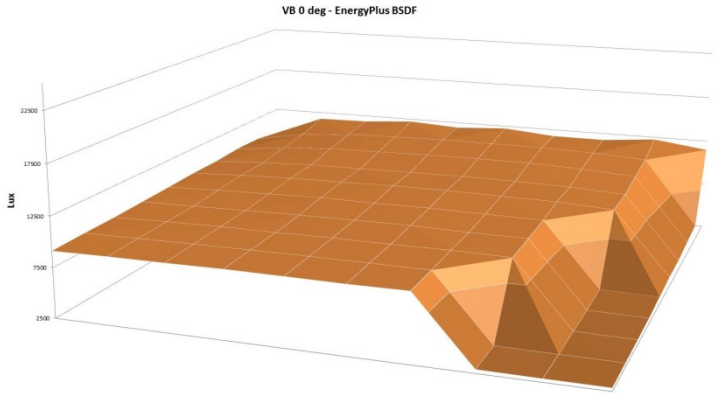



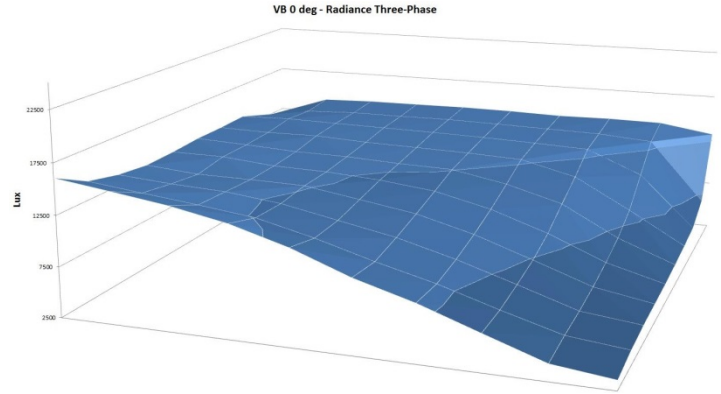
# Example of daylighting results





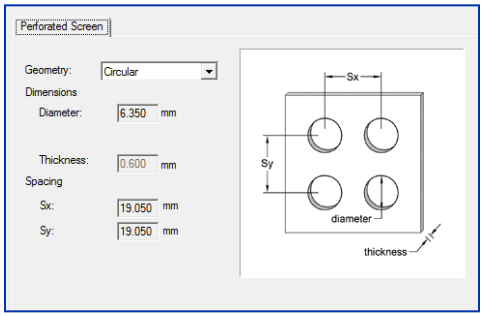


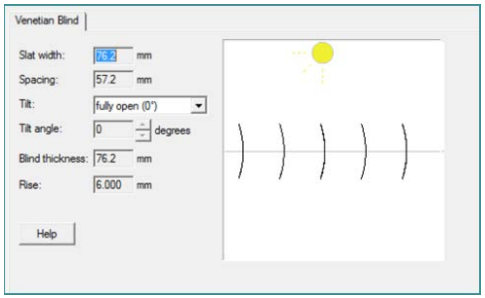



# Additional improvements

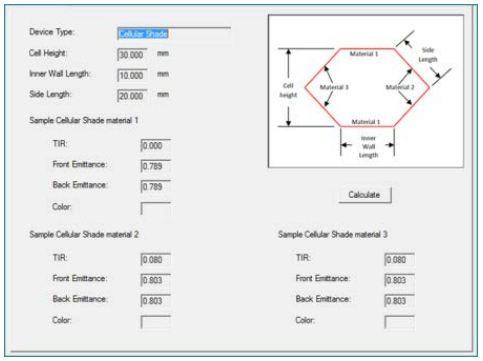
*Perforated screens*



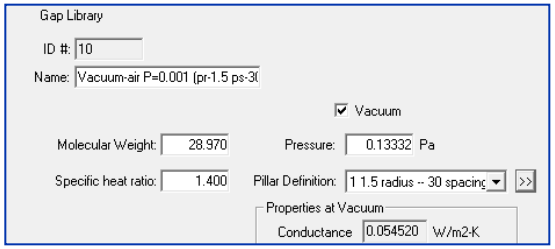

Vertical Louvers

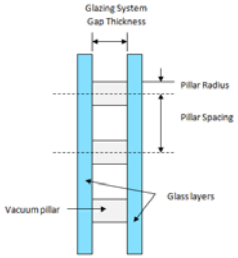


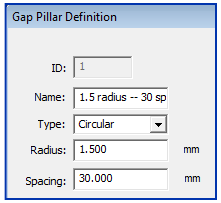

Cellular shades



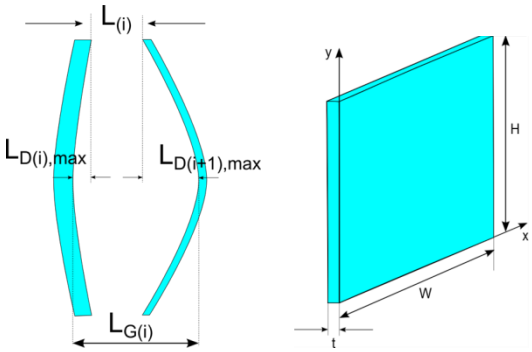

Vacuum glazing




Glazing deflection

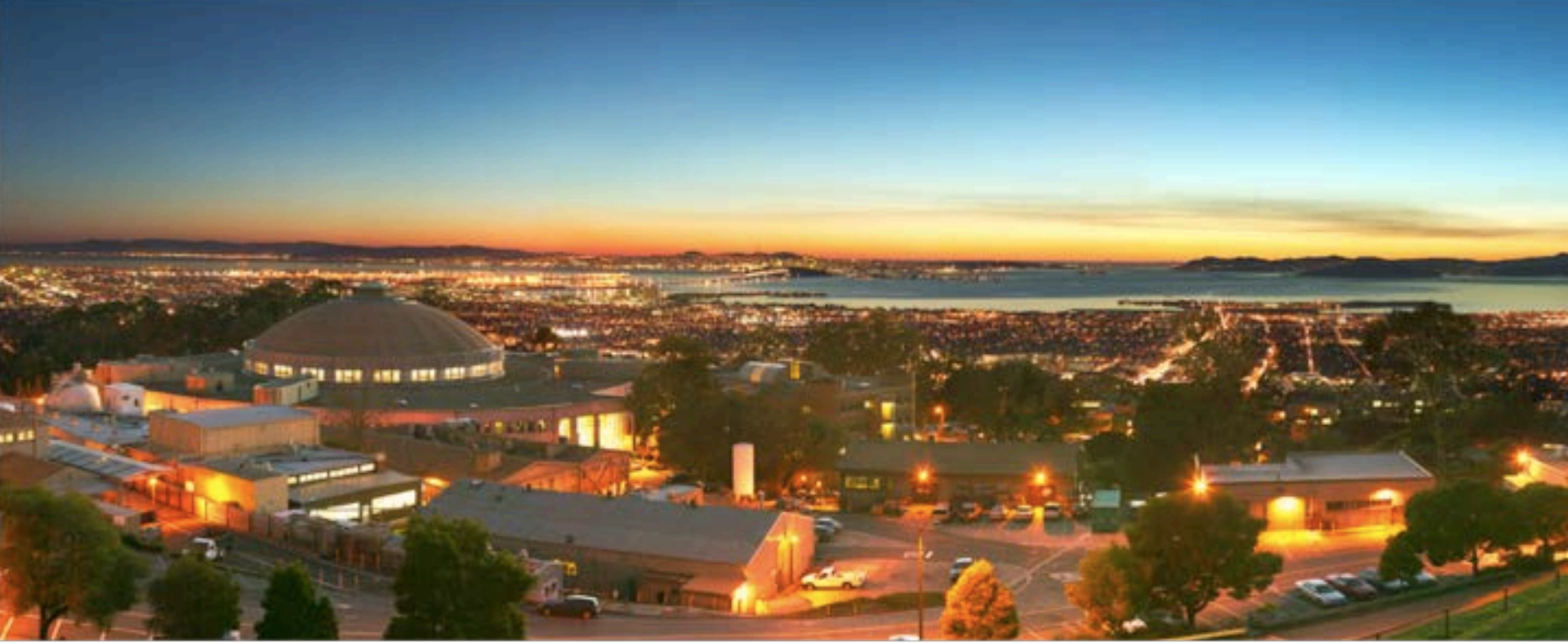



| Ufactor | SC | SHGC | Rel. Ht. Gain | Tvis | Keff | Gap 1 Keff |
|---|---|---|---|---|---|---|
| W/m2-K | | | W/m2 | | W/m-K | W/m-K |
| 1.667 | 0.422 | 0.367 | 278 | 0.691 | 0.0304 | 0.0304 |
| 1.870 | 0.425 | 0.369 | 282 | 0.691 | 0.0359 | 0.0304 |

*Multiple shading devices in a single window*

*Measured BSDF*

*Scheduled surface gains*



# Modelica Buildings Library & Co-Simulation with EnergyPlus for very Low Energy Buildings


Michael Wetter, Thierry S. Nouidui

Simulation Research Group

Building Technology and Urban Systems Department

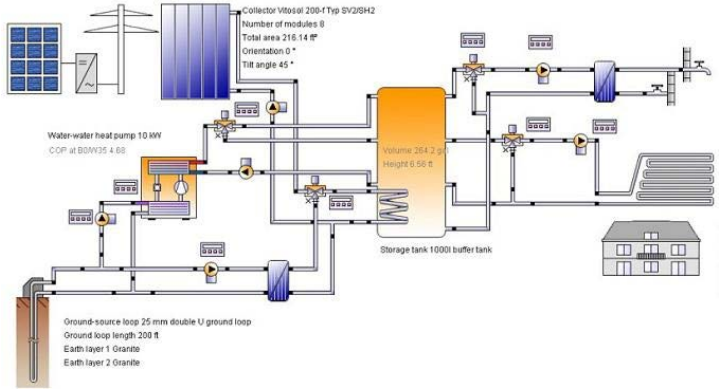
Environmental Energy Technologies Division


Seminar at LBNL, 05/30/2014

# Challenges

Buildings are becoming integrated and complex

Courtesy: cnn.com




Courtesy: energyhomes.org

Extending and using legacy tools for new systems and operations is difficult

State of the art tools are more flexible

TRNSYS 17

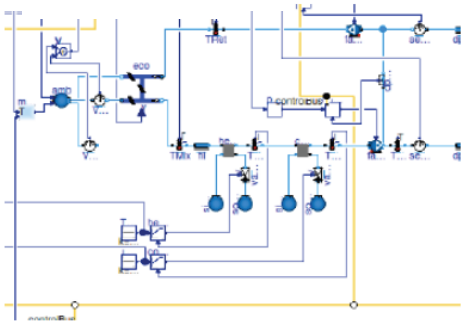
EnergyPlus

**BCVTB, FMI**

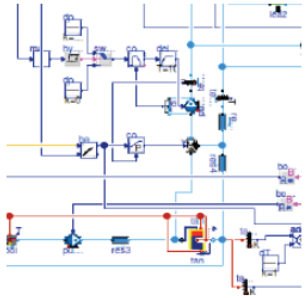
MODELICA

# Modelica Buildings Library

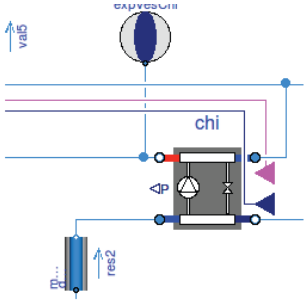
Air-based HVAC



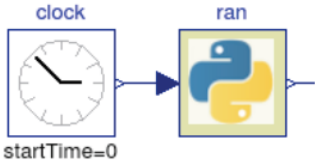
Hydronic heating



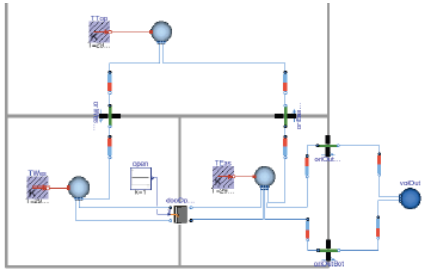
Chiller plants



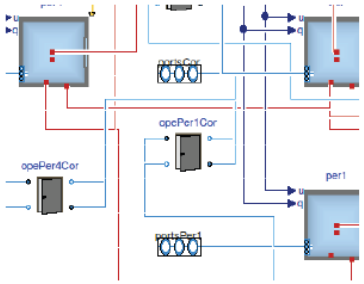

Embedded Python



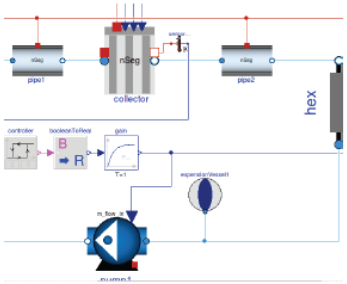

Natural ventilation,
Multizone air exchange,
Contaminant transport



Room heat transfer
Incl. window (TARCOG)

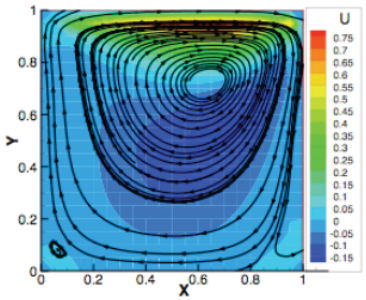



Solar collectors

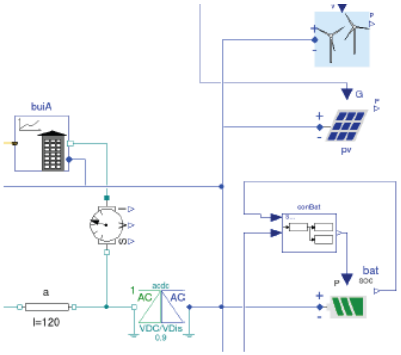



FLEXLAB

Room airflow (2014)




Electrical systems (2014)



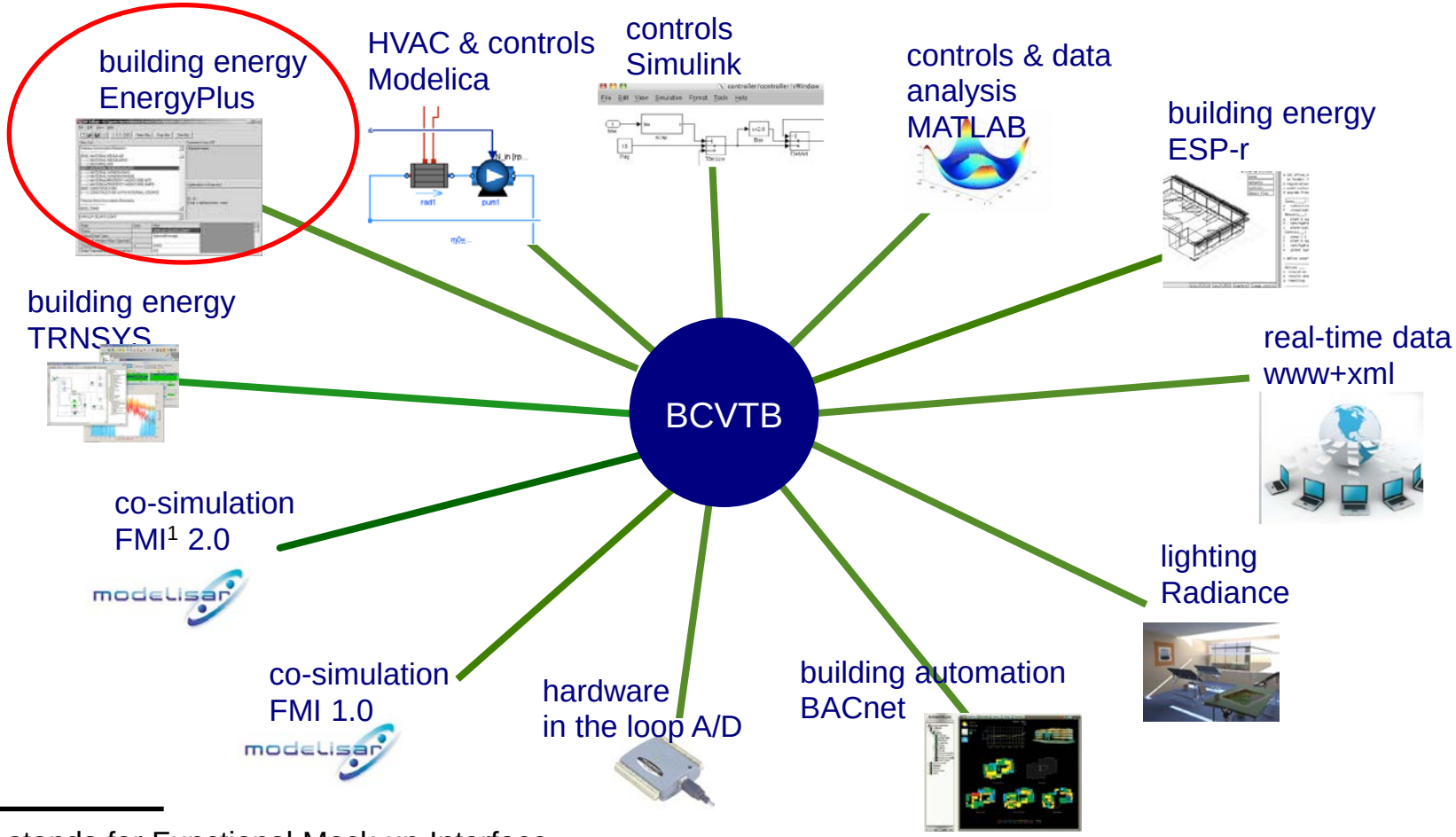

300+ validated component models.
Free, open source.
http://simulationresearch.lbl.gov/modelica

# Building Controls Virtual Test Bed

Free open-source middle-ware based on UC Berkeley's Ptolemy II program.

Synchronizes and exchanges data as (simulation-)time progresses.

http://simulationresearch.lbl.gov/bcvtb

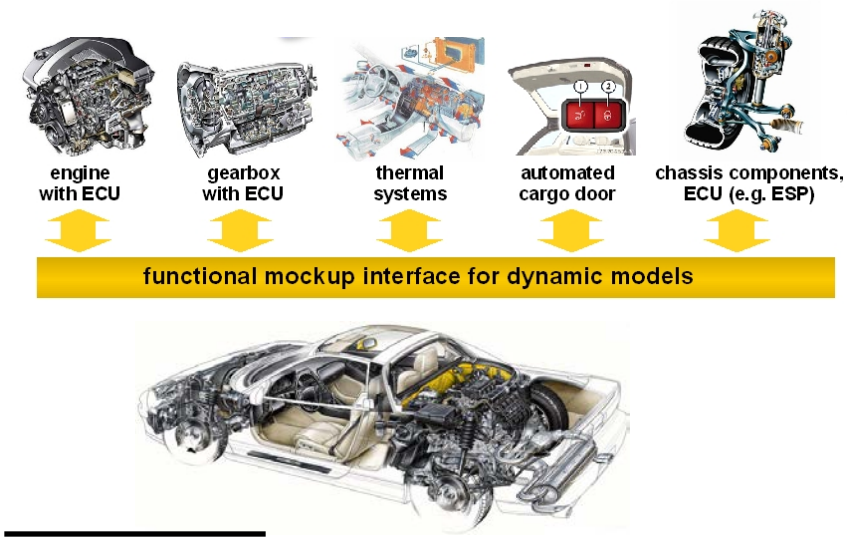


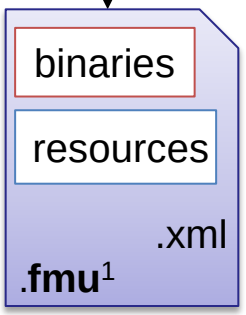

[1]FMI stands for Functional Mock-up Interface.

# Functional Mock-up Interface (FMI)

An open-standard for model-exchange and co-simulation
http://www.fmi-standarg.org

Initiated by Daimler AG
ITEA2 project: 30 partners, > 175 person years, > 28 million €, July 2008 - June 2011
50 tools currently supported
https://www.fmi-standard.org/tools



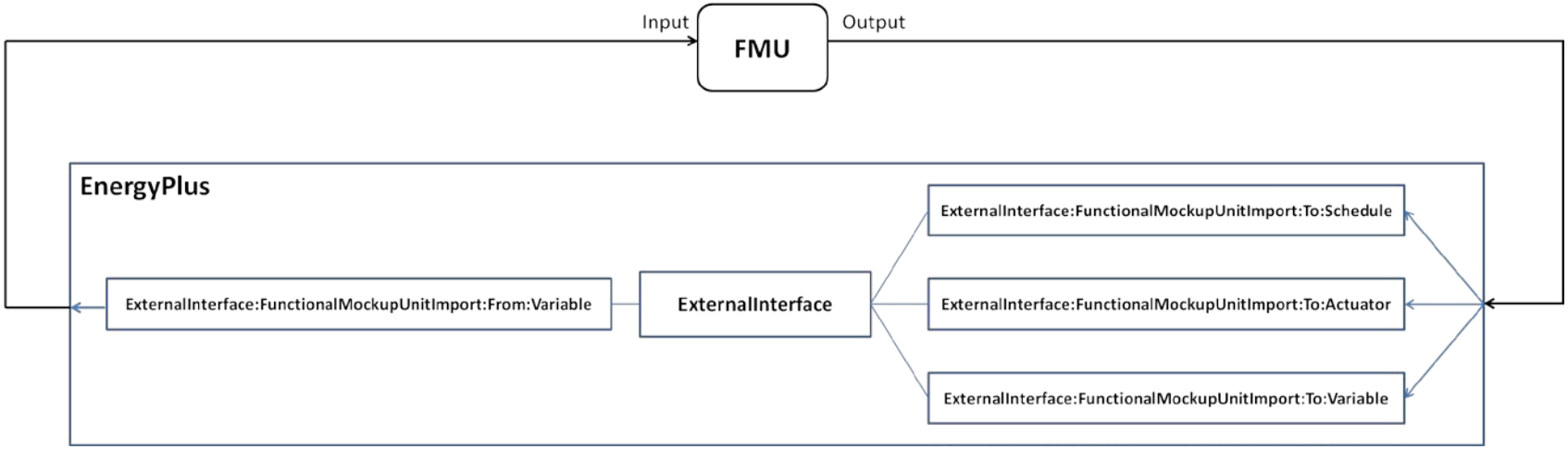




[1]FMU stands for Functional Mock-up Unit.

# FMU Import Interface in EnergyPlus

EnergyPlus: Whole building simulation program

- Pros: yearly building performance simulation
- Cons: idealized control semantics and lack of support for continuous time, discrete time and event driven systems makes it difficult to use for control design

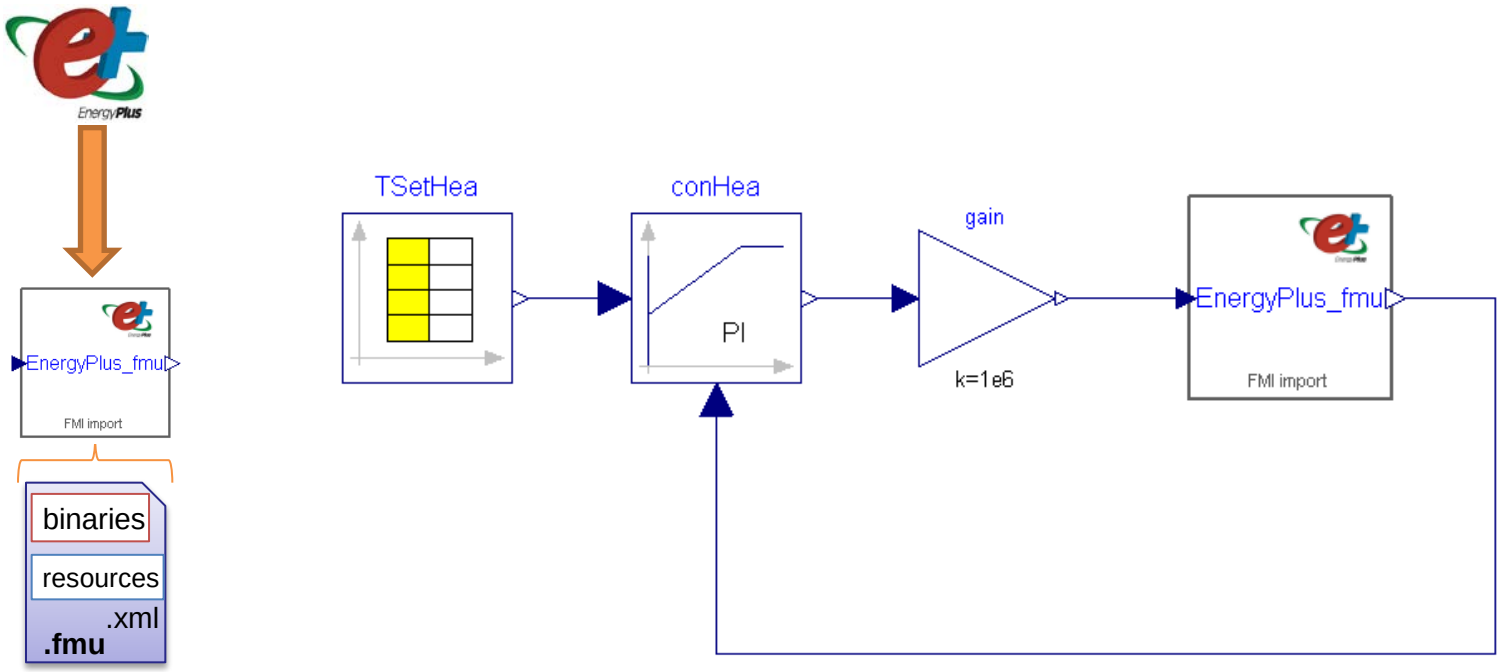



FMU import interface allows

1. developing models of HVAC or controls in Modelica,
2. exporting them as FMUs,
3. importing them in EnergyPlus for co-simulation.

# FMU Export Utility for EnergyPlus

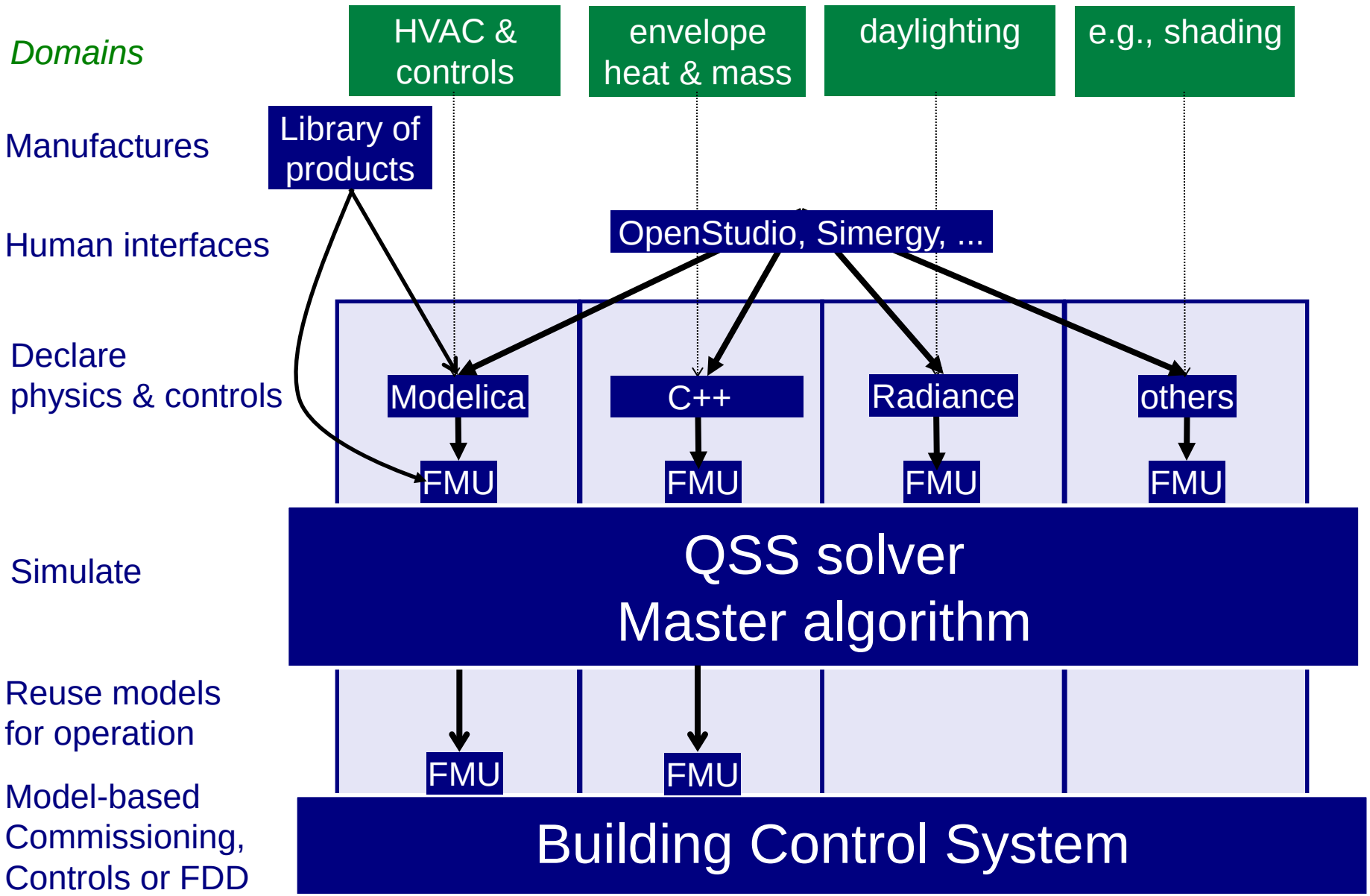
**EnergyPlusToFMU** is a free open-source tool for exporting EnergyPlus as an FMU.
http://simulationresearch.lbl.gov/fmu/EnergyPlus/export/index.html



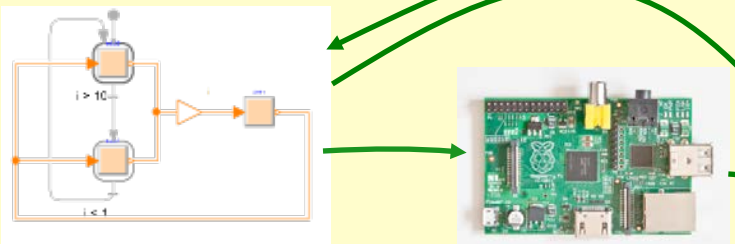

FMU export utility allows exporting EnergyPlus as an input/output block for

- designing and testing HVAC and controls,
- design of electrical demand response controller for a campus

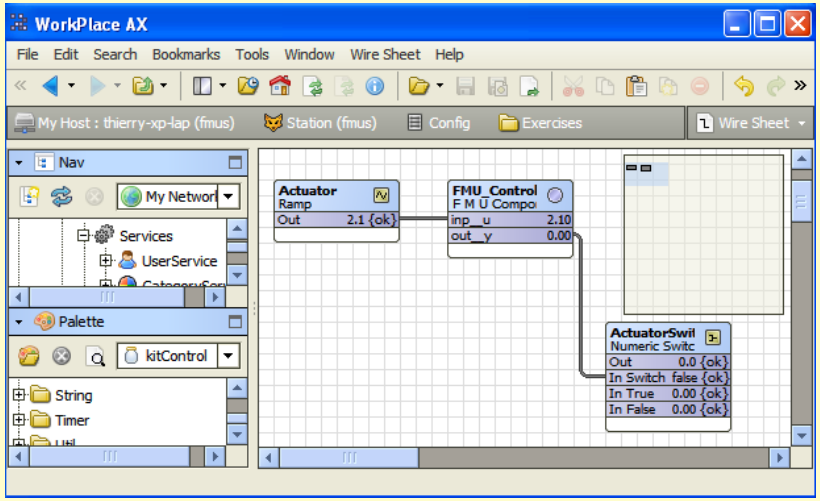
# Looking forward – “Son of EnergyPlus”

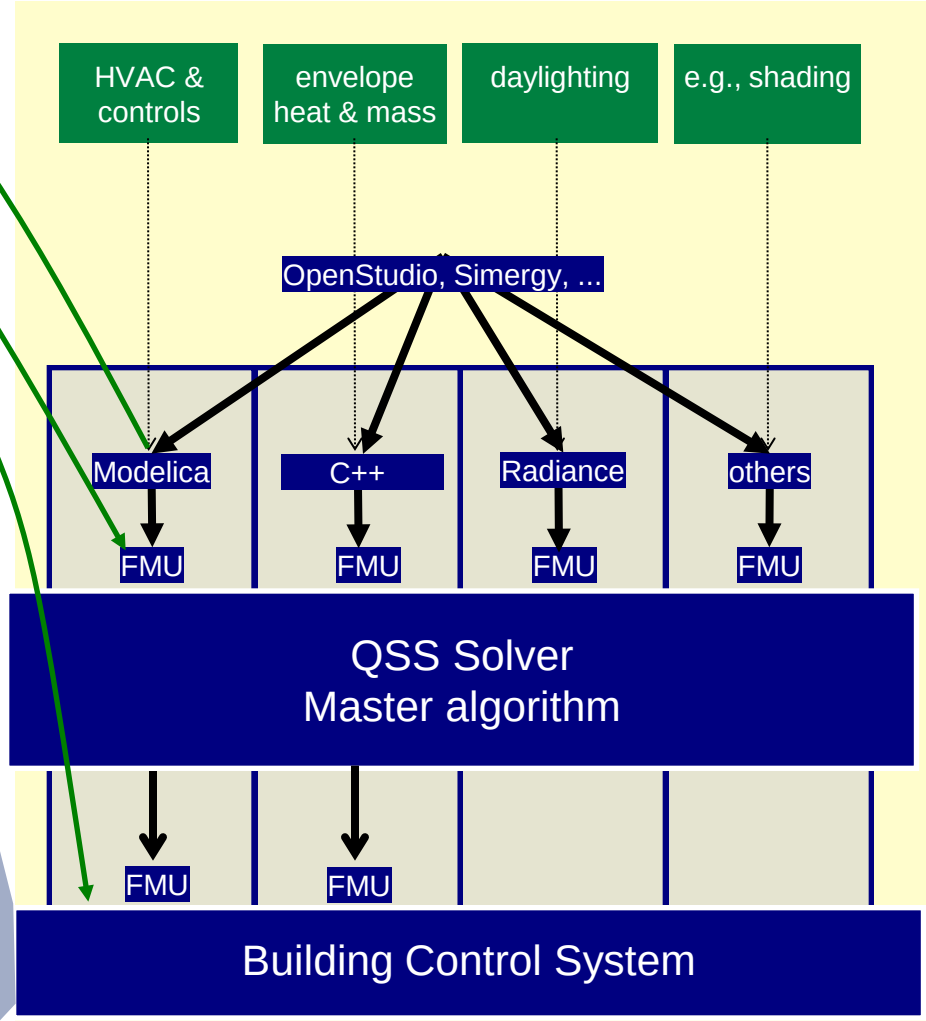


# “Son of EnergyPlus” capabilities will include the integration of new processes and the deployment of model to control systems, enabled through technology transfer from other communities



Design and deployment of energy-aware control and FDD sequences




Model and control algorithm deployment, e.g., to Niagara control platform.