



*Innovation for Our Energy Future*

## **OpenStudio**

An integrated Whole Building Analysis Platform



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**Commercial Buildings Research Group**

**National Renewable Energy Laboratory**

**Radiance International Workshop 2011**

**Berkeley, CA USA  
August 24-26, 2011**



# NREL RSF

## A Project that *Required* Integrated Modeling

# DOE/NREL RSF: Project Goals

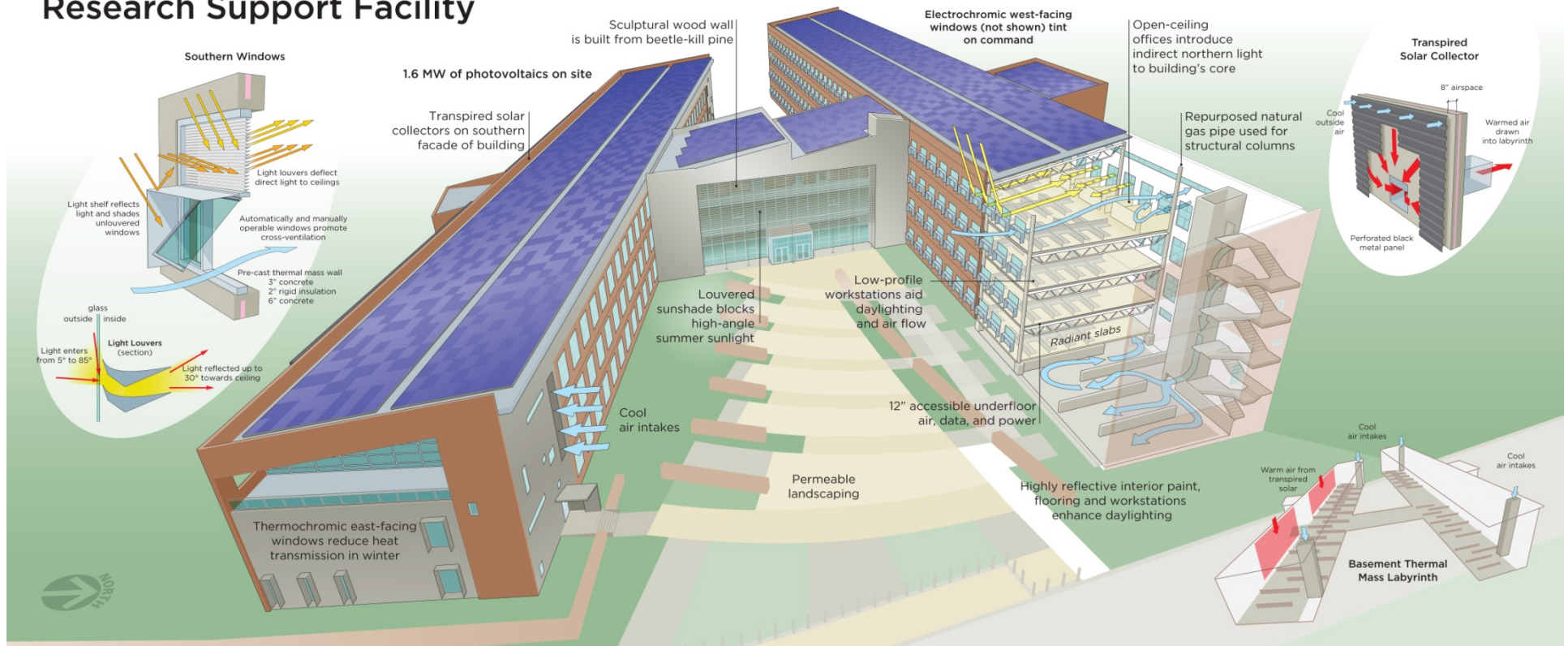
- 800+ people in DOE office space on NREL's campus
- 220,000 ft<sup>2</sup>
- Design/Build Process with required energy goals
  - 25 kBtu/ft<sup>2</sup>
  - 50% energy savings
  - LEED Platinum
- Replicable
  - process
  - technologies
  - cost
- Site, source, carbon, cost ZEB:B
  - Includes plugs loads and datacenter
- Firm fixed price of ~\$64 million
  - \$259/ft<sup>2</sup> construction cost (not including \$27/ft<sup>2</sup> for PV)
- Opened June 10, 2010



# Key Design Strategies

1. Optimal orientation and office space layout
2. Fully daylit office wings with high performance electrical lighting
3. Continuous insulation precast wall panels with thermal mass
4. Operable windows for natural ventilation
5. Radiant heating and cooling
6. Outdoor air preheating
  - Transpired solar collector
  - Datacenter waste heat
  - Exhaust air energy recovery
  - Crawl space thermal storage
7. Aggressive plug load control strategies
8. Data center outdoor air economizer with hot aisle containment
9. Roof top and parking lot based PV

# Research Support Facility

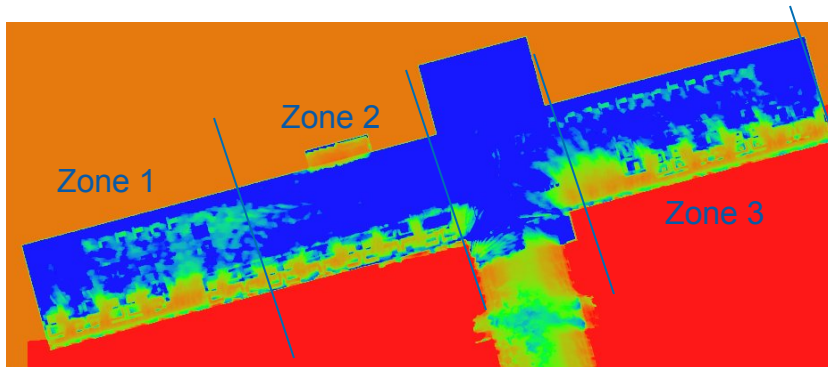


# Daylight/Energy Integration (3 years ago)

For the RSF calculations:

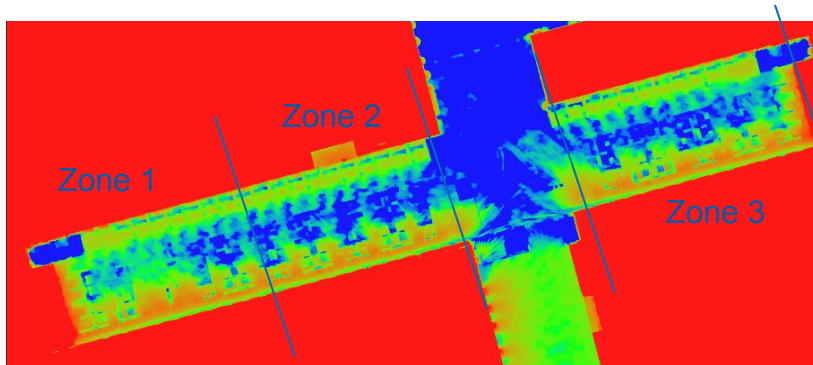
- Lightlouver geometry was explicitly modeled in Radiance
- Radiance's light backwards raytracing was used (no mkillum, no photon map)
- Cranked up the rendering parameters, waited a long time, and STILL assumed there was a significant underestimation of the daylight contribution
- Used SPOT to perform annual simulation of daylight performance and dimming response, generated schedule "include file" for DOE2 energy analysis
- Energy modelers included SPOT schedule in DOE2 energy runs
- Painful process, required much coordination among disciplines/models

# Radiance – Daylight Distribution



First Floor

Applied to Floors 1 & 2 in energy model



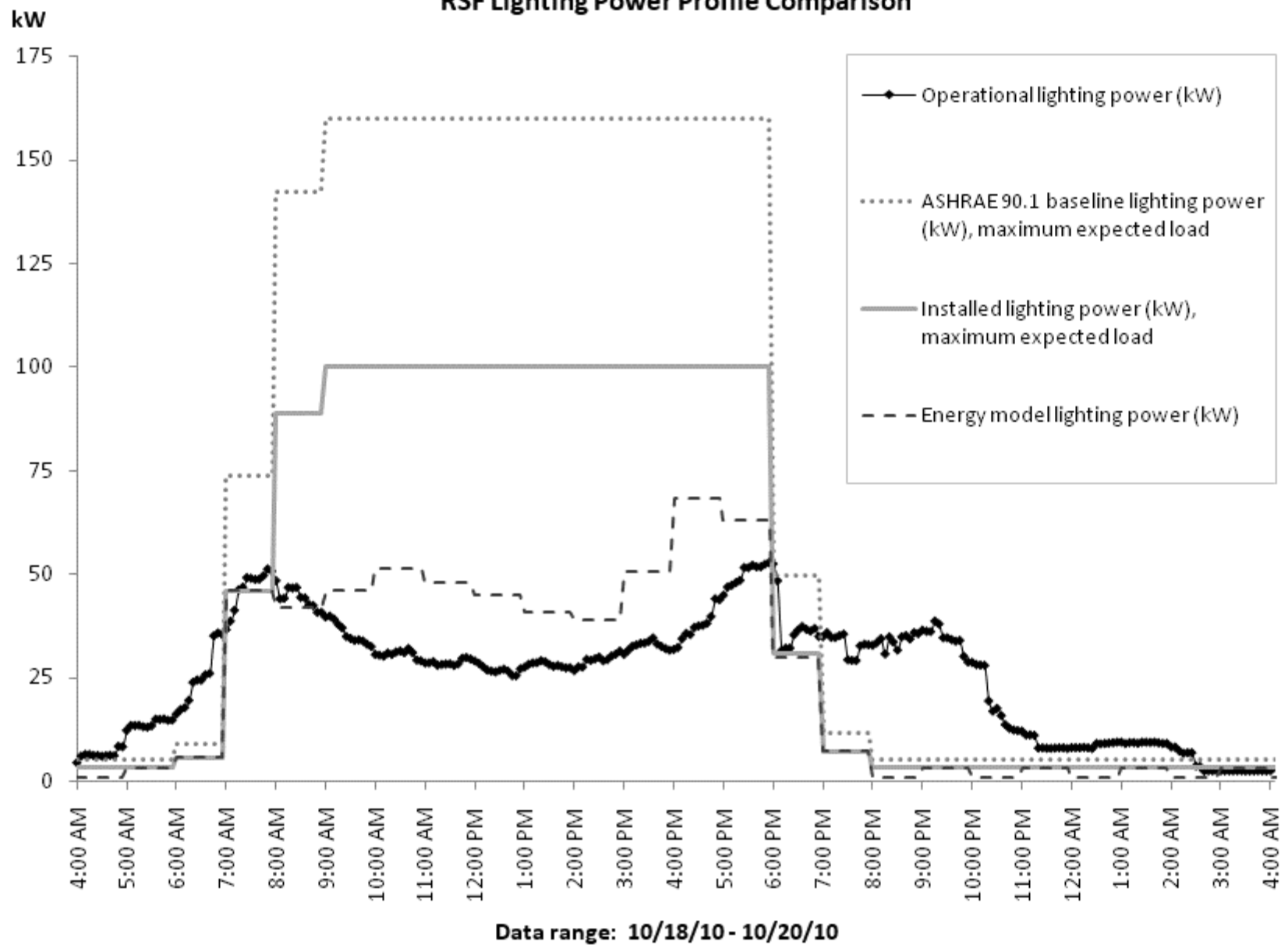
Third Floor

Applied to Floors 3 & 4 in energy model

Annual Daylight Availability – North Wing

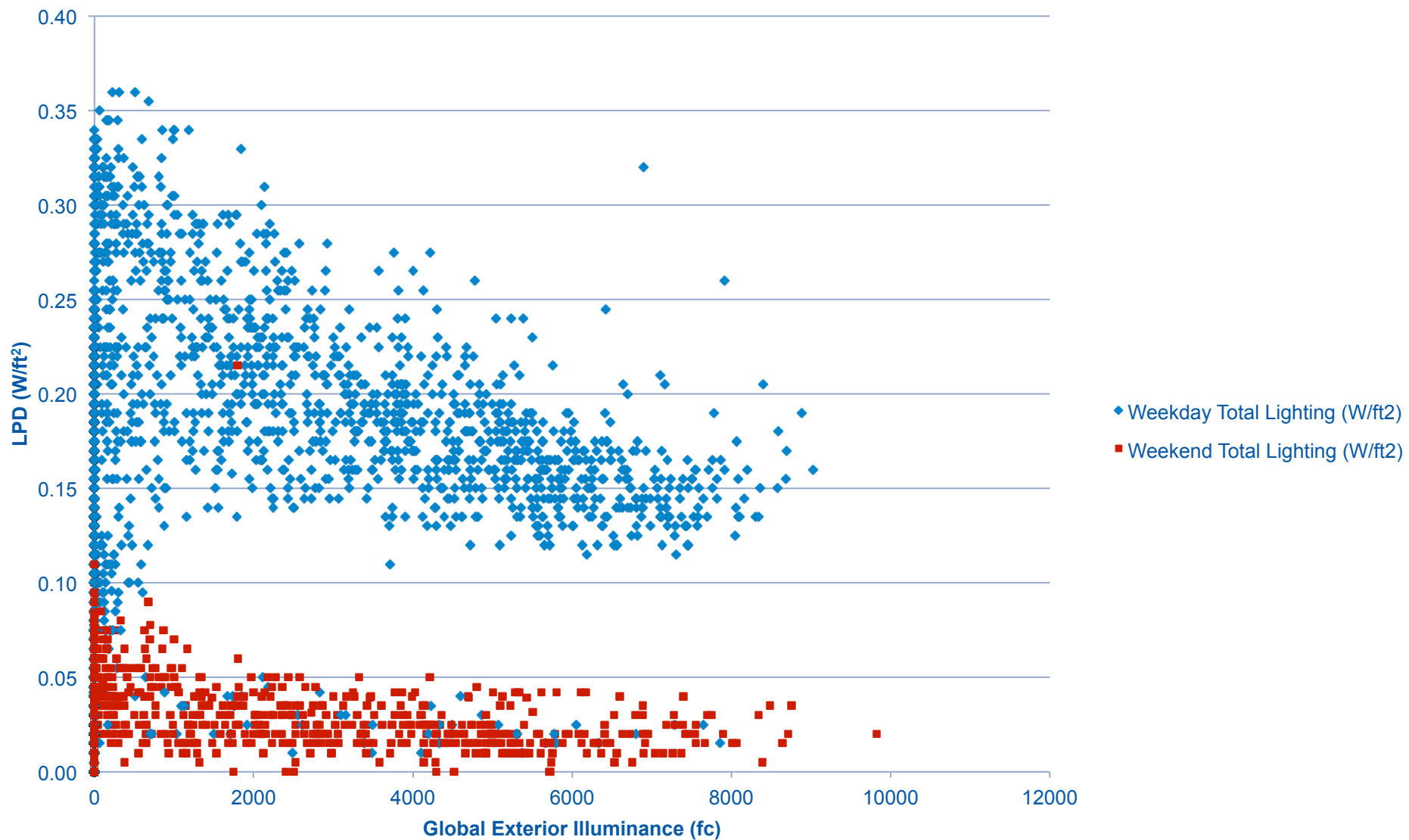
**Lighting Control Zones – East-West**

### RSF Lighting Power Profile Comparison

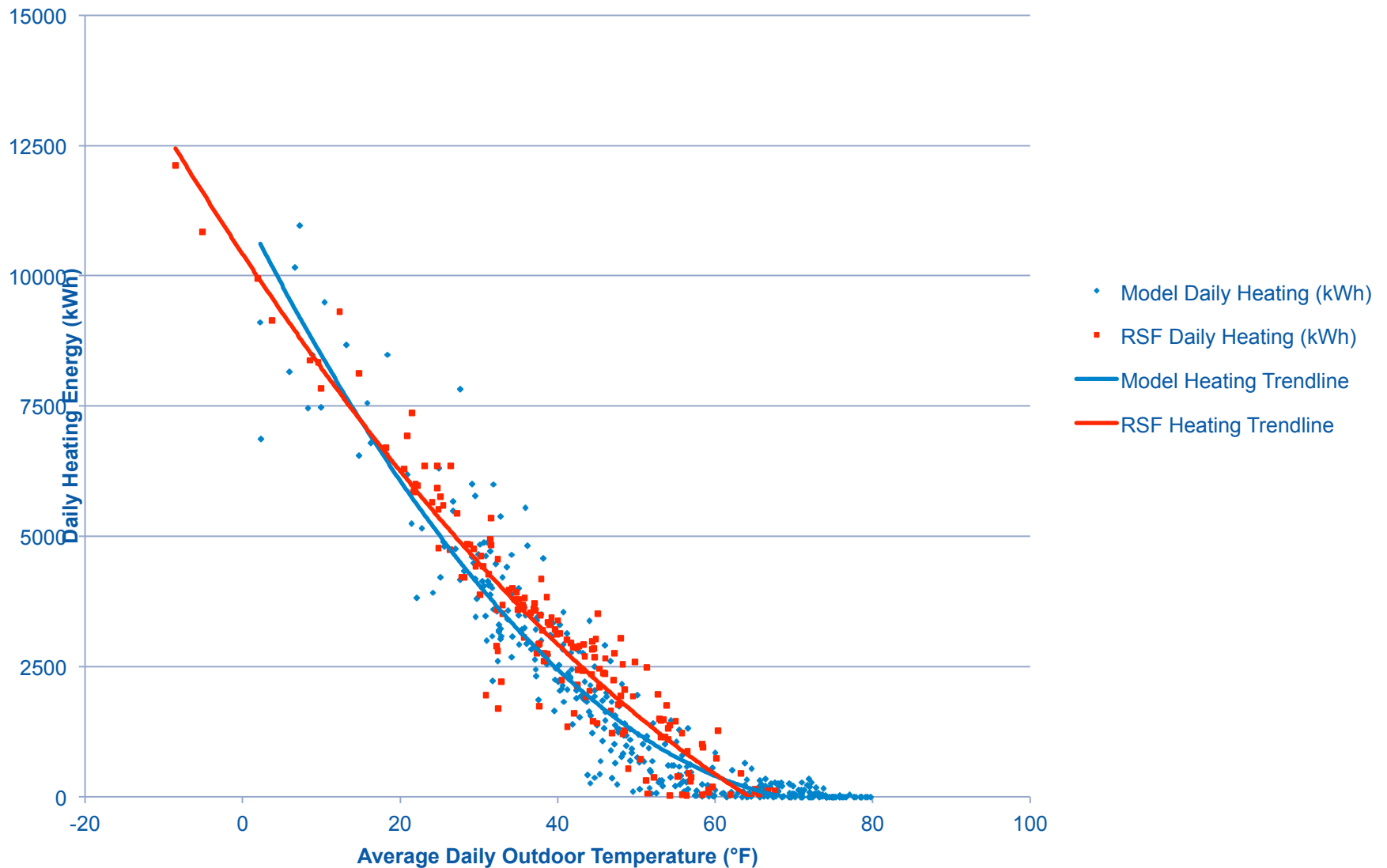


# RSF Lighting

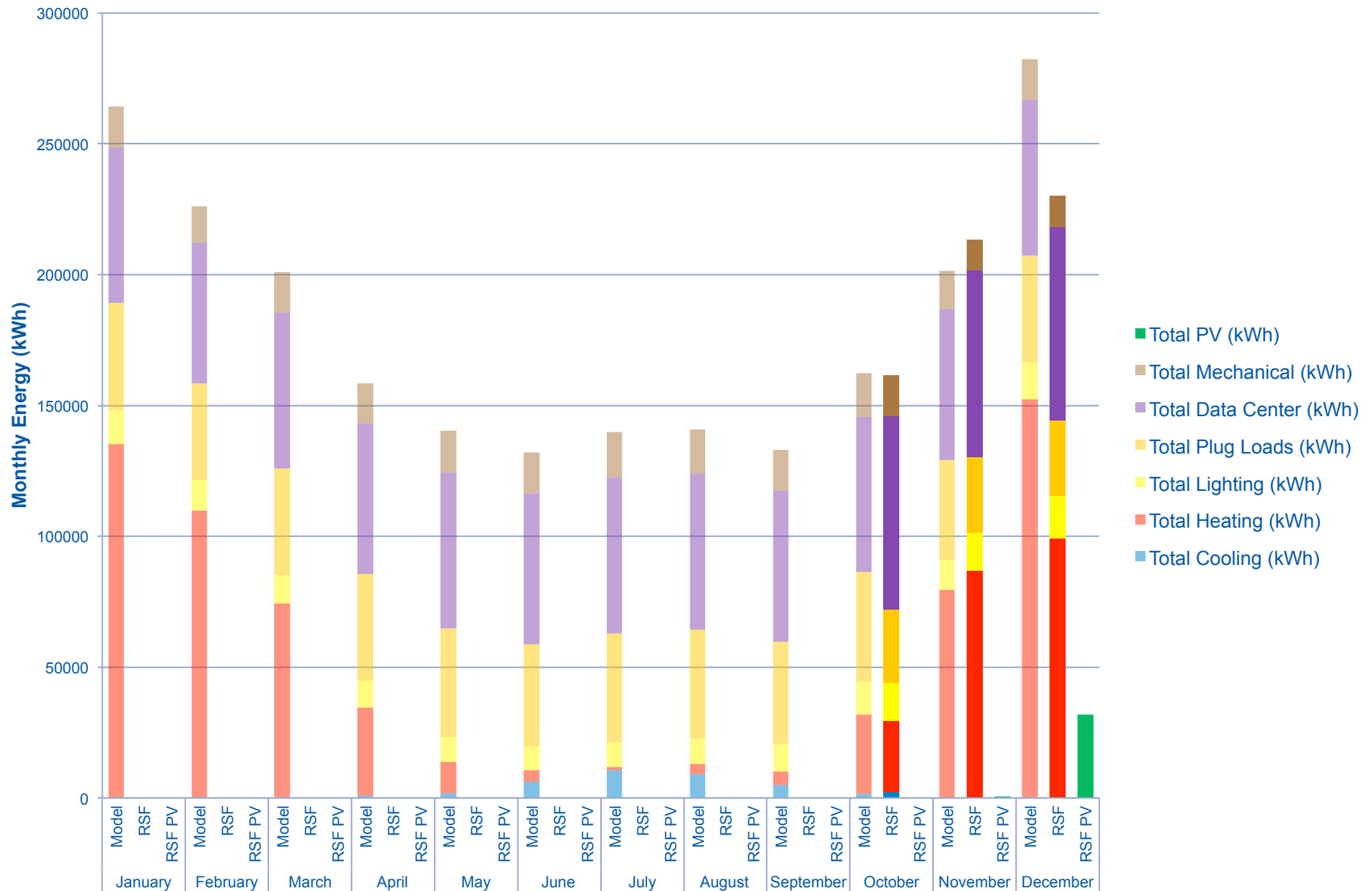
## RSF LPD vs Solar Illuminance



# October 2010 – February 2011 Daily Heating Energy



# Measured vs Modeled 2010 Monthly End Use Energy Consumption



# RSF Modeling Summary

High resolution simulation of highly interdependent building systems is possible, but painful

- Simulation tools have evolved, but remain disparate tools
- An integrated analysis *platform* is needed



# OpenStudio

## An integrated analysis platform

# What Motivates Us?

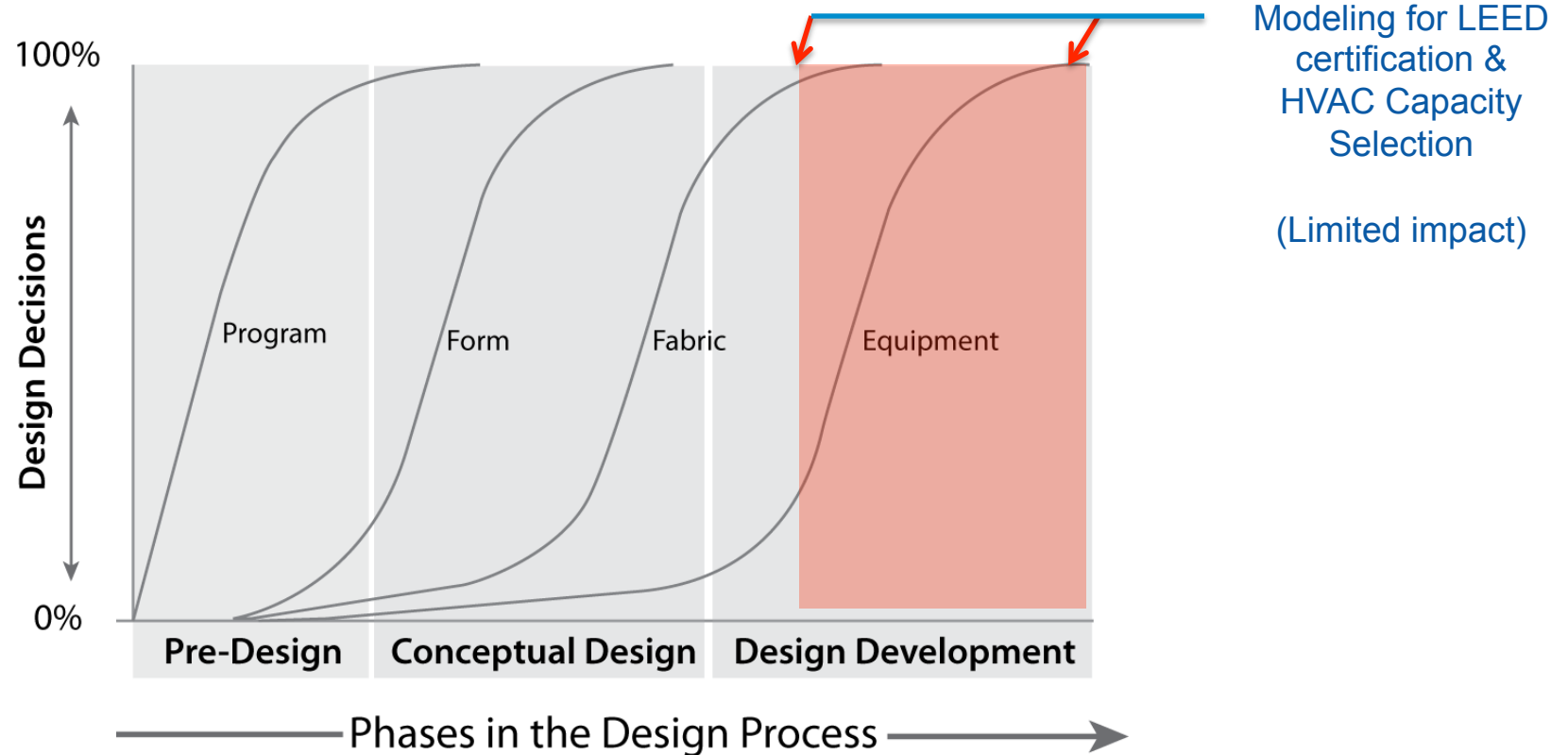
## NREL Commercial Buildings – Tools Development

We are committed to producing tools that:

- Create the maximum energy performance impact
- For the greatest number of buildings in the sector
- At the best pace
- And highest quality
- At low cost

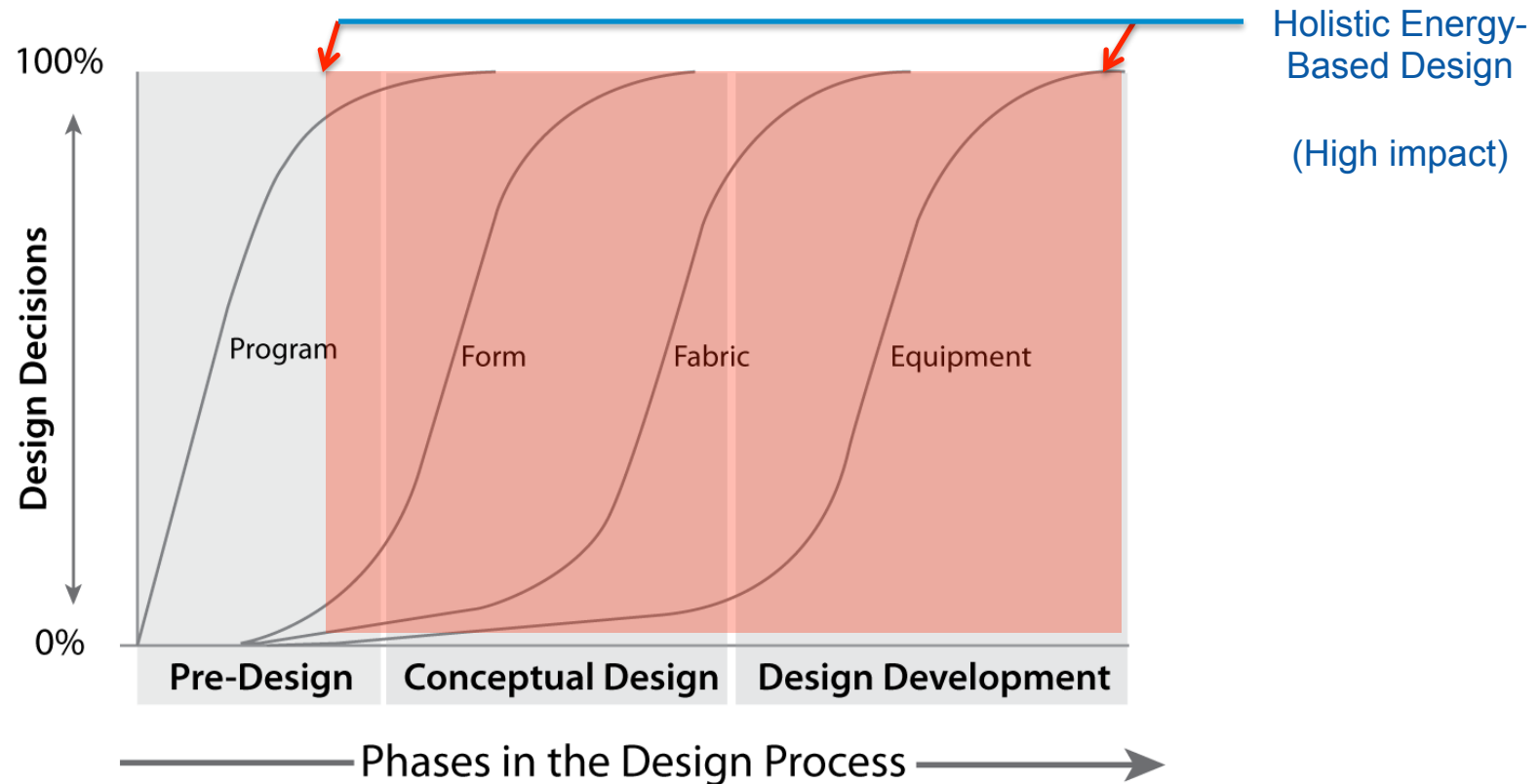
# The State of Affairs

Energy efficiency is often not a primary consideration during the building design process, and evidence of modeling and energy simulation is often used only to get a LEED certification if it is used at all.



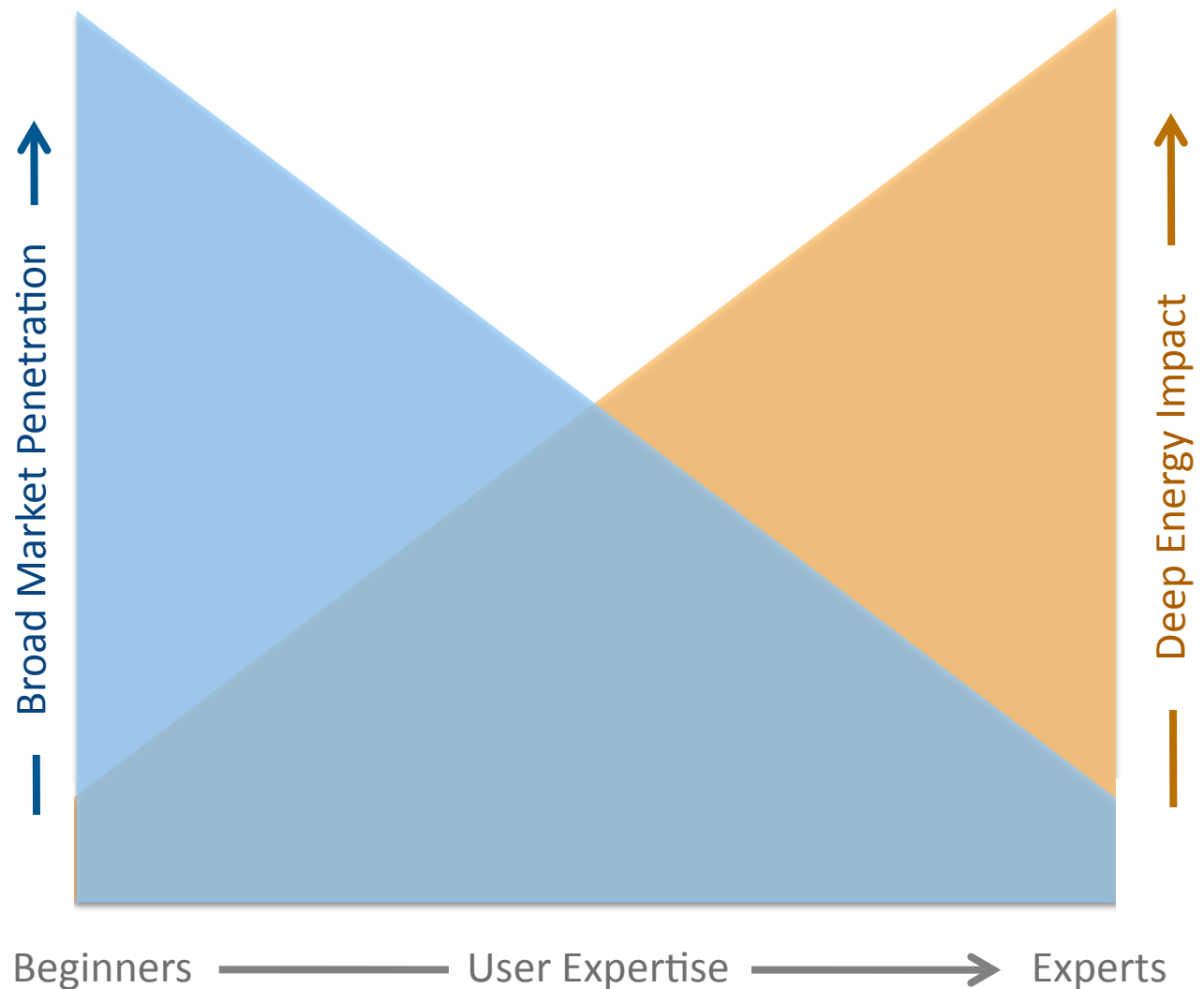
# The Real Opportunity

The greatest opportunity to impact new construction occurs before the first CAD drawing is produced. Tools that don't address the need for early decision making and rapid iteration will fail to unlock this potential.



# User Base Segmentation

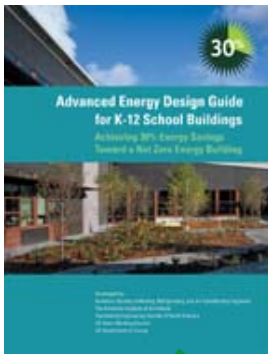
- Recognition of diverse expertise and user needs is critical for widespread and deep impact on the sector
- One size does not fit all



# Past Tools Development at NREL

Beginners ————— User Expertise —————> Experts

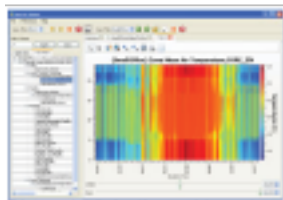
Design Guides



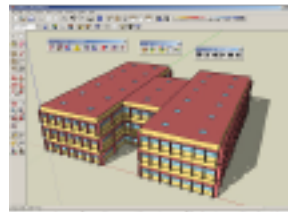
Example File Generator



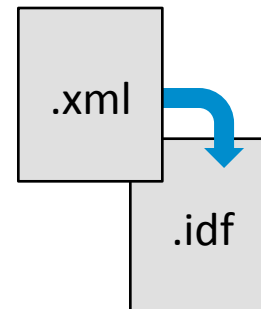
ResultsViewer



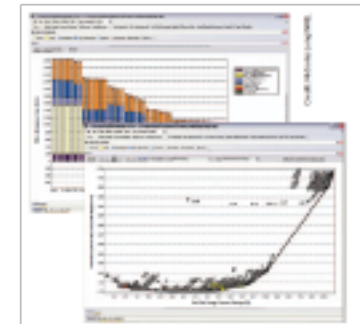
OpenStudio Plug-in



Pre-Processor

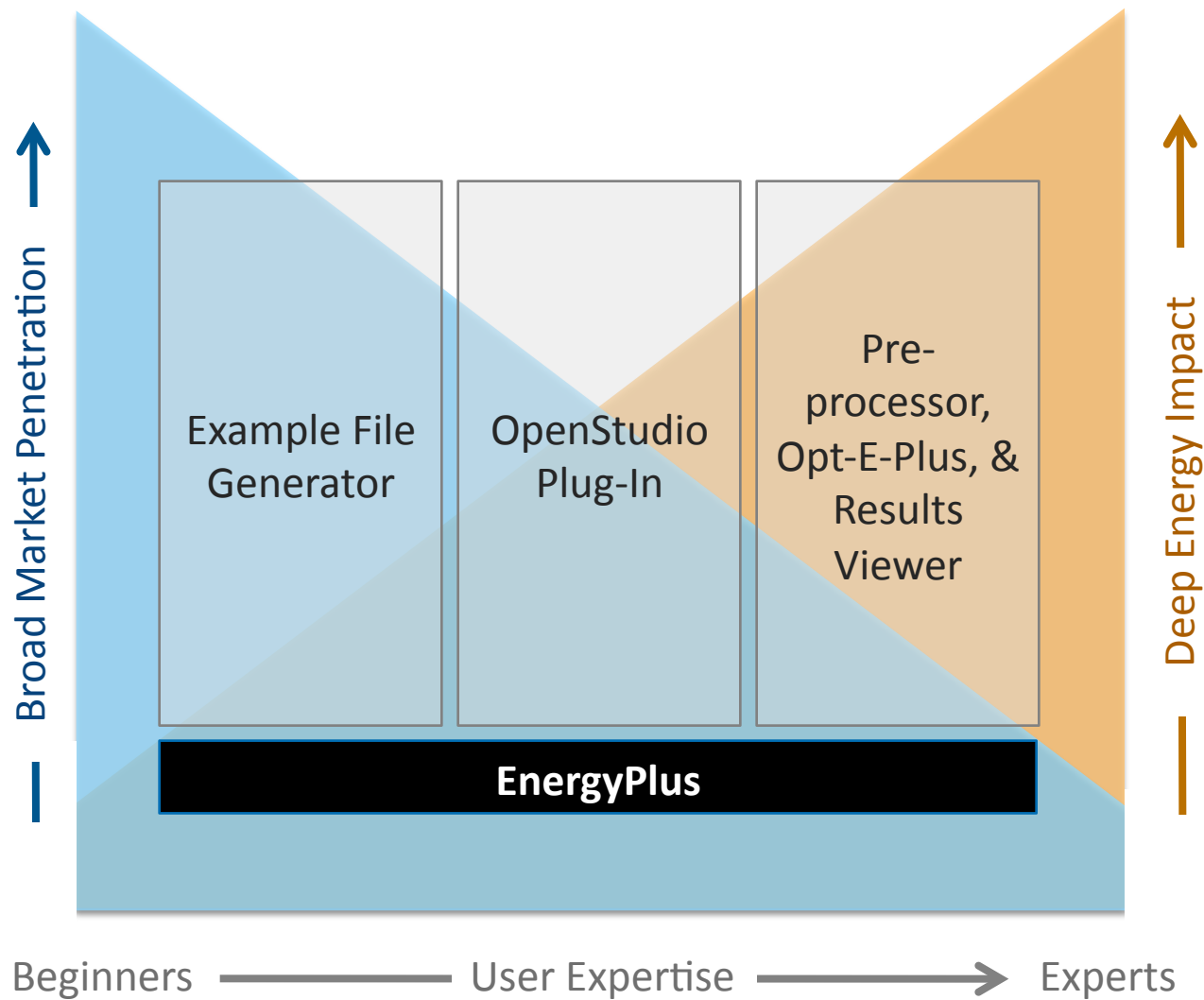


Opt-E-Plus



Core EnergyPlus development

# Adding Functionality was Challenging



# OpenStudio

- OpenStudio is:
  - Free
  - Open
  - Cross-platform
  - A framework for national labs, code/standard officials, and third parties to easily extend the base capability of EnergyPlus for diverse purposes
- This extended functionality includes but is not limited to:
  - User guided or programmatic model construction
  - Results visualization
  - Component libraries (e.g. MELs, building standard libraries)
  - Pre and post processing capabilities
  - Interoperability with other engines for optimization, analysis, etc.
  - Batch/runtime management

# Achieving Impact at Speed and Scale

1. **Touch as many buildings as possible** quickly by focusing on the left side of the spectrum
2. **Use simple tool interfaces** to enable education of this audience and make them capable of having meaningful conversations with experienced designers
3. Over time, these **beginners shift to the right** and become capable of deeper impacts
4. Since the foundation is capable, these **users are continuously enabled** as their expertise increases

# Simple Interfaces for Diverse Users

OpenStudio allows us to quickly build new interfaces that bring the power of energy analysis to a wide range of users

The image displays two overlapping screenshots of web-based energy analysis interfaces. The background screenshot is the 'Model Maker' interface, featuring a header with the NREL logo and a navigation bar with links like 'Requirements', 'About Building Model', and 'Contact Us'. It includes a welcome message and two main sections: 'Create a Simple Model' and 'Create a Detailed Model', each with a sequence of steps (Configuration, Building Information, Building Geometry, Building Activity, Submit) and a 'START' button. The foreground screenshot is the '179D Tax Deduction Quick Estimate (Beta)' interface, which has a header with the U.S. Department of Energy logo and a navigation bar. It includes a note about the tool's status and a 'The Quick Process' section with three steps: 1. Building and Location, 2. Energy Efficiency Strategies, and 3. Review Estimated Results. Each step includes a brief description of the process.

**Model Maker**

Welcome, Guest! [Log In](#) [Register](#)

Welcome to the EnergyPlus Model Maker - a free service developed by NREL and DOE to help make it easier to use and learn EnergyPlus. The web-based forms allow you to enter general information about the building you want to model. The application then automatically creates a complete EnergyPlus input file, runs an annual simulation, and then emails you the EnergyPlus input, output, DXF and other files along with an annual summary of the energy results.

**Create a Simple Model**

Configuration Building Information Building Geometry Building Activity Submit

**Create a Detailed Model**

Configuration Building Information Building Geometry Building Activity Building Fenestration Submit

**179D Tax Deduction Quick Estimate (Beta)**

\*\*\*Note: This tool is not approved for use at this time.\*\*\*

Here you can make quick and easy calculations of the estimated energy cost savings from improving the efficiency of your new or renovated commercial building. This tool helps you find out whether your improvements could qualify for a federal tax deduction (often referred to as a 179D deduction after the section number in the federal tax code). This tool does not replace the need for certification of the property performance from a qualified individual (a licensed contractor or engineer in the jurisdiction of the building location). Learn more about [tax incentives for commercial buildings](#).

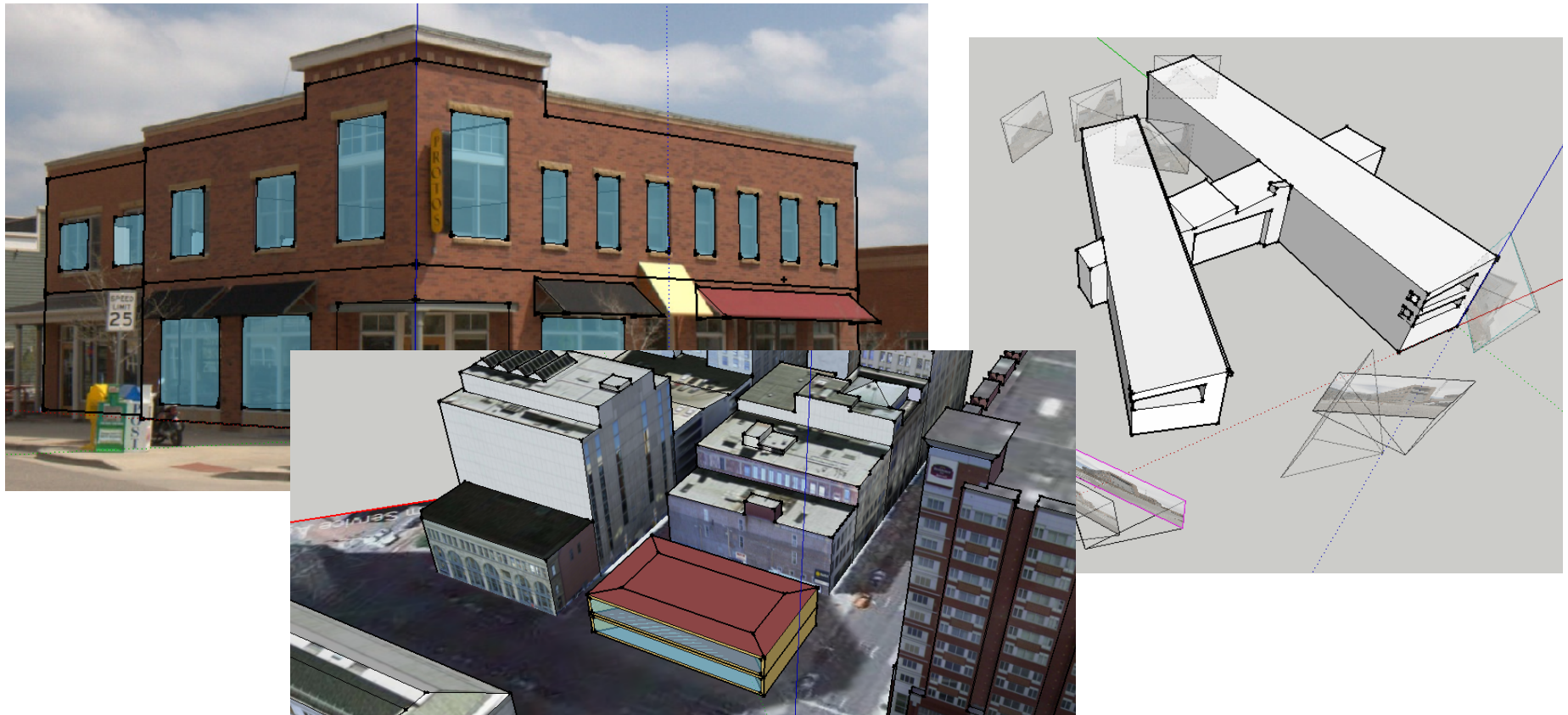
This tool is designed to help determine qualifications for partial deductions for envelope; lighting; and heating, ventilating, and air conditioning (HVAC). The savings estimates for the envelope and HVAC improvements are based on pre-run energy simulations for several building types across all climate zones in the United States. You may have to run your own calculations if your building type or configuration is not represented. Qualifications for the lighting deduction are based on installed lighting power and all buildings or space types included in ASHRAE Standard 90.1-2001 are included in this tool.

**The Quick Process**

- 1 Building and Location**  
To start the process, select your building type. You will see details for that building type based on the [U.S. Department of Energy's reference buildings](#). You will also enter the zip code for its location.
- 2 Energy Efficiency Strategies**  
The next step is to provide information about your energy efficiency strategies, including improvements to lighting; the building envelope; and heating, cooling, and hot water systems.
- 3 Review Estimated Results**  
At the end, you will get an estimate of your energy savings and find out whether you could qualify for a federal tax deduction.

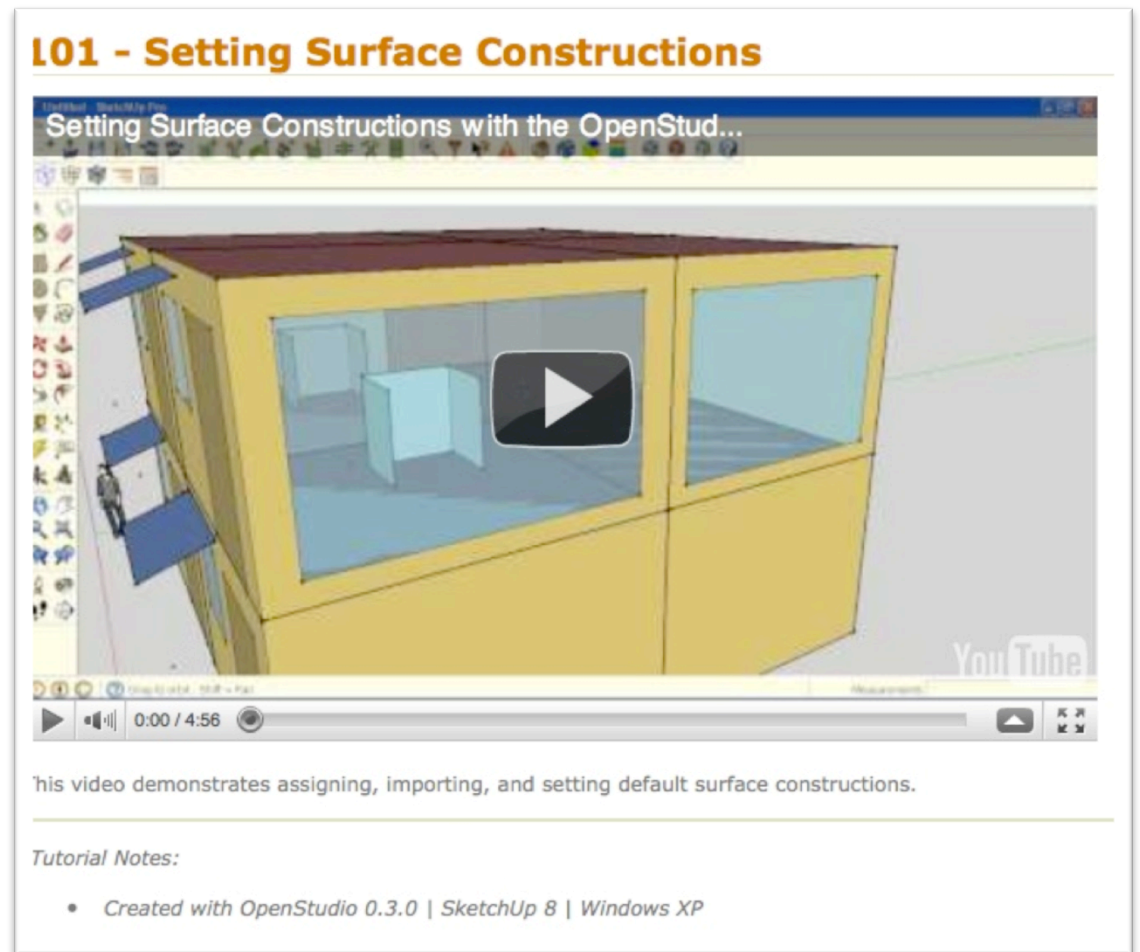
# What About Retrofits?

Retrofits represent a large portion of the sector which require particular tools and workflows since CAD drawings or models often don't exist. Approaches that automate model development or tie audit results to modeling outcomes will likely be preferred.



# Training and Workflows

- “Field of Dreams” was a nice piece of fiction
- We can’t assume people will use these tools just because we make them – even if they are free
- Workflows must be well documented and clearly explained in a way that eliminates mystery and compels users to action



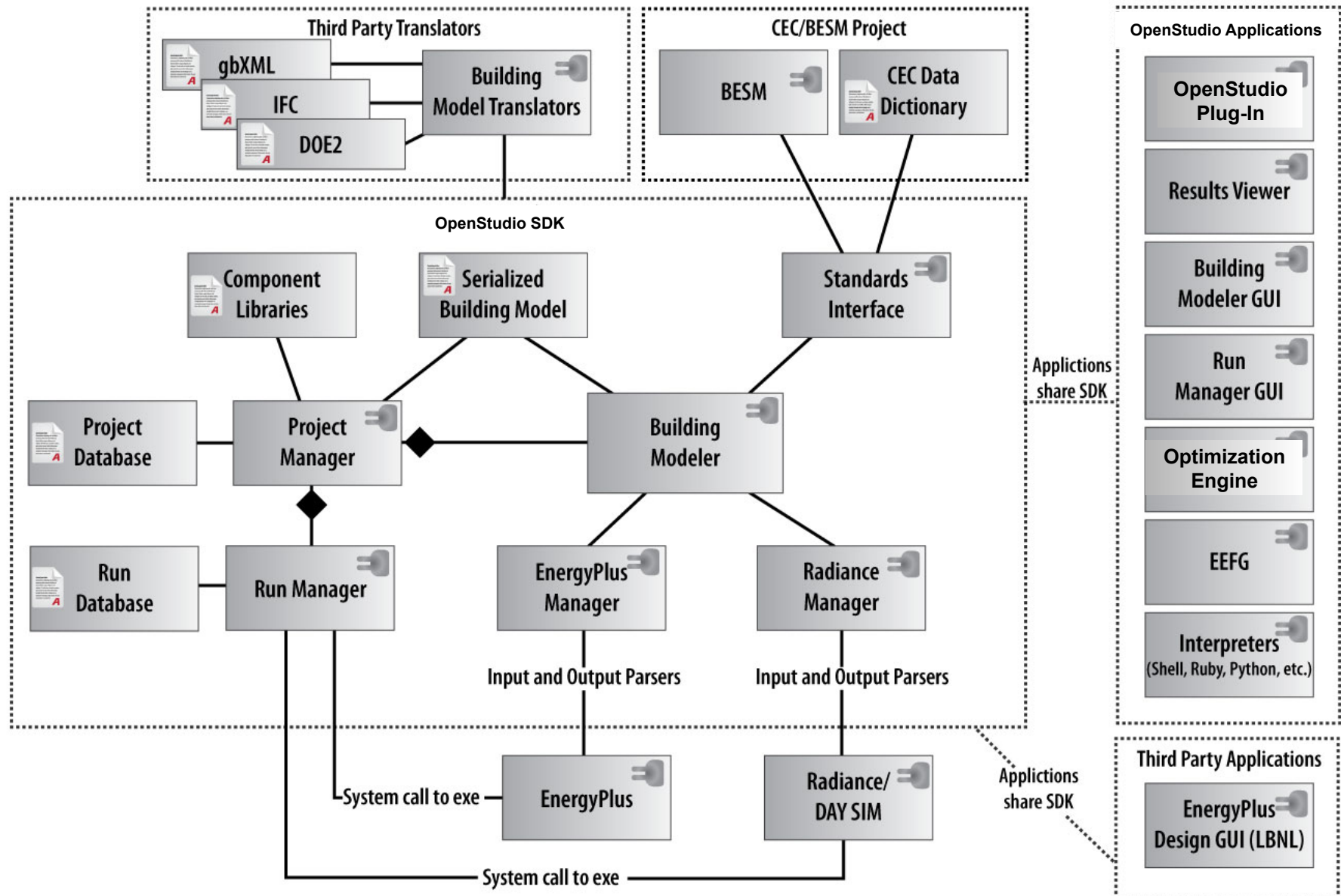


# OpenStudio Architecture

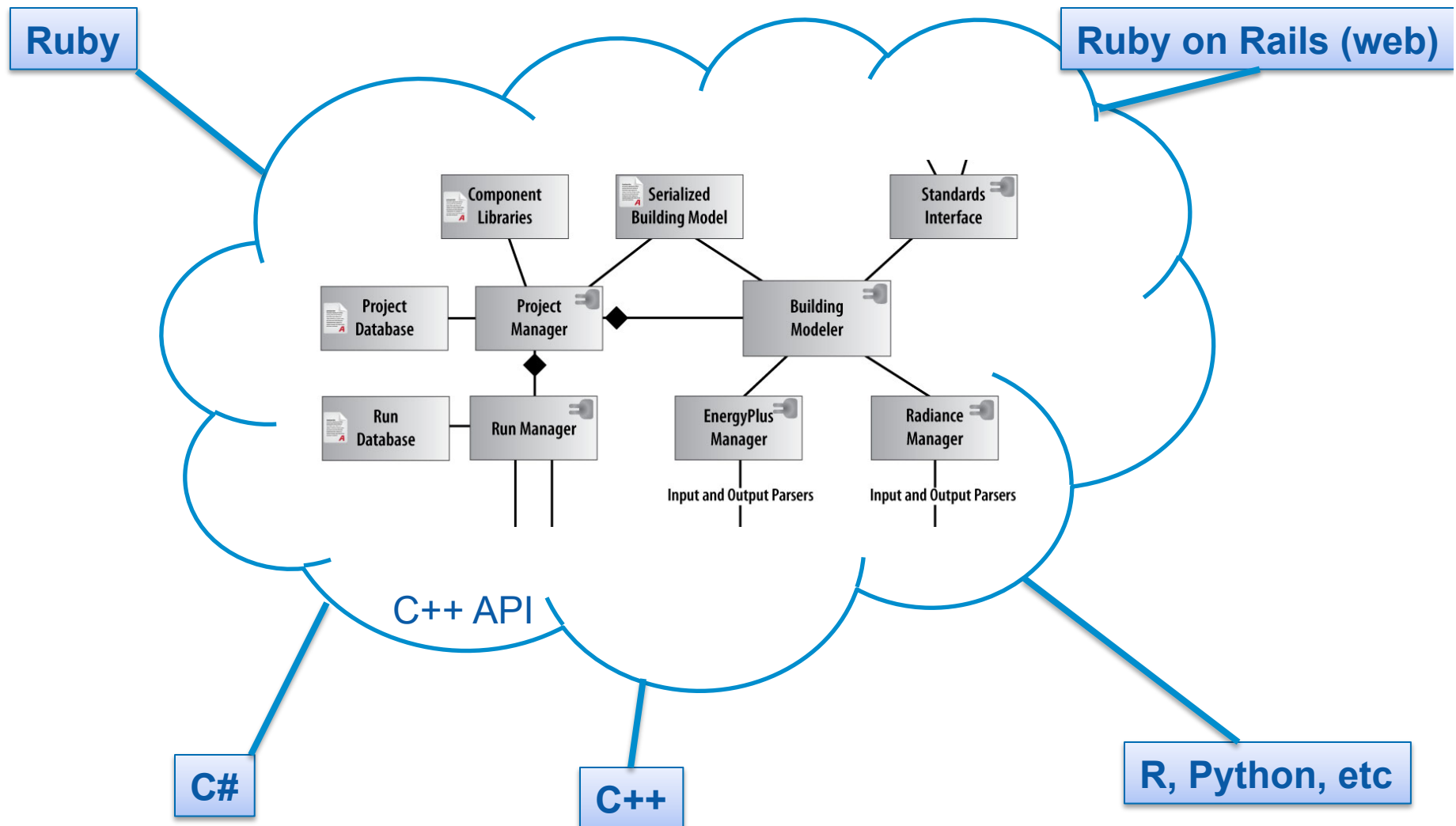
# Data Model vs Object Model

- Current Implementations use Data Models to exchange data (IFC, gbXML, bdl, idf)
  - Any application using data model must implement its own methods to modify data
  - Developer must start from scratch to determine domain logic, interdependencies, and simulation engine best practices
  - Typically proprietary implementation for the company
  - Bad practices/weak modeling hidden from user (black box)
- Object Model
  - Methods are part of the model
    - Adding building components are transparent
    - Encapsulates building domain knowledge
  - Common tasks are natural and do not require simulation engine specific knowledge
  - No longer transferring data, rather sharing functionality

# Architecture Diagram



# API Access (high level via SWIG)



# API Access

Ruby on Rails (web)

Ruby

```
def test_LinearScaleColorLevelsContourLevels
  matrix = ZeroKit::Matrix.new(10,10)
  for i in (0..9)
    for j in (0..9)
      matrix[i,j] = 10*i+j
    end
  end

  fp = ZeroKit::FloodPlot::create(matrix)
  fp.generateImage(ZeroKit::Path.new("./testMatrixConstructor.png"))

  fp.colorMapRange(20,60)
  ls = ZeroKit::linspace( 20,60,20 )
  fp.colorLevels(ls)
  fp.generateImage(ZeroKit::Path.new("./testLinearScaleColorLevels.png"))

  fp.contourLevels(ls)
  fp.showContour(true)
  fp.generateImage(ZeroKit::Path.new("./testLinearScaleColorLevelsContourLevels.png"))

  assert(fp)
end
```

```
#get frequency
@freq = params[:data_frequency]

#sort in order
selected_measurement_ids = selected_measurement_ids.sort

#get these measurements
@sel_measurements = @project.measurements.find(:all, :conditions => ["id in (?)", selected_measurement_ids])

#get number of measurements to graph
numMeasurements = @sel_measurements.size

if @freq == 'hour'
  @interval = ZeroKit::Time.new(0,1,0,0)
  #try to use ds_hours first (faster)
  @data = DsHour.find(:all,
    :select => "id, measurement_id, timestamp, value as avg_calc",
    :conditions => ["measurement_id in (?) and timestamp >= ? and timestamp <= ?", selected_measurement_ids, @interval.to_timestamp],
    :order => "timestamp, measurement_id")

  if @data.nil?
    @data = DataseriesRaw.find(:all,
      :select => "dr_id, dr_measurement_id, dr_timestamp, HO",
      :joins => "as dr left join dataseries_raws dr on (dr.d",
      :conditions => ["dr_measurement_id in (?) and dr.timestamp >= ? and dr.timestamp <= ?", selected_measurement_ids, @interval.to_timestamp],
      :group => "dr_measurement_id, DATE(dr.timestamp), HOUR",
      :order => "dr_timestamp, dr_measurement_id")
  end
end
```

C#

```
public void test_LinearScaleColorLevelsContourLevels()
{
  ZeroKit.SingletonApplication.instance().application();

  ZeroKit.Matrix m = new ZeroKit.Matrix(10, 10);
  for (uint i = 0; i < 10; ++i)
  {
    for (uint j = 0; j < 10; ++j)
    {
      m.__setitem__(i, j, 10 * i + j);
    }
  }

  ZeroKit.FloodPlot fp = new ZeroKit.FloodPlot(m);

  fp.generateImage(new ZeroKit.path("./testMatrixConstructor.png"));
  fp.colorMapRange(20, 60);

  ZeroKit.Vector ls = ZeroKit.utilities.linspace(20, 60, 20);

  fp.colorLevels(ls);
  fp.generateImage(new ZeroKit.path("./testLinearScaleColorLevels.png"));

  fp.contourLevels(ls);
  fp.showContour(true);
  fp.generateImage(new ZeroKit.path("./testLinearScaleColorLevelsContourLevels.png"));
}
```

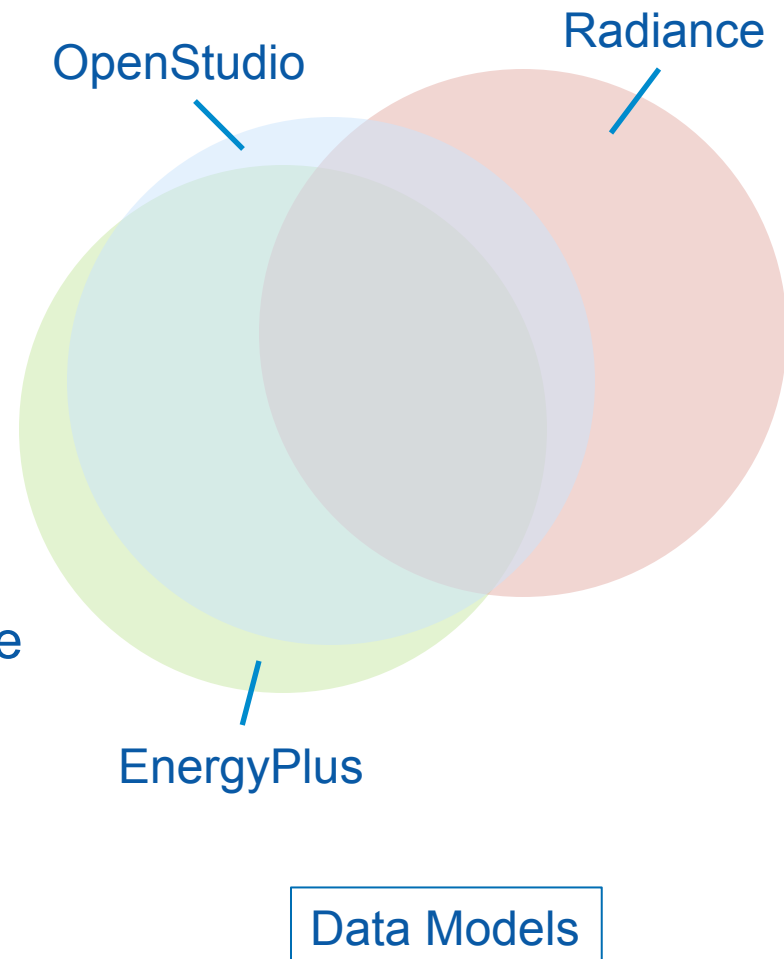
R, Python, etc

# Building Model

- Building Model at center of OpenStudio functionality
  - ‘Agnostic Model’ – supports translators to and from EnergyPlus, Radiance. Eventually/potentially IFC, gbXML, and DOE-2.
  - User interfaces similar to the Plug-In and Example File Generator
  - Perturbation and standards analysis
- Building Model consists of two parts:
  - Data Model
    - Acceptable parameters for simulation engine models
    - Saves model for archival and transmission
  - Object Model
    - Encapsulate logic and maintain consistency of the data model
    - Methods for user interfaces, perturbation, and standards analysis

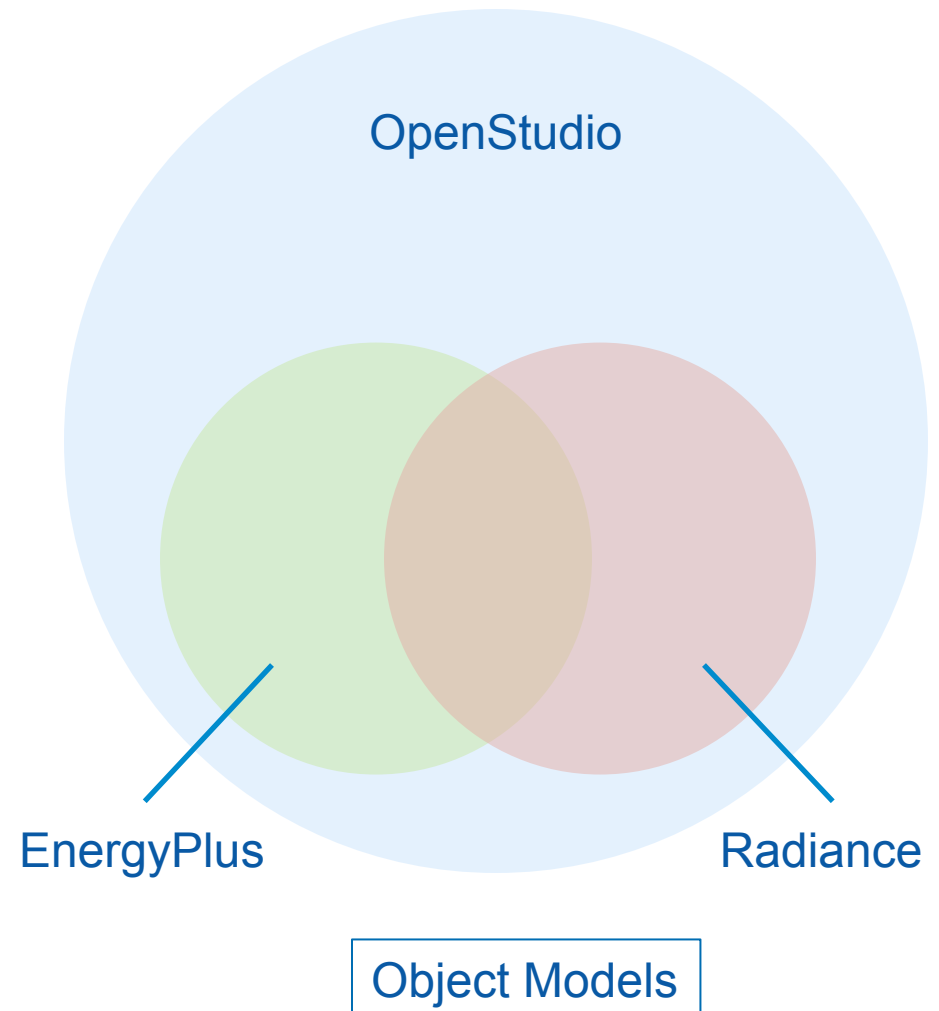
# Building Model – Data Model

- EnergyPlus Data Model
  - 585 objects defined
  - 2050 pages of documentation
  - Existing models and data sets
  - Reuse as much as possible
- Some objects in EnergyPlus are not needed in OpenStudio Data Model
  - Converted by translator
  - Parametric objects, simple geometry, etc
- Some objects needed by OpenStudio are not in EnergyPlus Data Model
  - Add new objects as needed
  - Space types, radiance data, example file generator inputs, etc



# Building Model – Object Model

- EnergyPlus has minimal definition of an Object Model in the IDD
  - Some relationships and acceptable substitutions are expressed
- OpenStudio significantly expands on the Object Model started by EnergyPlus
  - Defines parent/child relationships
  - Defines inheritance relationships
  - Defines methods of each object which can be used for perturbation
- OpenStudio translators enable connection of EnergyPlus and Radiance
- OpenStudio abstraction can facilitate integration with other engines





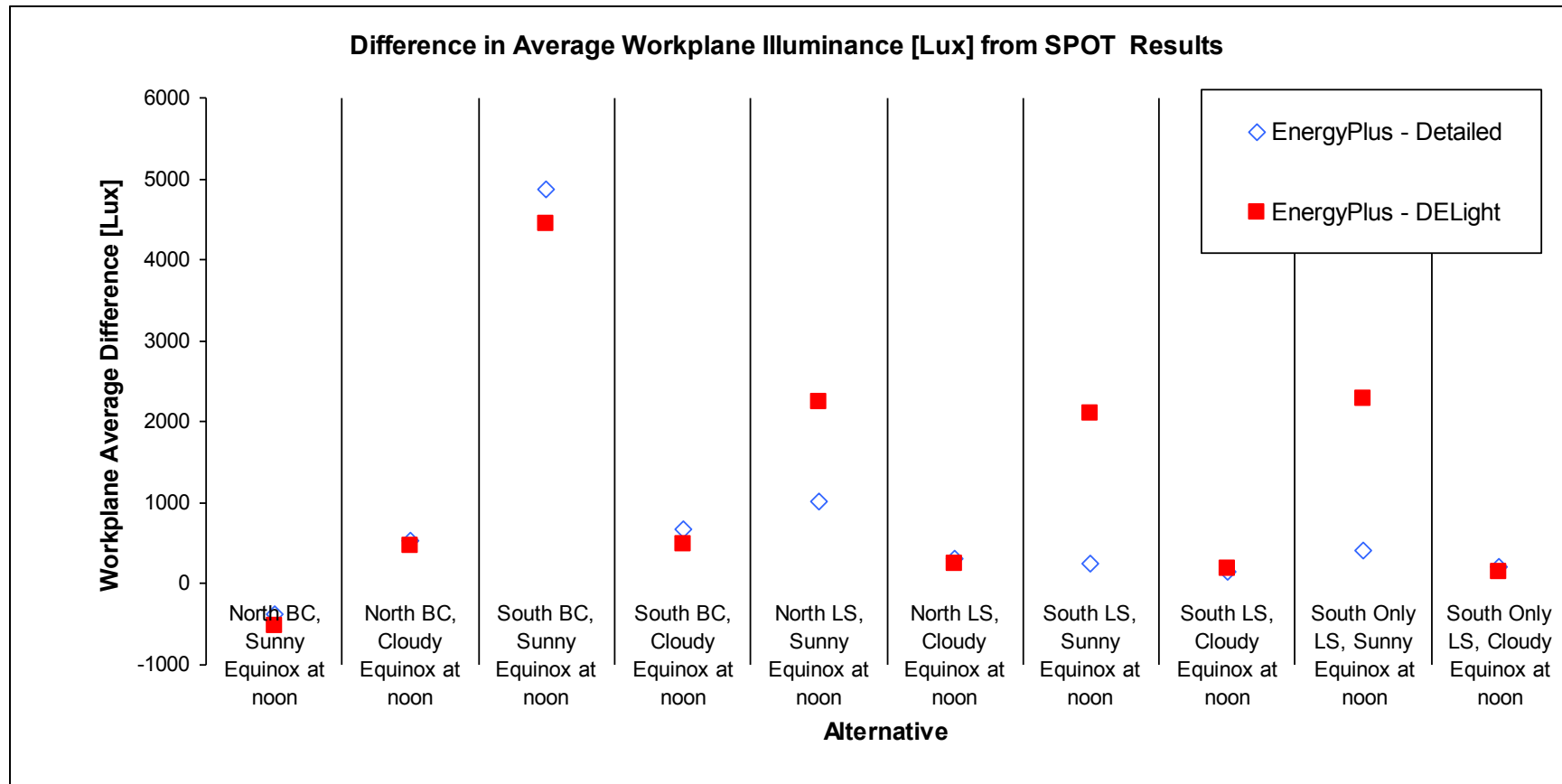
# Radiance Integration

# Lighting Simulation – Why Integrate?

- Daylighting is an important component in integrated, high performance building design
- Current energy simulation software has limited capability in lighting simulation
  - Geometrically limited
  - Lighting is load based, no spatial sensitivity
  - Daylight calculation is crude, *at best* (split flux)
- Rigorous lighting simulation tools exist
  - Radiance, Agi32, Autodesk 3DSMaxDesign
- Problem is they are **disconnected** from the energy simulation

# Lighting Simulation – Limitations

- Energy simulation tools lack a *rigorous* daylight simulation



EnergyPlus and Radiance Simulation Data Comparison

# Lighting Simulation – Why Radiance?

- Radiance is gold standard for accurate lighting simulation
  - Light-backwards ray tracing
  - Images and numeric analysis
  - Daylighting, electric lighting, glare evaluation
- Validated
  - Mardaljevic; 1997, 2000
  - Reinhart, Andersen; 2005
- Open Source since 2002
- Still evolving through DOE-ET and CA funding
  - Support for daylight coefficients
  - BSDF support for complex fenestration (CFS), user interaction

# Lighting Simulation – Why Radiance?

- Radiance simulations can inform design, regardless of complexity
  - Design validation
  - Photometric evaluation
  - Image-based glare analysis
  - (Climate-based) daylight modeling
  - Electric lighting
  - Lighting control simulation

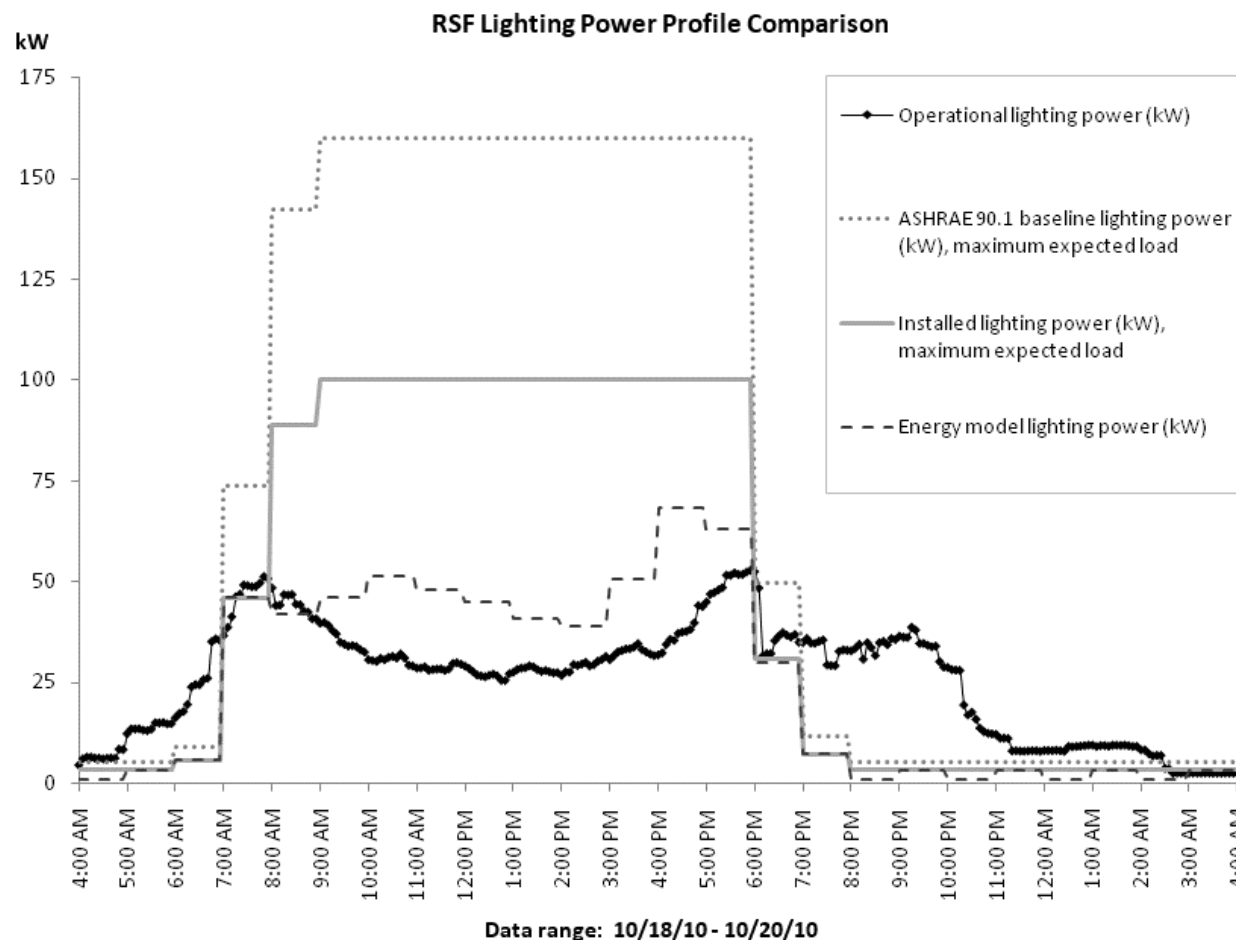
# Lighting Simulation – Why Radiance?

This is *easy* for Radiance (relatively speaking...)



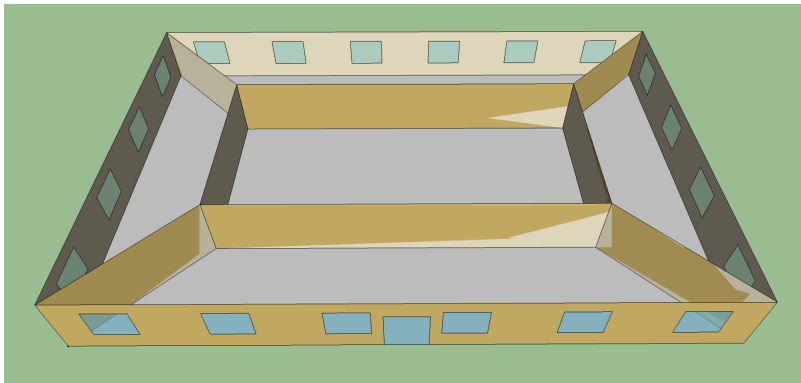
# Lighting Simulation – Why Radiance?

This, however, is **impossible**, without tying that performance back to the whole building energy simulation

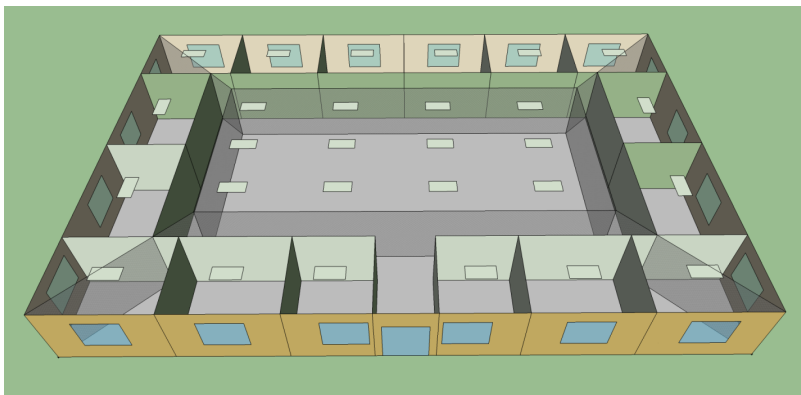


# Two Simulations, Two Models

- Energy and lighting simulations have different “needs”
- Models get out of sync
- Data sharing difficult



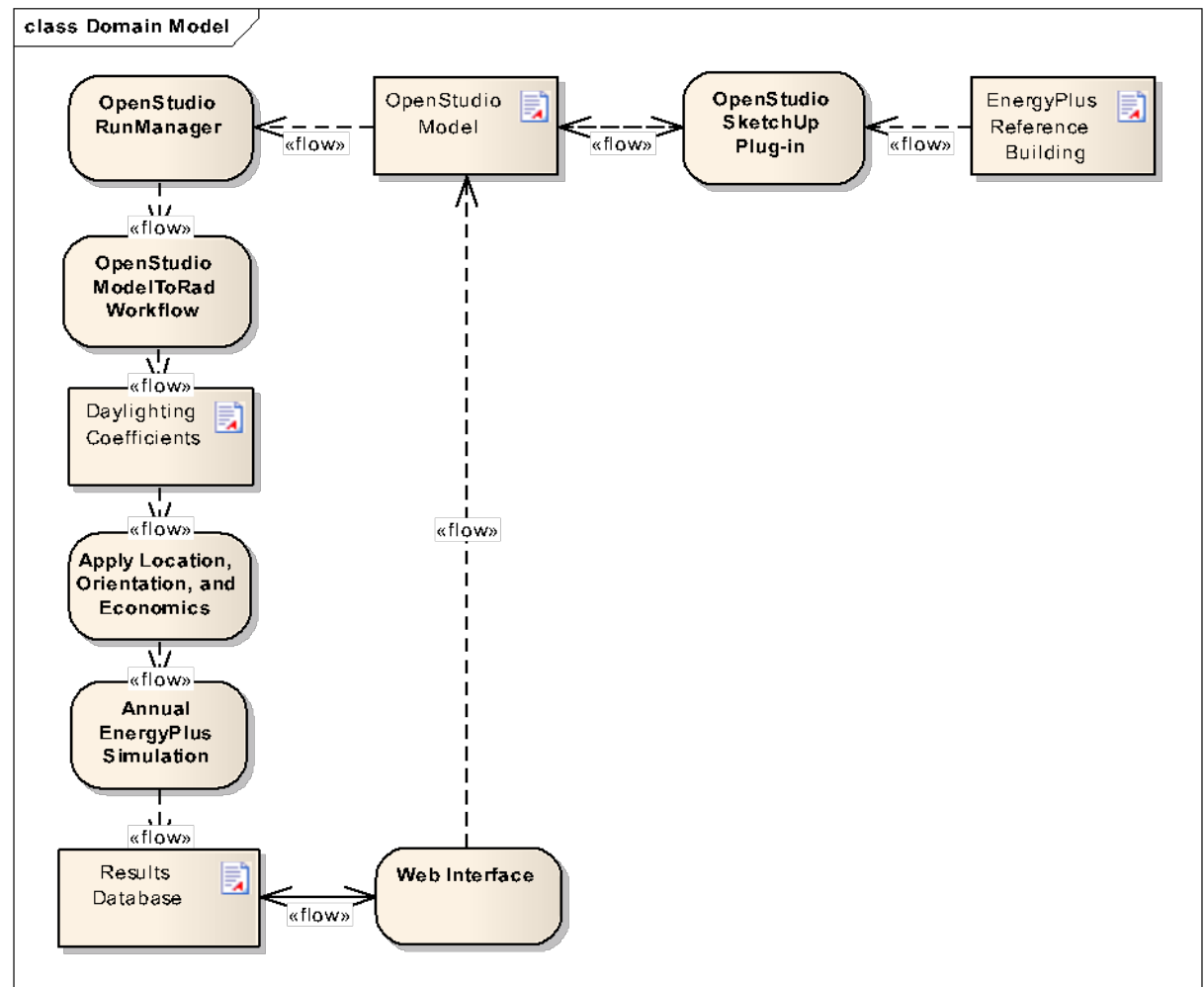
Typical energy model representation



Typical daylight (Radiance) model representation

# OpenStudio Model (\*.osm)

- Centralized model, maintains all simulation parameters
- Provides common data, plus simulation tool-specific objects
  - Interior partitions
  - Remove airwalls
  - Luminaires
  - Lighting control sensors
- Manages co-dependent workflows
- Unified data store



# Check it out.

<http://openstudio.nrel.gov>

The screenshot shows a web browser window titled "NREL: OpenStudio". The address bar displays "https://openstudio.nrel.gov/". The browser's toolbar includes a search bar with the Google logo and several bookmarked sites like "OpenStudio - S...", "theSOURCE Hom...", "NREL VPN", "OpenStudio - Pi...", "Accounts", "Flickr!", "Facebook", "rumblestrip", and "Lo...". The website header features the text "Commercial Buildings Research and Software Development" and the NREL logo. Below this, a navigation bar includes "OpenStudio" with a logo, "Welcome, Guest!", "Log In", and "Register". A secondary navigation bar contains links for "Home", "Downloads", "User Documentation", "Developers", and "Forums". A search bar with a "SEARCH" button is located on the right. The main content area has a heading "OpenStudio Webinar August 24th. Register for the webinar or find out more." followed by a paragraph describing OpenStudio as a cross-platform (Windows, Mac, and Linux) collection of software tools for whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance. Below this is a video player titled "What is OpenStudio" with a thumbnail showing the text "What is OpenStudio?" and a diagram of a building with a play button. To the right, a "News" section lists recent updates, including "OpenStudio - Whole Building Energy Modeling presented by NREL's Nicholas Long and David Goldwasser" on Wed 8/24/2011, "OpenStudio Bootcamp" hosted in Golden, CO on July 18th, and "OpenStudio Release 06/24/2011". The browser's status bar at the bottom shows "zotero".

NREL: OpenStudio

https://openstudio.nrel.gov/

OpenStudio - S... theSOURCE Hom... NREL VPN OpenStudio - Pi... Accounts Flickr! Facebook rumblestrip Lo... Bookmarks

Commercial Buildings Research and Software Development

NREL NATIONAL RENEWABLE ENERGY LABORATORY

OpenStudio Welcome, Guest! Log In Register

Home Downloads User Documentation Developers Forums

SEARCH

**OpenStudio Webinar August 24th. Register for the webinar or find out more.**

OpenStudio is a cross-platform (Windows, Mac, and Linux) collection of software tools to support whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance. OpenStudio is an open source project to facilitate community development, extension, and private sector adoption. OpenStudio includes graphical interfaces along with a Software Development Kit (SDK).

**What is OpenStudio**

What is OpenStudio?

News

OpenStudio - Whole Building Energy Modeling presented by NREL's Nicholas Long and David Goldwasser

Wed 8/24/2011 12:00pm (PT) / 1:00pm (MT) / 2:00pm (CT) / 3:00pm (ET)

OpenStudio Bootcamp

The OpenStudio development team hosted an OpenStudio Bootcamp in Golden, CO on July 18<sup>th</sup>...

OpenStudio Release 06/24/2011

DOE/NREL's newest version of OpenStudio suite of tools and SDK,

zotero

# Acknowledgements

- US Department of Energy
- OpenStudio development team (l to r):

Nicholas Long, Evan Weaver, Robert Guglielmetti, Alex Swindler, Kyle Benne, David Goldwasser, Marjorie Schott, Dan Macumber, Larry Brackney, Elaine Hale, Luigi Gentile Polese and Brent Griffith appear in front of an Open Studio computer visualization of the RSF building at NREL. Not pictured are team members Katherine Fleming, Jonathan Crider, Larry Ramey, and Jason Turner.

