OpenStudio
An integrated Whole Building Analysis Platform

Innovation for Our Energy Future

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National Renewable Energy Laboratory

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NREL RSF
A Project that *Required* Integrated Modeling

DOE/NREL RSF: Project Goals

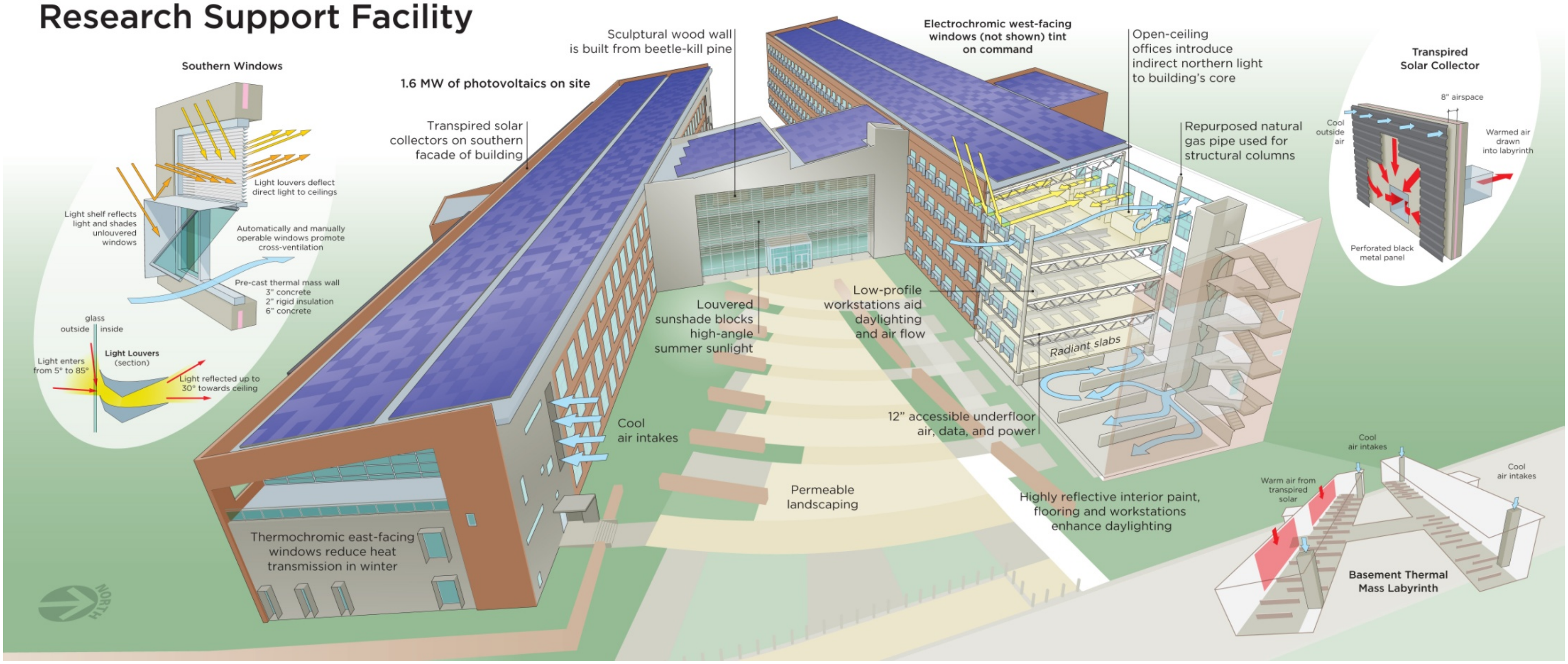
- 800+ people in DOE office space on NREL's campus
- 220,000 ft^2
- Design/Build Process with required energy goals
    - 25 $kBtu/ft^2$
    - 50% energy savings
    - LEED Platinum
- Replicable
    - process
    - technologies
    - cost

- Site, source, carbon, cost ZEB:B
    - Includes plugs loads and datacenter
- Firm fixed price of ~$64 million
    - $259/ft^2 construction cost (not including $27/ft^2 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



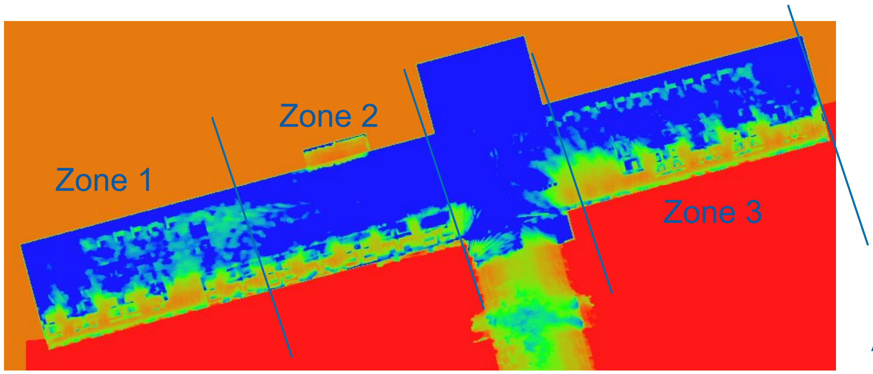
Daylight/Energy Integration (3 years ago)

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

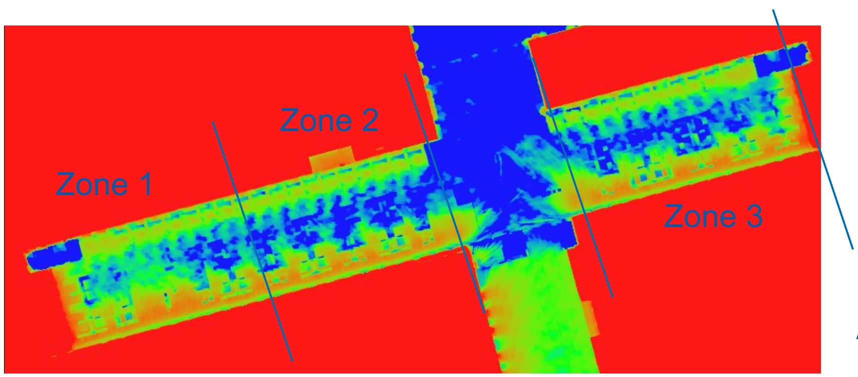
- Painful process, required much coordination among disciplines/ models

Radiance – Daylight Distribution



Applied to Floors 1 & 2 in energy model

First Floor



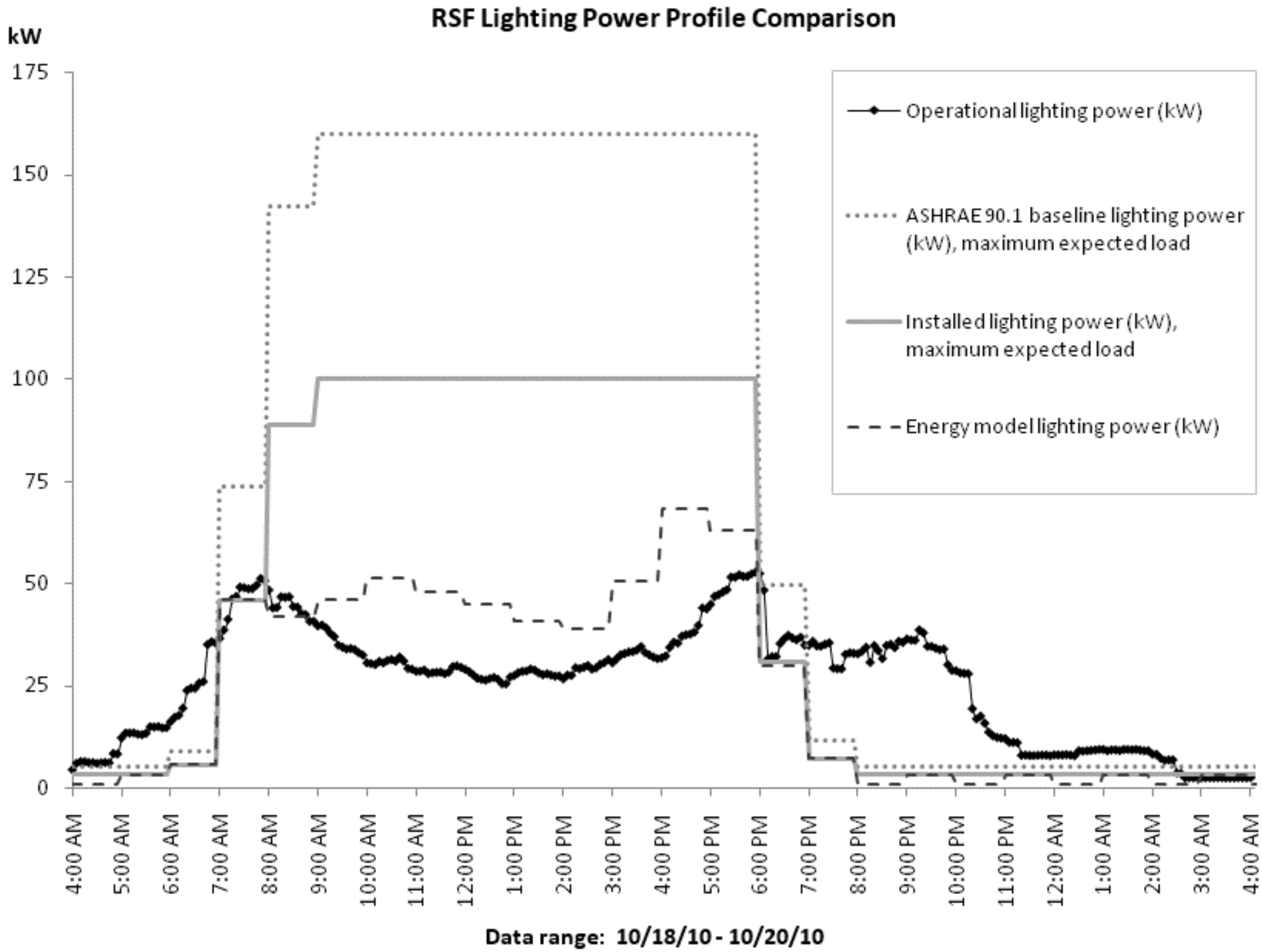
Applied to Floors 3 &4 in energy model

Third Floor

Annual Daylight Availability – North Wing

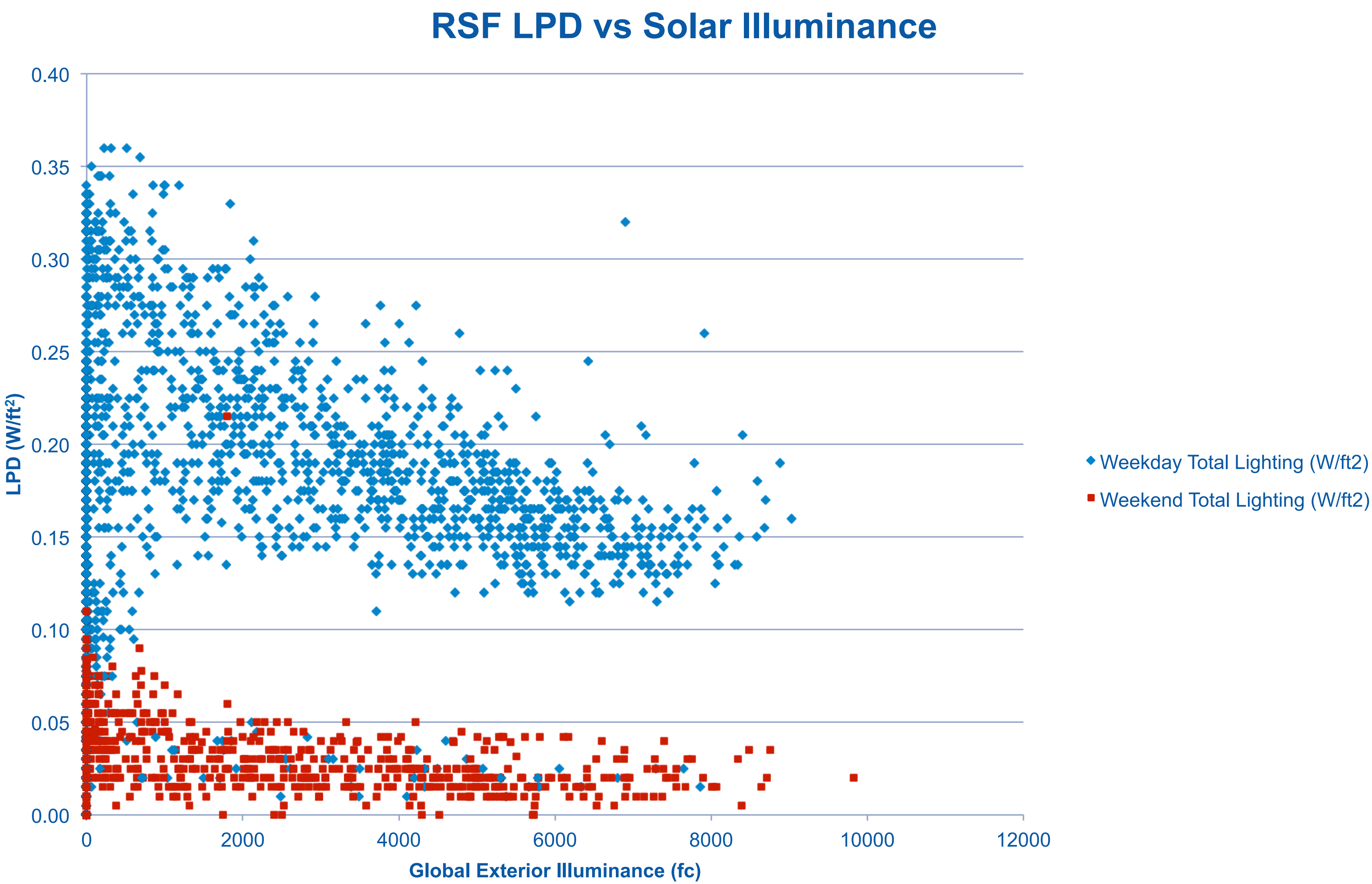
Lighting Control Zones – East-West

Images from R. Guglielmetti

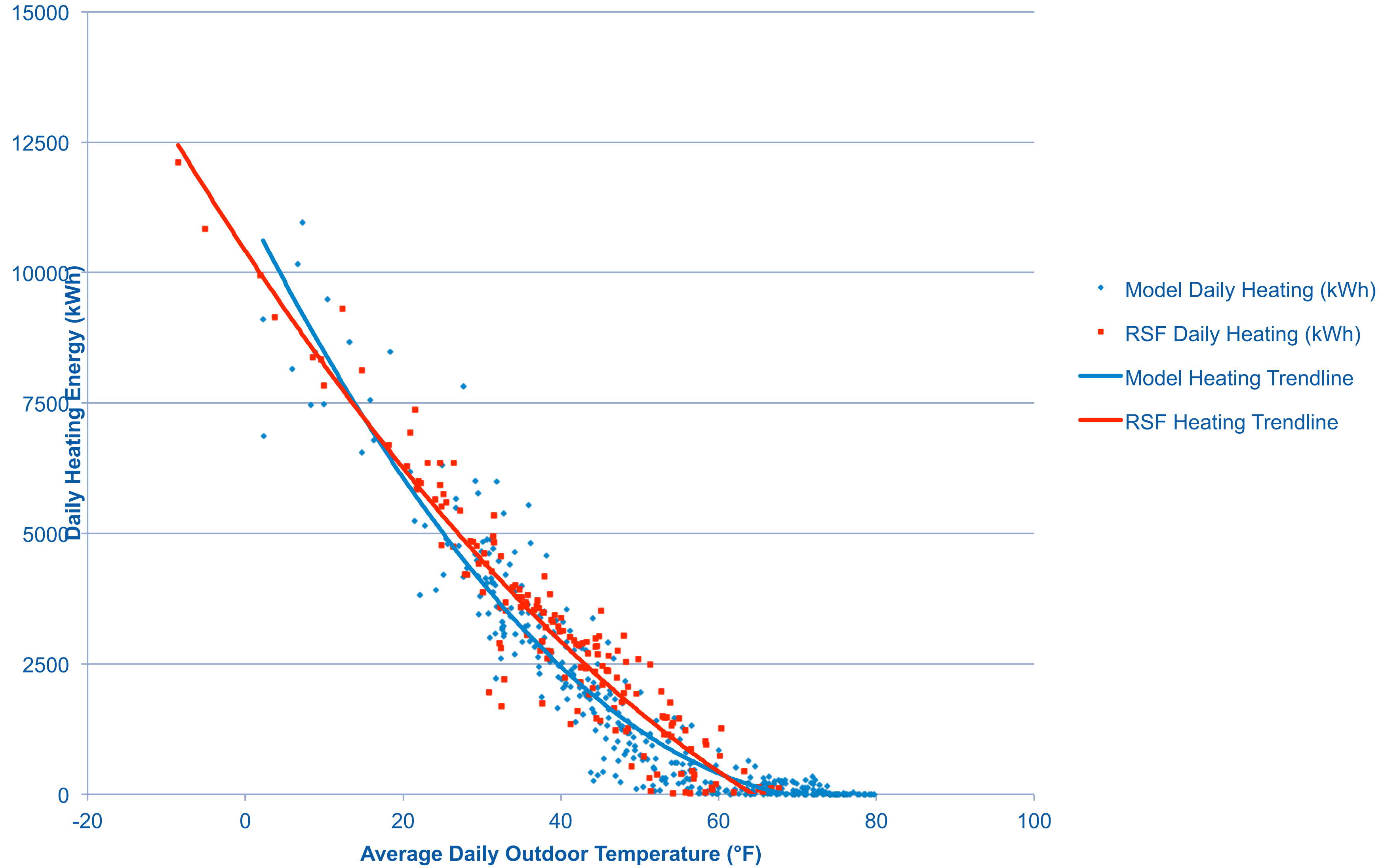


RSF Lighting Power Profile Comparison
kW
175
150
125
100
75
50
25
0
Operational lighting power (kW)
ASHRAE 90.1 baseline lighting power (kW), maximum expected load
Installed lighting power (kW), maximum expected load
Energy model lighting power (kW)
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
Data range: 10/18/10 - 10/20/10

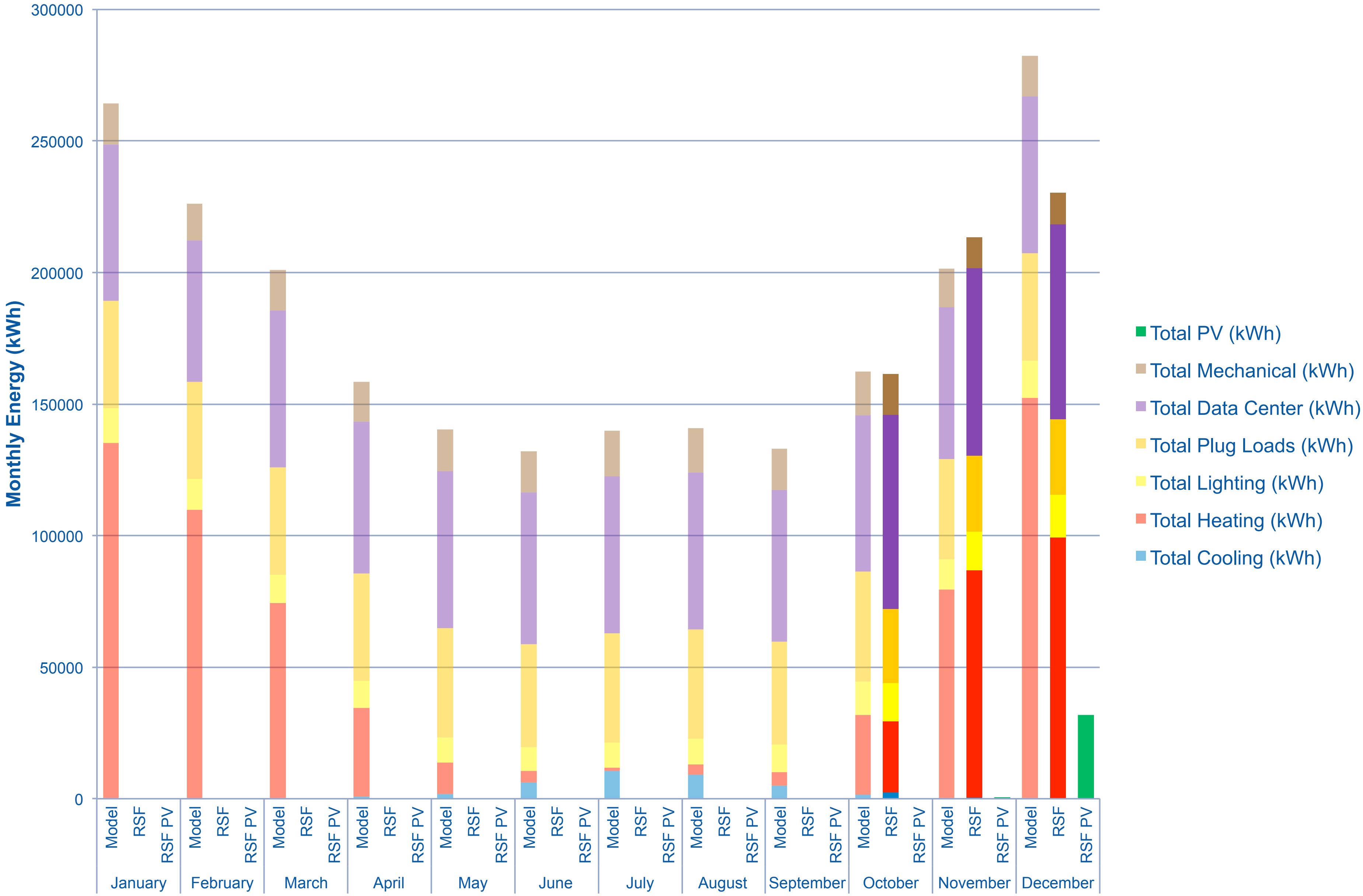
RSF Lighting



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

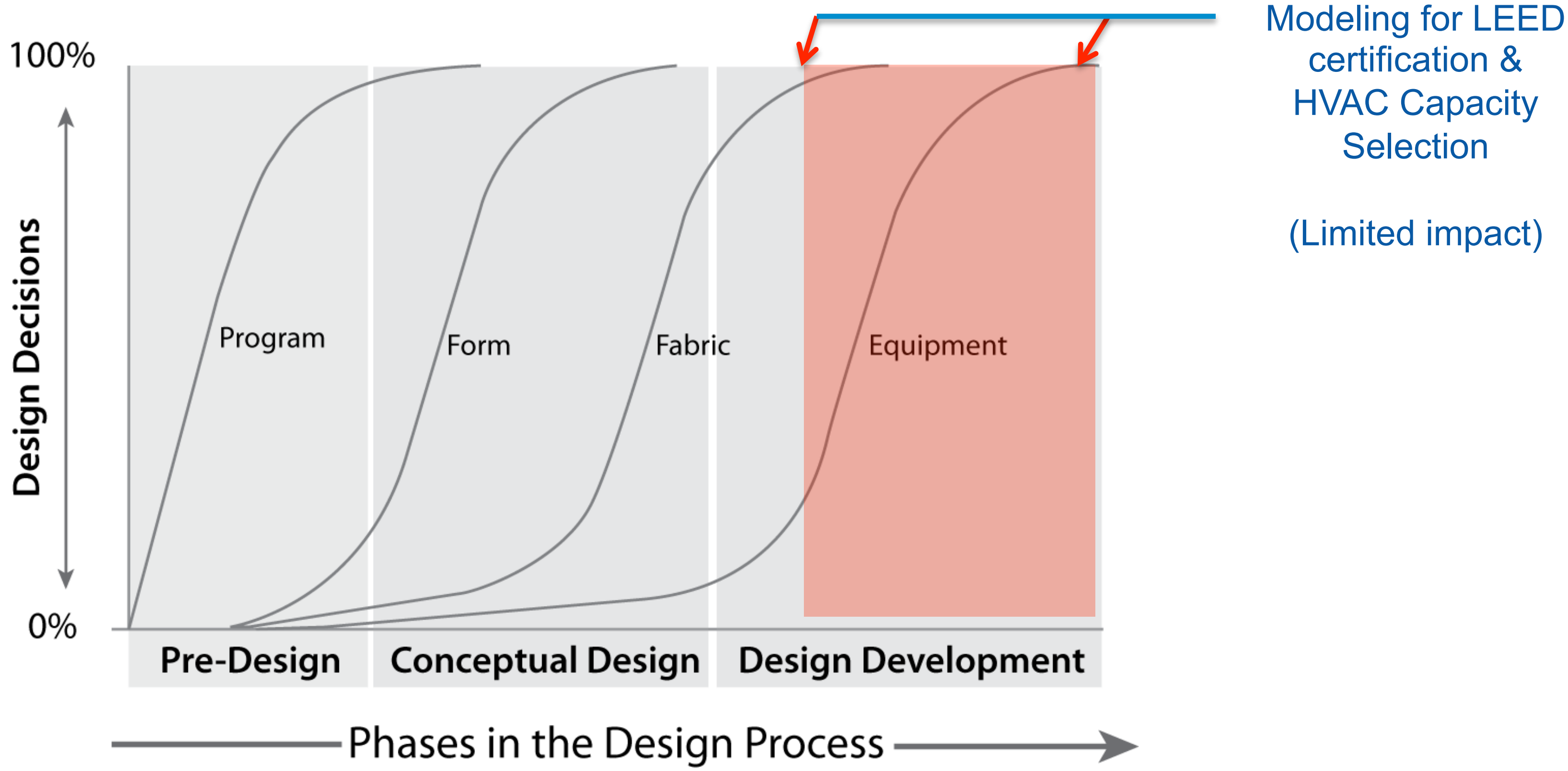
What Motivates Us?

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

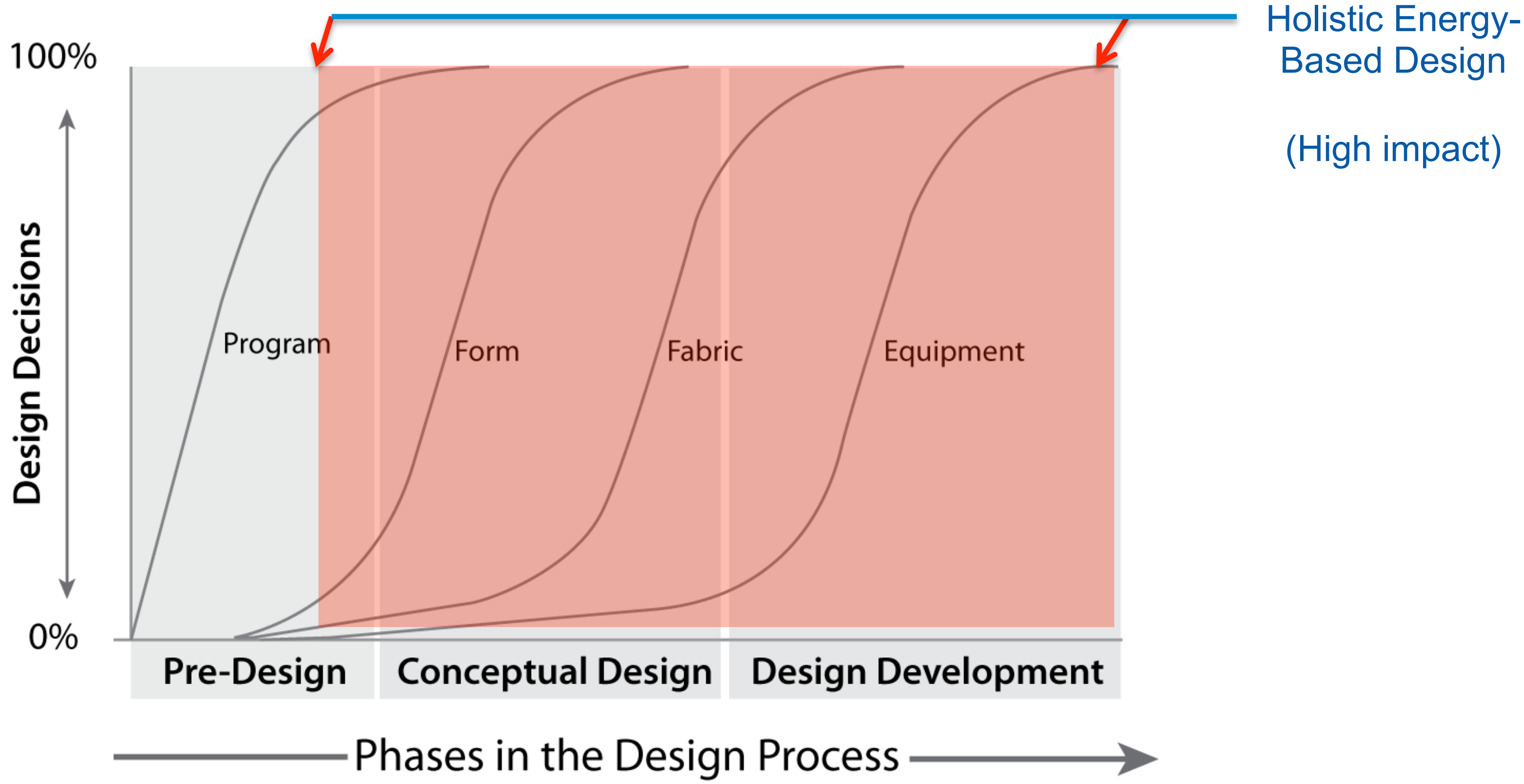
The State of Affairs

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.



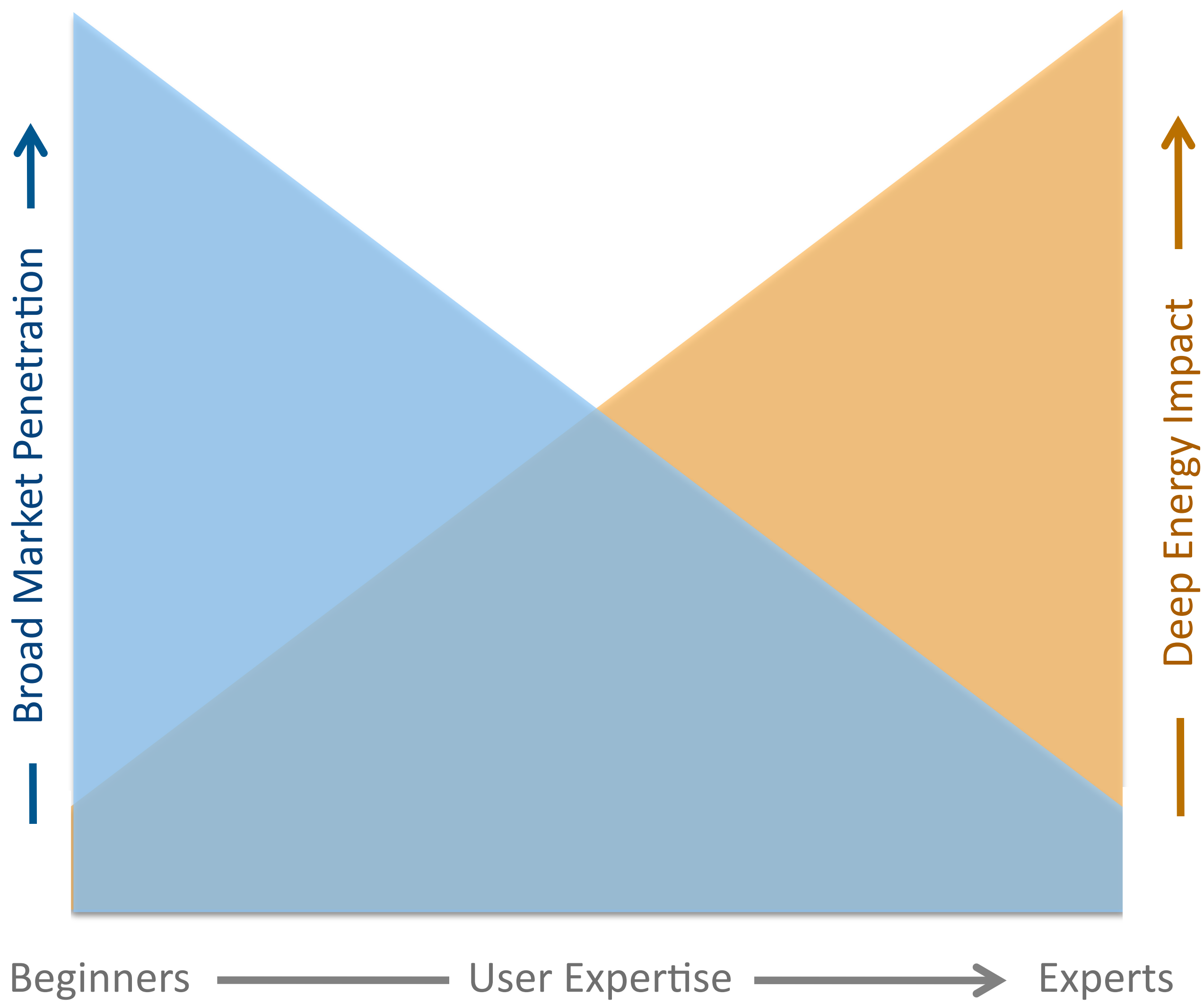
The Real Opportunity

The greatest opportunity to impact new construction occurs <u>before</u> 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.

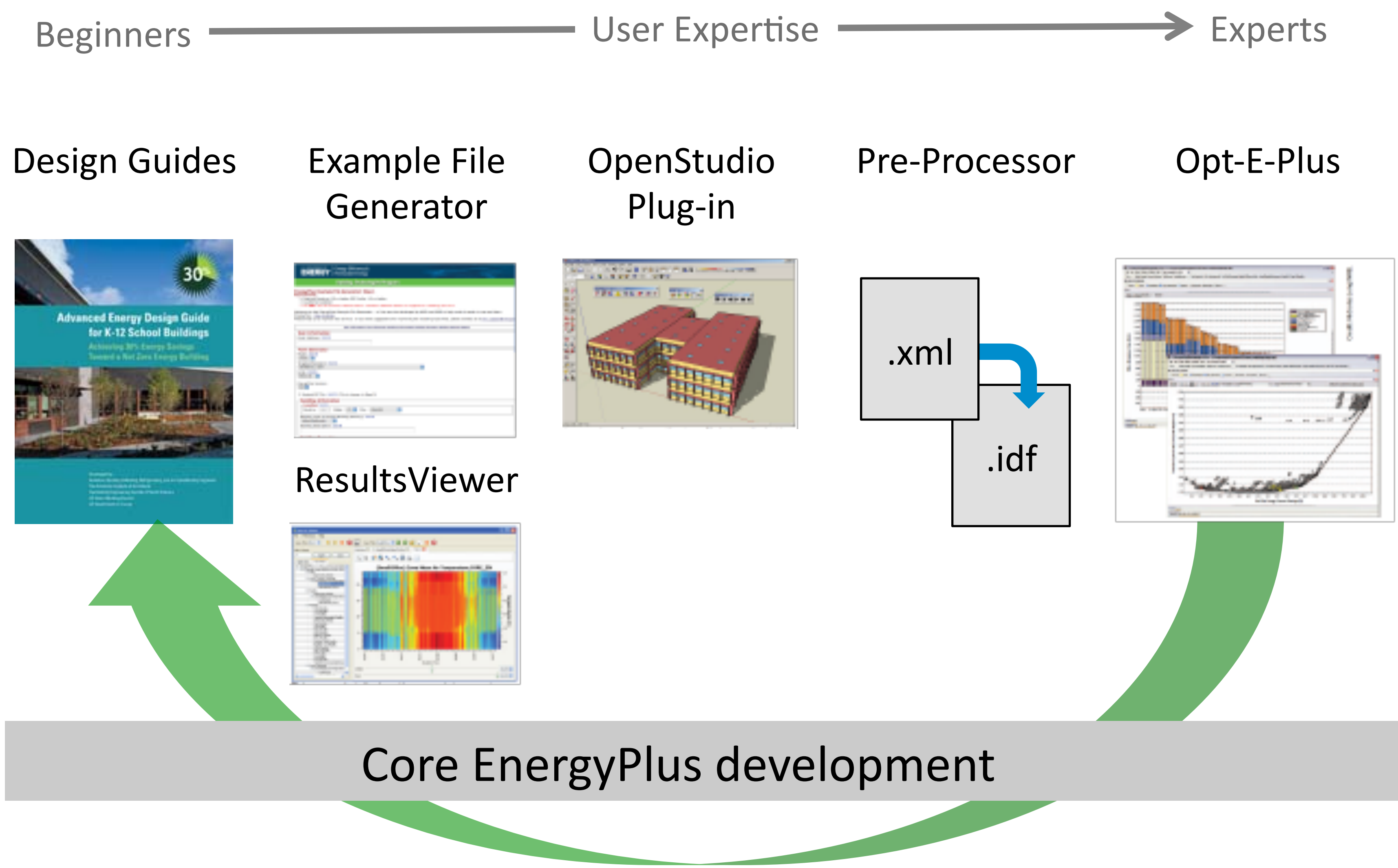


User Base Segmentation

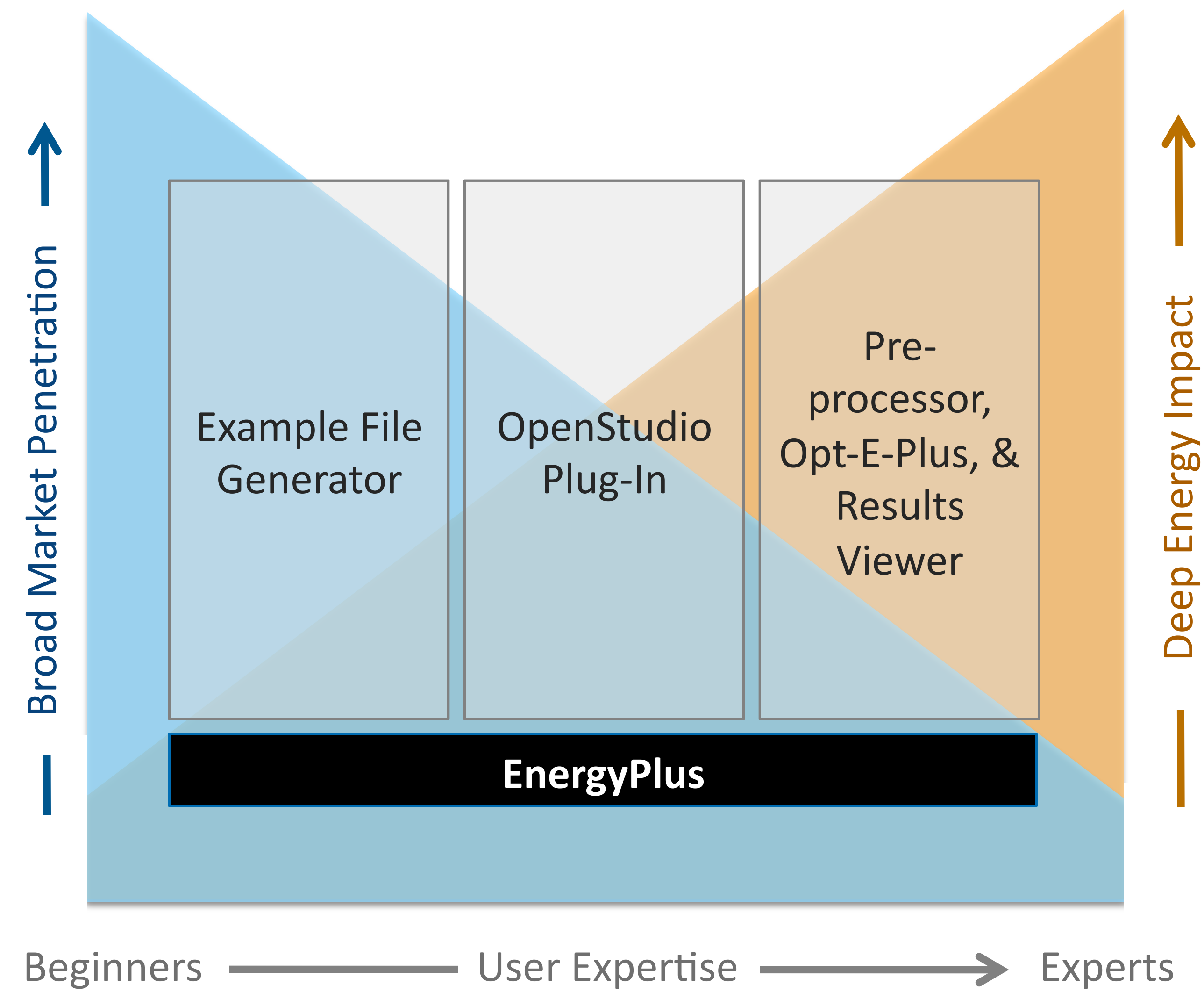
- Recognition of diverse expertise and user needs is critical for widespread and deep impact on the sector
- One size does not fit all



Past Tools Development at NREL



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

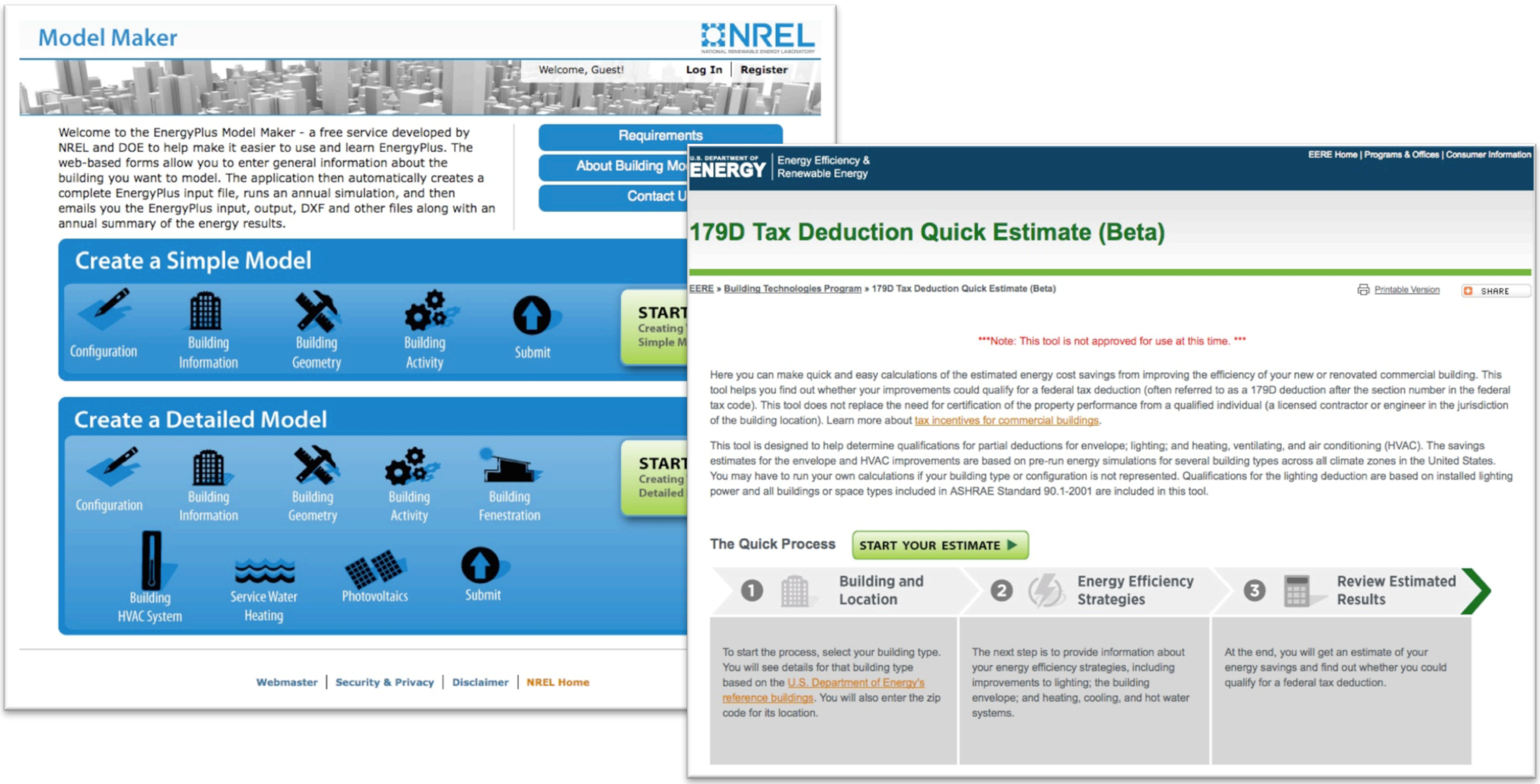
2. **Use simple tool interfaces** to enable education of this audience and make them capable of having meaningful conversations with experienced designers

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

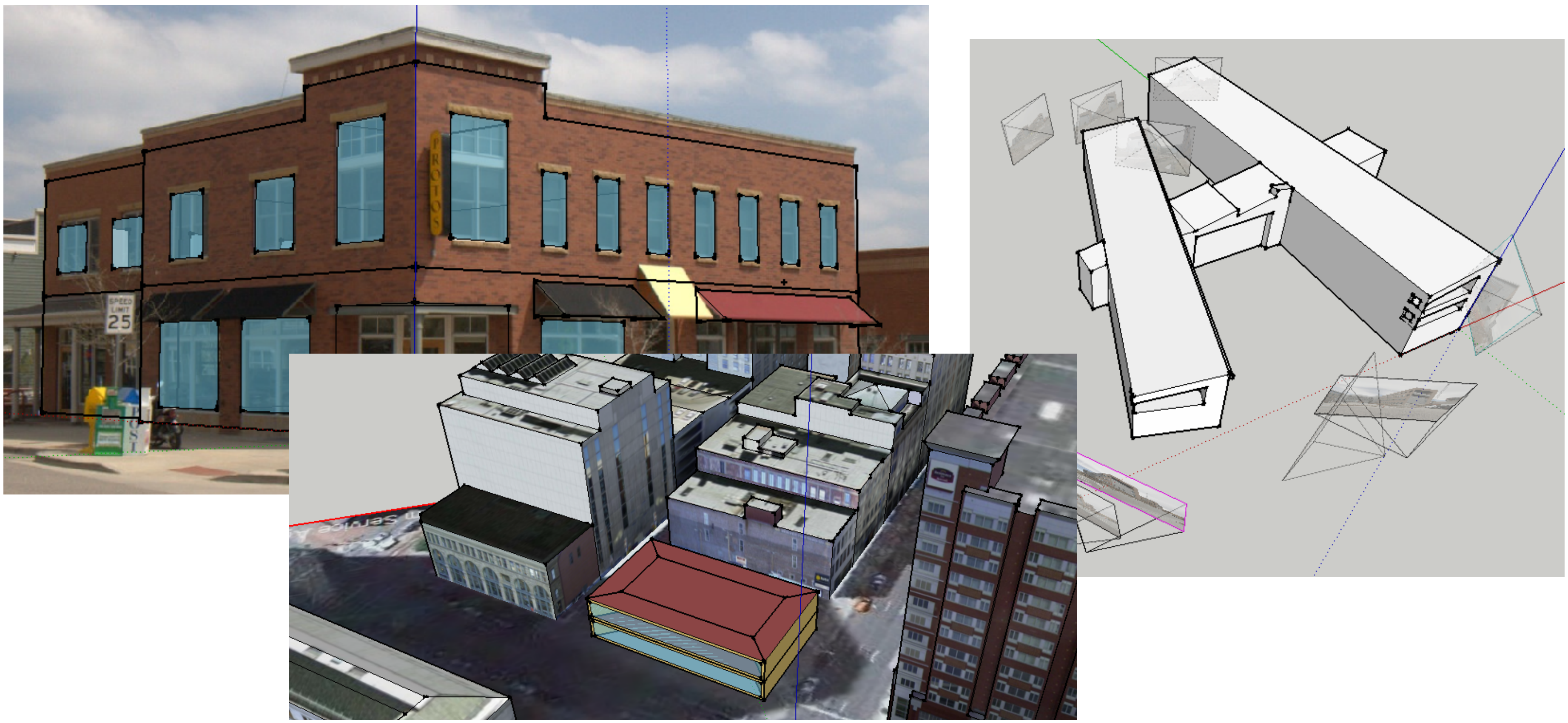
Simple Interfaces for Diverse Users

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



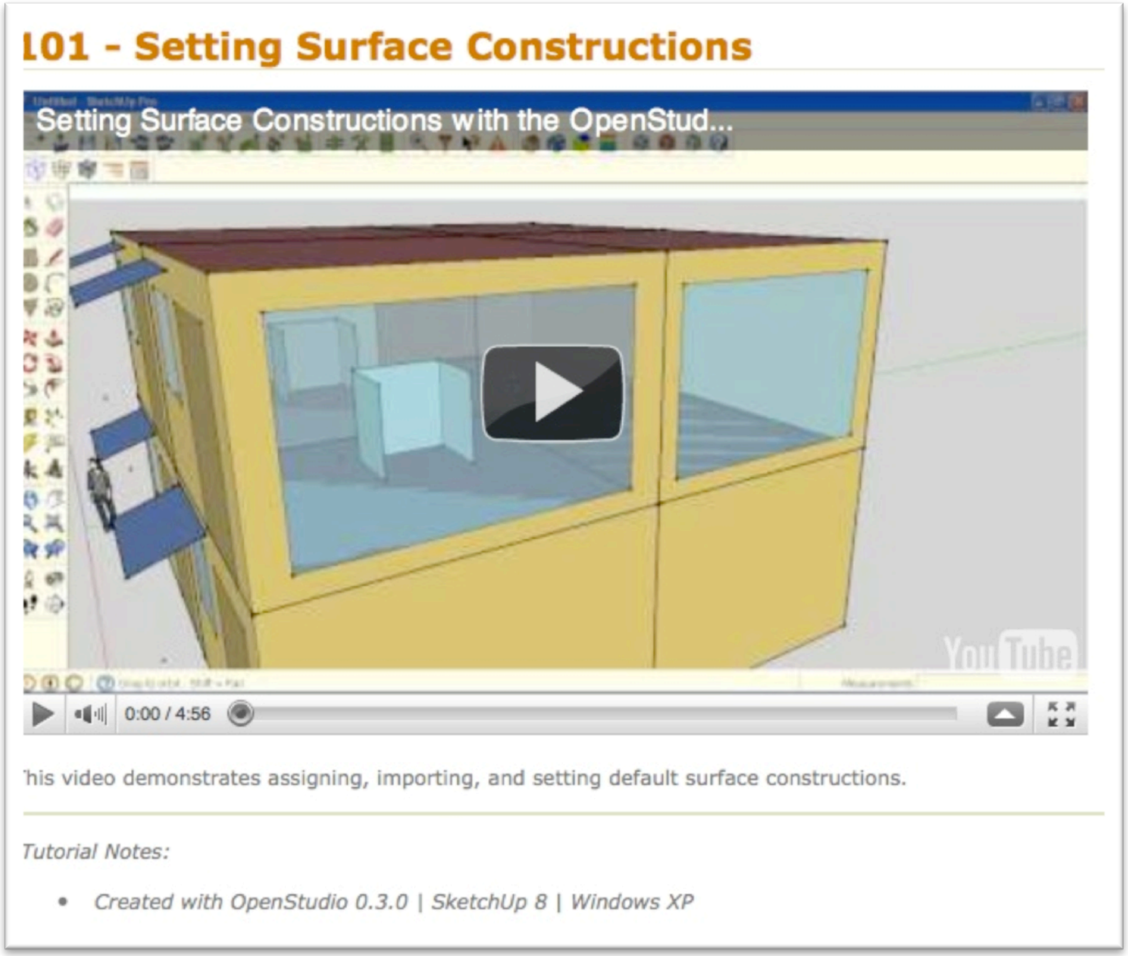
What About Retrofits?

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



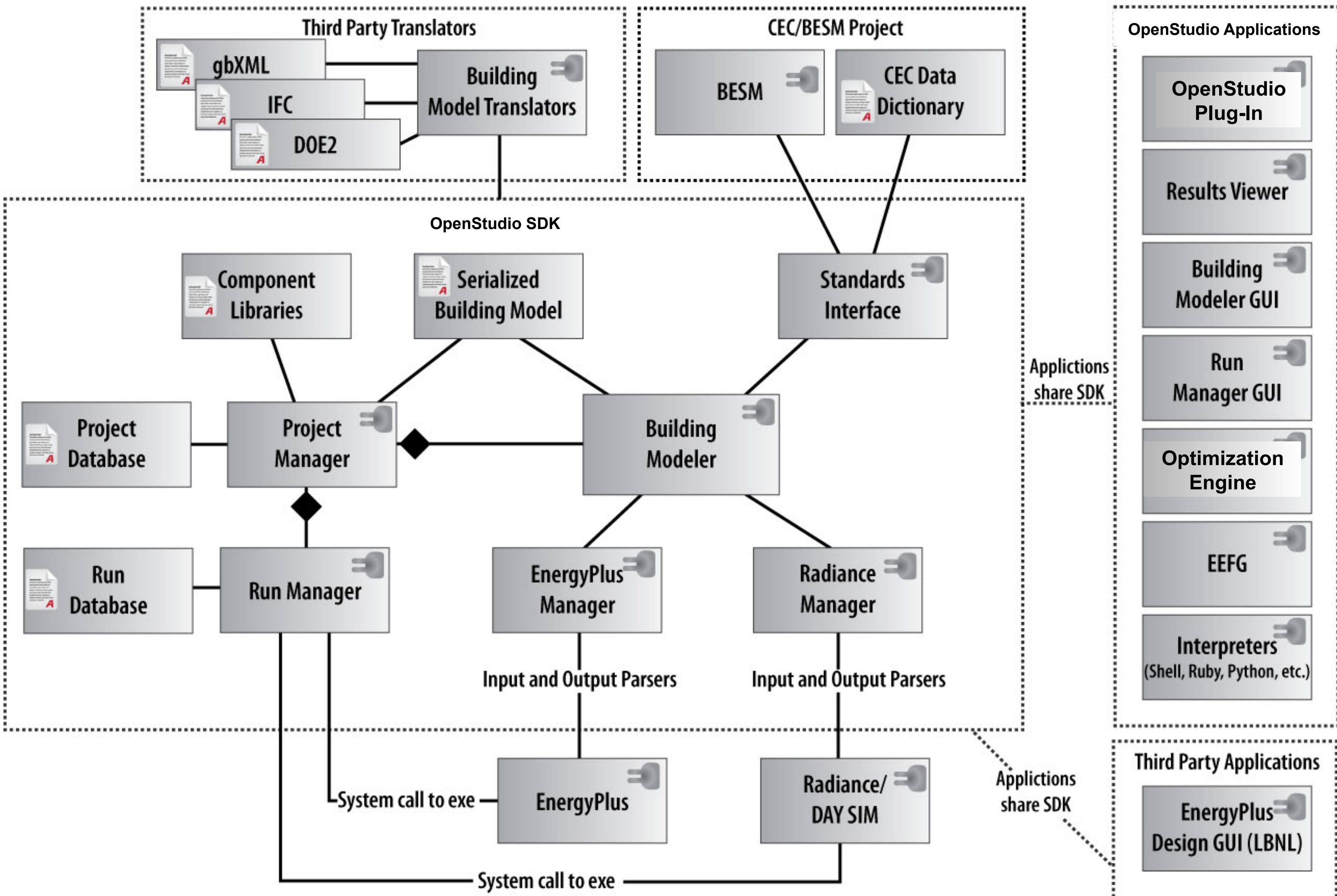
OpenStudio Architecture

Data Model vs Object Model

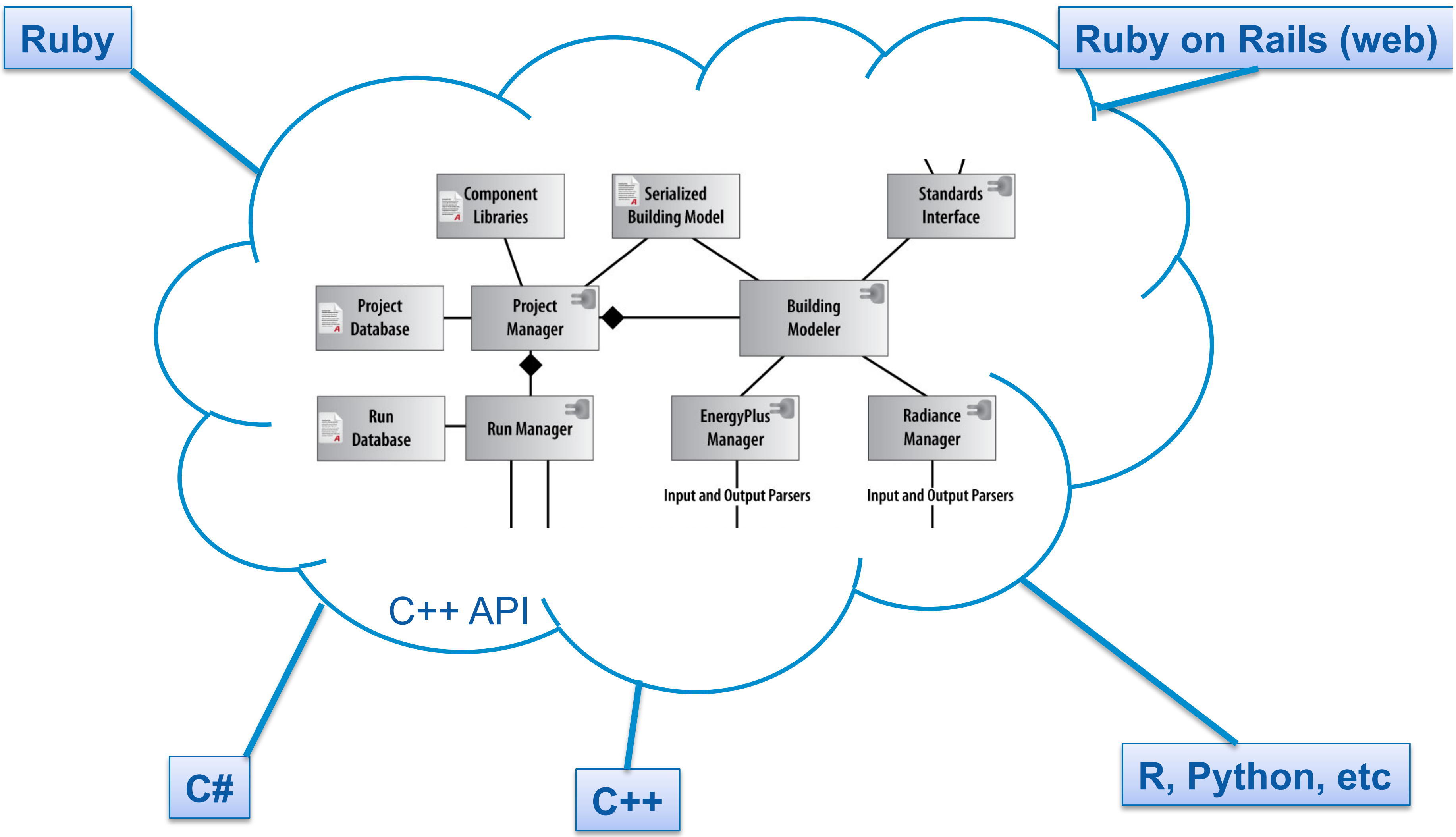
- Current Implementations use Data Models to exchange data (IFC, gbXML, bdl, idf)
  - Any application using data model must implement its own methods to modify data
  - Developer must start from scratch to determine domain logic, interdependencies, and simulation engine best practices
  - Typically proprietary 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
#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 (?

#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
                   :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_mods dm on (dm.d
                             :conditions => ["dr.measurement_id in (?) and dr.times
                             :group => "dr.measurement_id, DATE(dr.timestamp), HOUR
                             :order => "dr.timestamp, dr.measurement_id")
        end
```

Ruby

```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
```

Run Database

Run Manager

EnergyPlus Manager

Radiance Manager

C#

```csharp
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"));
}
```

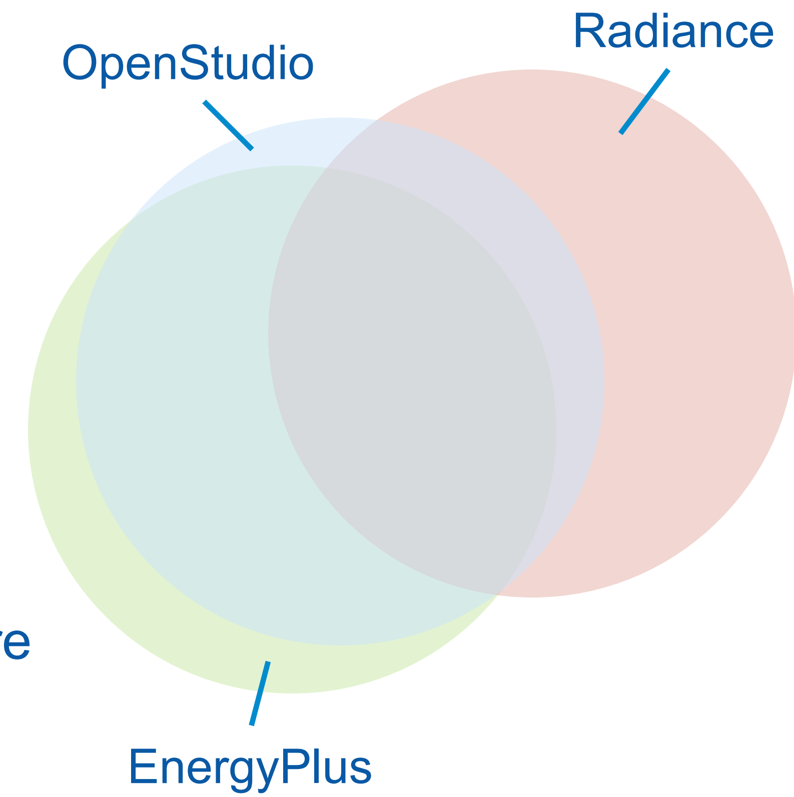
R, Python, etc

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

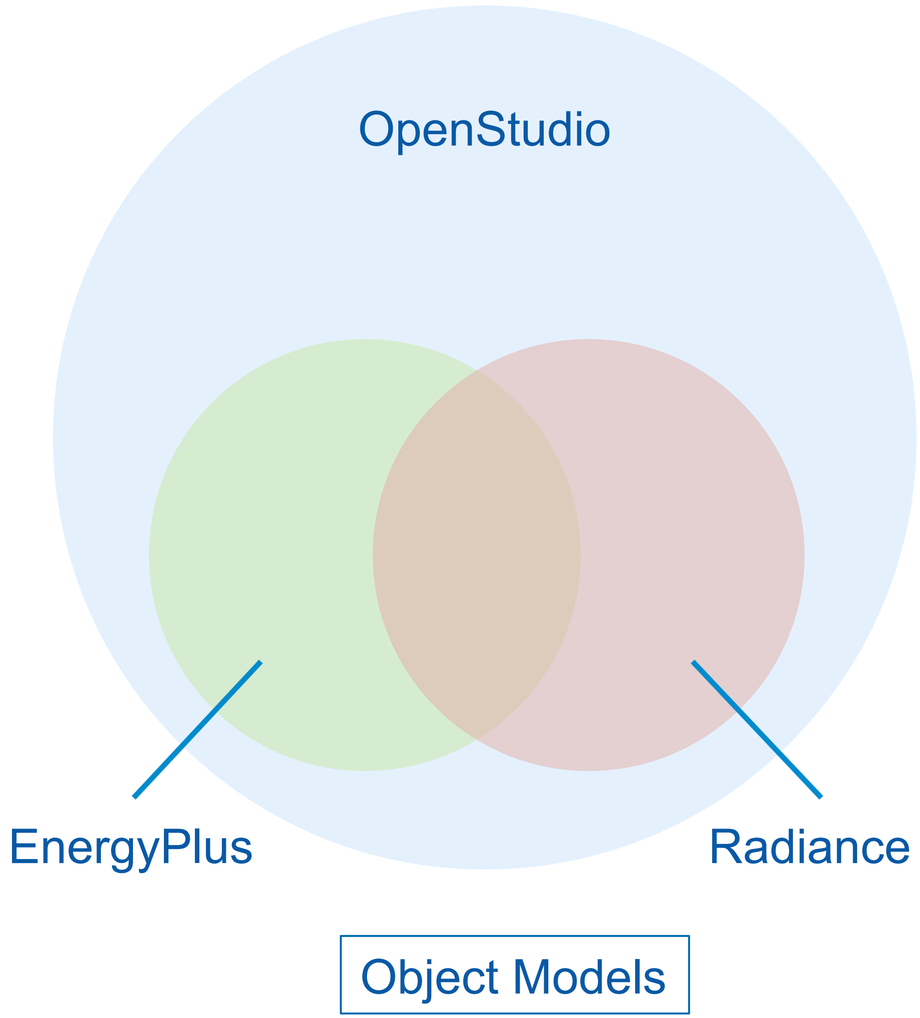
- EnergyPlus Data Model
  - 585 objects defined
  - 2050 pages of documentation
  - Existing models and data sets
  - Reuse as much as possible
- Some objects in EnergyPlus are not needed in OpenStudio Data Model
  - Converted by translator
  - Parametric objects, simple geometry, etc
- Some objects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



Data Models

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



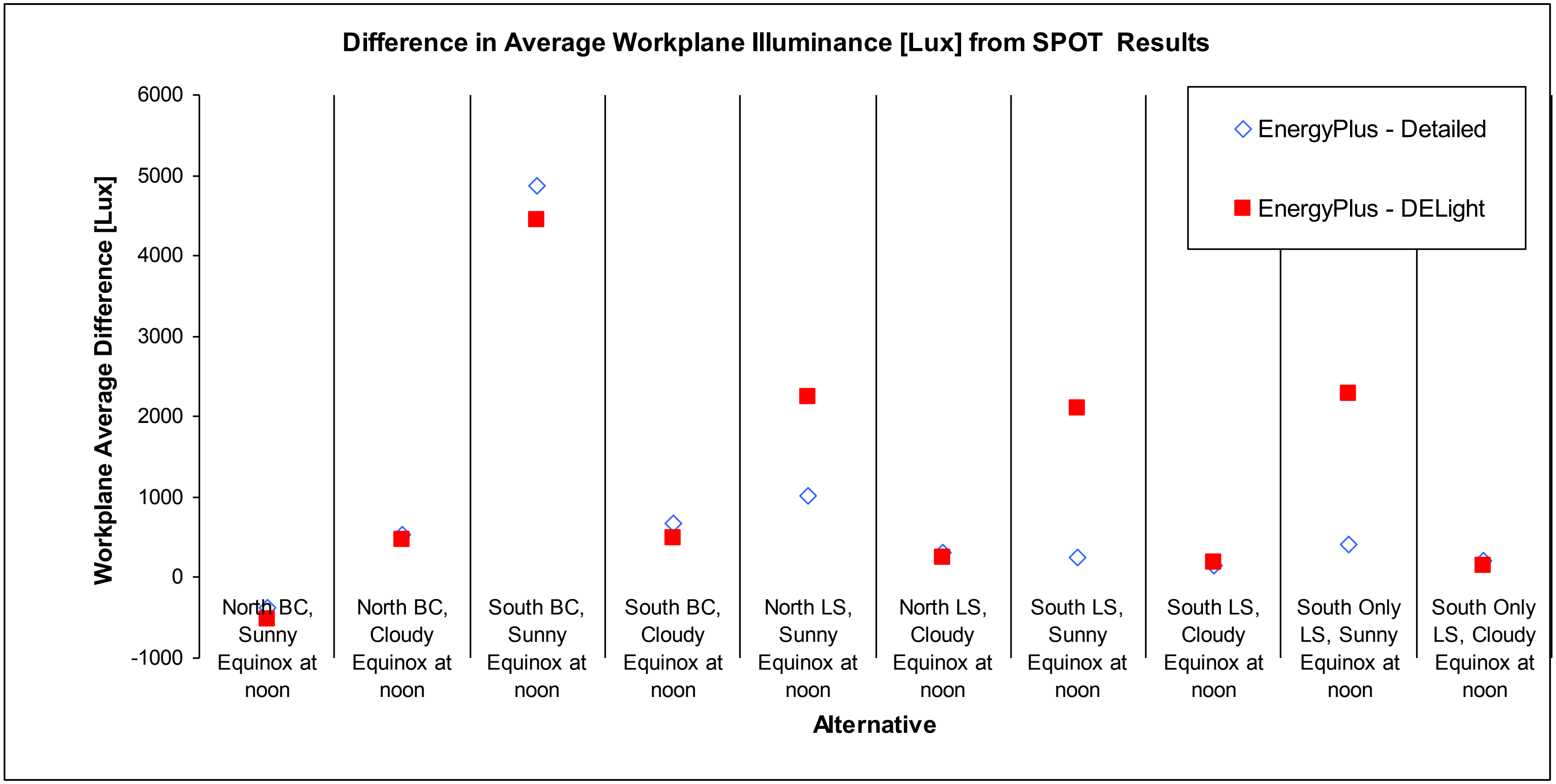
Radiance Integration

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?

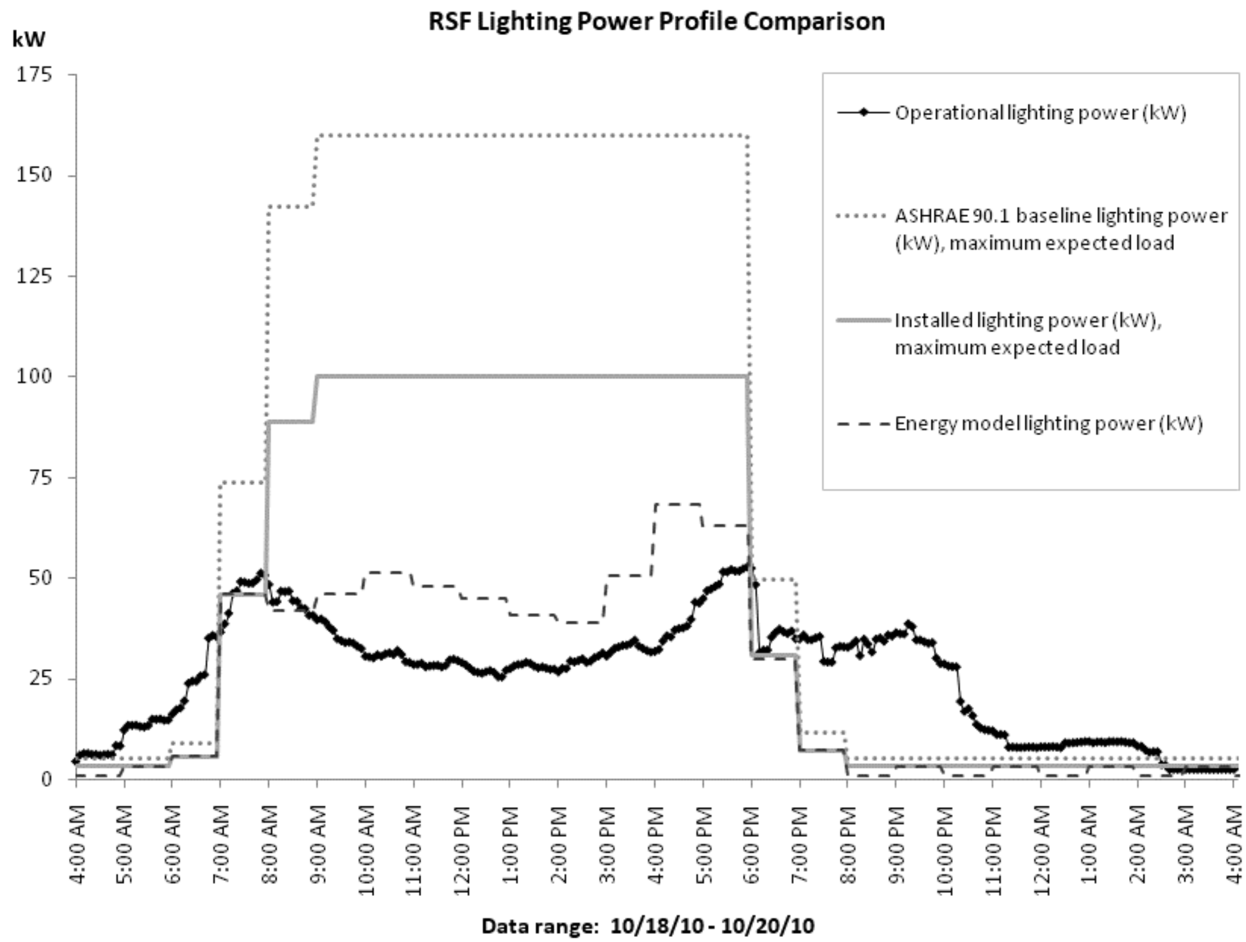
- Radiance simulations can inform design, regardless of complexity
  - Design validation
  - Photometric evaluation
  - Image-based glare analysis
  - (Climate-based) daylight modeling
  - Electric lighting
  - Lighting control simulation

Lighting Simulation – Why Radiance?

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

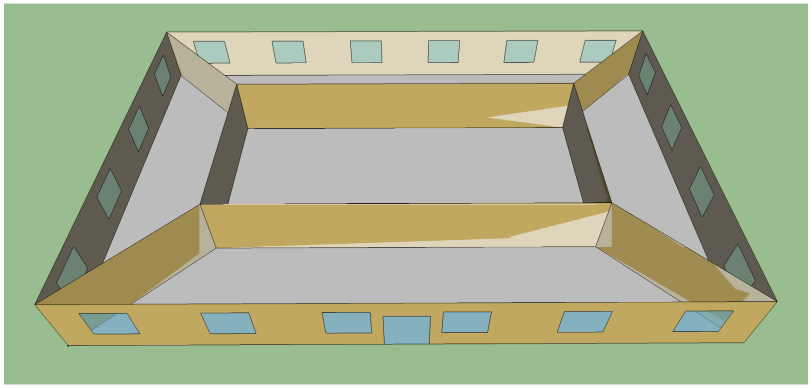
Lighting Simulation – Why Radiance?

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

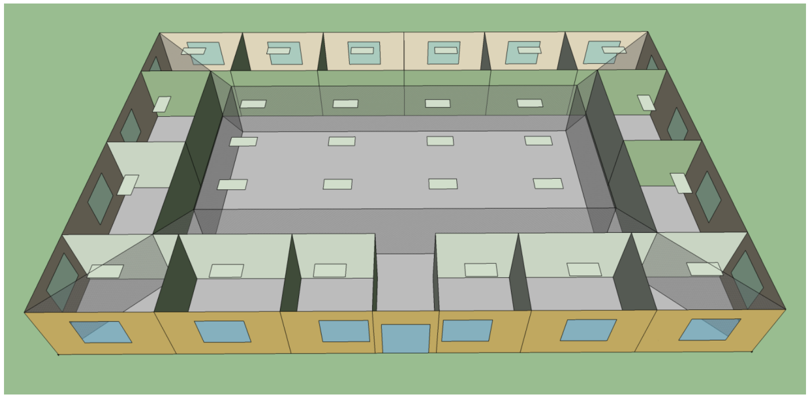


Two Simulations, Two Models

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



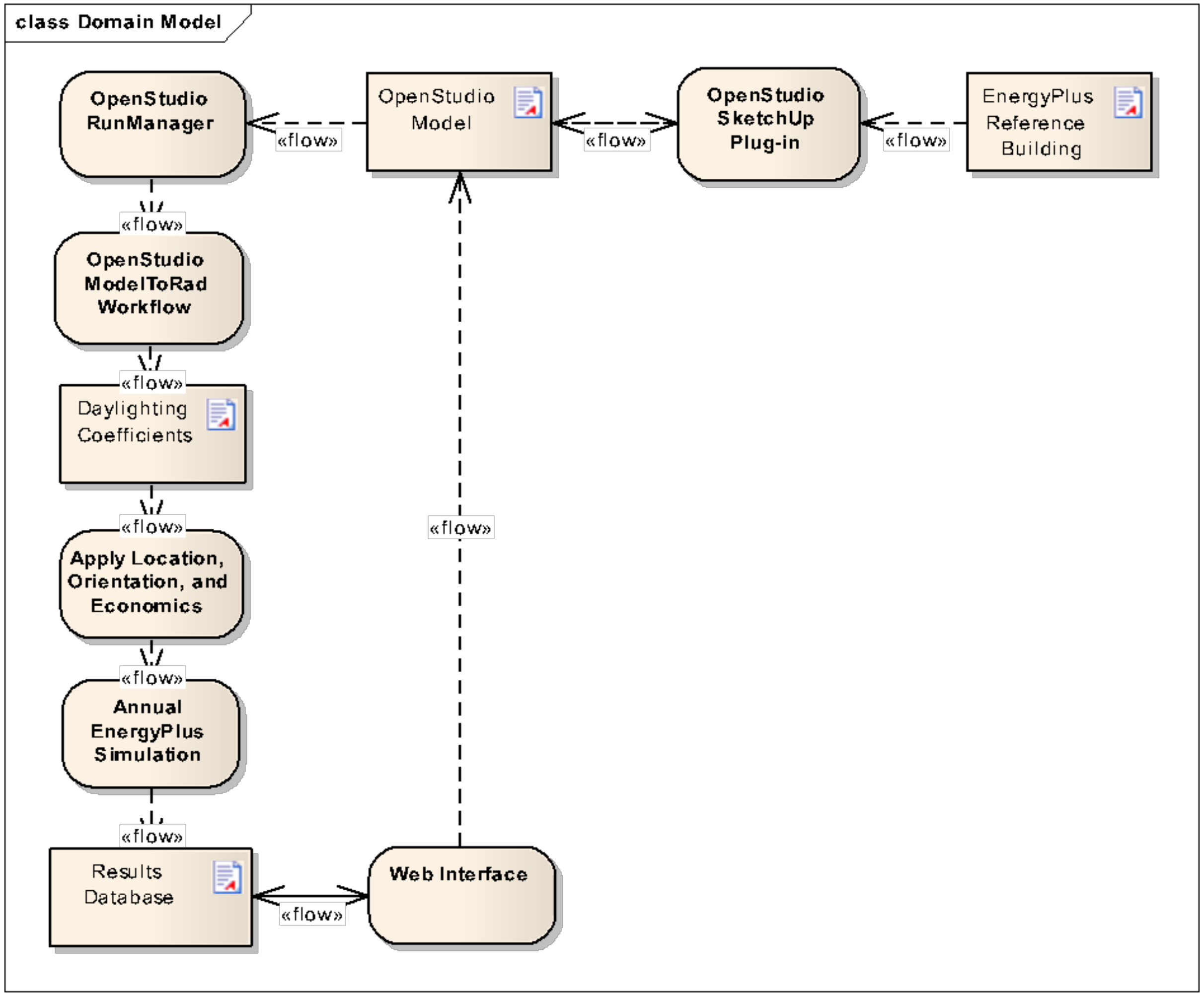
Typical energy model representation



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

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.