OpenStudio
An integrated Whole Building Analysis Platform

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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 ft²
• Design/Build Process with required energy goals
  • 25 kBtu/ft²
  • 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/ft² construction cost (not including $27/ft² 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

1.6 MW of photovoltaics on site

Transpired solar collectors on southern facade of building

Sculptural wood wall is built from beetle-kill pine

Electrochromic west-facing windows (not shown) tint on command

Open-ceiling offices introduce indirect northern light to building's core

Repurposed natural gas pipe used for structural columns

Low-profile workstations aid daylighting and air flow

12" accessible underfloor air, data, and power

Cost-effective solar array

Cool air intakes

Permeable landscaping

Highly reflective interior paint, painting and workstations enhance daylighting

Basement Thermal Mass Labyrinth

Innovation for Our Energy Future
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

Third Floor

Applied to Floors 1 & 2 in energy model

Applied to Floors 3 & 4 in energy model

Annual Daylight Availability – North Wing

Lighting Control Zones – East-West
October 2010 – February 2011 Daily Heating Energy

![Graph showing the relationship between daily heating energy (kWh) and average daily outdoor temperature (°F). The graph includes data points for both model daily heating and RSF daily heating, with trendlines for each.](./民族文化资料图.png)
Measured vs Modeled 2010 Monthly End Use Energy Consumption

- Total PV (kWh)
- Total Mechanical (kWh)
- Total Data Center (kWh)
- Total Plug Loads (kWh)
- Total Lighting (kWh)
- Total Heating (kWh)
- Total Cooling (kWh)
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
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 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.
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

Design Guides

Example File Generator

Core EnergyPlus development

User Expertise

OpenStudio Plug-in

Pre-Processor

ResultsViewer

.idf

Experts

Opt-E-Plus

.xml
Adding Functionality was Challenging

- Example File Generator
- OpenStudio Plug-In
- Pre-processor, Opt-E-Plus, & Results Viewer

Broad Market Penetration

Beginners  User Expertise  Experts

Deep Energy Impact
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
API Access (high level via SWIG)
def test_linearScalesColorLevelsContourLevels
    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

C#

public void test_LinearScalesColorLevelsContourLevels()
{
    ZeroKit SingletonApplication instance() application();
    ZeroKit Matrix n = new ZeroKit.Matrix(10, 10);
    for (suint i = 0; i < 10; i++)
    {
        for (suint j = 0; j < 10; j++)
        { n.setitem([i, j, 10 * i + j]);
        }
    }
    ZeroKit FloodPlot fp = new ZeroKit.FloodPlot(n);
    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'));
}

API
- Ruby
  - Ruby on Rails (web)
  - API
- C#
- C++
- R
- Python
- etc
Building Model

• Building Model at center of OpenStudio functionality
  • 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

Diagram:
- OpenStudio
- Radiance
- EnergyPlus
- Data Models
• 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

![Graph showing difference in average workplane illuminance [Lux] from SPOT results for different alternatives and weather conditions. The graph compares EnergyPlus and Delight simulation data.](image)

**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
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  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.