Thermal & Energy Analysis for Architects: Why, When, & How

Lori Ferriss, PE & Elaine Hoffman, CPHC
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SPEAKERS

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Project Manager in Architecture and Preservation at Goody Clancy
ICOMOS International Scientific Committee for Energy and Sustainability
Co-Chair of Association for Preservation Technology Zero Net Carbon Collaborative
B.S., M.Eng., Massachusetts Institute of Technology

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Architect/Co-chair of Goody Clancy 2030 Committee
B.A. in Environmental Studies, Tufts University
M.Arch, Columbia University
LEARNING OBJECTIVES

• Become familiar with the sustainability analysis tools available to designers and how to implement them

• Identify strategies to expand designers’ use of analysis tools

• Understand how design tools can be used to ensure compliance with energy codes

• Understand the terminology and fundamental principles of life cycle assessment
OVERVIEW

I. Introduction

II. Thermal Modeling - THERM

III. Energy Modeling - Insight360

IV. Life Cycle Assessment - Tally

V. Integrating the Process

VI. Discussion
SUSTAINABLE ANALYSIS TOOLS
Value of Analytical Thinking

“If you can’t measure it, you can’t understand it.
If you can’t understand it, you can’t control it.
If you can’t control it, you can’t improve it.”
- H. JAMES HARRINGTON
HOW WE GOT HERE AND WHERE WE’RE GOING
Emergence of Organizations and Standards

- 1974-1975: NESEA
- 1980s: “passive house” concept in US
- 1994: LEED
- 1997: New Buildings Institute
- 2002: Architecture 2030
- 2007: International Living Building Institute

Development of Software Tools

- 1982: AutoCAD
- 1992: GaBi
- 1994: WUFI
- 1995: THERM
- 1996: EnergyPlus
- 2000: Revit
- 2002: DesignBuilder
- 2005: Athena LCA Tools
- 2009: Sefaira
- 2013: Tally
- 2016: Insight360
THE PROCESS OF SUSTAINABLE DESIGN - STATUS QUO

Analysis as a Decision Making Tool

Design Model
CREATE DESIGN AND CONSTRUCTION DOCUMENTS

Energy Model
DETERMINE PROJECTED ENERGY CONSUMPTION

Energy Conservation Measures
THE PROCESS OF SUSTAINABLE DESIGN
Integrating Tools into the Design Process

BIM Model

Energy Model - Insight360

Detailed Energy Model

Thermal Model - THERM

Life Cycle Assessment - Tally

Hygrothermal Model - WUFI
CONTENTS

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THERMAL MODELING
WHY - Impacts of Thermal Bridging on Building Performance

- Thermal bridging can reduce effectiveness of insulation by ~40% (Morrison Hershfield, 2011)
- R-Values can vary from laboratory tested values by as much as 3-5x when installed in an assembly (Straube)
- Two primary impacts of thermal bridging:
  1. Affect total heat loss through the envelope
  2. Create local cold spots resulting in condensation, material degradation, and/or occupant discomfort
THERMAL MODELING
WHY - THERM by LBNL

• Calculates 2-D heat transfer of elements or assemblies based on finite element analysis
• Renders resulting temperatures across the section
• Simple to use in-house, independent of energy modeling or full envelope design by a consultant
• Understand the implications of material selection on R-Value early in design
• Understand how R-Value is impacted by how we detail assemblies and transitions
• Results feed into energy modeling for more accurate results
• Model assemblies to comply with building code requirements
• Graphic output can be used to communicate with clients and others
THERMAL MODELING
HOW - Evaluating Existing Conditions
THERMAL MODELING
HOW - Evaluating Retrofit Options

Existing Wall (shown in plan):
Calculated Baseline R-Value = 9.84 h·ft²·F/Btu
Simulated R-Value = 8.6 h·ft²·F/Btu

Retrofit Option A: Fill Stud Cavity w/ Closed Cell Spray Foam
Calculated R-Value = 20.4 h·ft²·F/Btu
Simulated R-Value = 15 h·ft²·F/Btu

Retrofit Option B: Fill Stud Cavity w/ Closed Cell Spray Foam + 1” Continuous Interior
Calculated R-Value = 26.4 h·ft²·F/Btu
Simulated R-Value = 25 h·ft²·F/Btu
THERMAL MODELING
HOW - Evaluating Retrofit Options

Existing Wall (shown in plan):
Simulated R-Value = **8.6 h·ft²·F/Btu**

Proosed Wall:
Simulated R-Value = **14 h·ft²·F/Btu**

THERMAL & ENERGY ANALYSIS FOR ARCHITECTS: WHY, WHEN, & HOW | BUILDING ENERGY BOSTON | MARCH 9, 2018
THERMAL MODELING
WHEN - Detailing and Material Selection

Thermally-Broken Brick Tie
R = 31.2 h·ft²·F/Btu

Standard Brick Tie
R = 8.6 h·ft²·F/Btu
THERMAL MODELING
WHEN - Evaluating Shop Drawings and Material Substitutions
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ENERGY MODELING - INSIGHT360
HOW - Generating an Energy Model in Revit
ENERGY MODELING - INSIGHT360

“Scalable Precision” in Generating the Model

BIM Energy Settings → CHOOSE Geometry Mode → CHOOSE Material Thermal Properties

Conceptual Masses

- Building Elements
- Both

<table>
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<tr>
<th>Conceptual Types</th>
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<tbody>
<tr>
<td>Mass Exterior Wall</td>
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<tr>
<td>Mass Interior Wall</td>
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<tr>
<td>Mass Exterior Wall - Underground</td>
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<tr>
<td>Mass Roof</td>
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<tr>
<td>Mass Floor</td>
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<tr>
<td>Mass Slab</td>
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<tr>
<td>Mass Glazing</td>
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<tr>
<td>Mass Skylight</td>
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<td>Mass Shade</td>
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<td>Mass Opening</td>
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<th>Schematic Types</th>
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<tr>
<td>Basic Wall</td>
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<tr>
<td>Exterior Wall</td>
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<tr>
<td>Insulated solid wall</td>
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<tr>
<td>Insulated stud wall</td>
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<tr>
<td>Insulated ceiling</td>
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<td>Insulated wall</td>
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<td>Insulated floor</td>
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<td>Insulated roof</td>
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<td>Insulated floor/ceiling</td>
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<td>Insulated wall/ceiling</td>
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<td>Insulated wall/floor</td>
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<tr>
<td>Insulated ceiling/floor</td>
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<tr>
<td>Insulated roof/ceiling</td>
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<th>Detailed Elements</th>
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<tbody>
<tr>
<td>Family: Basic Wall</td>
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<tr>
<td>Type: Exterior Wall</td>
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<tr>
<td>Total thickness: 1” 1/8”</td>
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<tr>
<td>Resistance (R): 12.9942 (0.1 N=°F/ft²BTU)</td>
</tr>
<tr>
<td>Thermal Mass: 3.0836 BTU/°F</td>
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</tbody>
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ENERGY MODELING - INSIGHT360

New Construction Example

Defined in Revit
- Project Location
- Building Use
- Building Mass/Building Elements

Iteratively Tested through Insight
- Building Orientation
- Window-Wall-Ratio - by elevation
- Window Shades – by elevation
- Window Type – by elevation
- Wall Construction
- Roof Construction
- Infiltration
- Lighting/Plug Load Efficiency
- Daylighting and Occupancy Controls
- HVAC Types (limited options)
- Operating Schedule
- PV Potential
ENERGY MODELING - INSIGHT360
Existing Building Example

**Defined in Revit**
- Project Location
- Building Use
- Building Orientation
- Window-Wall-Ratio - by elevation
- Window Shades – by elevation

**Iteratively Tested through Insight**
- Wall Construction
- Roof Construction
- Infiltration
- Window Type – by elevation
- Lighting/Plug Load Efficiency
- Daylighting and Occupancy Controls
- HVAC Types (limited options)
- Operating Schedule
- PV Potential
ENERGY MODELING - INSIGHT360

How to tell if your analytical surfaces are working
ENERGY MODELING - INSIGHT360

How to use Insight to drive decisions about your exterior glazing
Study each variable to determine significance to energy use intensity (EUI)
ENERGY MODELING - INSIGHT360
Understanding relative impact of each variable
ENERGY MODELING - INSIGHT360
Understanding relative impact of each variable
ENERGY MODELING - INSIGHT360
Window Types: defined within tiers of precision

Tier 1: Slider

Tier 2: Conceptual Options

Tier 3: Schematic Types
**ENERGY MODELING - INSIGHT360**

Insight360 vs. traditional energy model

**Insight360**

- **Inputs**: flexible to allow for scalable precision to evolve throughout your process
- **Process**: Meant to be run iteratively from within your BIM model
- **Output**: EUI range
- **Limitations**: Cannot parametrically test building form, limited HVAC presets
- **Advantages**: More nuanced HVAC evaluation

**BOTH**

- **Inputs**: specific numerical value across many fields
- **Process**: Limited ability to iterate; must export or create file from scratch, duplicates labor
- **Output**: Generate a specific estimate rather than a range
- **Essential tools for evaluating performance of design**
- Can be run from recorded weather data or regional averages, uses DOE-2 engine
LIFE CYCLE ASSESSMENT (LCA)
Scientific method for measuring the potential cradle to grave or cradle to cradle environmental footprint of materials, products, and services over their entire lifetime.
LIFE CYCLE ASSESSMENT (LCA)
WHY - Cradle to Grave Impacts

Adapted from K. Simonen, Life Cycle Assessment
LIFE CYCLE ASSESSMENT (LCA)

WHY - Impact Categories

- Global Warming Potential
- Ozone Depletion Potential
- Acidification Potential
- Eutrophication Potential
- Formation of Tropospheric Ozone (Smog) Potential
LIFE CYCLE ASSESSMENT (LCA)
WHY - Cradle to Grave Impacts

Source: IPCC 2013, Representative Concentration Pathways (RCP); Stockholm Environment Institute (SEI), 2013; Climate Analytics and ECOP, 2014.
Note: Emissions peaks are for fossil fuel CO2-only emissions.
LIFE CYCLE ASSESSMENT (LCA)
WHY - Impact Categories

WE HAVE 35 YEARS TO GET TO ZERO CARBON, SO WHY ARE WE STILL MEASURING IMPACTS BASED ON A BUILDING’S FULL LIFESPAN?

-Architecture2030
# LIFE CYCLE ASSESSMENT (LCA)

## Inputs

- Material Attributes & Quantity
- Project Location and Service Life

## Assessment

- Material’s GWP multiplier
- Material’s ODP multiplier
- Material’s AP multiplier
- Material’s EP multiplier
- Material’s TOP multiplier
- Material’s NRDP multiplier

## Outputs

- Global Warming Potential in kg CO2e
- Ozone Depletion Potential in kg CFC-11
- Acidification Potential in kg SO2
- Eutrophication Potential in kg nitrogen or kg phosphate
- Tropospheric Ozone Potential in kg NOx or kg O3 eq
- Non-renewable Resource Depletion Potential in MJ
LIFE CYCLE ASSESSMENT (LCA) Implementation

Excel Spreadsheet

U.S. Life Cycle Inventory Database

Environmental Product Declaration

Analysis Software Tools
IMPLEMENTATION - LCA SOFTWARE

HOW - Window Products
LIFE CYCLE ASSESSMENT (LCA)

HOW - Window Products
IMPLEMENTATION - LCA SOFTWARE

HOW - Window Products

DEFINE GLAZING

- Choose from material dropdown

DEFINE WINDOW FRAME

- Option to define service life of each element
- Material options with EPDS are noted
- Option to define material takeoff method
LIFE CYCLE ASSESSMENT (LCA)
HOW - Window Products

FINALIZE PROJECT SETTINGS

OPTION TO INCLUDE CONSTRUCTION IMPACTS

OPTION TO INCLUDE OPERATIONAL ENERGY
IMPLEMENTATION - LCA SOFTWARE
HOW - Window Products
IMPLEMENTATION - LCA SOFTWARE

HOW - Structural System Selection

Compare an equivalent 30’ x 30’ structural bay constructed of:

I. Concrete columns, beams, and slab
II. Steel columns, beams, and joists with concrete on metal deck
III. Glulam columns and beams with wood infill and a concrete topping slab
IMPLEMENTATION - LCA SOFTWARE

HOW - Structural Systems Comparison

![Graph showing structural systems comparison with various environmental impacts.]

Design Options:
- Concrete Framing
- Steel Framing
- Wood Framing (primary)
IMPLEMENTATION - LCA SOFTWARE

HOW - Structural Systems Comparison

Divisions
- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites

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<tr>
<td>03</td>
<td>57,782 kg</td>
<td>66.33 kgSO2eq</td>
<td>6.626 kgNeq</td>
<td>15,447 kgCO2eq</td>
<td>4.865E-004 CFC-11eq</td>
<td>930.4 O3eq</td>
<td>161,341 MJ</td>
<td>153,103 MJ</td>
<td>41,082 MJ</td>
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<td>05</td>
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IMPLEMENATION - LCA SOFTWARE

HOW - Existing Building Renovation Example

- 115,000 sf existing building from the 1970s
- Brick cladding and concrete structural system
- Comprehensive renovation including new systems and partition walls
IMPLEMENTATION - LCA SOFTWARE

HOW - Existing Building Renovation Example

Legend

FLOORS
- 6 1/2" Concrete Slab
- 8" Concrete Slab
- East Connector Ramp: East Connector Ramp
- Wood Deck

ROOFS
- 4" Concrete Slab
- 4" Concrete Slab 2
- 6 1/2" Concrete Slab
- Roof Type 2 - Membrane Roof on Wood Framing
- Roof Type 5 - Membrane Roof on MTL Deck 2
- Roof Type 6 - Standing Seam MTL on MTL Deck_GWB int.

STRUCTURE
- Concrete-Rectangular-Column_07300: 10 x 16
- Concrete-Rectangular-Column_07300: 10 x 31
- Concrete-Rectangular-Column_07300: 10 x 32
- Concrete-Rectangular-Column_07300: 10 x 48
- Concrete-Rectangular-Column_07300: 12 x 30
- Concrete-Round-Column: 16"
- HSS-Hollow Structural Section-Column: HSS4X4X1/2
- HSS-Hollow Structural Section-Column: HSS5X5X1/2
- Pile Cap-1 Pile Angled Notched_07300: 70"x70"x11"
- Pile Cap-1 Pile Angled_07300: 70"x70"x11"
- Pile Cap-1 Pile Unequal Width Notched_07300: 70"x91"x11"
- Pile Cap-1 Pile Unequal Width_07300: 70"x91"x11"
- Pile Cap-1 Pile_07300: 6"x6"x13"
- Pile-Steel Pipe: 24" Diameter

WALLS
- 12" - Concrete
- 33 - 5 5/8" 1xGWB Both Sides_GCA
- 4" CMU
- Exterior - Brick at Parapet_07300
- Exterior - Brick on CMU_07300
- Exterior - Concrete on MTL: Stud_07300

Exterior - Standing Seam Metal Wall - Existing_07300
Exterior A1 - Brick on MTL: Stud_07300
Exterior A2 - Brick on MTL: Stud_07300
Exterior A3 - Brick on MTL: Stud_07300
Exterior HoH- Brick on MTL: Stud_07300
Foundation - '0' Concrete
MS - 6" CMU_GCA
MB - 8" CMU_GCA
temp - AF: temp - AF

Windows
- Louvers with Trim: 63" x 120"

1% 16% 27%
3% 13% 5%
2% 2% 16%
8% 5%
IMPLEMENTATION - LCA SOFTWARE

HOW - Existing Building Renovation Example

Legend
- Net value (impacts + credits)

Life Cycle Stages
- Manufacturing [A1-A3]
- Transportation [A4]
- Maintenance and Replacement [B2-B4]
- Operational Energy [B6]
- End of Life [C2-C4, D]
IMPLEMENTATION - LCA SOFTWARE

HOW - Existing Building Renovation Example

Legend

Revit Categories
- Ceilings
- Curtain Panels
- Curtain Wall Mullions
- Floors
- Roofs
- Structure
- Walls
- Windows

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<td>1,162,931</td>
<td>2.906</td>
<td>245.6</td>
<td>782,119</td>
<td>0.01091</td>
<td>51.899</td>
<td>1.232E+007</td>
<td>1.150E+007</td>
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IMPLEMENTATION - LCA SOFTWARE
HOW - Existing Building Renovation Example

Avoided Global Warming Potential = 3,764,469 kgCO2eq
  = 800 passenger vehicles on the road for one year
  = burning 20 railcars of coal
  = operating 315 homes for a year
  = offset by growing 97,000 tree seedlings for 10 years
IMPLEMENTATION - LCA SOFTWARE
HOW - Existing Building Renovation Example

Avoided Global Warming Potential = 3,764,469 kgCO2eq
  = 800 passenger vehicles on the road for one year
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Total embodied Global Warming Potential of renovation = 782,118 kgCO2eq
IMPLEMENTATION - LCA SOFTWARE
HOW - Existing Building Renovation Example

Avoided Global Warming Potential = 3,764,469 kgCO2eq
  = 800 passenger vehicles on the road for one year
  = burning 20 railcars of coal
  = operating 315 homes for a year
  = offset by growing 97,000 tree seedlings for 10 years

Total embodied Global Warming Potential of renovation = 782,118 kgCO2eq

It takes = ~2 years of operation for the improved operational efficiency to payback the renovation impacts.
OVERVIEW

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ANALYTICAL WORKFLOW
Integrating tools into the envelope design process

BIM Model

**Insight360**
**DETERMINE R-VALUE OF EACH COMPONENT**
- Slab: Define assembly
- Wall: Define opaque wall assembly
- Wall: Define glazing components
- Roof: Define assembly

**Tally**
**DETERMINE EMBODIED CARBON OF ENVELOPE**
- Bill of materials: Slab assembly
- Bill of materials: Exterior wall assembly
- Bill of materials: Glazing components
- Bill of materials: Roof assembly

**Therm**
**DETERMINE PSI VALUES AT ANY POTENTIAL THERMAL BRIDGES**
- Slab details
- Slab details at exterior wall
- Exterior wall & window details
- Roof details at exterior wall
- Roof details

**WUFI**
**DETERMINE HYGROTHERMAL PERFORMANCE OF ENVELOPE**
- Whole building analysis

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Detailed Energy Model
DETERMINE PROJECTED ENERGY CONSUMPTION
Whole building analysis
How can tools be integrated differently through the design and construction process?

What is the best workflow for collaborative design using analytic tools?

What tools do you wish were available?

Have you engaged in knowledge sharing or education about analytical tools?

What tools make the biggest impact on the performance of the final building?

What tools best communicate the urgency of high performance, low-carbon design to clients?

Should certain tools be used exclusively by certain members of the design team?