A UNIQUE COLLABORATION

Energy Modeling Methodology is the result of a unique collaboration between the academic and professional worlds of architecture. Renee Cheng, Head of the University of Minnesota School of Architecture, created a semester long work/study program that pairs Master of Architecture students with local design firms to conduct research projects. This paper is a result of the pilot semester of the project.1

Students enrolled in the program split their time between the classroom and the office, but their focus is always directed by the research project. This structure harnesses the strengths of the university and the private sector in conducting mutually beneficial research. Architecture firms benefit from the exploration of innovative processes, tools, and techniques by university students and faculty, and the university is able to vet its research in the real world, using experienced professionals to shape academic concepts into adoptable methodologies. At the center of it all is an invaluable opportunity for students; they gain experience and make connections in the field while learning a unique skill set that makes them attractive to future employers.

Energy Modeling Methodology was written and researched by Christopher Wingate while paired with Meyer Scherer & Rockcastle, ltd. 2 The research is focused on developing an energy modeling methodology for small to medium sized architecture firms that can be used to help inform early concept, schematic, and design development decisions.

PROJECT TEAM

University of Minnesota School of Architecture
Program Coordinator - Renee Cheng, Head of School of Architecture
Faculty Advisor - Blaine Brownell, Assistant Professor
Student Researcher - Christopher Wingate, M.Arch Candidate

Meyer Scherer & Rockcastle, Ltd.
Program Coordinator - Thomas Meyer, FAIA
Project Support - Allison Salzman, AIA
    - Sam Edelstein

Karges-Faulconbridge, Inc.
Energy Simulation Engineer - Katherine R. Edwards

PROFESSIONAL PRACTICE

- Implement research on real projects and generate real world results
- Research reviewed by experienced professionals
- Research must fit within existing budgets, schedules, and work flows

ACADEMIC RESEARCH

- Explores the latest approaches, innovations, and technologies
- Encourages the technical and conceptual understanding of tools and processes through extended investigation

OPTIMIZED ENERGY MODELING PROCESS

- Inform decisions throughout the design process
- Easy to use
- Communicates graphically

PROJECT TIMELINE

Energy Modeling Methodology wouldn’t have been possible without the collaborative efforts of multiple organizations and individuals.

The program was structured to split the student researcher’s time between the classroom and the office. Christopher Wingate spent 10 hours per week conducting research for academic credit under the guidance of faculty advisor Blaine Brownell and an additional 15 hours per week at Meyer Scherer & Rockcastle. Research completed at MS&R was overseen by Thomas Meyer, founding principal, and counted for IDP credit. A team of MS&R professionals also provided weekly feedback on the progress of the project. Katherine Edwards, an energy simulation engineer from KFI, collaborated on portions of the research.

Energy Modeling Methodology was also informed by Christopher Wingate’s position as a teaching assistant for Thermal and Luminous Design, a graduate studio focused on sustainable design through energy modeling. The teaching position ran concurrently with the work/study program.

Firms that participate in the work/study program receive a strong return on their investment. During this study, MS&R invested 301 hours of its time into the program. It benefited from an additional 259 hours funded by the University of Minnesota. In a business climate that makes research and development difficult, this work/study program enables firms to push the profession forward by leveraging the resources and expertise of the University of Minnesota.

1. NCARB Intern Development Program, www.ncarb.org
Comparing Energy Modeling Software: EQuest and IES VE

Energy Modeling Methodology development began by choosing an energy modeling software. When the research project started, MS&R had already narrowed its search for an energy modeling program down to eQuest by the Department of Energy and IES VE by Integrated Environmental Solutions. MS&R initially wanted to use energy modeling at the beginning of the design process to help inform conceptual and schematic design decisions, so a set of selection criteria was developed with that goal in mind. The criteria was based around the steps necessary to create, analyze, and compare energy models of early conceptual schemes. Please see the following three pages for the full selection criteria matrix and score comparison between eQuest and IES VE.

Each category in the selection criteria matrix represents a step necessary to create an energy model or to run an energy modeling analysis. The categories are:

1. Climate Analysis - Use the software to analyze the site’s specific climate and its ramifications on design.
2. Design Model - Create an energy model from a design concept.
3. Base Model - Create a baseline energy model to compare performance of design options against.
4. Solar Shading - Use the software to run a shadow study.
5. Daylighting - Use an energy model to test daylighting performance.
6. Thermal Analysis - Use energy modeling to analyze thermal performance.
7. Conceptual Model Comparisons - Compare the performative characteristics of multiple concept models.

The subcategories are similar across each category, analyzing characteristics such as the time required to complete a task, ease of using the software, and the graphical quality of its output. This structure allowed the research team to compare software in a variety of ways. By averaging the software’s scores in each subcategory, a metric emerged that gave a quick overview of the energy modeling program.

For example, the average score of each category’s Time Required subcategory was calculated and given the title Speed. This metric is a score out of 5 that illustrates the amount of time it takes to complete a given task with the software. A higher score is always related to better performance. The other subcategories were scored and averaged in the same manner. The results can be seen at the bottom of the selection criteria in the scoring boxes labeled Speed, Ease of Use, Data Quality, Graphics, and Workflow.

IES VE received a higher total score than eQuest. It also outscores eQUEST in every subcategory, with the largest margins in Graphics and Workflow. This is due to IES VE being designed and marketed to architects as well as engineers. Although both software platforms will accurately model the energy performance of a building, IES VE is designed with visual thinkers in mind, emphasizing the ability to create spatially complex three dimensional qualities of the design concept. The process of creating an energy model always involves simplifying a design model, but a successful energy model will still retain the feel of the design intent, convincing the design team that the architecture is actually shaping the energy model’s performance. IES VE uses a Sketchup plugin to create its energy models, giving architects the ability to easily capture the volumetric intent of their designs. By contrast, eQUEST creates an energy model by tracing over an AutoCAD drawing, extruding floor plans, and controlling other geometric elements with spreadsheet-based parameters. This severing the connection between design intent and energy analysis, interrupting the feedback loop necessary to turn analytical tests into generative project ideas.
### Category Averages and Total Score

<table>
<thead>
<tr>
<th>Category</th>
<th>Score</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance and Accuracy</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>Quality of Data</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Graphical Output</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>File Import / Export Options</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>Total Score</td>
<td>117</td>
<td>97</td>
</tr>
</tbody>
</table>

### Notes
- **eQUEST**
  - 3.7: Five minutes.
  - 1.4: Technical data.
  - 4: Included data given great overview but not enough for detailed analysis.
- **IES VE**
  - 5: Three simple graphs contain key information.
  - 4: Geometry results are graphically rich but can only be exported as image files.
  - 4: Design model geometry is imported from SketchUp. Easy workflow.
  - 3: Finding geometry in SketchUp allows for strong 2D correlation between idea and model.

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### Design Model

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST Notes</th>
<th>IES VE Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>3-4 hours</td>
<td>3-4 hours</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>3-4 hours</td>
<td>Experience</td>
</tr>
<tr>
<td>Quality of Data</td>
<td>3-4 hours</td>
<td>Experience</td>
</tr>
<tr>
<td>Graphical Output</td>
<td>3-4 hours</td>
<td>Experience</td>
</tr>
<tr>
<td>File Import / Export Options</td>
<td>1 hour</td>
<td>1 hour</td>
</tr>
<tr>
<td>Strength of Link Between Actual Design and Design Model</td>
<td>2 hours</td>
<td>1 hour</td>
</tr>
</tbody>
</table>

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### Solar Shading

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST Notes</th>
<th>IES VE Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>3-4 hours</td>
<td>3-4 hours</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>3-4 hours</td>
<td>Experience</td>
</tr>
<tr>
<td>Quality of Data</td>
<td>3-4 hours</td>
<td>Experience</td>
</tr>
<tr>
<td>Graphical Output</td>
<td>1 hour</td>
<td>1 hour</td>
</tr>
<tr>
<td>File Import / Export Options</td>
<td>1 hour</td>
<td>1 hour</td>
</tr>
<tr>
<td>Integration of Solar Shading with Thermal Analyses</td>
<td>1 hour</td>
<td>1 hour</td>
</tr>
</tbody>
</table>

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### Daylighting

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST Notes</th>
<th>IES VE Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>3-4 hours</td>
<td>3-4 hours</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>3-4 hours</td>
<td>Experience</td>
</tr>
<tr>
<td>Quality of Data</td>
<td>3-4 hours</td>
<td>Experience</td>
</tr>
<tr>
<td>Graphical Output</td>
<td>1 hour</td>
<td>1 hour</td>
</tr>
<tr>
<td>File Import / Export Options</td>
<td>1 hour</td>
<td>1 hour</td>
</tr>
<tr>
<td>Ability to Test a Design's Effect on Daylighting Levels</td>
<td>1 hour</td>
<td>1 hour</td>
</tr>
</tbody>
</table>

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### IES VE

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>Speed</td>
<td>4.1</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>4.0</td>
</tr>
<tr>
<td>Quality of Graphics</td>
<td>4.7</td>
</tr>
<tr>
<td>Graphical Output</td>
<td>4.2</td>
</tr>
<tr>
<td>Total Score</td>
<td>3.7</td>
</tr>
<tr>
<td>Total Score</td>
<td>161</td>
</tr>
</tbody>
</table>

---

### Tools of Design

- **Climate Analysis**
- **Psychrometric Chart**
- **Diagramming Climate**
- **Wind Analysis**
- **Concept Massing Studies**
- **Energy Modeling & Concept Design**
- **Smarter Concepts**
- **Architecture 2030**
- **Integrated Energy Design**
- **Design Process 2.0**
- **Vitruvius Redefined**
- **Design Thinking Evolved**
- **Innovative & Conceptual Design**
- **Energy Modeling & Sustainability**
- **Energy Modeling & Design Development**
- **Iterative Development**
- **Optimizing R-Values**
- **Optimizing Glazing %**
- **Optimizing Daylight %**

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### About the Study

- **A Unique Collaboration**
- **Project Timeline**
- **ENERGY AND ESIP COMPARISON**

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### Why Energy Model?

- **Climate Change**
- **Architecture 2030**
- **Integrated Energy Design**
- **Design Process 2.0**
- **Vitruvius Redefined**
- **Design Thinking Evolved**
- **Tools of Design**
- **Energy Modeling & Sustainability**
- **Energy Modeling & Design Development**
- **Iterative Development**
- **Optimizing R-Values**
- **Optimizing Glazing %**
- **Optimizing Daylight %**

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### Energy Modeling Software Comparison

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<thead>
<tr>
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<th></th>
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<tbody>
<tr>
<td>eQUEST</td>
<td>3.74</td>
<td>4.2</td>
<td>4.5</td>
<td>3.7</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3</td>
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### Climate Analysis

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST</th>
<th>Notes</th>
<th>IES VE</th>
<th>Score</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>0</td>
<td>Not available.</td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>0</td>
<td>Not available.</td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Quality of Data</td>
<td>0</td>
<td>Not available.</td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Graphical Output</td>
<td>0</td>
<td>Not available.</td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>File Import/Export Options</td>
<td>0</td>
<td>Not available.</td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Strength of Link Between Actual Design &amp; Concept Model</td>
<td>2</td>
<td>Model is simplistic. 3D extrusion of AutoCAD. Doesn't feel like the design at all.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Design Model

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST</th>
<th>Notes</th>
<th>IES VE</th>
<th>Score</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>3</td>
<td>Two to four hours to create geometry. Four to eight hours to assign model data.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>4</td>
<td>Modeling is tedious. Importing model data is made easier by external import options.</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality of Data</td>
<td>4</td>
<td>Energy use and HVAC feedback is accurate. Daylighting results not available.</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphical Output</td>
<td>3</td>
<td>Results displayed in simple charts and graphs. No access to 3D views available.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>File Import/Export Options</td>
<td>3</td>
<td>Plots received AutoCAD drawings to create model. Graphical output in simple line drawings.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength of Link Between Actual Design &amp; Concept Model</td>
<td>2</td>
<td>Model is simplistic. 3D extrusion of AutoCAD. Doesn't feel like the design at all.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Base Model

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST</th>
<th>Notes</th>
<th>IES VE</th>
<th>Score</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>5</td>
<td>Model is created automatically.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>5</td>
<td>Model is created automatically.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality of Data</td>
<td>5</td>
<td>The automatically created base model has the same functionality as your design model.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphical Output</td>
<td>3</td>
<td>Model is created with some graphical output for the design model. Simplest charts and graphs.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>File Import/Export Options</td>
<td>1</td>
<td>Base model is created automatically, but the data is severely limited.</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Solar Shading

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST</th>
<th>Notes</th>
<th>IES VE</th>
<th>Score</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>3</td>
<td>Add solar extra two hours to modeling process.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>3</td>
<td>Shading devices must be defined as separate inputs for each opening.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality of Data</td>
<td>5</td>
<td>eQUEST is an accurate modeling program.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphical Output</td>
<td>1</td>
<td>Plots shade effects as a potential energy saving strategy (very limited).</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>File Import/Export Options</td>
<td>1</td>
<td>None. Shading is defined as separate inputs for each opening.</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integration of Solar Shading with Thermal Analysis</td>
<td>5</td>
<td>eQUEST accurately calculates the effects of shading on energy use.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Daylighting

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST</th>
<th>Notes</th>
<th>IES VE</th>
<th>Score</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>3</td>
<td>File separate daylight includes although shading does affect thermal analysis.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>3</td>
<td>File separate daylight includes although shading does affect thermal analysis.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality of Data</td>
<td>1</td>
<td>Daylighting level can not be calculated using shade effects. Energy performance results are calculated for each opening.</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>Graphical Output</td>
<td>1</td>
<td>Plot shade results as a potential energy saving strategy (very limited).</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>File Import/Export Options</td>
<td>1</td>
<td>None. Daylighting analysis is turned on via a check box.</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to Test a Design's Effect on Daylighting Levels</td>
<td>5</td>
<td>eQUEST accurately calculates the effects of shading on energy use.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Thermal Analysis

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST</th>
<th>Notes</th>
<th>IES VE</th>
<th>Score</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>5</td>
<td>Five to thirty minutes depending on complexity of model.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>4</td>
<td>Scheduling an HVAC systems input is helped by a wizard and smart default settings.</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality of Data</td>
<td>5</td>
<td>eQUEST is an accurate energy modeling software for a variety of design scenarios.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphical Output</td>
<td>3</td>
<td>Charts and graphs clearly illustrate impacts of design options and achievable savings.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>File Import/Export Options</td>
<td>3</td>
<td>HVAC systems must be manipulated in IES.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy Compared to Other Acceptable Modeling Programs</td>
<td>5</td>
<td>IES is an accurate energy modeling software for a variety of design scenarios.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Concept Model Studies

<table>
<thead>
<tr>
<th>Requirement</th>
<th>eQUEST</th>
<th>Notes</th>
<th>IES VE</th>
<th>Score</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Required</td>
<td>5</td>
<td>One hour per massing study to model. Two additional hours to analyze.</td>
<td>5</td>
<td></td>
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</tr>
<tr>
<td>Ease of Use</td>
<td>3</td>
<td>Geometry must be traced from AutoCAD plan. Wielded in importing model data.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality of Data</td>
<td>3</td>
<td>Can quickly compare design options by testing at key energy metrics. The design is not able to accurately model the impact of shading accurately.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphical Output</td>
<td>3</td>
<td>Charts and graphs may be imported somewhere limited.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>File Import/Export Options</td>
<td>3</td>
<td>Plots received AutoCAD drawings to create model. Graphical output in simple line drawings.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength of Link Between Actual Design &amp; Concept Model</td>
<td>2</td>
<td>Model is simplistic. 3D extrusion of AutoCAD. Doesn't feel like the design at all.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Category Averages and Total Score

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<thead>
<tr>
<th>Category</th>
<th>Score</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Quality of Data</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Graphical Output</td>
<td>2.3</td>
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</tr>
<tr>
<td>Total Core</td>
<td>11.7</td>
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<td>Energy Modeling Software Comparison</td>
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<tr>
<td>IES VE</td>
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<td>Graphical Output</td>
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<td></td>
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<tr>
<td>Total Core</td>
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<td>3.7</td>
</tr>
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</table>

### Score Notes

- 5: Excellent
- 4: Good
- 3: Average
- 2: Poor
- 1: Very Poor

### Energy Model Comparison

- **CLIMATE CHANGE**
  - **ARCHITECTURE 2030**
  - **INTEGRATED ENERGY DESIGN**
  - **DESIGN PROCESS 2.0**
  - **VITRUVIUS REDEFINED**
  - **DESIGN THINKING EVOLVED**
  - **TOOLS OF DESIGN**
  - **ENERGY MODELING INPUTS**
  - **ENERGY MODELING TIMELINE**
  - **ENERGY MODELING & CONCEPT DESIGN**
  - **SMARTER CONCEPTS**
  - **CLIMATE ANALYSIS**
  - **PSYCHOMETRIC CHART**
  - **DIAGRAMMING CLIMATE**
  - **WIND ANALYSIS**
  - **CONCEPT MASSING STUDIES**
  - **ENERGY MODELING & DESIGN DEVELOPMENT**
  - **ITERATIVE DEVELOPMENT**
  - **OPTIMIZING R-VALUES**
  - **OPTIMIZING GLAZING %**
  - **OPTIMIZING DAYLIGHT**

### Additional Notes

- HVAC systems must be manipulated in eQUEST.
- Charts and graphs clearly illustrate impacts of design options, but aesthetically lacking.
- Scheduling and HVAC systems input is complicated without help from M/E consultant.
- Results displayed in simplistic charts and graphs. No plan overlays or 3D views available.
- Energy use and ROI feedback is accurate. Daylighting studies not available.
- Model is simplistic 3D extrusion of AutoCAD. Doesn't feel like the design at all.
- Must retrace AutoCAD drawings to create model. Graphical output is image file only.
- Results displayed in simplistic charts and graphs. No plan overlays or 3D views available.
- Daylighting levels can be analyzed in plan, section, and perspective renderings.
- Full suite of daylight analysis tools available including the very accurate Radiance engine.
- Shading geometry imported from Sketchup. Graphic output limited to image files.
- Creating geometry in Sketchup allows for strong 3D correlation between idea and model.
While comparing eQuest and IES VE, the research team concluded that one of the most important aspects of an energy modeling software is its ability to create a model that matches the three dimensional intent of the design. The images on the right show the considerable differences between the programs’ approach to modeling.

eQuest creates a model by tracing and extruding masses from an AutoCAD plan. Other geometric information, like pitched roofs and glazing, is controlled by check boxes. The final model resembles an extruded box, modified by spreadsheet-like inputs. Complex sectional characteristics are impossible to capture.

IES VE uses a Sketchup plugin to create its energy models. This allows designers to accurately represent the design intent in their energy models. The 3D model is able to capture complex geometry, important sectional characteristics, and the intent of the design, building confidence that the energy model actually responds to changes in the architecture. This is the number one reason why IES VE was chosen over eQuest as MS&R’s energy modeling software.
CLIMATE CHANGE AND THE IMPACT OF THE BUILT ENVIRONMENT

Climate change. Global warming. Extreme weather. These themes seem to dominate news headlines as humanity’s impact on the planet shifts from scientific theory to a force that can be experienced first hand with increasing frequency. From the destruction of coral reefs to the shrinking of the world’s glaciers, it is clear that our climate is changing. The scientific community is in agreement that humanity is causing the change, and carbon dioxide is our weapon of choice. As we pump CO2 into the atmosphere by burning fossil fuels, it acts as a “greenhouse” gas, trapping the sun’s heat in our atmosphere and leading to a gradual increase in the Earth’s temperature. Scientists predict this will have dire consequences including rising sea levels, the increasing frequency of severe weather, drought, and a massive destruction of ecosystems across the globe. It is time for humanity to act, and the built environment is poised to play a pivotal role in redefining our relationship with climate.

Architecture 2030 explains that the building sector consumes nearly half of all energy produced in the United States. It was also responsible for 46.7% of U.S. CO2 emissions in 2010. To make matters worse, building sector energy consumption and CO2 emissions are projected to rise faster than any other source between now and 2030.

The graph U.S. Energy Consumption by Subdivided Sector shows that the vast majority of energy use attributed to the building sector is used to operate buildings. This includes all the energy needed to heat, cool, and light buildings over their life spans. For an even clearer illustration on how operating buildings impacts energy use, look at the graph U.S. Electricity Consumption By Sector; a full 75% of the electricity used in the U.S. goes into operating buildings.

If architects design buildings that are more energy efficient, we can drastically reduce the energy demands of the planet and slow the pace of global warming. With enough downward pressure, we can even reach carbon neutrality. So what are these targets and what does it take to get there? Architecture 2030 provides a guideline.

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“WE TEND TO RUSH TOWARD THE COMPLEX WHEN TRYING TO SOLVE A DAUNTING PROBLEM, BUT IN THIS CASE, SIMPLICITY WINS. BETTER BUILDINGS, RESPONSIBLE ENERGY USE AND RENEWABLE ENERGY CHOICES ARE ALL WE NEED TO TACKLE BOTH ENERGY INDEPENDENCE AND CLIMATE CHANGE.”
- Edward Mazria, Architect and founder of Architecture 2030

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Architecture 2030 is optimistic about the positive impact the built environment can have on reducing domestic energy use over the next twenty years. It points to the projection that by 2035, approximately 75% of the built environment will be either new or renovated. Architecture 2030 calls for architects to seize this opportunity, challenging them to design each new or renovated building to meet ever increasing energy targets, leading us to carbon neutrality by 2030.

Architecture 2030 developed its energy reduction targets by working backward from the greenhouse gas emissions reductions scientists predicted were necessary to reach by 2050 to avoid catastrophic climate change. In an interview with BLDG BLOG, Ed Mazria explains, “Working backwards from those reductions, and looking at, specifically, the building sector – which is responsible for about half of all emissions – you can see what we need to do today. We need an immediate, 50% reduction in fossil fuel, greenhouse gas-emitting energy in all new building construction. And since we renovate about as much as we build new, we need a 50% reduction in renovation, as well. If you then increase that reduction by 10% every five years – so that by 2030 all new buildings use no greenhouse gas-emitting fossil fuel energy to operate – then you reach a state that’s called carbon neutral. And you get there by 2030. That way we meet the targets that climate scientists have set out for us.”

ARCHITECTURE 2030 - A ROAD MAP TO RECOVERY

Meeting these targets requires the design of more energy efficient buildings, the development of new building technologies and systems, and the implementation of renewable energy sources. Of these categories, it is building design that can have the greatest impact on energy reductions. It is design that will create buildings that are in tune with their natural environments and harvest the local climate to condition their interiors, resulting in a more efficient, and more appealing, built environment.

ARCHITECTURE 2030 - A ROAD MAP TO RECOVERY

“THE MAJOR PART [OF A BUILDING’S ENERGY USE] - 40% - IS DESIGN. EVERY TIME WE DESIGN A BUILDING, WE SET UP ITS ENERGY CONSUMPTION PATTERN AND ITS GREENHOUSE GAS EMISSIONS PATTERN FOR THE NEXT 50-100 YEARS. THAT’S WHY THE BUILDING SECTOR AND THE ARCHITECTURE SECTOR IS SO CRITICAL. IT TAKES A LONG TIME TO TURN OVER”

- Edward Mazria, Architect and founder of Architecture 2030
“AN INTEGRATED DESIGN MIGHT BEGIN WITH THE REDUCTION OF HEAT LOADS IN THE OCCUPIED SPACE THROUGH THE USE OF ENERGY-EFFICIENT LIGHTING FIXTURES AND DAYLIGHTING. THAT MAY MAKE IT POSSIBLE TO REDUCE SUPPLY-AIR FLOW RATES, LEADING TO LESS PRESSURE DROP IN THE AIR-DISTRIBUTION SYSTEM AND ALLOWING FOR SMALLER FANS TO BE INSTALLED. FURTHER, AS A RESULT OF ALL OF THOSE DOWNSTREAM CHANGES, IT MAY ALSO BE POSSIBLE TO SPECIFY A SMALLER COOLING PLANT.”

- Energy Design Resources

INTEGRATED ENERGY DESIGN

Meeting the Architecture 2030 challenge requires rethinking how a project is delivered, bringing together owners, designers, and consultants to work towards creating sustainable and energy efficient buildings. Integrated Energy Design, a process developed by Energy Design Resources, outlines how to accomplish that. Of the process’s six steps, the first three provide the strongest guidance for our Energy Modeling Methodology.

1. Plan for energy efficiency right from the beginning of the design process.

The diagram on the right illustrates that the greatest potential to affect the energy use of a building occurs at the beginning of the design process. As the design continues, decisions are locked into place, making changes difficult. Therefore, it is imperative that planning for energy efficiency is implemented from the start.

2. Identify integrated design strategies that will reduce life-time costs while also improving occupant comfort.

Energy Design Resources gives an example of why integrated design strategies are so effective. "An integrated design might begin with the reduction of heat loads in the occupied space through the use of energy-efficient lighting fixtures and daylighting. That may make it possible to reduce supply-air flow rates, leading to less pressure drop in the air-distribution system and allowing for smaller fans to be installed. Further, as a result of all of those downstream changes, it may also be possible to specify a smaller cooling plant.” This process can result in energy savings, cost savings, and increased occupant comfort.

3. Run whole-system analyses that treat a building as a complete system, taking into account the interactions among all of the building’s systems.

According to Energy Design Resources, “Whole-systems analysis is an evaluative process that treats a building as a series of interacting systems instead of looking at building systems as individual components that function in isolation.” It takes a specialized tool to run a whole-systems analysis, and that tool is energy modeling. In order to deliver more sustainable buildings, we need to redefine our design process, planning for energy efficiency from the start, developing integrated sustainable design strategies, using energy modeling to analyze building performance.
In 27 BC, Vitruvius wrote a definition of architecture that is still relevant. He wrote that architecture must exhibit three qualities - firmness, commodity, and delight. Firmness is concerned with structure and construction systems; commodity is related to function, program, and budget; and delight describes the beauty, aesthetics, and emotional impact of a building.

A cornerstone of Energy Modeling Methodology is that building performance is viewed as an integral part of architecture. Energy modeling doesn’t reside outside of the design process, it is used to enhance architecture’s core qualities.

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Designing for energy performance is a natural extension of the Vitruvian Triangle. The emotional impact of a building is enhanced by optimizing its use of natural daylight, architecture’s environmental impact should be considered just as its function, program, and budget are, and energy performance directly effects a building’s structure and materiality.

Integrated energy modeling into the design process enhances a design team’s ability to understand the issues that affect a project, fully explore the impact of their design on architecture’s core qualities, and deliver a richer, more sustainable final project.

AN ANCIENT ROMAN ARCHITECT NAMED VITRUVIUS WROTE THAT A BUILDING MUST BE CONSIDERED ‘WITH REFERENCE TO FUNCTION, STRUCTURE, AND BEAUTY’: ‘…THINK OF THE VITRUVIAN FACTORS AS THE LEGS OF A TRIPPOD CALLED ARCHITECTURE. NONE CAN STAND ALONE; EACH IS DEPENDENT UPON THE OTHER TWO TO FORM THE WORK OF ARCHITECTURE!’

- James O’Gorman, from ABC of Architecture.

VITRUVIUS REDEFINED

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Before we can push the design process forward, we must first understand the thought process that powers it. Thomas Fisher, Dean of the University of Minnesota’s College of Design, diagrammed how design thinking was distinct from problem solving in a 2011 lecture to his Principles of Design Theory class.

Deductive and inductive reasoning are two types of problem solving. Throughout their academic lives, students are taught the value of linear thought processes, training them to search for one correct solution to a given problem. Deductive reasoning is more commonly known as the scientific method. It involves making a hypothesis, running experiments to test the hypothesis, and evaluating the resulting evidence to determine if it is correct. Inductive reasoning works in reverse; a person makes an array of observations, constructs generalizations that connect the observations, and arrives at a conclusion when a generalized statement can be used to explain the entire set of observations. Although these processes are useful, it is important to realize that they will only lead to solutions that lay in the original field of inquiry. These processes explain existing phenomena, they do not create new phenomena.

Creativity is powered by design thinking, a decidedly non-linear process. Design thinking involves addressing a problem by looking at a multitude of issues that define it and using them to generate and explore new avenues of possibility. Some discoveries will push the process forward while others will cause the designer to take a step back, revisiting prior assumptions. Still others will redefine the original problem all together, generating a unique trajectory of their own. It is precisely design thinking’s chaotic, non-linear nature that enables it to create in innovative discoveries. Architecture is very much a product of design thinking.

1. Tom Fisher Lecture, September 2011, University of Minnesota, College of Design
While non-linear design thinking powers creative innovation, architects must also inhabit the linear world of the design process to deliver a project. Energy modeling exists in this overlap, acting as a catalyst to help architects make informed decisions at each stage of development, leading to projects that can meet the Architecture 2030 challenge.

The creative process by its very nature pulls inspiration from a variety of sources, ensuring that the final result of a design, as well as the criteria used to judge it, will be unique. It is usually the architect’s own narrative that is used to test the merit of early conceptual development.

As a project progresses, the design must meet a variety of other demands, from structural loads to fire safety requirements. Energy performance should be thought of in the same way; the conceptual intent of a design must be balanced against given performance standards to improve the quality of the project. Energy modeling should be used at each stage of design to ensure energy performance and sustainability are addressed throughout the process.

Over time, this enhanced design process will result in accumulated sustainable expertise within the office. Energy modeling reacts to the specifics of a project, but the sustainable strategies it points to can be abstracted and digested as new and improved rules of thumb. Future designs will start from an ever-more informed position, improving the sustainability and energy efficiency of each successive building.
Architectural offices must accept that there is no single piece of software that consolidates all of the functionality necessary to create and execute a design. Rather, firms must work with a collection of tools, developing a workflow that matches the character of the office.

The diagram on the right maps the software tools and workflow patterns MS&R uses during design studies. The studies themselves are the building block of the design process. Each study uses the project's current state as input, explores the design, and creates output that can inform the project and spark the next study.

MS&R uses Revit as its primary modeling software and treats Rhino and Sketchup as design models. Design models can be thought of as digital sketches; the software enables quick explorations of ideas. However, much like a sketch can’t inform the project until it leaves the designer’s desk and is shared with the team, the results of design models don’t become fully interwoven into the project until they are deposited into Revit.

Energy modeling software enables MS&R to analyze the performance of design studies. IES VE uses Sketchup to create the 3D geometry for the energy model. It is not possible to import Rhino geometry directly into IES VE, however Sketchup can be used to translate Rhino geometry and then export it to IES VE.

MS&R’s software and workflow fosters collaboration within a design team while still allowing for individual creative freedom.
Design Phases and Software Implementation

MS&R uses a variety of software throughout the design process. Design Phases and Software Implementation illustrates when and how each software is used. The diagram also shows the weighted emphasis of the software at each stage of design. Rhino, Grasshopper, and Sketchup are used heavily in the beginning of the process, leveraging the ability of the software to quickly model and explore multiple concepts. Revit is integrated throughout, building up the digital model as the design progresses. Once the Construction Documents phase is reached, the majority of digital modeling occurs within the detailed Revit model.

Energy modeling is used during every phase, but it has the greatest impact on design at the beginning of the process. It is used during Concept and Schematic Design to analyze the climate and test the performance of early design studies, helping inform and improve design decisions.

Energy modeling has long been thought of as too complicated and specialized to be utilized in the design process effectively. Viewing it alongside other design software puts it in perspective; it is simply another tool that helps address a specific set of decisions that must be made during the design process. Effective implementation of energy modeling allows design teams to address a wider scope of issues, improving design decisions and ultimately the performance of the building itself.

<table>
<thead>
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<th>DESIGN PHASES AND TECHNOLOGY</th>
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The inputs that go into an energy model are common across all software packages. The modeling software combines climate data with information about the building form, construction types, occupancy types, occupancy loads, building systems, and building system schedules to analyze the energy use of the building.

These inputs can be broken into categories by looking at whether the architect or engineer is responsible for them during the design process. Climate is a given condition directly related to the project’s site. Building form, construction types, and occupancy types are controlled by the architect’s programming and design. Occupancy loads, building systems, and building systems schedules are in the engineer’s domain.

An energy model can be represented as a stacked set of inputs. When each input is defined with project specific information, the model will be at its most accurate, as shown in **Fully Defined Energy Model**.

If you don’t input project specific information into a category, the model will instead rely on pre loaded default settings. In this state, an energy model will still perform analyses, it just won’t be as accurate as a model that has been fully defined by project specific information. As each input becomes project-specific, the results become more accurate.
CURRENT ENERGY MODELING TIMELINE

Currently, energy modeling, if it happens at all, occurs at the end of design development. Engineering consultants create an energy model by defining each input based on the finalized design. Because the design is actually a composite of decisions made during the duration of the design process, the engineers in effect collapse a tree of decisions made over time and turn them into energy modeling inputs.

The results of this type of energy model are an accurate prediction of how the building will perform, but they are an ineffective design tool. The current process places energy modeling too late in the design process, turning it into more of an autopsy of performance rather than a generative tool to inform the design.

If we want energy modeling to be used to facilitate design decisions, it must be implemented at the start of a project and used throughout its duration. The following pages diagram what this process looks like.
ENERGY MODELING TIMELINE - PHASE I

Energy Modeling Timeline - Proposed Phase I shows how to implement energy modeling at the earliest stages of design. At the beginning of a project, the design team starts an energy model by defining Climate Data and Occupancy Types with project-specific information. When the team begins exploring massing and materials, they input information about Building Form and Construction Types into the model for different design options, running comparative tests between them. At this stage, the software’s output is accurate enough to evaluate the relative performance of the options.

Think of relative performance testing like a concept sketch. Concept sketches allow designers to evaluate how well different designs conform to the site and embody the concept, but are understood to not initially tackle issues like ADA accessibility and fire egress. Relative performance testing in energy modeling is similar; it informs the designers how different options perform against one another even though the results are not 100% accurate.

If engineers and architects share an energy model, it can be passed from architects to engineers as design development begins. Energy Modeling Timeline - Proposed Phase I realigns the creation of an energy model more closely with the way decisions are made during the design process. Phase II explores the potential of sharing an energy model during design development.
ENERGY MODELING TIMELINE - PHASE II

Energy Modeling Timeline - Phase II illustrates the power of sharing an energy model between architects and engineers during design development. As the design progresses and the model’s default settings are replaced by project-specific information, the results become more accurate. In Phase II, engineers and architects collaborate on the same energy model, using their combined knowledge to fully define all of its inputs and ensure accurate results.

After schematic design, architects hand the model to the engineers who fill in its inputs for occupancy loads, building systems, and building systems schedules. If the engineers hand the model back to the architects, both parties now have an energy model fully defined with project-specific information.

Equipped with a fully defined model, architects can now fine tune a project during Design Development by using the energy model to run iterative tests. Not only can the results be used to test how different options for building form and construction types perform against one another, the results are now an accurate projection of the building’s energy use.

Both relative performance comparisons and accurate performance projections are useful. By sharing an energy model, architects and engineers can start with relative comparisons early in the design process and work towards accurate projections as the design is developed. This will help the team integrate building performance into the entire design process, keeping projects on track to reach Architecture 2030’s performance goals.
Concept design provides an ideal opportunity for design teams to set aggressive energy goals and leverage energy modeling to steer projects towards them. During this phase, designers have a great deal of flexibility in exploring strategies to minimize energy use and maximize building performance. At the same time, the project schedule pressures the design team to be efficient in their explorations and design recommendations. Integrating energy modeling along with a clearly defined process will make the most out of this opportunity by helping designers make informed decisions.

The goal of the Energy Modeling Methodology during concept design is to help inform design decisions. To achieve this, it must be:

- Easy to use
- Able to efficiently compare design options
- Produce graphical output

A clearly defined process will help the design team utilize energy modeling efficiently. The process should follow these principles chronologically:

- Define energy goals
- Understand and diagram climate
- Identify possible passive and energy efficient design strategies
- Use energy modeling to compare design options
- Interpret results holistically
Sustainable and energy efficient buildings come in a variety of shapes and sizes but they share one thing in common - they respond to their local climates. Unfortunately, this is the exception rather than the rule for today’s built environment. Beginning with the Lever House in 1952, buildings became sealed boxes, separating themselves from climactic considerations and instead relying on cheap energy from fossil fuels to run HVAC systems that conditioned their interiors.

Architects must reverse this trend using a design process that embraces site sensitivity and uses passive strategies to harness local climactic conditions. This process starts with a thorough understanding of climate before design begins.

Two excellent tools that help a design team understand their site’s climate and its impact on design are IES VE and Climate Consultant. The following pages give an overview of the tools.
CLIMATE ANALYSIS - IES VE

Climate Metrics, an automated report within the IES VE energy modeling software, gives an excellent overview of climatic conditions. The report consists of three columns, one containing climate graphs, the second containing critical climate metrics, and the third serving as an explanation of how to read and interpret the first two.

The center graph in the first column is a strong starting point for analyzing climate. It quickly illustrates the months that have cold stress (require cooling), heat stress (require heating), or are comfortable (require little to no conditioning). It also shows when peak temperatures and rainfall occurs, and what months contain diurnal swings of greater than 9 degrees. In a snapshot, designers can start to understand the climate. If there are more heating stress months than cooling, the design should place emphasis on minimizing heating loads. If diurnal swings of greater than 9 degrees occur in the summer, there may be potential to use night flushing as a passive cooling strategy. And if these strategies didn’t immediately pop in your head, no worry; the explanatory column on the right points them out for you.

The information in the middle column has been paired down to the most important climate metrics. Reading and digesting it will give design teams a strong initial understanding of climate. For a more in-depth study, turn to Climate Consultant.
Climate Consultant is a free tool developed by UCLA. It is an excellent source for graphically representing climactic information.

The tool is used by loading a climate file and clicking through the various graphic representations of the data. Everything from monthly temperature range to wind roses are covered.

Walking through the Climate Consultant is an excellent way to study certain aspects of climate in detail. During the development of Energy Modeling Methodology, I was asked to research the climate in Tulsa for a library MS&R was working on. The design team was interested in how to cool a garden space next to the library using passive strategies. By looking at the graph Temperature Range, we quickly saw that the average temperature in July was 85 degrees. We also learned from the Dry Bulb x Relative Humidity graph that the relative humidity hovered around 66% in July. This combination of heat and humidity meant that passive cooling strategies relying on evapotranspiration wouldn’t be that effective. However, the wind patterns in the area showed that the summer breezes came directly from the south. This positioned them to flow right through the project’s outdoor garden. After learning this, the design team focused its initial passive cooling strategies around shading and harnessing the wind to passively condition the outdoor garden.

1. Climate Consultant, www.energy-design-tools.aud.ucla.edu
The Psychrometric Chart is part of the Climate Consultant software. www.energy-design-tools.ucla.edu

After a design team becomes familiar with climate, the next step is to determine how it might affect design. Luckily, a tool has been developed that clearly illustrates the effectiveness of a variety of passive design strategies in a given climate - the psychrometric chart.1

Psychrometric charts work by setting up a system of axes capable of graphing dry-bulb temperature, humidity ratio, relative humidity, and wet-bulb temperature. Climate data points are then graphed on the chart, usually in the form of hourly data for the entire year. Once these points are graphed, you can get a quick visual overview of the climate by looking at the pattern of dots.

A comfort zone is then imposed on the chart. This shows the ranges of temperature and humidity that people are comfortable in. Dots that land inside this area don’t need any heating, cooling, or humidity alteration to maintain human comfort. Dots that sit outside of it show the hours in the year where the climate does need conditioning to reach comfort levels.

Finally, a series of passive design strategies can be selected in the upper left hand corner. The user clicks on a strategy and an associated area is graphed on the psychrometric chart showing the climactic conditions it can effectively temper. One a strategy is active, the chart also calculates the percentage of yearly hours it effectively conditions.

Users can quickly cycle through the passive strategies, getting visual feedback on how effective each strategy is in their specific climate.

1. The Psychrometric Chart is part of the Climate Consultant software. www.energy-design-tools.ucla.edu

PSYCHROMETRIC CHART SHOWING NATURAL VENTILATION AND INTERNAL HEAT GAIN

PSYCHROMETRIC CHART SHOWING HUMAN COMFORT ZONE
The power of diagrams lies in their ability to bring phenomena into the visual realm, facilitating understanding and communication. In architecture, where practitioners are inherently visual people, diagramming a phenomena enables it to be part of the design conversation. Climate is not exempt from this rule; if climactic considerations are to be interwoven into the design process, they must be diagrammed throughout a project’s development.

After researching climate, designers should immediately begin diagramming its most important aspects alongside a project’s other generative forces. The graphic on the right was developed to facilitate MS&R’s understanding of the Tulsa climate and how it affected the design of a library they were working on. By simply overlaying climatic information like wind direction and magnitude and the sun path over an aerial view, they now become generative forces for the design. Can the design harness the summer winds and block the winter winds? Will the project be shaded by nearby buildings?

Adding key climate metrics to the graphic helps the design team gain a more nuanced understanding of how climate might affect the design. Will the high daily global radiation place an extreme cooling load on unshaded areas of the site? Does the high relative humidity make natural ventilation an ineffective strategy?

Finally, writing a short climate overview acts like a text-based version of a diagram; it quickly brings together salient information into a format that facilitates understanding and communication.
A project’s diagrams should continue to address climate throughout the design process. After completing the initial climate analysis for Tulsa, I explored passive and active strategies for conditioning the project’s outdoor garden space. First I created a graphic that combined the existing spatial constraints of the site with the climatic conditions that affected the design. Important climate metrics were placed on the sheet, ensuring they would be referenced during the process.

Wind flow and annual rainfall stood out as potential drivers of passive design, and they were added to the diagram. The resulting design proposal then looked at the ways water could be passively collected, stored, cooled, and then used to condition the garden and the interior of the library. A combination of evapotranspiration and harnessing the wind patterns might help further condition the air in the garden, and this precooled air could then be drawn through an an air / ground heat exchanger and used to condition the library’s interior.
IES VE was used to conduct a wind flow analysis for MS&R’s Tulsa Central Library project. After earlier diagrams identified the possibility of using the site’s wind flow patterns to passively cool the project’s garden space, the design team wanted to explore the issue in more detail using energy modeling.

MicroFlo is a computational fluid dynamics application that is a part of IES VE. It can be used to study internal or external air flow. For this study, the design team was interested in how a design option would affect wind flow through the garden area between the library and parking ramp. The project’s garden, library, parking ramp, and surrounding buildings were modeled as simple masses. The team then referenced the initial climate studies to determine the average summer wind speed and direction. The values, 16 feet per second blowing from South to North, were input in MicroFlo. The software then computed wind flow patterns through the site.

The images show the results of the analysis. They each depict a sectional slice of the modeled wind field that cuts through the garden. As the scale shows, red areas represent wind speeds of 16 feet per second and dark blue areas represent zones with speeds near 0 feet per second.

The design option explored in the lower image interrupts wind flow at the garden’s surface but still allows air to circulate above. The design team used this information to inform the next round of design explorations.

1. IESVE MicroFlo User Guide. www.iesve.com/content/downloadasset_2287
Massing studies are a cornerstone of concept design. Diagrams, hand sketches, and digital and physical models help architects visualize, test, and refine early massing concepts. Energy modeling can add another layer of analysis to the mix, allowing the design team to consider a massing option’s impact on energy performance as well.

Using energy modeling to test massing concepts ensures that issue of energy efficiency and sustainability will shape the design from its earliest stages. Because the design teams have so much creative freedom at the start of a project, feedback from early energy modeling can put a design on track to meet aggressive performance goals. Unfortunately, this inherent strength is also the process’s greatest challenge; because there are so many initial variables, it can be difficult to compare and analyze the performance of divergent concepts against one another. However, if design teams adopt a process that starts by clearly defining goals and ends with a wholistic comparison of design options across a wide range of selection criteria, the methodology can overcome this challenge and help inform those crucial initial design decisions.

CONCEPTUAL MASSING STUDIES COMPARISON

1. DEFINE THE GOAL
   - What questions are you trying to answer?
   - What variables are you testing?

2. CREATE SELECTION CRITERIA
   - Design decisions are complicated with a multitude of influences. Clear selection criteria facilitates decision making
   - Use existing standards as selection criteria when possible.

3. BUILD AN ENERGY MODEL
   - Simplify the model.
   - Model only the detail necessary to facilitate decision making.

4. RUN ANALYSES
   - What analyses are necessary to shape your decision?
   - What output is required to match your selection criteria?
   - Are there additional analyses that can give you a more holistic view of performance?

5. INTERPRET RESULTS HOLISTICALLY
   - Always think holistically. Sustainability is not an end goal, it is part of good design.
   - Balance energy modeling results with other important design aspects when making design decisions.
Lake Itasca Biological Research Station, a MS&R project targeting net-zero energy use, was used as the platform to develop much of the Energy Modeling Methodology. When research began, the project had already completed Schematic Design and was awaiting the start of Design Development. This allowed the research team freedom to focus on process development rather than project deliverables because the work was conducted outside of the standard fee and scheduling pressures of a project. This specific portion of the methodology, Concept Massing Studies, revisited early concept studies as the basis of comparison. Although these studies were conducted well after initial design decisions had been made, the process that emerged will be implemented on future MS&R projects to steer concept design.

An early challenge for the design team was to choose a massing option that not only responded to the project’s design drivers but also put it on track to achieve its net-zero energy goal. In response, I created a process that combined energy modeling with other selection criteria in comprehensively evaluating three different massing schemes. The first step in the comparison was defining its goal. The goal was defined as:

“Comprehensively compare massing options across selection criteria that integrating the project’s main design drivers with energy performance.”
Using energy modeling to help in the comparison of conceptual massing options is a powerful tool that is inherently difficult to use; because there are so many initial variables at play, it is a challenge to compare analysis results between massing options. However, by developing clear selection criteria, the design team can facilitate massing option comparisons that will help steer the project in a successful direction.

MS&R always strives to work with the client to clearly define a project’s goals at the outset of design. These goals become the benchmark of the project, acting as both a generative force and a set of criteria to judge design decisions against.

When creating selection criteria to facilitate the comparison of concept massing options, the research team began with the project’s goals. They were split into categories, Economic, Social, Cultural, and Environmental. The last category, Environmental, already contained aggressive performance standards that could be analyzed by energy modeling. The first three, while outside the domain of energy modeling, are integral to the project’s success. Including the entire lists ensures that massing options are compared in a holistic manner.

CREATE SELECTION CRITERIA

ECONOMIC
- Efficient to operate
- On budget
- Functional

SOCIAL
- Sensitive to historic fabric
- Building will be the visitor arrival point, meeting place, and social center
- Interior and exterior public spaces

CULTURAL
- Contemporary building that will not be confused with original historic buildings of the field station
- Embody the “field station” experience by enhancing outdoor activities and nature appreciation
- Posses a compelling identity

ENVIRONMENTAL
- Approach “zero net energy” within the limits of the budget
- Use natural light to illuminate interior during operating hours
- Utilize passive design strategies and make them an experiential and educational part of the building

Balance the Economic, Social, and Environmental impacts of various massing options.
USE EXISTING STANDARDS FOR SELECTION CRITERIA

While outlining selection criteria for the Itasca concept massing comparisons, the research team searched for existing standards that could be used to augment the list. The environmental category called for the design to use natural light to illuminate the interior during operating hours. IESNA standards exist that govern the lighting levels in various programmatic spaces. The research team adapted them to the project’s program and used them as a benchmark to test natural lighting performance when comparing massing options.

IESNA lists nine categories that cover a variety of programs in its lighting standards. Attached to each are a range of illuminance values required by the categories. The research team listed the various programs the Itasca project contained and, consulting the IESNA standards, chose the illuminance levels that matched. The selection criteria called for the design to use natural light to illuminate the interiors during operating hours; this chart contained the lighting levels required to meet this goal. And energy modeling analyses were later used to test if the concept massing options could hit these targets.

CREATE SELECTION CRITERIA

Balance the Economic, Social, and Environmental impacts of various massing options

ECONOMIC
SOCIAL
CULTURAL
ENVIRONMENTAL

- Approach “zero net energy” within the limits of the budget
- Use natural light to illuminate interior during operating hours
- Utilize passive design strategies and make them an experiential and educational part of the building

DESIGN PERFORMANCE SELECTION CRITERIA FOR THE ITASCA BIOLOGICAL RESEARCH STATION

ILLUMINANCE CATEGORIES AND ILLUMINANCE VALUES FOR GENERIC TYPES OF ACTIVITIES IN INTERIORS

<table>
<thead>
<tr>
<th>Type of Activity</th>
<th>Illuminance Category</th>
<th>Ranges of Illuminance</th>
<th>Reference Work-Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public spaces with dark surroundings</td>
<td>A</td>
<td>20-30-50</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Simple orientation for short temporary visits</td>
<td>B</td>
<td>50-75-100</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Working spaces where visual tasks are only occasionally performed</td>
<td>C</td>
<td>100-150-200</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Performance of visual tasks of high contrast or large size</td>
<td>D</td>
<td>200-300-500</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Performance of visual tasks of medium contrast or small size</td>
<td>E</td>
<td>500-750-1000</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Performance of visual tasks of low contrast or very small size</td>
<td>F</td>
<td>1000-1500-2000</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Performance of visual tasks of low contrast or very small size over a prolonged period</td>
<td>G</td>
<td>2000-3000-5000</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Performance of very prolonged and exacting visual tasks</td>
<td>H</td>
<td>5000-7500-1000</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Performance of very special visual tasks of extremely low contrast and small size</td>
<td>I</td>
<td>10000-15000-20000</td>
<td>Foot Candles</td>
</tr>
</tbody>
</table>

ITASCA DAYLIGHTING TARGETS

<table>
<thead>
<tr>
<th>Itasca Programmatic Spaces</th>
<th>Illuminance Category</th>
<th>Ranges of Illuminance</th>
<th>Reference Work-Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Area</td>
<td>E</td>
<td>500-750-1000</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Office Area</td>
<td>D</td>
<td>200-300-500</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Auditorium</td>
<td>D</td>
<td>200-300-500</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Mechanical</td>
<td>D</td>
<td>200-300-500</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Lobby</td>
<td>B</td>
<td>50-75-100</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Circulation</td>
<td>B</td>
<td>50-75-100</td>
<td>Foot Candles</td>
</tr>
<tr>
<td>Rest Rooms</td>
<td>B</td>
<td>50-75-100</td>
<td>Foot Candles</td>
</tr>
</tbody>
</table>

1. IESNA Illumination guidelines are published by IESNA. Pacific Northwest National Laboratory republished them on their website: www.wbdg.org/pdfs/usace_lightinglevels.pdf
Building an Energy Model

Energy modeling is used to analyze and compare the performative aspects of massing options. When creating the energy model, it is important to simplify it as much as possible. At this early stage of design, it is important for an energy model to be quick to make and to be able to provide enough information to facilitate a relative comparison. These energy models don’t have to accurately predict the building’s energy use down to the nearest kBTU/sf. Instead they need to contain only the detail necessary to differentiate them from one another and capture each concept’s unique features that may affect energy use.

The building’s geometry should be simplified. Any rooms that are similar should be grouped together into a single zone. The images on the right show an early concept plan for Itasca. The second image illustrates how the energy model combines multiple offices into a single zone as well as combining the lab spaces and their support areas. This speeds up the modeling process considerably while still keeping enough definition to provide results accurate enough to facilitate a relative comparison.

Because IES VE uses a Sketchup plugin to create its energy models, going from concept sketch to three dimensional energy model is quick and easy. The images on the right start by showing a concept drawing that has been imported into Sketchup. Because the most important differences were the sectional characteristics and glazing placement between the massing options, these were captured in detail. Again, using Sketchup makes modeling this detail very easy.

When creating an energy model in Sketchup, do not model wall thickness. Energy models deal in zones, looking at the space between defining elements, not at the elements themselves. Define the geometry with simple planes.1

After the sketchup model is complete, the IES Plugin automates the process that converts it into an energy model. The plugin searches the model for enclosed areas and turns them into zones that can be read by IES VE. Finally, it exports the converted model into IES VE where the full suite of analyses can be run on it.

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RUNNING ANALYSES

Once an energy model is created, design teams need to choose analyses that will provide them with the information necessary to make an informed decision. For the Itasca project, our selection criteria was broken into four categories: economic, social, cultural, and environmental. Energy modeling analyses can help test the performance of the concept massing options in the environmental category.

The environmental category of the selection criteria called for a building that approaches zero net energy, uses natural light, and utilizes passive design strategies. The first two criteria, energy use and natural lighting, can be easily analyzed by an energy model. It is much more difficult and time consuming to analyze passive design strategies with an energy model, so the design team instead relied on climate research and the psychrometric chart to determine what passive strategies might be effective.

A massing concept’s energy use can be determined by running a thermal analysis with IES VE ApacheSim. Remember that the performance comparisons between massing options will be relative; define the building geometry and make quick assumptions about the rest of the energy modeling inputs. When running a thermal analysis, focus on heating and cooling loads instead of energy use, as building systems, an unknown at this point in the process, have little effect on them.

Daylight analyses use IES VE Flucs DL. Run tests for the winter and summer solstice. Then measure and graph lighting levels in foot candles to enable comparisons with the lighting selection criteria.

1. IES VE ApacheSim User Guide. www.iesve.com/content/downloadasset_2883
**INTERPRETING RESULTS**

The final steps in comparing conceptual massing options is compiling the analyses, interpreting the results, and making a decision. The most important thing to remember is to think holistically.

The graphic on the right brings together the four massing options, the energy modeling results, and the original selection criteria. Architecture must respond to a wide range of factors; combining all of this information helps ensure that each concept is evaluated against the full range of selection criteria.

To facilitate the decision making process, the concepts can be scored for each selection criteria. Design teams can also weight the scores if certain aspects of the project are deemed more critical than others.

After scoring the concept options, the design team elected to continue in the direction of Concept 4. Although it had the highest energy use with 79 kBtu/sf, it also contained a much higher glazing percentage than the rest of the models. The concept outperformed the rest in daylighting and was the only one to achieve the IESNA lightning benchmarks. And the unique section, with skylights on the south streaming into a sun corridor and then through a translucent panel and into the lab, received high marks for using passive design strategies as experiential elements.

If the concept massing comparison wasn’t done holistically, this option may have been tossed out for its higher energy use. But, after looking at the full range of design drivers, it was decided to be the best direction for the project.

**INTERPRET RESULTS HOLISTICALLY**
Balance energy modeling results with other important design aspects when making design decisions.
Energy modeling is a perfect match for the design development phase. During design development, large-scale decisions have been made, a concept has been locked in, and the project team spends the majority of their time fine tuning the design. Energy modeling thrives in this environment, leveraging its strength as an analytical tool that is most effective when studying isolated variables. Designers can use energy modeling to help dial in a range of design development decisions using iterative analyses.

An iterative analysis takes one variable, be it the R value of a wall, the building’s glazing percentage, or the geometry or a room, testing baseline performance against a series of options that all slightly modify it. By using iterative analyses, the design team can optimize conditions. In practice, this usually involves using energy modeling to find a range of optimized conditions and setting them as bracketed targets for the design to hit.

**PROCESS GOAL**
Aid designers in fine tuning a design

**GUIDING PRINCIPLES**
Easy to use
Able to efficiently compare design options
Produce graphical output

**METHODOLOGY**
Create a baseline energy model of the schematic design
Identify key aspects of the design to fine tune
Use iterative analysis to bracket optimized conditions
Interpret results holistically
OPTIMIZING R-VALUES

As buildings strive to reach higher levels of energy efficiency, the quality of their envelopes becomes very important. Having a well insulated, well designed, and well constructed envelope is critical to the performance of a design. So just how much insulation is necessary? Energy modeling can help answer this perennial question.

R-value is a measurement of thermal resistance used to describe the performance of building materials. It is expressed as the thickness of the material divided by its thermal conductivity. Materials with higher insulating capacities have a higher R-value. The R-value for an assembly is calculated by adding the R-values of its component parts together. U-value, used to describe the thermal resistance of windows, is simply the reciprocal of R-value.

Energy modeling and iterative analysis can help design teams dial in optimized target R-values for a building’s envelope.

As a target, the values help guide the design while still allowing for the flexibility necessary to address design decisions holistically. While iterative analysis will provide a range of optimized R-values, it is still up to the design team to factor in the cost, durability, constructability, sustainability, and aesthetic and conceptual impact of designing the envelope to achieve the recommended values.
**OPTIMIZING R-VALUES**

The design team for MS&R’s Itasca Biological Research Center wanted to determine target values for effective levels of insulation in the project’s envelope. The process began by creating a base energy model, setting the envelope’s R-values to code-minimum levels. The performance of this base condition was analyzed using IES VE ApacheSim and graphed as the design’s total annual heating and cooling load.1

Each assembly was then studied independently using iterative analysis. With the rest of the building remaining at code-minimum levels, each successive iteration would raise the R-value of the assembly being tested by 5 and model its impact on heating and cooling loads. Eleven iterations were completed for each assembly.

The results all show that heating and cooling loads are reduced when the assembly’s R-value is increased. However, by studying the slope of each graph, the design team could see where the performance benefits of additional R value began to plate out. When the cost of increasing an assembly’s R-value is factored in, it became clear that these changes in slope signaled the point where increased insulation no longer carried a strong return on investment. These target values were highlighted in yellow. The lighter shade of yellow indicated increased R-values that, while not returning a large performance benefit, might still be necessary to achieve the project’s net-zero energy targets. The orange line marks where the R-values were previously set during schematic design.

The top row of graphs also illustrates the relative performance benefits of addressing one assembly against another. The graphs show that increasing the window R-value

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1. IES VE ApacheSim User Guide: [http://www.iesve.com/content/downloadasset_2883](http://www.iesve.com/content/downloadasset_2883)
OPTIMIZING GLAZING PERCENTAGE

Glazing percentage has a strong impact on a project’s energy use and daylighting potential. It is important to balance these effects when using energy modeling to optimize them.

The study on the right was used to optimize the glazing percentage on Itasca’s south facing sun corridor. Daylighting targets were developed before beginning the analysis. Because the project is pursuing LEED certification, the design team used LEED Credit 8.1 - Daylighting and an associated Innovation in Design credit to serve as the target. The standard called for 95% of a design’s regularly occupied spaces to achieve daylighting levels between 25 and 500 foot candles measured at 9:00 am and 3:00 pm on September 21st.

IES VE includes a LEED Credit 8.1 navigator that analyzes the design for credit compliance. I simply modeled the sun corridor with a variety of glazing percentages in IES VE, ran the navigator, and interpreted the results. The top image shows the graphical output from the IES VE analysis. It marks areas of the design that comply with the standard in green. It also reports the percentage of the design that complies. This allowed me to quickly hone in on glazing percentages and patterns that achieved the standard.

After running a series of iterative analyses, I found the minimum glazing percentage that still achieved the daylighting targets. Thermal analysis was carried out by engineering consultants, revealing that the minimum condition actually didn’t out perform the original heavily glazed design due to a balance between passive heating gains and lowered heat losses. Because of this, the design team felt free to maximize the glazing to capture the unique site views of Lake Itasca.
OPTIMIZING DAYLIGHT

Daylighting can be optimized by analyzing glazing percentage as well as glazing design. Intelligent sizing and placement of glazing will facilitate daylighting. The studies shown on this page were completed to optimize glazing in the Itasca Biological Research Center's lab spaces. Once again, an iterative approach to energy modeling was used.

Because the study was focused solely on the labs, I created a new energy model of a single lab space and an adjacent section of sun corridor. The sun corridor was included because the labs are designed to pull daylight from the sun corridor. Like the glazing percentage optimizations shown on the previous page, these studies used LEED Credit 8.1 - Daylighting as the target and the IES VE navigator to test for compliance.

What is unique about the challenge of studying the placement of glazing is that there are unlimited possibilities; it would be impossible to methodically test all of the possible permutations in search of an optimal design. Instead, designers must analyze results for trends, leading them towards designs that meet the criteria.

The first set of analyses studies the effect of moving a north-facing skylight up. The results indicated that this brought more daylight into the interior. The second set of studies builds off this and shows the minimum glazing size and placement of three design options that all achieve the target daylighting levels.
OPTIMIZING DAYLIGHT

The final step in the daylight optimization studies was to test the resulting geometries holistically. After finding two glazing options for the lab space that achieved the daylighting targets, they were diagrammed to test their ability to facilitate the project’s other goals. In a sense, this brought the process full circle, combining a detailed daylighting analysis with the original climate diagrams to help the team make an informed design decision. Both options lent themselves well to harnessing the site’s wind flow patterns, bringing in the summer breezes through low windows in the south facade and allowing them to vent out of the operable skylight. However, Lab Section 3 provided additional shading for the skylights from the summer sun, added more south facing roof surface area for mounting PV panels, and furthered some of the project’s original aesthetic intentions.

By using a combination of analysis techniques and always striving to present results graphically and in a holistic manner, the design team was able to make well informed decisions throughout the process. This kept the project on track to be successful in not only meeting energy performance goals, but also in achieving excellence in the other areas of architecture described by Vitruvius - firmness, commodity, and ultimately, delight.