Governor's Energy Office

Prepared for: Colorado Governor's Energy Office

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ENERGY MODELING: A GUIDE FOR THE BUILDING PROFESSIONAL

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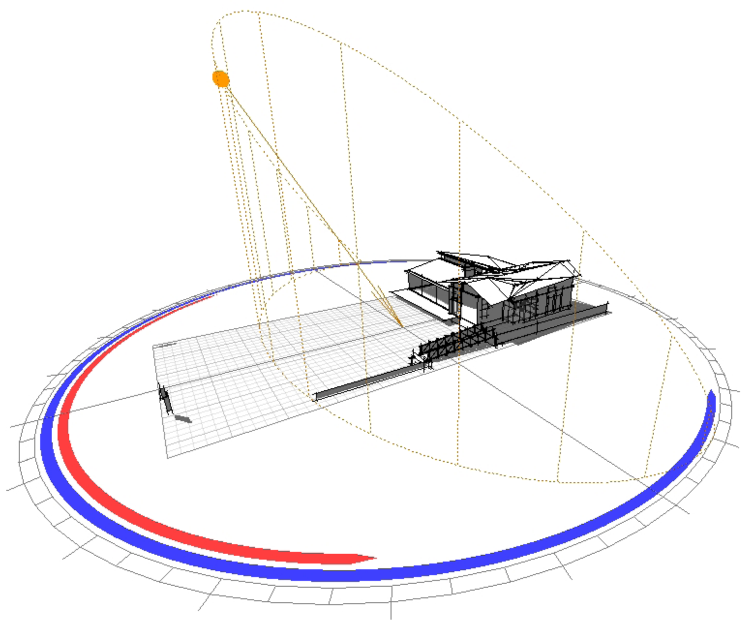
TABLE OF CONTENTS

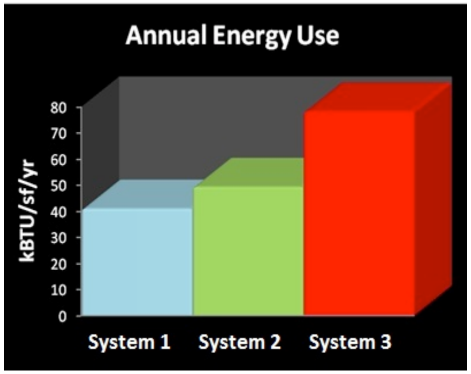
ENERGY MODELING CONTENTS



Sun path analysis.

Modeling image courtesy of M.E. Group

INTRODUCTION TO MODELING



The technology of building systems is ever-changing. Pick up a recent copy of any building industry magazine and one is likely to find a whole host of new mechanical and electrical technologies and high performance systems designed to create the better building. Which combination is right for your facility? Selecting and coordinating systems can make anyone feel overwhelmed. Fortunately, these decisions do not need to be made blindly. Energy modeling can inform this decision making process and take some of the guesswork out of designing a high performing building. A robust energy model can weigh various design options in a way that other tools cannot, and it can supplement other decision criteria. Running a variety of models allows one to not only test feasibility, but to make informed cost-benefit analyses of various design options during any stage in the design process.

Energy modeling can be completed by the project team's mechanical engineer, or it may be performed by an independent consultant. Regardless, the job of the energy modeler is to continuously advocate for high performance throughout the design, construction, and building start-up process. Modeling is key to high performance design and should be performed early and iteratively to inform the design. With a building simulation professional on the team and contributing to the integrated design process, any building has a greater chance of meeting high performance energy targets. Additionally, many green building certification systems require energy modeling for compliance.

Energy modeling is commonly used to help engineers, architects, and owners decide how to design elements of the building envelope and how to pair appropriate envelope materials with the mechanical and electrical systems design. This type of modeling is commonly referred to as a design energy model. While energy models are frequently used for assisting these types of design decisions, there are other types of energy models. Design models are also often used as a "comparison model" of a building's energy performance to that of a standard building of the same size, shape, and use. Although not typical, accurate design models can estimate a building's annual or monthly energy use and costs. Although energy models are an excellent comparison tool, predictive modeling can be very difficult. Because of natural changes in weather, occupant activity, and system use after construction, the simulated results may vary greatly from the actual building performance. If the energy model will be used as a prediction or verification tool after construction, it is recommended that the simulation be calibrated to match actual building performance. By comparing the calibrated simulations with actual utility costs, the model becomes a critical tool in the Measurement and Verification process for ensuring optimum system and building performance.

This design guide is intended to give the building professional an overview of energy modeling. It will discuss the process of developing and using a model, outline the types of analyses that can be made, and share ways to utilize a model to best fit the needs of your building.

What is Energy Modeling

Energy modeling is the use of computer-based simulations to assess energy consumption, daylighting effects and other characteristics of a building design. It allows for the analysis of various design considerations prior to the construction phase of a project. In this way, energy modeling can help optimize alternatives and allow the design team to prioritize investment in the strategies that will have the greatest effect on the building's energy use and occupant comfort.

Energy Model Types and Uses

An energy model used for comparison purposes will compare the performance of a design case to that of a representative, industry standard, base case. A number of operational assumptions will be the same in both models (e.g. occupancy schedules, climate file). The model results will be in the form of a percentage savings in annual energy use and/or costs of the design case when compared to the base case. This comparative approach is best used to set energy goals during the design process.

An energy model used for predictive purposes will report a range of anticipated energy performance for the actual building. A sensitivity analysis will be used to demonstrate links between model inputs and the range of results. The chosen inputs will have an associated error tolerance, which ideally decreases as the design progresses. This model approach is best used to establish thresholds for comparison in the measurement and verification (M&V) of actual building performance after occupancy. Occupant use and behavior patterns are often the least predictable input to any building simulation. See detailed explanation of model types on page 6 for more information.

Data Inputs for Energy Modeling

Along with the architectural and mechanical elements of a building, the energy modeling professional will input physical location and weather data, occupant density and activity, schedules for equipment and lighting use and other information pertinent to the metrics to be evaluated. Many of the programs will accept details for multiple whole-building design concepts, allowing for a side-by-side comparison of various options.

Using the Results

Models can be made for a wide variety of analyses. The most common models estimate energy use, energy expense, and carbon dioxide emissions. Models can also analyze other characteristics such as the effectiveness of natural ventilation strategies and daylight penetration. In this way, energy modeling can aid in the design process, be a tool in cost analysis, and serve as confirmation that implemented systems are operating as expected once construction is complete.

What the Models Do Not Predict

Energy models are excellent tools for indicating relative changes in energy use comparisons between design options and of relative energy use. However, design phase energy models which are not calibrated with actual operating data do not predict absolute energy use during occupancy. Additionally, the energy model does not have the ability to accurately predict fluctuations in occupant behavior or utility costs. When compared to the energy model, atypical weather and changes to scheduled use are often the two largest drivers to a building's performance. Typically, un-calibrated energy model results should never be used for predictive purposes and most modeling professionals will explicitly exclude this liability in their reports.

Figure 1:
A typical 3-D representation in an energy model.

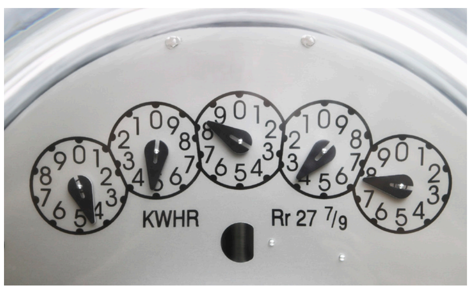
Modeling can:

Provide a baseline for energy use comparison.

Assist Lifecycle Cost Analysis.

Create documentation for building certification.

Generate a calibrated model for Measurement and Verification after occupancy.



BEST USES OF THE ENERGY MODEL

The Energy Model as a Comparative Tool

Modeling can assist the project team throughout the design process. Comparing multiple design concepts side-by-side allows for quick, inexpensive evaluation of the impacts of various design and system options. The energy results from a comparative study should be viewed as indicating relative performance from one option to another, and not as a definitive energy performance value. The full range of consequences from design decisions is not always obvious or clear cut. For example, using a radiant system may have the combined effect of generating energy savings through reduced fan energy, the ability to achieve comfort with reduced space temperature settings, and reduced air infiltration or exfiltration. The interrelated nature of factors, such as these, makes the effects of a design decision difficult to measure without robust energy modeling. Many times, an accurate cost vs. benefit analysis of a design decision cannot be completed without the help of a computer simulated analysis.

The Predictive Energy Model

Energy modeling results can be used for budgeting purposes before the owner receives their first utility bill. A predictive energy model will estimate the building's annual energy use and costs. This information may be used for life cycle cost analysis (as described below), utility cost budgeting, or evaluation and sizing of renewable energy systems. If the project team is interested in using simulation results as a predictive tool, it is imperative that this is discussed with the modelers and design team beforehand. Typical, comparison type models will often not include the details or cost schedules necessary to accurately estimate future costs.

Life Cycle Cost Analysis

Life Cycle Cost Analysis (LCCA) is the process of determining the full cost of a building or mechanical system throughout the entire period of ownership. This figure includes the purchase price, cost of operation and maintenance, and any other expenses involved in the ownership of the building. Additionally, LCCA considers factors such as inflation and projected fuel cost adjustments. While the initial capital costs (purchase price, staff training, etc.) are important considerations, they do not give the complete picture. Results from a robust energy model can be a powerful tool for refining design strategies and finding the best uses for limited finances.

Modeling Documentation for Building Rating Certification

Several green building certification/rating systems require the use of energy modeling and modeling documentation in order to earn energy use reduction credits/points. Comparison of modeled performance between the building design and that of a baseline design is the basis for point allocation for the primary energy credit under both the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design rating system (LEED) and the Colorado Collaborative for High Performing Schools criteria (CoCHPS). The baseline model is defined by both LEED and CoCHPS using the guidelines established by ASHRAE 90.1 for a minimally compliant building. Neither rating system requires that specific software be used for the comparison. However, any modeling software must meet the minimum performance requirements set by ASHRAE 90.1 and the software must be approved by the certification/rating authority (i.e., USGBC).

Measurement and Verification

After construction is completed, the model can be used as a tool in measurement and verification (M&V) to achieve on-going energy accountability. M&V is the process of measuring actual performance of a system or building once it is in operation. That information is then used to calibrate the energy model to match the existing building's performance. Once calibrated, the results can be compared to find and address issues, errors, or oversights in the building systems. This is the verification process. The M&V process can serve many purposes. The primary use is to verify that the building is operating as expected and as close as possible to its maximum efficiency. Without calibration, it is very difficult to use design phase assumptions to accurately predict energy use during actual building operation. Normal changes in operation, maintenance, weather and schedules will change the building's performance from the design results. However, comparison of modeled to actual performance data can help identify issues with equipment and spur corrective action. The energy model should be used to the fullest benefit possible during operation as well as design; it can also be a powerful tool in the hands of the facility management staff. Performance outside the expected range could indicate that equipment is improperly calibrated or not operating properly. If issues are discovered, further tracking can verify that the issues have been corrected. Ongoing tracking of building performance is important for facilities managers to identify equipment in need of servicing throughout the life of the building. Using M&V is a way to proactively operate and maintain buildings in order to maximize building efficiency and energy savings and it can earn points and/or satisfy prerequisites in various green building rating systems.

Asset Evaluation

Asset evaluation of buildings is in its infancy. An asset evaluation provides an assessment of the physical attributes of the building based on the components specified in the design (such as mechanical systems, building envelope, orientation, etc.) and is evaluated using a building energy model. A few states in the United States are beginning to require such an evaluation at the point of sale or lease. In the United Kingdom and in Europe there are programs in place that require an asset rating. Since the primary purpose of the asset evaluation is to facilitate the comparison of the energy performance for buildings of the same type, a key issue of an asset rating is the specification of modeling input parameters assumed to appropriately characterize standard building usage. This normalization is typically achieved through standard occupancy, operational, and equipment schedules that reflect a typical or "average" building or occupancy type. To obtain an asset rating the asset evaluation must be compared to some benchmark performance standard. This benchmark could be the baseline model established by ASHRAE Standard 90.1 or a standard prototypical building developed in the Commercial Building Benchmark Model project of the US Department of Energy.

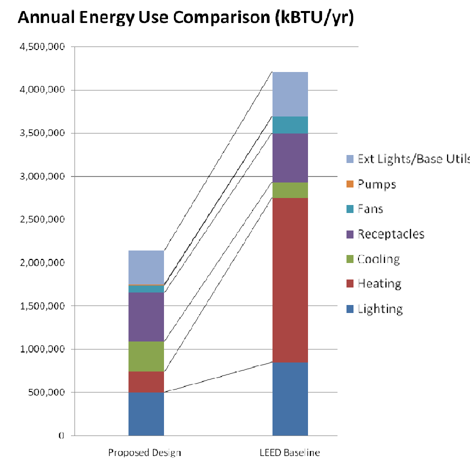


Figure 2:
Energy use comparison between baseline and proposed design.

Graphic courtesy of M.E. Group

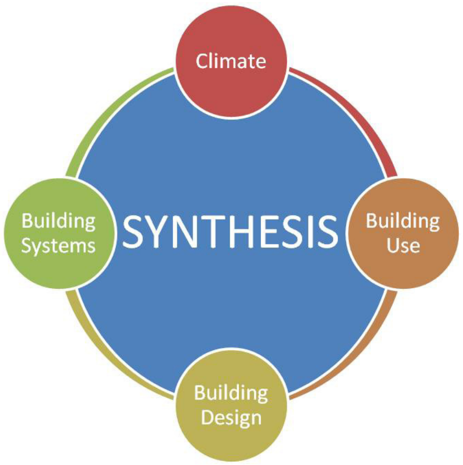


Figure 3:
Integrated Design Flow

Image based on graphics from Betterbricks.com

ENERGY MODELING THROUGHOUT THE DESIGN PROCESS

For a project to reach its optimum efficiency, consider adding an energy modeling professional to the team. The role of the modeler is both analytical and pragmatic, energy modeling should be used to motivate and encourage the design and construction team as part of an integrated process.

An integrated process includes the active and continuing participation of owners, building occupants, code officials, commissioning agents, cost consultants, civil engineers, mechanical and electrical engineers, structural engineers, specifications specialists, and specialized consultants.

This diversified team of consultants will use the energy model and modeling professional to shape and refine the built environment and its components throughout the building process. The following pages outline the importance of energy modeling and the critical steps to energy modeling in each phase of design:

- Pre-design
- Schematic Design
- Design Development
- Construction Documents

To achieve the best energy efficiency and highest performing buildings, impacts to energy efficiency should be considered with every decision. Gains in energy efficiency seldom are achieved by one big idea, rather it is a thousand small ideas which are combined to reach the lowest energy use targets. For example, the color of ceilings, walls, and carpets will impact a room's daylight performance. Lighter colors reflect more daylight and therefore, when coordinated properly with lighting controls, can help reduce the amount of electrical lighting needed. Sometimes interior colors are selected very late in the design process and can have unforeseen consequences if not coordinated accurately with the energy model.

Pre-Design and Conceptual Design

Energy modeling can be of the greatest benefit at the early conceptual and schematic phases of design. During the preliminary phases, the data garnered from the modeling exercise can inform the design at little to no cost. As the design progresses, changes become increasingly more expensive and more difficult to employ. Creating the model adds yet another layer of documentation to the process and in this way serves as a systems check, ensuring that there is agreement throughout the design team.

In the pre-design and conceptual design stage, use modeling to evaluate the natural climate and site conditions. This climate analysis is critical for creating basic building forms, orientations, and space allocation/programs that work with the natural environment. The U.S. Department of Energy and several other agencies regularly create and maintain databases of weather profiles for each climate zone and major city in the U.S. Many modeling software packages can transform thousands of measured climate data points into easy functional references and scales. The images to the right include a wind rose and psychrometric weather study for an entire year. This type of information provides the project team with a concise snapshot of the climate conditions at the project site.

The modeling process helps design team members begin conversations about efficiency and performance goals. Use the energy model to create energy use targets and energy improvement goals.

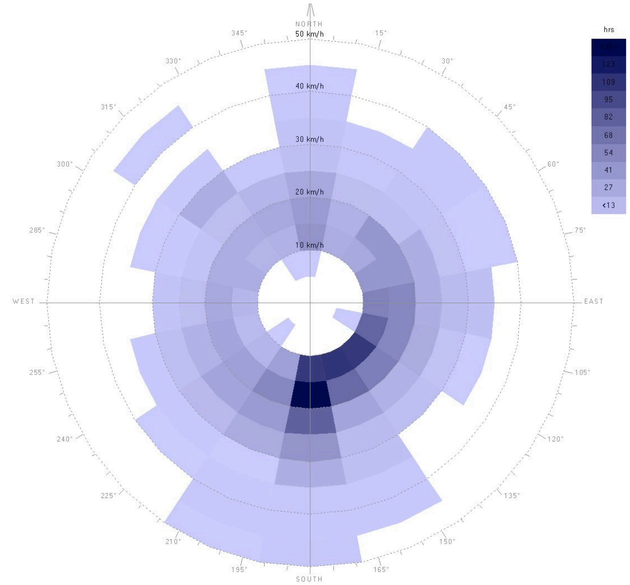


Figure 4:
Wind Rose – indicates wind speed and duration through the year.

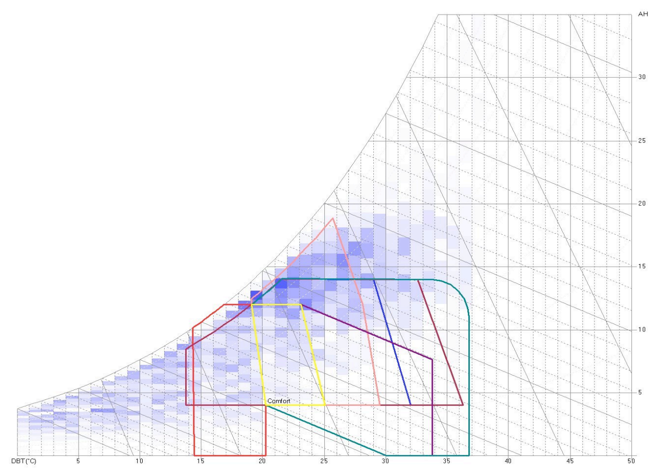


Figure 5:
Psychrometric Scatter Plot – indicates temperature and humidity levels through the year.

The information that is gathered and analyzed in the energy modeling process can help the design team to:

Understand the Climate
- Wind Patterns
- Solar Radiation and Path
- Temperature Ranges

Identify Key User Criteria
- Illumination Levels
- Indoor Temperatures
- Ventilation Rates
- Schedules of Use

Systems
- Set Energy Use Goals
- Evaluate Potential Efficiency Strategies
- Preliminary Load Analysis

ENERGY MODELING THROUGHOUT THE DESIGN PROCESS cont.

Schematic Design

During Schematic Design, the energy model can assist in evaluating a variety of conceptual ideas. The layout of rooms, the distribution of windows, the location for HVAC equipment, and many other general concepts are evaluated and determined. While these decisions may seem primarily functional in nature, each can affect the energy consumption and comfort of the inhabitants in ways that the energy model will help determine. This is also the ideal time to use the model to test a variety of envelope insulation options. For example, the modeling results may prove that an increased first cost for additional insulation not only provides a year after year reduced operating cost, but it may also prove that reduced mechanical system cost can more than offset the increased insulation costs. HVAC system analysis can then also begin during Schematic Design. Establishing the most appropriate system to implement in the project should occur as early in the design as possible. Once this is established, the conversation regarding potential energy conservation measures (ECMs) can begin in earnest.

Schematic energy modeling can analyze and optimize:

- Form and Orientation
- Building Envelope
- Potential HVAC Options
- Thermal Loads and Zoning Strategies
- Daylighting Strategies
- Passive, Active, and Hybrid Systems

Schematic modeling can assess:

- Peak Electrical Demand and Control Strategies
- Occupant Thermal Comfort
- Energy Use

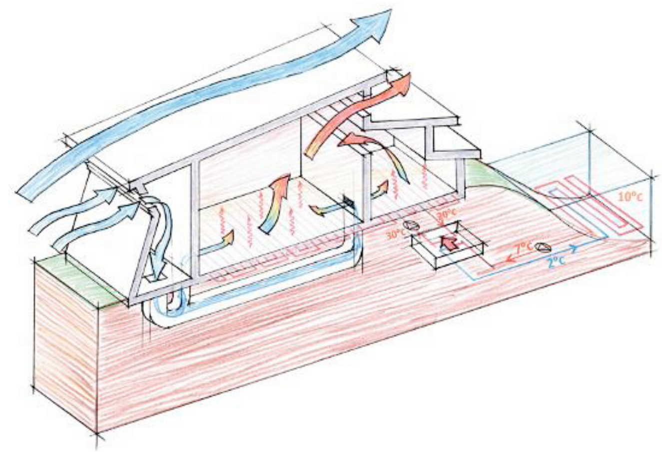


Figure 6:
Hesquiaht F.N. School
Impact of Ventilation Strategies on Building Form

Graphic courtesy of Vladimir Mikler, M.Sc., P.Eng

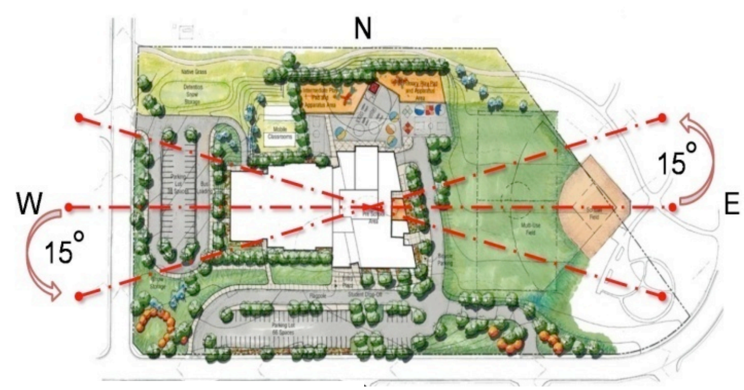


Figure 7:
Optimized Building Orientation and Form
(Long Axis is within 15 degrees of E/W axis)

Graphic courtesy of RB+B/Hutton Architects

Design Development

The Design Development phase involves the refinement of the building configuration and systems. Design team members determine the minimum efficiency requirements for equipment and fenestration, wall assemblies, vent and diffuser positioning, lighting layout and shading strategies during this phase. A robust energy model can assist in all of these decisions. This is also the first phase in which a life cycle cost analysis can be performed with some accuracy.

Design Development Strategies

- Optimize Building Envelope
- Enhance HVAC Selections
- Tune Mechanical Controls Systems
- Integrate Lighting and Daylighting Control
- Identify Opportunities for Energy Recovery

Construction Documents Phase

During the Construction Documents phase, the energy model assists in establishing set points for appropriate equipment calibration. Fan speed, thermostat setback, equipment power-up schedules and many similar settings can be optimized prior to construction. Many energy modeling programs allow for parametric analysis, running multiple iterations with slight setting modifications in order to investigate specific goals such as energy consumption, fan power use or energy demand reduction.

Performance Documentation

Building performance may be validated by simulating and comparing the actual building's design and a standardized baseline building. This enables the project team to:

- Assess impacts of construction changes
- Generate documentation for rating systems such as LEED and CO-CHPS
- Estimate actual energy use Commissioning Checks
- Confirm the building is operating within the design intent for the following or similar parameters:
  - Infiltration Rate
  - Operational Schedules
  - System Setpoints

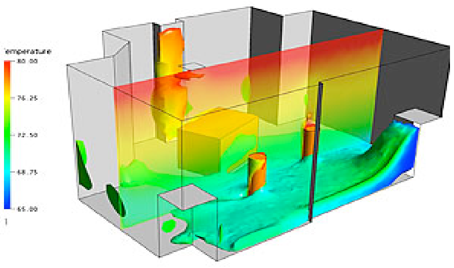


Figure 8:
Computational Fluid Dynamics can be used to verify design decisions and optimize critical spaces.

Modeling image courtesy of Price HVAC

FINDING AND WORKING WITH AN ENERGY MODELER

To select and work with an energy modeler the owner or project manager should:

- Create a thorough request for proposals to ensure that the required modeling scope is addressed so bidders can provide accurate pricing.
- Provide complete and detailed information to the energy modeling consultant.
- Use the modeling results to enhance the building's design and document building performance.

Creating an RFP/Solicitation for Energy Modeling Services

A thorough solicitation for proposals is the first step in both receiving accurate pricing and finding a qualified professional. Below is list of recommended data to include with each request for proposals:

1. Building Information
   a. Building/Campus Program and Purpose
   b. General Building Size Estimates
   c. Project Location
   d. Additional Specific Modeling Requirements (as applicable)
      i. Computational Fluid Dynamics (particularly for naturally ventilated spaces)
      ii. Daylight Analysis
      iii. Hygrothermal Analysis (moisture transport through building materials)
      iv. Specific Software Requirements (if any)
2. Schedule for the Project Design and Construction
3. Project Goals
4. Project Budget
5. Suggested Proposal Evaluation Criteria – example:
   a. Experience – 30%
   b. Modeling and Design Approach - 50%
   c. Cost – 20%
6. Proposal Deadlines and Procedures for delivering questions and answers.

Model Inputs and Requirements

Most experienced modelers will be able to create a basic simulation from simple sketches and narratives. This quick type of model can then be used to inform the design in real time during the earliest phases of design. However, as the design progresses, it is important that the energy model be updated with specifics and details that will actually be provided. It is recommend that the energy modeler attend preliminary kickoff meetings, charrettes, and consultant coordination meetings to ensure that the model is kept up to date throughout the design schedule.

1. User Information, Schedules and Program
2. Architectural Plans, Elevations, Sections and Details
3. Mechanical and Electrical Plans and Equipment Selections

The details listed above will be used to form the building within the model, and then simulate the building use throughout the year.

Model Outputs and Reports

The Energy Modeling report gives the design team a snapshot of the energy performance of the project in its current form. Each modeling report should include:

Building and Systems Overview Narrative

- Model Inputs Summary
- Detailed Simulation Results
- Recommended Energy Conservation Measures (ECM's)

The system and building narratives serve as a verification tool for designers and owners to ensure that the modeling inputs are accurate and in-line with the project goals. The classic maxim in the profession of energy modeling is "garbage in, garbage out," a computer based simulation can only be expected to perform correctly when its users have input the correct data. As well as serving as a verification of input accuracy, the report also details input differences between any comparative models that may have been created; giving a better understanding as to the significance of the results. For example, a single modeling report may include multiple iterations to demonstrate the cost/benefit analysis of additional wall insulation or mechanical system upgrades.

Perhaps the most important modeling summary is the Simulation Results report. This report will include a brief summary of total annual energy consumption and cost, as well as a breakdown of the energy consumption by system or equipment type. This data will be provided for the proposed and current design, along with any alternates being simulated. To understand the significance of the energy model results, a baseline model will typically be prepared for comparison with all options. Baseline models are often required for building rating system certifications, tax credit records, and other documentation.

Finally, encourage all modelers to provide recommended design revisions and additional energy conservation measures (ECMs) with each report. Early in the stages of design these recommendations might be substantial revisions to building orientation, construction type, or footprint. In later design phases, ECMs should focus on optimizing the details of envelope assemblies, mechanical systems, control sequences, and energy recovery options.

KEY RESULTS AND METRICS

- Annual Energy Cost
  - Total and by Utility Type
- Annual Energy Use
  - Total and by Equipment Type
- Peak Electrical Demand
- Energy Use Intensity
- Baseline Comparison and Savings

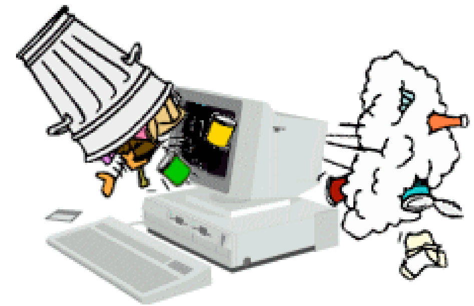


Figure 9:
Gargabe in, garbage out

FINDING AND WORKING WITH AN ENERGY MODELER cont.

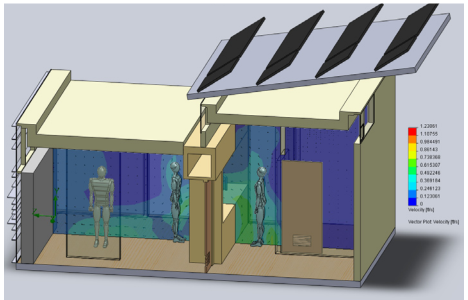


Figure 10:
Natural ventilation analysis.
NREL Conceptual study.

Modeling image courtesy of RMH Group

Using the Energy Modeling Reports

Through the different stages of design, owners, architects, and designers can use the report to enlighten the building design and use. Listed below is a sample of the design questions that can be investigated through energy modeling to increase building performance.

Conceptual Design

- What are the project energy goals?
- What will our key energy reduction strategies be?
- Are there opportunities for the following?
  - passive heating/cooling
  - natural ventilation
  - daylighting

Schematic Design

- Where should windows be located or removed?
- What is the optimum window to wall ratio?
- Which sun control geometries are most effective?
- Can daylighting be used effectively through top and side lighting strategies?
- What insulation values are most effective?
- Is thermal mass beneficial?
- Which mechanical systems meet the project goals and requirements?
- Can thermal loads be reduced or thermal comfort increased by improved form and massing?

Design Development

- How can direct glare be controlled?
- Are there additional opportunities for energy recovery?
- What control sequences improve our energy efficiency?

Construction Documents and Closeout

- How have late changes during design and construction affected energy reduction strategies?
- Are the modeling assumptions appropriate for the actual construction?
- Is the final model competed and ready for design performance documentation, code submission, utility program submittals, and LEED documentation?

ENERGY MODELING SOFTWARE

The engine of any modeling software is the core programming that drives the performance and functionality of the software. Many programs may use the same engine, but each brand of modeling software provides a different interface, giving each program a different appearance and in many cases different design and modeling options. The most commonly used engines are DOE-2 and EnergyPlus, both developed by the US Department of Energy. While DOE-2 is more common and maintains industry acceptance, EnergyPlus is more recently developed and has been designed with more functionality. A newer entrant into the whole building analysis field is Apache SIM, utilized in IES Virtual Environment. Apache SIM seeks to provide a platform to assess each aspect of thermal performance, from annual energy consumption and carbon emissions down to individual surface temperatures. Other tools are available for informing specific design considerations such as Radiance, which models daylighting potential.

Tips for a Quality Energy Model

- Complete the first model during the schematic design.
- Create accurate systems and occupant schedules with input from user groups and maintenance staff.
- Report energy use index (kBTU/sf/yr) at each milestone in the design process.
- Model real equipment (process loads) instead of a standard approximation (ie 25% of energy cost of baseline).
- Note how the energy model differs from the real building.
- Consider seeking 3rd party review of the modeling inputs and results.

ASSISTANCE / LINKS

Governor's Energy Office Home
http://rechargecolorado.com

U.S. Dept of Energy -Building Technologies Program
http://www1.eere.energy.gov/buildings/

U.S. Dept. of Energy - Modeling Analysis Tools
http://apps1.eere.energy.gov/buildings/tools_directory/alpha_list.cfm

ASHRAE 90.1 Energy Standard for Buildings
http://www.techstreet.com/standards/ashrae/90_1_2010_i_p_?product_id=1739526

Governor's Energy Office Modeling Webinar
http://rechargecolorado.com/images/uploads/pdfs/100831_Building_Modeling_Webinar.pdf

Commercial Building Initiative: Energy Modeling Software
http://www1.eere.energy.gov/buildings/commercial_initiative/modeling_software.html

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