

ENERGY MODELING AT EACH DESIGN PHASE: STRATEGIES TO MINIMIZE DESIGN ENERGY USE

Kendra Tupper¹ and Caroline Fluhrer¹
¹Rocky Mountain Institute, Boulder, CO

ABSTRACT

Design teams often use energy modeling as an accounting or code compliance tool to establish that minimum requirements are met. Used in this way, significant opportunities to inform and improve building design are overlooked. Properly used, energy modeling can provide outputs that optimize a building's energy consumption, reduce life cycle costs, and even reduce first cost. This paper will review how and when design teams typically use energy modeling in each design phase (concept phase, schematic design, design development, and construction documentation) and describe strategies for each phase that can lead to lower energy use buildings.

INTRODUCTION

Can that energy model report be done tomorrow? How many LEED points will this building earn? What is the latest stage that energy modeling can start? These are the frequent demands of clients, architects, and project managers that detract from the value of strategic energy modeling. In today's energy modeling world, consultants spend a significant amount of time building, debugging, and reporting results, and are left with relatively little time to question results, explore alternatives, communicate opportunities to the design team, and push the implementation of key design recommendations. The goal of this paper is to identify opportunities, at each design phase, for energy modelers to present useful information at the right time in the right manner in order to facilitate the design of low energy buildings.

While modelers will not apply every idea or opportunity this paper presents, it is useful to understand how to be a strategic energy modeler and maximize impact while avoiding pitfalls. While modelers will always face frustrations, these can be lessened by the satisfaction of knowing that the design team implemented modeling recommendations in the actual design. Strategies presented here can help energy

modelers maximize implementation of energy efficiency recommendations to drive down energy use in buildings. Note that while this paper focuses on energy modeling for new commercial buildings, many of the strategies are also applicable to existing commercial buildings (and some to new and existing residential).

INTEGRATED DESIGN PRIMER

Overview

Experience and actual building performance show that the most energy efficient buildings result when the following three key ingredients are present:

1. An educated, motivated, and committed building owner;
2. A talented, innovative, and committed design team; and
3. An integrated design process.

Other key factors that contribute to low-energy use buildings include characteristics of the building climate, site, and use, utility rates, operations, and the overall capital budget.

There are many definitions or explanations of integrated design (Prowler, D. et al, 2008), though most emphasize continuity, interaction, and iteration. The goal of using the integrated design process is to produce a building that is cost-effective, resource-efficient, and aesthetically appropriate. While the typical design phases in an integrated process remain the same (concept phase, schematic design, design development, and construction documentation), the distribution of time and the dynamics of the interactions are quite different. Figure 1 and Figure 2 illustrate how, in the integrated design process, the design team should spend more time in the earlier design phases as compared to the effort they expend in the typical process. They will need less time in the later phases during an integrated design process, as fewer last minute changes, errors, or budgeting crises occur.

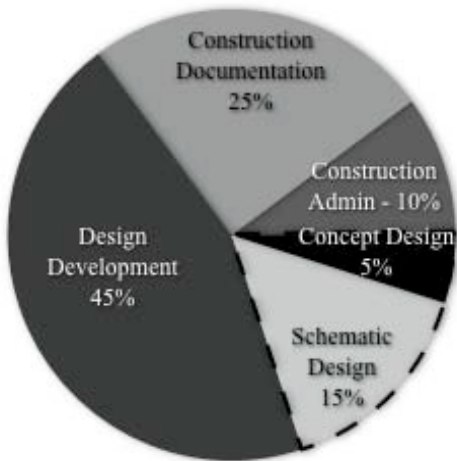


Figure 1 Typical Distribution of Time

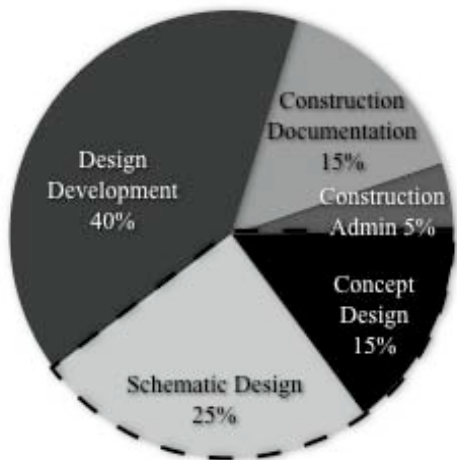


Figure 2 Integrated Design Distribution of Time

The Right Steps in the Right Order

One key aspect of integrated design that most closely relates to the energy design of buildings is following the *right steps in the right order*. An integrated design approach to low-energy building design should chronologically follow these basic steps or principles (of course a successful integrated design requires more than following a checklist.):

1. Define Needs: Define the need/service required first, not the equipment or capacity needed to provide it.
2. Identify Appropriate Measures: Identify which efficiency measures should be analyzed for a specific building and climate.
3. Reduce Loads: Reduce loads on mechanical systems through passive design measures.
4. Plan System Layouts: Design systems to reduce pump and fan power.
5. Select Appropriate & Efficient Technology: Select the most appropriate system type/s and

use the most efficient equipment available (most people start here!).

6. Optimize Operation: Incorporate controls and demand response measures.
7. Seek Synergies: Assess waste streams and other resource areas for possible use/reuse.
8. Explore Alternative Power: Incorporate renewable energy technologies and purchase green power or carbon offsets.

By following these steps, design teams can minimize the need for the initial installation of energy-consuming systems and minimize lifetime energy use and costs.

ENERGY MODELING SCOPE OF WORK

Much of the potential impact of energy modeling is determined by the scope of work laid out in the modeling contract before the modeler has even begun to understand the building design. The most typical energy modeling scope of work is simply to develop a model for LEED documentation purposes. A step beyond this scope often includes exploring alternative energy efficiency measures or system types. This traditional scope of work dramatically limits the potential impact of energy modeling.

To maximize the impact of energy modeling and its outputs throughout the integrated design process, the design team should consider the following tasks¹:

- Create a goal setting theoretical minimum energy model;
- Develop other models (daylight, CFD, spreadsheets, etc.) to feed into the energy model or energy saving calculations;
- Evaluate design *packages* in the energy model and use outputs from the energy model to inform a life cycle cost analysis;
- Use the model and life cycle cost analysis to evaluate value engineering options in the late stages of design; and
- Use the model (if appropriate) in the development and execution of a measurement & verification plan (not explicitly discussed in this paper).

These additional tasks can significantly contribute to maximizing energy use reductions and the building owner should include them in the project scope.

CONCEPT PHASE ENERGY MODELING

Energy modeling should always be aimed towards *providing information that will drive the critical*

¹ All tasks may not be in the energy modeler's scope of work, but someone on the design team should undertake them.

decisions applicable to that design phase. In the concept design phase, the most critical task is aligning the design team around the energy-related goals for the project. Once this goal setting exercise is complete, it is up to the energy modeler to determine what additional modeling studies would be most impactful.

These initial concept phase decisions are critical as they can determine the majority of a building's energy use profile. Unfortunately, energy modeling is rarely leveraged in the concept phase to provide information that could drive these critical decisions. This is a most likely a function of the contractual arrangement between the modeler and the design team that results in modelers joining design teams during late schematic or early design development. This is missed opportunity, since energy modeling in the concept phase can be a very powerful tool for the entire design team. This section discusses opportunities for how energy modelers can influence goal setting, building programming, design criteria, and design alternative decisions to create low energy use buildings.

Goal Setting

In the concept phase, the most critical elements for an energy modeler to influence are the energy-related goals. These may include a target for annual energy use per unit area (e.g. kBtu/sf/year), a percent reduction below a certain baseline (e.g. 40% below an ASHRAE 90.1-2007 baseline), or specific strategies (e.g. no mechanical cooling). Because there will be a limited number of known variables at this early stage, the energy modeler has free reign to create the lowest energy use building possible to show what targets are possible.

A useful way to think about this exercise from a modeling perspective is in terms of the "theoretical minimum" energy use. This concept is often used in efficiency potential studies and is referred to as the "technical potential". The theoretical minimum energy use is the lowest technically possible (using today's technology) energy use for the building, before investigating renewable energy opportunities. By providing this type of aggressive data point to the design team, the energy modeler can help change the discussion from one focused on defining incremental improvements (e.g. more efficient lighting) to one focused on real design challenges (e.g. how can we naturally ventilate this building to get closer to the theoretical minimum energy use?). In theory, the only barrier to achieving the minimum energy use should be cost; however, if the design team combines energy efficiency strategies in the right way, even cost barriers can be overcome (Lovins, 2008).

Creating a rough theoretical minimum energy model should not be a huge time investment, as the goal is not a high level of accuracy, but rather to simply demonstrate what is technically (and approximately) possible to encourage the establishment of aggressive energy goals. Often in the concept phase, the only information available is square footage by program type. This is both a challenge and an opportunity to establish proper layout to maximize daylighting, views and thermal zoning synergies.

The first step in concept design energy modeling is creating a rough baseline model (e.g. ASHRAE 90.1-2007 Appendix G model) for the appropriate building type. Here, the modeler should approximate the size and form and take short cuts to minimize the time investment. Once the modeler completes a rough baseline, it is useful to "calibrate" the model against benchmarks (e.g., the EIA Commercial Building Energy Consumption Survey data) to ensure the energy use intensity is within an expected range.

Next, it is useful to apply the right steps in the right order to begin to explore possible energy use reductions, starting with first defining the needs.

Define Needs

Building programming is fundamentally what drives the need for energy use in buildings. Without a program need, there is no need to construct a building. If the space programming need can be cut in half, the building size, the total first cost, and the associated energy use can also be reduced. While a smaller building does not correlate to earning more LEED points or reducing the energy intensity, it does impact total energy use (which is the ultimate goal).

Another large driver of energy use during in the concept phase is design criteria. Depending upon the climate and building usage patterns, a 2-degree difference in the setpoint temperature can significantly impact the cooling loads. The modeler can change typical design criteria (e.g. temperature or humidity setpoints, footcandle levels, OA quantities) simply to demonstrate the energy impact of various design criteria. Examples of energy modeling studies that can affect service and need definition decisions include:

- Reduce the building size by 10%;
- Change cooling and heating set points;
- Change the percentage conditioned floor area;
- Vary the outside air quantity by 30%; and/or
- Group zones with similar thermal needs.

Outputs described in this section can most usefully be summarized in bar charts (see example Figure 5).

Identify Appropriate Measures

Energy modelers will need to exercise judgment to determine which strategies are relevant to the particular project under investigation. A quick climate analysis can help inform the applicability of natural ventilation, economizers, evaporative cooling, etc., and will help determine which measures might be appropriate to investigate. A sample output appears in Figure 3 below.

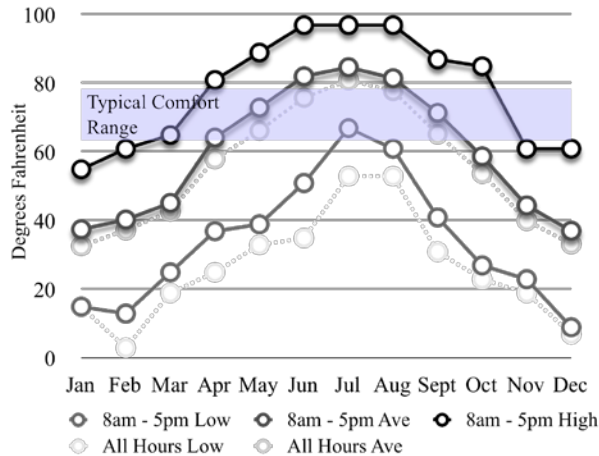


Figure 3 Sample Climate Analysis Output – Dry Bulb Temperatures for Operating and All Hours

Beyond this quick analysis, it is often useful to examine hourly or binned climate data to determine what percentage of operating hours could benefit from certain strategies. Next, the modeler should evaluate outputs from the rough baseline model to further hone in on the most appropriate solutions. Outputs from the energy model that are particularly useful include; annual energy end use breakdown, and peak and annual heating and cooling load contributions.

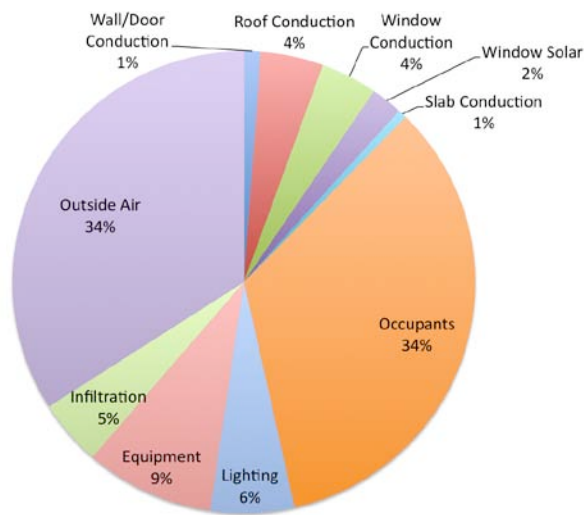


Figure 4 Sample Peak Cooling Load Contributions

Figure 4 shows a breakdown of peak cooling load contributions for a manufacturing plant, clearly indicating that occupant heat gain and outside air loads dominate cooling demands. Since it's impractical to propose eliminating occupants, efficiency strategies should focus on minimizing the amount of outside air and passively removing the sensible and latent loads from the required ventilation air.

Important questions to ask while determining appropriate measures to investigate include:

- Is the building heating or cooling dominated?
- Is the cooling load dominated by internal gains or climate?
- What are the major contributions to peak and annual heating and cooling loads? (i.e. outside air, solar heat gain, infiltration, etc)
- Is the cooling driven by sensible or latent loads?
- What percentage of the operating hours could benefit from passive strategies?

Reduce Loads

Passive measures are a critical driver of building energy use as well as capital and long-term operating costs. It is much more cost-effective to install high performance windows that reduce the cooling load by 20 percent, than to install a second chiller that will have to be run and maintained for the next 30 years. The goal of examining load reduction measures is to reduce peak and annual cooling and heating loads, as these are what determine the type and size of mechanical equipment the building requires. The strategies to investigate should have been defined in the previous exercise focused on identifying appropriate measures. Common strategies that typically lead to large load reductions include:

- Improve exterior envelope properties;
- Examine the size and location of glazing;
- Evaluate shading options (overhangs and fins);
- Rotate the building (orientation);
- Apply passive cooling (i.e. night sky cooling, natural ventilation);
- Use thermal mass to store energy and re-release it when it is needed;
- Use daylighting to reduce electric lighting needs; and/or
- Reduce installed lighting and equipment power (should be considered here since it impacts loads).

Figure 5 below shows how these load reduction strategies can be combined, resulting in a greater than 50 percent cooling load reduction.

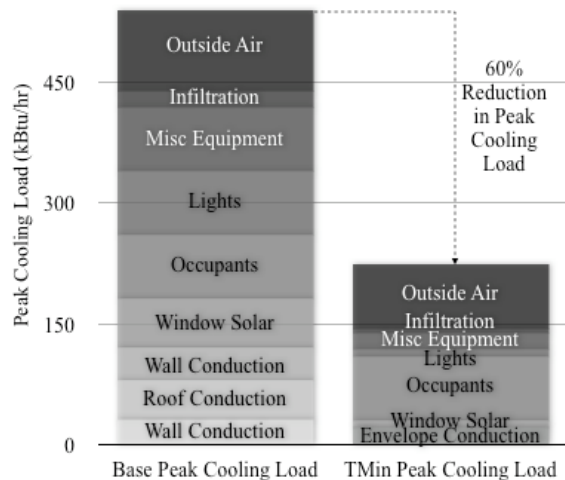


Figure 5 Sample Concept Phase Output – Theoretical Minimum Peaking Cooling Load

System Design: Appropriate & Efficient Equipment

Once the modeler reduces loads as much as possible and considers efficiencies for the system layout, it is then time to consider what technology and system design is best suited to provide the (greatly reduced) remaining lighting and HVAC services needed in the building. Again, the suite of options should come from the exercise of identifying appropriate measures for the specific building and climate. For example, a desert climate with a large diurnal temperature swing could be well suited to evaporative cooling, or natural ventilation coupled with nighttime flush.

Regardless of the specific technologies being evaluated, the process should always include optimizing the layout and sizing of ductwork and piping to reduce fan and pump power. Because of the relationship between friction and pipe and duct diameter², a small reduction in friction can translate into large fan and pump savings. This concept is often overlooked, and early energy models should be used to show the magnitude of this potential savings.

Optimize Operation

After selecting technologies, model the impact of aggressive control and operating strategies, such as:

- Lighting controls (daylight and occupancy sensors) and plug load management strategies;
- HVAC controls (night setback, OA reset);
- Thermal storage; and
- Future impact of plug-in vehicles.

² Friction is inversely proportional to ~ the fifth power of pipe diameter; increasing pipe diameter by 50% decreases pipe friction by 86%.

Seek Synergies

Next, look for ways to reuse waste streams such as heat recovery or the collection and reuse of cooling condensate for irrigation. The modeler should examine hourly load shapes and investigate opportunities for coupling waste heat/cool streams with heating or cooling demands. It is difficult to capture the true effects of heat recovery directly within the energy model; at this phase, it is sufficient to assume a reasonable percent reduction for certain end uses. In the later phases, hourly spreadsheet calculations are often required to account for these synergies.

Explore Alternative Power

Lastly, do quick analyses of what renewable energy sources or green power purchases are applicable. Use simple software (e.g. PV Watts) or even rules of thumb to estimate the cost of providing renewable energy to power the remaining (very small) annual energy use.

Outputs and Communication

A useful output from the concept phase exercises is a brief concept phase report detailing:

- Percent savings for each individual measure;
- Cumulative cooling or heating peak load reductions from package of combined measures (to suggest that HVAC equipment can be significantly downsized or eliminated);
- Pie charts showing energy end use and peak cooling or heating loads by end use; and
- Cumulative percent energy savings (e.g. the theoretical minimum).

In addition, the modeling should provide recommendations for the actual project goals. These may include quantitative energy intensity targets, percent savings reductions below a baseline, or better yet, tangible design goals such as “eliminate perimeter heating system” or “achieve 100% daylight autonomy.”

However, experience shows that providing a written report is often not the most powerful strategy to creating change. The energy modeler should also set up a dedicated phone call or portion of a design team meeting to present the results, respond to questions, and discuss the opportunities.

The desired outcomes from this concept phase energy modeling effort are two-fold: First, to generate consensus from the design team and client on the energy-related project goals and second, to create buy-in such that the design team is excited about the opportunities and motivated to reach the identified goals in future phases.

SCHEMATIC DESIGN MODELING

For most modelers, this is the phase in which they join the project team and typical priorities include collecting inputs for the model. While some modelers might actually start building the energy model in this stage, it is more common to hold off until design development, when building geometry is finalized and dramatic changes to the model (that translate to a larger time investment) are minimized.

In the ideal or integrated design approach, the schematic design (SD) phase is the time to build a more detailed energy model and evaluate various combinations of energy saving features. The energy modeler should be aware that large changes to geometry, system types, etc. may require a complete rebuild of the model in design development.

SD differs from the concept design phase when the energy modeler has free reign to influence the team. Here, the modeler should focus on the specific design options that cannot be easily changed later, such as:

- Building siting and orientation;
- Exterior envelope constructions;
- Glazing size and location;
- Thermal zone and space configuration;
- Shading and daylighting strategies;
- System features that impact floor or ceiling space (e.g. bigger ducts); and
- HVAC system type options.

This analysis should be an iterative process, which constantly revisits the potential to downsize or eliminate mechanical systems, ensures compliance with goals, and evaluates options from a comprehensive life cycle cost analysis (LCCA) framework.

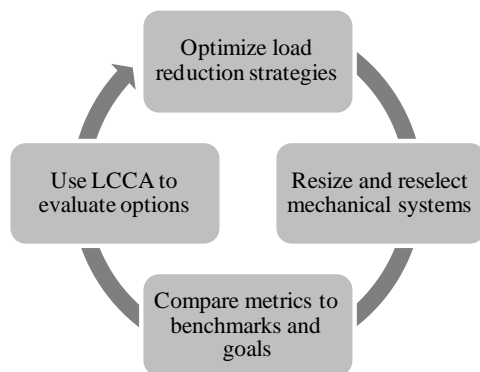


Figure 6 Schematic Design Analysis Procedure

Life Cycle Cost Analysis and Packages of Measures

Typical outputs from energy modelers include annual energy savings or annual energy cost savings for

specific measures. While these outputs are useful in terms of understanding which measures provide the biggest relative energy impact, they do not inform decision makers about the economic value or return of those measures, or more importantly, specific combinations of those measures.

Outputs such as net present value (NPV), return on investment (ROI), or internal rate of return (IRR) provide additional useful decision-making criteria. These standard financial decision making metrics (as opposed to kBtu or annual energy cost savings) are much more meaningful to those making investment decisions. However, to provide these types of metrics, the modeler (or other designated design team contributor) must go one step beyond the energy model and create a high level life cycle cost analysis model.

The main difference between providing a simple payback figure (typically just the capital cost divided by the annual energy cost savings) and providing NPV, ROI or IRR is that the consultant includes cash flows in the analysis. A simple payback calculation generally underestimates the true economic value of the energy efficiency investment, as it ignores other important benefits (rebates, depreciation expenses, maintenance savings, etc.). LCCA enables decision-makers to fully understand the economic justification for an integrated sustainable design. Table 1 provides an example of the type of information a consultant should present.

Table 1 Sample LCCA Summary

	Package #1	Package #2
Incremental capital costs		
Annual operating cost savings		
Simple payback period		
Net Present Value		
Internal Rate of Return		
Annual CO ₂ emissions		

Beyond representing financial metrics over the life of the building, it is often possible to design a very low energy building that has *lower* capital costs than the baseline approach. These capital cost reductions result from the ability to downsize, or even eliminate, pieces of equipment. This type of analysis is only successful if the energy modeler conducts analysis on *packages* of measures, rather than isolated measures. For instance, it is often difficult to justify the cost of better windows in isolation. However, when the analysis can incorporate the capital cost savings from completely eliminating a perimeter heating system, the economic picture is much more representative of reality.

To best inform the client, it is most useful to present

the results of LCCA for several different design packages. The first package should always be the baseline design; then, the NPV or IRR from this investment can be the baseline value against which alternative options are compared. This requires some additional effort on the part of the design team to produce a schematic design and capital cost estimate for the “business as usual” building design. This baseline is essential in order to take credit for capital cost reductions from system elimination.

After creating the baseline, the team can create several different packages or scenarios of energy efficiency measures and system alternatives. It is often useful to create packages that satisfy different goals, such as optimizing NPV or minimizing fossil fuel consumption.

Other Schematic Design Inputs

Unfortunately, there is no single software program that can perform every type of required analysis. Schematic design is an ideal time to evaluate what other software tools (see Figure 7) are required to inform the design.

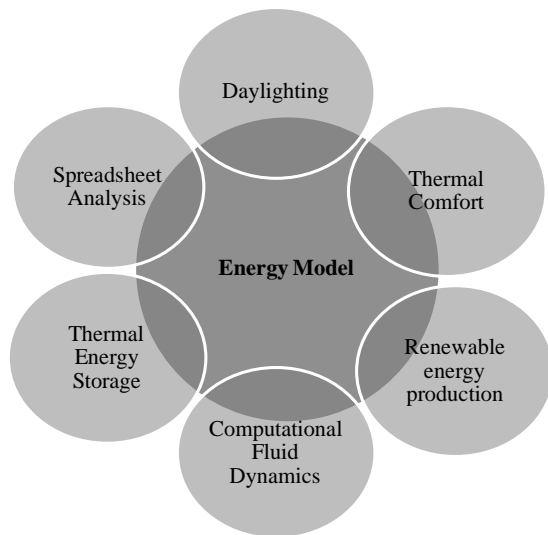


Figure 7 Types of Analysis Tools Commonly Required to Supplement an Energy Model

Key Outputs (Schematic Design)

The key output from the schematic design phase is an energy report that recommends an aggressive package of efficiency measures and HVAC equipment based on the energy modeling and LCCA results. This package (or packages) should also be compared to baselines (i.e. ASHRAE 90.1-2007) and to goals set in the concept design phase.

Modelers can present summary results in a tabular format that clearly shows the incremental capital cost, incremental annual cost savings (that includes items

beyond just energy), NPV, simple payback of the package, and any other information requested by, or deemed helpful for, the owner.

In summary, while the modeler focused only on providing energy related outputs during concept design, in SD the modeler should provide energy AND economic outputs. It is critical to introduce the economic repercussions of decisions during schematic design. This will help to avoid value engineering and last minute (expensive) changes later in the process.

DESIGN DEVELOPMENT MODELING

In the design development (DD) phase, typically a modeler creates a proposed building model and evaluates various energy efficiency measures. Common outputs include a baseline annual energy cost compared to a proposed annual energy cost that the consultant uses to calculate LEED points. It is also common practice to provide a table showing additional energy efficiency measures not currently in the design with their relative annual energy cost savings.

In the DD phase of the *integrated* design process, the energy modeler should instead focus on:

- Evaluating specific design options and decisions by updating the energy and LCCA models (to defend against value engineering);
- Periodically reviewing the design for variations from recommendations and continuously referring back to initial goals;
- Evaluating and suggesting specific products or manufacturers that can achieve the recommendations from schematic design;
- Optimizing control strategies;
- Ensuring that all thermal comfort and indoor air quality criteria are being satisfied, and
- Revisiting how measures are modeled in the software to improve accuracy of the model.

Depending upon how much the design has evolved, it may be necessary to start the model over to re-build the correct geometry and zoning, or edit the text based input files to cut and paste new geometry and zones.

Quality Control

While it is essential to check the quality of inputs and outputs throughout all phases of energy modeling, it is especially crucial during DD, when the team is finalizing details and comparing overall results to benchmarks and goals. It is important to continually verify that all loads are being met, and to cross check key metrics such as kBtu/sf and peak heating and cooling size metrics (e.g. cfm/sf or sf/ton) with industry standards and typical values.

Key Outputs

At the end of design development, most critical decisions should have been made, thus most of the value of modeling is complete. Outputs (e.g. the impact on the NPV of a particular package by adding or deleting a measure or projected LEED points) should primarily be in response to what the design team or building ownership requests.

CONSTRUCTION DOCUMENTATION MODELING

In an ideal world, very little should be required of the energy modeler in the construction documentation (CD) portion of an integrated design process. Here, the focus should be on documenting the design. It is important to ensure that final drawings and other design documentation include the intended energy efficiency features and provide enough detail for the as-built building to achieve all project design goals. The final energy modeling deliverable in this phase should be a summary of energy and financial metrics for the proposed versus baseline design and additional required documentation (e.g. LEED credit templates).

Of course, it's unrealistic to expect that there will be no value engineering or specification changes late in the game. As a result, there is quite often a need for additional energy modeling during CD (and even into Construction Administration) to address potential changes that could impact energy consumption.

Document Modeling Approach

Finally, a critical task during this phase is to clearly document all inputs and assumptions to the energy model. Aside from the obvious benefits of being able to quickly access and verify all assumptions and workarounds, it is quite common to receive questions on the model several months (or even years!) later, often in reference to measurement and verification or LEED review comments. It is equally common to "inherit" a model created by a former employee.

Documenting assumptions will save time and facilitate the justification of results, especially when complex workarounds were required. Important things to document include, but are not limited to:

- Basic building/site info;
- Conditioned and total square footage;
- Description of baseline used (i.e. ASHRAE 90.1-2004, with all addenda);
- Actual site location and weather file location used for energy model;

- Detailed list of inputs and assumptions for Proposed and Baseline models - note when external calculations were required;
- Description and visuals of thermal zoning;
- Detailed description of mechanical systems and how the systems were modeled;
- Explanations of anything that could not be directly modeled and the workaround used;
- Description of energy conservation measures and related assumptions ; and
- A list of what is included under each end use category for a given modeling program.

CONCLUSION

In the typical design process, design teams use energy modeling primarily as an accounting tool. In an integrated design process, energy modeling should inform the design and facilitate a comprehensive life cycle cost analysis. It is essential to provide energy modeling outputs in a timely manner in metrics (e.g. dollars and cents) and in ways (e.g. face to face) that result in implementation. This paper presents various strategies that can help energy modelers to provide the type of information that will impact critical decisions in each design phase. These strategies can maximize implementation of energy efficiency recommendations to drive down energy use in buildings.

NOMENCLATURE

ASHRAE – American Society of Heating Refrigeration and Air Conditioning Engineers

CD – Construction Documentation

CFD – Computational Fluid Dynamics

cfm – cubic feet per minute

DD – Design Development

EIA – Energy Information Administration

HVAC – Heating, Ventilation and Air Conditioning

IRR – Internal Rate of Return

kbtu – thousand British thermal unit

LCCA – Life Cycle Cost Analysis

LEED – Leadership in Energy and Environmental Design

NPV – Net Present Value

OA - Outside Air

SD – Schematic Design

sf – square feet

REFERENCES

Prowler, D., Vierra, S. 2008. Whole Building Design, Whole Building Design Guide, National Institute of Building Sciences.

Lovins, A.B. 2008. Natural Capitalism, Chapter 6 downloadable at: <http://www.rmi.org/rmi/Library>