Understanding the Energy Modeling Process – Simulation Literacy 101

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1.0 INTRODUCTION

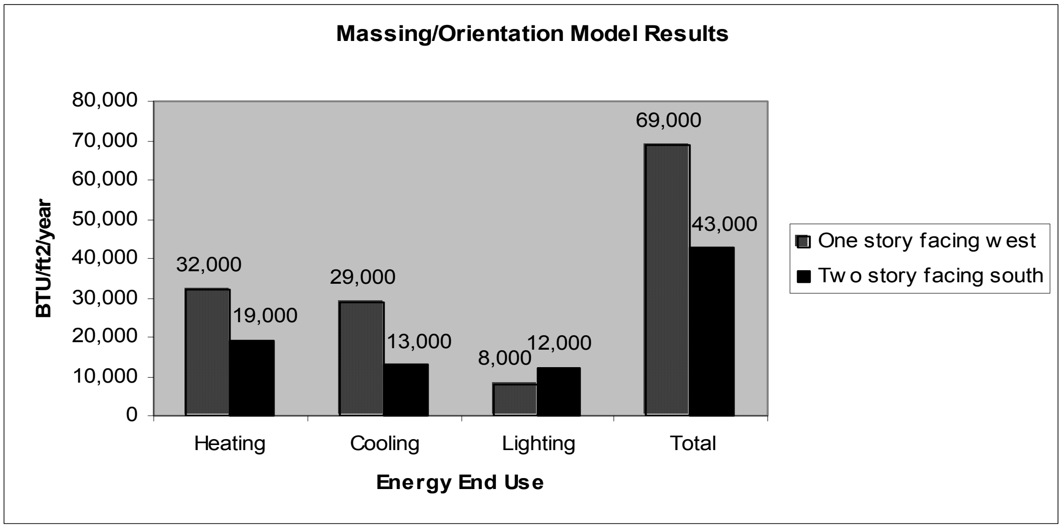
The goal of this presentation is to demystify energy modeling for the design professional and facilities planning professional. By energy modeling, we mean using computer-based tools to simulate the energy use of a building throughout an entire year of operation. This is commonly referred to as annual energy use simulation.

LEED requires energy modeling to assess the energy use of a building and to quantify the savings attributable to the proposed design. In many cases, architects and building owners are inexperienced with the energy modeling process and don't know how to harness this powerful tool to inform the design and decision-making process. Properly used, energy modeling can help optimize the building design and allow the design team to prioritize investment in the strategies that will have the most effect on the building's energy use. This session seeks to put the architect or facility owner in a position to direct the modeling process effectively and to be able to evaluate the validity of the output presented.

2.0 WHY MODEL?

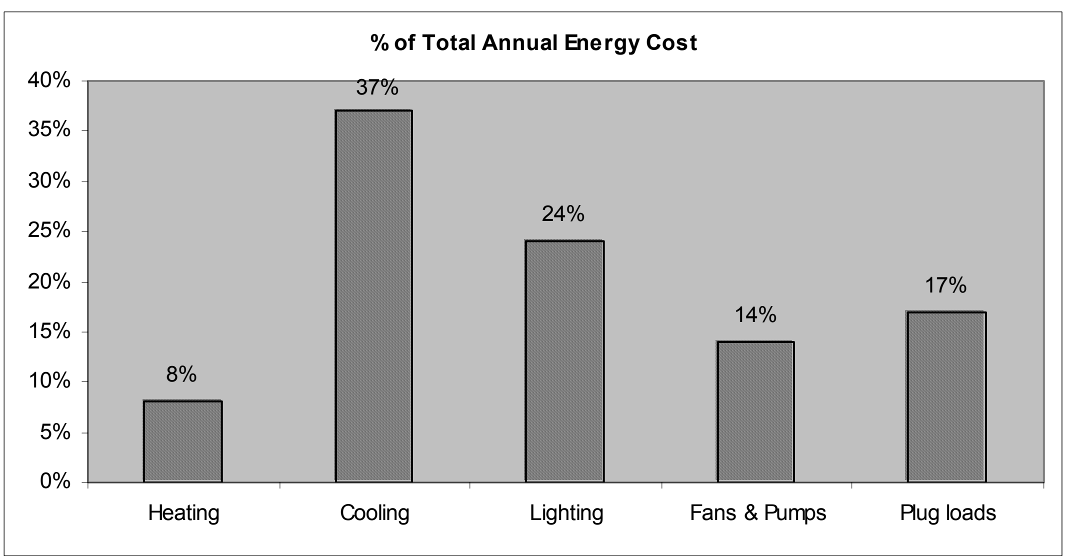
LEED requires energy modeling if any of the 10 credits possible under EA 1 are to be attained. However, energy modeling predates LEED, and there are more fundamental reasons to model. I view the energy model as a continuous process that gets more detailed and refined (and we hope, accurate) as the design process progresses. In the majority of cases I have witnessed, the model is made operational so late in the design process that opportunities to use it to guide design decisions have been lost, and it is merely an after-the-fact, record-keeping exercise. It can be a powerful tool in an integrated design process. The following looks at how an energy model might be used throughout the design phases.

1 – During the Conceptual Design of the project, energy modeling can provide valuable input. In a process such as this, a skilled modeler might quickly assemble a simplified model of the building, perhaps with a single zone per major occupancy type (e.g., classrooms, labs, offices), which can be used to test the effects of site location, building massing, and orientation. Imagine comparing two design concepts, one which places a one story building on a flat open portion of the site, with a western orientation, while the other is a two story design partially built into a hillside facing south. Results might look like this:

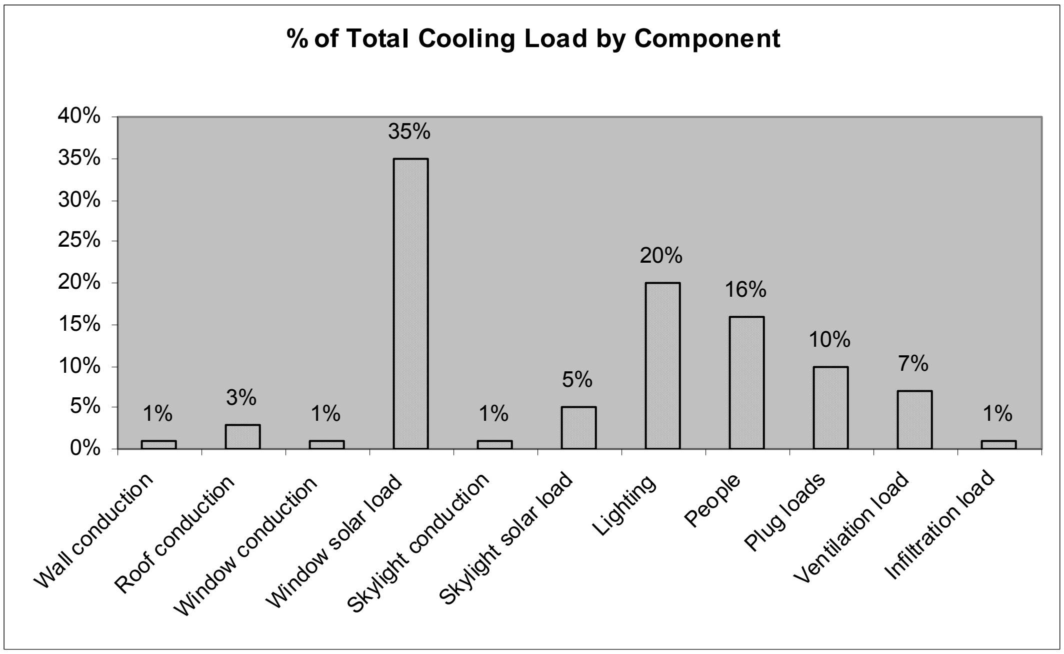


This kind of feedback is rarely available early in the design process, which is ironic since this is often where the biggest opportunities are! Many modelers are reluctant to build a model when so much is yet unknown. Yet, with good professional experience combined with the default values built into some modeling software (eQuest and Energy-10 are two good examples) a model can be quickly built which may not be terribly accurate but is perfectly adequate for comparing alternate scenarios, where relative differences are more important than deadly accuracy.

2 – In Schematic Design, energy modeling allows those involved in the design process to optimize their focus on the most promising energy saving strategies. Seeing how the energy consumption of a building breaks down by fuel type, task, and building component allows the design team to focus on the major drivers of energy use. As an example, imagine that the schematic design model shows the following output:



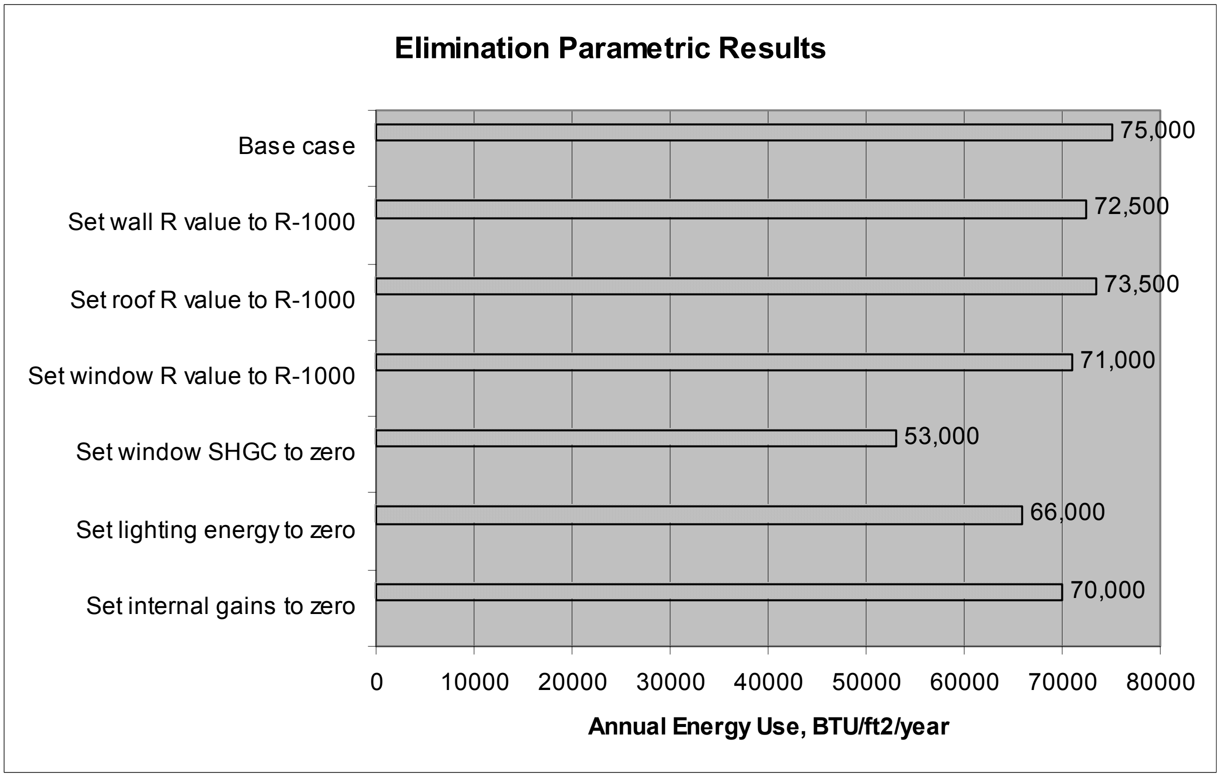
Heating overall is a small portion of the energy bill, so the focus can lessen on this load and shift to cooling and lighting. It would be wise to look at strategies that reduce cooling loads. We know that if cooling loads drop, then Fans & Pumps energy will also drop – less energy is being moved around the building. We also know lighting energy has to be removed by the cooling system, so that reducing lighting energy will also reduce cooling energy. A logical next step is to look at the breakdown of the cooling load for the building, which may look like this:



Since the two largest components of the cooling load are the solar gain through the windows and skylights, and the heat gain from lighting, strategies to examine may include: building orientation, daylighting, more efficient lighting, more appropriate lighting levels, better lighting controls, lower Solar Heat Gain glazing, shading for glazing, etc.

3 – In Design Development, energy modeling permits parametric studies to be done. Elimination parametrics is a diagnostic technique that allows a better understanding of the energy use impact of each building component. A series of simulations are done that set one component of energy use to zero at a time. When the results are viewed, a clearer picture of how the building uses energy emerges.

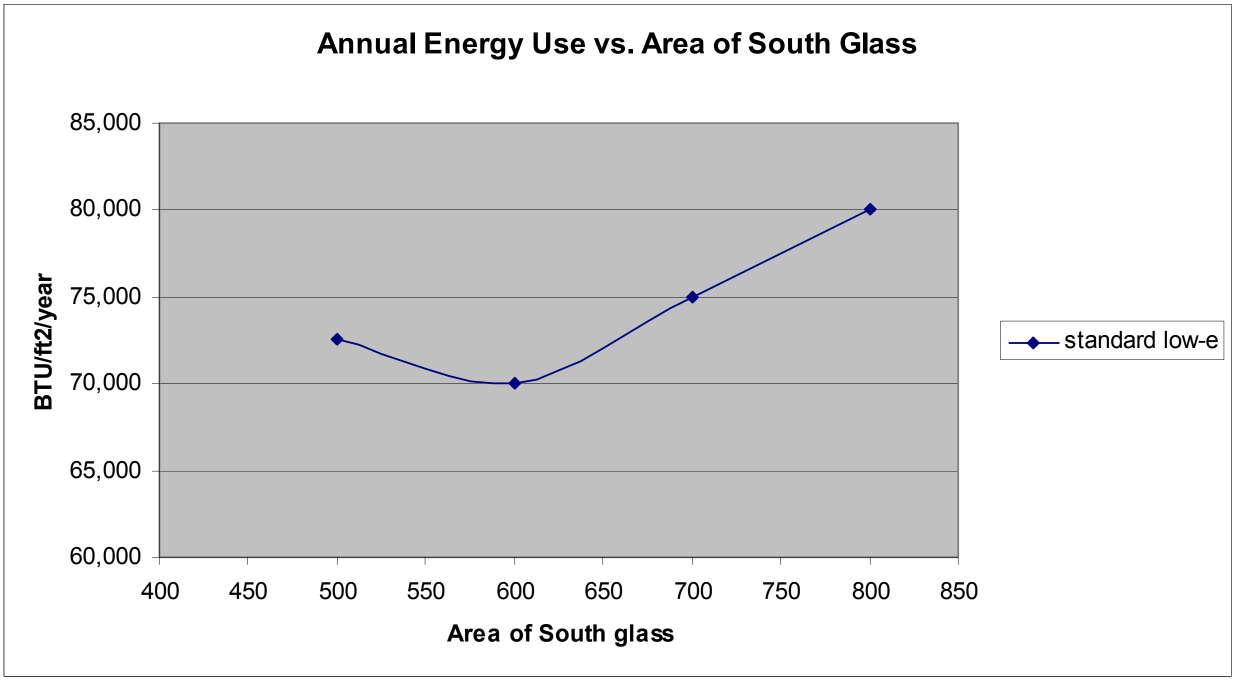
Perhaps our early design phase modeling led us to orient our building so that most of the glazing is facing south. For some reason (maybe it's in an historic district) we haven't been able to include exterior shading on the building. Here's an example of elimination parametrics for the building:



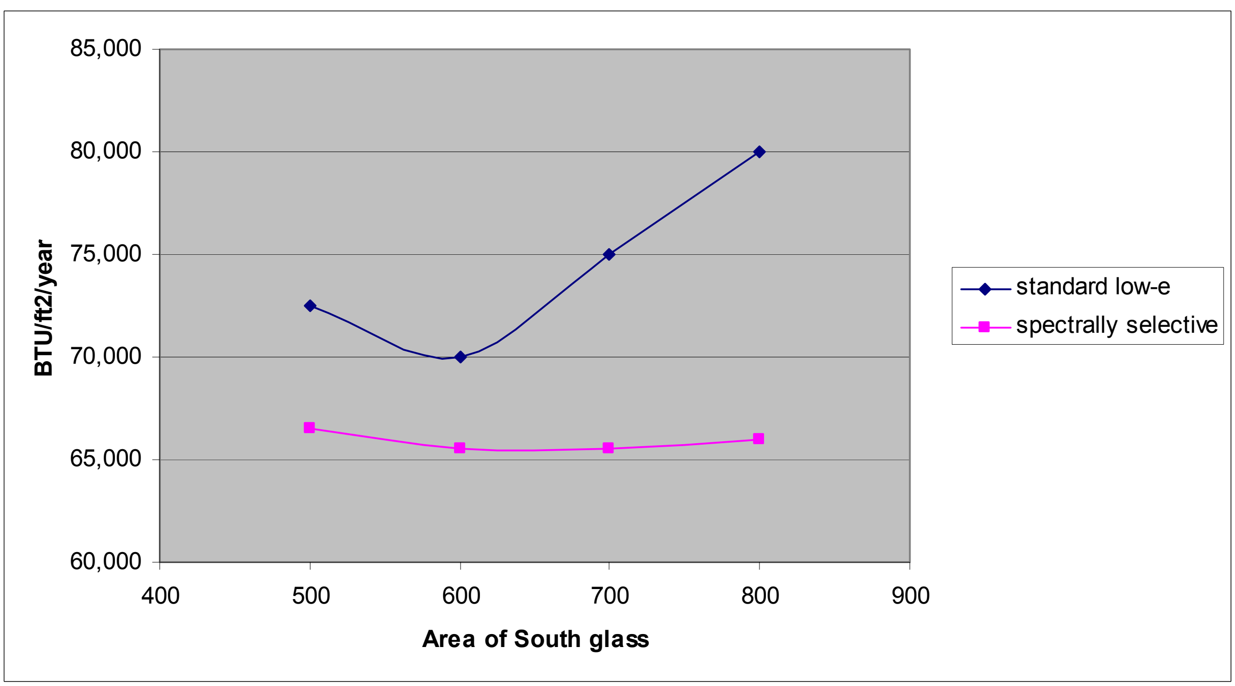
The larger the difference between the length of the bar for the Base Case and any subsequent bar, the more that component affects the overall energy use of the building. We can see from this chart that the biggest impact is from changing the Solar Heat Gain Coefficient (SHGC) of the window glass, which is the fraction of the energy incident on the glass that gets inside. What this result tells us is that if we set the solar heat gain through the glass to zero, the building's energy use would drop by 29%. This building's energy use is dominated by its cooling load, which is dominated by the solar heat gain through the window glass. The designer should look at the quantity and type of glass, since appropriate shading has been ruled out for other reasons. The next largest impact comes from setting the lighting energy to zero. This tells us to look at opportunities to reduce lighting wattage, use better lighting controls, and to see if we can increase effective daylighting without adding more cooling load due to solar gain.

We can see that increasing the insulating value of the walls, windows, and roof from the base case all have modest effects on energy use. This lets us know that additional investment in the insulation is not a priority compared to other strategies.

This result leads us to study whether we have optimized the type and amount of glass in the building, so we would do another type of parametric study. Here we will keep everything about the building constant, but vary first the area of glass in the model. The base case building has 700 ft2 of south glass. We'll choose to look at a standard low-emissivity, argon-filled glazing. The results might look like this:

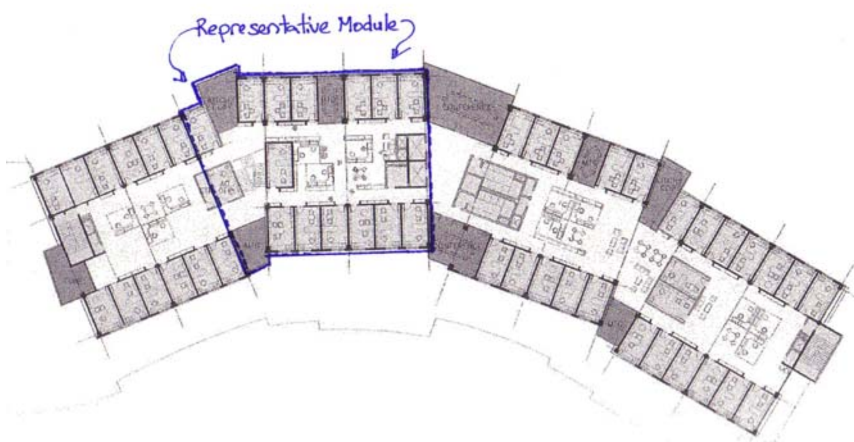


We can see that there is an optimum area of south glass at around 600 ft2. This may be because cooling load is reduced when the glass is reduced from 700 ft2 to 600 ft2, yet 600 ft2 is still sufficient to do the daylighting task well. Let's say that we'd really like the additional glass for other reasons, so we should look at a spectrally selective glazing that lowers the SHGC substantially, increases the R value slightly, and lowers the visible light transmission slightly.



The more efficient glazing has a different optimum area, and yields a lower energy use at every area studied. Cooling load is notably reduced, and daylighting is still effective. The added glazing comes at a cost, both in cost per ft2 of the glass, and in the additional window area. This study enables the designer to value the increased annual savings vs. the up-front added costs. Using energy modeling in this fashion often highlights how each additional increment of energy efficiency usually yields a smaller increment of savings. Recognize that sometimes savings accrue in other capital systems that offset the increased investment (an example would be envelope upgrades in a cold climate building that permit elimination of perimeter heating.)

In a large building with repetitive elements, one way to simplify the modeling process when doing parametric analysis is to only model a representative fraction of the building. On a recent project, a building with approximately 160,000 ft2 of office space was modeled by using one representative slice of the building that was 1/24th of the actual area.



4 - During the Construction Document phase, energy modeling allows comparison of the proposed design with the code minimum base case. This happens to some extent when we do the modeling for LEED, but the LEED system is hamstrung by using the ASHRAE 90.1 Energy Cost Budget Method, so you can't take credit for all the savings that occur over what might have been the true base case. Following 90.1's myriad of rules about what we must do for the base case and proposed case will under-estimate the real savings that can occur due to thoughtful design (see paper by Dan Nall at Austin 2002.) Outside of the LEED process, we can use modeling to look at the energy use reduction that results from *all* the strategies you choose to implement, including massing, orientation, HVAC system upgrades, novel control strategies, fan systems optimization, and glazing area optimization.

3.0 MODELING INPUTS AND ASSUMPTIONS

A model is an attempt to simulate the energy operation of (usually) an as-yet-unbuilt project. As such, there are many unknowns about that building which must be estimated and input into the model. A typical set of modeling inputs may include:

Location
- Climate data
- Interior conditions and setpoints

Envelope –
- Areas, orientations, solar absorptances, and U values of all opaque building surfaces
- Areas, orientations, Solar Heat Gain Coefficient, Visible light transmittance, U value, and shading of all glazing components
- Mass of building components
- Infiltration rates

Internal Gains –
- Lighting in Watts/ft2
- Plug loads in Watts/ft2
- People, sensible and latent (moisture) loads

Schedules –
- Lighting schedules
- Plug loads schedules
- Occupancy schedules

Systems –
- Heating system type – source, distribution, terminal units
- Cooling system type – source, distribution, terminal units
- Ventilation system type
- Fan and pump inputs
- Economizers and/or heat recovery systems
- Domestic hot water system
- Specialty systems (e.g., commercial kitchens)
- Renewable energy systems

There will be literally hundreds of inputs that need to be entered to build a model. Some user-friendly programs have built-in industry standard defaults that speed up early model creation. The responsibility for the accuracy of these inputs resides in different team members. The client must supply their best estimate of the occupancy of the building daily and seasonally, in detail. They must supply location data – weather data if there is no nearby standard weather station data, and any pertinent site features, such as shading of the building by topography, vegetation, or adjacent buildings. The client should supply a list of plug loads likely to be in the building and their frequency of use. Nameplate data for wattage of most plug-in equipment will be higher than what the equipment uses, so actual measured data is always more accurate (in one case the MEP engineer estimated over 10 Watts/ft2 for plug loads for a building yet the prospective occupants had a measured usage of 1 Watt/ft2 in their existing building. Making an error of this magnitude drastically oversizes the cooling system, adding useless capital cost). The architect must communicate the building envelope inputs, with special attention to unusual items such as high performance glazing, shading devices, or unusually lightweight or massive construction. The lighting designer should be asked to ballpark lighting wattage for the different occupancy types. The design team should discuss with the MEP engineer appropriate mechanical system types to put into the model.

If the modeler is the MEP engineer, that person must understand very clearly the difference between an annual energy use simulation, which seeks to model the building throughout an entire year with its *typical* usage, and design load modeling, in which the goal is to size the heating and cooling system equipment to handle the reasonably expected *peak* heating and cooling loads. Engineers tend to add safety factors in a lot of places, and the peak design loads they calculate, especially for cooling, tend to result in systems that are oversized (this is not news….) Oversizing has many penalties for the building owner, including higher capital outlay. The Architect and/or Owner who wants to protect the budget should look just as carefully at the inputs and assumptions for the design loads as for the annual simulation. Some things worth checking include:

- What are the assumed outdoor and indoor design conditions? If the peak is designed for an outdoor condition that occurs once a year for a few hours, and simultaneously the system is being asked to maintain 72F inside, an oversized system will be the result.
- Is this a building carefully designed to be daylit, yet the model has all the lights on at full tilt at the same time the building is experiencing peak solar input?
- Are there more people in the building than is reasonably possible because every space is calculated at peak occupancy, even though those people packing the conference rooms can't be in their offices at the same time?

Annual simulation attempts to predict the actual building operation, not its peak, so schedules and other inputs should reflect that objective.

The person for whom the model is being done (this may be the Owner or the Architect) should ask the modeler for a complete listing of all of the inputs that they have used for the model and check to see that they represent the proposed building accurately. Ask for a document that has a table for each major occupancy and all of the inputs for that occupancy. Ask questions pertinent to your building type – for example, ask how the model sets ventilation air quantities – is it varied by number of people in the building, or is it constant volume? The Owner should review the inputs before modeling is begun so that they can agree they accurately represent their intent.

Common errors to look carefully for are:

- plain old slipped-a-decimal-place data entry errors – 100 ft2 of glazing instead of 1000 ft2
- incorrect lighting and plug load power densities (usually too high)
- incorrect glazing characteristics
- people count is at peak in all spaces at once, which virtually never happens. An example of this is a dormitory in which all student rooms are fully occupied while all the public spaces are also set to peak occupancy. This may lead to the model calculating ventilation air at 3-4 times the actual amount needed by the occupants of the building.

The watchword of any simulation process is "garbage in, garbage out." The team needs to take joint responsibility to ensure that the inputs are reasonable. Don't get hung up on whether the office lighting will be 1.1 or 1.0 Watts/ft2 at this stage! I usually request the modeler to first produce the base case code building model. The reason for this is that the inputs are likely to be familiar and that getting a good baseline is a solid foundation for all the work yet to come. Also, the energy use of a code-minimum building is more likely to be familiar so the modeler can more easily evaluate whether the model is sufficiently accurate.

4.0 GETTING, AND VETTING, THE OUTPUT

OK, so the model is built, it's time to run it and see if we believe the results. Sometimes the output or conclusions we are presented with are rather far from physical reality. The output should be presented by the modeler in a form that can be read and understood by the Owner and the Architect. If the person producing the model sends a stack of printouts direct from the modeling software that exceeds the size of the Manhattan phone directory and requires the Rosetta Stone to decipher put it directly into your recycled paper pile and ask for a concise document written in English. The output report should include energy use month-by-month and annually for heating, cooling, DHW, mechanical system electrical consumption, lighting electrical consumption, plug load electrical consumption, and other electrical consumption (such as elevators). The report should show heating and cooling consumption by building energy use component - how much is due to walls, roofs, windows, infiltration, ventilation air, etc. This guides us to look for the areas where we can make the biggest savings. The report should include a table of areas for each building component (walls, roof, windows, etc.) as a quick check on the accuracy of the take-offs.

Getting the monthly output helps us vet the validity of the model. Does cooling energy rise in the winter vs. the summer? Something's probably out of whack. Getting component output also promotes insight. Is infiltration the largest load amongst the heating components? Unlikely to be true in a commercial building.

One of the most effective ways to vet the model is to become familiar with energy use benchmarks for typical buildings of the same use in a similar climate. Owners of multiple buildings can build a database of energy use by building type for both the thermal and electrical components of energy use. Architects can investigate the energy use of buildings they have designed in the past (this is good practice in any case, as it serves to inform the goal setting process in the formative stages of the project.) Databases of building energy use are available from the government (EPA's Target Finder). Some good benchmarks for quickly understanding whether the model is on track include:

- Total annual energy use per ft2.
- Annual energy use per ft2 for heating, cooling, and electricity.
- CFM of ventilation air per person of expected occupancy
- Ft2 per ton of cooling

If the output seems out of bounds based on the past experience, then a more detailed look at the model output is in order. Can a physical explanation be constructed for what seem to be anomalous results? On a cold climate institutional building the modeler concluded that there was no benefit to wall insulation greater than R-6. I asked for, and tried to generate myself, a physical explanation for this unlikely conclusion. No one was able to explain this result. A simple hand calculation of heating energy saved by going from an R-6 wall to an R-19 wall during the building's unoccupied hours yielded energy savings seven times what the model showed. Something here was off, and no one could explain it physically. Usually persistence will turn up the error.

Once the base building model is operational and yielding believable results, then it's time to set the items to be examined parametrically. The decisions that need to be made in the proposed building are continually informed by the powerful ability of the robust model to answer the What If? questions. It has the potential to be a highly interactive process that teaches all involved, while funneling the Owner's resources to the places where the most effect can be made.

5.0 ACCURACY OF THE MODEL

As the saying goes, the map is not the territory. No model will accurately predict the actual energy use of the building; there are just too many variables to control. Among them are:

- The building construction may not be exactly as drawn; especially as regards the prediction of air leakage if that is a significant factor (as it can be in skin-dominated buildings.)
- The occupants will use the building differently than predicted – more hours, or less equipment, or something similar.
- The model uses a typical year climate model and extreme years may vary 20-30%.

The value of the model is in comparing alternate schemes and seeing the differences in energy use that result. The differences will tend to be more accurate than the absolute values. Don't sweat the petty things (or was it don't pet the sweaty things?)

6.0 LIMITATIONS OF THE SOFTWARE

There are many different software packages out there. Some are sold by vendors of HVAC equipment, some are free from the government or electric utilities, and some are privately written and sold. None are perfect, and it's important to understand their unique limitations.

As much as possible, know whether the software proposed for modeling is appropriate for the building that is going to be created. If a good portion of the building will be below grade, does the software handle that well? If daylighting is a key strategy, will the model have enough daylight modeling capability to be able to turn lights down when daylight is available? If the building will use advanced HVAC systems, such as structurally integrated radiant heating and cooling, can the software model this explicitly (very few can.) Will the model produce comfort criteria such as Mean Radiant Temperature in occupied spaces? Can it model natural ventilation? Enthalpic heat recovery? The majority of the modeling software commonly used will have a hard time with much of the above, so the rule is buyer beware – make certain you know what you're getting before you commit significant resources to the modeling effort.