EFFECTIVE EARLY COLLABORATION BETWEEN ENGINEERS AND ARCHITECTS FOR SUCCESSFUL ENERGY-EFFICIENT DESIGN

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ABSTRACT

During the design process, the energy analyst is often included too late to influence the outcome of the design, leaving little opportunity for engineers to collaborate with architects in the design of energy efficiency aspects of the building envelope and systems that affect heating, cooling, and ventilation loads.

The authors of this paper have developed several modeling and graphical techniques to optimize building envelope and system components early on in the design process. During this early collaboration the emphasis is especially on factors affecting choices of window glazing and shading, solar heat gain coefficients, and wall insulation to enhance energy-efficient architecture. More importantly, the presentation of results supported by meaningful visual representations has shown itself to be an effective way to to communicating key recommendations to design team members.

INTRODUCTION

When it comes to engineers working effectively with architects, there are two broad categories of energy analysis where collaborating early on in the design process can significantly impact the ultimate energy efficiency of the final building. In both these cases, energy modeling is critical to getting useful results.

- **Energy code compliance.** Work in this area typically deals with questions of envelope components and ways to ensure the building meets state or local energy code requirements.
- **Optimizing energy efficient systems.** Work in this category goes beyond mere envelope evaluation and addresses the broader question of what constitutes an energy-efficient building.

If the energy analyst is engaged at the beginning of schematic design (SD), there is plenty of opportunity to consider alternate design options and maximize energy savings.

However, if the energy analyst does not get involved until the end of design development (DD) or even later during the construction documentation (CD) phase, many key design decisions will have already been fixed. At this point energy modeling becomes a mere design validation or "accounting" exercise to document whatever energy savings features might have been incorporated into the design. This late-stage involvement is especially a problem if a project is trying to maximize LEED® energy points. By this time, many opportunities for efficient design will have been lost.

Sometimes the objectives of maximizing LEED points by minimizing energy costs can conflict with other requirements, such as the architect's desire to maximize glazing.

Our job as energy analysts is to inform design decisions early, even though questions about many energy efficiency options cannot be answered accurately or concisely without a complete building model.

Just as important as getting the energy analysis done at appropriate times is the challenge of communicating useful and meaningful results to the design team. This paper address the kinds of analysis that helps inform decisions about energy efficiency early in the design. The paper also describes ways to effectively communicate these results to architects and the design teams.

ENERGY CODE COMPLIANCE – A PRIMARY FOCUS ON THE ENVELOPE

In Oregon, as in many states, there are three paths to energy code compliance:

Prescriptive. This path is primarily a checklist of envelope components, lighting power densities, HVAC performance efficiencies, and service hot water requirements. There is also a maximum window-to-wall ratio (WWR or percent glazing) of 40%. To pass code, all aspects of a building must comply with these prescriptive requirements.

Simplified Trade-Off Analysis (STA). This approach allows trading off of "better" walls for "bad" windows. In effect you can compensate for glazing that doesn't meet prescriptive shading coefficient or U-factor values with improved wall insulation. The STA is all about the envelope, and doesn't consider other aspects of the building design that influence loads, such as lighting power densities, daylighting, or the HVAC systems. In Oregon, we use CodeComp, a software analysis tool, to evaluate compliance. Curtain wall window systems typically cannot achieve a U-factor much better than 0.40. For this reason, most high-rise buildings are pushed into the STA approach for compliance, since even if they can be designed with less than 40% glazing, they cannot meet the prescriptive 0.37 U-factor requirement for the windows.

Whole Building. With this approach, the actual building as designed must be modeled according to some very specific rules then compared to a code-equivalent reference building that is also modeled by the same rules. The modeling rules are very restrictive and difficult to implement. For example, the modeling must be done in DOE-2.1E, which compels an analyst to use line-by-line BDL input in an INP file. Relative to the STA approach, the whole building analysis is very time consuming and therefore very expensive. Only a handful of Oregon projects have ever resorted to this approach.

These three compliance paths – prescriptive, trade-off and whole building – are like successive filters...if you can't pass with one, you proceed to the next.

CodeComp – Simulation to analyze total energy use compared to a reference building

A straightforward prescriptive compliance approach is most common for relatively simple design/build spec projects. However, our clients usually follow the STA (or "trade-off" approach) and then the energy analysis work gets interesting. One of the most common questions asked early on is: "How much glazing can we design into this building and still comply with code?"

Of course, the answer is not as simple as giving our architect clients a specific percentage. It turns out the answer depends on multiple factors including the type of windows chosen, which side of the building the windows are placed on, and whether windows are shaded. The best way to answer the question is to use the compliance tool itself, CodeComp, to perform a range of "what if" analyses and characterize a complete answer.

CodeComp is a software analysis tool developed by Architectural Energy Corporation that runs on a DOE-2.1E engine to analyze the envelope components of a building. The CodeComp interface is easy to use, organizing the building envelope details into a hierarchical structure of floors, opaque external surfaces and transparent windows associated with each wall on each floor, by orientation. The surfaces between floors are treated as adiabatic so only the highest level has a roof and the lowest level has a floor. Most of the work in developing CodeComp inputs focuses on geometric take-offs to determine the height and width of the glazing and the total wall areas for each building orientation at each level. The software also takes into account window shading where applicable.

The first point of critical collaboration between the energy analyst and the design architects is in getting accurate area take-offs for the CodeComp inputs. Often, the first question asked is how to measure the window area, and the answer is pretty direct: you must include the window frames as part of the window area when measuring the take-offs.

A secondary effort is the specification of the layers and properties of the materials that make of up the wall assemblies. Finally, detailed inputs of window characteristics, including shading coefficients and U-factors, are also included. By the time you're done creating a model in CodeComp, you've defined all the important energy-related characteristics of the building's envelope components.

Behind the scenes, CodeComp generates a reference, code-equivalent building referencing the design building for its parameters. Once you perform a simulation, CodeComp determines the difference between the heating and cooling loads of the reference building compared to the design building. Without going into detail about all the assumptions and defaults, it is enough to say the key outputs for of any CodeComp analysis are the heating and cooling margins, reported in millions of BTUs per year (MBtu). For a building to pass compliance, both the heating *and* cooling margins have to be positive. In other words, the projected heating and cooling loads for the design building must not exceed the heating and cooling loads of the reference building.

Selecting a window shading coefficient – what are my choices?

It is in the iterative analysis of trying to get a building to pass CodeComp in both heating and cooling where the collaboration with architects pays off. With all the envelope data input into CodeComp, it becomes a very quick exercise to analyze a range of key input alternatives. Typically, the main variables we evaluate are window-to-wall ratio, shading coefficient (or solar heat gain coefficient–SHGC), window assembly U-factor, and vertical and horizontal window shading for different wall faces or orientations.

It should be noted that daylighting, as an energy-efficiency option, is not treated as a factor in envelope compliance analysis. It would be interesting to evaluate the effect of shading coefficient, window shading, or window-to-wall ratio on diminished daylighting visual transmittance. But such analysis is not within the scope of the project work reported here.

However, in high-rise condominiums, which are the main buildings represented in the results of this paper, daylighting advantages are typically dwarfed by the effects that window area and shading coefficient have on heating and cooling loads. In other building types, those with larger lighting loads – offices for example – daylighting might compete with lower WWR or shading coefficient for appreciable energy cost savings.

Figure 1 is an example of a CodeComp analysis for a high-rise condo where we analyzed the effect of ranging the shading coefficient (SC) on the overall heating and cooling loads. There were several goals, and these were not necessarily in concert: to choose an aesthetically attractive glass, meet code compliance, and save energy. Given the preferred glass and a fixed window-to-wall ratio, as selected by the architects, the question was: What will it take to meet compliance? Figure 1 graphs the CodeComp results for varying shading coefficients, with blue and red lines for the cooling and heating margins, respectively. Here the window-to-wall ratio and the U-factor for the glazing are both held constant. In order to pass CodeComp, the heating and cooling margins must *both* be above zero. In other words, to pass at a given shading coefficient, if you draw a vertical line at a given shading coefficient, the line must intersect the both red and blue line *above* the X-axis zero line.

For this project, the shading coefficient needed to be between 0.36 and 0.42 to pass code. These results provided guidance to the architects for what range of shading coefficient would be acceptable for the window type selected. For a different window with a different U-factor, the graph would look significantly different.

Figure 2 plots pairings of window assembly U-factors and WWR levels (percent glazing), showing how these combinations affect heating margin as determined by CodeComp analysis.

For this building, a mixed-use high-rise with apartments on most of the upper floors, heating load was the main concern, so cooling margin was not plotted. Any points to the right of zero in the Y-axis show as passing; points to left are failures. The map shows clearly that as the window-to-wall ratio increases for a particular U-factor the passing margin shifts to the left, and it gets harder and harder for the building to pass compliance. For very low U-factors, as low as 0.34, the building can accommodate more than 60% WWR and still pass. But for U-factors as high as 0.46, the WWR would have to be lower than 40% for the building to pass.

The message here, from the energy analyst to the architect, is this: Knowing which options are acceptable *before* making your glass selection will help avoid costly changes of the glass type later on.

In Figure 3, a set of parametric analysis results (Runs A through M) describe the relative impacts of a range of changes to the window components of a building's envelope, how they affect both the cooling peak and total cooling energy relative to the current design. Various values of SC, U-factor, and percent glazing are compared on the same chart. With this information architects and design engineers can readily see which changes have the most significant effects.

General glazing trend analysis

Once the basic geometry of a building is fixed, architects have several options for adjusting the heating and cooling margins, and they can choose among alternatives or combinations of alternatives:

- Reduce the glazing, sometimes replacing vision glazing with spandrel, which is treated as a wall type rather than as a window;
- Change the window U-factor, sometimes going with triple glazing or argon-fill;
- Increase or decrease the shading coefficient;
- Include overhangs or shading for the windows;
- Modify the insulation levels of the walls.

In many cases, architects find that increasing the wall insulation might help with the heating margin but adversely affect the cooling margin. Or, reducing the solar gain with a lower shading coefficient might benefit the cooling margin, but it also lessens the contribution of solar insolation so the heating load is increased.

Using CodeComp, we've found that once a building reaches about 48% WWR, the simple trade-off options of wall insulation for window improvement – with either SC or U-factor, or both – become narrower, and the maximum WWR peaks at about 55%. At very high levels of glazing it becomes problematic to get a building to pass compliance with window/wall trade-offs. At some threshold, no matter how much you change the wall insulation levels or reset the window shading coefficient, a building will not pass code compliance. It is this kind of information that architects need early on in the design, before wall assembly and window details are fixed.

Of course, general trending of these kinds of results is predicated on the type of building analyzed. Most of our analysis has been conducted on high-rise condos. If a building has high internal gains, for example, satisfying heating loads will not be a problem, so compliance analysis would focus on lowering shading coefficients, enhancing shading, and applying other factors to reduce cooling loads.

In hospitals, where ventilation loads dominate because of large air change requirements, envelope changes often have very little relative impact on overall energy use compared to HVAC control measures.

Again, envelope code compliance is upstream from HVAC efficiency considerations. This point alone reinforces the principle that a very energy-efficient building is one built on a design that integrates architectural and engineering considerations. In essence, the principal of minimizing loads first, with effective architectural design, takes precedence. Only after envelope loads are minimized does it make sense to begin optimizing lighting and HVAC systems.

TRADE-OFFS: EFFICIENCY VS. COSTS

Beyond early analysis and collaboration for energy code compliance, architects and building owners are interested in the cost impacts of building system improvements, especially relative contributions to the LEED® Energy and Atmosphere Credit 1 points. Because LEED emphasizes energy cost savings instead of just Btu or kWh reductions, whole building modeling is required to get useful results.

Early on in the design process, we use simplified models, such as those that can be created with the eQUEST Wizard. Realistically, it is not possible to get very accurate results when a building is still at a very conceptual stage of design. However, we can and do analyze results on a comparative or relative basis to give architects information they can use.

In one study, a more general energy analysis of a renovated historic warehouse looked at the impact on energy costs from varying window parameters for various floors and on different sides of the building. The results are shown in Figure 4. In this analysis we examined the effects of varying shading coefficient while maintaining a constant overall U-factor (frame and glazing combined) of 0.44 Btu/hr-sf-°F. The energy cost savings of the changes in shading coefficient are relative to the point at which all the curves intersect, represented by an ASHRAE 90.1-2004 code equivalent shading coefficient of approximately 0.45.

Here are some conclusions that can be drawn from the results in Figure 4:

- Reducing the shading coefficient to less than 0.45 improves the energy cost savings for LEED.
- Increasing the shading coefficient to greater than 0.45 reduces the energy cost savings for LEED.
- Reducing the shading coefficient is more critical on the 5th floor penthouse windows for the LEED energy cost savings. (For the same shading coefficient reduction, the energy cost savings for the 5th floor is more than the savings on the 3rd and 4th floors combined).
- The shading coefficient on the north glazing has little to no impact on the whole building energy cost savings.
- Changing the shading coefficient has the most dramatic effect the south, west, and east windows, but a negligible effect on the north windows.

Although you would have predicted some of these results, or at least the trends, it's the quantitative impacts that matters to the building owner.

With these kinds of analysis results, our clients are able to make choices about the relative trade-offs of investing in one type of window over another, by location and orientation. Just as important, early decisions about the impacts of window selection helps architects and owners maximize LEED points, which is often a key objective in energy efficient design.

The next set of results, as depicted in Figure 5, map a set of potential window design options and focusing on energy costs for a mixed use high-rise complex in Seattle. Figure 5 indicates combinations of SC and U-factor for three key design points: applicable combinations corresponding to Seattle city code, ASHRAE 90.1-2001, and the preferred design.

Using the key and a color spectrum to show gradations, architects are able to make very quick visual evaluations of the relative impacts of adjusting their design choices. When trying to minimize energy costs, which is a goal of LEED, this kind of color detail makes it easy to determine the impact of window design changes.

The analysis of early design options isn't limited to just the envelope. At the beginning of schematic design (SD) ecocharrettes are often held to brainstorm ideas for energy efficient design. We typically prepare pie charts, like the one shown in Figure 6, that show the relative percentage of energy by end use in buildings similar to the one under consideration. We adapt end use data from utility sources or from the CBECS database, available from the US DOE, Energy Information Administration.

The main value of this kind of graphical information is how well it shows which end uses have the greatest potential for energy efficiency improvements. For example, it often comes as a surprise that space heating uses five or six times the amount of energy used for space cooling in the Pacific Northwest. Once we explain that end use energy for heating or cooling is the energy it takes to serve the load, and how loads differ from end uses, most of the ecocharrette audience leaves with a more realistic expectation of the opportunities for energy use reductions.

In Figure 7, a parametric simulation analysis of a range of HVAC systems shows the relative change in energy costs, on per sq.ft. basis, for each type of system. These systems include fan coil (FC) units, water source heat pumps (WSHP) and ground water heat pumps (GWHP), radiant heating, and package terminal air conditioning (PTAC) systems. Even more interesting, especially to the building owners, is the contribution of each system to LEED energy points. For example a ground water heat pump (GWHP TT model) can achieve the equivalent of nearly 2.5 LEED energy points using a relatively small amount of annual end-use energy, about $0.10 per sq.ft. The TS model of the water source heat pump (WSHP TS), however, achieves about 1.0 LEED energy point but its annual costs in energy use is more like $0.15 per sq.ft.

CONCLUSIONS AND RECOMMENDATIONS

Although in principal, it is easy to conjecture the general trends resulting from combinations of WWR, SC, and U-factors, such qualitative evaluations are usually not specific enough to guide architectural decisions early in the design.

Using the simulation and modeling techniques we've just described, applying CodeComp as compliance and an analysis tool for example, we've been able to provide early and specific recommendations to architects on key design parameters that affect building envelope loads. In particular, results have addressed optimum window shading coefficients, trade-offs between shading coefficients and wall insulation or window U-factor, as well as the implications of reducing or increasing the window-to-wall ratio.

Furthermore, using simplified models of buildings before detailed design is completed allows energy analysts to compare alternatives. Information about relative energy costs and energy savings is useful to architects and owners, but only if the information can be reported in a meaningful way. The graphics and analysis techniques we have used help to inform key design decisions early on. The combination of both the modeling techniques and innovative, visual information design has led to better cooperation between engineers and architects early in the design process, and ultimately to more efficient buildings as a result of this collaboration.

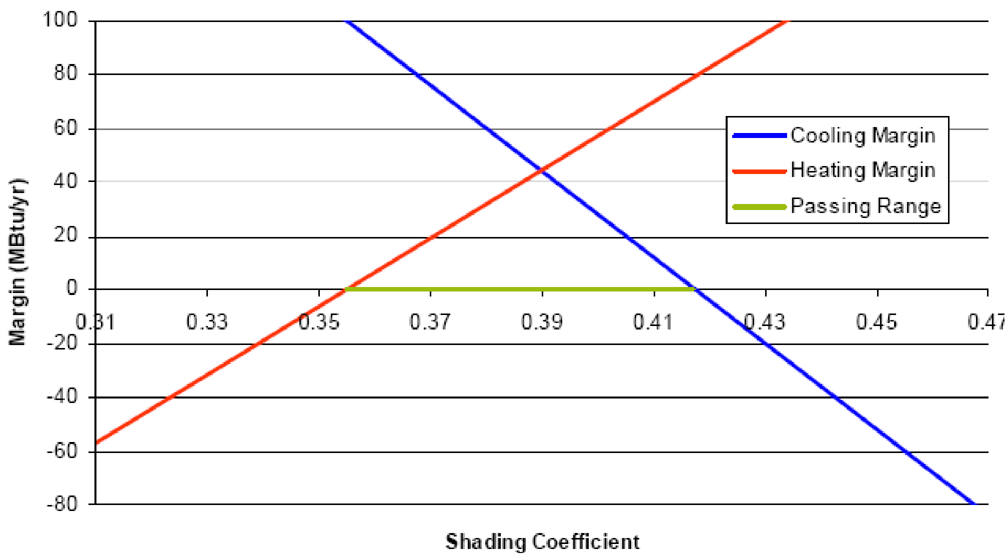

Figure 1 – Heating and Cooling Margins (MBtu/yr) vs. Shading Coefficient

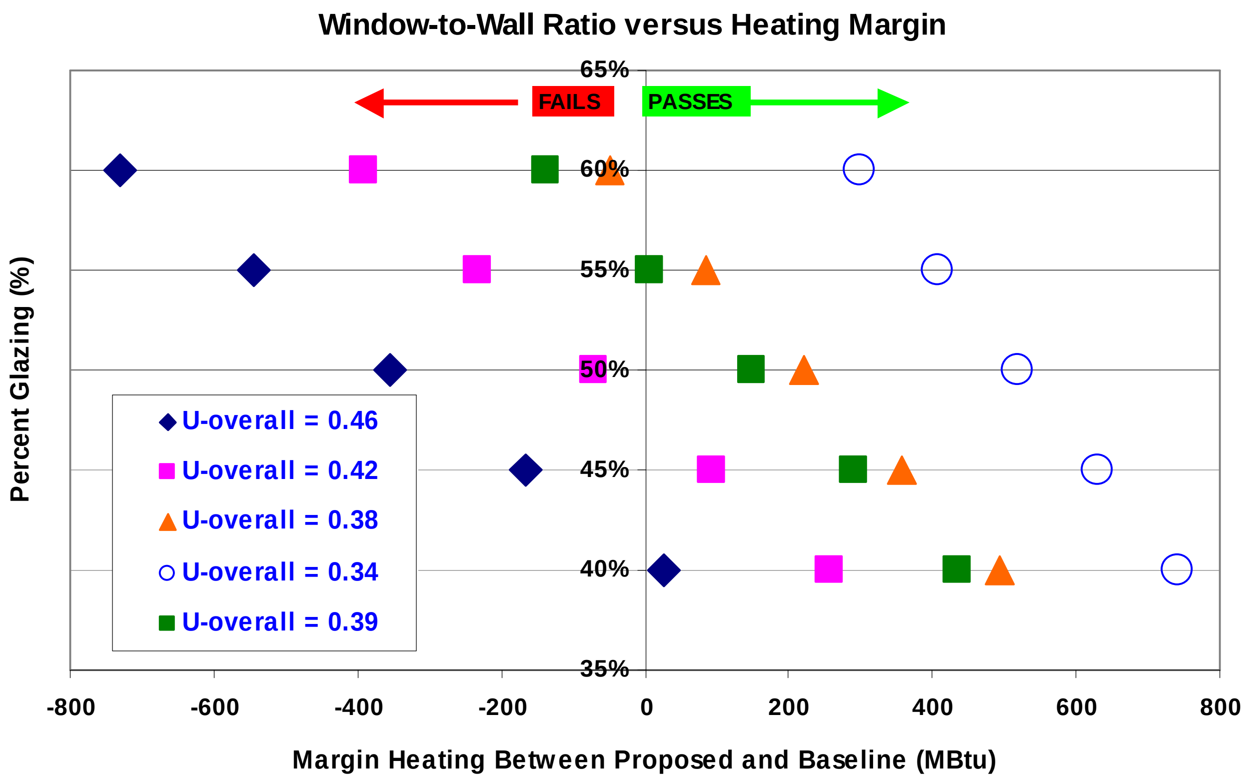

Figure 2 – Window-to-Wall Ratio (WWR) vs. Heating Margin (MBtu/yr)

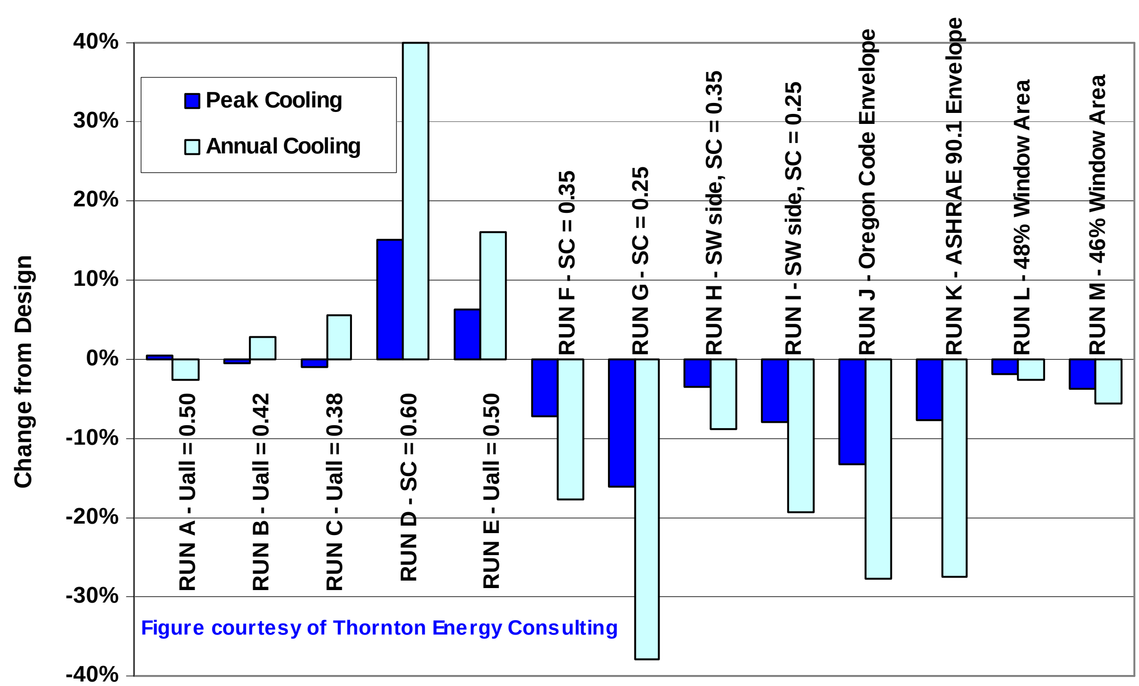

Figure 3 – Percent Change in Cooling Energy and Peak Cooling for Various Envelope Components

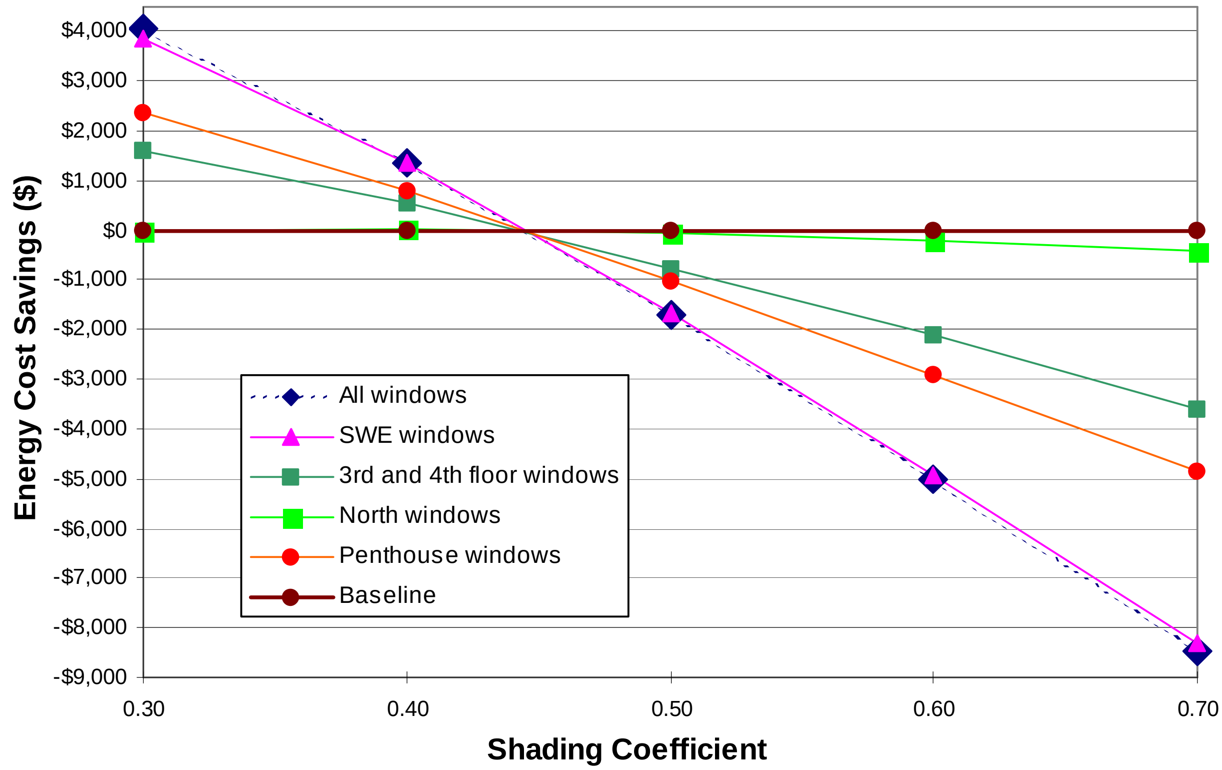

Figure 4 – Energy Cost Savings ($) vs. Shading Coefficients for Various Window Options

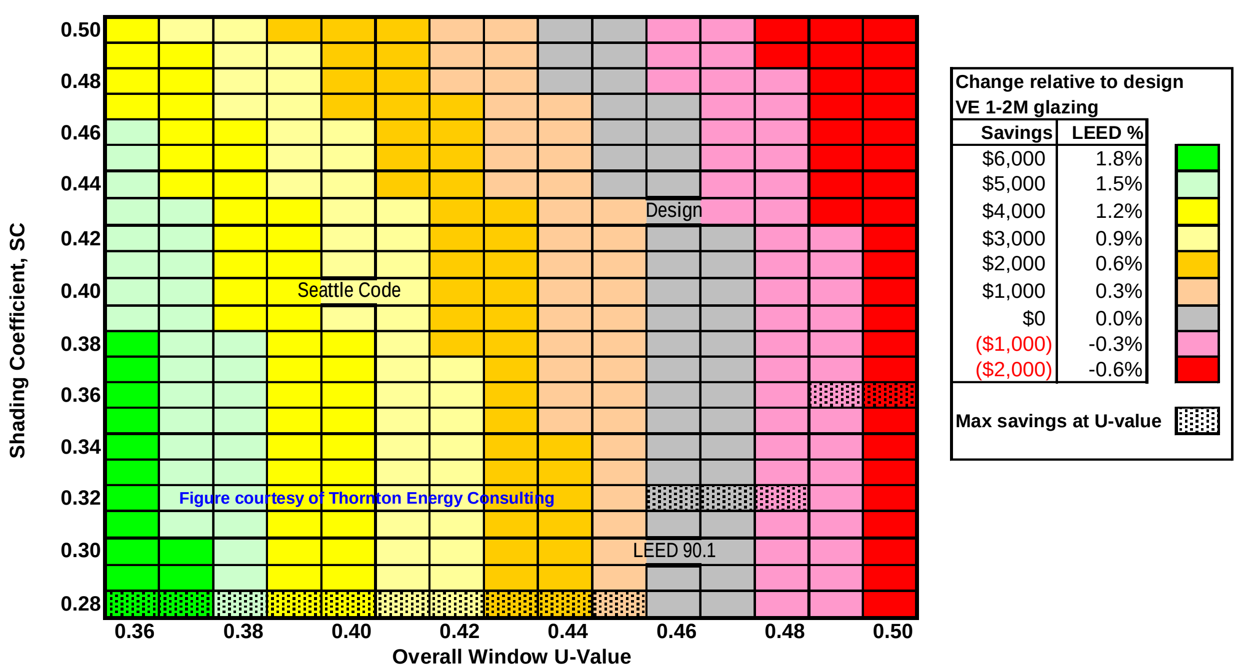

Figure 5 – Relative Cost Savings and LEED Percentage Changes for Various Combinations of Shading Coefficients and Overall Window U-Values

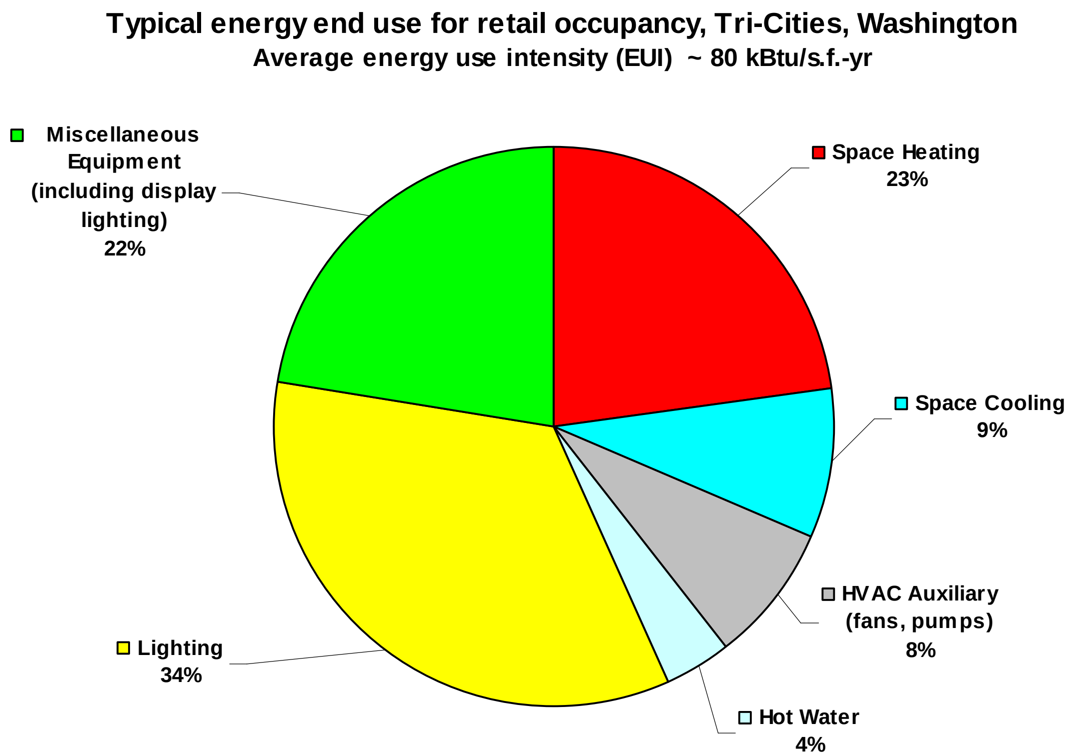

Figure 6 – Typical Energy End Uses for a Sample Building

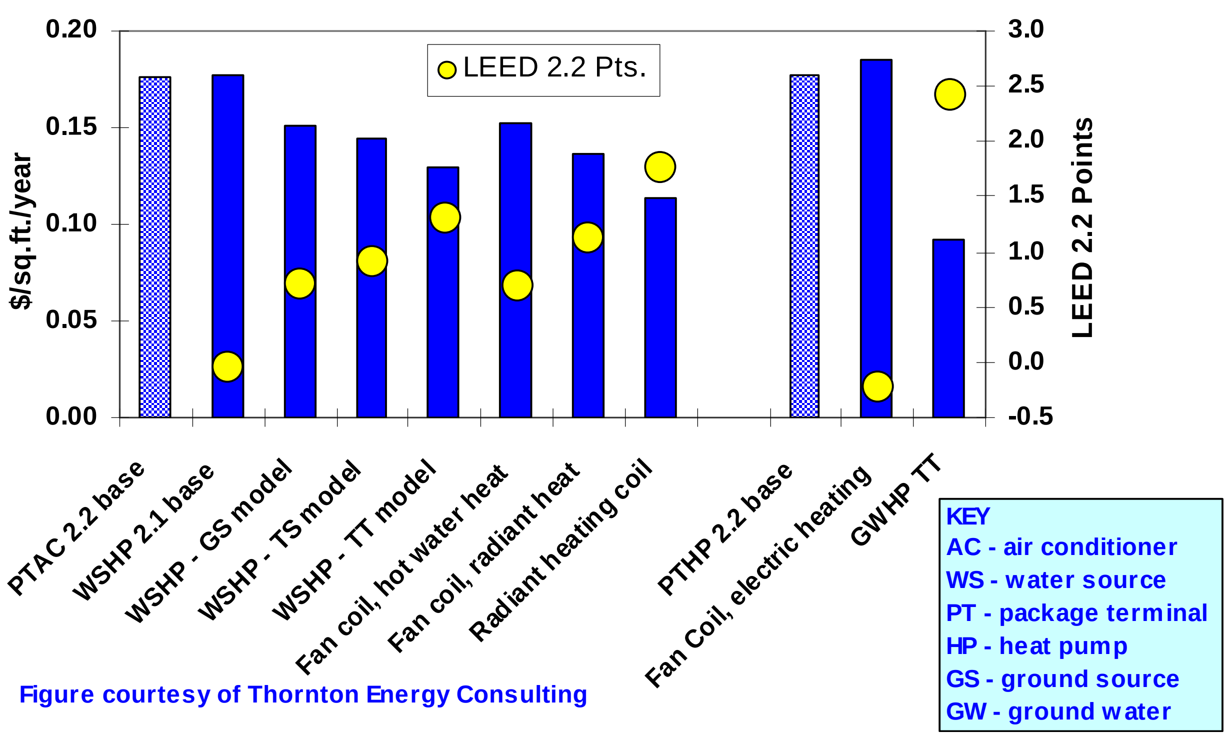

Figure 7 – Energy Use ($/sf-yr) and Applicable LEED-NC 2.2 Points for Several HVAC Systems