

BEopt: Software for Identifying Optimal Building Designs on the Path to Zero Net Energy

Preprint

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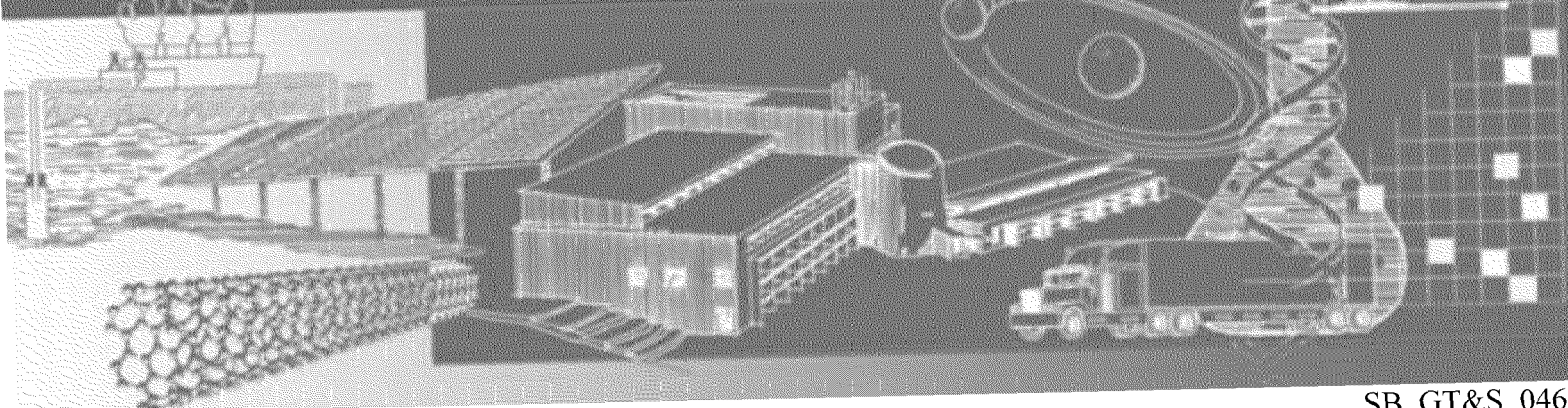
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BEOPT: SOFTWARE FOR IDENTIFYING OPTIMAL BUILDING DESIGNS ON THE PATH TO ZERO NET ENERGY

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ABSTRACT

A zero net energy (ZNE) building produces as much energy on-site as it uses on an annual basis, using a grid-tied, net-metered photovoltaic (PV) system and active solar. The optimal path to ZNE extends from a base case to the ZNE building through a series of energy-saving building designs with minimal energy-related owning and operating costs.

BEopt is a computer program designed to find optimal building designs along the path to ZNE. A user selects from predefined options in various categories to specify options to be considered in the optimization. Energy savings are calculated relative to a reference. The reference can be either a user-defined base-case building or a climate-specific Building America Benchmark building automatically generated by BEopt. The user can also review and modify detailed information on all available options in a linked options library spreadsheet.

BEopt calls the DOE2 and TRNSYS simulation engines and uses a sequential search technique to automate the process of identifying optimal building designs along the path to ZNE. BEopt finds optimal and near-optimal designs along the path based on *discrete* building options reflecting realistic construction options. BEopt handles special situations with positive or negative interactions between options in different categories.

The BEopt software includes a results browser that allows the user to navigate among different design points and retrieve detailed results regarding energy end-use and option costs in different categories. Multiple cases, based on a selected parameter such as climate, can be included in a BEopt project file for comparative purposes.

1. BACKGROUND

1.1 Types of Zero Energy Buildings

Historically, fully autonomous zero energy buildings have been built independent of any connection to the utility grid. In a new approach, the zero *net* energy building promises more widespread applicability. The ZNE building uses grid-tied, net-metered PV and active solar to produce as much energy on-site as it uses annually.

1.2 Source versus Site Energy Accounting

ZNE can be defined in terms of site energy, used at the building site, or source energy (sometimes called primary energy). Source energy provides a metric for assessing total energy use when dealing with multiple fuel types. From a societal point of view, source energy better reflects the overall consequences of energy use and is appropriate for ZNE buildings analysis. For electricity purchased from a utility, site energy can be converted to source energy to account for power plant generation efficiency and electrical transmission and distribution losses. The source-to-site energy ratio for electricity typically has a value of about 3, depending on the mix of electrical generation types (coal-fired, natural gas combined cycle, nuclear, hydropower, etc.)

2. THE PATH TO ZERO NET ENERGY

Energy and cost results can be plotted in terms of annual costs, the sum of utility bills and mortgage payments for energy options, versus percent energy savings, as shown in Figure 1. The path to zero net energy extends from a base case (e.g., a current-practice building, a code-compliant building, or some other reference building) to a ZNE

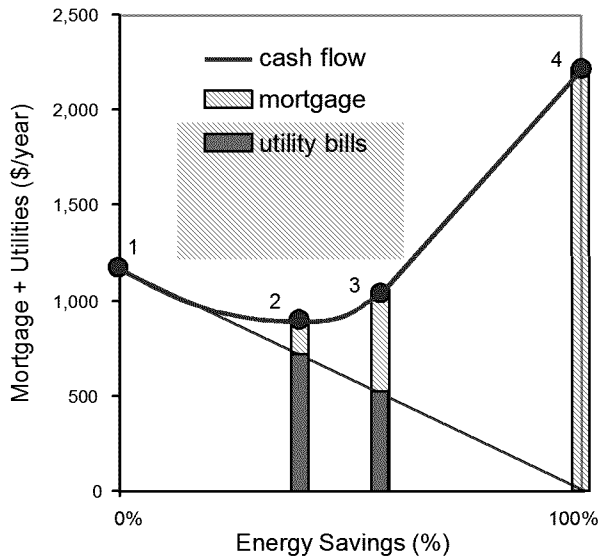


Fig. 1: Conceptual plot of the path to ZNE.

building with 100% energy savings. The optimal path is defined as the lower bound of results from all possible building designs (i.e., connecting minimal cost points for various levels of energy savings). Alternatively, net present value or other economic figures of merit could be shown on the y-axis.

Points of particular significance on the path are shown in Figure 1 and can be described as follows. From the base case at point 1, energy use is reduced by employing building efficiency options (e.g., improvements in wall R-value, furnace AFUE, air conditioner SEER, etc.) A minimum annual cost optimum occurs at point 2 (assuming the minimum does not occur at the base case). Additional building efficiency options are employed until the marginal cost of saved energy for these options equals the cost of producing PV energy at point 3. From that point on, energy savings are solely a result of adding PV capacity until ZNE is achieved at point 4.

3. BEOPT SOFTWARE

BEopt is a computer program designed to find optimal building designs along the path to ZNE. In addition to an optimization search, BEopt includes: 1) a main input screen that allows the user to select from many predefined options, those to be used in the optimization, 2) an output screen that allows the user to display detailed results for many optimal and near-optimal building designs, and 3) an options library spreadsheet that allows a user to review and modify detailed information on all available options. These BEopt interface components (inputs, library and outputs) are the subject of this paper.

The main input screen allows a user to select from predefined options in various categories (e.g., wall type, ceiling type, window glass type, HVAC type, etc.) to specify options to be considered in the optimization. The user can also review and modify detailed information on all available options and the Building America Benchmark (1) in a linked options library spreadsheet.

BEopt calls the DOE2 (2) and TRNSYS (3) simulation engines and automates the process of identifying optimal building designs along the path to ZNE using a sequential search technique (4). At each step along the path, BEopt runs individual simulations for all user-selected options and searches for the most cost-effective combination of options.

The BEopt sequential search technique has several advantages. First, it finds intermediate optimal points along the entire path (i.e., minimum-cost building designs at different target energy savings levels, not just the global optimum or the ZNE optimum). Second, *discrete* rather than *continuous* building options are evaluated, reflecting realistic construction options. Third, multiple near-optimal designs are identified at each particular energy savings level, providing design alternatives.

BEopt has the ability to handle special situations caused by interactions between options. Special situations with negative interactions are handled by looking back along the path and continually re-evaluating previously rejected options (to properly identify the potential of large-savings options and options involving trade-offs between categories). Positive interactions between categories are accommodated by allowing the user to define combined options in BEopt (to ensure that such potentially synergistic combinations are evaluated during optimization).

Multiple user-defined cases can be included in a BEopt project file. Multiple cases are often used to analyze building performance as a function of climate. Cases can also be used to study how building performance is affected by economic parameters, PV system characteristics, or the options selected for optimization. Up to 20 cases can be defined, with case tabs displayed along the bottom of the screen. Once an optimization has been completed, each case contains input screens and an output screen.

The main output screen includes a results browser that allows the user to navigate among the results associated with each (optimal and non-optimal) building design simulated during optimization. For each building design, the browser will display detailed results regarding energy consumption, costs, and options. If multiple cases exist in a project file, a Combined Graphs output screen will be available.

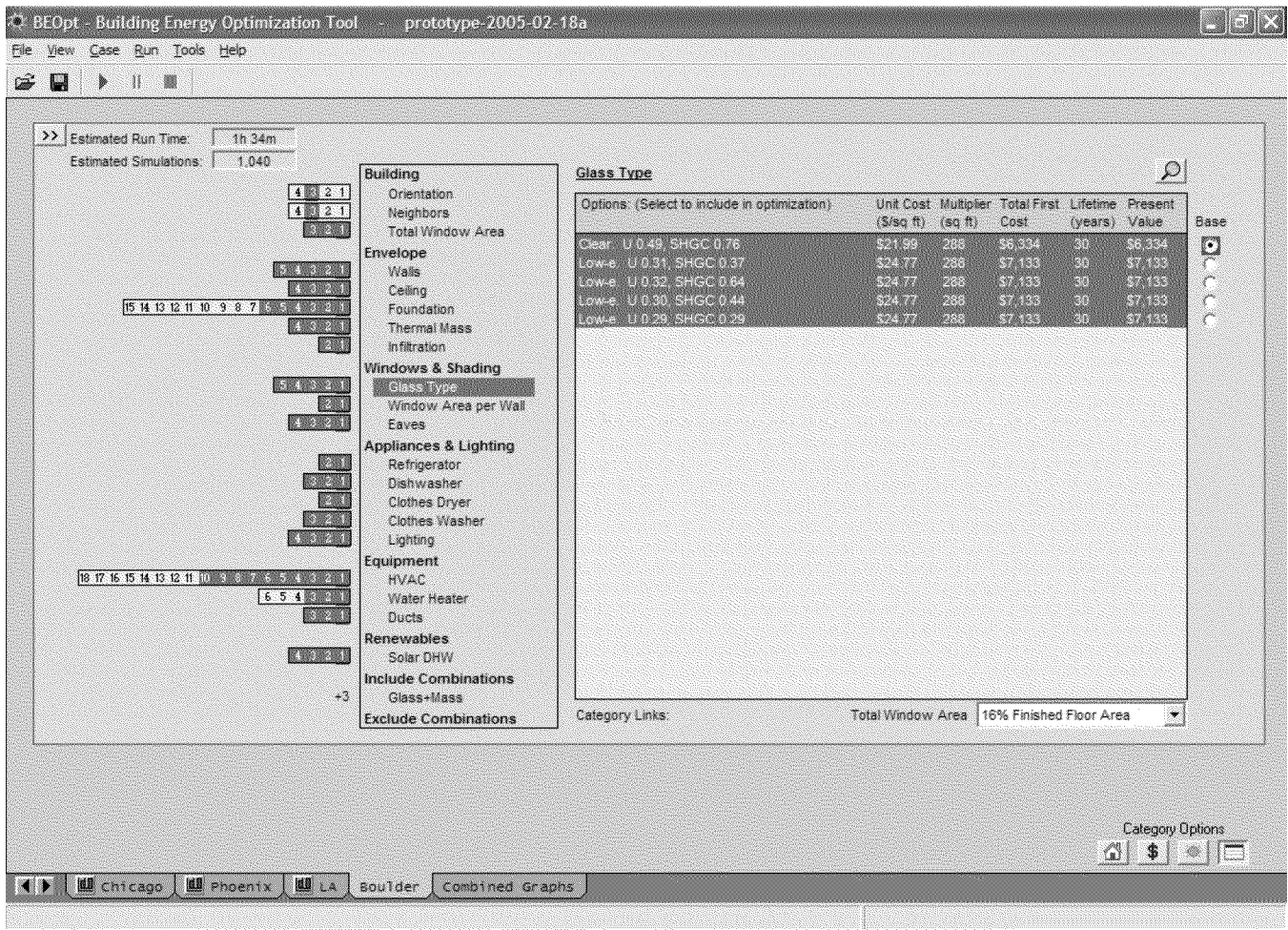


Fig. 2: BEOpt main input screen.

4. INPUT SCREEN (OPTION SELECTION)

Upon opening a project file, BEOpt scans the options library spreadsheet and loads categories and options associated with the project (Figure 2).

Option categories are divided into eight groups: Building, Envelope, Windows & Shading, Appliances & Lighting, Equipment, Renewables, Include Combinations, and Exclude Combinations. Selecting a category causes the options in that category to be listed in the display window. The user can then select options in each category to be included in the optimization. The summary matrix on the left side of the screen shows currently selected options by option number, and the estimated number of simulations and run time for the optimization are displayed.

The radio button that is selected and highlighted in red designates the option included for the user-specified base case. Detailed information on all options can be viewed and modified by selecting the magnifying glass button located at

the upper-right corner of the options box. This will open the options library (described later).

A user may want to select only a single option in a particular category to specify a building characteristic. For example, if the building site dictates the building orientation as east, only the east option needs to be selected. However, if various orientations are possible, multiple options could be selected for BEOpt to consider during optimization.

In other situations, subsets of options may be mutually exclusive. In the Foundation category, for example, options exist for slab on grade, crawl space, and basement configurations. If slab on grade is the desired foundation type, only options of this type should be selected. Ultimately, the user chooses whether or not subsets of options should be treated as mutually exclusive or not. For example, should the optimization include all space heating and water heating equipment options (both gas and electric) or should only electric options or only gas options be considered? Performance characteristics of different options may also determine their selection (or de-selection).

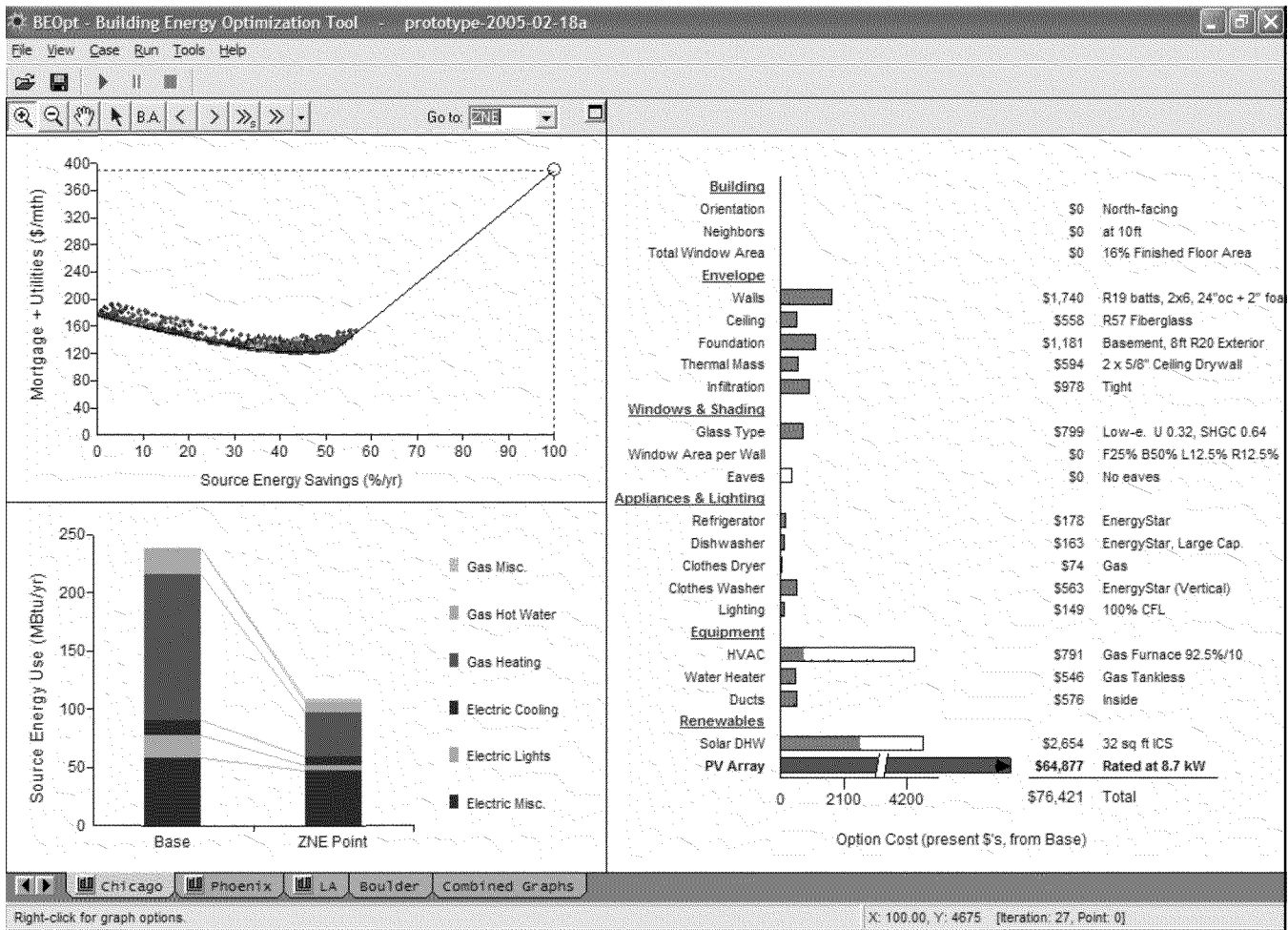


Fig. 3: BEopt output screen.

For instance, glazing types with low solar heat gain coefficients (SHGCs) may not be desired in a climate where passive solar heating is desirable.

Finally, the user is provided the ability to explicitly include or exclude certain combinations of options for evaluation. For example, if the user is interested in the interaction between south-facing glazing area and additional thermal mass, simply selecting available options within these two categories may not suffice. This is caused by the nature of the sequential search optimization technique – an option from either the thermal mass category or the glazing area category must first be *independently* cost-effective in order for the combination of additional thermal mass and glazing area to be evaluated by BEopt. However, if the user has the technical experience to recognize this situation, an Include Combinations category (Figure 2, “Glass+Mass”) can be created in which these combinations are explicitly selected for the optimization. Likewise, the user can create Exclude Combinations categories such that certain combinations are explicitly excluded from the optimization – usually as a way

of reducing runtime for combinations that the user knows are not cost-effective.

With the options selected, BEopt can run an optimization of the possible combinations of options. For selected options similar to those in Figure 2, optimization would involve approximately 1000 simulations and approximately 1.5 hours of computer run-time.

5. OUTPUT SCREEN (RESULTS BROWSER)

Once an optimization process has been run, the output screen can be displayed. Figure 3 illustrates a typical example of the output screen. For each case, the BEopt output screen displays the results in three different graphs: the path to zero net energy graph located in the upper left corner of the screen, the end use graph in the bottom left corner, and the option costs graph on the right side of the screen.

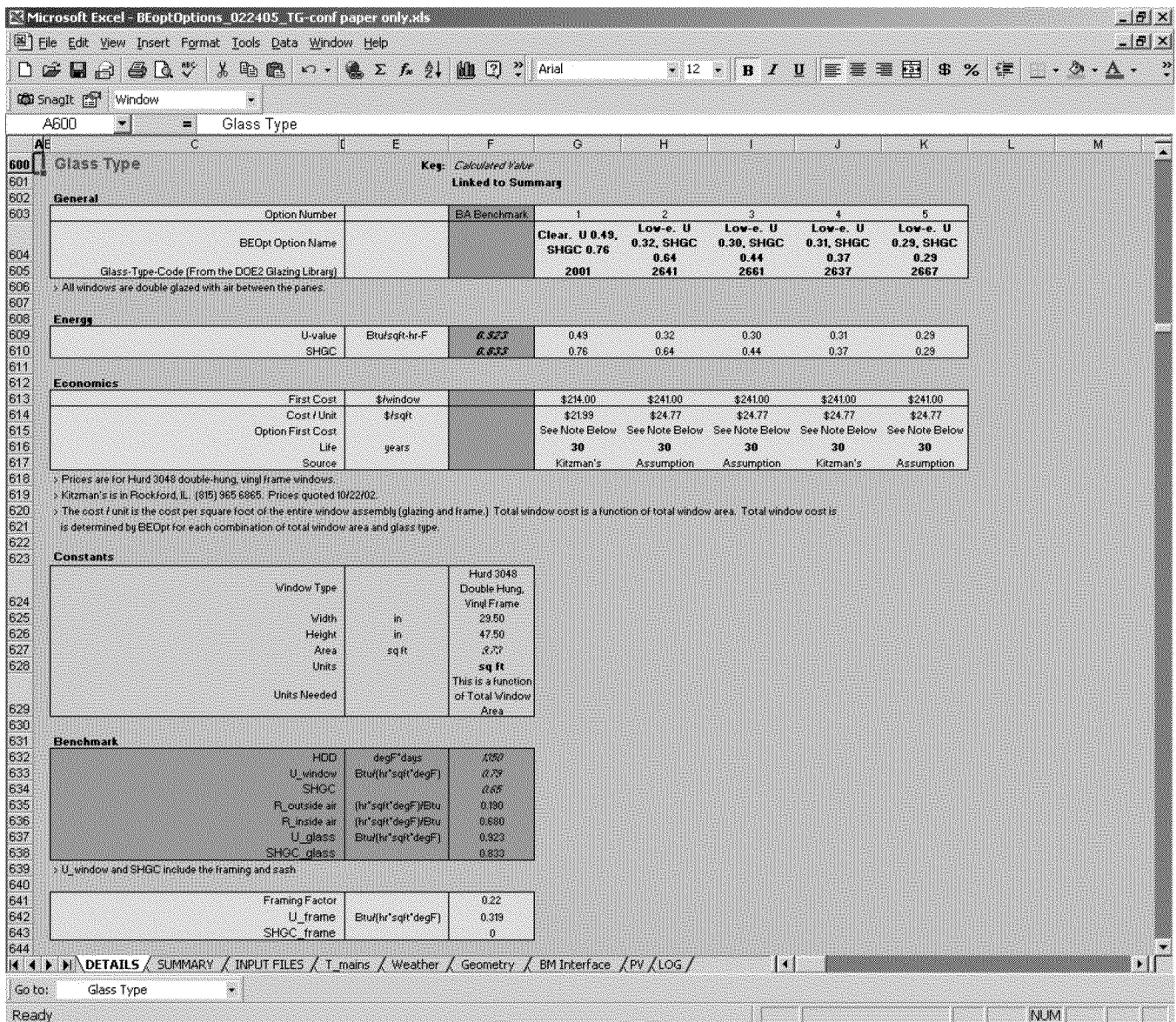


Fig. 4: BEopt options library spreadsheet.

5.1 Path to Zero Net Energy Graph

This graph details the optimal and near optimal points along the path to zero net energy. The x-axis displays the percent of energy saved compared to the base case while the y-axis shows annual energy-related costs. Energy savings are calculated relative to a reference: either a user-defined base-case building or a climate-specific Building America Benchmark building automatically generated by BEopt. Energy-related costs include: utility bills, the cost of efficiency measures included in the mortgage payment, and the present value of future replacement costs for options with lifetimes less than the analysis period, typically 30 years.

Each colored marker represents a particular simulated building design. Points shown in the same color and symbol shape are combinations that were simulated during a particular optimization iteration. (Therefore, the number of colors matches the number of iterations performed by BEopt.) The curve connects the points with the lowest annualized energy cost for any given energy savings.

For any selected point, BEopt will display associated results in the End Use Breakdown and Options Costs graphs. The user can quickly navigate to optimal points at specified energy savings. The user can also zoom in and select any (non-optimal) point on the graph. The sequence through which BEopt determined the optimal points during the optimization can be followed one iteration at a time or

replayed entirely by clicking the “step” and “play” buttons on the results toolbar.

5.2 End Use Graph

End use values (gas misc., gas hot water, gas heating, electric cooling, etc.) are shown as colored stacked bars. The left-hand bar shows results for the base case; the right-hand bar shows results for the selected point. The user can select whether the y-axis shows building energy consumption in terms of: source energy (MBtu/year), site energy (MBtu/year), or cost of energy (\$/year).

5.3 Options Cost Graph

The options cost graph displays data by category with bar outlines indicating the maximum possible option cost within the set of selected options. For a selected point, the shaded bars and values indicate option costs. Option names are shown to the right. Option costs shown are relative to the base case and totaled at the bottom of the column.

When two or more cases contain output, a Combined Graphs tab appears to the right of all other case tabs. This tab displays an output screen (there is no associated input screen) with all cases compared on the same three graphs previously described. The path-to-zero-net-energy curves are overlaid, while the option cost graph and the end use graph compare results for zero net energy designs for each case.

6. OPTIONS LIBRARY

The options library spreadsheet (Figure 4) contains detailed information for all the BEopt categories and options. While some users may only use the BEopt input screens to specify optimization inputs, access to the options library allows the user to review and modify specific characteristics of each option such as energy properties and cost assumptions.

Each category worksheet lists the option numbers across the top of the screen. The Building America Benchmark is listed before the available options. The details of each category are grouped under three subtitles (General, Energy, and Economics). Values in bold-faced type are linked to a summary worksheet and used in the simulation input files. Additional worksheets in the file allow access to the DOE2 and TRNSYS input files for more advanced users.

7. CONCLUSIONS

The BEopt computer program uses simulation and optimization to find optimal and near-optimal building designs along the path to zero net energy. To facilitate

effective use of optimization, the BEopt user interface includes the following features:

The main input screen that allows the user to select from many predefined options, those to be used in the optimization,

The output screen that allows the user to display detailed results for many optimal and near-optimal building designs,

The options library spreadsheet that allows a user to review and modify detailed information on all available options,

Energy savings calculated relative to a reference: either a user-defined base-case building or a climate-specific Building America Benchmark building,

Multiple cases that allow analysis of different climates, economic parameters, PV system characteristics, or the options selected for optimization, and

Combined graphs that allow comparison of results from multiple cases.

8. ACKNOWLEDGMENTS

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9. REFERENCES

- (1) Hendron, R., Building America Research Benchmark Definition, NREL/TP-550-37529, National Renewable Energy Laboratory, February 2005
- (2) York, D. and Capiello, C., eds., 1981, DOE-2 Reference Manual (Version 2.1A), Lawrence Berkeley National Laboratory, Berkeley, CA
- (3) Klein, S., et al, 1996, TRNSYS: A Transient System Simulation Program – Reference Manual, Solar Energy Laboratory, University of Wisconsin, Madison, WI
- (4) Christensen, C., Barker, G., Horowitz, S., A Sequential Search Technique for Identifying Optimal Building Designs on the Path to Zero Net Energy, Proceedings of the Solar 2004, Portland, OR, American Solar Energy Society, 2004

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