Vote Early, Vote Often: Using *ENERGY-10* to Design Low-Energy Buildings

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ABSTRACT

It is a generally accepted maxim that the greatest opportunity to impact energy use in building design (in both new and existing construction) occurs early on in the design or retrofit process. While building energy simulation can be an extremely useful tool to help identify of viable alternatives, the difficulty of use and complexity of many energy simulation tools often negates their effectiveness and acceptance in early-stage design activities.

The *ENERGY-10* program was conceived to overcome these hurdles by providing a framework to easily articulate and compare many energy alternatives long before detailed design work has begun (facetiously, the watchwords are "*Vote Early, Vote Often*"). Many model development tasks are automated including generic building take-offs, equipment sizing and definition of energy efficiency strategy (EES) alternatives. Tasks that previously took hours and days have been shortened to minutes. Evaluations are based on hour-by-hour simulations of both daylighting and thermal performance. An extensive set of graphical outputs greatly aids the process of assimilating and understanding the results.

This paper describes the Energy-10 program and lessons learned in applying this tool, over the past five years, to the design of low-energy buildings.

Introduction

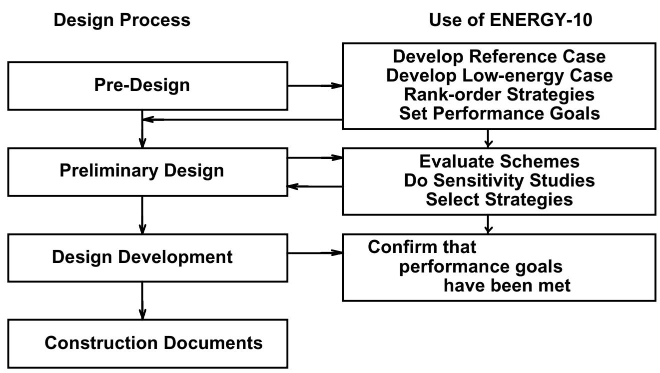
We are now seeing the emergence of a new generation of computer-based energy design tools. These tools focus on the user interface and offer the opportunity to get quick and simple estimates of energy performance in the early design phase yet harness the full power of detailed hourly simulation to accurately capture interactive effects. A new aspect of these tools is also that they try to view the energy performance in a holistic perspective, that is, they include other performance criteria such as daylighting, comfort, economic and environmental considerations. *ENERGY-10* epitomizes this new generation of tools and is the first to obtain wide distribution in the United States.

ENERGY-10 is not just software—the accompanying book, *Designing Low-Energy Buildings,* provides guidance in the application of each of the highlighted strategies and serves as an important tool in both university courses and training workshops, where the program has seen its greatest impact. Emphasis was placed on the front end and the back end—the user interface and the output graphics—because these areas had been neglected in many previously developed energy analysis tools.

ENERGY-10 Overview

The two main philosophies embodied are the *whole-building or integrated design* approach and the importance of the *early design stage.* The whole-building or integrated design approach emphasizes the need to take many different design aspects into account, as opposed to traditional design where only a few aspects are considered and optimized.

While the traditional approach typically concentrates on initial costs and aesthetics, the integrated design approach performs simultaneous evaluation of the interaction of heating, cooling and daylighting. The program automatically calculates the required sizes of HVAC equipment so this important tradeoff is included in the evaluations.



ENERGY-10 compliments the design process, providing the right information at the right time. Experience has shown that the most critical phase is pre-design. *ENERGY-10* was designed to be particularly effective in the early stages when the information is most valuable.

Figure 1: Using *Energy-10* in the Design Process

Smooth and easy integration of energy efficiency in the early design phase was a prerequisite of *ENERGY-10* (Figure 1). This was based on the observation that the traditional available programs for thermal and daylighting evaluation were so difficult to use that they were only being employed late in the design process—when it was too late to significantly affect the end product. However, the program is also quite useful in later design phases. The figure shows the intended use of *ENERGY-10* during the evolution of the design process.

ENERGY-10 is targeted to buildings less than 10,000 square feet (hence the name). This size category constitutes about 76% of all commercial buildings and 22% of commercial building floor space in the United States.

The program requires only 5 inputs to start the simulation and analysis process:

- geographic location (from 239 U.S. sites and several foreign options)
- total floor space
- intended building use (from a list of nine)
- number of stories
- type of heating, ventilation and air conditioning (HVAC) system (from a list of 12)

(Users have a choice of five systems of units, USA, metric (energy in kWh, Cal, or Joules) and SI.

From these basic inputs, *ENERGY-10* automatically creates two simple "shoebox" buildings: one is a reference building that emulates a building constructed using standard design practices; the other is a low-energy building that incorporates a number of energy-efficient options. Each shoebox may have up to two thermal zones. All variables excluding the five parameters mentioned above, are defaulted to reflect typical construction practices. These variables include materials and constructions, windows and doors, and schedules of internal gains. All variables can be edited subsequently. It is also possible to change all the default parameters. Within just a few minutes, the user can be studying detailed results that identify the primary energy issues of his or her building and sort out the most effective strategies that can be used to save operating energy or operating costs.

As the design process evolves, the user edits the building descriptions to represent the building as it becomes more complex. Walls and roof planes can be added as the design becomes more articulated. As the design proceeds, the building descriptions become more detailed and more representative of the building being designed and less like the original shoebox.

ENERGY-10 facilitates the quick evaluation of various strategies by automatically applying and rank ordering those desired. Tables 1 and 2 list the currently implemented and planned energy efficiency strategies in Energy-10:

Table 1: List of Currently Implemented Energy Efficiency Strategies

Daylighting	Energy-Efficient Lights	Glazing
Passive Solar Heating	Shading	Insulation
Thermal Mass	Air Leakage Control	High-Efficiency HVAC
HVAC Controls	Economizer Cycle	Reduced Duct Leakage

Table 2: List of Planned Energy Efficiency Strategies

Photovoltaics	Natural Ventilation	Evaporative Cooling
Exhaust-Air Heat Recovery	Solar Air Preheat	Solar Water Heating

(Photovoltaics is expected to be completed by the end of FY2000.)

The Simulation Engines

Thermal analysis uses the California Nonresidential Simulation Engine (CNE) written by the Berkeley Solar Group (BSG), which employs a multizone, thermal-network solution (Wilcox et al, 1992). CNE has been validated using the BESTEST protocol adopted by the U.S. Department of Energy (Rudkoff and Neymark, 1995). The Lawrence Berkeley National Laboratory (LBNL) has been fully responsible for all the daylighting aspects of *ENERGY-10*. The daylighting simulation engine incorporates the split-flux routine used in the DOE-2 computer program (Winkelmann and Selkowitz, 1985), which is also used in LBNL’s Building Design Advisor (Papamichael, 2000). This technique is suitable for evaluating daylighting from windows and skylights. CNE integrates the detailed hour-by-hour daylighting calculation with a subsequent thermal evaluation. Thus the reduction in heat into the building as a result of dimming the lights is properly accounted in the thermal loads. In the future, an interface to the EnergyPlus simulation engine is currently planned.

During the setup of daylighting for a shoebox geometry, the program automatically creates five lighting zones in each thermal zone (Figure 2), as shown in the schematic, including complete geometrical descriptions of each window and interior wall surface (if the building is narrower than 30 ft, one zone is created).

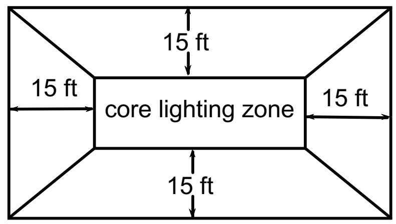


Figure 2: Configuration of "Shoebox" Daylighting Zones

The simulation program first calculates daylighting illuminance at a control sensor location for each of 20 sun angles for each aperture. Using these results, illuminance values are then calculated for each hour for each lighting zone.

The reduction in artificial lighting is calculated based on either a continuous-dimming or stepped control algorithm.

For more complex geometries, the user *may* enter the surfaces, aperture locations, and control characteristics of each lighting zone up to a maximum of 10 for each thermal zone. However, this process is tedious and error-prone because it is not yet automated and the 3-dimensional coordinates of each element must be specified. In practice, most users prefer to utilize hourly daylighting results calculated for rectangular geometries in conjunction with thermal calculations made for the complex building. Experience has shown that the errors incumbent in this approach are second-order and acceptably small. A few users undertake the more detailed approach. In any case, *ENERGY-10* is not a daylighting design tool—the purpose of the simulations is simply to estimate the savings due to dimming and to capture the thermal effects of daylighting.

Thermal Analysis

ENERGY-10 automatically creates the input file for the CNE thermal simulation engine based on the building parameters in the dialog boxes. The simulator then transforms the building description into a thermal network model. The thermal network solver uses 15-minute time steps (for numerical accuracy) and iterates to find an energy balance at every step, accounting for heat storage in each material layer. A rigorously enforced energy balance is important for accurate simulation of highly interactive strategies used in good passive design.

Twelve HVAC systems options can be simulated in Version 1.3. A key feature of the CNE simulation engine is that it iterates to find a consistent solution of the loads and systems calculations, a feature not found in most United States thermal simulation programs. The system options are summarized in Table 3:

These are the systems used in more than 95% of all residential and small commercial buildings.

Table 3: Energy-10 HVAC System Options

HVAC System	Heating System	Cooling System	Air Distribution
Air Source Heat Pump/ER Backup	HP/ER Backup	A-A HP	Forced Air
Baseboard Electric Heat	BB Electric	none	none
DX Cooling with Elect Furnace	Electric Furnace	DX	Forced Air
DX Cooling with Gas Furnace	Gas Furnace	DX	Forced Air
Gas-Fired Unit Heater	Gas/Radiant	none	none
Heat & Vent with Elect Furnace	Electric Furnace	none	Forced Air
Heat & Vent with Gas Boiler	Gas Boiler	none	Forced Air
Heat & Vent with Gas Furnace	Gas Furnace	none	Forced Air
PTAC AA HP with ER Backup	HP/ER Backup	DX	Thru the Wall
PTAC with ER BB Heat	BB Electric	DX	Thru the Wall
PTAC with ER Heat	Electric Coil	DX	Thru the Wall
PTAC with Gas Boiler & HW Coil	Gas Boiler/HW Coil	DX	Thru the Wall

Automatic Ranking.

A common use of building simulation programs is to rank the effectiveness of various energy efficient strategies (EESs) being considered. This time consuming process is automated in *ENERGY-10*. The software incorporates a process called APPLY which takes a selected combinations of EESs and automatically modifies the simulated building description as if the measure(s) had been "applied." The RANK feature is similar to APPLY except that the EESs are applied individually rather than in combination. When the user selects a set of EESs and then clicks on RANK, the program applies the first EES, performs a simulation, saves the results, removes the EES, applies the next EES, and so forth until all the EESs have been applied and simulated. The program then ranks the results according to any of several desired criteria (lowest annual energy, lowest annual operating cost, etc.) and displays the results.

Automatic HVAC Sizing

A key feature of *ENERGY-10* is called AutoSize. AutoSize calls CNE to compute the rated capacities of HVAC equipment required to meet winter and summer design-day loads. When enabled, which is the default, this calculation happens automatically prior to any simulation. All the complex interactions that occur are properly accounted. For example, the reduction in fan operating energy associated with using better windows is evaluated. The RANK operation takes account of such interactions.

It is well known that the added cost of an energy-efficient building need not exceed that of a conventional building because the cost of other upgrades (insulation, windows, high efficiency equipment, shading, etc.) can be paid out by money saved from the reduced cost of installing smaller HVAC equipment. This interaction makes it imperative to get early and accurate estimates of required HVAC rated capacities to serve as the basis for justifying other energy efficient strategies. Properly done, the result is a building that requires far less energy to operate yet costs no more to construct. The hang-up in achieving this result has usually been the added cost of design. With *ENERGY-10*, this barrier has been lowered.

Help

ENERGY-10 incorporates an extensive and comprehensive online Help system. This facility has received acclaim from many users. It incorporates a graphical approach that pops up descriptions from dialog boxes. Help also includes a wealth of user advice, exercises to assist users in learning the program, and graphical representations wherever possible. A user manual is available ("Mastering Energy-10") in addition to the workshop guide ("Designing Low Energy- Buildings: Passive Solar Strategies & Energy-10") provided with each copy of the software.

Workshops, Training, and User Support

Designing Low-Energy Buildings is used in a workshop environment in conjunction with the *ENERGY-10* program. The Sustainable Buildings Industry Council (SBIC) conducts two-day workshops to help designers understand the issues of energy efficiency and provide them with a suitable analysis tool. The workshop agenda alternates between lectures that describe design techniques and hands-on use of the *ENERGY-10* program at computer terminals. Four workshops were given in 1997, 16 in 1998 and the total for 1999 will be 23 workshops. These are held at facilities with computer labs, often on campus. Nine instructors have been certified by SBIC to present workshops and seminars.

Development Plans

SBIC maintains a hot line and compiles a list of user complaints, problems, and suggestions. Users have been generally quite satisfied but want more features. The feedback has been invaluable for understanding how the program is used and how it can be modified to be more effective. *ENERGY-10* users tend to be small architectural firms or consultants that have not historically used building simulation. Typically it takes them 2 to 4 days to become reasonably proficient with the program.

One problem reported is that some users object to having to do take-offs on their plans. It is extremely easy to get started with a shoebox design because the process is automatic. However, progress slows during the preliminary design phase, when the actual building design must be described to the program. The user must compute wall, roof, and window areas and enter these numbers into the appropriate dialog boxes. The time and numerical detail required for these tedious calculations is perceived as a barrier. The proposed solution is to provide a graphic input routine (called *Sketch*) that would allow the user to draw the building on the screen using the mouse. The program would then compute the necessary building areas, etc. required by *ENERGY-10* for the analysis. It is a daunting challenge to develop this graphic input module, but work has been started on it. *Sketch* should be fully integrated into *ENERGY-10* in 2001. This will account for site shading by trees and neighboring buildings and also facilitate description of the daylighting geometry inside the building.

Work is well along to add photovoltaics (PV) as a new strategy in *ENERGY-10*. The benefits are: (1) users who had not been considering PV can easily evaluate its performance, (2) PV users who use *ENERGY-10* for their analysis will be likely to improve the rest of the building design, and (3) the evaluations will be more integrated with other strategies than those done with stand-alone programs. This is because the hourly electric load calculated by *ENERGY-10* not only accounts for electric demand schedules but also for HVAC electric use in response to weather and occupancy and dimming of lights as a result of daylighting. TRNSYS will be used as the simulation engine for PV.

The PV EES will be implemented to define all the parameters required to simulate a PV system. The APPLY operation will automatically make changes in the building description to add a PV array, the associated conversion and battery storage systems (if desired), thermal connections to the building, control algorithms, and special electric tariffs. The user will define these in the PV Characteristics dialog box.

The peak-shaving benefit of a PV array will be determined during the simulation. Since the peak is usually on a hot, clear summer afternoon, the PV system will be operating at its peak. This can easily double the cost-effectiveness of an installation in areas where electric utility peak-demand charges are high. The first phase of the PV development is expected to be complete by the end of FY2000.

Impact

First released in June 1996*, ENERGY-10* has enjoyed good acceptance by the design and consulting audience that it targets. As of September 1999:

- 1160 *Designing Low-Energy Buildings with ENERGY-10* packages have been sold.
- 32 two-day workshops have been presented with an average attendance of 20.
- 8 workshops are scheduled throughout the United States for Sept–December 1999.
- 23 seminars have been presented in a wide variety of forums.
- Site licenses have been purchased by 40 colleges and universities where the *Designing Low-Energy Buildings with ENERGY-10* package is being used as the teaching tool in architectural and engineering courses. This use of the tool has been particularly effective.

A survey conducted in the spring of 1998 by the Passive Solar Industries Council (PSIC); who are contracted to provide distribution, user support, and training; found that

- The predominant number of users are architects (37%), followed by engineers (18%) and energy analysts (17%)
- Many are academics (19%), students (18%), and project managers(7%)
- The program is most commonly used to analyze residences (by 75% of users), offices (by 54% of users), assembly buildings (by 18% of users), warehouses (11% of users), and an assortment of other commercial and institutional building types.
- 29% have used the program on more than 10 projects, 17% on 6 to 10 projects, and 40% on 2 to 5 projects
- 58% find the program more technically successful that other building evaluation software they have used
- 63% find the program more user friendly than other building evaluation software they have used.

Designing Low-Energy Buildings with ENERGY-10 received a Progressive Architecture award for research.

Lessons Learned

The aggregate lesson from the application of Energy-10 *in the pre-design phase* of building design is that significant decisions can (and should) be made before any thought is given to detailed building form or geometry. For example, parameters which are broadly climate-driven can be determined:

- Proper choice of glazing.
- Proper choice of insulation.

Critical information can be obtained regarding:

- The relative benefit of a daylighting strategy.
- The relative benefit of increasing HVAC component efficiencies.
- The relative benefit of a shading strategy.
- The relative benefit of energy-efficient lights.
- The relative benefit of placing ducts inside the thermal envelope (to reduce duct-leakage effects).
- The desirability of adding internal thermal mass.
- The impact of reducing infiltration.

Experience has shown repeatedly that the overall energy picture usually does not change much as the building goes through preliminary design as a result of changes in geometry.

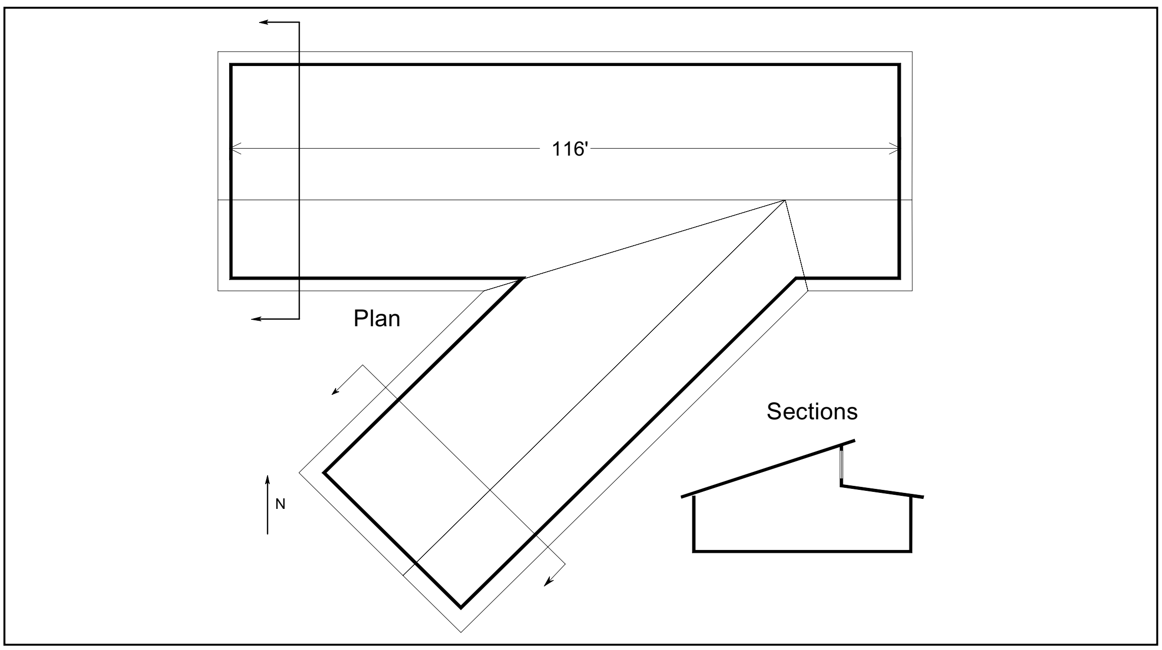


Figure 3: Office Building Preliminary Design

This trend is illustrated below for a representative Energy-10 case study for a 6500 ft^2

office building in Columbia, Missouri. The *ENERGY-10* energy analysis of the preliminary design shows only a small change compared to the Lower Energy Case shoe box despite major geometrical changes as the analysis progressed.

In this case study the design progressed toward a very articulated geometry chosen to bring more daylight into the building. Area take-offs for this preliminary design, shown in Figure 3, were calculated. There are 7 wall orientations rather than 4. There are four roof planes rather than 1. The number of windows is increased from 45 to 50, with 80% located on the south and southeast, primarily in vertical clerestory sections.

In this case, heating has increased 50% because wall surface area is greater; however, heating was small anyway. Cooling is decreased 7% by the better orientation of windows, despite the increased area. The KEEP function of *ENERGY-10* was used to show the design progression. Results from each step were "kept", and the results displayed, as shown in Figure 4:

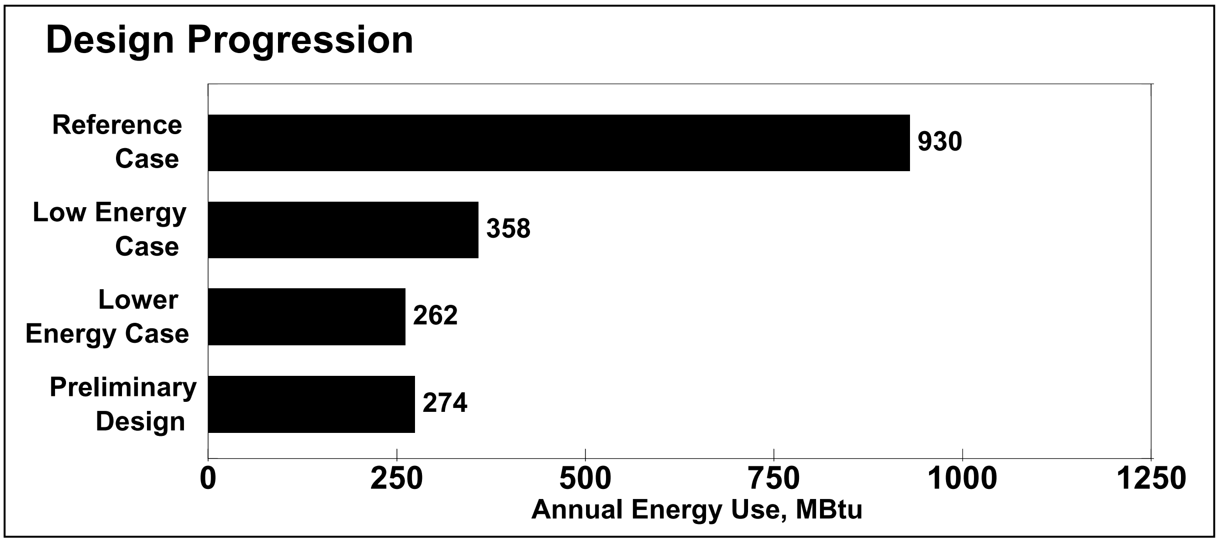


Figure 4: Typical Annual Energy Use Estimates during Preliminary Design

Similar results have been found in similar situations. Many processes that effect energy use are not greatly affected by the details of building geometry and there are often compensating effects.

While the exact value of estimated energy and operating cost will change during the design process, most go/no-go decisions regarding which strategies to include will, in almost every instance, *not change much as the geometry changes* during the design phase. (The possible exception to this may be daylighting and shading.) It is far easier to carry out these general screening evaluations with the simple shoebox geometry than struggle with the much more complex geometry of most actual buildings. It is simply more efficient to do it early. Later the actual geometrical design can be evaluated to see the final effects.

Experience in actual buildings has shown that savings due to HVAC sizing can very likely pay for the all the other upgrades.

For example, in the case study building, one change of great significance is the large overall reduction in HVAC capacity, comparing the original reference case to the preliminary design. The AutoSize results, which only required about 2 seconds to compute prior to each simulation, are as follows:

Table 4: Example of HVAC Autosize Results

Description	Reference Case	Preliminary Design
Rated Heating Capacity, kBtu/h	386	113
Rated Cooling Capacity, tons	27.5	12.6
Rated Air Flow, CFM	10740	5310

The latter two have the greatest effect on installed costs. The decreases are a direct result of the reduced heating and cooling loads. (NOTE: The Energy-10 results summary report typically shows significant operating cost reductions due to reduced size and runtime and higher efficiency of air-distribution fans. Insights such as this are a valuable part of displaying the *ENERGY-10* results.)

In the case study building, the largest remaining component of energy use is internal gains due to plug loads - this single category accounts for 52% of the total estimated annual energy cost.

Conclusions

Designing Low-Energy Buildings with ENERGY-10 was written to fill an identified need and has been well received by designers and energy consultants. It is fast, easy to use, and accurate. It allows the user to quickly identify cost-effective energy-efficient strategies based on detailed hourly simulation analysis that accounts for interactive effects. With care, a design team should be able to develop a building that uses about 50% as much energy as a typical building yet costs no more to build, provides a better working and living environment, and accounts for less than ½ the emissions of $CO_2/SO_2/NO_x$ of a typical building. Many cases of such buildings exist. For a good example, see http://www.light-power.org/harmonylib/index3.htm on the internet. This describes the Harmony Library in Ft. Collins, Colorado, a beautiful 30,000 sf building.

Acknowledgments

Funding for *Designing Low-Energy Buildings with ENERGY-10* is from the U.S. DOE. The Program Manager is Dru Crawley, Office of Energy Efficiency and Renewable Energy. Programming of *ENERGY-10* was done at NREL, at LBNL, and at BSG. NREL conceived the program, programmed the front end, and has managed the development effort. LBNL was responsible for the daylighting portions of the program, including the daylighting simulation engine, and providing technical advice on all aspects. BSG developed the thermal simulation engine and programmed the output graphics. SBIC developed the guidelines book, *Designing Low-Energy Buildings*.

Designing Low-Energy Buildings with ENERGY-10 is distributed by SBIC. Information about Energy-10 is available at *http://www.sbicouncil.org/enTen/*. Additional information is available at *http://www.nrel.gov/buildings/energy10*.

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