# *ENERGY-10:* A DESIGN-TOOL COMPUTER PROGRAM

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## ABSTRACT

A major barrier to using energy simulation tools during the design process of a building has been the difficulty of using the available programs. The *ENERGY-10* program overcomes this hurdle by automating many of the time-consuming tasks, shortening the time required from hours or days to minutes. Building descriptions are created automatically based on defaults. The APPLY and RANK features speed the process of comparing the performance of energy-efficient strategies by automatically modifying the building description and sequencing the operations. Graphical output greatly aids the process of assimilating and understanding the results. This paper describes the program's features, simulation engines, the associated design guidelines book, and the workshop training program. It also outlines planned enhancements including a capability for photovoltaics simulation, and the steps required to make the program useful outside the United States.

## INTRODUCTION

*ENERGY-10* is a PC-based building energy simulation program for smaller buildings that focuses on the early stages of the architectural design process and the integration of daylighting, passive solar design, low-energy cooling, and energy-efficient equipment into high-performance buildings. Developed specifically as a design tool, the program facilitates quick evaluations. Its simulation engines perform whole-building energy analyses for 8760 hours per year that include both daylighting and dynamic thermal calculations. The target audience for the program is building designers, architects, heating, ventilation, and air-conditioning (HVAC) engineers, utility officials, and architecture and engineering students and professors.

*ENERGY-10* is applicable to both residential and nonresidential buildings. Version 1 simulates one or two thermal zones, which limits its application to smaller buildings—generally less than 1000 $m^2$ (10000 $ft^2$).

The alpha test version of *ENERGY-10* was released in 1994, the beta test version in 1995, and Version 1.0 in June 1996. The first upgrade to the original program, Version 1.1, was released in February 1997.

## PLATFORM

*ENERGY-10* operates under Microsoft Windows. All routines are written in the C language (Visual C++, etc.). A Pentium processor is recommended with 16 MB of RAM. This equipment can complete a pair of annual simulations, including one daylighting simulation, in 2 minutes on a machine running at 133 mHz.

## *ENERGY-10* IN THE DESIGN PROCESS

Experience has demonstrated repeatedly that to affect the design of a building, energy simulation analysis must be performed early in the design process, before a building description has been developed (Burt Hill Kosar Rittleman, 1987).

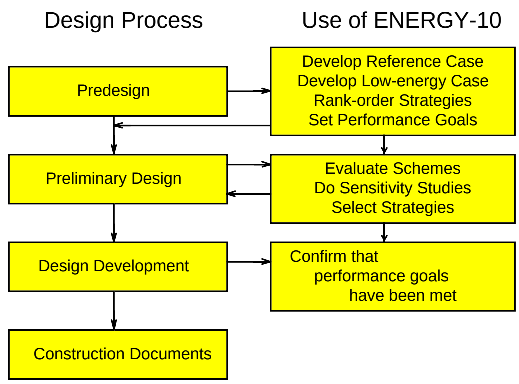


Figure 1. How *ENERGY-10* integrates into the design process.

Fig. 1 shows how *ENERGY-10* complements the traditional architectural design process from beginning to end.

*ENERGY-10* automatically sets up and simulates two building descriptions, a reference case and a low-energy case, based on a few inputs. The program then automates the process of both applying and ranking a variety of energy efficiency and passive solar measures. It integrates thermal issues with daylighting issues in a package that gives preliminary results before the building is designed. It emphasizes the use of passive solar measures, including daylighting, passive solar heating, and ventilation cooling, as design options to be integrated with efficient equipment and shell designs. As the design evolves, the particulars of the actual building schemes are entered into the program and the simulations rerun to track progress.

## FEATURES OF *ENERGY-10*

AutoBuild**.** In the predesign phase, two complete building descriptions are generated automatically; a *reference case* and a *low-energy case*, based on only five key characteristics—location, building use, HVAC system, floor area, and number of stories—information that is known in predesign. The reference case is a basic rectangular shoe-box building that satisfies the building requirements and has all the attributes of the building to be designed, such as appropriate internal gain schedules, glazing-to-wall ratio, and constructions. The low-energy case is the same building but modified to incorporate a set of energy-efficient strategies (EESs). Results from the simulation of these two buildings give the designer important pieces of information: (1) They show the energy use pattern of a typical building of the desired size, in the right climate, having the appropriate internal gains for a building of the desired type. The balance between heating, cooling, and other energy uses is determined. (2) The simulations identify the potential for energy and cost savings from a particular set of strategies. Less than 15 minutes after starting a new project, the user can be studying these results.

Side-By-Side Comparisons. Two building descriptions, Bldg-1 and Bldg-2, are carried in the database at all times, facilitating comparisons. Initially used for the two shoe boxes created by AutoBuild, these two buildings can subsequently be used to compare the performance in two climates, the effect of a single change, or the effect of multiple changes.

Automatic Apply. There are 10 EESs to choose from in *ENERGY-10*. The APPLY feature facilitates the incorporation of any or all of these strategies. The user first selects any set of desired EESs from a menu and then clicks on APPLY. The program creates a complete new Bldg-2 by modifying Bldg-1 according to a prescription. For example, if the *Insulation EES* is selected, all of the walls in the building might be changed to 15 cm construction (RSI-3.3), the roof changed to RSI-7, and the perimeter insulated with 5 cm of foam. The user gets to specify exactly what changes will be made. (APPLY is used automatically during AutoBuild to create the original low-energy case starting from the reference case.)

The 16 EESs are listed below with the 10 that are currently implemented shown in bold. (The remaining 6 are described in the guidelines book and will be implemented in the future.)

| | |
|---|---|
| **Daylighting** | **Energy-Efficient Lights** |
| **Glazing** | **Passive Solar Heating** |
| **Shading** | **High-Efficiency HVAC** |
| **Insulation** | **Economizer Cycle** |
| **HVAC Controls** | Air Leakage Control |
| **Thermal Mass** | Evaporative Cooling |
| Natural Ventilation | Exhaust-Air Heat Recovery |
| Photovoltaics | Solar Water Heating |

The results of an APPLY of 10 EESs are shown in Fig. 2 for a 609 $m^2$ (6500 $ft^2$) bank building in Columbia, Missouri:*

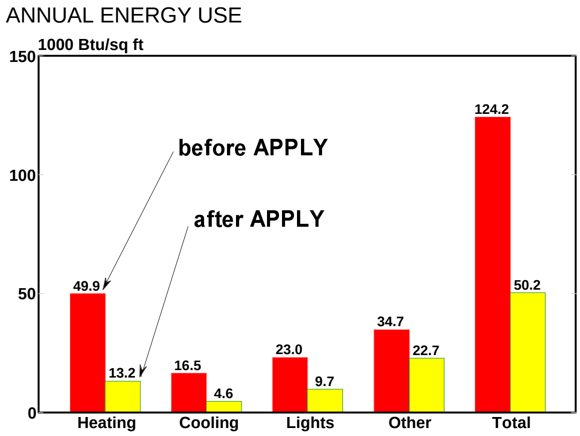


Figure 2. Building performance before and after 10 energy-efficient strategies are applied in *combination*

Because APPLY makes it easy for the user to do an evaluation, *ENERGY-10* serves as an effective mechanism to encourage the adoption of new energy-efficient technologies into buildings. The user can quickly change the building description to represent the addition of the technology and 2 or 3 minutes later he or she can be inspecting the results. Technologies which might not have been considered can be investigated quickly.

Automatic Ranking. A common use of building simulation programs is to rank the effectiveness of various energy efficient strategies being considered.

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* This graphic and those shown later show performance in USA units. This is because the program presently outputs only these units. It would misleading to depict the graphics in metric units because this is not a current option. As mentioned later, a metric option is underway but not yet implemented.

This time consuming process is automated in *ENERGY-10*. 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. An example, for the 609 m$^2$ bank in Columbia, Missouri, is shown in Fig. 3.

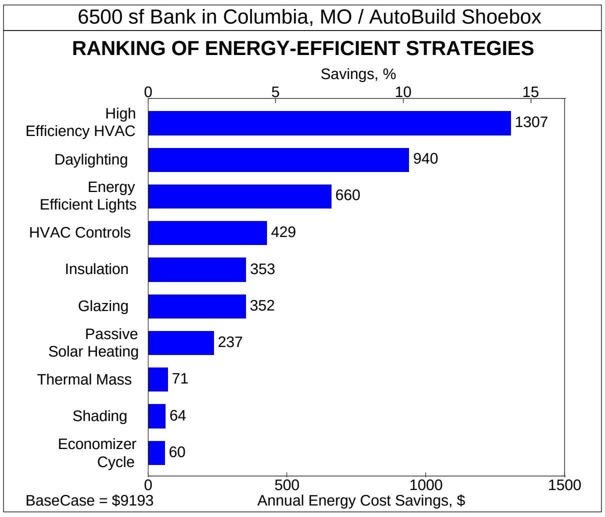



Figure 3. Annual energy cost savings resulting from each of 10 EESs applied *individually*

<u>Graphic Output</u>**.** Twenty graphic outputs are available that compare the Bldg-1 results with Bldg-2 results. Bar graphs, such as the APPLY example on the previous page, compare overall loads, costs, and cost breakdowns by end use. Line graphs, such as the example below, show monthly loads, daily-average profiles for each month, daylighting effectiveness, and actual hourly results for any period. Bar-graph comparisons of a selected sequence of design schemes can be displayed. All graphical results can be printed directly or copied to the Clipboard as metafiles for inclusion in a report. This feature was used in the writing of this paper—all of the graphs were copied directly from *ENERGY-10* and then edited slightly for style. These graphs can be used to educate the client and to demonstrate the value of good building design.

In one of the bar graphs, operating costs are calculated and displayed, as shown in Fig. 4.

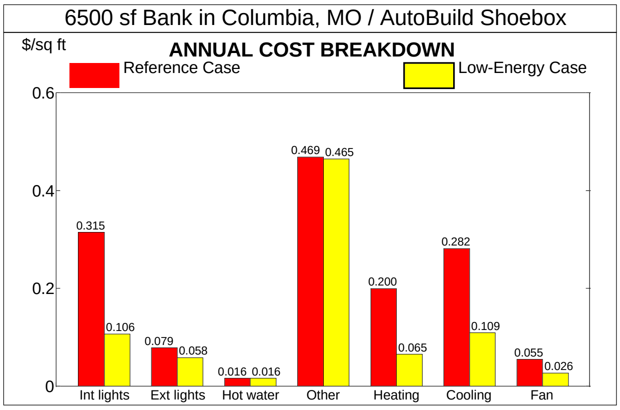



Figure 4. An example of *ENERGY-10* output, showing annual operating cost for purchased energy according to end use

In this example it is apparent that the designer would have to reduce the "other" category, which consists largely of plug loads, to affect a significant reduction below the low-energy case.

Fig. 5 shows the hourly performance during 7 days for Bldg-2, here identified as the low-energy case.

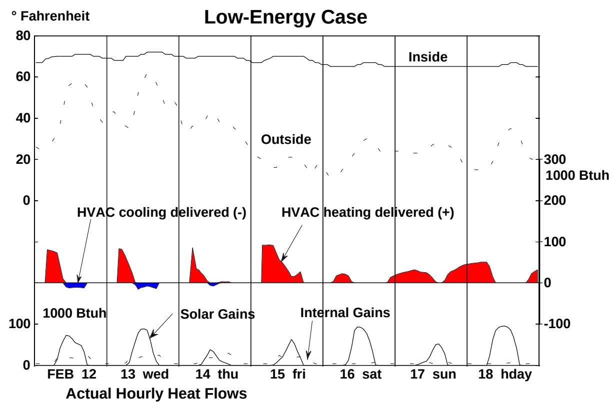



Figure 5. Hourly simulation results for 7 days in February. HVAC graphs show energy delivered to the building (+) or removed from the building (-) by the HVAC system. Another plot (not shown) indicates energy into the HVAC system.

<u>Other Features</u>. The program includes libraries of materials, constructions, and schedules that can be modified or extended from within the building-description dialog boxes. An extensive help facility provides definitions and instructions for all parameters and procedures, helpful hints, assumptions made in the calculations, the basis of the defaults, and warnings regarding the range of applicability.

## DEFAULTS

During AutoBuild, all building parameters are defaulted based on the selected building use category—assembly, education, grocery, lodging, office, retail, residential, restaurant, or warehouse. There are default constructions for walls, roofs, windows, doors, etc. and default thermostat settings, wall heights, wall glazing fractions, and occupancy and internal gain schedules. Initially, the construction defaults are defined according to typical practice and the schedules for internal gains replicate the national-average values for the United States for each of the categories according to the U. S. Energy Information Agency. All of these defaults can be changed to reflect user preference after the program is installed.

After AutoBuild, the user can change all parameters and the schedules can be adjusted if the user has particular information for the building being designed.

## EVOLVING THE BUILDING DESCRIPTION

As the building proceeds from predesign into preliminary design, the building description in *ENERGY-10* must be modified to represent the various schemes being considered. This is done by editing the initial low-energy case generated by AutoBuild. The APPLY and RANK features can be used at any point to evaluate global changes, as described above. Other changes, such as modifications in the building take-offs, can be made by editing values, such as the area of a particular wall, within the appropriate dialog box within the graphical user interface. 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 shoe box created by AutoBuild.

At each stage of the design, a new simulation can be performed to check progress. The results of the design evolution can be documented using the KEEP feature. At the end of preliminary design, the KEEP plot, which is automatically generated, might appear as shown in Fig. 6.

## 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). *ENERGY-10* has been validated using the BESTEST protocol adopted by the U.S. Department of Energy (DOE). The daylighting simulation engine, written at the Lawrence Berkeley National Laboratory (LBNL), incorporates the split-flux routine used in the DOE-2 computer program (Winkelmann and Selkowitz, 1985). This technique is suitable for evaluating daylighting from windows and skylights. *ENERGY-10* 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 accounted for in the thermal simulation.

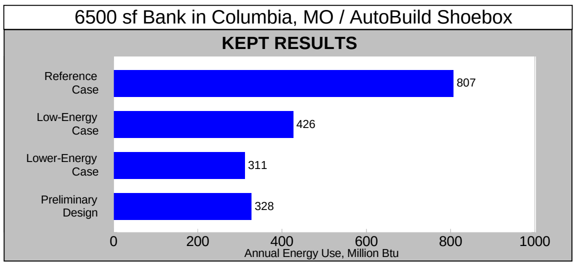
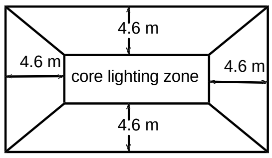



Figure 6. An example of a KEEP graph. Results "kept" for each of the four cases shown can be displayed. The example displays annual energy use, however, there are 10 other plotting options (heating, cooling, cost, peak electric use, etc.).

## DAYLIGHTING

During an APPLY of the Daylighting EES for a shoe box geometry, the program creates five lighting zones in each thermal zone, as shown here, including complete geometrical descriptions of each window and interior wall surface (if the building is narrower than 9.2 m (30 ft), one zone is created).




For more complex geometries, the user would enter the surfaces, aperture locations, and control characteristics of each lighting zone up to a maximum of 10 for each thermal zone.

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. An example of the results of this calculation is shown on the next page.

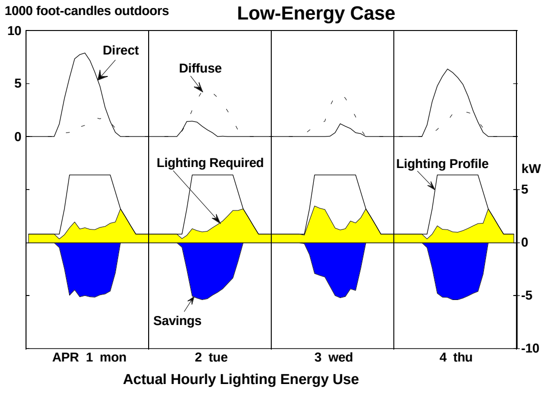



Figure 7. Results of the dimming of lights resulting from available daylight in the building for 4 days in April. The lighting profile is the total required light, the savings (shown inverted for clarity) is the amount of dimming, and the lighting required is the difference between the two.

## THERMAL ANALYSIS

*ENERGY-10* automatically creates the input file for the 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 EESs used in good passive design.

Ten HVAC systems options can be simulated in Version 1. A key feature of the CNE simulation engine is that it iterates to find a consistent solution of the loads and systems calculations.

## ADDING THERMAL MASS

During an APPLY operation, thermal mass is added to the building by adding massive internal partitions. The reason is to avoid changes the heat loss properties of the building that might result from specifying massive external constructions because this would confuse the interpretation of the ranking results.

If a decision is made to add thermal mass, the user can distribute the thermal mass in any desired way at a later time—within external walls, internal partitions, roof, or floor—by specifying constructions for these elements that include massive layers near the inside surface.

## THE GUIDELINES BOOK

*ENERGY-10* is the software component of a Building Guidelines project. The other component, a book called *Designing Low-Energy Buildings*, is distributed with the *ENERGY-10* program. It provides background information for energy-efficient design, instructs the reader on how to use the *ENERGY-10* program, and contains a full description and design advice for the 16 EESs.

## WORKSHOPS AND TRAINING

*Designing Low-Energy Buildings* is used in a workshop environment in conjunction with the *ENERGY-10* program. The Passive Solar Industries Council (PSIC) conducts two-day workshops both nationally and locally 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. Attendance at the first four workshops has been 20 to 30 persons with a high percentage of architects.

## USER FEEDBACK

The program has been in distribution for just a few months and about 350 copies have been sold. PSIC 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. Bugs have been found and places where the program is either misleading or less than intuitive have been identified.

*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. Although the sample is so far quite limited, several design teams report that the program is having the desired effect—they have actually altered their building design as a result of the performance evaluations.

One problem reported is that some users have a difficult time going beyond the AutoBuild stage. It is quite easy to get started with a shoe-box 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 three-dimensional coordinates of surfaces and apertures must be determined and entered to do a daylighting analysis. The time and numerical detail required for these tedious calculations is perceived as a barrier. Users would prefer an automated procedure for calculating and conveying this information.

## PLANNED ENHANCEMENTS

A PSIC Task Group met to consider a long list of possible enhancements to *ENERGY-10*. These include fixing existing problems, ideas that were planned for the first release but not included because of time constraints, and new features. All potential enhancements were thoroughly discussed and an initial prioritization was developed, accounting for the difficulty of each feature and the benefit.

Interim releases will be made that focus first on fixing bugs and eliminating recurring problems and then on features that were deferred earlier. Users will be able to work in USA or metric units. Heat pumps will be included and a feature called AutoSize will be added. In *AutoSize*, the simulation engine is used to determine HVAC rated capacities required to meet thermal loads on both heating and cooling design days. Thus HVAC capacity reductions that accompany energy-efficient strategies can be accounted properly during a RANK operation.

Beyond these changes, the following features are planned, roughly in order of priority. It is likely that the first 10 will be included in Version 2.

- Implement *Sketch* (see below)
- Evaluate any number of zones
- Implement enhanced daylighting
- Implement remaining EESs
- Include more HVAC systems
- Report value engineering
- Implement AutoComply*
- Automate/graph elimination parametrics
- Evaluate sunspaces
- Evaluate Trombe walls
- Report comfort conditions
- Calculate ground heat flow
- Output spreadsheet formats
- Develop case studies
- Report environmental impact
- Implement transpired collector EES
- Develop *WeatherMaker*
- Evaluate horizon shading
- Develop as a standards tool
- Calculate inter-zonal airflow
- Provide for batch runs
- Provide for computer-aided design (CAD) integration
- Draw shading masks
- Develop short-term energy monitoring (STEM) evaluations within E10

## SKETCH

*Sketch* is a planned feature that will allow the user to enter the building description graphically rather than numerically—building takeoffs will be automated. This will be especially useful during the preliminary design phase of a project and addresses the input problem outlined earlier in the discussion under User Feedback. *Sketch* will be far less than a full-blown CAD implementation. The user will progress through several steps using a wizard. In the first steps the building will be drawn in plan using the mouse and divided into zones. Zones will then be assigned to use categories and HVAC systems. In the next steps, windows and doors will be located, working in both plan and elevation views. Then daylighting zones will be defined. In the final step, the graphical depiction will be converted to an *ENERGY-10* building description. With the incorporation of *Sketch*, the program will be able to handle any number of zones and complex HVAC service to various zones.

## PHOTOVOLTAIC EES

Work has been started 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. An existing PV simulation engine will be adapted and included.

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.

* AutoComply would create a reference case that automatically complies with a standard.

## USE OF *ENERGY-10* OUTSIDE THE UNITED STATES

There has been considerable interest in adapting *ENERGY-10* for use in other countries because the motivating factors that led to the development of *ENERGY-10* are present throughout the world. Version 1.0 is not suitable for use outside the United States because it works only in USA units (inches, Btu, etc.).

As mentioned earlier, the National Renewable Energy Laboratory (NREL) is in the process of including an option for other systems of units. Users will select from five options, U.S.A. and four metric sets. The metric sets will use meters and millimeters as the measures of length with three options for the unit of energy—kWh, joules, and kCal—covering conventional practice of most countries. Users will be able to enter the building description and view the results in any of the units sets even if the project was initiated in another units set. They will also specify the abbreviation for their unit of currency and input costs in those units.

However, it will take far more than the incorporation of a metric option to make *ENERGY-10* useful outside the United States. The eight steps outlined below would be required to make *ENERGY-10* fully effective.

1. Developing several country-specific weather-data files. *ENERGY-10* reads packed binary weather files compiled by BSG based on hourly data in TMY2 format. In most locations, weather data are available that could be readily adapted. Any weather files so created would become freely accessible to any user (download from the Internet, etc.).

2. Developing libraries of typical country-specific items, for example, materials properties and wall sections. Local distribution would include expanded libraries. The capability to edit and add libraries entries already exists in *ENERGY-10*.

3. Inclusion of defaults appropriate to country-specific construction practice. The defaults in *ENERGY-10* can be set separately for each building use type and for each energy-efficient strategy. The defaults are stored in the startup file. Local distribution would include this file.

4. Adjustments to Help to reflect the above changes. Help is a separate file. It would be necessary to compile a new Help file that includes units-specific and country-specific information. (The current file alludes to USA units throughout.) The changes could be made starting from the U. S. word-processor file, which is about 50,000 words long.

5. Developing a country-specific guidelines book. The PSIC guidelines book, *Designing Low-Energy Buildings*, is always distributed with *ENERGY-10*. It must be adapted to be appropriate to the local situation (units, sample building located in an appropriate city, local materials and practice, etc.).

6. Developing and implementing a country-specific training program. Workshops are seen as an essential part of dissemination. These might be similar to the two-day workshops in the United States, mixing lectures and hands-on practice with *ENERGY-10* at computer terminals. Training the trainers will be necessary. Presentation materials and the curriculum could be adapted from those used in the United States.

7. Other adjustments that are country specific. For example, the United Kingdom has expressed a requirement for hourly calculations of natural ventilation and determining the number of hours that the temperature exceeds specified threshold levels. In instances such as this, modifications of the source code are required in one or another of the main executables within *ENERGY-10*. Specific arrangements could be with NREL or BSG to make the necessary changes. All modifications will become part of *ENERGY-10*, included in subsequent upgrades and accessible by all users.

8. Translation of language. In many non-English-speaking countries, building designers are sufficiently fluent in English to use the current *ENERGY-10*. However, this is less true in the architectural profession than, for example, the engineering profession. Help, the manual, and *Designing Low-Energy Buildings* might need to be translated. Translating the words on the computer screen is a more complex issue. If the situation warrants, NREL could implement a language preference. This is not envisioned at present and would need to be arranged at a future time. Once this has been done the first time, however, it will be very easy to include the option for other languages.

The best way to accomplish the adaptations enumerated above would be to develop an agreement with a local entity in each country. NREL and PSIC would work with this entity to guide them in developing all the necessary elements of an effective program. BSG would convert the weather files. The local entity would be responsible for most of the effort and for disseminating the program within the country. Initial discussions are underway with entities in several countries.

The need for *ENERGY-10* in developing countries may be greater than in the developed world. Huge dislocations are taking place throughout the world. There are an estimated 60 million people moving to new locations each year. These people will require new houses and new buildings to work in. The potential implications in terms of environmental degradation and the need for new electric generating capacity are profound. Energy use can be reduced by at least 50% simply through correct building design. The buildings might not cost any more to construct because the costs of the energy-efficient features are often offset by savings resulting from reductions in the installed HVAC capacity.

In many mild climates, the need for heating, cooling, and lighting can be reduced to small backup systems required only occasionally. Peak electric loads can be shifted to off-peak hours. In many locations, natural ventilation can take the place of the costly and energy-intensive practice of central fan-forced ventilation systems combined with vapor-compression cooling. However, detailed simulation analysis is required to accurately size the system, predict how it will operate throughout a typical year, and perform trade-off evaluations of different strategy options. Simulation of natural ventilation is already possible in the CNE simulation engine and suitable connections to *ENERGY-10* will be developed.

*ENERGY-10* can also be used to evaluate the comfort in buildings that are not fully air-conditioned or even buildings that are allowed to free float as is the practice in many locations.

## CONCLUSIONS

*ENERGY-10* was written to fill an identified need and has been well received by designers. 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. Enhancements are planned that respond to identified user needs and to make the program suitable for use in other countries.

## ACKNOWLEDGMENTS

Funding is from the U.S. DOE. The Program Manager is Mary-Margaret Jenior, 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. PSIC developed the guidelines book, *Designing Low-Energy Buildings*. Particular thanks go to Scott Crowder, Will Sare, Bruce Wilcox, Rob Barnaby, Rob Hitchcock, Bill Carroll, Adrian Tuluca, Don Prowler, Bill Bobenhausen, Steven Ternoey, Greg Franta, Fred Roberts, Helen English, and Blaine Collison.

*ENERGY-10* is distributed by the Passive Solar Industries Council, 1511 K St. NW Suite 600, Washington, D.C. 20005, +1-202-628-7400, ext 210, e-mail psic@aecnet.com. A description ,upgrades, and weather files are available on the Internet at http://www.nrel.gov/buildings/energy10/.

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