DESIGNING LOW-ENERGY BUILDINGS
WITH
ENERGY-10

Dr. J. Douglas Balcomb
National Renewable Energy Laboratory

George Beeler
AIM Associates

SOLAR 98

23rd National Passive Solar Conference
American Solar Energy Society
(paper #006)

June 13-15, 1998

Albuquerque, New Mexico

DESIGNING LOW-ENERGY BUILDINGS WITH *ENERGY-10*

Dr. J. Douglas Balcomb
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, Colorado 80401
doug_balcomb@nrel.gov

George Beeler
AIM Associates
210 Fourth Street
Petaluma, CA 94952
aimassocia@metro.net

ABSTRACT

Low-energy building design works best through a process that starts with energy calculations in predesign that identify the best energy-saving opportunities and continues with follow-up calculations as the design proceeds. An example of this process was the design of the Environmental Technology Center for the Sonoma State University in California. The *ENERGY-10* design-tool computer program proved to be ideally suited for the purpose, providing critical information quickly and at an early stage. Starting with a goal to reduce energy consumption by 80% below the regulated maximum, *ENERGY-10* identified strategies that approached the goal even before design was initiated. The paper tracks the use of *ENERGY-10* through the design process. At the end of schematic design, *ENERGY-10* calculations confirmed that the goal of 16800 Btu/ft^2 had been attained—an extremely low-energy building. Design drawings and simulation results are presented. Construction will start in 1998.

1. INTRODUCTION

A major barrier to using energy simulation tools during the design process of a building has been the level of difficulty and the amount of time it takes to use the available programs. The *ENERGY-10* design-tool overcomes this hurdle by automating many of the time-consuming tasks, shortening the time required for data input from many hours to a few 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 operations. Graphical output greatly aids the process of assimilating and understanding the results. This paper describes how *ENERGY-10* was used in the design of the Environmental Technology Center at Sonoma State University in Rohnert Park, California, located in a coastal valley 50 miles north of San Francisco.

1.1 ENVIRONMENTAL TECHNOLOGY CENTER

The 2200 ft^2 Environmental Technology Center is to be part of the Sonoma State University EarthLab, a one-acre outdoor site used by Environmental Studies and Planning and other departments at the university. The EarthLab will contain an agro-ecology research greenhouse, an herb garden, demonstration gardens, a production composting area, and experimental growing beds. The purpose of the Environmental Technology Center building is "to teach, display, and be a state-of-the-art, beautiful and inspiring example of energy efficiency, passive solar, daylighting, renewable energy, and resource-efficient materials." Other criteria include the use of products of low embodied energy made in a sustainable manner, the use of recycled materials, and low maintenance. The design team set a site-energy use goal of 20% of the level allowed by the California Title 24 regulations. This goal corresponds to 16800 Btu/ft^2 per year. Daytime occupancy will be from 4 to 6 with gatherings of 100 during special events once a month. Most of the funds required for the EarthLab has been raised from various external sources. AIM Associates was selected as the project architect.

1.2 CLIMATE

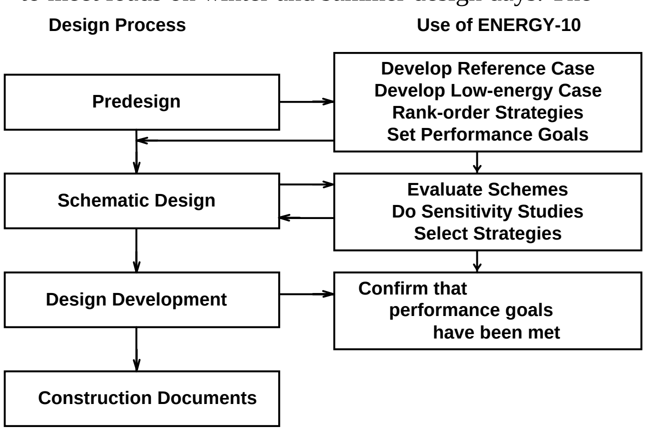
The climate of Rohnert Park is very mild—2960 heating degree-days and 316 cooling degree-days (base 65°F). Temperature swings in the summer are huge. The average daily high in August is 83°F and the average daily low is 52°F, providing ideal conditions for night-ventilation cooling of thermal mass to maintain comfort through the following day. Peak afternoon temperatures sometimes exceed 100°F. The summers are very sunny with almost no rain, and evaporative cooling is effective because of the low humidity. Passive solar heating works well in the winter months. Although the climate is conducive to low-energy building design, most contemporary construction does not take advantage of the opportunities—this results in large cooling systems, high peak loads, and high energy consumption.

1.3 *ENERGY-10*

ENERGY-10 is a PC-based building energy simulation program for smaller buildings that focuses on integrating the energy-saving strategies of daylighting, passive solar heating, low-energy cooling, and energy-efficient equipment during the early stages of the architectural design process (1-3). Developed specifically as a design tool, the program facilitates quick evaluations. Its simulation engines perform whole-building energy analyses for 8760 hours per year, integrating daylighting and dynamic thermal calculations.

Figure 1. Shows how *ENERGY-10* can be effectively integrated into the design process, identifying key activities at each stage.

Figure 1. Integration of *ENERGY-10* with the design process.



When a calculation is initiated, *ENERGY-10* first uses the simulator to determine the HVAC system capacities required to meet loads on winter and summer design days. The simulation then steps through the year iterating to find an energy balance at each hour accounting for heat storage in each material layer. A key feature of the simulator is that it iterates to find a consistent solution for the building load and the HVAC system at each time step.

2. PREDESIGN ENERGY CALCULATIONS

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. One should understand the important energy issues in the building to be designed. The following key activities should take place:

- Determine the performance of a reference case
- Determine the performance that can be attained
- Identify the important energy-savings strategies.
- Set quantitative performance goals for the project

Evaluation of the Environmental Technology Center was started using the AutoBuild feature of *ENERGY-10*. AutoBuild automatically generates two building descriptions. The *reference case*, Bldg-1, is a rectangular shoe box that has all the attributes of the building to be designed, such as appropriate internal gain schedules, the glazing-to-wall ratio, and constructions. AutoBuild relies on a set of predefined defaults for each of the nine building use categories recognized by the program. AutoBuild requires only five inputs; climate (we used a weather file for nearby Santa Rosa), building use (we used *Education)*, building floor area based on external dimensions (we used 2150 ft^2), height (one-story), and the type of heating, ventilating, and air-conditioning (HVAC) system (we used *DX Cooling with Gas Heating*). The first simulations for the *reference case* building yielded 88700 Btu/ft^2, in good agreement with the 83700 Btu/ft^2 Davis Energy Group estimate computed with the COMPLY24 computer program (we converted electrical source energy, which is the basis of Title 24, to site-energy by dividing by 3).

The *low-energy case*, Bldg-2, was also generated automatically during the AutoBuild process. It has the same geometry as the *reference case* modified to incorporate a set of energy-efficient strategies (EESs). This is done using the APPLY feature of *ENERGY-10*. APPLY modifies the building description by globally changing it to affect any desired combination of EESs. The program creates a complete new Bldg-2 by modifying Bldg-1 according to a prescription. For example, when the *Insulation EES* was applied, all of the walls in the building were changed from R-8.9 construction to R-19.6, the roofs changed from R-19 to R-38, and the perimeter insulated with 2 in of foam. The user specifies the changes to be made.

The 12 EESs currently automated in *ENERGY-10* are:

Daylighting	Energy-Efficient Lights
Glazing	Passive Solar Heating
Shading	High-Efficiency HVAC
Insulation	Economiser Cycle

HVAC Controls	Air Leakage Control
Thermal Mass	Reduced Duct Leakage

The results of simulating the *low-energy case* (incorporating an APPLY of all 12 EESs) yielded a total energy use of 35200 Btu/ft^2. In less than 15 minutes after starting the evaluation, the program produced results that showed the balance between heating, cooling, lighting, and other energies for two options: (1) a typical building of this size and type in this climate, and (2) a building with improved components and controls. We were still far from the goal and clearly needed to address the largest energy use of the *low-energy case* building, which was internal gains caused by "plug loads"—computers, copiers, and other equipment plugged into receptacles. The *ENERGY-10 Education*-building default is a peak use of 1.06 W/ft^2, a number based on the national-average energy use for all educational buildings in the United States.

We needed a more realistic starting point based on the actual anticipated use of the building and chose a peak-use value of 0.56 W/ft^2, corresponding to 1200 W of connected load (perhaps a copier and 3 computers). Additionally, we assumed that all lights, including external lights, were shut off at night and that hot water energy use was cut in half to 0.18 W/ft^2 peak. After these changes, the simulation gave a total energy use of 21800 Btu/ft^2, a 75% reduction compared to the original *reference case*. Figure 2 shows our progress to this point. We were close to meeting our goal.

A review at this time revealed:

- Heating energy requirements were almost eliminated by a combination of better insulation, air-tightening, and passive solar heating.
- Lighting energy requirements were reduced from 15100 Btu/ft^2 to 5000 Btu/ft^2 (a 67% reduction), mostly by daylighting, by installing 25% more efficient lights, and by turning lights off when they are not needed.
- "Other" energy—plug loads, hot water, and fan

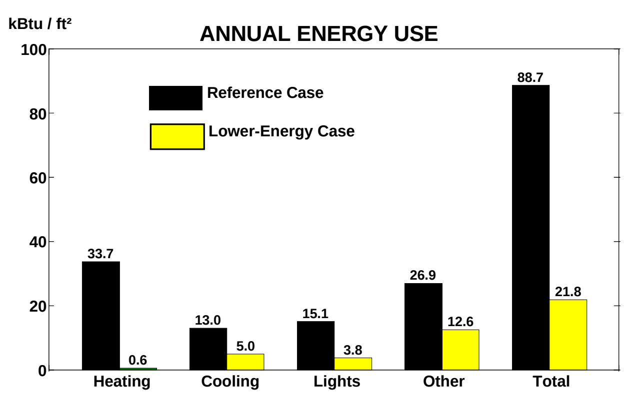


Figure 2. Comparison of the reference case with a low-energy case that has reduced internal gains.

energy—was reduced from 26900 Btu/ft^2 to 12600 Btu/ft^2 (a 53% reduction) but remained the largest energy use.

- Cooling energy, at 5000 Btu/ft^2, was identified as our next target, to be addressed either with night-vent cooling or evaporative cooling or a combination of the two (the HVAC system used up to this point is a conventional gas furnace, vapor-compression chiller, and forced-air distribution).

2.1 Ranking Strategies

An effective use of building simulation programs is to rank the effectiveness of various energy-efficient strategies being considered. 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. We used the option of omitting one strategy at a time rather than adding one strategy at a time because we knew that we were going to use most of the strategies and wanted to find out which were the least effective. The results are shown in Figure 3.

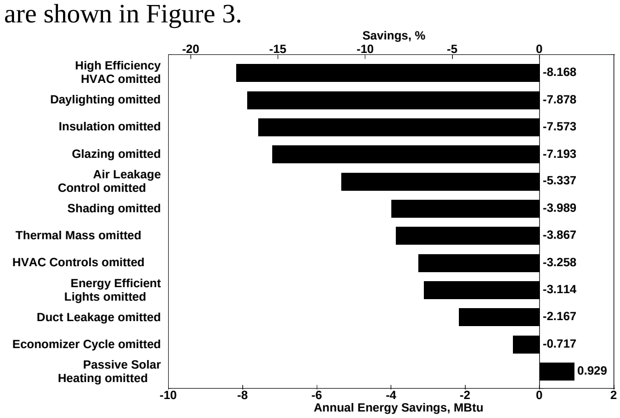


Figure 3. Ranking strategies, omitting one strategy at a time. "Savings" show as negative values because omitting the strategy increases energy use above the 47 million Btu low-energy case

We would definitely *not* want to omit the five at the top of the list. The next five are also effective. Passive solar costs energy because the remaining need for heat is so small and because the redistribution of windows decreases the performance of daylighting. Because this can be remedied through the daylighting design, passive solar heating was retained as a strategy. The economiser cycle is marginal because the need for cooling is primarily when the outside temperatures are high.

2.2 Evaluating Night-Vent Cooling

Given low outside temperature conditions at night, a building can be kept comfortable by using a technique called night-vent cooling. A comprehensive annual evaluation is beyond the current capabilities of *ENERGY-10*; however, with a little effort it is possible to do a "work-around" calculation for a selected time period. We picked the last week in August—the hottest period of the year. To simulate natural ventilation, we used a fixed forced ventilation of 4600 CFM during the night hours and set the thermostats to prevent the HVAC system from heating or cooling the building. The first time that we did the calculation, we noted that the building warmed up too fast, reaching excessively high temperatures in the afternoon. To remedy this, we increased the internal mass. This decreased the building temperature swing and increased the minimum inside temperature. Movable shading devices are assumed to reduce summer solar gains.

Results of the ventilation simulation are shown in Figure 4. The plot shows how the building cools off at night as a result of night flushing and warms up during the day to peak values that were always less than 79°F. despite 99°F outside temperature peaks. With the elimination of cooling, predicted energy use is just below the goal—14900 Btu/ft^2—and we had not yet started design.

We were still working with a shoe box. However, we made a lot of assumptions that must be incorporated into the design; night-vent cooling, component U-values, daylighting performance (calculated based on windows and skylights), air-tightening, shading, and equipment efficiencies.

3. SCHEMATIC DESIGN

The schematic design phase could now begin. We knew which issues would be critical to energy performance. Daylighting dictates the design more that the other EESs. We wanted to bring the light in high—from the roof if possible—to provide an even distribution and prevent glare.

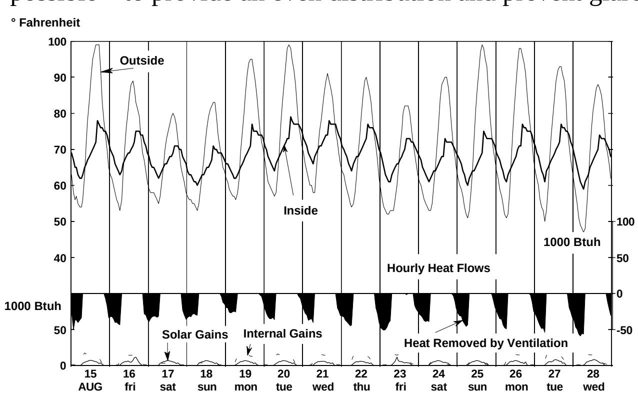


Figure 4. Results of night ventilation in August.

A single high roof monitor was selected. We knew that the additional surface area created by a tall sloping roof would not present a problem, because the increased heating load could be easily met by passive solar.

ENERGY-10 is not a daylighting design tool—it only evaluates the overall lighting and thermal energy implications. We turned to George Loisos, who used the RADIANCE ray-tracing program to evaluate daylighting. His results served as the basis for the design of the roof monitor. A large monitor was selected to provide adequate daylight (50 foot-candles) under overcast conditions. The calculated lighting distribution and contrast ratios are satisfactory under beam conditions.

Night-vent cooling also dictated the need for a high roof to create the large stack effect required to induce natural ventilation at night. We did not want to use fans to force night-vent cooling. Instead, we would count only on the stack effect to induce airflow because there is often little wind at night. A separate hand calculation determined the inlet and outlet areas required to achieve the 4600 CFM airflow given the inside and outside temperatures. A backup evaporative cooling system would be installed for peak occupancy periods.

To accommodate passive solar heating, we designed a sunspace on the south-east side to serve as an air-lock entry to keep out hot summer afternoon air. The south-east orientation provides morning warmth but avoids over heating in the afternoon. We also made provision for Trombe walls on the south side. Trombe walls store solar heat for use in the evening hours and are, therefore, a better way to implement a part of the passive solar heating in this climate than direct gain because of the large diurnal swings of outside temperature—heat is needed at night but seldom during the day.

3.1 Analyzing The Schematic Design

As the building proceeds through schematic design, the building description in *ENERGY-10* must be modified to represent the various schemes being considered. During the process, the 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.

We calculated the areas of each major wall and roof plane, and the total area of windows on each façade and entered the numbers into *ENERGY-10*. The conditioned gross floor area was 2090 ft^2, based on outside dimensions, excluding the sunspace-entry.

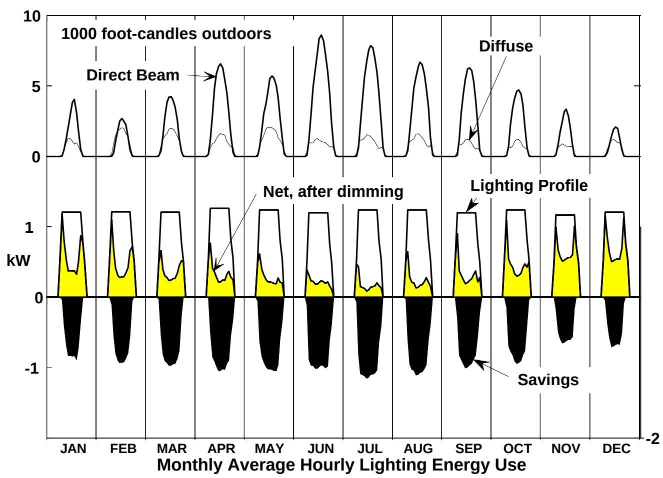
Because the *ENERGY-10* simulations, based on windows and skylights in the shoe box, were consistent with the estimates made by Loisos using RADIANCE, we used the illuminance values computed by *ENERGY-10* to estimate the annual lighting-energy savings and the corresponding thermal effects. Figure 5 shows the average daily behavior for each month. Of the 2.4 kWh/ft^2 of lighting energy that would have been required in the absence of dimming, 1.5 kWh/ft^2 (61%) is saved, leaving 0.9 kWh/ft^2 of lighting load supplied by artificial lights. This estimate may be pessimistic because these occupants will most likely turn off all but a few task lights during daytime hours.

Figure 5. Daylighting performance

The results of the simulation of the schematic design are shown in Figure 6, compared with the last predesign shoe-box results. (We assumed cooling is eliminated by night-vent cooling.) The schematic design has a predicted annual energy use of 14200 Btu/ft^2, just under the 16800 Btu/ft^2 goal. The schematic design is shown in Figure 7.

4. OTHER ASPECTS

The building will have a cooling system installed, primarily to meet loads during peak occupancy periods when as many as 100 people may be in the building. These will be infrequent and not affect the annual energy use



much. It would be imprudent not to install some active cooling in a climate where the temperature exceeds 100 °F. The system is being designed by the Davis Energy Group.

A photovoltaic system will be installed with panels integrated into the roof. The building performance will be monitored.

4. CONCLUSIONS

The Environmental Technology Center promises to be an extremely low-energy building. This paper is a case study of how a design tool should be used during the design process. The critical factor is to use the tool early, *before* the building has been designed, to evaluate energy characteristics during the predesign phase. This establishes the relative importance of heating, cooling, lighting, and other gains to the overall performance of a typical building
and provides an early indication of not only the potential saving possible through the application of energy-saving strategies but the relative importance of each strategy. Energy performance targets can be set before design commences. Then as the design proceeds, performance can

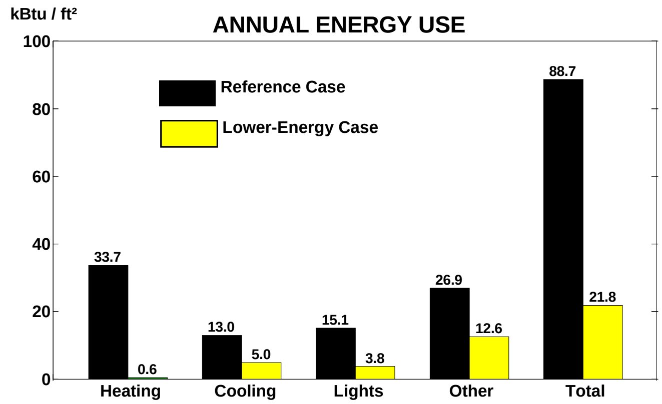


Figure 6. Results of the simulation of the schematic design, compared with the last pre-design case.

be checked at each stage to see whether the target has been met.

As this case study has demonstrated, the *ENERGY-10* design tool is well suited to providing critical information at the key points in the design process when it is most valuable. Energy performance considerations can be factored into the design of a building easily and with little expenditure of time.

The energy characteristics of every building are different because of differences in climate, building use, size other factors. In the case of the Environmental Technology Center, the mild climate offered the possibility of extremely low energy consumption. Low night-time summer temperatures offered the option of night vent cooling. The tool provided the means to evaluate strategies as a basis for selection and proceed with confidence.

5. ACKNOWLEDGEMENTS

Funding for *ENERGY-10* and for this paper is provided by the U.S. Department of Energy. The Program Manager is Mary-Margaret Jenior, Office of Energy Efficiency and Renewable Energy. Programming of *ENERGY-10* was done by National Renewable Energy Laboratory, by the Lawrence Berkeley National Laboratory, and by the Berkeley Solar Group. The Passive Solar Industries Council (PSIC) wrote the accompanying guidelines book, *Designing Low-Energy Buildings*.

We wish to thank Joe Armstrong, Jean Merriman Falbo, and Rocky Roehwedder at Sonoma State University for their contributions and support.

Christina Carew at the Davis Energy Group graciously provided results of COMPLY-24 simulations.

ENERGY-10 is distributed by PSIC, 1511 K St. NW Suite 600, Washington, D.C. 20005, (202) 628-7400, ext. 210. Descriptions of *ENERGY-10* are available on the Internet at:

http://www.nrel.gov/buildings/energy10/ or
http://www.psic.org

6. REFERENCES

(1) Balcomb, J. D. and R. C. Crowder, The *ENERGY-10* Design Tool Computer Program, Proceedings of the. 20th Passive Solar Conference, Minneapolis, MN, American Solar Energy Society, July 15-20, 1995.

(2) Balcomb, J. D. and D. Prowler, *ENERGY-10*: The Making of a Design Tool, Proceedings of the 22nd Passive Solar Conference, American Solar Energy Society, April 25-30, 1997, Washington, D.C.

(3) Balcomb, J. D.,*ENERGY-10:* A Design Tool for Low-Energy Buildings, Proceedings of Building Simulation '97, International Building Performance Simulation Association, Prague, Czech Republic, 8-10 Sept 1997.

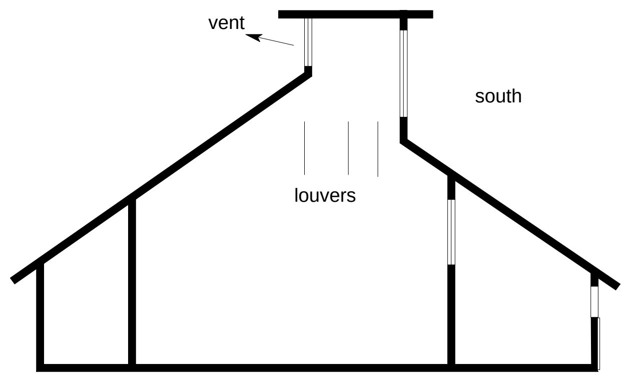


Figure 7b. Schematic design of the Environmental Technology Center (north-south section)

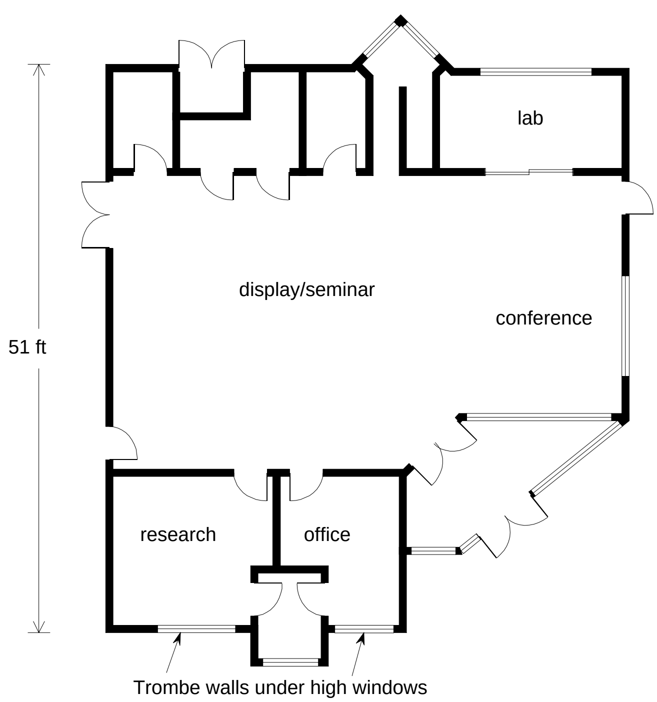


Figure 7a. Schematic design of the Environmental Technology Center (plan view—north is up)