VITAL SIGNS

THERMAL MASS IN PASSIVE SOLAR AND ENERGY-CONSERVING BUILDINGS

Bruce Haglund
Professor, University of Idaho

Kurt Rathmann
Research Assistant, University of Idaho

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THERMAL MASS IN PASSIVE SOLAR AND ENERGY-CONSERVING BUILDINGS

This sheet outlines the building performance activities at each level of investigation for the Thermal Mass Resource Package. While each activity can be performed as a stand-alone exercise, certain exercises require information from prior levels in order to give maximum benefit.

VITAL SIGNS

THERMAL MASS IN PASSIVE SOLAR AND ENERGY-CONSERVING BUILDINGS

INTRODUCTION TO THERMAL MASS

An essay examination was given on the thermal properties of buildings. There were two respondents to question six:

> 6. Describe the interrelationship between thermal energy and mass.
>
> *"All material in nature, the mountains and the streams and the air and we, are made of Light which has been spent, and this crumpled mass called material casts a shadow, and the shadow belongs to Light."*
>
> *—L. Kahn*
>
> *"$E = mc^2$"*
>
> *—A. Einstein*

Kahn, like many students, was confused by the difference between visible and thermal radiation and believed that the thermal energy was poetically turned into mass, rather than merely being stored in the mass. On the other hand, Einstein overstated the case with a brief, but dazzling theoretical statement which urges that mass and energy are interchangeable while he overlooks the ordinary, day-in day-out workings of thermal mass, in which the mass simply stores thermal energy when in abundance and releases it during times of need.

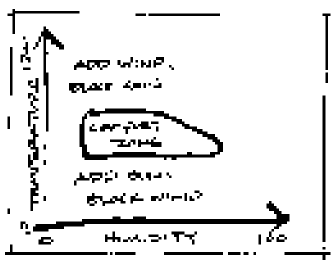
Thermal mass offers the architect the opportunity to manage thermal energy flows of a building to the advantage of its occupants without the use of large amounts of high-grade fuels.

Salk Institute where the Pacific sunset has been magically transformed to mass.

THERMAL MASS PRIMER

This primer describes the theoretical basis of thermal mass use in heating and cooling buildings. It is intended to serve as a comprehensive "highlight film" of mass use, rather than a complete, seminal work on thermal mass. Important references which complement and extend the "highlights" presented here are cited in this primer and in the annotated bibliography.

THERMAL MASS IN BUILDINGS



Olgyay's Bioclimatic Chart reveals passive strategies based on climate conditions.

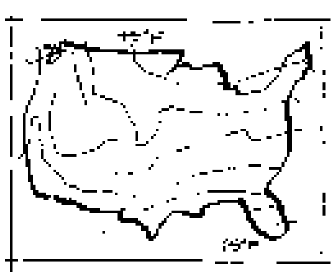
Thermal control

The diurnal changes in temperature and solar radiation pose challenges for maintaining thermal comfort for people in buildings. Each day of the year offers the possibility of conditions that can be judged as too hot or too cold. Passive and energy-conserving buildings seek to manage the available thermal energy by lowering peaks and filling valleys in order to maintain conditions for human comfort. Thermal mass is one of the powerful tools designers can use to control temperature.

Desired effects of thermal mass

A humble material, mass ideally acts as a thermal flywheel for a building both diurnally and annually. It can absorb and store excess thermal energy when the building's thermal load is high and release the energy when the load is low. This ability can mediate the diurnal temperature swings by absorbing excess heat by day and releasing it by night during both heating and cooling seasons. Appropriately sized thermal mass can help buildings manage their thermal energy resources when coupled with both passive heating and cooling strategies.

For buildings that use solar gain as a heating strategy, diurnal effects can be managed by absorbing the bulk of the heat of the winter sun during the day, while keeping the air temperature moderate, and releasing the heat at night to prevent the air temperature from plummeting. For buildings that use forced or natural ventilation as a cooling strategy, diurnal effects can be managed by mass which absorbs the heat of internal building loads during the summer's day (keeping the air cool) and the day's accumulated heat is flushed by cool air each night. Annually, when mass is coupled directly to the bulk of the earth it can provide a cooling advantage in the summer by presenting a surface temperature near the average earth temperature (see map). The heating advantage of coupling to the "insulating earth" is problematical—on a cold night a well-insulated wall (R-30) will lose heat to the



Average U.S. groundwater temperatures show the thermal potential for earth-sheltering.

Compare the performance of an uninsulated concrete wall (R-3) to that of a similar uninsulated, ground-coupled concrete wall (R-3) and a built-to-code frame wall (R-20). Assume that the thermostat temperature is 65°F, the outside temperature is 35°F, and the earth temperature is 55°F.

The rate of heat loss, $UA\Delta T$, for one square foot of each wall is:

1. The uninsulated concrete wall—

$$UA\Delta T = (1/3)(1)(30) = 10 \text{ btuh/ft}^2$$

2. The earth-coupled concrete wall—

$$UA\Delta T = (1/3)(1)(10) = 3.33 \text{ btuh/ft}^2$$

3. The built-to-code frame wall—

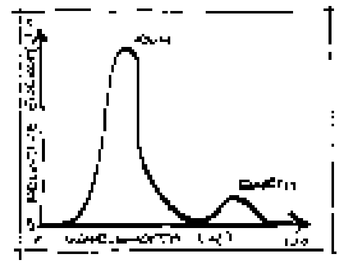
$$UA\Delta T = (1/20)(1)(30) = 1.33 \text{ btuh/ft}^2$$

As you can see, the earth-coupled concrete wall outperforms its uninsulated sibling, but is similarly left in the dust by the code-compliant wall.

exterior at a rate that is slower than through an earth-coupled, eight-inch concrete wall (R-3)—(see box).

Heat transfer modes

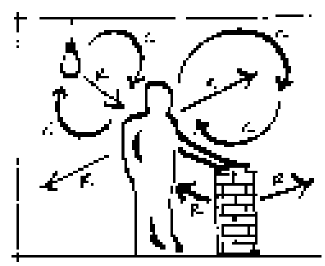
Three methods of heat transfer between the mass and the environment can occur—by near infrared radiation (from the sun), by far infrared radiation (from/to all terrestrial sources), and by conduction/convection (from/to fluids or solids at a higher/lower temperature). The magnitude of the temperature difference determines the rate of heat flow—the greater the difference, the faster the flow.


Solar radiation is near-infrared, while terrestrial radiation is far-infrared.

Thermal mass exposed directly to the sun, unlike most other building materials, is effective in absorbing and storing a great deal of the radiant energy. Similarly, mass exposed to terrestrial radiant sources (such as lamps, people, and equipment) will absorb and store a large amount of the radiation. When the mass' surface temperature exceeds those of the air and adjacent surfaces, the mass will experience a net conductive/convective and radiant loss to its surroundings. Mass will gain heat by conduction/convection from a warmer fluid or solid and will likewise lose heat to a cooler fluid or solid. This trait is especially important during a building's cooling cycle when thermal mass is flushed with fresh air.

Heat transfer process

Heat flows from warm objects to cool objects by radiation, conduction, and convection. In a thermal mass this is a four-step process. Step 1: Heat is radiated to the surface of the mass by a warmer object (the sun, people, lights, equipment, etc.). Step 2: Heat is conducted from the warmed surface to the cooler interior of the mass. Step 3: When the mass surface becomes warmer than other objects in the room, it radiates heat to them. Step 4: Heat from the warmer interior is conducted to the cooler surface. For mass to be effective this process must occur in a time frame that approximates the thermal cycle of the building—usually a diurnal cycle.


Conductive heat exchange between person and warm mass and other radiant (R) and convective (C) paths.

The thermal mass affects both the occupants of and the air temperature in a space. To be comfortable, people need to lose heat, through radiation (R), conduction/convection (C), and/or evaporation (E). This rate of heat loss should equal the rate of heat gain through metabolic (M), radiant (R), and conductive/convective (C) processes to maintain comfort over the long term. When conductive loss to cool air and radiant loss to cool surfaces are too rapid, discomfort results—likewise, for gains from warm air and warm surfaces (including the sun). Thermal equilibrium, which is equivalent to long-term human comfort, is described by the formula:

$$M \pm C \pm R - E = 0$$

Conductive heat loss to a material can be sensed by touching its surface with our fingertips or the back of our hand, but this simple test may not reveal its value as thermal storage. Our skin temperature is ordinarily above 80°F, so we sense a loss of heat to surfaces that are above desirable room temperature for heating (65–70°F) and skin temperature. These "cool" surfaces are actually providing valuable thermal comfort. Remember, we must be losing heat at a moderate rate in order to remain comfortable.

The formula for thermal storage is:

$$Q = C_p \cdot \rho$$

where: Q is heat stored

C_p is specific heat

ρ is density

Ideal thermal mass

In order to be effective as a thermal mass, a material must have a high heat capacity, a moderate conductance, a moderate density, and a high emissivity. It is also important that the material serve a functional (structural or decorative) purpose in the building.

Among common building materials, wood does not make a good thermal mass because it not only has a low heat storage potential, but is also not very conductive. Therefore, heat is not conducted readily to the material's interior to be stored for later use, but is rejected prematurely (as surface temperature rises) by radiation to cooler objects. Steel, while having a seemingly high potential for heat storage, has two drawbacks—its low emissivity indicates that a large majority of the incident radiation is reflected, rather than absorbed and stored, and its high conductivity signals an ability to quickly transfer heat stored in the material's core to the surface for release to the environment, thus shortening the storage cycle to minutes rather than the hours needed for diurnal thermal tempering. Glass also seems to have a high potential for heat storage, but it is relatively transparent to near infrared radiation and reflective of far infrared radiation. Adding pigments to glass (especially blue and green) increases its ability to absorb radiation, which can become a thermal problem during the cooling season. In the case of both steel and glass, masses that are large enough to act effectively as diurnal thermal masses are so large, heavy, and costly that they are not practical.

Concrete and other masonry products are ideal, having a high capacity for heat storage, moderate conductance that allows heat to be transferred deep into the material for storage, high emissivity to allow absorption of more radiation than that which is reflected. When sized properly, concrete is effective in managing diurnal energy flow. Conveniently, structural concrete and thermal mass share common dimensions, so there is no wasted mass when building a structure. Water is also effective as a thermal mass in that it has high potential for

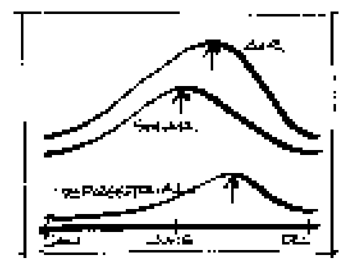
Common building materials have the following thermal storage characteristics:

Material	C_p (Btu/lb-°F)	ρ (lb/ft^3)	Q (Btu/ft^3-°F)
Wood	0.57	27	15.4
Steel	0.12	489	58.7
Glass	0.18	154	27.7
Concrete	0.156	144	22.4
Water	1.0	62.3	62.3

[This means, for example, that when a cubic foot of wood is raised in temperature by one degree it has stored 15.4 Btu.]

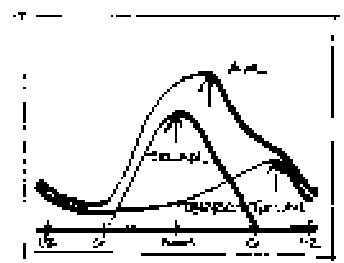
heat storage and it can be effective in a diurnal thermal management scheme. Water use is more problematical in that, unlike concrete, it serves no structural purpose in construction, but when stored in clear or translucent containers can provide light and/or views through the (normally opaque) thermal mass.

The earth as thermal mass
On the global scale the earth acts as an effective thermal mass for its atmosphere. Air temperatures near the earth's surface show both diurnal and seasonal time lags due to the storage capacity of the earth's surface materials (stone and water) and re-radiation of stored energy. Consequently, average daytime temperatures occur in midafternoon rather than at noon, and average annual high temperatures occur in August (in the northern hemisphere) rather than at the summer solstice. A few feet of soil near the surface store and release solar radiation seasonally. Deeper (below the frostline) conditions are more thermally stable—maintaining a temperature below, but near, the human comfort zone.



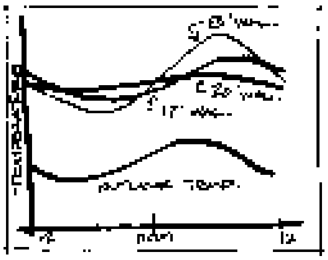
Annual solar and terrestrial radiation combine to create seasonal time lag of air temperature.

Building underground or berming a structure uses the mass of the earth as a means of moderating outside temperature extremes. Below the frostline, the temperature of dry earth hovers above or below a relative constant (see map). Approximately 2–12 feet below the surface, the ground temperatures will fluctuate somewhat with the seasons, but seasonal highs and lows will lag by as much as three months. The seasonal time lag, created by the earth, is a factor of soil type, soil diffusivity ($k/\rho \cdot C_p$), depth below grade, groundwater conditions, and climatic characteristics. Dry soils, deep locations, and low annual air temperature changes offer the smallest annual ground temperature fluctuations.



Diurnal solar and terrestrial radiation combine to create daily time lag of air temperature.

During the heating season, the earth cover effectively lowers the number of heating degree days by providing a comparatively high outdoor design temperature (equal to the earth temperature, rather than the air temperature). The cold air is separated from the building's envelope by the earth and infiltration is practically eliminated. During the cooling season, the earth reduces the number of cooling degree days by preventing solar radiation from striking the building's envelope. When no insulating layer exists between the mass and the earth, the earth can also serve as a direct heat sink. When a building experiences high internal loads or above-freezing winters, direct conductive contact can be beneficial, otherwise, an uninsulated coupling might cause a high rate of heat loss in winter. The best practice is to insulate down to the frostline. An earth-coupled building tends to moderate the annual average temperature of its surrounding earth, unless the earth is highly conductive (caused by high moisture content or flowing water). A method for estimating the cooling potential of uninsulated walls against the earth is provided in *MEEB* on page 274. Some general rules for earth cooling are listed on page 205 in Lechner's *Heating, Cooling, and*



Effects of concrete walls of various thickness on direct gain spaces (after Mazria).

Lighting. If solar and internal gains counterbalance the winter heat loss, uninsulated walls sized for summer loss are a possibility.

Temperature swings

Mass, by storing and releasing excess heat, moderates temperature swings inside a building. The volume and thickness of thermal storage determines the magnitude of interior temperature swings. The time necessary for heat to be released by various thermally massive materials is called thermal lag. The optimal size, color, and location of the thermal mass depends on the building's design strategy, energy requirements, occupancy patterns, and climate.

For example, in internal-load-dominated buildings which must expel heat, it is important that the mass not retain the heat and release it in the building during peak occupation. When the primary energy source to be managed is a room full of electric lights and computers, or active children, the character of the design temperature swing may not resemble the familiar-looking sinusoidal solar curve. Additionally, when temperature cycling occurs around thermostat set-points, the swings are actively moderated by the HVAC system resulting in the potential short-circuiting of the passive performance of the thermal mass by removing heat before it can be stored. A better understanding of thermal mass behavior under these complex circumstances will result in properly integrated strategies for managing interior temperature swings and reducing mechanical system energy use.

Air temperature vs. radiant temperature

In a non-massive space, the air temperature and the surface temperature of the walls, ceiling, floor, and furnishings are about equal. When mass is used effectively, its surface temperature can differ significantly from the temperature of the air and other surfaces—the difference is greatest when the mass is fully charged or fully discharged. The resulting mean radiant temperature (MRT) can be calculated.

$MRT = T_g + 0.24 + V*0.5(T_g - T_a)$,

where

T_g is globe temperature,

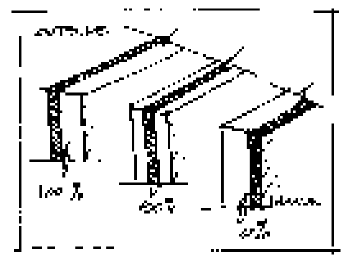
V is room air velocity in ft/min,

T_a is air temperature.

An added bonus is that small differences in surface temperature compensate for larger differences in air temperature. Thermally massive indoor spaces that have been designed to effectively store heat gains produce somewhat higher MRTs compared to lightweight buildings. On the other hand, if the same space is ventilated at night during the cooling season, the MRT is lowered before daily peak occupancy, providing a cooling effect. The radiant temperature to air temperature ratio is about 1:1.5. For example, if a room is comfortable when air and surface temperatures are all 65°F, raising the surface temperature to 66°F allows the air temperature to fall to 63.5°F to maintain the same level of comfort. For this reason, in spaces influenced by thermal mass, air temperature alone is not a good indicator for comfort.

Effective placement

The cardinal rule (with one significant exception—courtyard cooling—noted below) for effective thermal mass is to place it inside the insulated skin of the building. A masonry wall with exterior insulation is a thermally elegant construction. It is effective during both heating and cooling seasons. During heating seasons it can store solar and internal gains by day and release the heat by night. During the cooling season it gains heat from interior sources during occupied periods and can be flushed of heat at night. A masonry wall that is insulated on the interior is thermally isolated from internal gains and solar gains that enter the building through glazing. Its mass is virtually useless in management of indoor temperatures. Uninsulated masonry walls are thermally perverse, conducting summer heat gains into the building (especially true of east- and west-facing walls) and conducting internal heat to the exterior in winter—granted, with a thermal lag determined by the thickness of the masonry. In vernacular architecture for hot arid climates this perversity is mitigated by using extremely thick (2–3 feet) masonry walls to avoid diurnal transmission of heat.



Thermal mass loses effectiveness as insulation position shifts from exterior to interior.

The distribution of the thermal mass inside the building is also important. The mass must be proximate to the primary thermal stimuli in the space and unhindered by thermal obstructions such as carpeting, wall coverings, and suspended ceilings. When solar gain is being exploited, the mass should be exposed to the sun for extended periods for maximum effectiveness.

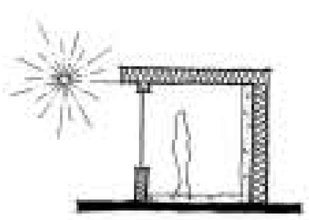
Night insulation enhances the efficacy of thermal mass during the heating season. This improvement comes not from added effectiveness of the mass, but from reduction of the thermal liability of the glazing—its low R-value in comparison to other building components. Switchable insulation may also be used effectively as day insulation to improve mass cooling strategies, such as roof ponds.

THERMAL MASS IN BUILDING DESIGN

Thermal mass is a crucial ingredient in the success of most passive solar heating strategies, active heating and cooling strategies, and some passive cooling strategies. It often is used to optimize the performance of energy-conserving buildings that rely primarily on mechanical heating and cooling strategies.

This section is intended to present the basic features of each distinct thermal mass strategy while reserving more detailed discussion for other, more comprehensive texts.

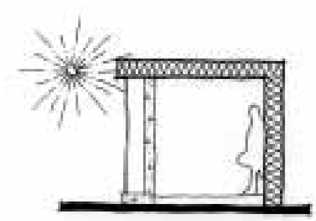
PASSIVE HEATING STRATEGIES



Direct gain diagram

Direct gain

The success of this strategy is dependent on the thermal mass absorbing excessive heat gains while the sun is entering the space during the heating season. Ideally, the thermal mass should be directly exposed to the sun all day and its surface should remain relatively unobstructed. A rule-of-thumb is for the mass area to exceed the glass area by an minimum factor of three. Higher ratios of up to 9:1 are recommended depending on mass type, exposure, thickness, occupancy patterns, energy requirements, and climate. Masonry surfaces greater than 4 to 6 inches in depth are less thermally effective. During the cooling season the sun should be excluded from the space.

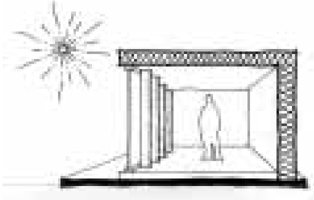


Trombe wall diagram

Indirect gain

In indirect gain strategies thermal mass separates the collector from the conditioned space. The thermal mass manages the flow of heat energy through the separator's time lag property. Operable vents or other convective connections between the collector and the space can augment daytime temperatures by allowing warm air to enter the space. Several different indirect gain strategies are in widespread use—Trombe walls, water walls, roof ponds, and sun spaces (green houses).

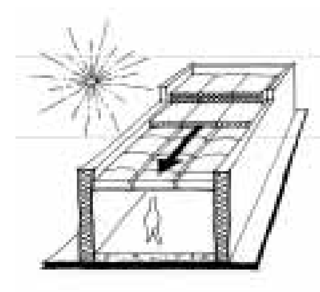
Trombe walls, commonly constructed of concrete or masonry, are placed directly between the south-facing aperture and the interior space. The use of night insulation enhances the efficacy of this system considerably. When daytime comfort is a design goal, thermocirculation vents can provide warm air to raise the air temperature in the space.



Water wall diagram

The water wall, placed between the south-facing aperture and the space, has the added benefits of a higher overall heat capacity and a potential translucency that lets diffused light into the space—but water wall performance predictions are usually based on opaque, unvented systems. Air circulation between the collector and the space is usually uninhibited by loosely placed water containers. Night insulation will improve the efficacy of this system.

The roof pond or skytherm places the thermal mass in the roof structure. It is dependent on a switchable, exterior insulation scheme to make it effective for both heating and cooling. In the heating mode, the insulation is deployed at night, while in the cooling mode, the insulation is deployed during the day. The thermal mass, water in containers such as waterbed mattresses, must remain in direct thermal contact with the interior of the building. A structural steel deck is the typical thermal connector for this system.



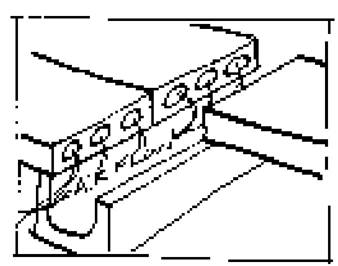
Roof pond diagram

A sun space is an occupied space that serves as a solar collector for the building. Thermal mass should be used in the sun space to maximize its habitability and may be used between the sun space and the building to help manage the building's thermal flow.

PASSIVE COOLING STRATEGIES

High-mass cooling

High-mass passive cooling strategies use mass to store internal heat gains which are flushed each night by using natural ventilation or fans as appropriate. Although mechanical forced-air handlers technically create a hybrid solution, they are commonly integrated with high-mass cooling. In conjunction with heat-avoidance strategies, high-mass cooling methods can be appropriate in all but the most humid regions. They have the greatest potential in hot, dry climates that experience high diurnal temperature swings.



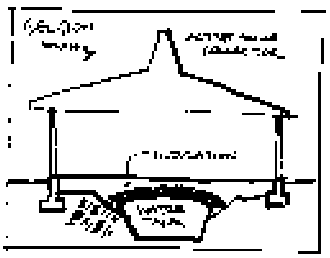
Core-floor construction can be diurnally flushed of stored heat.

Internal-load-dominated buildings constructed of thermally massive materials have the most to gain from incorporating nocturnal ventilation and/or radiation cycles. The office building for the Emerald People's Utility District near Eugene, Oregon, provides a good case study for this strategy using hollow core, precast concrete slabs and CMU walls with all cells grout-filled. The walls and floor are flushed with night air both at their surfaces and through the floor's hollow cores.

Courtyard cooling

The most significant exception to the cardinal rule for mass placement is the use of mass in exterior courtyards for cooling in hot, arid climates. In this instance, a thermally massive courtyard floor surrounded by a building buffered with a shade-giving arcade provides cooling, primarily by radiation to the cool, clear night sky. The nighttime radiation cools the mass and the air trapped in the courtyard. The cool air is drawn into the building, replacing warmer air which rises. During the day the shading arcade protects the building from direct solar gain and the cool mass in the courtyard floor absorbs a significant amount of solar radiation. John Reynolds has found that the most thermally effective courtyards are those whose mass floor has an unobstructed view of the night sky—no trees or vegetation block the radiant path.

A Courtyard in Colima, Mexico acts as a cooling device for the adjacent building.



Henry Mathew house uses a large water tank for seasonal heat storage.

ACTIVE HEATING STRATEGIES

Rock beds and water storage tanks are essential ingredients for the success of an active solar heating system. Active systems use mass to store thermal energy so that it can be used for heating on demand. Appropriately sized thermal masses can be used to manage thermal energy both diurnally and seasonally. Unlike mass used in passive systems, mass in active systems is usually thermally isolated from both the collector and the conditioned space and, therefore, may be used to store heat all summer for winter use.

THERMAL MASS SUBSTITUTES

Phase change materials

By taking advantage of the energy stored and released during change-of-state, materials that have a melting point near room temperature can replace thermal mass without the bulk of large masonry structures or large water containers. These materials are commonly called phase change materials (PCMs). Technical problems with storage and endurance have prevented these materials from coming into wide-spread use. However, the potential for PCMs is great. For example, converting one pound of ice at 32°F to one pound of water (1/62.3 ft^3) at 32°F requires the "storage" of about 1,000 Btu, conversely, about 1,000 Btu are released as the water freezes. A temperature change of 1°F requires about 50 cubic feet (7,000 pounds) of concrete to store 1,000 Btu. The reduction in mass and volume offered by PCM use is potentially enormous.

CODE CONSIDERATIONS

There are no code requirements for the use of thermal mass in buildings. When meeting the R-value requirements of a prescriptive code, an exterior masonry wall with insulation on the inside is considered to be the thermal equal of a similar wall with the insulation on the outside. It is obvious to the informed designer that the latter will outperform the former. However, all energy codes that offer compliance by meeting performance criteria reward the use of thermal mass. The "reward" is that code-compliant performance can be attained with lower insulation levels or larger glazing areas than in low-mass buildings. Keep in mind that energy codes describe the worst thermal performance allowed by law.

The thermal benefit of mass in building performance can be calculated by hand- or computer-based methods. The best way to (vicariously) appreciate the role of mass is to compare the performance of a design that uses mass effectively with a similar design that has little effective mass. Well-designed passive and energy-conserving buildings should outperform code requirements by at least 30%, provide optimal human comfort, and delight the occupants' aesthetic sense.

LEARNING UNITS AND PROTOCOLS FOR FIELD EVALUATION

INTRODUCTION TO LEARNING UNITS

This section presents five learning units which incorporate all three levels of Vital Signs field protocols. The learning units are presented in their entirety to convey a structured and holistic approach to building analysis. The learning units can be used in a course in sequence to guide students through a thorough analysis of a building. If an instructor desires to perform a partial analysis or to address multiple environmental issues in a course of study, the individual protocol, appropriate to the task-at-hand, can be disaggregated from the body of a learning unit. The following outline attempts to demonstrate and categorize the makeup of each learning unit.

Learning units vs. field protocols
Vital Signs field protocols are each assigned a level, characterized by length and depth of engagement. These levels are listed below with their Vital Signs defining criteria and the Thermal Mass Resource Package techniques appropriate to each protocol level.

Level 1—single day with hand-held instruments, observations, interviews, and survey techniques

Techniques—visit preparation, drawing, photography, user surveys, observation, interviews, document analysis, *UISUN*

Level 2—visits up to a few weeks in duration, hand-held instruments, collection of physical measurements and modest simulation exercises

Techniques—temperature data loggers, pyrometers, data analysis, *Solar-5*

Level 3—study for one or more seasons, data acquisition systems

Techniques—utility bill disaggregation, data analysis, *Solar-5,* findings

The Thermal Mass Resource Package protocols are incorporated in learning units that form an ascending sequence from the simplicity of level 1 to the complexity of level 3.

Learning Unit #1: Computer-Aided Schematic Design

Protocol 1A—*UISUN* Parametrics—Level 1

Learning Unit #2: Thermal Mass Strategy Analysis

Protocol 2A—Diagrammatic Thermal Analysis—Level 1

Learning Unit #3: On-Site Thermal Mass Survey

Protocol 3A—Observation and Analysis—Level 1

Protocol 3B—Surveys and Interviews—Level 1

Protocol 3C—Monitoring Thermal Mass—Level 2

Protocol 3D—Building Time Constant—Level 2

Learning Unit #4: Thermal Mass Performance Model

Protocol 4A—Computer-Based Thermal Model—Level 3

Protocol 4B—12-Day Performance Comparison—Level 2

Learning Unit #5: Thermal Performance Critique

Protocol 5A—Presentation of Findings—Level 3

Class planning

A course description for a seminar that incorporated all the learning units is given in Appendix 1 as a guide to the reader. Each learning unit was tested by the students, their write-ups analyzed, and the learning units refined and improved.

LEARNING UNIT #1

COMPUTER-AIDED SCHEMATIC DESIGN

Goals

This learning unit is intended to familiarize the student with the building being studied; the importance (or lack of importance) of passive heating and thermal mass in the building's design; and the use of computer-based tools for design, analysis, and evaluation of thermal systems.

The exercises are intended to be performed off-site and do not require a site visit (although a visit could be helpful). *UISUN,* a computer-based schematic design tool, is used to analyze the building because (1) it requires only five input parameters to describe the building, (2) it focuses its analysis on only one aspect of thermal design (passive heating), and (3) it allows quick side-by-side comparisons of different design scenarios to be calculated and displayed.

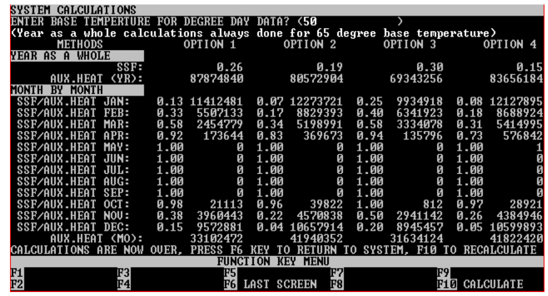
UISUN software and users' manual are provided—see Appendix 2

Discussion

Computer-based tools can take the drudgery out of calculating thermal performance for buildings. These calculations can be the basis for analysis of an existing building or for making design decisions for a new or remodeled building. Moreover, a computer-based tool can allow the designer to play out "what if?" scenarios by changing a single design variable and comparing results. Computer power and speed allow this type of parametric investigation to be repeated over and over to help the designer understand the relative importance of various strategies.

For this Learning Unit you will choose a space with a south-facing aperture in an energy-conserving building to study the effectiveness of its design. You will use *UISUN*, an SLR method computer program, to make parametric comparisons of the effectiveness of possible passive solar heating strategies for the space. *UISUN* is a user-friendly, DOS-based program that allows you to calculate the solar contribution to space heating with minimal building information. Consequently, it can be used early in the design process to help make design decisions, or it can be used parametrically to evaluate an existing design. The SLR (solar load ratio) method was developed at Los Alamos National Laboratory as a hand calculation procedure for predicting passive solar heating of residential and small commercial buildings. The algorithms for the method are based on empirical observations of several different passive solar configurations. The method supports calculations for 94 different systems in 219 different U.S. and Canadian climates. It only calculates heating requirements (with no adjustments for shading devices); no consideration is given to cooling. The output from the month-to-month calculation demonstrates the seasonal variation in passive solar heating contributions.

There is a range of parameters that you can explore with *UISUN:*



UISUN calculation screen.

1. **Base temperature.** *UISUN* allows you to chose a degree-day base temperature of 50, 55, 60, or 65°F. The base temperature choice strongly affects the calculated performance. Therefore, it is important to choose an appropriate base temperature in order to accurately model the thermal performance of your building. Traditionally, degree-day base temperature has been calculated for 65°F. The assumption is that the thermostat is set at 70–72°F, so that internal gains in a residence will make up the difference (5–7°F) between the base temperature and the thermostat setting. Today's residential energy codes call for higher insulation levels, which inhibit heat loss and reduce the balance point temperature. Therefore, a lower base temperature is appropriate. A good guess is about 55°F for code-compliant residences. Moreover, for nonresidential buildings a lower base temperature is appropriate because of greater internal heat gains from electric lights, occupants, and equipment. Commercial buildings often have balance point temperatures that are well below the 50°F minimum of *UISUN.* In fact, the appropriate base temperature should be approximately equal to the balance point temperature of the building. The larger the internal load, the lower the base temperature should be. *UISUN* assumes a constant base temperature, when in fact, the balance point temperature changes with occupancy. You should think of this base temperature as an "average" balance point temperature. (See *InsideOut* C1.5 and E1.8 for more information.)

The formula for calculating the balance point temperature (at any instant) is:

$$T_{bal} = T_{in} - (HG_{int}/HL)$$

where

T_{in} = interior temperature (ºF)

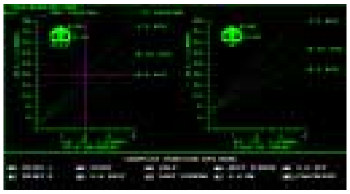
HG_{int} = internal heat gain rate (btuh)

HL = heat loss rate (btuh/ºF)

Warning: *UISUN* always makes the annual calculations for SSF (solar savings fraction) and auxiliary heat based on a degree-day base temperature of 65°F. Only the month-to-month calculations will reveal the effect of a lower degree-day base temperature selection.

2. **Climate.** Although *UISUN* is capable of calculations for 219 North American climates, only 20 climates are included on the program diskette. The climate files that are on the program diskette are representative of the range of climates present in the continental United States. If you want to use a climate that is not on the program diskette, you must create a climate file using the *UISUN* utility program DBEDIT and data from *Passive Solar Design Handbook, vol. III*.

3. **System type.** For each climate file provided or created, there are 94 variations of the four basic passive solar heating systems—direct gain, Trombe wall, water wall, and sun space. Within each basic system type there are revealing choices to be made—e.g. differences in mass thickness, night insulation strategies, number of glazings.



BLC help screen

4. **BLC (building load coefficient).** The BLC is defined as the daily heat loss through all non-solar-gain surfaces of a building. The assumption is that the solar aperture is adiabatic (no loss or gain) or causes a net heat gain. The formula is:

$$BLC = \Sigma(U \cdot A) \cdot 24$$

This formula indicates that normally you must calculate the heat loss for infiltration and all skin elements of the building (except the solar aperture) in order to calculate BLC. *UISUN* has an interactive graphic help screen that allows you to estimate BLC based on assumptions about the floor area, insulation level, percentage of glazing, infiltration rate, and building type and configuration. Using this help screen you can easily make an educated guess of the BLC. If you require a more accurate BLC, you may use any software package that calculates U·A (do not input values for the south aperture) and simply multiply that value by 24. *Wattsun-5* is such a program. The other alternative is doing the BLC calculation by hand.

5. **Aperture size.** Aperture size may be varied with complete flexibility.

Fortune cookie message: Put the data you have uncovered to beneficial use.

***UISUN* nuances.** *UISUN* allows four design options to be calculated side-by-side. If more simultaneous calculations need to be analyzed, *UISUN* data must be hand-entered into any spreadsheet program (*Excel*, *Lotus 1-2-3*). The only known bug in *UISUN* is that the graphics that appear green on the screen do not print out on all printers. If this is the case, *UISUN* data may be entered into a spreadsheet program to replicate or enhance the screen graphic printout (see Appendix 2, page 19 for an example).

More information

Passive Solar Design Handbook, volumes II and *III,* explain the SLR method and its theoretical basis and contain the data needed to construct the *UISUN* climate files.

Mechanical and Electrical Equipment for Buildings, Chapter 5, Section 5.6 gives a brief explanation of the SLR/LCR method and offers explanation and data for calculating heat loss. The balance point temperature is explained on page 231.

The Passive Solar Energy Book is an encyclopedic reference for passive heating design strategies.

Sun, Wind, and Light and *InsideOut* give explanations of and methods for calculating the balance point temperature.

PROTOCOL 1A (LEVEL 1)

***UISUN* PARAMETRICS**

By performing this protocol you will gain an understanding of the importance of passive solar heating in your study building.

Preparation

In order to perform this protocol the following preparation must be made:

1. Measured drawings for the building to be studied must be made or obtained.

2. A brief training session on *UISUN (see Appendix 2 for User's Manual).*

3. A visit to or slide presentation of the study building.

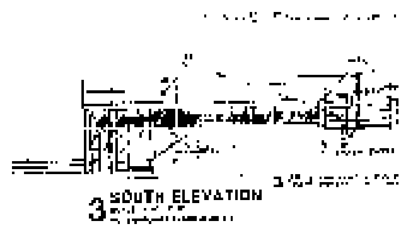
4. A library search for published information about the building.

Liberty Elementary School plan

Procedure

Select one room in your assigned building that uses a passive solar heating strategy. It must have south-facing aperture.

1. **Describe the building and room you are studying.** Discuss your assumptions about it. Sketch it in plan, N–S section, and South elevation. Identify the thermal mass in your drawings. Annotate your sketches to show its floor, south aperture, and thermal mass surface areas. Also note its wall, ceiling, and floor insulation levels (R-values).



Liberty Elementary School elevation

2. **Use *UISUN* to evaluate the building's solar heating performance as it exists.** (*WATTSUN* can be used to help determine the BLC when a more accurate value is required.) Use this calculation as the base case for comparisons with your parametric run results. Fully annotate your computer output to help explain the circumstance of your studies and the significance of the results.

3. **Run a series of *UISUN* parametrics** to determine the roles of mass, aperture, internal gains, and insulation in the performance of the room. As a minimum, vary independently each of the following:

a) base temperature (speculate on the appropriate base temperature for your study building)

b) system type (explain the difference in mass configuration and amount in each option)

c) aperture size (reduce and enlarge the aperture)

d) building skin insulation level (this changes the BLC)

e) use of night insulation on the aperture.

4. **Check the regional portability of your room and its solar heating design.** Compare the "as is" configuration with diverse climatic settings—Charleston, Dodge City, Madison, and Phoenix, as a minimum.

5. **Analyze the results of your parametrics.** Compare the relative effects of mass, glass, and insulation. Discuss the interdependencies among these factors.

6. **Write an analytic conclusion for your findings.** Critique the design of the room you've analyzed and its role in the entire building design. Critique your analisys method for the space.

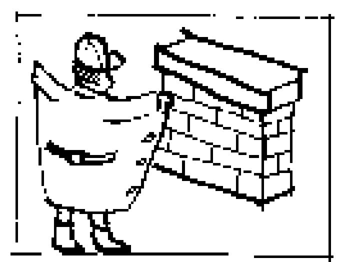
Assemble your work in an 8½" x 11" or 11" x 17" format portfolio. The presentation should be professional quality—clear and rational.

LEARNING UNIT #2
THERMAL MASS STRATEGY ANALYSIS

Goals
This learning unit is intended as a preparatory step for a site visit. In the exercise the full range of thermal strategies are analyzed for two selected spaces. The analysis is focused on the use of thermal mass in the building, but requires an integrated strategy analysis. It extends the lessons of Learning Unit #1 from passive heating to all thermal strategies, from stand-alone systems to integrated systems.

The exercises are intended to be performed off-site prior to a site visit. Both graphic and written descriptions of the building are needed to complete the exercise with panache.

Discussion
Thermal mass is useful for providing thermal stability in both passive and mechanically tempered buildings. The most effective mass is directly exposed to powerful external stimuli as well as thermal stimuli within the conditioned space. These stimuli include direct solar radiation, night sky radiation, lights, equipment, and people.


Expose yourself to vertically-oriented mass for most efficient thermal transfer.

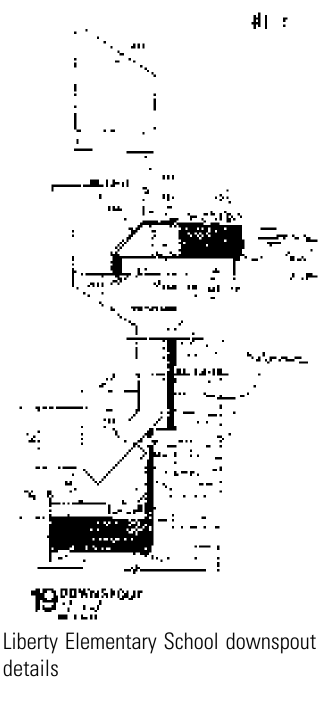
There are five basic criteria for determining if the thermal mass in the building is being exploited to its fullest extent.

1. The total surface area of the mass is exposed to thermal stimuli. It is not obstructed by architectural features, such as dropped acoustic ceilings, carpets, and furnishings. These features act as obstructions or insulators and reduce the efficiency of the mass.

2. The surface of the mass is visible to radiant sources (sun, night sky, people, lights, and equipment). Mass surfaces that are oriented perpendicular to the radiation from a source are more effective than those that are oriented obliquely to it. A wall is more effective in receiving radiation from a standing person than is a ceiling. On a diurnal basis, a floor is more efficient in receiving radiation from the sun than a wall that is perpendicular to the solar aperture.

3. The mass is located within the insulated skin of the building. Mass outside the thermal skin of the building has little or no effect on the building's interior conditions or its occupants. There are two notable exceptions to this rule: thermal mass with switchable exterior insulation (as in a roof pond strategy) and earth-coupled thermal mass (especially when coupled below the frostline). In the first exception the mass can take advantage of diurnal changes in thermal stimulus and thermal need; in the second exception the mass can take advantage of the annual thermal stability of the earth.

4. The mass thickness is optimized. To be effective in a diurnal cycle masonry generally needs to be 4-6" thick when one surface is used or 8-12" thick when both surfaces are used. Water, because it is convective, is not limited in dimension for effective use.


Liberty Elementary School downspout details

5. The mass is accessible to natural or mechanical ventilation air for effective night-air flushing during the cooling season. Heat can be removed from the mass surface by conduction/convection to cooler air. Maximizing the surface area of the mass in direct contact with the cool air maximizes the ability to control and accomplish diurnal cooling.

More information
Sun, Wind, and Light contains a complete roster of thermal mass strategies for heating and cooling as well as rules-of-thumb for sizing the mass.

InsideOut contains a range of thermal mass strategies for heating and cooling and more detailed calculation procedures for mass sizing and effectiveness.

PROTOCOL 2A (LEVEL 1)
DIAGRAMMATIC THERMAL ANALYSIS

This protocol is seen as preparatory to an on-site visit to your assigned building. Analysis of the construction documents will help you discover interesting features that merit further examination and will serve as a basis for evaluating the difference between the architect's intent and the building as it exists.

Preparation
The only information that you need to accomplish this exercise is:

1. Measured drawings of the building obtained from the architect or drawn from on-site observations.

2. Published descriptions of the building. For energy-conserving buildings these articles often describe systems and strategies for heating and cooling.

Procedure
For this exercise examine and analyze the architectural drawings of your assigned building to form an understanding of its thermal mass strategies.

1. From the drawings, pick one space in the building that appears to use thermal mass effectively and one that does not. Sketch/diagram each space showing the day and night relationships between the mass and thermal stimuli (sun, night sky, people, lights, and equipment) during both the heating and cooling seasons.

Liberty Elementary School sectional analysis

2. For each space sketch/diagram its thermal enclosure. Analyze the completeness (any thermal bridges?) and switchability (seasonally and diurnally) of the insulating skin. Draw the natural or mechanical air flows over the mass surface that can facilitate cooling.

3. For each space note the thickness of its thermal mass and architectural obstructions, such as dropped acoustic ceilings, carpeting, and furnishings that will hinder the effectiveness of the thermal mass.

4. Focusing on the two selected spaces, describe, analyze, and critique the overall thermal mass strategy of the building.

Assemble your work in an 8½" x 11" or 11" x 17" format portfolio. The presentation should be professional quality—clear and rational.

LEARNING UNIT #3

ON-SITE THERMAL MASS SURVEY

Goals

This exercise is intended to present comprehensive site visit activities for studying the role of thermal mass in buildings. It includes several protocols that range from subjective to objective, each describing pre-visit, visit, and post-visit procedures.

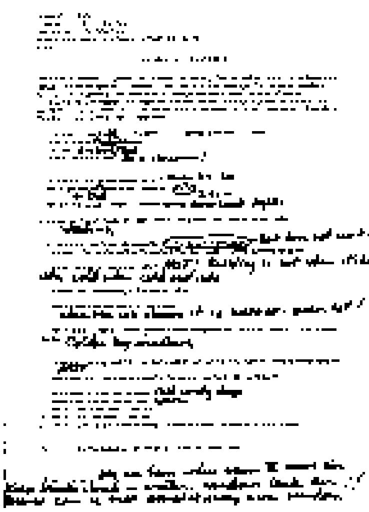
Discussion

For this learning unit you will prepare for and conduct a site visit to explore the role of thermal mass in the heating and cooling of your building. In order to collect all pertinent information you must be well-prepared for your visit and must employ a range of data-gathering techniques. Learning Units #1 and #2 act as orientation to your building and its performance. Among the activities that you must prepare for are:

- surveys of and interviews with users and operators
- observations and photographs
- on-site monitoring

Site visits are often trial-and-error affairs, even with impeccable planning. Consequently, a follow-up visit is usually needed to fill in the observation gaps from the initial visit. Plan on making two site visits.

Surveys and interviews



Completed sample survey

An essential source of information about your building is the group of people who operate and use the building. Their insights can be tapped through interviews and surveys. A short, easy-to-answer survey designed to uncover the nuances of daily and seasonal occupancy should be prepared in advance of your site visit. Remember that 30% return is phenomenal for a survey, so make yours clear and concise, easy to fill out, and easy to return in order to assure a reasonable number of responses. The surveys will add to your anecdotal understanding of the building if they solicit short answers or essays rather than yes–no responses.

On-site interviews with a few key people—the building manager, the building operator, users of key spaces—will assure that you get their vital input. You should make appointments with these people before your site visit and prepare a list of issues that you want to cover to ensure that your interviews are successful. You may want to tape or video record (with permission) your interviews to be sure that no details of the conversations are later overlooked. Users and operators are especially aware of the thermal schedule for the building and the interventions that aid or hinder its energy efficiency. They also can offer insight on building operation and response during the remainder of the year. These insights will be valuable for this and later learning units.

Observation and photography

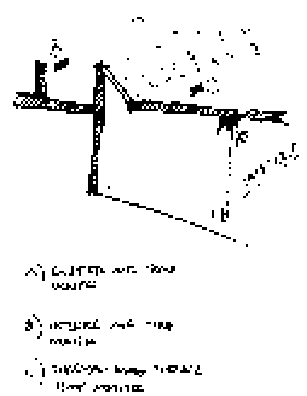
Through careful observation, you should be able to compare the building as it is used (from your site visit) to the architect's intentions for its use (from the drawings). It is especially important to confirm the location and configuration of the thermal mass, record the surface conditions of the thermal mass, and record glazing and shading features. As solar and energy-conserving buildings mature through use, many of their design features also change. The older the building, the more likely it has been renovated. Thermal mass can become obscured through the placement of furnishings, addition of carpeting and wall-hangings, and completion of remodeling projects. Fenestration, which has the role of connecting the thermal mass to solar radiation during the heating season, can be remodeled by adding or subtracting fixed or movable shading devices or by changing the glazing to alter its transparency to radiant heat. These changes can greatly modify the relationship between mass and sun. It is also important to note diurnal heating, cooling, and fan use; the occupancy schedule; machine and equipment use schedules; and weekly and seasonal differences in building use for later modeling and analysis of the building's thermal performance.

Annotated photograph of Liberty Elementary School

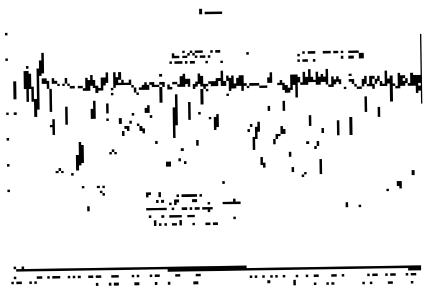
Use photography to record your observations, document your visit, and as a medium for in-class presentation of your building. If you opt for image processing, plan ahead so that you choose a format of photographic images (slides, prints, video) that can be processed with image capture and graphics software, such as *Adobe Photoshop.*

Monitoring and the time constant

On a one-day visit the most important indicator to monitor is the surface temperature of the thermal mass. If the mass temperature differs significantly from the air temperature and the surface temperature of non-massive materials, the mass is contributing to the heating or cooling of the room. (If the mass temperatures are uniform, the mass' role is indeterminate.) A hand-held, laser-aimed pyrometer can give instantaneous readings of surface temperature which can be compared to conventional thermometer readings of air temperature. However, these instantaneous measurements give little information beyond a yes–no understanding of the current status of the thermal mass. This status can be made hard to interpret by "outside" factors, such as HVAC system operation, insulating materials, and pre-existing thermal conditions. Infrared video gives instantaneous visual comparisons of the surface temperatures of everything in its field of view. These data are helpful in determining the heating and cooling sources in a space and the effectiveness of its thermal barriers. It can also show changes over the time of the video. Nonetheless, the infrared recording is difficult to fully understand and its time span is limited by the length of the videotape.



Surface temperature monitoring setup for HOBOs in Liberty Elementary School



Sample HOBO plot shows 4 weeks of indoor, outdoor, and mass temperatures at Liberty Elementary School.

A better monitoring technique employs data loggers that acquire both mass and air temperatures over time, so that context and temperature response to thermal loads can be determined. An ideal monitoring period should include a time period, such as an evening, weekend, or vacation when the building is allowed to drift (HVAC system is off) so that its passive and unloaded characteristics may be observed and compared to its mechanical and loaded characteristics. When the inside and outside air temperatures are compared (especially in graphic format) with the surface temperature of the mass, an understanding of the mass effect can be obtained.

Interior mass temperature can be measured by inserting a HOBO probe into a small hole (measure its depth) drilled into the masonry (a ¼" masonry bit works well). Get permission before you do this and make sure to patch the hole with spackle or drywall compound after you've finished.

The long-term measure of mass effect is the building time constant, τ, which describes the time-delay effect of mass. The building time constant can be predicted by the formula:

$$\tau = \text{(building capacitance)}/\text{(building UA)}$$

This vital sign can be easily correlated from temperature measurements—the building air temperature (at a thermostat location) and the exterior air temperature—while the building is allowed to drift thermally (usually over the weekend or overnight). Ask the building operator when thermal drift is allowed—your monitoring data, especially the HOBO plots, should distinctly show the occurrence of thermal drift.

Select the building temperature, T_{start}, at the beginning of a thermal drift period and a building temperature, T_t, that occurs "t" hours later, after a steady decrease or increase in building temperature driven by the temperature differential between indoors and outdoors. Measure ΔT simultaneously with T_{start}. The thermal mass effect can be calculated by:

$$T_t = T_{start} + \Delta T(1-t/\tau)$$

Therefore, the building time constant, τ, can be calculated:

$$\tau = t/(1-[(T_t-T_{start})/\Delta T])$$

For our purposes the most convenient data acquisition instrument is the HOBO Temp datalogger. Each HOBO datalogger can be launched for an appropriate time period (to cover installation visit through recovery visit) from a PC. Each data point on each datalogger will be time-tagged so that data can be related to real-time events and data from various dataloggers can be correlated. Spreadsheet software, such as *Excel* or *Lotus 1-2-3*, can be used to plot, compare, and analyze HOBO data collected on-site.

HOBO plot detail shows thermal drift during a weekend at Liberty Elementary School.

Special care must be taken in installation of the dataloggers. Air temperature probes must be located in stable positions without the unintentional influence of solar radiation, air from the HVAC system, or radiation from heat producing lights or equipment (the thermostat location **should** meet these criteria—this is the proper place to monitor temperature if you are trying to calculate the building time constant [Protocol 3D]). Outdoor air temperature monitors should be mounted in a position that is always in the shade—any direct solar radiation will cause the recorded temperature to spike well above actual air temperature. For accurate measurement of the surface temperature of the mass, the HOBO sensor should be isolated from the air temperature and direct solar radiation with a small piece of insulation (adhesive weather-stripping or pipe insulation works well).

More information

Mechanical and Electrical Equipment for Buildings, Chapter 5, Example 5, page 190, gives an outstanding description of and complete calculations for thermal mass use in the energy-conserving Emerald Peoples' Utility District building.

"Passive Solar Thermal Simulation—Three Models," F. C. Wessling, *Proceedings of American Solar Energy Society Annual Meeting*, 1978 shows the importance of modeling (or measuring) internal temperatures of thermal mass when predicting thermal performance in massive buildings. It confirms the suitability of the thermal network analogy for modeling the effects of thermal mass and reveals the importance of measuring (modeling) the internal temperature of the mass.

PROTOCOL 3A (LEVEL 1)

OBSERVATION AND ANALYSIS

In this protocol you will use your powers of observation (assisted by backup equipment, such as video or still cameras) to discover how thermal strategies are implemented in the building. Your previsit preparations will aid your comparison of the designer's intentions to their implementation and systems use.

To ensure completion of all field trip tasks and to compensate for unexpected findings on the first site visit, plan on a second trip.

Preparation
In order to gain the most from this protocol, students should have:

1. sketches or construction documents for the building
2. photographic equipment
3. tape measure—25' or 50' length
4. permission to visit and photograph the building
5. appointments with key personnel—building manager, occupants
6. ability to use analysis software—image processing

Completion of Learning Units #1 and #2 is recommended.

Procedure
For this exercise you will prepare for, conduct, and report on a site visit to your assigned building.

Pre-visit:

1. identify thermal issues in the building
2. identify thermally interesting spaces (see LU #1 & #2)
3. obtain permission to visit and photograph the building
4. make appointments to meet with key personnel

Visit:

The field trip to the study building is intended to attain Vital Signs Level 1 protocol goals—"Brief visit, limited instrumentation appropriate to a single-day visit. Will involve observations, interviews, and survey techniques." On the field trip you will be expected to:

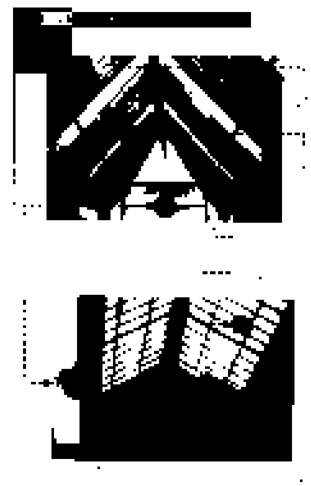
1. ascertain the operating schedule and occupancy of the building
2. confirm location and configuration of the thermal mass and insulation

3. record surface conditions of mass, including obstructions

4. record glazing and shading features

5. determine and record the location, wattage, and use schedule of equipment and lights

6. photograph the building and selected details



Analytical photos of Liberty Elementary School

Post-visit report:

Write-up your field trip by describing the preparations and the visit procedures. Analyze the findings from your visit. Present your findings to the seminar paticipants.

Your written and oral presentations should include:

Introduction Describe your pre-visit preparation and theories.

Body Description and analysis of your observations. Use prose, analytical drawings, and annotated photographs to explain the use of thermal mass and energy-conservation strategies in the building. Contrast the building as it exists with the architect's plan for the building. Include a brief history of why changes (if any) were made. Note features that are especially effective or especially ineffective.

Conclusion Explain your findings and describe situations that require further study.

Assemble your work in an 8½" x 11" or 11" x 17" format portfolio. The presentation should be professional quality—clear and rational.

PROTOCOL 3B (LEVEL 1)

SURVEYS AND INTERVIEWS

In this protocol you will gain insight on the thermal conditions in the building through both in-person interviews and answers to preprinted surveys. Much can be learned about the annual cycles and special conditions through these interactions with the occupants.

To ensure completion of all field trip tasks and to compensate for unexpected findings on the first site visit, plan on a second trip.

Preparation
In order to gain the most from this protocol, students should have:

1. sketches or construction documents for the building
2. tape recorder
3. survey forms for occupants
4. permission to visit the building
5. appointments with key personnel—building manager, occupants

Completion of learning units #1 and #2 is recommended.

Procedure
For this exercise you will prepare for, conduct, and report on a site visit to your assigned building.

Pre-visit:

1. prepare survey forms
2. identify thermal issues in the building
3. identify thermally interesting spaces (see LU #1 and #2)
4. obtain permission to visit the building
5. make appointments to meet with key personnel
6. make arrangements to distribute surveys to building occupants and for collecting them later

Visit:

The field trip to the study building is intended to attain Vital Signs Level 1 protocol goals—"Brief visit, limited instrumentation appropriate to a single-day visit. Will involve observations, interviews, and survey techniques." On the field trip you will be expected to:

1. survey/interview building operators and occupants
2. ascertain the operating schedule and occupancy of the building

3. determine and record the location, wattage, and use schedule of equipment and lights

Post-visit report:

Write-up your field trip by describing the preparations and the visit procedures. Analyze the findings from your visit. Present your findings to the seminar participants.

Your written and oral presentations should include:

Introduction Describe your pre-visit preparation and theories.

Body Commentary on the interviews and surveys. Write-up salient points gleaned from both interviews and surveys. Include transcripts of interviews and returned surveys as supplemental material.

Conclusion Explain your findings and describe situations that require further study.

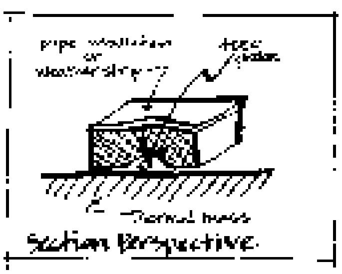
Assemble your work in an 8½" x 11" or 11" x 17" format portfolio. The presentation should be professional quality—clear and rational.

PROTOCOL 3C (LEVEL 2)
MONITORING THERMAL MASS

In this protocol you will use self-contained portable dataloggers (HOBOs) to monitor thermal conditions in your study building. Advance planning for placement of the data loggers is crucial to the success of this protocol. Coordinate placement of the HOBOs with key personnel (building operator, occupants) to ensure that the dataloggers are not tampered with. Post-visit analysis of the data gathered is also critical to this protocol's success.

To ensure completion of all field trip tasks, recover the HOBOs, and to compensate for unexpected findings on the first site visit, plan on a second trip.

Use duct tape to mount sandwich bag then place HOBO in bag.



To isolate probe from air temperature so that mass surface temperature can be measured, use a small piece of pipe insulation.

Preparation
In order to gain the most from this protocol, students should have:

1. sketches or construction documents for the building
2. training in the use of HOBO dataloggers
3. prelabeled and launched HOBO dataloggers with installation equipment including sandwich bags, duct tape, pipe insulation, portable drill w/masonry bit, and spackle.
4. tape measure—25' or 50' length
5. permission to visit the building and install dataloggers
6. appointments with key personnel
7. ability to use analysis software—spreadsheets

Completion of learning units #1 and #2 is recommended.

Procedure
For this exercise you will prepare for, conduct, and report on a site visit to your assigned building.

Pre-visit:

1. launch HOBO dataloggers
2. identify thermal issues in the building
3. identify thermally interesting spaces (see LU #1 and #2)
4. identify potential locations for dataloggers
5. obtain permission to visit the building and install data loggers
6. make appointments to meet with key personnel

Visit:

The field trip to the study building is intended to attain Vital Signs Level 1 protocol goals—"Brief visit, limited instrumentation appropriate to a single-day visit. Will involve observations, interviews, and survey techniques." On the field trip you will be expected to:

1. confirm location and configuration of the thermal mass and insulation
2. record surface conditions of mass, including obstructions
3. record glazing and shading features
4. monitor masonry surface and air temperatures

To ensure completion of all field trip tasks and to compensate for unexpected findings on the first site visit, plan on two trips.

Post-visit report:

Write-up your field trip by describing the preparations and the visit procedures. Analyze the findings from your visit. Present your findings to the seminar group.

Your written and oral presentations should include:

Introduction Describe your pre-visit preparation and theories.

Body Explain your monitoring strategy and its results. Sketch/diagram the HOBO placement scheme in your building. Describe the reasons for their placement and analyze the results. Comparative graphs of temperature plots for indoor air, outdoor air, and mass surface (and subsurface) temperatures with appropriate annotation can be invaluable in providing an explanation of thermal mass behavior.

Conclusion Explain your findings and describe situations that require further study.

Assemble your work in an 8½" x 11" or 11" x 17" format portfolio. The presentation should be professional quality—clear and rational.

PROTOCOL 3D (LEVEL 2)
BUILDING TIME CONSTANT

For this protocol you will monitor indoor and outdoor temperatures during the building's thermal drift period in order to calculate the building time constant.

To ensure completion of all field trip tasks and to compensate for unexpected findings on the first site visit, plan on a second trip.

Preparation
In order to gain the most from this protocol, students should have:

1. sketches or construction documents for the building
2. training in the use of HOBO dataloggers
3. prelabeled and launched HOBO dataloggers with installation equipment including sandwich bags and duct tape
4. tape measure—25' or 50' length
5. permission to visit the building and install dataloggers
6. appointments with key personnel
7. ability to use analysis software—spreadsheets

Completion of Learning Units #1 and #2 is recommended.

Procedure
For this exercise you will prepare for, conduct, and report on a site visit to your assigned building.

Pre-visit:

1. launch HOBO dataloggers
2. identify thermally interesting spaces (see LU #1 and #2)
3. identify potential locations for dataloggers
4. obtain permission to visit the building and install dataloggers
5. make appointments to meet with key personnel

Visit:

The field trip to the study building is intended to attain Vital Signs Level 1 protocol goals—"Brief visit, limited instrumentation appropriate to a single-day visit. Will involve observations, interviews, and survey techniques." On the field trip you will be expected to:

1. confirm location and configuration of the thermal mass and insulation

2. record surface conditions of mass, including obstructions

3. monitor indoor and outdoor air temperatures

To ensure completion of all field trip tasks and to compensate for unexpected findings on the first site visit, plan on two trips.

Post-visit report:

Write-up your field trip by describing the preparations and the visit procedures. Analyze the findings from your visit. Present your findings to the seminar group.

Your written and oral presentations should include:

Introduction Describe your pre-visit preparation and theories.

Body Explain your monitoring strategy and its results. Sketch/ diagram the HOBO placement scheme in your building. Describe the reasons for their placement and analyze the results. Comparative graphs of temperature plots for indoor air and outdoor air temperatures with appropriate annotation can be invaluable in explanating the building time constant calculation.

Conclusion Explain your findings and describe situations that require further study.

Assemble your work in an 8½" x 11" or 11" x 17" format portfolio. The presentation should be professional quality—clear and rational.

One week of indoor, outdoor, and mass temperatures plotted for Liberty Elementary School

LEARNING UNIT #4

THERMAL MASS PERFORMANCE MODELING

Goals

This exercise is intended to familiarize the students with methods of modeling a building's thermal performance using sophisticated computer software and to interpolate actual building performance from utility records. The detailed protocol for utility bill disaggregation is given in the Vital Signs Resource Package "Whole Building Energy Use (Residential)." Students are also given the opportunity to compare predicted, actual, and monitored performance to gain insight into which thermal strategies do and do not operate according to the designer's intent.

Discussion

Sophisticated thermal analysis software can be used to gain insight into the workings of solar and energy-conserving buildings. Furthermore, comparison of actual building performance to predicted performance can reveal problems in implementation of energy conservation strategies and can identify areas where improvements can be made. The results of the thermal analysis and analysis of the actual building performance can be compared to standards for energy conservation to evaluate the relative efficiency of the building.

The most complex and complete computer-based analysis tool for thermal performance is *DOE-2* for mainframes or personal computers. *DOE-2* is very complex, requiring a level of training that is inappropriately extensive for a semester-long course in thermal evaluation. However, there are several less complex and more user-friendly programs that can be operated with considerably less preparation and with satisfactory simulation results. Among these are Mac-based *Energy Scheming* and PC-based *Solar-5, Energy 10,* and Softdesk *Energy.* For this exercise choose one of the simulation programs. (The authors have chosen *Solar-5,* whose nuances are reflected in the documentation of this resource package.) In order to accurately predict the performance of the building, it is critical to carefully input a complete and accurate description of the building. If unexpected results occur after the simulation is run, the first thing to check is the accuracy of the input file. These programs have the ability to produce a wide array of graphic and tabular data. It is up to the user to interpret these data so that they become valuable information. Output tables and graphics should be annotated and highlighted to demonstrate understanding of or questions about significant qualities of the thermal performance of the building.

Complete information on *DOE-2* use is available in *The User News*, a free newsletter. Contact Kathy Ellington, Editor; MS: 90–3147; Lawrence Berkeley Laboratory; Berkeley, CA 94720; Fax 510–486–4089; e-mail <kathy%gundog@lbl.gov> to be placed on the mailing list.

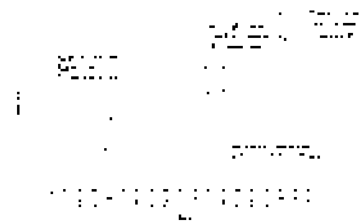
The truth about the actual thermal performance and energy use of the building is contained in its utility bills. See Vital Signs Resource Package "Whole Building Energy Use (Residential)" for a complete discussion and procedure for disaggregation of utility bill information. In order to accurately disaggregate the bills it is important to correlate observations about the building's operating schedule with bill data. Your observations and interviews in Learning Unit #3's site visit are crucial to accurate disaggregation of the bills. Especially important to successful analysis of the utility bills are diurnal heating, cooling, and fan use; the occupancy schedule; machinery, lights, and equipment use schedule; and weekly and seasonal differences in building use.

There are several standards for determining the relative effectiveness of energy-conserving buildings. In applying standards for energy use it is important to compare with similar building types in similar climates (or using climate-independent data) in order to avoid comparing the proverbial apples with oranges.

More information
The Vital Signs Resource Package "Whole Building Energy Use (Residential)" contains procedures for disaggregation of utility bills.

The Vital Signs resource package for *Solar-5,* "Measurement and Display of Thermal Performance of Buildings," gives complete information on its use and the use of actual climate data.

The articles by Charles C. Benton and F. C. Wessling in the *PSDATE Reader* discuss the importance of measuring temperature within the thermal mass.



Two years of electrical use at Liberty Elementary School

Two years of natural gas consumption at Liberty Elementary

PROTOCOL 4A (LEVEL 3)

COMPUTER-BASED ANNUAL THERMAL MODEL

In this protocol you will harness the power of a sophisticated thermal analysis program to model the thermal behavior of your study building. Disaggregated utility bills for the study building will form a performance context for your modeling. Comparative analysis of the results can give you insights into successful and unsuccessful thermal strategies.

Preparation
In order to complete this Learning Unit you will need:

1. monthly utility bills for the building for at least one year

2. measured drawings of the building

3. information about occupancy, equipment and lighting use schedules, mechanical heating, cooling, and ventilation strategies (gained in LU #1–#3)

4. training on a suitable computer-based thermal analysis program(s)—*Solar-5, Energy 10,* Softdesk *Energy, Energy Scheming,* or *DOE-2*

5. appropriate weather files for the thermal analysis program

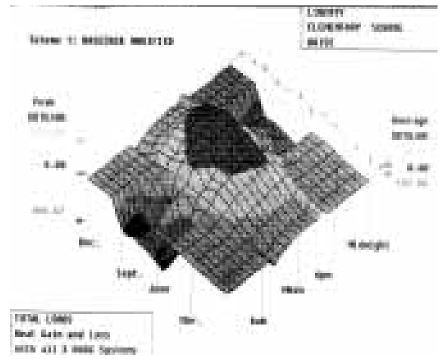
6. training in the use of a data analysis program, such as *Excel*

Procedure
This protocol is intended to allow you to examine the role of mass in the thermal comfort of buildings. You will analyze the building as a whole, using both actual performance data and performance predictions. Information gathered and insights gained from the preceding learning units help inform your analysis for this learning unit.

1. Use the utility bills and information gathered during the site visit (observation and building operator interview) to determine actual performance of the building. Disaggregate the utility bills based on your knowledge and educated guesses about the building's operation. [See the Vital Signs Resource Package "Whole Building Energy Use (Residential)" for disaggregation procedures.] Discuss any assumptions you have made. Convert all energy units to Btu so you can compare systems and buildings using different energy sources. It is helpful to use a spreadsheet program to convert units and to analyze the disaggregated data—graphic display/analysis is especially helpful.

2. Use *Solar-5* (or another thermal modeling program) to predict the energy use/thermal performance of the building. Model the building with and without thermal mass to help form an understanding of the importance of mass in the building's performance. Annotate all the *Solar-5* printouts to demonstrate your understanding of the nuances of the building's operation.

3. Compare the actual (from utility records) and predicted (from *Solar-5* analysis) performances of the building. Critique its design and operation. Compare the results of these analyses with performance standards for similar buildings. Explain what steps can be taken to achieve even greater energy savings.



Total annual loads per *Solar 5* for Liberty Elementary School

Assemble your work in an 8½" x 11" or 11" x 17" format portfolio. The presentation should be professional quality—clear and rational.

PROTOCOL 4B (LEVEL 2)

TWELVE-DAY PERFORMANCE COMPARISON

In this protocol you will compare the monitored data from Protocol 3C to a twelve-day *Solar-5* model that uses climate data for the same time period in place of the annual TMY (typical meteorological year) data that *Solar-5* usually uses.

Preparation
In order to complete this Learning Unit you will need:

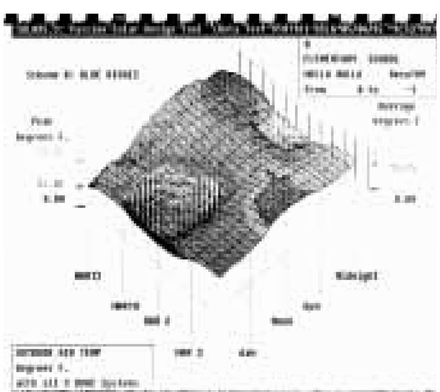
1. measured drawings of the building

2. information about occupancy, equipment and lighting use schedules, mechanical heating, cooling, and ventilation strategies (gained in LU #1–#3)

3. training in *Solar-5* computer-based thermal analysis program.

4. appropriate weather files for the thermal analysis program for the exact period monitored in LU#3.

Procedure
This protocol is intended to help you to examine the role of mass in the thermal comfort of buildings during a short time period. You will analyze the building as a whole, using both actual performance data and performance predictions. Information gathered and insights gained from the preceding learning units help inform your analysis for this learning unit.

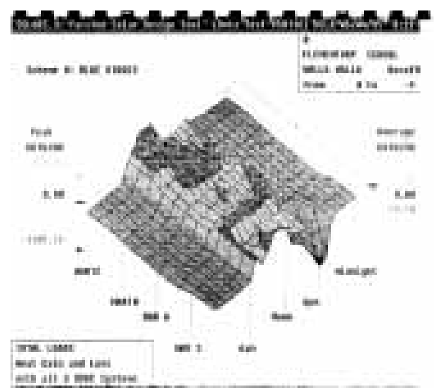


Solar 5 12-day outdoor air temperature plot for Blue Ridge Elementary School

1. Use the building documents and information gathered during the Protocol 3 site visit (your observations and building operator/occupant interviews) as input for *Solar-5* (or another thermal modeling program) to predict the energy use/thermal performance of the building. To help confirm your monitored performance data, you should be able to get weather data for *Solar-5* for the duration of your data-gathering period. Model the building with and without thermal mass to help understand the importance of mass in the building's performance. Annotate all the *Solar-5* printouts to demonstrate your understanding of the nuances of the building's operation.

2. Compare the actual (from your monitoring) and predicted (from *Solar-5* analysis) performances of the building. Critique its design and operation. Compare the results of these analyses with performance standards for similar buildings. Explain what steps can be taken to achieve even greater energy savings.

Assemble your work in an 8½" x 11" or 11" x 17" format portfolio. The presentation should be professional quality—clear and rational.



Solar 5 12-day total load plot for Blue ridge Elementary School

LEARNING UNIT #5
THERMAL PERFORMANCE CRITIQUE

Goals
In this capstone exercise the student performs a comprehensive analysis of the thermal performance of the study building. Through both written and oral presentation, the student may impart the findings of her/his extensive study of a building to an audience of peers. An exceptional written analysis would be the equivalent of a technical paper for presentation and publication.

Discussion
Learning Units #1–4 have afforded you the opportunity for detailed critical analyses of your study building through various “lenses.” Through these exercises you have increased your knowledge of the thermal operations of the building. It is essential to the advancement of the state-of-the-art of energy-efficient building that architects share the information gained through analysis of building performance. Both success stories and unmet expectations are valuable lessons learned for formulation of the next generation of energy-conserving buildings. The most viable forum for presentation of these findings is the technical conference, such as the American Solar Energy Society Annual Passive Solar Conference. Your task is to reflect on the knowledge you have gained from the various exercises, form a cohesive understanding of the strengths and weaknesses of the building, and synthesize these into an informative written and oral presentation to interested practitioners, researchers, and educators.

The typical format for a written paper is an abstract, summarizing the entire paper in a paragraph, followed by a descriptive and analytical body that presents your findings about the building. You should include both general descriptions of the workings of the building and specific findings of telling aspects of the building’s performance. Use annotated photographs and computer printouts, diagrams, and survey/interview responses to illustrate your work. The paper should be a thorough analysis of the building but should also be as succinct as possible. The length limit is six pages, including illustrations and charts.

More information
See the *Proceedings* of one or more of the American Solar Energy Society National Passive Solar Conference or Annual Meeting for examples of papers prepared for technical conferences. The article by Haglund *et al* in the *PSDATE Reader* (contents listed in the bibliography) is one such paper.

PROTOCOL 5A (LEVEL 3)
PRESENTATION OF FINDINGS

In this protocol you will demonstrate your understanding of the thermal workings of the study building through oral and written presentation of your analysis of the building.

Preparation
Completion of Learning Units #1–4.

Procedure
This capstone exercise for the course will result in presentation in both written and oral form. You will critically examine the building and present problems and suggested solutions. The breadth of your work should include at least:

1. abstract of whole paper
2. thermal performance hypothesis
3. comments on appropriateness of thermal strategies
4. critique of effectiveness
5. problems found
6. suggested solutions
7. items for further study/investigation
8. lessons learned from the building and the course

Assemble your work in an 8½" x 11" or 11" x 17" format portfolio. The presentation should be professional quality—clear and rational.

APPENDIX 1 CLASS PLANNING

INTRODUCTION

The techniques and issues described in this resource package were integrated into an advanced seminar on thermal evaluation of buildings, Arch 499 Passive Solar Design and Thermal Evaluation (PSDATE), at the University of Idaho during Spring Term 1995. The following syllabus gives the structure of that course.

Although advanced students studied complex buildings during the seminar, the protocols described (especially level 1 protocols) may be extracted and applied to less complex buildings for beginning students.

COURSE DESCRIPTION

The intention of this course is to advance the student's understanding of passive solar design and the underlying thermal principles necessary to describe thermal performance. It recognizes the intrinsic interdependencies of natural systems, mechanical systems, building occupants, and building/energy codes. The discussion and exercises will be centered on three current and distinct models for analysis of thermal performance.

This year's class is supported by a grant from the Vital Signs project. Our Vital Signs assignment is to study the effect of thermal mass on the performance of existing energy-conserving, active/passive solar buildings and to initiate "work-ups" of these buildings. The grant moneys have supported preliminary work in scouting of and information gathering for the candidate buildings for class study. Study team field trips and some supplies will also be supported. The Vital Signs project will also lend us sophisticated equipment for making on-site, "guerrilla" monitoring forays during the field trips.

The format for the class is a combination of seminar and workshop, featuring considerable hands-on experience with monitoring and evaluation techniques. Students will evaluate existing buildings, focusing on analysis rather than design. However, design implications will be at the heart of the discussion. Each of the three models for analysis is associated with a state-of-the-art, computer-based thermal analysis tool. These tools will be fully integrated into the coursework.

Grading

5 exercises @ 10 points each

1 point off for late work

Texts

PSDATE Reader—available at UI Bookstore

(See Appendix 2 for contents.)

Software

UISUN	public domain	UI
Solar-5	public domain	UCLA
WATTSUN	public, licensed	WSEO

(See Appendix 2 for software reviews.)

Buildings

Farm Credit Bank — Spokane, WA
(17-story, daylighted office building, elongated on the east-west axis with solid cores as the east and west walls)

Central Pre-Mix Office — Spokane, WA
(two-story, earth-sheltered office building with south-facing aperture)

Liberty Elementary School — Boise, ID
(one-story, daylighted elementary school with classrooms facing all cardinal directions)

Blue Ridge Elementary School — Walla Walla, WA
(two-story, earth-sheltered elementary school with south-facing aperture)

Pendleton Junior High School — Pendleton, OR
(two-story, active solar, earth-sheltered school with south- and south by southeast-facing glazing)

Course Schedule

Jan	17	Introduction—Context—Building Assignments
	24	Solar Buildings—SLR Method Lecture—*UISUN* Workshop
	31	Direct/Indirect Gain Seminar—**Present Assignment #1** (LU #1)
Feb	7	ASHRAE Calculation Method Lecture
	14	*Solar-5/Wattsun* Workshop
	21	Thermal Mass Review—Energy Code/Model Conservation Standards
	28	Thermal Mass Strategies Seminar—**Present Assignment #2** (LU # 2)
Mar	7	Site Visit Preparation Seminar
	14	Thermal Network Method Lecture
	21	***Spring Break—No Class***
	28	CALPAS-3 Workshop
Apr	4	Solar Building Survey Lecture
	11	"Guerrilla" Monitoring Seminar—**Present Assignment #3** (LU #3)
	18	Advanced Solar Building Lecture
	25	Thermal Performance Seminar—**Present Assignment #4** (LU #4)
May	2	***Undergraduate Thesis Week—No Class***
	9	Final Project Write-Up Due—Final Seminar—**Present Assignment #5** (LU #5)

VITAL SIGNS

APPENDIX 2 *UISUN* USER'S MANUAL

***UISUN* VERSION 1.0**

Your copy of *UISUN* is specifically for IBM-PC/AT or P/S 2 with an EGA/VGA (or later) Graphics Card (color) and IBM or Epson Graphics printer. It may not run on other systems.

Your system must contain the command DEVICE=ANSI.SYS in the CONFIG.SYS file of your DOS bootup disk. *UISUN* runs under DOS. We've include our CONFIG.SYS file on the diskette as an example.

You may install and run *UISUN* on your hard disk by copying the contents of the diskette to the hard disk. It will run best on the hard disk. Execute the program by typing UISUN (enter) after the DOS prompt.

Your delivery should include:

UISUN.EXE	SLRMAIN.EXE
RESONE.HLO	RESTWO.HLO
RESTHREE.HLO	RESFOUR.HLO
RESFIVE.HLO	RESSIX.HLO
COMMINFL.HLO	COMMCRNR.HLO
COMMDETA.HLO	COMMTINF.HLO
COMMTCRN.HLO	COMMTDET.HLO
HALOHERC.DEV	HALOEPSN.PRN
APPC.DAT	ANALYZE.EXE

22 weather files (BOSTON.MA for example)

EDITDB.EXE

(Allows you to add weather files by entering data from *THE PASSIVE SOLAR DESIGN HANDBOOK VOL III* App. D & F and to edit or scan existing weather files.)

TESTF1	TESTF2

(our example data files - note that data files are normally manipulated on the program disk, but may be specified to any disk by including the drive designation in their names, e.g. c:testf3)

HALOHERC.DEV	HALOEPSN.PRN
READ.ME	CONFIG.SYS

BUILDING DESIGNER FRIENDLY SOFTWARE

UISUN is based on Balcomb's SLR method for passive solar heating calculations.

Its spread-sheet format allows simultaneous calculations for up to four designs.

***UISUN* SHAREWARE INFORMATION**

You are welcome to copy the software without a fee and you are encouraged to share it with others. *UISUN* was developed by University of Idaho Architecture students under a grant by the Washington Water Power Company and is being completed and maintained by the Department of Architecture. *UISUN* is not sold commercially, so your nominal $25 donation will support maintenance and development of your custom copy of the software. You will also be informed of the availability of updates. If you discover problems with *UISUN*, please send us screen copies denoting and explaining the problem. Thank you for your support!

Contact: BRUCE HAGLUND

DEPARTMENT OF ARCHITECTURE

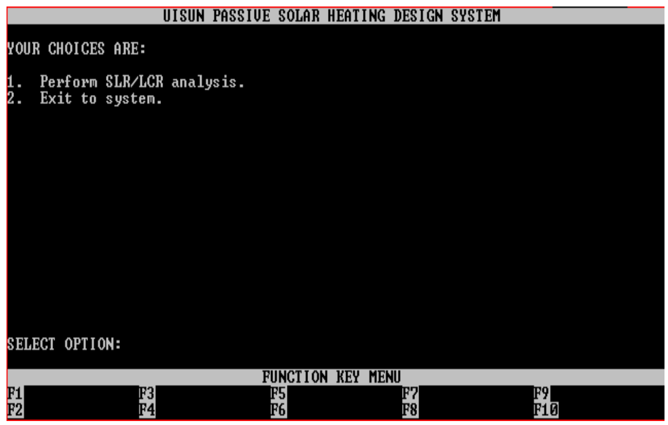
UNIVERSITY OF IDAHO

MOSCOW, IDAHO 83844-2451

phone 208-885-6781

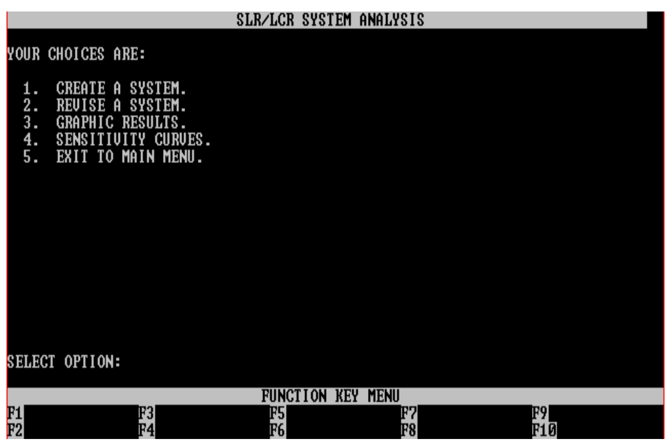
fax 208-885-9428

e-mail <bhaglund@osprey.csrv.uidaho.edu>



INITIAL SCREEN
Select "1. Perform SLR/LCR analysis." by pressing "1" or "F1"

The SLR MAIN MENU will appear next.

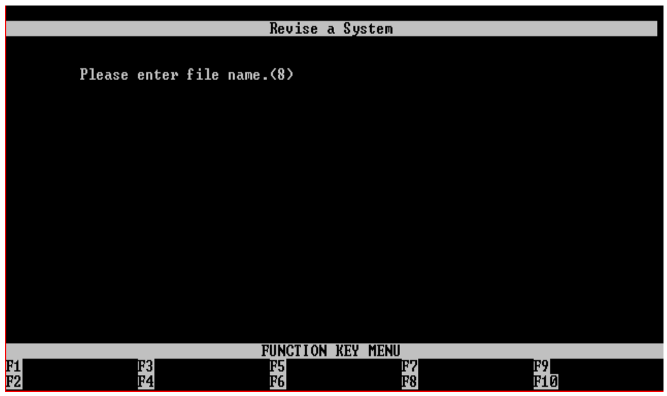


SLR MAIN MENU
Select "1. CREATE A SYSTEM." to build a new data file.

Select "2. REVISE A SYSTEM." to edit an old data file.

Select "3. GRAPHIC RESULTS." to produce graphic analysis of an old calculated file.

Select "4. EXIT TO MAIN MENU." to return to **INITIAL SCREEN**.



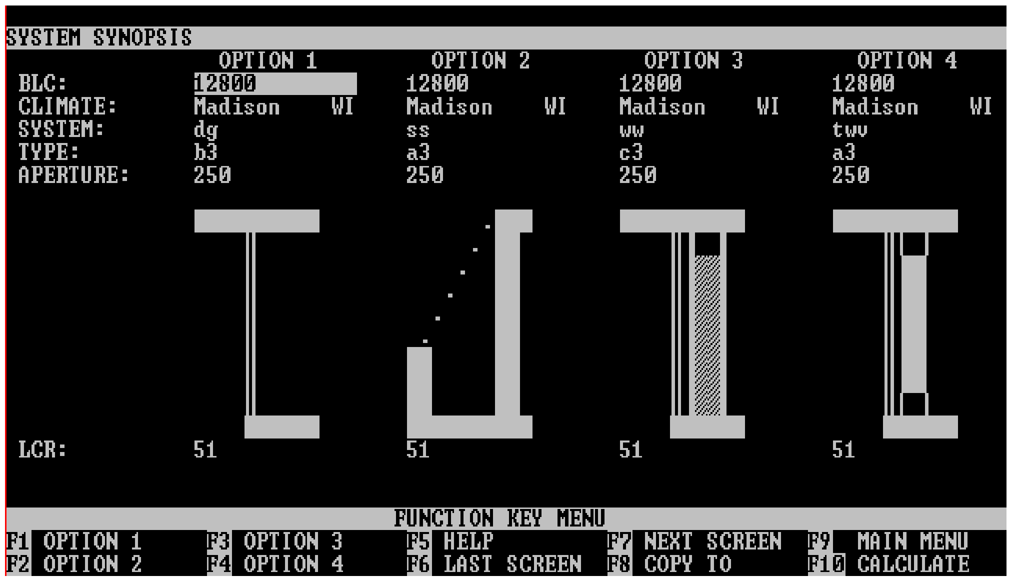
CREATE A SYSTEM MENU (blank)
Type in a new file name. (8 character maximum)

REVISE A SYSTEM MENU (blank)
Type in an old file name.

CREATE A SYSTEM MENU (filled in)
Type in descriptive information. (50 character maximum)

REVISE A SYSTEM MENU (filled in)
Displays descriptive information.

Type “Y” to proceed or “N” to change any information.



MAIN SPREAD-SHEET (filled in)

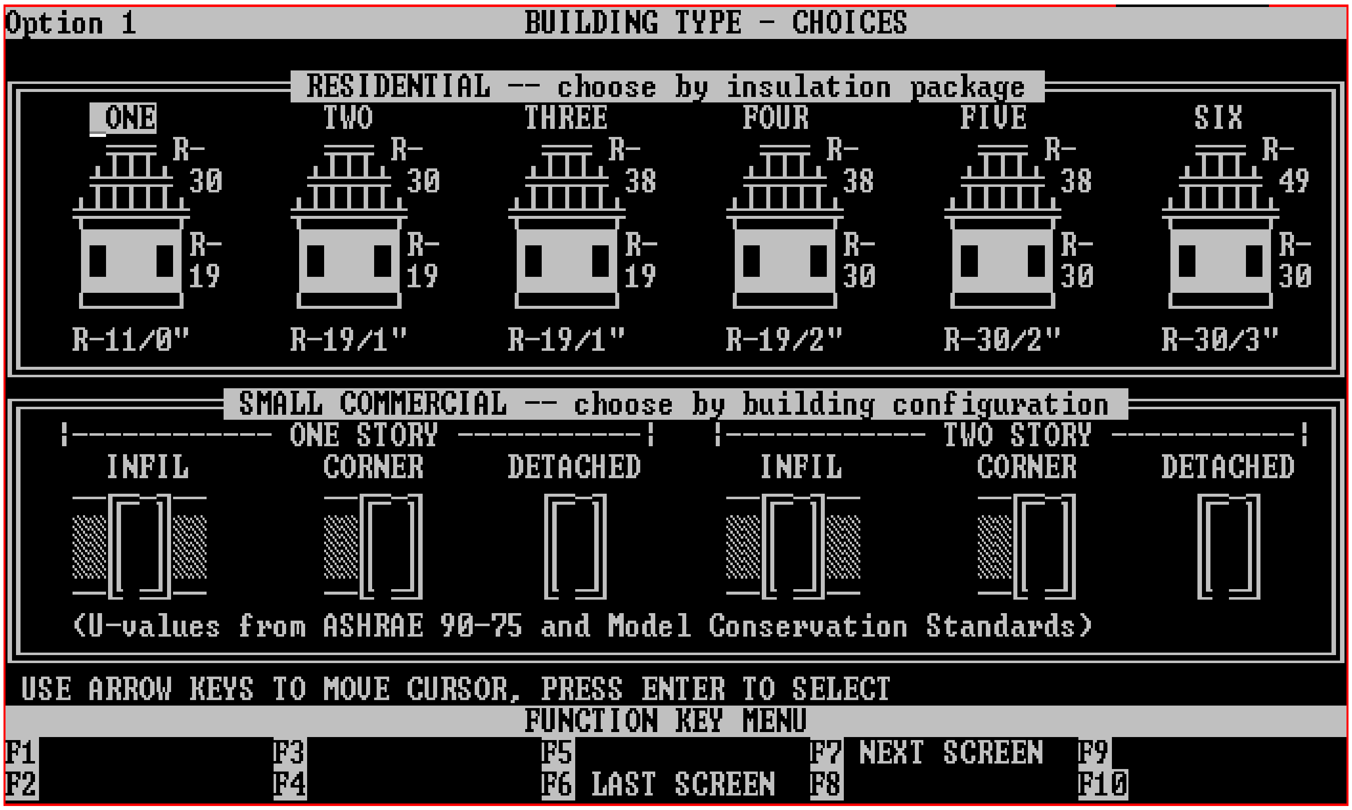
The light bar cursor (reverse video) may be moved to any spread-sheet location by using the keyboard arrow keys and data may be entered or revised in any order.

The full set of function keys (F1-F10) is operable as indicated by the **FUNCTION KEY MENU** at the bottom of the screen.

Data for each of the spread-sheet positions can be generated or explained by placing the light bar cursor on the desired position and pressing “F5,” the help key.

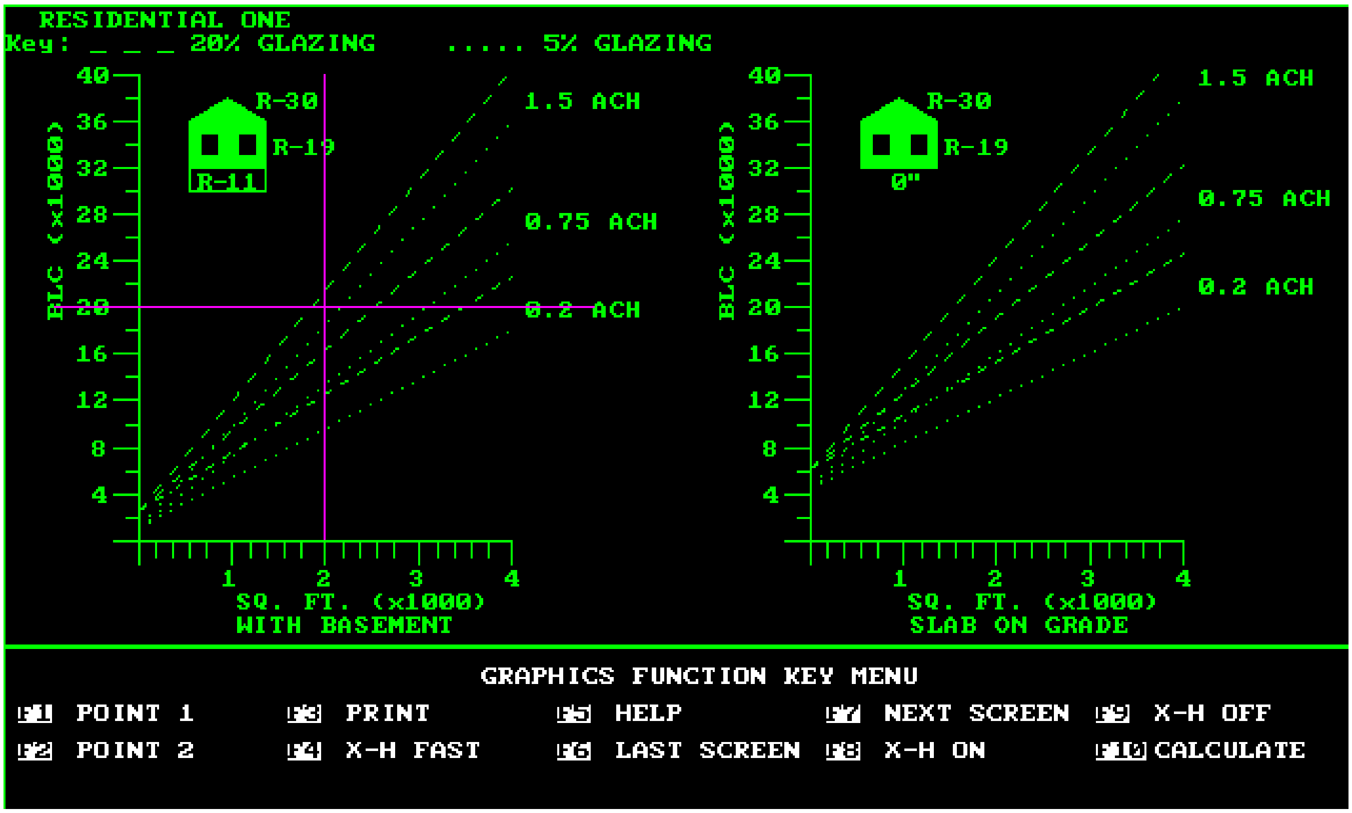
When the spread-sheet is completed to your satisfaction, press “F10,” to initiate the **CALCULATE SCREEN.**

No matter what action is taken all the data placed in the spread-sheet will be saved for future use or revision in the file you named on the **CREATE** or **REVISE A SYSTEM MENU.**

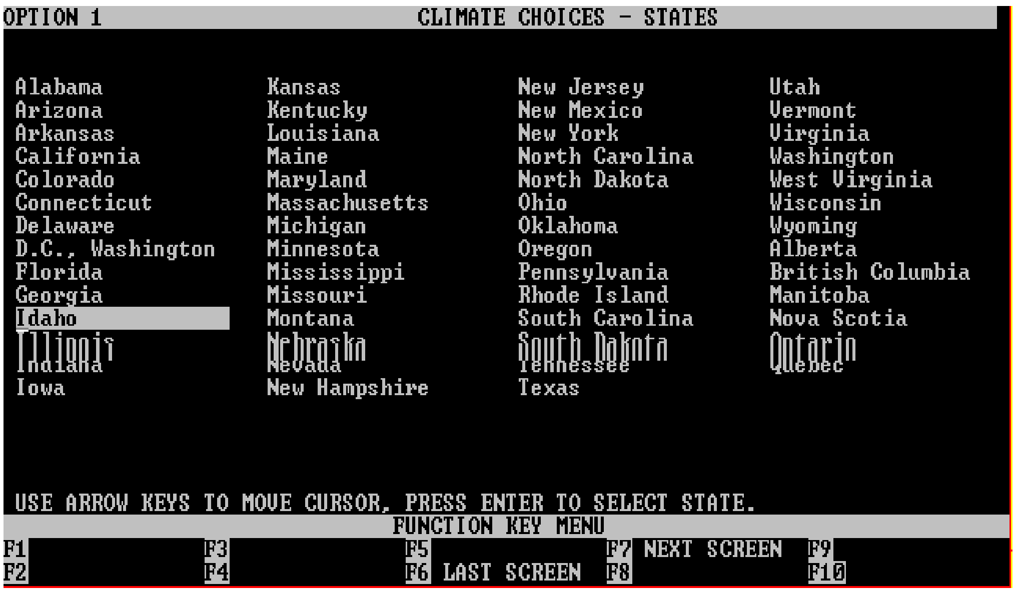


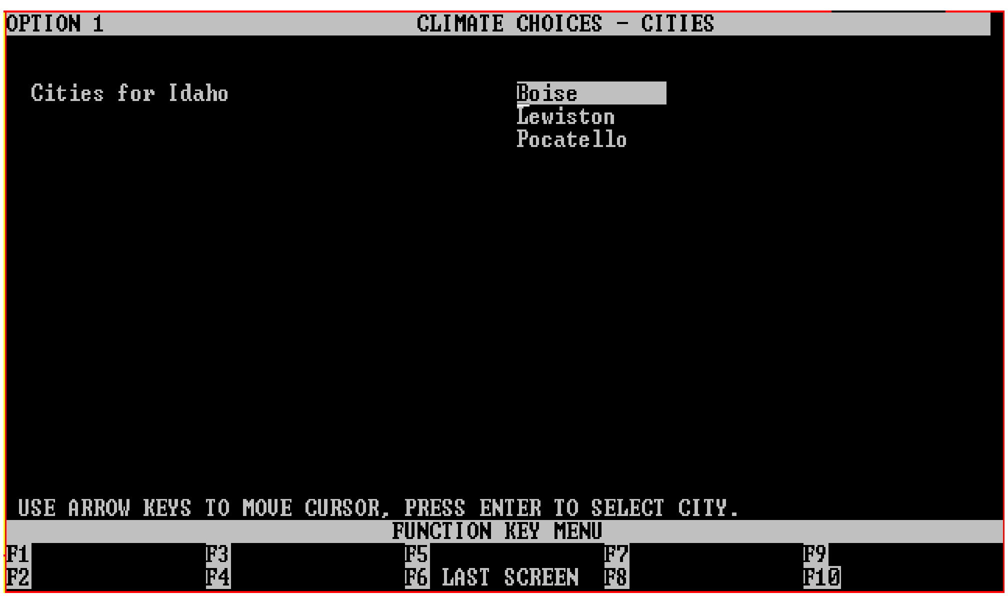
BLC HELP SCREEN (first screen)

Use the light bar cursor to select an appropriate Building Type and Insulation Package for residences or Building Height and Position for commercial buildings.



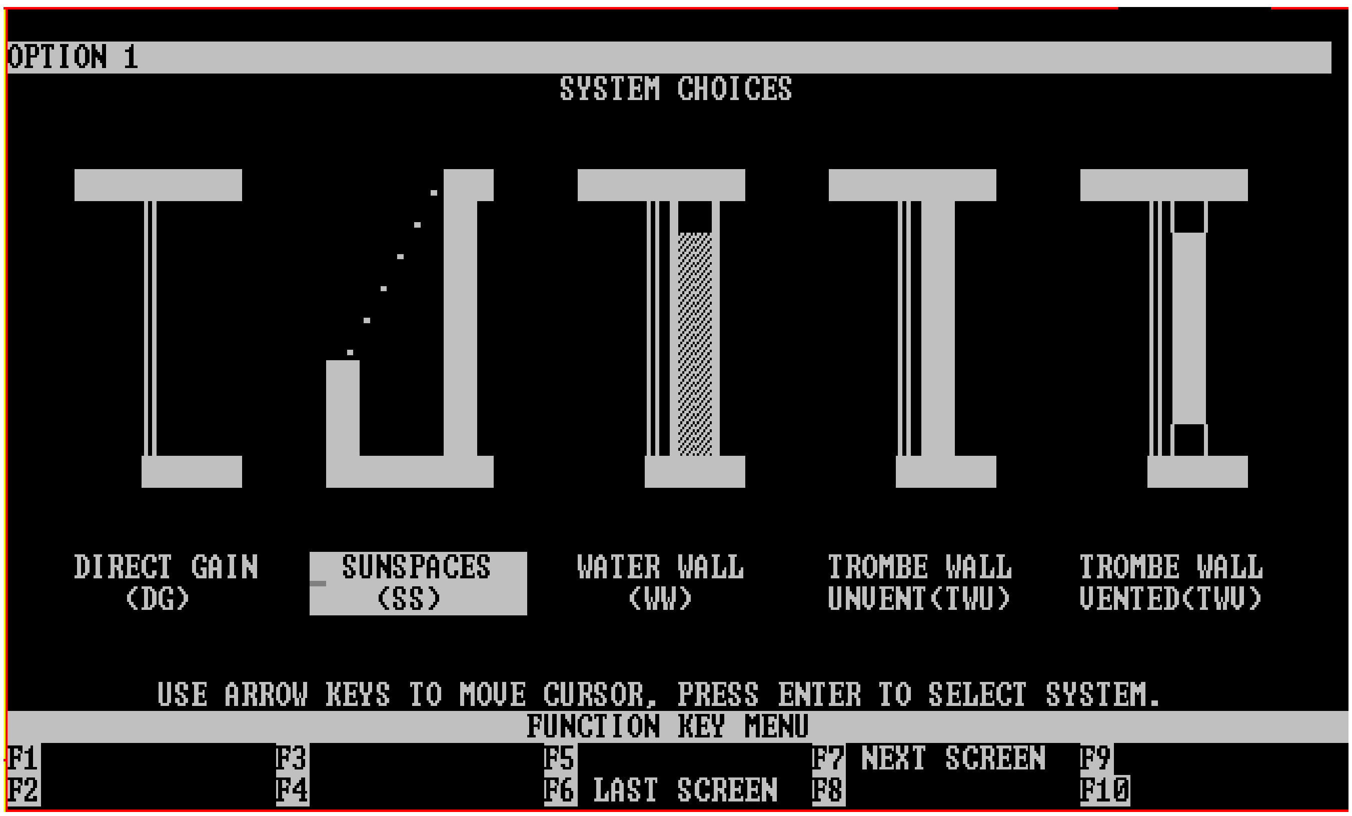
BLC HELP SCREEN (second screen)
Use the cross-hair cursor to estimate the BLC by lining up the floor area with % glazing and ACH (air changes per hour). Press "ENTER/RETURN" to enter data on **MAIN SPREAD-SHEET.** The **MAIN SPREAD-SHEET** reappears with the BLC filled in.





CLIMATE HELP SCREENS

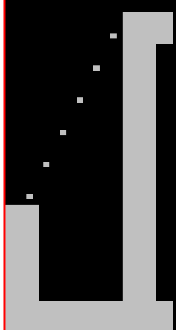
Use the light bar cursor to select state and city.



SYSTEM CHOICE HELP SCREEN
Use the light bar cursor to select system.

TYPE CHOICE HELP SCREEN will appear next

OPTION 1 SUNSPACE CHOICES



DESIGNATION	TYPE	TILT (DEGREES)	COMMON WALL	END WALLS	NIGHT INSULATION
a1 *	attached	50	masonry	opaque	no
a2 *	attached	50	masonry	opaque	yes
a3 *	attached	50	masonry	glazed	no
a4	attached	50	masonry	glazed	yes
a5 *	attached	50	insulated	opaque	no
a6 *	attached	50	insulated	opaque	yes
a7 *	attached	50	insulated	glazed	no
a8	attached	50	insulated	glazed	yes
b1	attached	90/30	masonry	opaque	no
b2	attached	90/30	masonry	opaque	yes
b3	attached	90/30	masonry	glazed	no
b4	attached	90/30	masonry	glazed	yes
b5	attached	90/30	insulated	opaque	no
b6	attached	90/30	insulated	opaque	yes
b7	attached	90/30	insulated	glazed	no
b8	attached	90/30	insulated	glazed	yes

USE ARROW KEYS TO MOVE CURSOR, PRESS ENTER TO SELECT TYPE. more...

* - Sensitivity Curves available for these choices.

FUNCTION KEY MENU

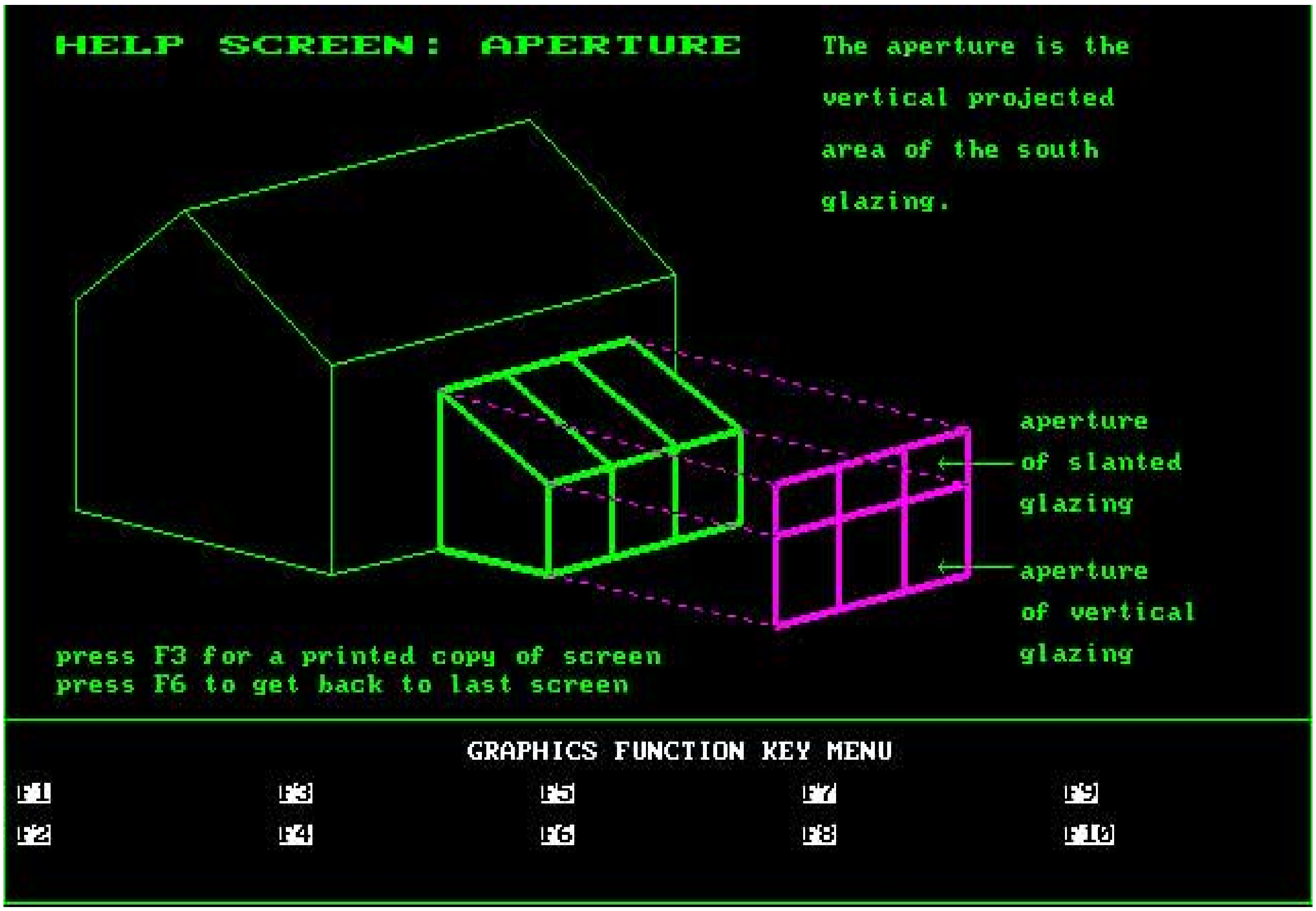
F1 F3 F5 F7 NEXT SCREEN F9

F2 F4 F6 LAST SCREEN F8 F10

TYPE CHOICE HELP SCREEN

Use the light bar cursor to choose system type.

See Balcomb's *Passive Solar Design Handbook vol 3* for a full explanation of data.



APERTURE HELP SCREEN
(information only)

```
SYSTEM CALCULATIONS
ENTER BASE TEMPERTURE FOR DEGREE DAY DATA? (50,55,60,65,70)
(Year as a whole calculations always done for 65 degree base temperature)
      METHODS              OPTION 1      OPTION 2      OPTION 3      OPTION 4
YEAR AS A WHOLE
                SSF:
      AUX.HEAT (YR):
MONTH BY MONTH
 SSF/AUX.HEAT JAN:
 SSF/AUX.HEAT FEB:
 SSF/AUX.HEAT MAR:
 SSF/AUX.HEAT APR:
 SSF/AUX.HEAT MAY:
 SSF/AUX.HEAT JUN:
 SSF/AUX.HEAT JUL:
 SSF/AUX.HEAT AUG:
 SSF/AUX.HEAT SEP:
 SSF/AUX.HEAT OCT:
 SSF/AUX.HEAT NOV:
 SSF/AUX.HEAT DEC:
      AUX.HEAT (MO):
                              FUNCTION KEY MENU
F1              F3              F5              F7              F9
F2              F4              F6 LAST SCREEN  F8              F10
```

CALCULATION SCREEN (blank)
Use the light bar cursor to select the base temperature.

Select the base temperature about 5 degrees F below the building's balance point temperature.

SYSTEM CALCULATIONS

ENTER BASE TEMPERTURE FOR DEGREE DAY DATA? (50)

(Year as a whole calculations always done for 65 degree base temperature)

METHODS	OPTION 1		OPTION 2		OPTION 3		OPTION 4	
YEAR AS A WHOLE								
SSF:		0.26		0.19		0.30		0.15
AUX.HEAT (YR):		87874840		80572904		69343256		83656184
MONTH BY MONTH								
SSF/AUX.HEAT JAN:	0.13	11412481	0.07	12273721	0.25	9934918	0.08	12127895
SSF/AUX.HEAT FEB:	0.33	5507133	0.17	8829393	0.40	6341923	0.18	8688924
SSF/AUX.HEAT MAR:	0.58	2454779	0.34	5198991	0.58	3334078	0.31	5414995
SSF/AUX.HEAT APR:	0.92	173644	0.83	369673	0.94	135796	0.73	576842
SSF/AUX.HEAT MAY:	1.00	0	1.00	0	1.00	0	1.00	1
SSF/AUX.HEAT JUN:	1.00	0	1.00	0	1.00	0	1.00	0
SSF/AUX.HEAT JUL:	1.00	0	1.00	0	1.00	0	1.00	0
SSF/AUX.HEAT AUG:	1.00	0	1.00	0	1.00	0	1.00	0
SSF/AUX.HEAT SEP:	1.00	0	1.00	0	1.00	0	1.00	0
SSF/AUX.HEAT OCT:	0.98	21113	0.96	39822	1.00	812	0.97	28921
SSF/AUX.HEAT NOV:	0.38	3960443	0.22	4570838	0.50	2941142	0.26	4384946
SSF/AUX.HEAT DEC:	0.15	9572881	0.04	10657914	0.20	8945457	0.05	10599893
AUX.HEAT (MO):		33102472		41940352		31634124		41822420

CALCULATIONS ARE NOW OVER, PRESS F6 KEY TO RETURN TO SYSTEM, F10 TO RECALCULATE

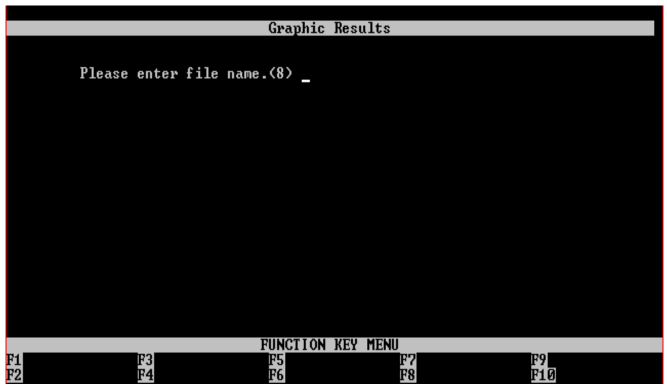
FUNCTION KEY MENU

F1	F3	F5	F7	F9
F2	F4	F6 LAST SCREEN	F8	F10 CALCULATE

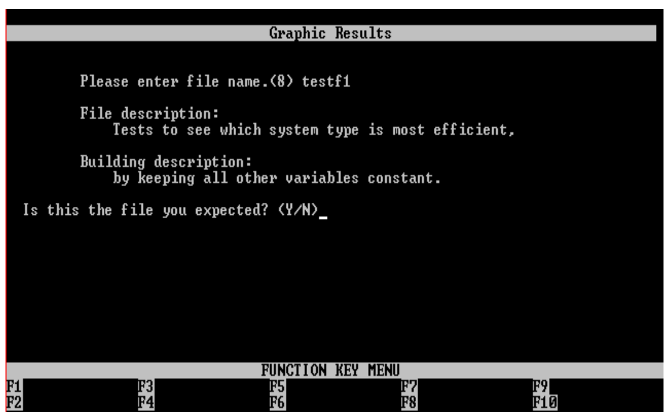
CALCULATION SCREEN (filled in)

Press "F10" to recalculate at a different base temperature. (first calculation data is lost).

Press "F6" to return to **MAIN SPREAD-SHEET**.

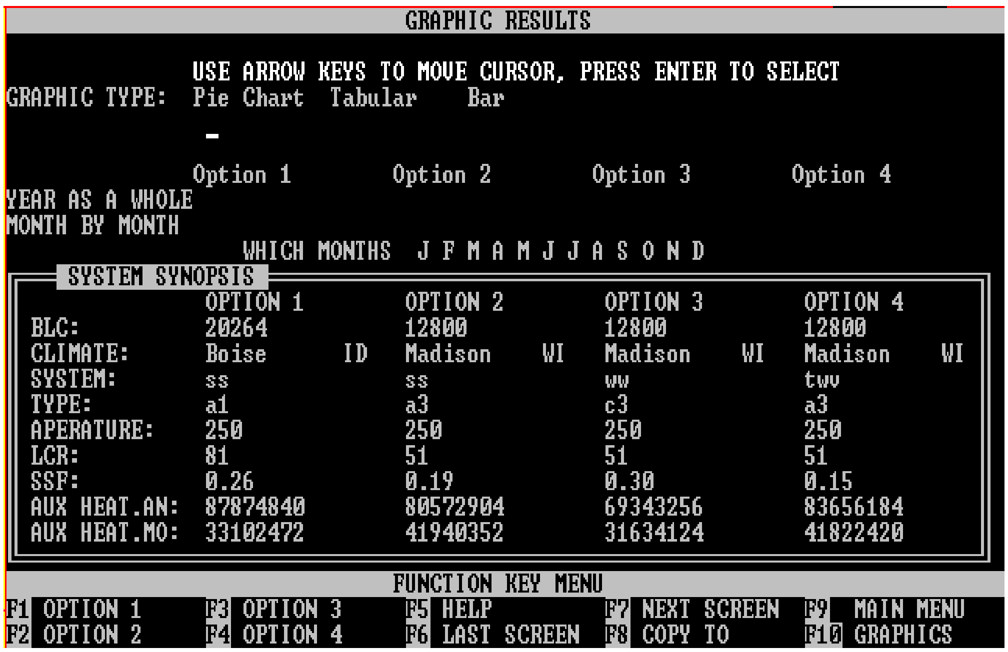


GRAPHIC RESULTS SCREEN (blank)
Provide the file name of the file that has been calculated.



GRAPHIC RESULTS SCREEN (filled in)
Confirm that the correct file has been selected.

Press “Y,” to continue or press “N” to try again.



GRAPHIC RESULTS SPREAD-SHEET
Use the arrow keys to manipulate the cursor.

Select the output with the “ENTER/RETURN” key or the “X” key.

Deselect or erase selections with the space bar.

When the desired output is selected, display output by pressing “F10.”

PIE CHART YEAR-AS-A-WHOLE OUTPUT
(sample)

Use F3 to print output.

TABULAR

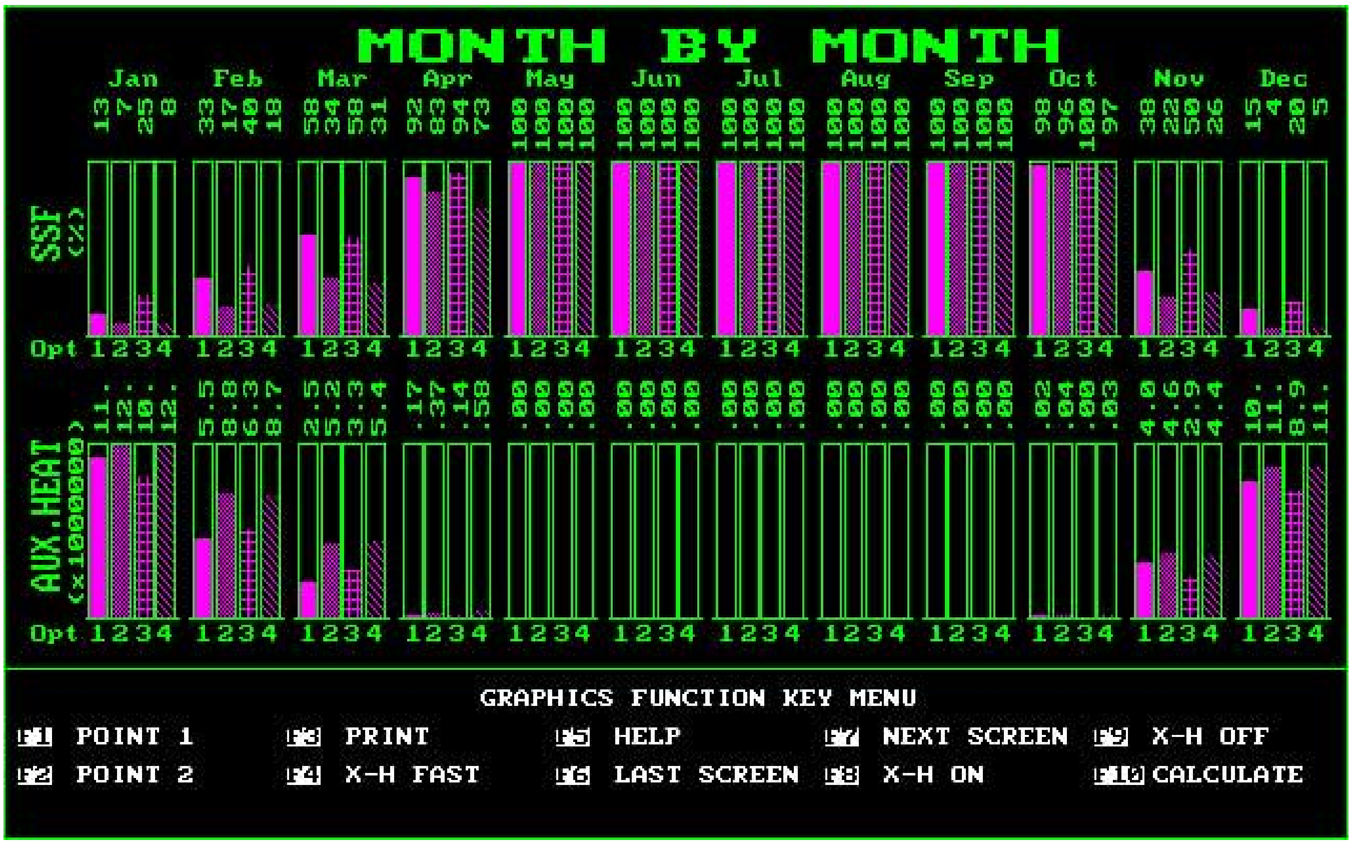
METHODS	Option 1		Option 2		Option 3		Option 4	
YEAR AS A WHOLE								
SSF:		0.26		0.19		0.30		0.15
AUX.HEAT (YR):		87874840		80572904		69343256		83656184
MONTH BY MONTH								
SSF/AUX.HEAT JAN	0.13	11412481	0.07	12273721	0.25	9934918	0.08	12127895
SSF/AUX.HEAT FEB	0.33	5507133	0.17	8829393	0.40	6341923	0.18	8688924
SSF/AUX.HEAT MAR	0.58	2454779	0.34	5198991	0.58	3334078	0.31	5414995
SSF/AUX.HEAT APR	0.92	173644	0.83	369673	0.94	135796	0.73	576842
SSF/AUX.HEAT MAY	1.00	0	1.00	0	1.00	0	1.00	1
SSF/AUX.HEAT JUN	1.00	0	1.00	0	1.00	0	1.00	0
SSF/AUX.HEAT JUL	1.00	0	1.00	0	1.00	0	1.00	0
SSF/AUX.HEAT AUG	1.00	0	1.00	0	1.00	0	1.00	0
SSF/AUX.HEAT SEP	1.00	0	1.00	0	1.00	0	1.00	0
SSF/AUX.HEAT OCT	0.98	21113	0.96	39822	1.00	812	0.97	28921
SSF/AUX.HEAT NOV	0.38	3960443	0.22	4570838	0.50	2941142	0.26	4384946
SSF/AUX.HEAT DEC	0.15	9572881	0.04	10657914	0.20	8945457	0.05	10599893
AUX.HEAT (MO):		33102472		41940352		31634124		41822420

FUNCTION KEY MENU

F1 OPTION 1	F3 OPTION 3	F5 HELP	F7 NEXT SCREEN	F9 MAIN MENU
F2 OPTION 2	F4 OPTION 4	F6 LAST SCREEN	F8 COPY TO	F10 CALCULATE

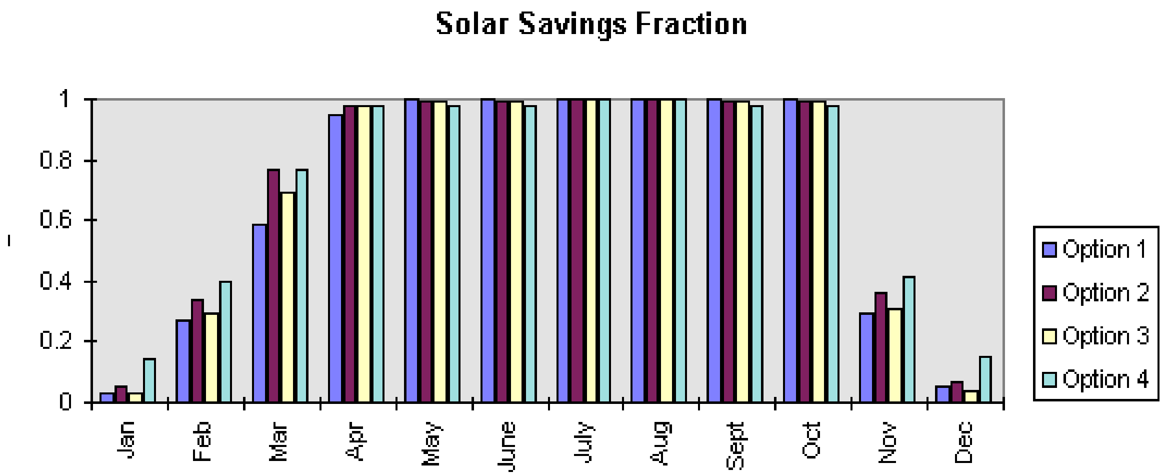
TABULAR OUTPUT
(sample)

Use PRINT SCREEN to print output.



BAR GRAPH MONTH-BY-MONTH OUTPUT
(sample)

Use “F3” to print output.



TABULAR AND GRAPHIC OUTPUT USING MICROSOFT *EXCEL*
As a DOS application, *UISUN* is accessible through Windows' File Manager. "Run" *UISUN* from Windows and proceed with your calculations. From the **SYSTEMS CALCULATIONS SCREEN** (or **TABULAR SCREEN**) export the data into an *EXCEL* spread-sheet.

1. Press "ALT+ENTER" simultaneously to create a *UISUN* "window."

2. From the pull-down menu select "EDIT" then "MARK."

3. Highlight only the SSF and the AUX. HEAT monthly data, then press "ENTER."

4. Press "ALT+TAB" simultaneously to access *EXCEL*.

5. "PASTE" the tabular data onto a spreadsheet.

6. Using the DATA pull-down menu, select "TEXT TO COLUMNS."

7. Choose the "fixed-width" field format, and create the desired graph.

This option allows a greater range of outputs available through *EXCEL*'s myriad graphics capabilities. By overlaying multiple outputs (merging spread-sheets), useful comparisons can be generated. Given the limited graphics capabilities of *UISUN*, the manipulation of tabular data through *EXCEL* becomes a logical next step in the creation of models for study and presentation.

VITAL SIGNS

BIBLIOGRAPHY Thermal Mass in Passive Solar and Energy-Conserving Buildings

MIT PRESS SERIES

Anderson, Bruce, editor, *Solar Building Architecture*, MIT Press, Cambridge, MA, 1990.
This book addresses the integration of architecture and solar technologies. The chapter, "Building Interiors: Thermal Energy Storage," is of particular relevance as it deals almost exclusively with passive strategies and their relationships to (mostly residential) architectural spaces. Numerous examples of existing residential and some commercial buildings are referenced to clarify the discussion. The last chapter exposes the ramifications of passive solar design on non-residential buildings. It not only focuses on architectural integration issues, but presents other considerations as well. These include: effects on occupants, economics, integration with conventional system controls, and code developments.

Balcomb, J. Douglas, editor, *Passive Solar Buildings*, MIT Press, Cambridge, MA, 1992.
A large portion of this book is dedicated to passive heating and cooling simulation and mathematical modeling techniques. Although computer software has been developed for this type of analysis, the historical context is interesting. Chapter 5, "Materials and Components," contains a short discussion on sensible and latent thermal storage media with applicable references to related publications. Chapter 8, "Building Integration," provides an interesting overview of the Passive Solar Commercial Buildings Program (PSCP). The impact of this program is reviewed, indentifying a number of passive systems in commercial buildings. Some general findings are reviewed including post-occupancy evaluations. Chapter 9, "Performance Monitoring and Results," contains a discussion of thermal and energy-related performance monitoring methods. It provides a good overview of different approaches and techniques ranging from whole-building energy use to component testing. A number of significant early projects are described.

Cook, Jeffrey, editor, *Passive Cooling*, MIT Press, Cambridge, MA, 1989.
While this book focuses on all aspects of passive cooling, Chapter 6 offers an excellent overview of system concepts and the role of storage materials. In addition, the end of the chapter discusses passively cooled commercial buildings, and summarizes general findings through case study. Areas of further research are addressed on pages 559–560. This tome is a good source for earth-coupling, roof pond systems, and air-core night ventilation.

de Winter, Francis, editor, *Solar Collectors, Energy Storage, and Materials*, MIT Press, Cambridge, MA, 1990.
This highly technical work approaches solar technologies from a material and component perspective. There is very little discussion of architectural integration or post-occupancy factors. Chapters 16-19 provide a great deal of information on energy storage systems, providing everything from concepts and modeling to testing and research for the analytically oriented. This book is useful as a comprehensive resource on phase change storage materials and systems.

BOOKS

***The Architect's Handbook of Energy Practice: Active Solar Systems*, The American Institute of Architects, Washington, D.C., 1982.**
and
***The Architect's Handbook of Energy Practice: Passive Heating and Cooling*, The American Institute of Architects, Washington, D.C., 1982.**
These two handbooks provide a good selection of possible "work-up" buildings in different regions utilizing passive and/or active systems. They introduce passive/active concepts and strategies, although primarily geared towards skin-load-dominated buildings. The passive handbook presents a useful rule-of-thumb process associating climate and collector area. The consequential reduction in heating load is given for approximately 100 U.S. cities.

Brown, G.Z., Bruce Haglund, Joel Loveland, John S. Reynolds, M. Susan Ubbelohde, *InsideOut: Design Procedures for Passive Environmental Technologies*, John Wiley & Sons, Inc., New York, 1992.
and
Brown, G.Z., and Virginia Cartwright, *Sun, Wind, and Light: Architectural Design Strategies*, John Wiley & Sons, New York, 1985.
Although outstanding stand-alone texts, these two work best as a team. *Sun, Wind, and Light* follows the *InsideOut* workbook closely with excellent illustrations and case studies. For example, the Bateson Building facilitates a discussion of mechanical ventilation and thermal mass. Calculation exercises are provided in *InsideOut* for heating and cooling strategies using thermal mass, including night ventilation and roof ponds. A method for "checking" thermal mass based on the interior temperature swing follows this section.

Dean, Thomas Scott, *Thermal Storage*, Franklin Institute Press, Philadelphia, PA, 1978.
Despite its title, this book gives only rudimentary information regarding thermal storage systems. Focusing on active strategies, the author discusses the components of the system (storage materials and their containment) while ignoring the issues of architectural integration and commercial application. It does offer a concise (if overly simplified) historical overview of the pioneers in thermal storage technologies, acknowledging the Anasazi cliff dwellings in the American Southwest as well as the innovations of Steve Baer.

Givoni, Baruch, *Passive and Low Energy Cooling of Buildings*, Van Nostrand Reinhold, New York, 1994.
The role of thermal mass in nocturnal ventilating and radiant cooling systems is covered extensively in chapters 3 and 4. The strategies are presented in the form of investigative studies and experiments performed by the author and other researchers. Few existing, occupied buildings are discussed as a means of conveying the cooling principles. As such, the results are applicable to similar generic situations and conclusions drawn are somewhat universal. Chapter 6 discusses the earth as a cooling source. This book is an excellent reference on direct and indirect earth coupling addressing the "human factor" in designing earth-sheltered buildings.

Lechner, Norbert, *Heating Cooling Lighting: Design Methods for Architects*, John Wiley & Sons, New York, 1991.
This excellent companion textbook to Stein and Reynolds' *MEEB* gives added purpose to heating, cooling, and lighting decisions with the depletion of nonrenewable resources and the degradation of the environment as persistent factors. The "quickie" basic principles relating to thermal mass balance between technology and human comfort. While the information is primary in nature, good examples are mentioned throughout. Chapter 15 offers a number of commercial case studies where thermal mass is critical for effective cooling.

Meltzer, Michael, *Passive and Active Solar Heating Technology*, Prentice Hall, Inc., Englewood Cliffs, NJ, 1985.
This book provides simplified explanations of passive strategies for the owner–builder. It offers an uncomplicated thermal mass sizing method based on material type, thickness, and location.

Olgyay, Victor, *Design with Climate: A Bioclimatic Approach to Architectural Regionalism*, Van Nostrand Reinhold, New York, 1992.
A distinctly regional approach to occupant well-being and form-making. The emphasis is placed on site-scale strategies rather than building/component strategies for heating and cooling. The thermal effects of materials are discussed in chapter 10. The effects of heat capacity and thermal resistance are comparatively defined using temperature curves, and a method for calculating the time lag requirements is provided.

Panchyk, Katherine, *Solar Interiors*, Van Nostrand Reinhold Company, New York, 1984.
The author explores the relationship between the exterior and the interior incorporating the analysis of human thermal responses. The basic passive strategies are reviewed emphasizing the properties of numerous building materials, lightweight and massive. Discussions on mass obstructions, as well as the links between mass and spatial planning, activities, and occupancy schedule/profile are included in chapter 9.

Sodha, M.S., N.K. Bansal, A. Kumar, P.K. Bansal, and M.A.S. Malik, *Solar Passive Building: Science and Design*, Pergamon Press, New York, 1986.
This highly technical reference covers all aspects of passive heating and cooling. Mathematical models are provided in conjunction with scientific theoretical descriptions. This comprehensive, all-inclusive book can be quite daunting as the material is presented "by engineers, for engineers." Balancing this approach, chapter 9 offers an excellent rule-of-thumb design process that dissolves the engineering and thermo-physical properties of materials into an easy-to-swallow method. The application of thermal mass is discussed, however, it is limited to residential situations.

Stein, Benjamin, and John S. Reynolds,*Mechanical and Electrical Equipment for Buildings*, Eighth Edition, John Wiley & Sons, Inc., New York, 1992.
This textbook and professional reference provides basic principles, calculation procedures, case studies, and extensive tables, figures, and diagrams of all aspects of environmental control, including passive solar design. Beginning on page 259, a step-by-step calculation procedure for the performance of night ventilation of thermal mass is detailed. An excellent case study on the office building for the Emerald People's Utility District outlines the integrated aspects of all energy conservation strategies including the core flush system through precast concrete slabs.

***PSDATE READER*—(bibliography of articles included)**

"Codes for Conservation," Northeast Sun, Northeast Sustainable Energy Association, Feb. 1988, pp.12–15.
This article reviews and compares the energy codes of several New England states.

Barnaby, Charles S., "CALPAS-4 and Beyond—Microcomputers, Graphics, and Building Energy Simulation," *Proceedings from Building Energy Simulation Conference*, 1985, pp. 66–71.
This paper describes CALPAS-3 and shows how its successor, CALPAS-4, will address some of its shortcomings.

Benton, Charles C., and James M. Akridge, "TNODE: A Microcomputer-Based Thermal Network Simulation Program," *Proceedings from American Solar Energy Society Annual Meeting*, 9th Passive Solar Conference, American Solar Energy Society, 1984, pp. 43–48.
This paper describes a general purpose thermal network simulation computer program written at Georgia Tech and available through the Designers' Software Exchange. The usefulness of *TNODE* as a teaching tool is presented through a simple example problem.

Haglund, Bruce, Chuck Horgan, and Bob Voertman, "Microcomputer Software as a Means of Informing the Design Process on Passive Heating," *Proceedings from American Solar Energy Society Annual Meeting*, American Solar Energy Society, 1987, pp. 491–494.
This article provides an excellent synopsis of *UISUN's* background and capabilities. See appendix 2 for User's Manual

***The Idaho Training Manual,* Idaho Department of Water Resources, 1986**
The manual serves as an educational document to accompany the Model Conservation Standards (MCS), issued by the Northwest Power Planning Council. The *PSDATE Reader* outlines the first of four chapters only, giving the overview of the MCS. The additional chapters discuss energy fundamentals, MCS for commercial buildings, and MCS for low-rise residential buildings.

Wessling, F.C., "Passive Solar Thermal Simulation—Three Models," *Proceedings from American Solar Energy Society Annual Meeting*, American Solar Energy Society, 1978, pp. 97–101.
This paper presents three different thermal mass models—a uniform mass, a two-node mass, and a multi-node mass—which are compared to a measured case study of a solar gain space.

SOFTWARE

CALPAS-3
A comprehensive thermal simulation program based on the thermal network analogy. This promising package has an awkward, card-file-like interface. A graphic interface successor, *CALPAS-4*, was promised, but never delivered.

DOE-2
This program is the most comprehensive and detailed thermal model. *DOE-2* has versions that run on mainframes, workstations, and microcomputers. Contact Lawrence Berkeley Labs; Simulation Research Group 90-3147; University of California; Berkeley, CA 94720 for details on all versions.

Energy Scheming
This Mac-based package is extremely user-friendly. It can be employed early or late in the design process. The interface is almost exclusively graphic—working equally well with either sketches or construction drawings.

Energy 10
This package promises to be a comprehensive, user-friendly simulation tool. It is currently in its beta-test release. Contact NREL for more details.

Softdesk *Energy*
This package is a DOS/Windows-based version of *Energy Scheming* that runs in conjunction with Softdesk's CAD software.

Solar-5
This user-friendly thermal simulation program is being developed by Murray Milne at UCLA. It covers a wide variety of building types and climates. Its graphic output is uniquely descriptive and evocative. Its use is covered in the Vital Signs Resource Package, "Measurement and Display of Thermal Performance of Buildings."

UISUN
Based on Balcomb's SLR method, this package is able to calculate passive solar heating contributions for a wide variety of systems in a wide variety of North American climates. It is particularly user-friendly and is helpful as a design tool in the schematic design phase. A complete user's manual is given as Appendix 2.

Wattsun 5.x
This program is basically a residential construction code compliance software package for the Pacific Northwest. However, it is extremely user-friendly and has the capability of calculating heat loss (U·A) and comparing the performance of various residential constructions.