Passive Solar Labs BETA

For use with **Passive Solar Architecture,** 2011, Chelsea Green Publishing.

Sun position
site selection,
microclimate,
air movement,
passive solar building design,
air flow and comfort,
solar hot water,
solar cooker,
daylighting,
green materials,
photovoltaics,
integrated design,
landscape, and
community design
with class syllabus
checklists and resources

By David A. Bainbridge and Ken Haggard ©2011

Note: These labs involve cutting tools, materials that may break, get hot, stick to skin or clothes or be otherwise dangerous. Safety glasses, other protective gear as needed, and careful instructions and supervision with safe and good working conditions are the responsibility of the instructor. Keep MSDS safety materials on site and visible.

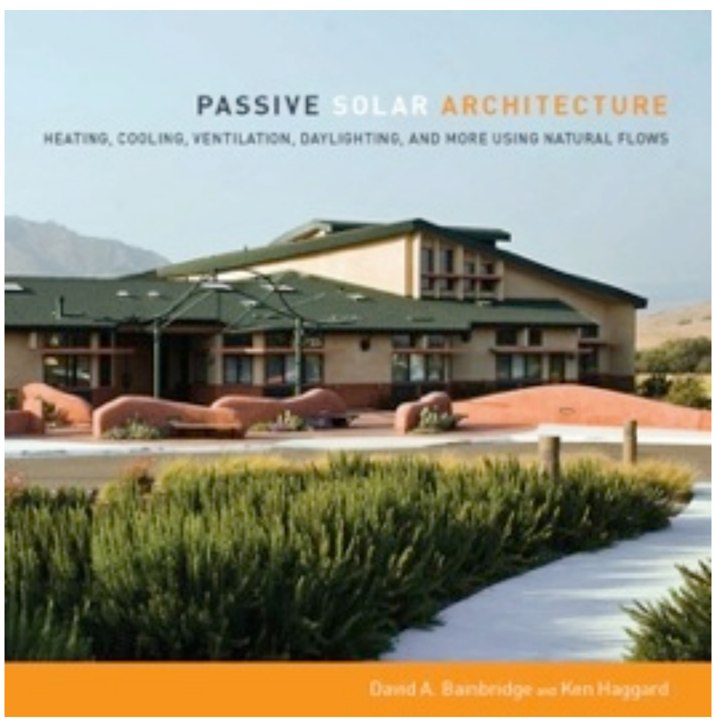
Passive Solar Architecture

2011. David A. Bainbridge and Ken Haggard. Chelsea Green Publishing.

Order from Chelsea Green, KH at FractalArchitecture.com, or your local bookstore.

This book is a major work. It uniquely emphasizes the interplay between passive solar building and the other elements of sustainable design, and relates real-world examples of building design to broader issues of sustainability. Passive Solar Architecture is a welcome addition to any bookshelf on green architecture and sustainability. —Margot McDonald, professor of architecture, California Polytechnic State University, San Luis Obispo, and past-president, American Solar Energy Society

This book is a treasure! Drawn from the coauthors' and contributors' decades of successful experience, Passive Solar Architecture is both inspiringly broad in scope and delightfully detailed. City and neighborhood planning is intermixed with many small gems—such as a metal water wall detail to capture winter sun—and examples in climates from around the world. This is a welcome and unique resource for my university seminars in passive heating and cooling. —John S. Reynolds, FAIA, Professor of Architecture Emeritus, University of Oregon, and Honorary Past Chair, American Solar Energy Society



Why labs are so important

The great secret of eduction is to combine mental and physical work, so that one kind of exercise refreshes the other. John Jacques Rousseau

THE EXTINCTION OF EXPERIENCE

The experience students have had before attending university is more variable than ever, but one change has been very dramatic - we call it the extinction of experience. It is not uncommon for students in architecture, design, or engineering to have very little experience in doing anything with real things. They may be wizards on the computer and Ipad, but increasing numbers of them have never measured, cut, or assembled anything except paper and cardboard. Torches, hammers, nails, power tools, and the need for precision in measuring and cutting are often foreign concepts to many students. It has been increasingly common to encounter students who have never used a hammer, saw, shovel or tape measure.

Many have had very little exposure to materials or tools. This is a critical handicap in design. Even limited exposure to real things can make a big difference in wiser use of materials and elegance of design.

Students building a straw bale bench at USIU (after building one bench they got so involved they raised the money to buy materials and built a straw bale amphitheater). Construction was supervised by a very generous adjunct professor.

Field research is also critical. The environment students live in is often missed as they stumble by using earpods and cell phones while texting. Or while driving to and fro in hectic traffic to multiple jobs.

Getting out and measuring temperatures and microclimate conditions can improve understanding of microclimate and site variability. This increases design sensitivity and facilitates sustainable design.

A good way to involve students is to involve them in monitoring campus locations. What makes buildings, classrooms and outdoor spaces comfortable? Or uncomfortable?

When? Why? Transects across campus can be very revealing. Building evaluation can be even more instructive when occupant interviews are done.

Most students love it. It also is very visible and can increase enrollment and interest in sustainable design courses and majors. A set of bright green vests might be a good investment with Sustainable Building Lab stenciled on them.

Visits to sustainable buildings are very popular with students as well. Many engineering and design firms are very proud of their work and willing (thanks to all who have helped us) to devote time and resources to showing students how their buildings and businesses work. The lightbulb of career options is often lit on these visits.

Students love real projects

NOTE: Send us your suggestions for additional labs or improvements to these. sustainabilityleader(at)gmail.com.

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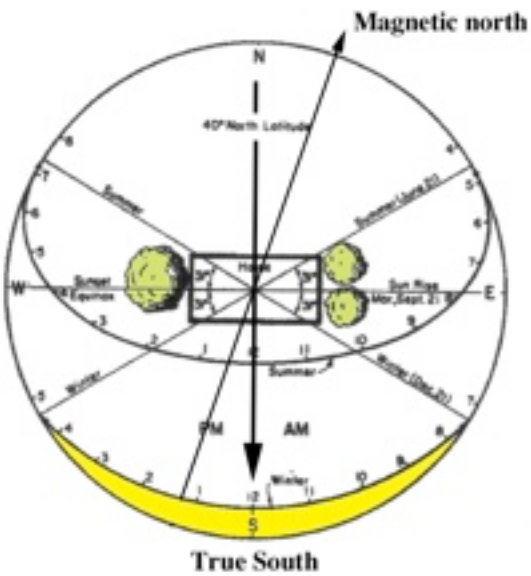
Sun position and site selection

The only completely safe nuclear reactor is 93 million miles away

SOLAR SOUTH, SUN POSITION, SITE EVALUATION, SOLAR SIMULATOR

SOLAR SOUTH



The importance of solar orientation is stressed throughout the book. You can look at sun angle charts on page 26. Solar altitude and azimuth are important factors in heating, cooling, daylighting, solar control and ventilation.

Today you can look up a site address on Google Earth and quickly determine the latitude and longitude, elevation, and true directions. If you are working with just a compass you need to know the magnetic declination from true south or north for the site (see page 26 in the book). Higher quality compasses will allow magnetic declination to be set by rotating a ring. On a plain compass simply mark magnetic north with a pen. In San Diego for example the magnetic declination is 14° east of north. So when the needle points to the 14°E mark on the compass the S on the case faces true south.

We have found that it is helpful to focus on True South (northern hemisphere) and prefer putting true south on all drawings instead of the more common north or magnetic north. The sun we want to use in the Northern Hemisphere midlatitudes is the South sun. In the colder far north SE and SW become more important for spring and fall heating.

There are also several ways to determine solar south without a compass. These are not as simple as they might seem so you might consider having your class research these and have a competition to see who can come the closest to true south. This can help people visualize sun paths over the year.

Most solar books focus on the midlatitude temperate zone. It is important to recognize these passive principles also apply in the polar and equatorial regions.

This can be done as a learning exercise—and to help prepare people to work in other climate zones and locations. We have included a broader range of sun positions in our book (page 26).

Students might also be asked to review the Passive Solar Design Guide for Alaska (http://www.alaskasun.org/pdf/PassiveSolar.pdf) and to look on-line for successful passive solar homes in Fairbanks, Alaska. The passive principles shown in the Panama Canal housing (page 97) can also provide insight for low latitude buildings in other hot humid climates.

SITE EVALUATION

The availability of sun on the site is determined using a site selector, sun charts, or photographic methods (see page 26 for solar charts). Google Earth can be helpful as well for seasonal landscape related shading from hills and canyons.

A solar site selector is an easy tool to use and well suited for students. Shade from nearby trees and buildings are the most common problems. Review of building sites can help reinforce the importance of the placement of trees when landscaping. A site selector could also be used to do some selective pruning to improve solar access.

The solar site selector

Many other types of evaluation can be done. The advent of digital cameras can make it relatively easy to do a 360 site photo. By keeping the camera perfectly level on a tripod and noting altitude angles to a number of points you can lay out a sky map and estimate solar potential.

To estimate energy you will also need solar radiation monitoring data. This is sadly limited in much of the U.S. but some is available from NOAA and from NREL, state energy organizations, and other data providers. Try http://www.nrel.gov/rredc/solar_resource.html, http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/mon2/state.html, http://www.nrel.gov/midc/ as well as state resources.

In some cases data will be limited to percent possible sunshine.

SUN PIN CHART

Simple sun pin charts are included in the book, page 54. These are very simple to make and surprisingly useful. They help students, designers and clients better understand the design opportunity and sun paths in relation to building form. Solar access in winter and solar control in summer may be equally important.

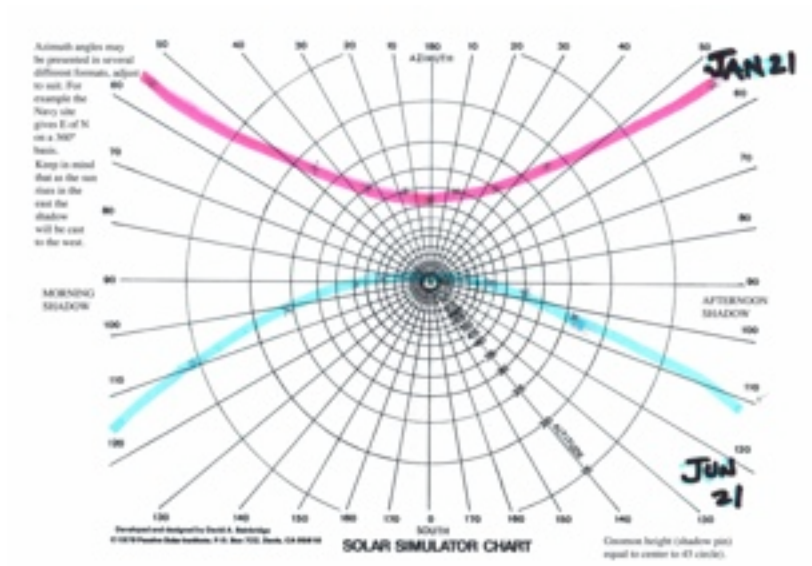
SOLAR SIMULATOR

More site specific sun positions for passive solar heating and solar control can be evaluated using models and a solar simulator. This provides more accurate site data (for a specific latitude instead of the nearest latitude offered) and plotting sun path and shadows can be done for specific design days. To assemble the solar simulator print the chart on the next page. Then locate or calculate the altitude and azimuth tables for your site latitude for the design days of interest, typically January 21, June 21, and September 21/March 21.

This can be for the exact latitude. Solar position data is available from a range of web resources, the Navy site is simple and is the one I usually use www.usno.**navy**.mil/USNO/astronomical.../data.../alt-az-us. The time is standard time rather than solar time but the elevations at 180° are at solar noon. These can be approximated and are well within the margin of error of the solar simulator pin diagram.

The NREL site offers many more options http://www.nrel.gov/midc/solpos/solpos.html. A number of others calculators are available on line, and simple tables are presented in a range of books.

Then mark these on the angle chart using different pen colors. Connect the points with smooth curves. Then paste the completed chart onto a sheet of cardboard or 1/4 inch plywood. Cut a nail or screw so that it provides the right pin (gnomon) height and is perpendicular to the chart. This can be force-fit through a mounting hole and glued. Or for a more robust mounting insert or glue a magnet at the pin point, then cut a nail to the correct height, including the magnet height. The pin can be laid down for travel. Make a couple of spares.



It is easiest to use this simulator with a tripod with a ball mount. For older tripods a 1/4"x20 t-nut will work. This can be hammered into a wood block that is glued to the sheet. For a more robust mount use a 1/4 bolt through the wood with larger washers on both sides with a coupling nut. The model can then be tilted to show the sun pattern for any given time on the design days.

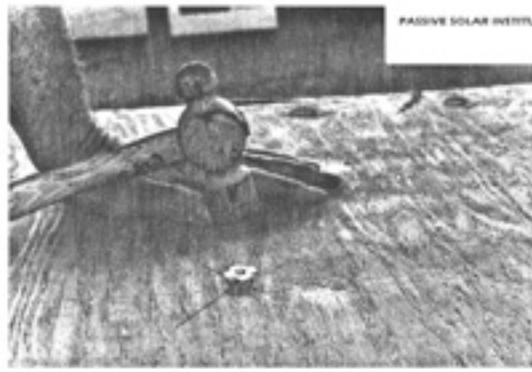
Take a series of digital photos hour by hour on the design day to see where the sun/shadow falls.

Alternatively the site specific sun chart can be reduced to the size of a pin diagram and then placed on the roof or mounting base of a larger model.

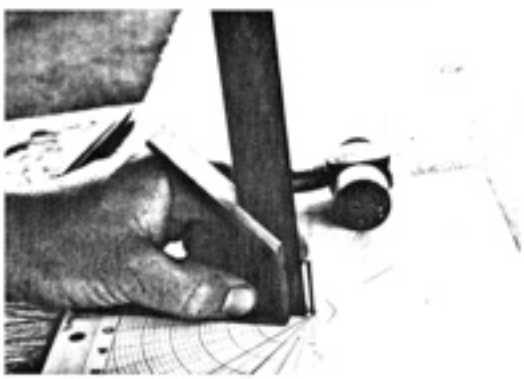
Building and using the solar simulator

A 1/4 inch or 3/8 inch plywood sheet with a nut sized to fit on a ball mount tripod is most convenient (many are 1/4"x20). But it can be hand held, or angled simply by using blocks or braces

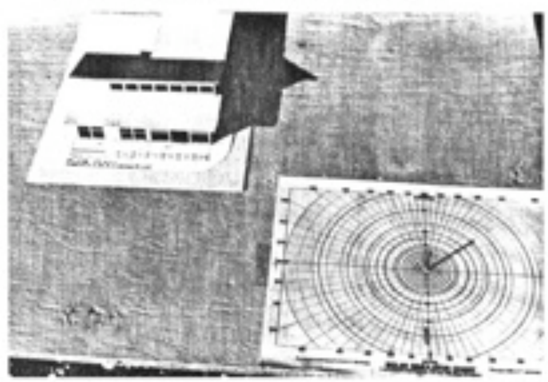
Drill Hole in Center of Board



Insert T-nut and set with hammer



Mount Solar Chart and Pin



Mount on tripod and test models

Model size

The scale of the model can be adjusted to fit the tilt table. 1/8" to a foot may be convenient for larger buildings, but 1/4" to a foot or larger can be easier to photograph.

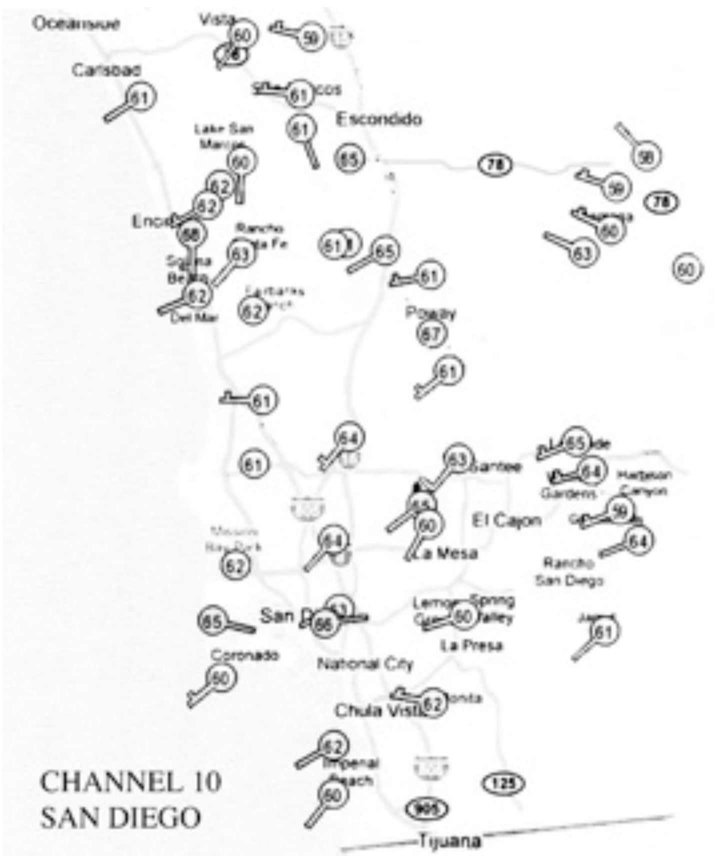
The chart can also be mounted on the base or flat roof of a model and rotated by hand through the sun path. LEDs are very directional and can be used inside to simulate sun--but the sun is better.

The chart can be used on a larger scale model for detailed daylighting or solar control studies for each room.

Microclimate

Meteorological variables are not only subject to vertical changes near the ground, but to horizontal variations within short distances. Rudolph Geiger

UNDERSTANDING MICROCLIMATE



Most people are largely oblivious to microclimate–moving from a mechanically heated and cooled house to a climate controlled car to a climate controlled office. One of the first class labs should be a microclimate lab.

Student teams can be assigned temperature/climate transects across the campus or within a building. Using a a regular and radiant thermometer (and wind speed monitors, humidity monitors, solar radiation meters as available) they are asked to plot temperatures on a Google map or building plan.

Data can also be arrayed in tables or charts to include surface temperatures (pavement, concrete, grass, water), wall temperatures facing different directions (brick, wood, ivy covered), relative humidity, etc. These can be linked to photos or Google street view as well.

Monitoring within buildings, dorms or apartments is also important. Typical measurements would include walls, ceilings, floors, windows, and doors – both inside and out. This can be done over a day and night sequence. The impact of venetian blinds (open/close) or curtains can also be included.

Teams can be asked to look for energy leaks on cold winter days or heat sources on hot summer days. Even better if you can borrow or rent an IR camera.

The radiant temperature thermometer is a great learning tool (meters without laser pointer are preferred for younger students).

SITE MICROCLIMATE

Climatic conditions can vary dramatically within a small distance, as shown on page 23 of the book. Traditional weather stations are set in representative areas, deliberately avoiding areas where variations will be more dramatic. The guidelines for monitoring can be reviewed at www.nws.noaa.gov/directives/sym/pd01013002curr.pdf.

Homes and buildings are often built in microclimates that are much more extreme than the nearest data source -- or more rarely milder microclimates. One of the first steps in designing sustainable buildings is developing a better understanding of microclimate. This has to be local and site specific. The data for the nearest weather stations can be collected (start with NWS, NOAA, university and state climate resources, weatherunderground http://www.wunderground.com/, and other web sites) and then correlated with measurements taken on site. In California we often use http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca4412.

Weather tapes are available for some sites. These can be used for more complex simulations of building performance. But be aware of differences between the weather tape site and the building site.

Site conditions can be measured by students on repeated days or with data logging instruments. Max/min thermometers are also useful -- and results can be quickly compared with reported data from the nearest official weather sites. In San Diego we have very complex microclimates and the TV stations do microclimate forecasts. There are also an incredible number of reporting stations. But in some locations there may only be one station -- not very close.

Temperature

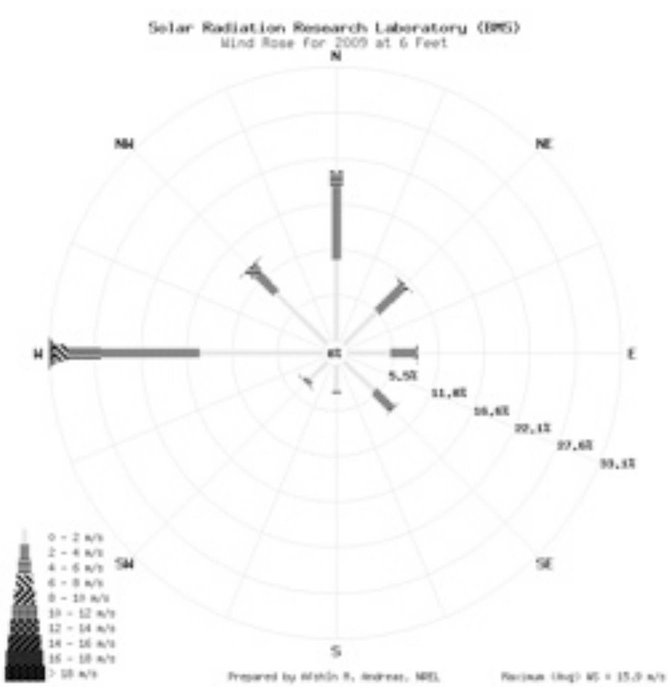
Air temperature is one of the most commonly measured design factors. It is necessary but not sufficient. Understanding how current patterns of measurement developed is useful (see Geiger - The Climate Near the Ground). When measuring air temperature for comparison with official stations it is important to match conditions to NWS rules:

Over level terrain (earth or sod) typical of the area around the station, and at least 100 feet from any extensive concrete or paved surface.

All attempts will be made to avoid:
(1) areas where rough terrain or air drainage are proven to result in non-representative temperature data,
(2) areas where water tends to collect, and
(3) areas where drifting snow collects.

If the instrument is within a shelter, position the shelter so it opens to the north (to protect the instruments from direct sun exposure) with the floor 4 to 6 feet above the surface. Shelters should be located no closer to an obstruction than four times the height of the obstruction.). Never believe everything you read. For some examples of problems with weather stations see: www.norcalblogs.com/watts/weather_stations/

Wind speed



Wind speed and direction are also very important. The key concerns include: wind speed and direction during winter and summer design days or design months.

Develop a wind rose for the site.

Extreme winds and wind direction are also important for design. Wind patterns, cold air drainage and other considerations can be evaluated using balloons filled with helium or bubbles (see appendix x in the book for recipes).

If wind machines are being considered for electricity or mechanical power then wind speed above the ground becomes even more important and a tower with an array of meters may be needed (see Paul Gipe. 2004. **Wind Power: Renewable Energy for Home, Farm and Business**, Chelsea Green).

Humidity

Relative humidity is important for cooling design and comfort. RH within buildings is also important for considerations of condensation, mold and health. If RH meters are available building transects can be very informative, and RH related to showers, baths or cooking. Dew point determination with a glass or tin cup full of ice is an instructive exercise.

Dry bulb and wet bulb temperature data may be found at nearby weather stations. Key issues are the extremes - especially for cooling. Often this will be frequency of time above certain thresholds.

Humidity and evaporation data (Class A evaporation ponds) help with cooling estimates from cool pools and roof ponds, see pages 107 to 116 in the book. You can make your own evaporation pan using a galvanized bucket (http://cesonoma.ucdavis.edu/files/27260.pdf).

Radiation

Solar radiation measurements require a bigger equipment outlay but can be helpful where data is limited. Percent possible sunshine data may be reported nearby.

Precipitation

Rainfall is important for consideration of rainwater harvesting. Snow on the ground records help estimate the gain in reflection for south facing windows and passive systems.

A campus weather station

If your campus does not already have a weather station you might consider developing one. The innovative High Tech High School in San Diego included a weather station in the design. Here is a typical example of a higher level system:

Colorado State University

The weather station is located on campus just northwest of the Lory Student Center. Weather observations consist of automated measurements of temperature, humidity, wind speed and direction, pressure, solar radiation and soil temperatures updated every 10 minutes. There are also manual measurements taken every 12 hours of precipitation, snowfall, cloud and sky conditions, visibility, evaporation, winds, temperature, humidity, and other standard weather variables. The Fort Collins Weather Station is an historical part of the university. Data collection began near the site of the former "Old Main" in the 1870s.

Daily climate records are complete and available in a variety of digital and hardcopy forms since January 1, 1889 making this one of Colorado oldest weather stations and an incredible scientific resource.

A web cam can add more life to the weather station web page. CSU points theirs to the mountains. www.atmos.colostate.edu/webcam/index.php

Direct Connect Weather Station

http://www.weatherhawk.com/signature-series

Microweather stations can be set up for a relatively small investment and can be set to put measurements on line. These are available from many vendors. Students can then have access to local climate data for design challenges. Look for the nearest weather station as well, California has an excellent program called CIMIS (www.**cimis**.water.ca.gov).

Air flow in and around buildings and comfort

AIR MOVEMENT

A good exercise for a lab on air flow is the evaluation of an existing building (preferably more than one story). This can be done at low cost with a series of helium filled balloons - everyone in class brings one with a long ribbon tail and weight. These are arranged in hallways and rooms and tested with windows open, doors open or closed, transom windows open or closed, and HVAC on or off. Flow patterns can be mapped (see page 263-264). The direction of lean can be marked or photographed. Or the balloons can be set free and followed. A noisy but entertaining exercise (better on the weekend when the noise will not disrupt classrooms).

Air movement can also be followed with smoke or bubble, see page 264. Some types of incense make good smoke for air flow analysis.

Exterior air flow around buildings using bubbles can be very informative and fun. Try it on a windy day and calm day. Hot day, cool day.

Noise measurements for fans, ventilation systems, and ducts are also informative. Fan noise or vibration can be very irritating.

Excellent guide for more detailed analysis!

http://arch.ced.berkeley.edu/vitalsigns/res/downloads/rp/airflow/HEER1-BG.PDF

AIR MOVEMENT PLAYS A CRITICAL ROLE IN COMFORT -- IT CAN BE VERY HELPFUL TO ASK PEOPLE HOW COMFORTABLE THEY FEEL

Comfort questionnaires can be very simple - but still add useful information. Comfort problems are often air flow problems - either too cold with air flow in winter or too hot without air flow in summer. A survey can be very instructive (next page).

Comfort Satisfaction

Draft occupant survey	1	2	3	4	5
1 Temperature Comfort:					
Uncomfortable Comfortable					
2 How Cold it Gets:					
Uncomfortable Comfortable					
3 How Warm it Gets:					
Uncomfortable Comfortable					
4 Temperature Shifts:					
Too Frequent Comfortable					
5 Ventilation Comfort:					
Uncomfortable Comfortable					
6 Air Freshness:					
Stale Air Fresh Air					
7 Air Movement:					
Stagnant Air Good circulation					
8 Ability to open windows					
Inadequate Adequate					
9 Noise Distractions:					
Too Distracting Comfortable					
10 Background Noise Levels:					
Too Much Noise Comfortable					
11 Specific Noises (voices, equipment):					
Too Noisy Comfortable					
12 Noise from Ventilation Systems:					
Too Noisy Comfortable					
13 Noise from Lights:					
Buzzing Lights Comfortable					
14 Noise from Outside the Building:					
Too Noisy Comfortable					
15 Visual Privacy:					
Uncomfortable Comfortable					
16 Conversation Privacy:					
Uncomfortable Comfortable					
17 Telephone Privacy:					
Uncomfortable Comfortable					
18 Electric Lighting Comfort:					
Uncomfortable Comfortable					
19 Ability to control light level:					
Inadequate Adequate					
20 Glare from Lights:					
Uncomfortable No Glare					
21 Glare from Windows:					
Uncomfortable No Glare					
22 Access to Daylight:					
Inadequate Adequate					
23 OVERALL: WORKSPACE HELPS OR HINDERS					
Makes work more difficult -- easier					
24 HOW SATISFIED ARE YOU WITH PHYSICAL ENVIRONMENT?					
Dissatisfied Satisfied					
25 HOW DO YOU THINK THE BLDG AFFECTS YOUR HEALTH					
Worsens Improves					

adapted from NEW BUILDINGS INSTITUTE, INC. 2006

This might be offered on line using Survey Monkey
www.surveymonkey.com/

Passive solar building

ORIENTATION, ENERGY EFFICIENCY, THERMAL MASS, SOLAR GAIN

To drive home the importance of solar design (orientation, shape, window placement, insulation, thermal mass, solar control, evaporation) on building performance, students are divided into teams that design, build, and monitor a model solar home or building.

Materials – foil faced polyiso foam board or cardboard, acrylic sheet in various small sizes, plastic film, bubble pack, sheet rock screws

Tools – serrated knives, rulers, tapes, sharpies, declination chart, compasses
Equipment: student provided usb temp data logger, stem type thermometer

The assignment provides a week of design time – but students being students they often design on the spot. Students work at an outdoor lab where each team is given a 4x8 sheet of 1" foil faced foam insulation (doubled cardboard could also be used), small pieces of acrylic sheet, plastic film and bubble pack for windows, 2.5-3" sheet rock screws for assembly (these just push into the foam by hand and seal seams effectively), tape (either aluminum foil duct tape for more permanent models or masking tape for shorter. The foil tape finishes off the seams and tidies up the models so they can be monitored for weeks or months. Students can also be introduced to foam caulk of different expansion ratios (to experience the permanence of polyurethane on your hands!)

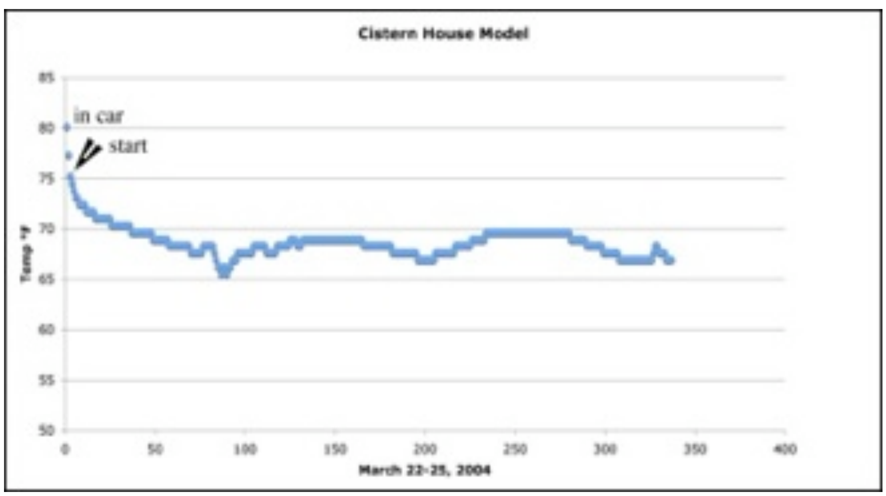
A lab session of 2-3 hours is usually sufficient to finish their houses. They then are encouraged to find **Solar South** (a lesson in magnetic declination), review the site for solar access, and orient the model. They provide an operable door to place at least one temperature data logger inside. The stem thermometer can be placed through the roof to provide a visible temperature comparison on site. More data loggers may be used to monitor thermal mass temperatures or to compare room orientation.

An outside air temperature monitor is used to provide baseline info for students and to compare with the nearest weather station.
The models are monitored for a week or two (depending on the weather) and then the data is downloaded and graphed by the students (Onset data loggers with Boxcar have worked well).

The teams then meet to discuss the results and develop a remodeling plan to improve performance. This is done in a second lab session.

The natural tendency is to add too many windows - and we always get some dramatic overheating in one or two models (the solar oven trap many designers fell into in the 1970s). They also learn that buildings can be dramatically improved with relatively simple changes.

Improvements are usually quite good as the lesson of over-glazing is learned and relearned every year. The house is then monitored for another week or two and then the students review the "lessons learned" and prepare a final report.



Although physical modeling at this size is very imperfect (not scalable as daylighting is) the exercise is very effective. Students enjoy designing and building a home and naming it. It provides a visible and reportable event for student papers and social media. With our large international student presence at AIU we usually had very multinational design teams – and that added to the fun. Students always learn a great deal from the solar models they build. They are much more knowledgeable after this very simple exercise than they are after a number of lectures, quizzes and videos. Hands on really helps!

ADDED LESSON: Orient house in antisolar direction (E/W/N) and monitor difference.
ALTERNATIVE LAB: This could also be a cooling lab test with radiant sky and evaporative cooling.

Thermal mass

Catch and store heat or coolth

Exposed stained and polished concrete floor

Thermal mass is an important component of most passive solar designs. It may be concentrated (a water wall) or dispersed (plastered straw bale or doubled or phase change wallboard). Getting a feel for the performance of different types of thermal mass is desirable. Thermal mass -- see page 59-67 and internet resources.

Students will study thermal mass performance.
Materials – plastic bags, concrete, masonry block, sand, brick, adobe block, stones, wood, water bottle, bees wax, etc.

Equipment – Scale to weigh mass. IR radiant thermometer, thermometers or recording thermometers. Sledge hammer and saw to cut wood or break plaster, blocks, bricks.

Thermal Mass Performance
Heat gained (or lost) = Mass * delta T * specific heat

Measure out equal amounts of water and other mass materials. Start with the least breakable material (stone or concrete) and match weights as closely as possible. Place mass in plastic bags in full sun (but out of wind). Record temperature every ten minutes, then bring to shaded area with uniform air temperature and record the fall in temperature every ten minutes.

Minutes	Temp TM1	Temp TM2	Temp TM3	Temp TM4	Temp TM5
Sun					
10					
20					
30					

Shade					
40					
50					
60					

Then calculate the temperature gains (0-30 minutes) and losses for the different materials (30-60 minutes).

Calculate the heat absorbed: Wt * deltaT * specific heat (either metric or standard)
Calculate the heat loss: Wt * deltaT * specific heat (either metric or standard)

Which material stored the most heat? Which lost heat fastest?

Specific Heat BTU lb °F	
Aluminum	0.21
Brick	0.20
Concrete	0.16
Sand	0.19
Glass	0.18
Gypsum	0.26
Potatoes	0.82
Steel	0.12
Wood, oak	0.57
Wood, pine	0.67
Water	1.00

Converting between Common Units 1 Btu/lb$_m$^{o}F = 4186.8 J/kg K = 1 kcal/kg^{o}C

Other advanced lab options:
Phase change materials are attractive for many thermal mass applications. These take advantage of the heat of fusion. Have the students build and test a phase change coffee cup using two aluminum or steel cans with paraffin or bee's wax in between them. What advantages would this have?

	Melting Point	Heat of Fusion
Cocoa butter	93°F	26 BTU lb
Paraffins	105-250°F	varies widely by type and mix
Bee's wax	145°F	76 BTU lb

Test wallboard with nano-wax also for thermal storage.

suggested by a lab exercise by the Florida Solar Energy Center see their materials at www.fsec.ucf.edu/en/education/k-12/curricula/sm1/index.htm