Passive Solar Architecture Pocket Reference

ISES

International Solar Energy Society

Editor of Series:

D. Yogi Goswami

Ken Haggard David Bainbridge Rachel Aljilani

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Preface

Passive Solar Architecture is solar energy and resource optimizations applied to our built environment. Therefore passive solar is a highly integrated endeavor affecting the design professions, architecture, city and regional planners, structural, mechanical and civil engineers, landscape architects and product designers. As such passive solar design is equal parts art, science and technology.

The amount of building in human society is prodigious and inevitable. Hence if passive solar applications can become a pervasive and rigorous part of these efforts we can have hugely beneficial effects on our looming problems of fossil fuel depletion and climate disruption as well as producing more comfortable and joyous buildings and surroundings.

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Third in a series of pocket reference books, the *Passive Solar Architecture Pocket Reference* adds to the publications provided by ISES enabling readers to make informed decisions, calculations or just become more knowledgeable in this important field.

Monica Oliphant
ISES President
(2008 - 2009)

Passive Solar Architecture Pocket Reference Book

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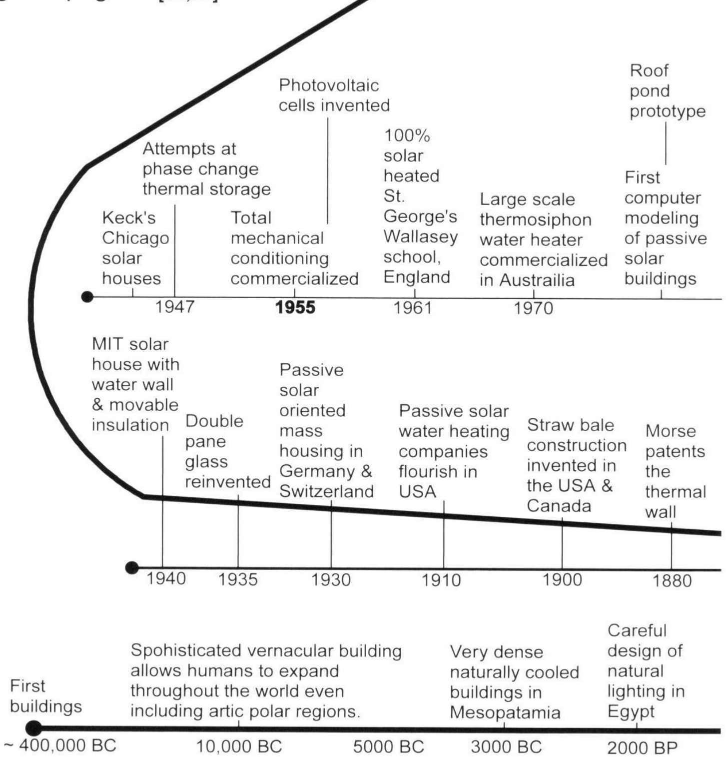
Contents

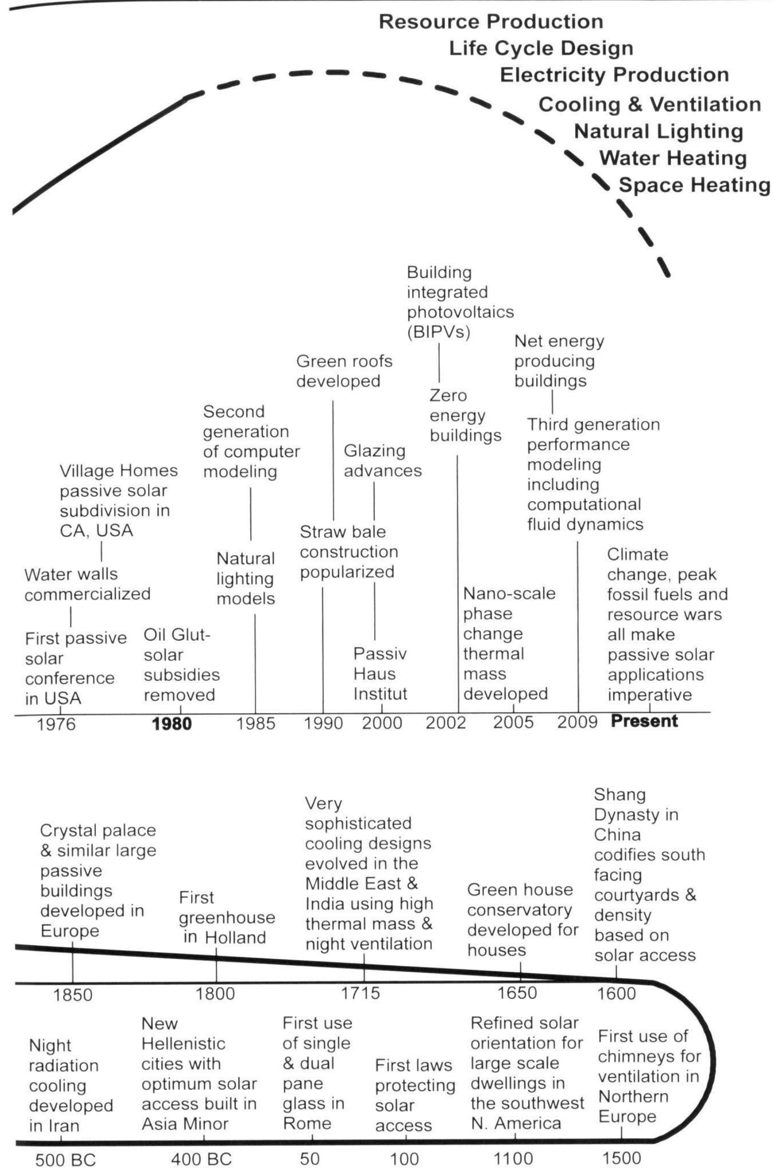
Passive Solar Architecture

Passive architecture has been part of architecture from the beginning. There have been historical periods of very sophisticated passive design followed by periods of neglect, but overall there has been a gradual evolution of our abilities to develop buildings that passively respond to the heating, cooling, lighting and ventilation needs of the occupants. This evolution has gained speed with the development of material technology, the rise in the cost of fossil fuels and the ability to model building performance.

The most recent evolution has been accompanied by an enlargement of the functions that passive buildings can accomplish, as shown on the upper right of page 2. [34,37]

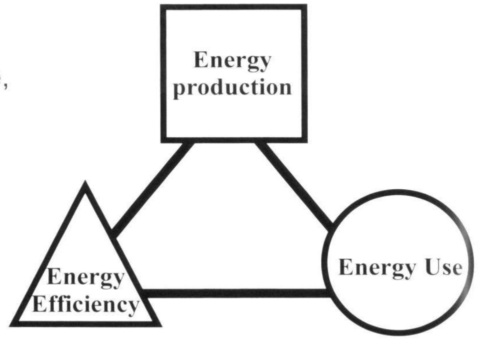


An Evolving Art - Technology



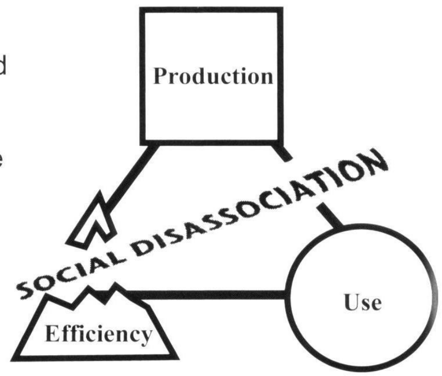
DEFINITIONS

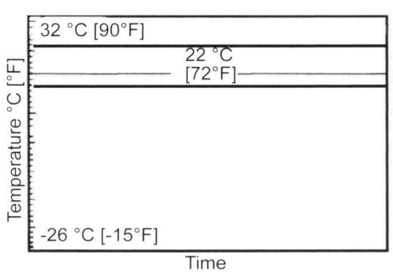
The elementary relationships between energy production, use, and efficiency are the first considerations in passive solar design.



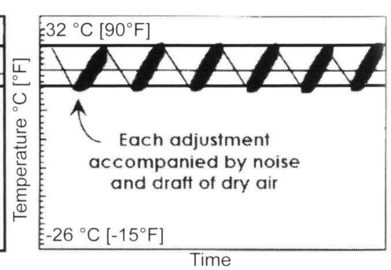
Efficiency, effective operation with a minimum of waste, must relate to both production and use for the whole to be efficient.

Our industrial society has so isolated production and use that very few people think about their use of energy. The result is while we've become more efficient with production we've become very wasteful with our use of energy, especially in buildings.





"Ideal" temperature balance in static theory.

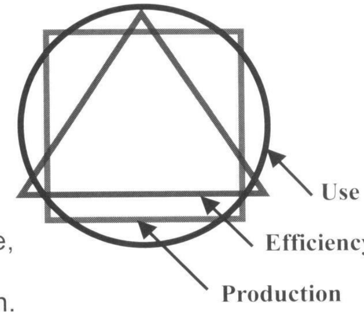


Reality for mechanical systems.

Passive design is the reuniting of production, use, and efficiency at the scale of individual buildings.

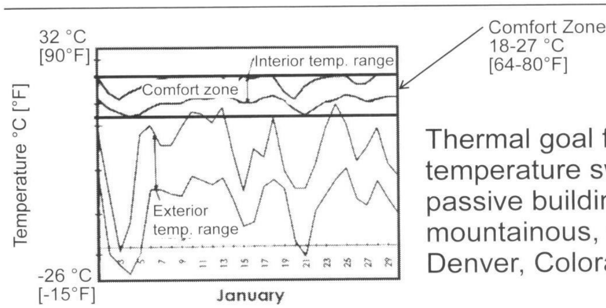
A Passive Building [36]

1. Uses on-site sources of energy.
2. Relies on natural energy flows with a minimum of moving parts.
3. Integrates production, use, and efficiency by the building's design and form.



Passive design is more than efficiency, since it also involves on-site energy production.

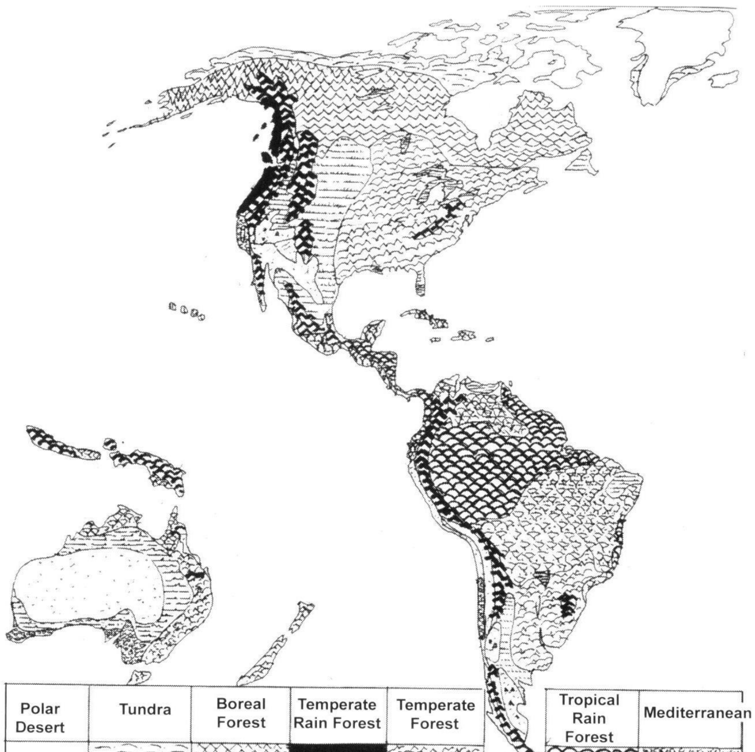
Another unique character of passive solar architecture is the goal in regard to interior air temperatures. Instead of attempting to maintain a steady ideal temperature, a passive goal is to keep the chaotic change in temperature limited to a comfort zone defined by the biome of the site.



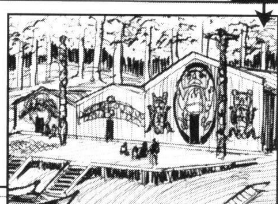
Thermal goal for interior temperature swings for a passive building in a mountainous, cold biome; Denver, Colorado, USA [5]

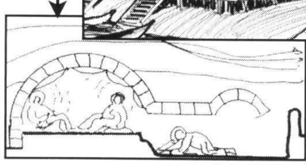
SECTION 1: LOAD DETERMINANTS &

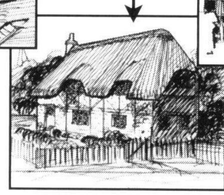
Passive solar architecture is also about reconnecting buildings to the uniqueness of place and climate. By doing this, we can build a better environment and reduce the cost and impacts of energy and resources used.

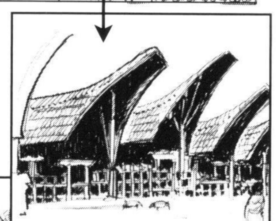


Polar Desert	Tundra	Boreal Forest	Temperate Rain Forest	Temperate Forest	Tropical Rain Forest	Mediterranean



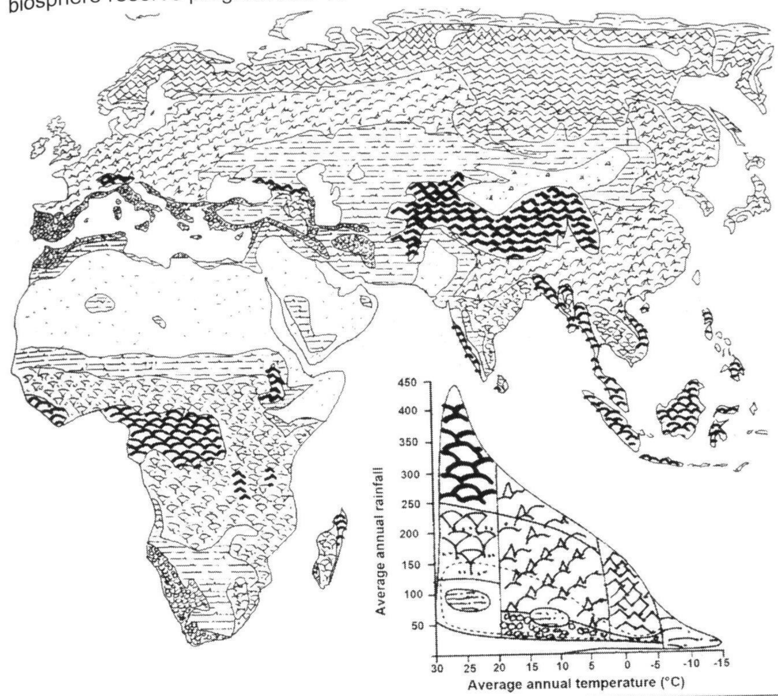




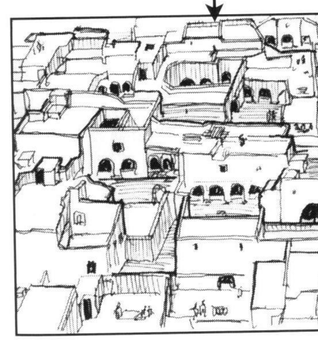


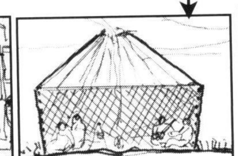
RESPONSES: Worldwide Biomes & Climate

One useful tool is the context of biomes. A biome is an ecological community of plants and animals extending over a large natural area. Worldwide biomes repeat over different continents due to similar environmental patterns. The UN biosphere reserve program lists 15 different biomes as illustrated here. [33,49]

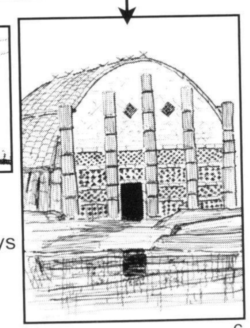


Mountains	Cold Desert	Hot Desert	Tropical Savannah	Temperate Savannah	Grasslands	Lakes & Marshes	Mixed Island System

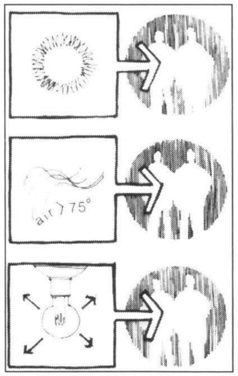




Vernacular architecture is always expressive of the biome in which it is constructed.



Thermal Sources [70]

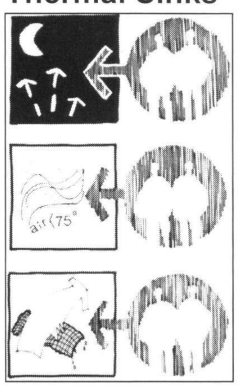


Solar Radiation
Solar radiation acts as a heat source for a building through direct, diffuse and reflected radiation. Diffuse radiation is the component of sunlight which reaches the ground after scattering and reflection by the earth's atmosphere.

Outside Air
Outside air when it is warmer than about 24°C [75°F] can act as a heat source for most buildings.

Internal Metabolism
People, appliances, lights and cooking all add heat to the interior of a building and could be considered on-site heat sources.

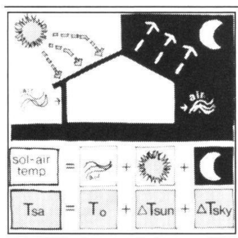
Thermal Sinks



Sky & Space
Some heat is always radiated from a building out to the sky. Under certain circumstances the upper atmosphere and space can act as an appreciable heat sink.

Outside Air
Outside air that is cooler than about 24°C [75 °F] can act as a heat sink. This is typically the case where nights are cool.

Wet Surfaces
Wet surfaces provide on-site sinks because heat is absorbed when water evaporates.

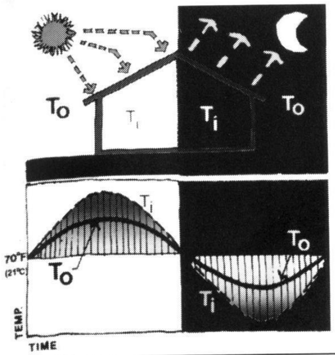


Sol-Air Temperature (T_{sa})
The sol-air temperature is a fictitious, exterior air temperature, which would have the same effect on the building as the combined affects of the on-site sources and sinks which are acting on the building.

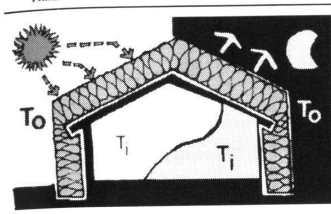
The difference between the sol-air temperature and the actual air temperature depends on many factors, including the strength of the solar radiation reaching the surface, the dew point of the air and the amount of wind. Other factors affecting sol-air temperature are related to the surface of the building, such as materials, colors and the ability of the surface of the building to radiate heat, particularly to the sky.

On a clear day in mid latitudes, the sol-air temperature range can be -1-49°C [30-120°F] while the actual air temperature range is 4-32°C [40-90°F].

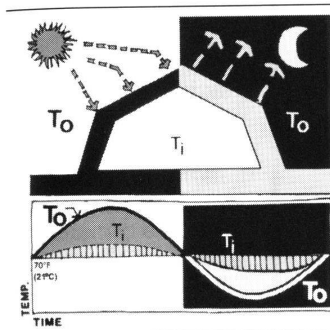
Passive Responses to Sources & Sinks [70]



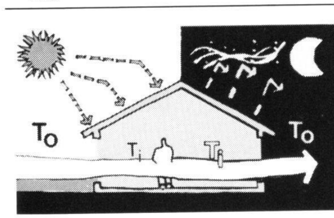
A light weight building or tin box with no insulation is the worst building method for climates with hot days and cold nights. During the day, the walls, roof and interior air temperature become greater than the outdoors, so it is hotter inside than outside. During the night, the walls, roof and interior air temperature fall below that of the outside air, making it colder inside than outside.



Well insulated lightweight construction, like a thermos bottle, reduces the heat gain and loss. This type of building can make our energy use more efficient, but will not optimize the interior environment. Heat gain and loss through windows and interior gains are not affected by the well insulated envelope. The interior will be too cold or too hot sometimes.



A heavy mass building will dampen the sol-air and actual temperature swings inside the building. The thermal mass in the structure will absorb heat during the day and release it at night to warm the interior space. In an extreme mass building like an Egyptian pyramid, the interior temperature remains almost constant. For this reason, heavy mass buildings are indigenous to climates with an average sol-air temperature of 21°C [70°F].

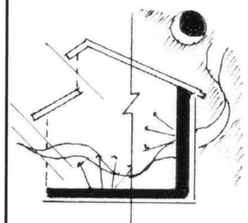
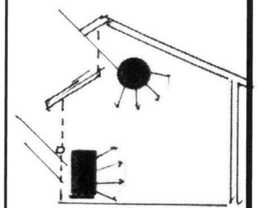
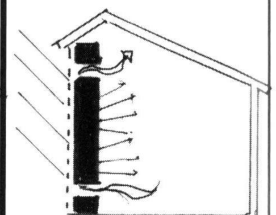
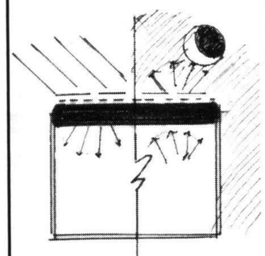
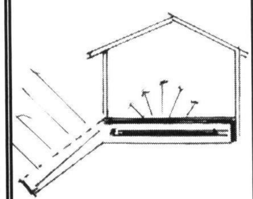
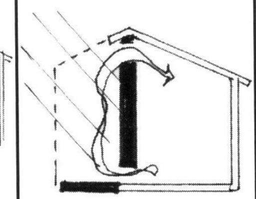


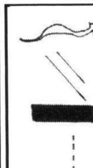
High mass buildings are not appropriate for all situations. In hot humid climates, the heat sink of the night sky is removed by the water vapor of the surrounding air, so the high sol-air temperature stays relatively constant. The only passive cooling mechanism available is evaporation from a wet surface in this case. The appropriate building form is a building with a well designed roof for maximum shade and no walls at all to allow optimal air passage.

Classic Passive Systems [46,68,70,74,81]

Six very basic approaches to passive heating were evolved for residential scale buildings in the 1980's.

They have become the "classic" approaches and form the basis of today's effort. High performance buildings that seek to be net energy producers often integrate several of these approaches. [69,71,72,75,76,83]

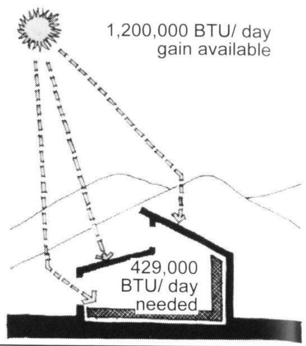
Direct Systems		Indirect Systems		Isolated Systems	
#1	#2	#3	#4	#5	#6
DIRECT GAIN/ DISTRIBUTED MASS	DIRECT GAIN/ CONCENTRATED MASS	THERMAL WALLS	ROOF PONDS	THERMOSIPHON	SUN ROOM
					
Good for balanced heating and cooling.	Good for a heating load dominated condition.	Good for a heating dominated condition.	Good for balanced heating and cooling condition, superior cooling application.	Good for a heating dominated condition.	Good for very cold conditions and areas with short growing seasons.
Quick morning response. + Views not blocked. + Best response to night vent cooling. - Movable window insulation will enhance the system. - Must take care to avoid glare and fading of furnishings.	Quick morning response. + Views not blocked. + More storage capacity than #1. - More expensive thermal mass.	Can enhance morning response by venting as shown, unvented wall is cheaper and just as good in some climates. - Loss of views to equator. - Limited radiation response to 8 m [25 ft.].	Large radiative transfer area gives superior comfort. + Potentially free from equator orientation. + Frees up wall areas and views. - Requires large movable insulation system over the ponds. - Difficult to construct without industrial production of components.	Frees up walls for other purposes. - Requires a sloping site toward equator or lower floor to mount air collector. - Limited amount of mass.	Can use attached space for plants, views and usable space. - Interior is mostly convectively coupled, so less controllable than radiant systems 1-5.



Heating & Cooling Potential [67,70]

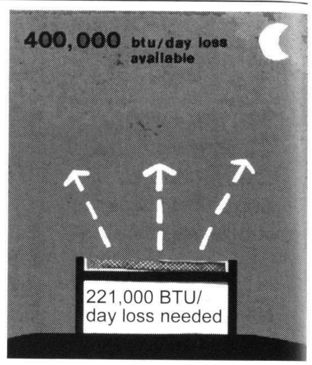
Heating Potential (cold mountain climate)

Harvesting heat on-site requires understanding your heat sources and needs. In the example to the right, 5243 W [429,000 BTU/day] are needed to bring the indoor air temperature into the comfort range. At the same time, 14640 W [1,200,000 BTU/day] of heat gain fall onto the structure.



Cooling Potential (hot, dry desert climate)

On-site cooling is possible using the diurnal temperature swing in a hot climate that cools down at night. In the example to the right, the day time heat gains require a reduction of 2697 W [221,000 BTU/day]. During the night, 4881 W [400,000 BTU/day] can be radiated to the night sky using a roof of thermally massive material such as water or phase change salts. [64,84,85,86,88,92]



Cooling Potential (hot, wet tropic climate)

This passively cooled housing at the Panama Canal has had excellent comfort since 1916 by utilizing the following:

- raised building to increase breezes
- allowing maximum cross ventilation 24 hours per day
- optimizing shading and color
- segregating heat producing functions like kitchen and bathrooms
- providing ceiling fans in each room
- utilizing a large well vented attic

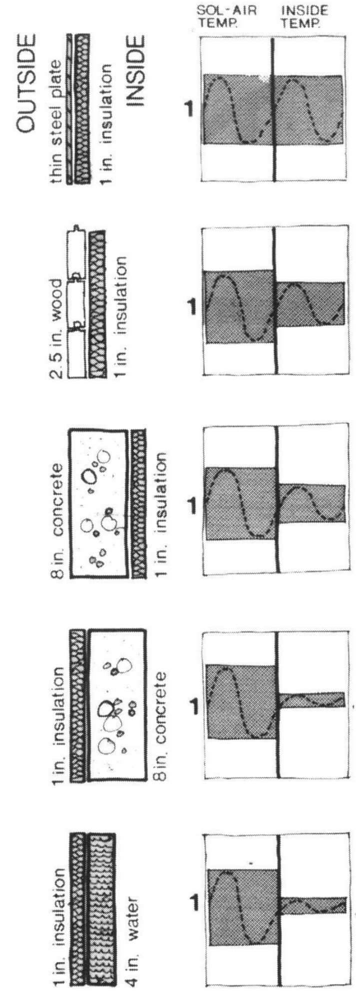
Optimizing Thermal Mass & Insulation [66,70]

Heavy walls must have two qualities to dampen diurnal changes in the exterior environment to keep the interior temperature relatively constant: heat capacity, the ability to store heat and the ability to resist or insulate against heat flow.

The most effective way to maximize the two qualities, heat capacity and insulation, in a building is to use two separate materials. One material should have a low heat capacity and high resistance to heat flow while the second material has a high heat capacity and low resistance to heat flow. Placing the insulating material near the external environment, less heat transfers into and out of the building. Heat that does enter or is generated in the building will not change the temperature of the interior rapidly since the material with high heat capacity will slowly be absorbing or storing the heat.

The building's mass dampens the temperature fluctuation. An adobe or concrete structure with insulation on the exterior can take advantage of these material properties for passive heating & cooling.

Externally insulated water walls are ideal for two reasons: water has over twice the heat capacity of concrete by volume and heat flow through water is more rapid since fluid can transfer heat by internal convection currents. Externally insulated mass construction is common in most passive designs except those that use isolated heat storage arrangements such as a rock bed thermosiphon system. [65]

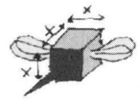


Keeping the well-insulated, thermally massive building tuned to the season is the key to year round comfort. Tuning the building to utilize the appropriate on-site thermal sinks or sources at the appropriate time is not difficult. A classic example is the equator facing window with an overhang that allows low winter sun in and shades out the sun in the summer when it is high. Tuning in this case involves proper sizing of the window to allow enough heat gain during the winter, proper overhang placement for summer sun control, and sufficient thermal mass for storing and distributing the sun's heat.

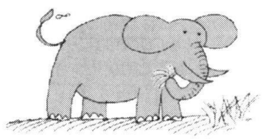
Building Metabolism & Response

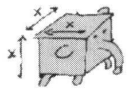
Cube Area (A) = X x X x 6 = x^2 x 6

Cube Volume (V) = X x X x X = x^3



Assume x = 1
A = 1 x 1 x 6 = 6
V = 1 x 1 x 1 = 1
Cubic Area/Volume ratio = 6/1 = 6





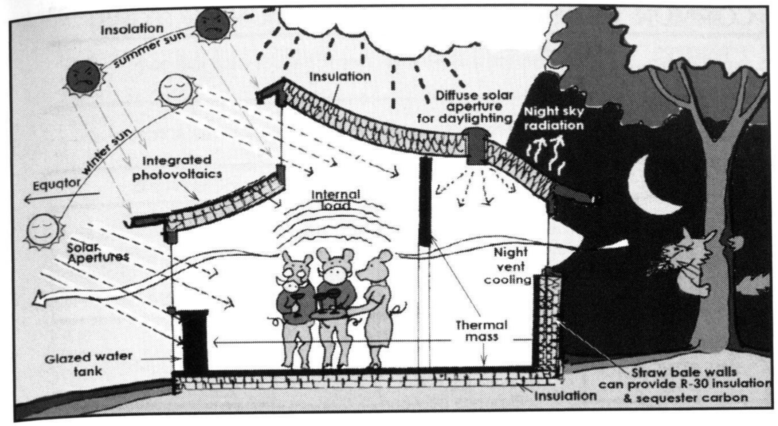
Assume x = 300
A = 300 x 300 x 6 = 540,000
V = 300 x 300 x 300 = 27,000,000

Cubic Area/Volume ratio = 540,000/27,000,000 = 0.02

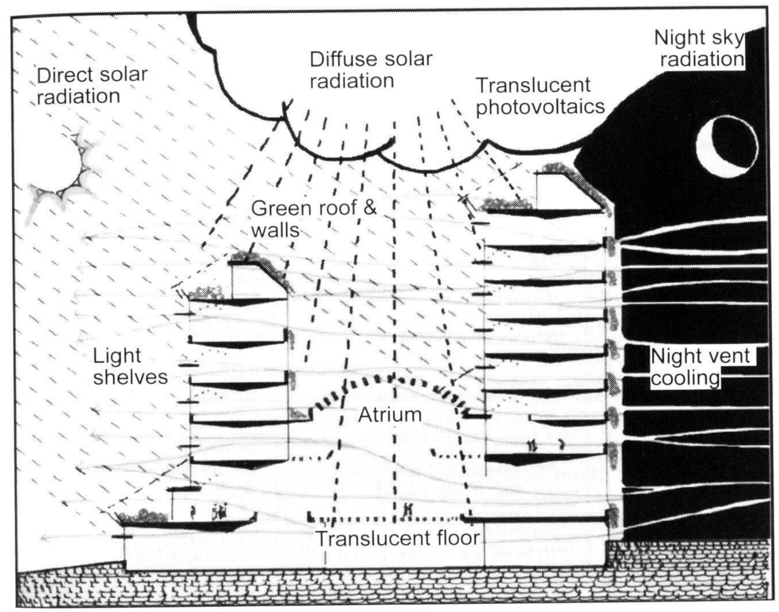
Hummingbirds and elephants are far different creatures in regard to their metabolism and food intake because the difference in their ratio of skin to internal volume.

The metabolism of buildings is similar and will vary depending on occupancy use and size.[22]

"Skin"-Dominated Building		Internal Load-Dominated Building
Residences, small office buildings, small schools	**Example**	Large office buildings & schools, commercial facility & assembly spaces
Spread out	**Form**	Compact
Low	**Surface to volume ratio**	High
2-3	**Exterior walls per room**	0-1
15.6 °C [60 °F]	**Balance point temperature**	10 °C [50 °F]
Yes, except for very hot climate	**Use of passive heating**	No, except for very cold climates
Yes, except for very cold climates	**Use of passive cooling**	Yes
Easy	**Daylighting**	More difficult



The metabolic differences between large and small buildings make their passive solar components quite different.



COMMON TERMS, UNITS & CONVERSION FACTORS

1. PASSIVE ARCHITECTURE	Term most commonly used in the USA and Germany	
2. SOLAR ARCHITECTURE	Term most commonly used in most of Europe and Asia	
TERM	**DESCRIBES**	**UNITS**
3. INSOLATION	The solar radiation on site usually measured as energy falling on a horizontal surface in energy per area per unit of time.	[SI] MJ/m^2 day [SI] Kwh/ m^2 day [US] BTU/ft^2 hour
4. DEGREE DAYS (HEATING)	Thermal needs on site for comfort most often measured as the difference between average daily temperature and a base temperature of 18°C [65°F] or 23°C [74°F]	HDD 18°C [65°F]
5. DEGREE DAYS (COOLING)		CDD 18°C [65°F] CDD 23°C [74°F]
6. SOL-AIR TEMPERATURE	A fictitious temperature that expresses the combined effect of the site's thermal sources and sinks on a building.	[SI] °C [US] °F
7. INSULATION	Resistance to heat flow by various building materials, the inverse of heat flow. R = 1/U	[SI] m^2 °C/ W [US] ft^2 hour °F/ BTU
8. BUILDING'S HEAT GAIN/ LOSS COEFFICIENT	Conductive thermal loss or gain by the buildings envelope $Q = \Sigma UA\Delta T$ for each component of the weather skin.	[SI] W/ Δ°C [US] BTU/ hour Δ°F
9. AIR INFILTRATION	Amount of air leakage through the weather skin of the building.	Air changes/ hour (ACH)
10. THERMAL MASS	Materials of high heat capacity in the interior of the building. Measured in specific heat, C $C = Q/ (weight)(\Delta T)$	[SI] kJ/ kg ΔT °C [US] BTU/ lb ΔT °F
11. BUILDING TIME CONSTANT	The characteristic time at which the building's thermal charge will change as it exponentially approaches ambient conditions. $\tau = c/u$	Essentially, a measure of the combined effects of mass and insulation expressed in hours.

PARTICULAR TO PASSIVE SOLAR ARCHITECTURE

Emphasizes the process of using architectural elements to perform thermal functions.	Advantages: more descriptive of the evolution into other resource issues (water, waste, etc.) see pages 71-80.
Description of the primary energy source by the building which can be both active and passive.	Advantages: does not imply an artificial separation between passive and active solar applications used in the building.
RANGE	**CONVERSION**
0.65 MJ/ m^{2}day (December- Reykjavic, Iceland) 30 MJ/ m^2*day (June- Phoenix, Arizona)	1 MJ/ m^2 = 0.72 BTU/ ft^2 = 0.0028 kwh/ m^2 1 kwh/ ft^2 = 0.357 MJ/ m^2 = 322 BTU/ ft^2 1 BTU/ ft^2 = 0.0031 kwh/ m^2 = 1.35 MJ/ m^2
HDD 29 DD/yr (52 DD/yr US) Key West, Florida, USA HDD 8542 DD/yr (15376 DD/yr US) Resolute Bay, Canada	DD [SI] = 0.555 DD [US] DD [US] = 1.8 DD [SI]
CDD 0 DD/yr (0 DD/yr US) Eureka, California, USA CDD 5409 DD/yr (9736 DD/yr US) Death Valley, California, USA	
Sol-air temperature is usually lower by 6°C [11°F] at night and can be higher by 17°C [30°F] during the day.	
Wood Sheathing 0.176 [1 US] Standard Construction 3.7 [21 US] Well Insulated Residence 7 [40 US] Super insulation 17.6 [100 US]	R [SI] = .176 R [US] R [US] = 5.68 R [SI]
	[W/ m^2°C] * 0.176 = BTU/ hour * ft^2 °F [BTU/ hour * ft^2 °F] * 5.678 = W/ m^2 °C
Standard residence USA 1.0 Good passive residence 0.5 Very tight construction such as in Northern Europe 0.2	For health purposes, buildings with an air change of less than 0.35 per hour should employ some method of supplementary ventilation like an air to air heat exchanger as used in the German Passiv Haus approach.
Masonry: 1.045 KJ/ kg°C [0.25 BTU/ lb.°F] Water: 4.18 KJ/ kg°C [1 BTU/ lb.°F] Phase Change: 10.45 KJ/ kg°C [2.5 BTU/ lb.°F]	KJ/ kg °C = 0.24 BTU/ lb. °F BTU / lb. °F = 4.18 KJ/ kg °C
Gypsum wall shell 0.5 hour Passive Building 12 hours Good passive building 24 hours Super passive building 80 hours	

SECTION 2: CONTEXTUAL ASPECTS

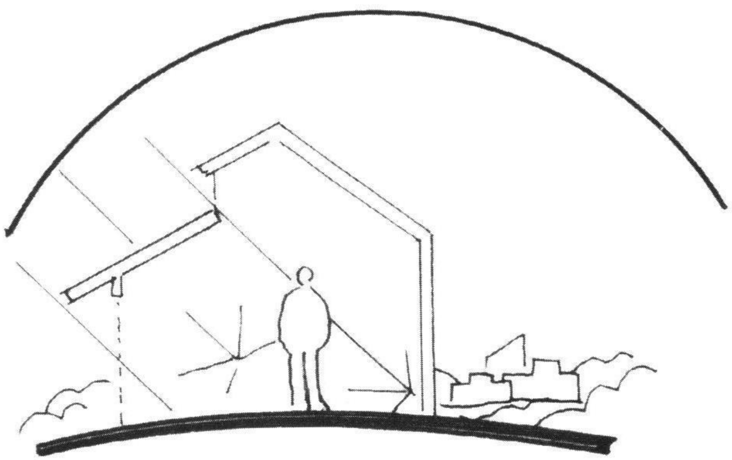
MEAN RADIANT TEMPERATURE

(MRT): The combined effects of surface temperatures and angles of exposure at one point in space

EFFECT OF CLOTHING

(CLO): The measurement of the thermal resistance of clothing from the skin to the outer layer of clothing ranging from 0 to 5:

1 CLO = 0.155 $m^{2/v}$ $_{2°F}$



Passive solar architecture is a symbiotic response to the context in which it occurs. Although the following pages look at different aspects, the relation to each other and the building as a whole is equally as important as specific data.

Micro-Climate [94]

One of the tenets of modern design was that with industrial progress, architecture could be freed of the constraints of the site. Passive solar design reverses that assumption, proclaiming that the site is a major design consideration not only compositionally, but in regard to thermal sources and sinks the site offers to serve the building's energy needs. [2]

The unique characteristics of site can be expressed in the concept of micro-climate. While it is generally recognized that steep coastal mountains and island biomes can have great micro-climatic variations, great variation can also exist elsewhere. The classic study of micro-climate done in the Neotoma Valley, Ohio, USA, using 109 weather stations in a 0.65 km^2 area illustrates how even in mid-continent, micro-climates can greatly vary. [1]

Difference in highest temperature ---------	21 °C [38°F]
Difference in Jan lowest temperature-----	22° C [40°F]
Difference in the time of the last spring frost---	73 days
Difference in the time of the first fall frost--------	64 days
Difference in the number of frost free days-----	152 days

Solar radiation in and night sky radiation out are the most important determinants of micro-climate. These are effected by the sun's path, the topography, the landscape and type of land cover. It is the interaction of site elements and climatic elements that determine specific micro-climates.

Site	Climate
Soil type	solar and night sky radiation rule of thumb: Every 10 degrees the site slopes north equals a move of 10 degrees latitude north. Every 10 degrees the site slopes south equals a move south by 10 degrees latitude.
Ground surface	air temperature
Topography	temperature, wind, humidity, cold air drainage
Vegetation	precipitation, air flow, humidity, temperature
Water body	air motion and temperature, reflected sun, evaporative cooling
Human activity	urban heat island

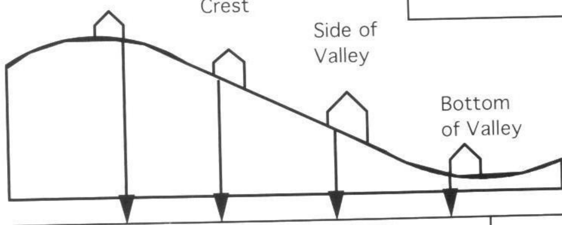
Urbanization can reduce heating load by 10 DD,increase winter temperatures by 1-2°C,decrease annual solar radiation by 15-20%, increase precipitation by 5-10% and cloud cover by 5-10 (mechanical air conditioning is a major player in the urban heat island effect). [4]

Hour by hour data is needed for the simulation models described on pages 53-54. Digital monitoring devices have made it easy to collect micro-climate data directly at the site. [95] This allows weather tapes from distant locations to be checked and adjusted.

Climate data is available from a wide range of sites see:
Http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm
For USA http://www.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html.

Site Selection

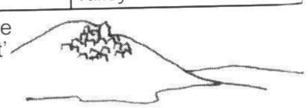
The choice of building site should take into account micro-climate and other specific site characteristics. Shown below are many of these site aspects for choosing a site for residential scale construction.



+ advantage
- disadvantage
o depends on specifics

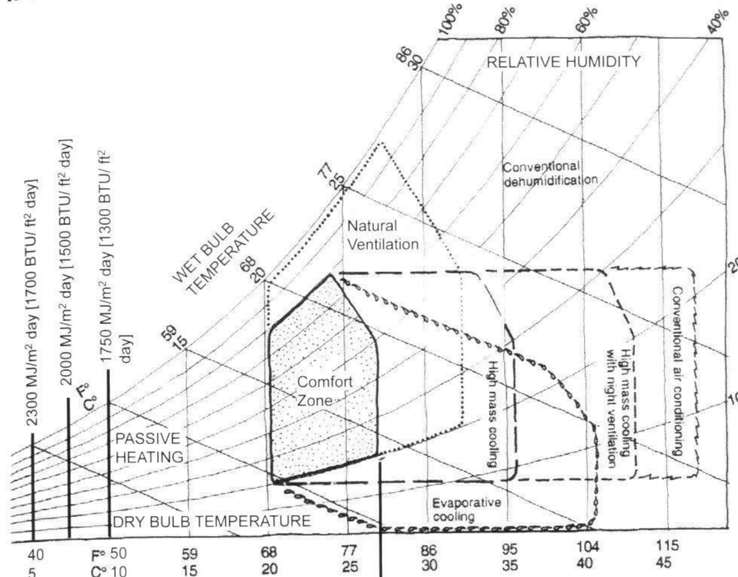
	Top of Hill	Military Crest	Side of Valley	Bottom of Valley	Notes:
View from	+	+	o	-	
View to	-	+	+	+	Protecting public viewsheds is a site selection consideration.
Solar Access	+	+	+	-	Valley floors can often be shaded in the winter.
Wind	-	+	o	+	Wind speeds can be 2.5 times greater at ridge tops increasing air infiltration.
Air Drainage	+	+	o	-	Pooling of cold air at night can increase heating loads.
Noise	-	o	o	+	Noise is like views, if you can see it, you can hear it.
Fire	-	o	o	~	With global warming, wild fires will increase. Fire storms are most intense at hill tops.
Earthquake Damage	-	o	o	-	Earthquake damage is usualy greatest at ridge tops & saturated soils.
Ease of Construction	-	o	o	-	Access can be harder at hill tops. Water table problems greater in valley bottoms.

Historic hill-towns of Southern Europe illustrate the many advantages of using a 'military crest' building site.

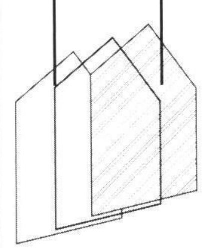


Comfort Parameters & Passive Strategies [3,5,7,8,9,10,11,46]

Psychrometrics chart allows the plotting of specific climatic data in relation to standard comfort zone and appropriate passive design strategies.



CLO Value	Attire
0.3	shorts, short sleeve shirt, sandals
0.5	long pants, open neck shirt
1.0	typical business suit
1.5	heavy suit, vest
2.0	Chinese winter wear

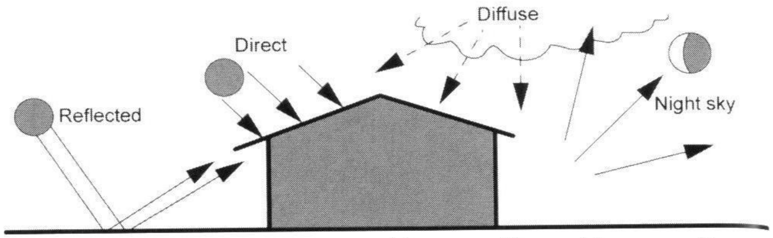


The zone of passive applications can be further enlarged by shifting the comfort zone in three ways:

1. Decreasing the difference between mean radiant temperature (MRT) and body temperature (see page 22 & 23), a difference of 3° in MRT can shift the comfort zone 2° degrees.
2. Adjusting the time of day use-patterns, such as a siesta, as is done in many places nearer the equator.
3. Adjusting the attire and CLO value.

Recent research has shown how strongly comfort is influenced by mean radiant temperatures and expectations.

Radiation Effects on a Building [93]

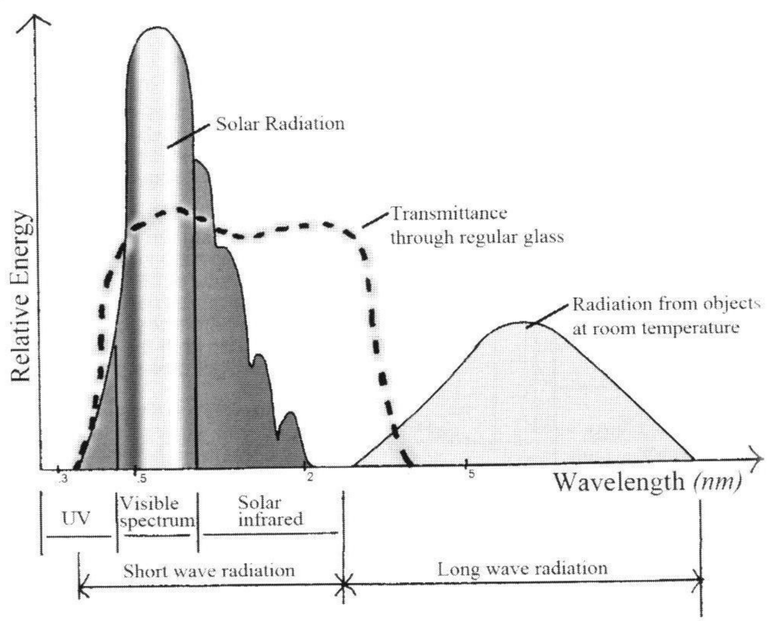


In areas of strong sun & high cooling loads, **reflected** radiation (mostly from the ground) can be an important aspect of heat gain in the cooling season. Reflected radiation can be utilized for heating when snow conditions exist.

Direct solar radiation has the spectral characteristics shown below. Recent advances in glazing have given us the ability to be selective in regard to the short wave spectrum.

In areas of low direct sun strength and dominant overcast skies, **diffuse** radiation reflected from the sky and clouds can be major components of the radiation a building receives.

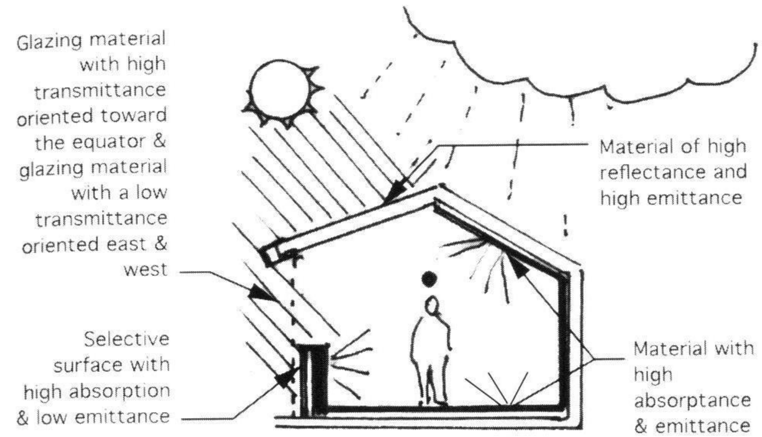
In areas with clear **night sky** and low humidity, night sky radiation can be up to one third of daily direct insolation and a substantial cooling resource.

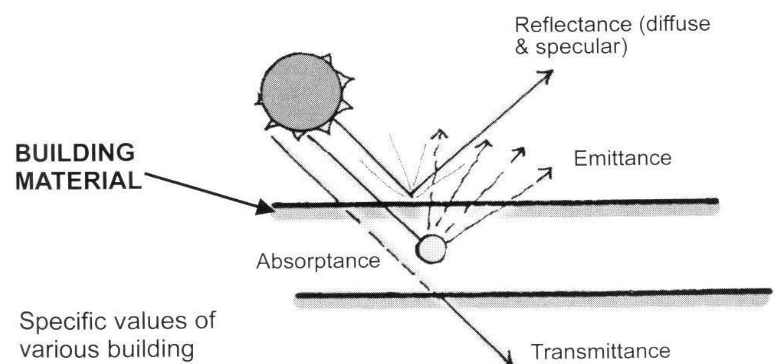


Radiation Effects in a Building

Equally important is how a passive solar building transfers energy internally, one unique characteristic is that heat is transfered by radiation rather than convection using hot or cool air. This means the mean radiant temperature and the interior surfaces of the building are similar. The result is a greater feeling of comfort and well being.

SHOWN FOR A TEMPERATE CLIMATE



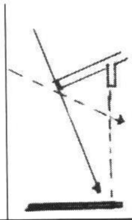
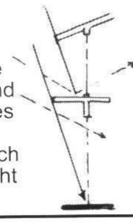
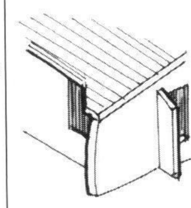
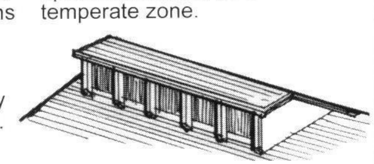


Specific values of various building materials are listed on pages 23.

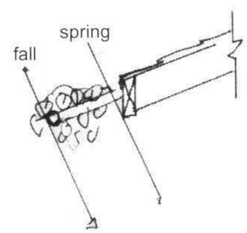
Radiative Properties of Building Materials [46,70,89,90,91]

Material	Reflectivity – Diffuse unless marked [S] for specular	Absorption	Emissivity @ 10-39°C [50-102°F]	Notes:
ENVIRONMENTAL				
Meadow	1.2 - 3.0			For materials of high transmissivity see pages 33-34.
Soil	0.80 - 3.0			
Lass	0.10 - 0.35			
Sand	0.2 (dry) 0.6 (wet) [S]			
Fresh snow	0.75 - 0.98			
BUILDING EXTERIOR				
Asphalt	0.10 - 0.30	0.72 – 0.82		
Gravel	0.25 - 0.30	0.70 – 0.75		
Concrete	0.25 (rough) 0.64 (smooth)	0.60		
Concrete block	0.40 (gray) 0.20 (dark)	0.60		
Stucco	0.80 (white) 0.60 (light color) 0.30 (dark)			
Brick	0.45 (red) 0.25 (dark)			
Cool roof	0.70		.75 - .91	
Polished aluminum	0.85 [S]			
Galvanized metal	0.60	0.40	0.28	Although base metal roofs appear reflective, they are not good in cooling situations due to their low emissivity.
Galvanized metal (painted)	0.77	0.23	0.90	Selective surfaces that collect energy efficiently yet emit little back are useful in concentrated thermal mass applications, see page 34.
Paints				
White	0.60 – 0.77	0.20		
Flat black	0.10 – 0.90	0.96		
Aluminum paint	0.60	0.30-0.40		
Selective surface black		0.92	0.45	
Nickel oxide on metal film		0.95	0.08	
BUILDING INTERIOR				
Plaster- white		0.08		
Smooth concrete painted white	0.80			
Wood paneling	0.64			
Glazed tile	0.50 (light) - 0.25 (med) - 0.10 (dark)			
Carpet	0.45 (light) - 0.25 (dark)			
Stainless steel	0.60 [S]			
Aluminized glass	0.74 [S]			

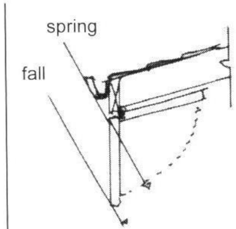
Control of Radiation [70]

		Shading Factor:
1. Horizontal or sloping overhangs facing the equator	 These devices take advantage of the difference between the altitudes of summer and winter sun. High spaces may require two overhangs, one of which can also serve as a light shelf, see page 67. 	0.25
2. Wing walls	 When sun angles are very low in the morning and evening, an equator facing wall or east and west walls can utilize wing walls as they provide better control than horizontal overhangs.	0.30
3. Winglets	Small wing walls at the scale of fins between windows can help block early & late sun. Combining 1 & 3 to create an optimized dormer for a temperate zone. 	0.15

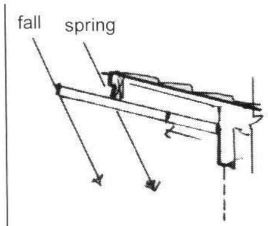
This type of control is very straight forward for the seasonal extremes, but becomes more complex in spring and fall. This is because the thermal mass of the earth tilts the seasons while the sun angles are the same; early spring is usually a heating season and early fall is usually a cooling season. This seasonal variation is likely to become less predictable with changes in weather patterns, so the trend should be an increase in the demand for adjustable solar control devices for overhangs and intermittent use of shade cloths.



Steel Fascia Extension With Deciduous Vine



Fascia Extension Flap



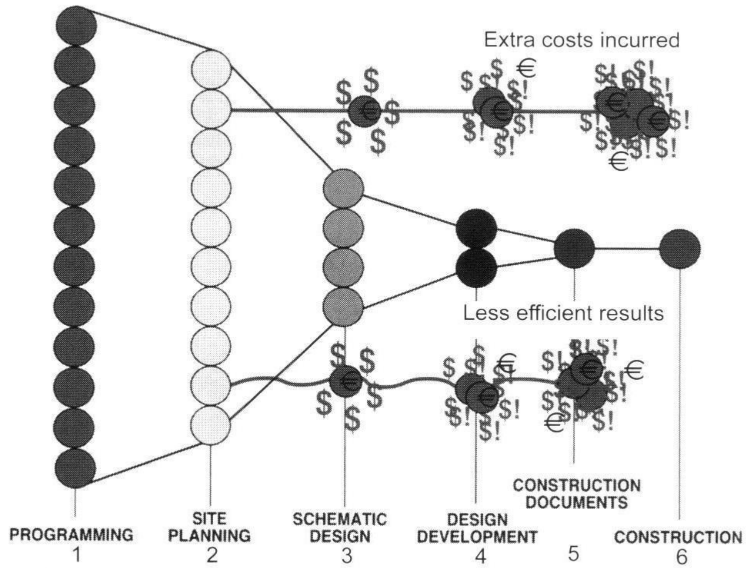
Sliding Fascia Extender

For calculation process, see page 47.

Programming

Passive considerations need to be part of each phase of work starting with programming. Leaving passive considerations out of the early phases of work, and attempting to graft them on later as illustrated below, results in less cost effective integration. Trying to add passive solar and sustainability elements at the end of a project's design or during construction often hinders success.

Passive Solar Considerations & Relative Cost ($, €) per Design Phase



The myth that passive solar buildings cost more to build has been fueled by this lack of commitment to passive strategies throughout the design and construction process. In reality, passive solar buildings can be similar in cost to conventional buildings and often less because they often reduce the need for expensive mechanical systems which can often be ⅓ the cost of a building. Reducing mechanical systems to the status of back-up systems saves in up-front capital costs as well as operating costs.

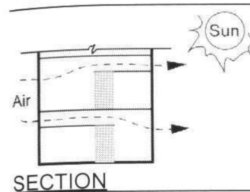
The importance of the programming phase of work as a prerequisite to the later phases cannot be overestimated as it greatly affects each successive decision as illustrated on the following page.

Planning for Passive Solar Architecture

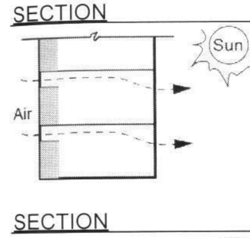
The following example is for multi-story moderate-to-high density housing. It illustrates the relationship between programming and planning for passive solar architecture.

In many locations solar access and night ventilation with some thermal mass can provide most of the heating, cooling and day-lighting needs of this building type because the heat gain/loss coefficient is small for compact units of this nature.

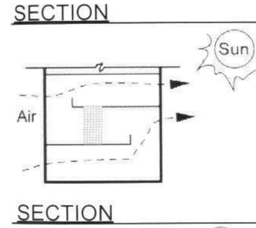
To be equitable and effective, all units need direct solar access and night ventilation capability while maintaining acoustical privacy. Unless this is part of the program statement however, the double loaded corridor circulation decision is likely because it is assumed to be simple and inexpensive. Unfortunately, it also negates equitable and efficient passive conditioning.



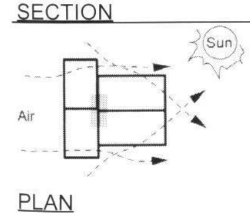
To remedy this situation this corridor design would require a good sized plenum over the corridor and half of each unit to allow cross ventilation. However, this still does not resolve the inequity that only half the units have good solar access.



Another approach, not likely to be considered without a good passive programmatic statement, is a single loaded corridor. This allows secure natural ventilation at night and gives all the units solar access.



A third approach is the skip level system of circulation pioneered by Le Corbusier in his Radiant Cities concept. This would require less corridor than the two previous approaches, but complicates the unit layout as well as universal accessibility.



Another approach that would fulfill the passive solar program goal would be clustered units around a vertical circulation element.

Corridor

Cultural Context [37]

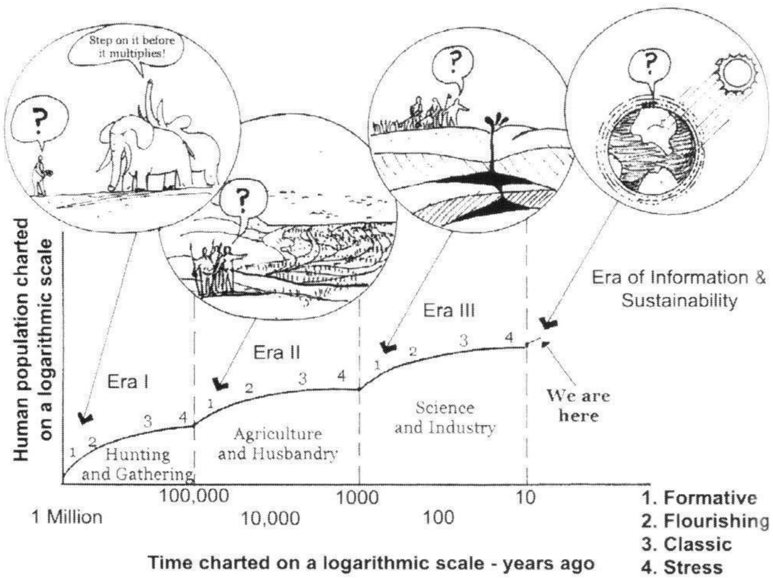
A demographic look at the history of world population growth reveals patterns that repeat though three successive cultural eras.

Each era has a different resource and energy basis described by their names.

These patterns also reveal three different times of stress, the third of which we are in at the moment. We are also in the process of evolving a new cultural era based on information and sustainability.

Continuity and sustaining human society depends on making this transition.

Passive solar architecture is a key part of this transition.

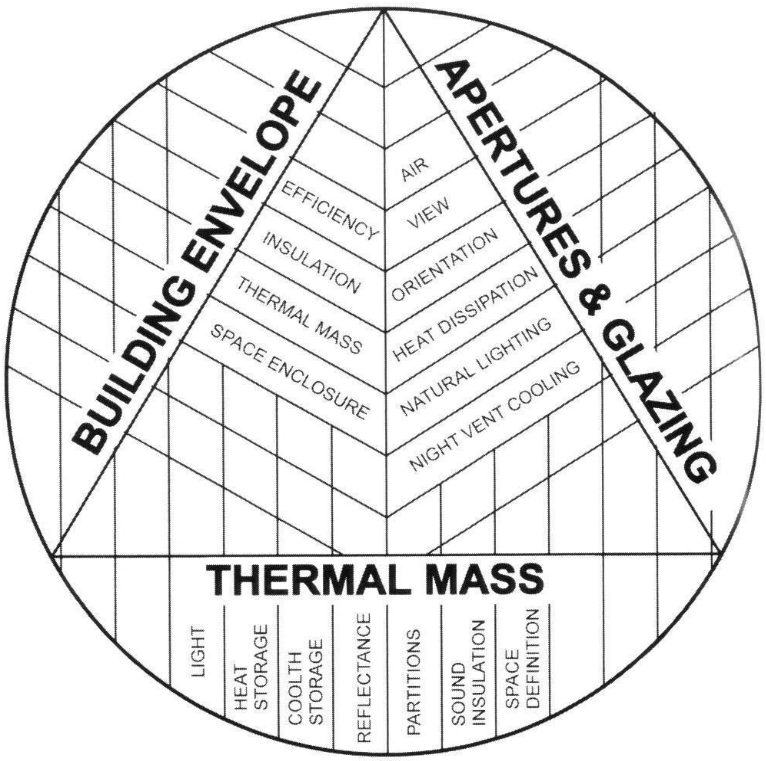


The transition implied on page 27 will require changes in the way we use energy and resources but also will affect our perceptions and goals.

Architecture is a cultural and social artifact as much as a technical planning and construction process and therefore historically has carried a message of the times expressed in space, order, form and materials as well as functions served.

Similarly, passive solar architecture will have this power as it becomes more common and robust. The attitudes on the right side of this chart need to become part of our architectural vocabulary.

PASSING INDUSTRIAL CULTURE		EVOLVING SUSTAINABLE CULTURE
Goal: Maximize efficiency "effective operation with a minimum of waste and effort"		Goal: Maximize health " state of being, sound or hole" "well-being"
Thus as a classic industrial culture, we:		To evolve as a sustainable culture, we:
Look for parts	1	Look for wholes
Simplify the parts	2	Reintegrate wholes and parts
Disconnect from externalities, especially in regard to waste and ecological damage	3	Consider externalities; waste is seen as a resource
Make process as large as possible to achieve economies of scale	4	Make processes as small as possible to reduce undesirable side effects while increasing efficiency by miniaturization
WHICH RESULTS IN:		
Creation of monocultures	5	Creation of polycultures
Wealth at the expense of health	6	Wealth and health are part of a diverse whole that can be optimized
Economy of large scale	7	Economy of miniaturization "a representation on a much reduced scale;" smaller but still complete unto itself



To achieve the efficiency of symbiosis, different components must serve multiple purposes. In passive solar architecture, a wall is more than a wall - it may be part of an insulating envelope, a space divider, a solar collector, thermal mass, a light reflector or a director of breezes. Every component in the architectural whole must serve several functions at the same time.

Building Envelope

A passive building must first be an energy conserving building. This prerequisite allows passive design to take the next step to on-site energy production. Energy conservation begins with the building envelope. Three aspects of an energy conserving envelope are insulation, reduction of air infiltration and energy efficient construction.

Range of insulation values in R SI [R US] for a passive "skin" dominated building.

Biome	Subtropical	Temperate	Cold	Very cold
Roofs	3.3 [19]	8 [45]	10.5 [60]	17.6 [100]
Walls	7 [11]	5.3 [30]	7 [40]	17.6 [100]

Energy Efficient Construction

The above nominal insulation value is typically much higher than the actual value of the wall because of conduction through framing and less than perfect installation. Added framing for openings, joints, fire breaks, or seismic resistance can reduce insulation values 10-25%. Insulation performance can also be degraded by moisture build-up, so placement of a vapor barrier is important and will vary depending on climate. Venting the cold surface of insulated walls or simplifying moisture control with a closed cell foam type insulation can minimize these losses. However, the production process, useful life, disposal and the potential for hazardous off-gassing in a fire are life cycle considerations for insulation. Certain insulation materials such as straw bales should be allowed to breathe water vapor, rather than seal in vapor with a barrier. In this case, providing weep screeds at the bottom of the wall is important. [73]

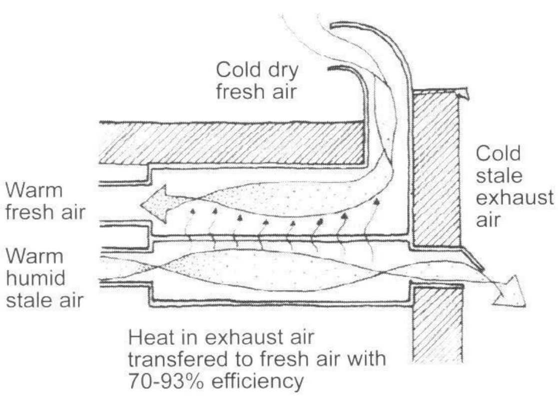
Weatherization & Air Infiltration

Infiltration losses can be just as great as conductive losses and may easily account for half of the winter heat loss in a well insulated, but poorly weatherized building. Weather stripping doors, windows, caulking and sealing building joints, access holes and other areas will reduce unwanted infiltration.

Recent improvements in insulation and glazing techniques have made air infiltration the prime contributor to winter heat loss; however, tight buildings are complicated by the need for fresh air to maintain the health of its occupants.

Approaches to Air Infiltration & Fresh Air Needs	
1. Fresh air occurs by default	Traditionally, the air change per hour (ACH) of residential scale buildings was such that fresh air needs were provided by air infiltration only. This is still the case for passive cooling in humid climates utilizing ventilation cooling.
2. High efficiency passive solar building	In contrast to traditional mechanical conditioned buildings with sealed windows and little individual control of ventilation, the goal is to have control of ventilation, so fresh air is available when and where wanted. A super-insulated passive solar house should perform so well, that it is possible to have some windows slightly open almost all winter.
3. Hybrid system (passive - active)	The envelope is very tight with less than 0.5 ACH and fresh air is provided by a ventilation system using an air to air heat exchanger.

A fresh air intake should be provided for any fireplace, stove or furnace. Chemical properties of interior materials and their behavior will affect the fresh air needs of the occupants. Non-toxic materials, finishes and furnishings are preferable. Proximity to smoking areas, perfumes and other odors contribute to air quality and ventilation needs as well.



Air-to-Air Heat Exchanger [46]

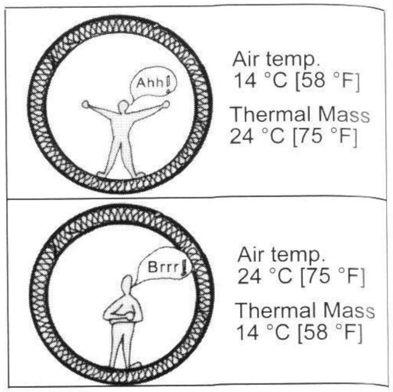
R-Values of Common Envelope Materials [23-31,46]

Insulation Type (Note: Value may very with installation method)	RSI per cm thickness	R [US] per inch thickness	RSI per thickness indicated	R [US] per thickness indicated
Blanket or Batt mineral fiber				
8.6 cm [3.5"]			2.0	11
14 cm [5.6"]			3.3	19
19 cm [7.5"]			4.0	22
24 cm [9.5"]			5.3	30
28 cm [11"]			7.0	38
38 cm [15"]			8.8	50
Boards & Slabs				
Polystyrene (extruded)	0.35	5.0		
Cellular Polyurethane	0.40	6.0		
Cellular Polyisocyanurate	0.49	7.0		
Cellular phenolic (closed cell)	0.87	8.2		
Loose Fill				
Cellulosic Insulation	0.23	3.4		
Perlite Expanded	0.23	3.4		
Perlite Dense	0.18	2.6		
Pumice	0.14	2.0		
Rice Hulls	0.14-0.20	2-3		
Vermiculite	0.14	2.1		
Spray Applied				
Aircrete	0.27	3.9		
Polyurethane Foam	0.4	6.0		
Cellulosic Fiber	0.22	3.8		
Glass Fiber	0.26	3.8		
Reflective Insulation				
Reflective material in center of air cavity			0.6	3.2
Transparent Insulation				
Honeycomb Polycarbonate 50 mm			0.5	2.8
Honeycomb Polycarbonate 100 mm			0.9	5.3
Capillaries Polycarbonate 100 mm			1.0	5.9
Capillaries Acrylic Glass 100 mm			1.1	6.3
Aerogel between Dual Glazing 35 mm			5.8	36.3
Vacuum Panel 2.5cm [1"]			3.4	50
*Recent concerns about indoor air quality in tight buildings has generated the increased use of **non-toxic, natural products for insulation.***				
Wool Fiber	0.27	3.8		
Wool Felt	0.23	3.3		
Hemp	0.21	3.0		
Cotton	2.5	3.5		
Flax	0.21	3.0		
Cork	0.22	3.2		
Straw bale 46 cm [18"]	0.10-0.20	1.5-2.0	2.8	33

Thermal Mass [77]

Large amounts of interior thermal mass are characteristic of passive solar architecture in temperate climate zones. The effectiveness of thermal mass is shown here, where the mean radiant temperature (MRT) is 40% more effective than air temperature in providing comfort. Humidity and air motion affect comfort, but MRT is the dominant factor in perceiving comfort.

Architectural thermal mass has two distinct categories: Concentrated and distributed.



Concentrated (C) thermal mass allows for the greatest amount of thermal mass radiatively coupled to the sun if it is an outside, equator facing wall with glazing. It usually consists of water or thick masonry although advances in phase change material offers additional opportunities.

Distributed (D) thermal mass is spread over a greater area of the building's interior. It has a large surface area and although some may be radiatively coupled it is largely coupled to solar heat or cool air by convection.

	Specific Heat		**Heat Capacity**		**Most common application**			**Mass Type**
Material	KJ/ kg°C	BTU/ lb.°F	KJ/ m³°C	BTU/ ft³°F	Thickness shown	KJ/ M²°C	BTU/ ft²°F	C or D
Water (2)	4.20	1.00	4181	62.4	Tank 23 cm [9"]	957	46.80	C
Concrete (3)	1.00	0.2	1507	22.5	10 cm [4"] slab	144	7.00	C & D
					30 cm [12"] wall	460	22.50	C
Masonry Stucco (4)	0.84	0.2	1253	18.7	5 cm [2"] wall & ceiling	65.5	3.20	D
Brick	0.79	0.2	1045	15.6	15 cm [6"] wall	160	7.80	D
Gypsum Plaster (5)	1.09	0.3	703	10.5	1.3 cm [1/2"]	6.80	0.33	D
					1.7 cm [5/8"]	11.0	0.54	D
					3.5 cm [1-1/8"] wall	22.0	1.08	D
Phase change granules in plaster or gypsum wall board					1.3 cm [1/2"]	160	7.80	D

1. Water has been successfully used as concentrated mass and has the following advantages:

- Highest heat capacity, short of phase change material
- Can distribute heat internally by convection
- Least expensive of all the materials listed on page 33
- Natural non-toxic material if kept free of algae

Applications of water as concentrated thermal mass are:

- Glazed steel tank behind windows
- Steel or plastic tubes of water
- Roof pond with movable insulation
- Thin shell structure with internal bladder

2. Uses of masonry as concentrated thermal mass include:

- Glazed masonry units below windows
- Glazed mass walls
- Floor, slab & structural walls

3. Distributed mass is relatively thin and can consist of walls, ceilings and partitions. Although less efficient for heating, it is superior for night vent cooling because of its large surface area for heat transfer to air. It can be used to supplement concentrated mass. Traditionally, distributed thermal mass has been a relatively expensive addition to standard construction; however, phase change materials that can be added to wallboard or plaster promises to change this drastically.

4. Thermal mass is usually the most expensive part of a passive system for a temperate climate. Therefore, dual use of other architectural elements such as floor slabs, structure and finished surfaces will reduce cost if kept uninsulated from the interior space. To inexpensively add distributed mass, gypsum wall board ceilings and walls may be doubled in thickness. Although not as effective as most other materials this is a relatively inexpensive way of adding more distributed mass.

5. Concentrated mass needs to be as absorptive as possible, even to the point of using selective surfaces on the areas facing the sun. In contrast, distributed mass needs to be somewhat reflective so that light and heat are spread over a greater area. Light colored interior surfaces including distributed mass, help with natural lighting and the prevention of glare.

Apertures [78,79,80]

As modern architecture matured most buildings became smooth seamless envelopes, sealed to allow thermal conditioning and lighting by mechanical and electrical equipment. The result of this highly differentiated approach was freedom from orientation, apertures and personal control; but this also created high energy demand and costs. In contrast, orientation is an integral aspect of passive solar architecture, providing lighting, heating, cooling, personal control and contact with the exterior environment.

Type of Aperture Listed by Single Function

		FUNCTION	CLIMATE	ARCHITECTURAL APERTURE OR RESPONSE	CONCERN
Solar radiation	Direct	Heating	Cold or Temperate	Ideally, each room should have a solar aperture, see page 59.	Seasonal control is needed, avoid flat roof apertures
Solar radiation	Diffuse	Lighting, some heating	Cold or Temperate	Diffuse radiation in an overcast sky is from the whole sky dome. In large buildings, a glazed atrium is helpful.	
Night sky radiation		Cooling	Hot, dry	Open courtyard with colonnade or toldo for protection from solar radiation, serves as an aperture to the night sky. Roof top terraces are also effective.	Visual & acoustic privacy
Light flow		Lighting	Any	Limited horizontal reach of windows as walls of 3.7 m [12'] can be increased to 12m [40'] by treating the whole room as a light aperture. Transparent floors, windows between rooms and spatially diverse atriums can make the whole building a light aperture.	Control of overheating must be considered
Air flow		24 hour cooling	Hot or Humid	The whole building can become an air plenum and aperture for maximum cross ventilation day and night. Flow can be enhanced by building shape and landscape elements. Semi-outdoor spaces like terraces, decks and screened lanais are useful.	Insect screens are essential to allow optimal use. Screens however can reduce air flow see page 51
Air flow		Night vent cooling	Temperate	Apertures in the envelope oriented to the prevailing breezes are designed to scour distributed thermal mass with night air.	Apertures must allow security from entry to insure use
Air flow		Reduce infiltration	Cold or Temperate	Entry foyer can act as an air lock vestibule at all outside doors.	
Air flow		Wind protection, heating	Cold or Temperate	Strong winds can increase infiltration by up to 250%. Landscape barriers, courtyards or atriums can be used for wind protection. Building shape and profiles can be used to tame eddies.	Complex turbulent flows can be designed for, using computational fluid dynamics software

Glazing [46]

U-Value (U): The measure of heat loss or gain through a material known as conduction and the inverse of the R-value; U = 1/R. Usually ranges from 0.1 (RSI 1.76 = [R = 10] to 1.20 (RSI 0.15 = [R = 0.83].

Solar Heat Gain Coefficient (SHGC): A measure of how much heat flows through the glass to the interior of the building, compared to amount that strikes it, usually ranging from 0.2- 0.9. SHGC is especially important for passive heating.

Shading Coefficient (SC): The measure of a window's ability to block solar heat relative to 3 mm [1/8"] clear glass.

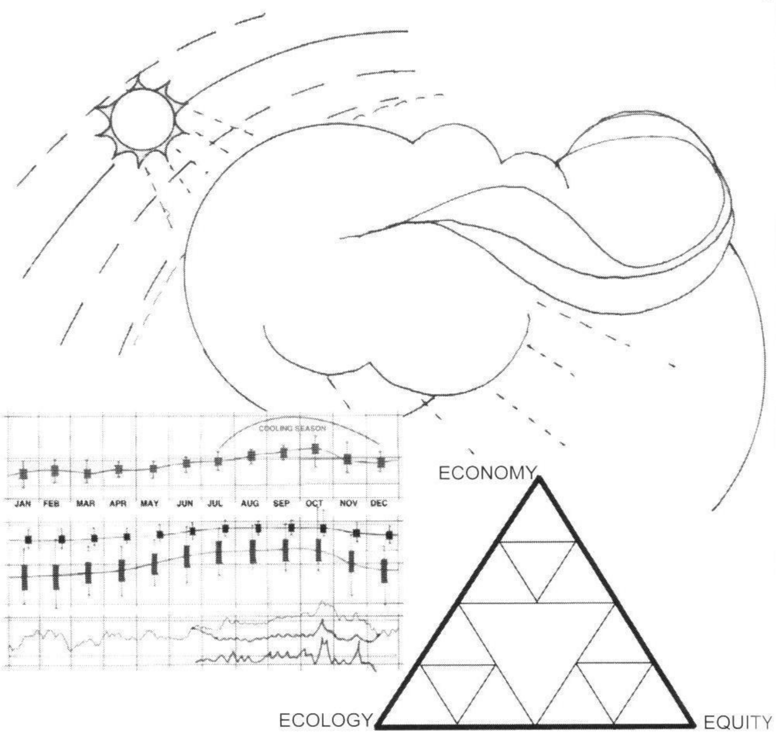
Visible (Daylight) Transmittance (Tvis): A measure of the relative amount of sunlight passing through a glazing assembly, usually ranging from 0.3 - 0.8. A higher number yields more light for daylighting.

Air Leakage (ALR): The measure of how much infiltration (air leakage) exists around a window, door or skylight with a known specific pressure difference.

Condensation Resistance: Measured between 0 to 1 with a higher rating corresponding to better resistance against condensation or moisture due to thermal fluctuations.

Glazing Type Typical window assemblies	**U-value** **W/m^2°C**	**U-value** **BTU/ ft^2°F**	**SHGC**	T_{vis}
Single-glazed Clear (Alum. frame)	7.37	1.30	0.79	0.69
Double-glazed Clear(Alum. frame)	3.63	0.64	0.65	0.62
Double-glazed Clear (wood or vinyl frame)	2.78	0.49	0.58	0.57
Double-glazed Bronze (Alum. frame)	3.63	0.64	0.55	0.47
Double-glazed Bronze (wood or vinyl frame)	2.78	0.49	0.48	0.43
Double-glazed Low-E (low-emissivity 0.20, wood or vinyl frame)	1.87	0.33	0.55	0.52
Triple-glazed Low-E 0.08 w/ argon (wood or vinyl frame)	1.70	0.30	0.44	0.56
Double-glazed spectrally selective Low-E 0.04 w/ argon (wood or vinyl frame)	1.65	0.29	0.31	0.51
Double-glazed spectrally selective Low-E 0.01 w/ argon (wood or vinyl frame)	1.76	0.31	0.26	0.31
Triple-glazed Low-E 0.08 w/ krypton (insulated vinyl frame)	0.85	0.15	0.37	0.48
Triple-glazed Clear w/ air (wood or vinyl frame)	1.93	0.34	0.52	0.53

SECTION 4: DESIGN TOOLS



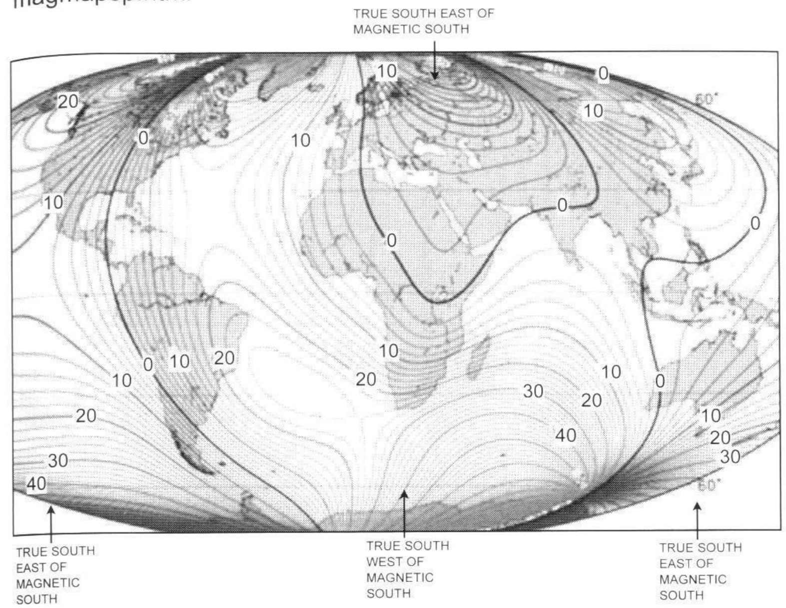
Design of passive solar architecture is more complex than that of a traditional modern building. The sun's path in relation to the site is dynamic. Air-flow in relation to the site is irregular and at times turbulent. The interior temperature is chaotic within limits of the comfort zone which is determined as much by culture and social mores as scientific measurement.

Until sophisticated computer simulation became available, prediction of performance was very difficult because of the multiple variables involved. Even the economics of green building is best described by a fractal.

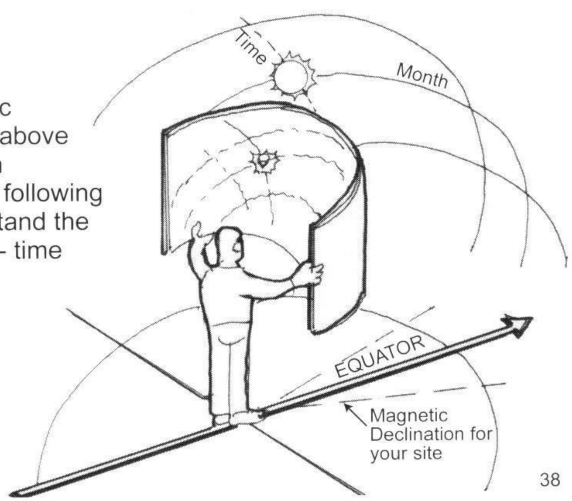
Passive solar architecture embraces this complexity to develop architecture that is more wholistic and less of an abstraction.

Sun - Earth Relationship (Sun Path Diagrams)

Passive solar design relies on an intimate feeling for sun locations at any time, day or month. For detailed isogenic maps of N. America, S. America, Europe, Middle East, Orient/ New Guinea, Australia and New Zealand visit: http://www.geo-orbit.org/sizepgs/magmapsp.html

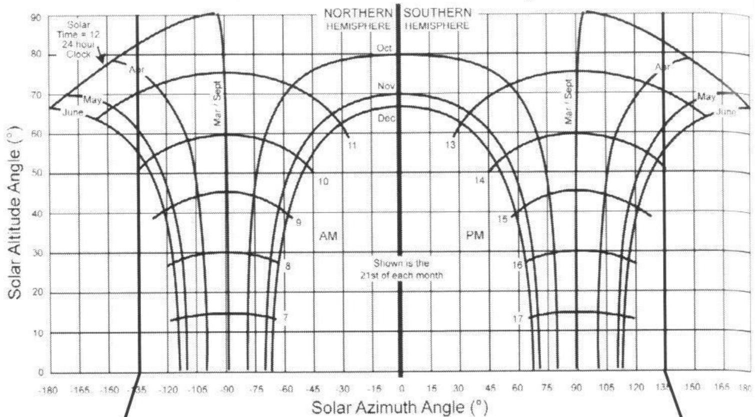


Use the magnetic declination map above and the sun path diagrams on the following pages to understand the sun- earth - site - time relationship.

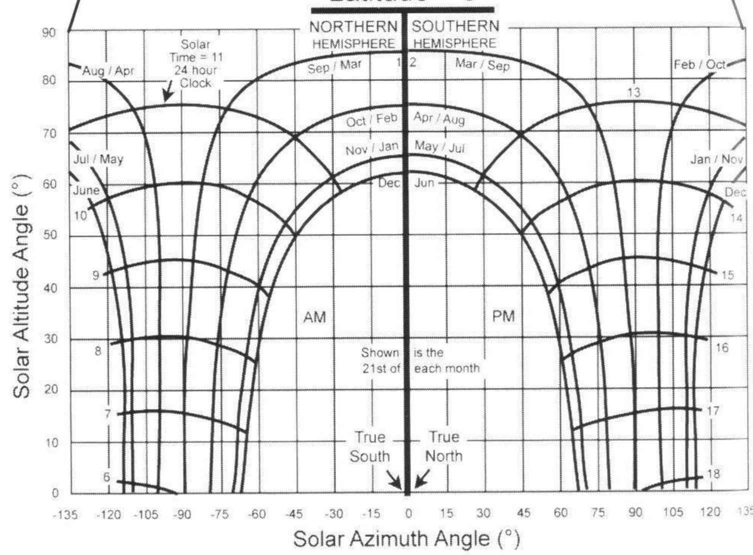


Sun Path Diagrams

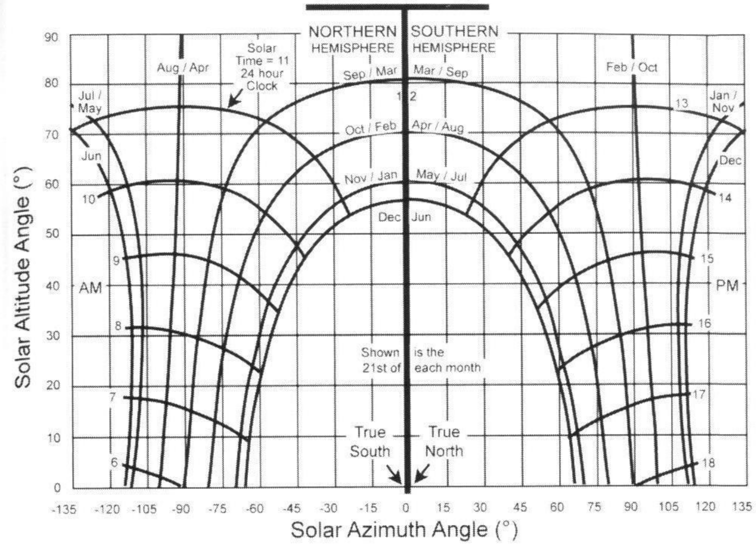
Solar Azimuth 0° = Towards Equator



Latitude = 5°



Latitude = 10°



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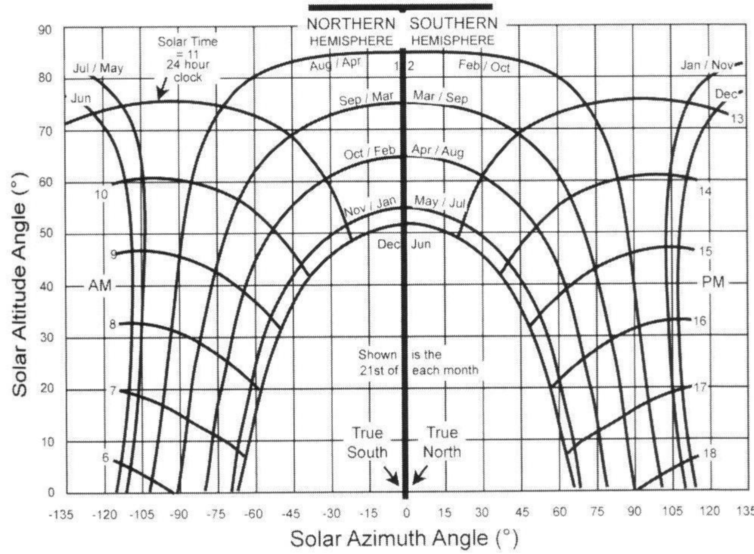
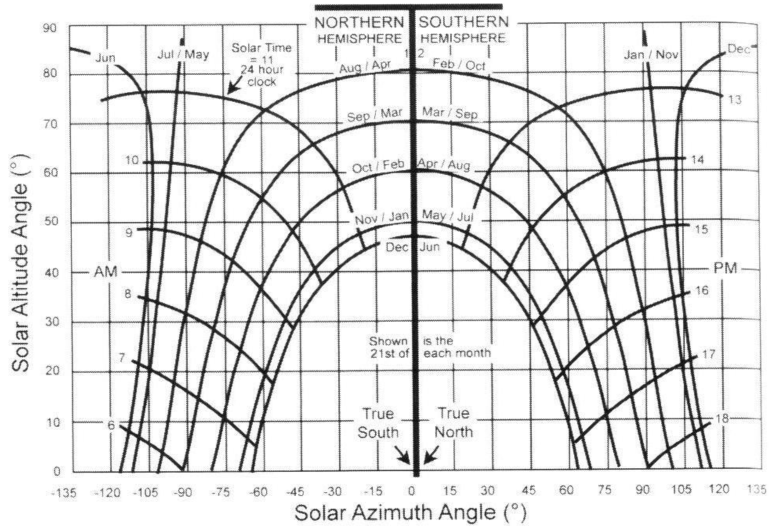
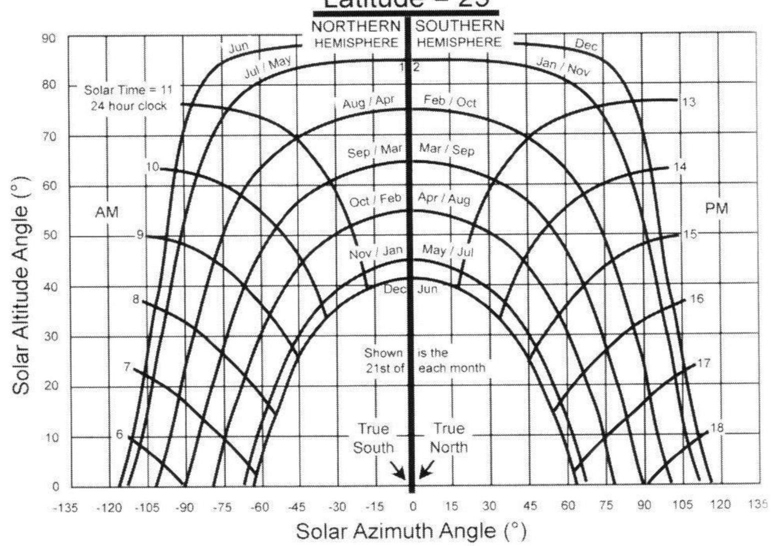


Latitude = 20°



Latitude = 25°



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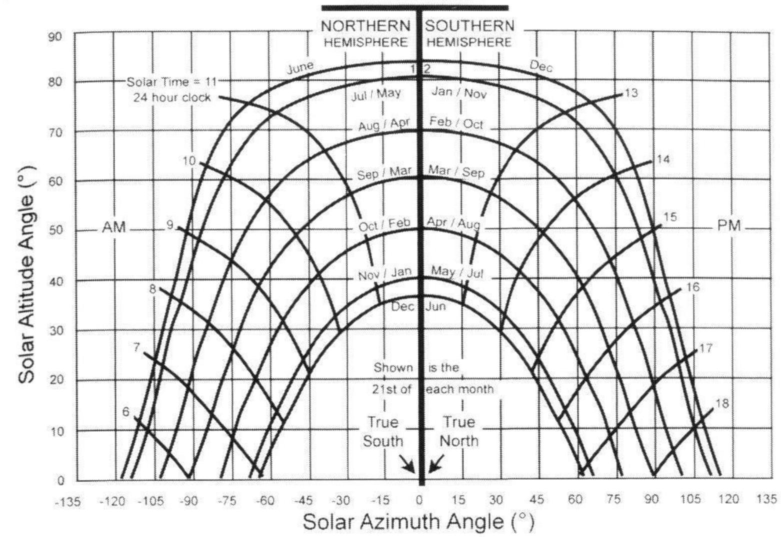

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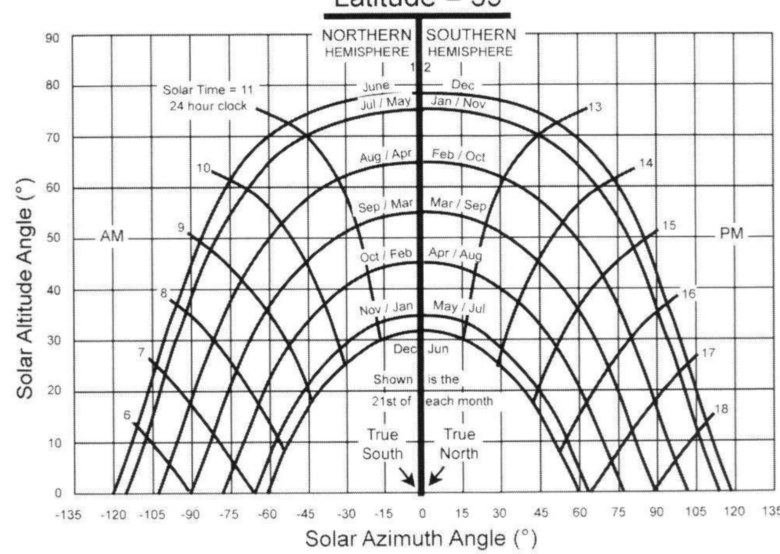

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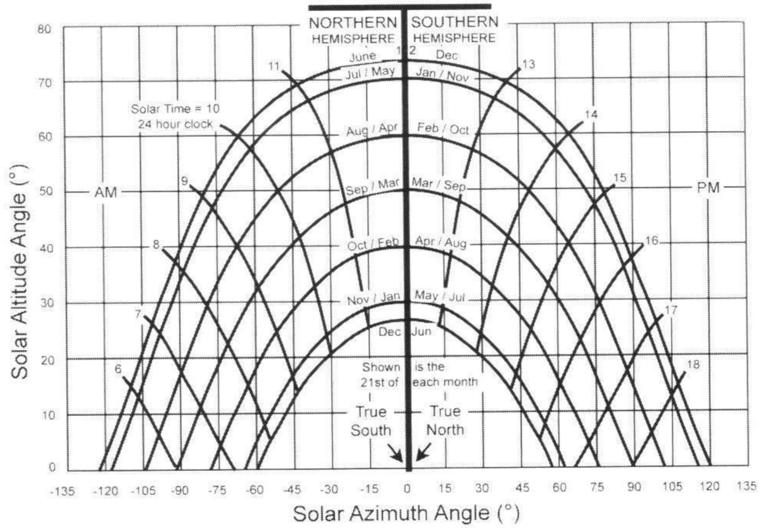

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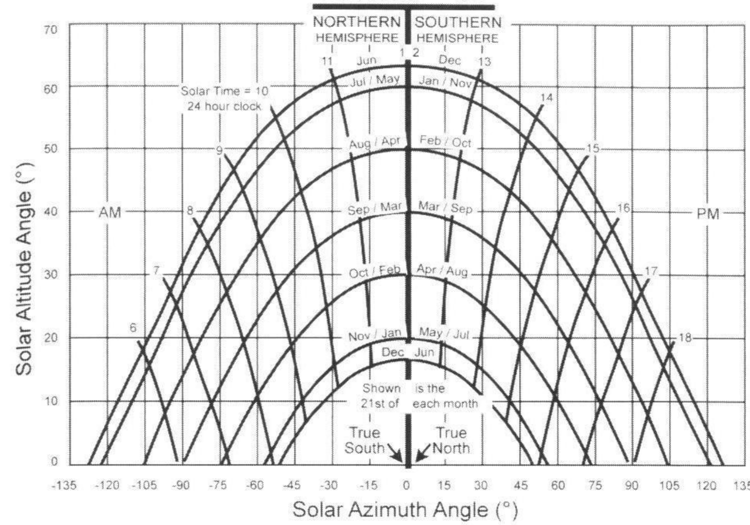

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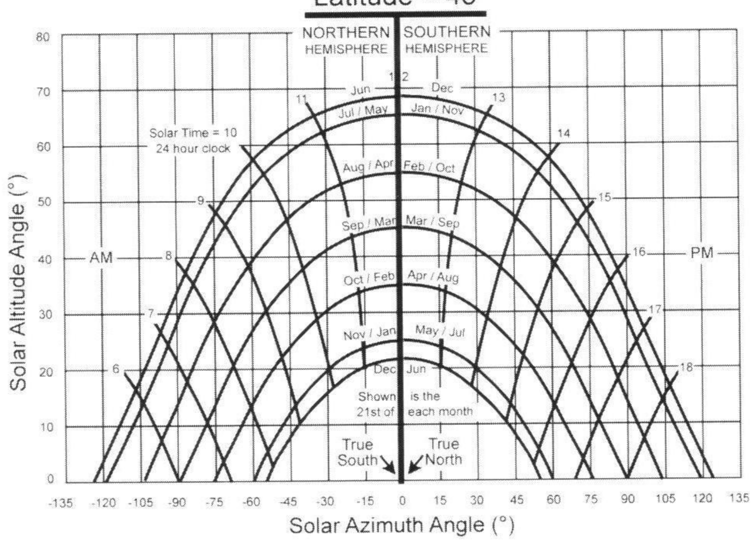

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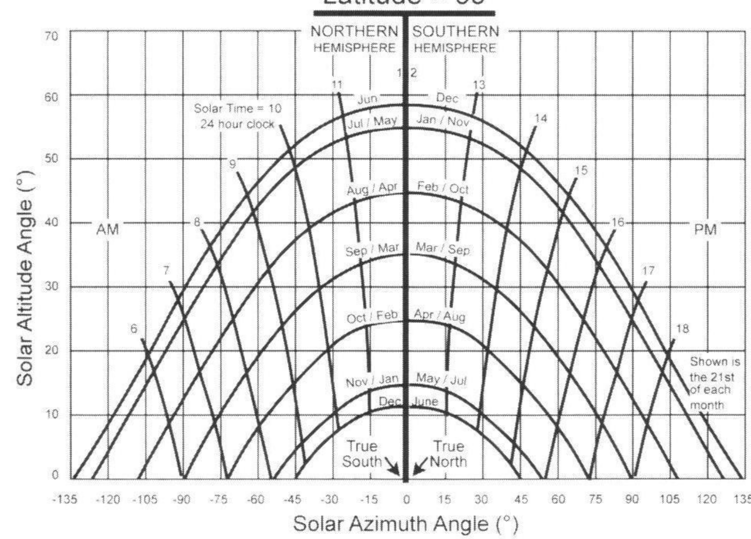
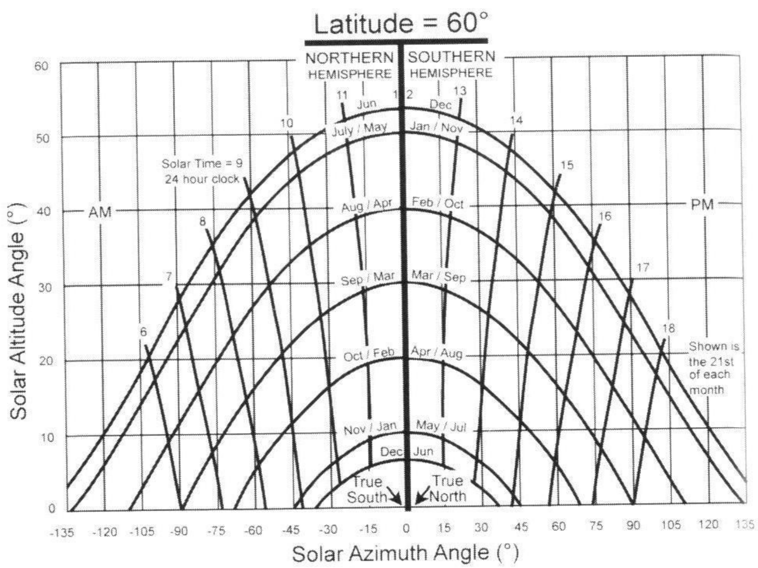
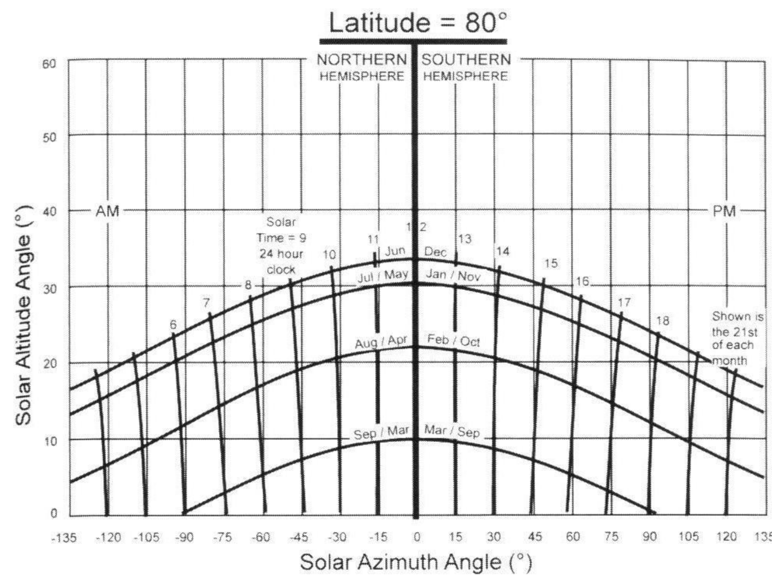



Latitude = 60°
NORTHERN HEMISPHERE
SOUTHERN HEMISPHERE
Solar Time = 9
24 hour clock
AM
PM
Jun
Dec
July / May
Jan / Nov
Aug / Apr
Feb / Oct
Sep / Mar
Mar / Sep
Oct / Feb
Apr / Aug
Nov / Jan
May / Jul
Dec
Jun
True South
True North
Shown is the 21st of each month
Solar Altitude Angle (°)
Solar Azimuth Angle (°)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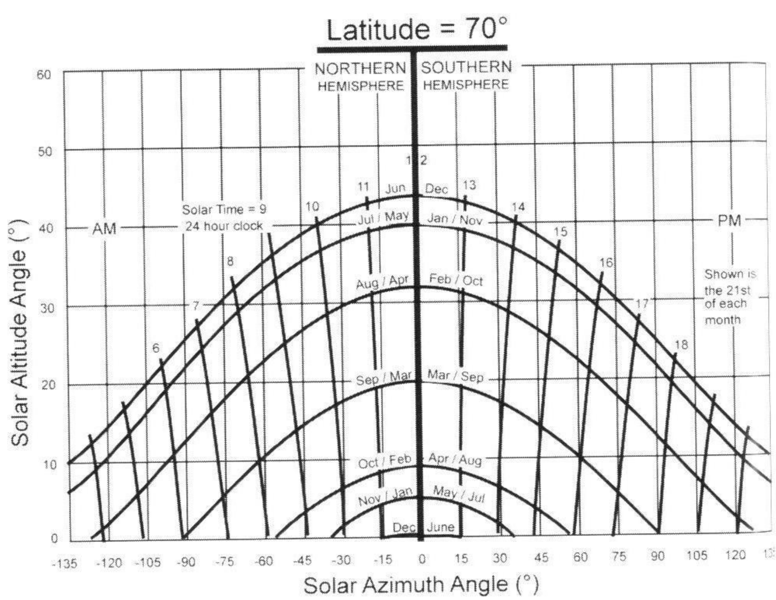
NORTHERN HEMISPHERE
SOUTHERN HEMISPHERE
AM
PM
Solar Time = 9
24 hour clock
Jun
Dec
Jul / May
Jan / Nov
Aug / Apr
Feb / Oct
Sep / Mar
Mar / Sep
Shown is the 21st of each month
Solar Altitude Angle (°)
Solar Azimuth Angle (°)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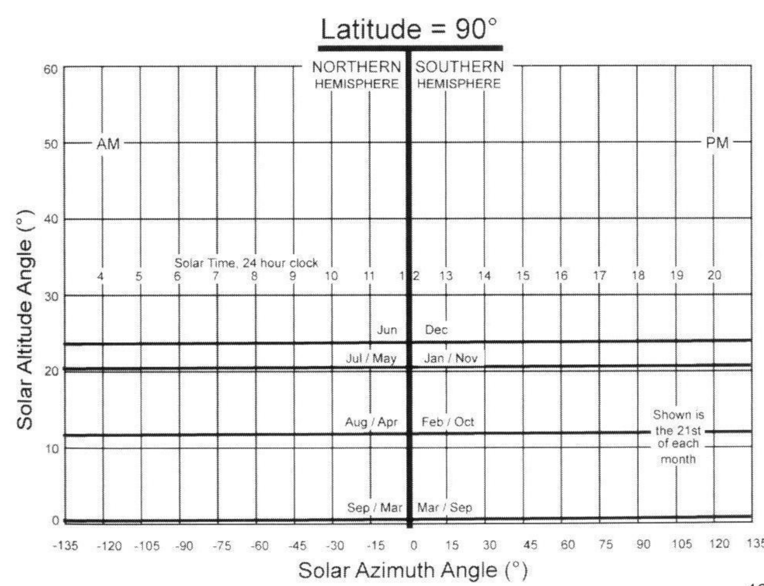
NORTHERN HEMISPHERE
SOUTHERN HEMISPHERE
AM
PM
Solar Time = 9
24 hour clock
Jun
Dec
Jul / May
Jan / Nov
Aug / Apr
Feb / Oct
Sep / Mar
Mar / Sep
Oct / Feb
Apr / Aug
Nov / Jan
May / Jul
Dec
June
Shown is the 21st of each month
Solar Altitude Angle (°)
Solar Azimuth Angle (°)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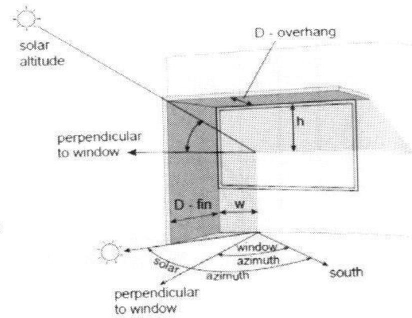
NORTHERN HEMISPHERE
SOUTHERN HEMISPHERE
AM
PM
Solar Time, 24 hour clock
Jun
Dec
Jul / May
Jan / Nov
Aug / Apr
Feb / Oct
Sep / Mar
Mar / Sep
Shown is the 21st of each month
Solar Altitude Angle (°)
Solar Azimuth Angle (°)

Sun - Building Relationship (Sun Peg Diagrams)

Using the preceding sun path charts, you can calculate for sun and shade as shown to the right. This is good for specific details, but for the whole building it is often easier to create a digital or physical model. Physical models can utilize the sun-dial device called a sun peg diagram. The following sun peg charts will show the exact position of sunlight and shadow on a model of any scale, on any date, at any time of day between shortly after sunrise and shortly before sunset.



1. Find the chart nearest your latitude.
2. Make a copy of the chart.
3. Construct a peg whose finished height above the chart surface corresponds to the "peg height" shown on your copy of the chart. This peg must stand perfectly vertical relative to the model.
4. Mount your copy of the chart on the model to be tested. The chart must be perfectly horizontal over its entire surface, and the true north or south arrow must correspond exactly to true north or south on the model.
5. Mount your vertical peg at the location shown on the chart.
6. Choose a test time and date. Take your model out into direct sunlight.

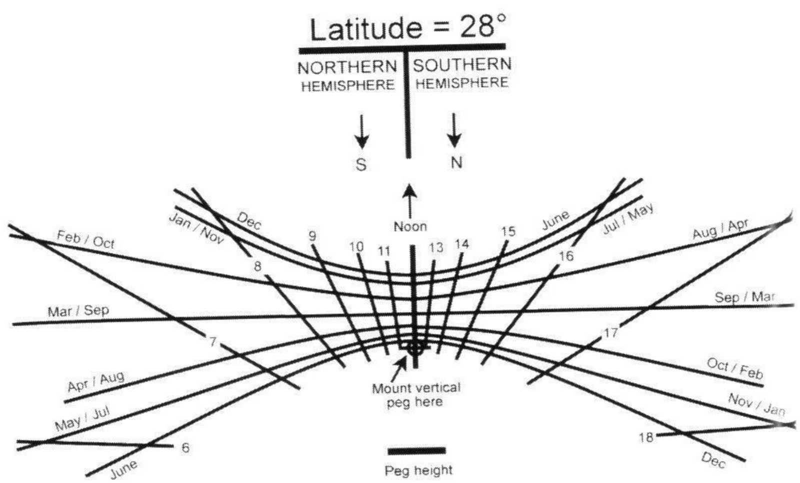
For overhang shading:

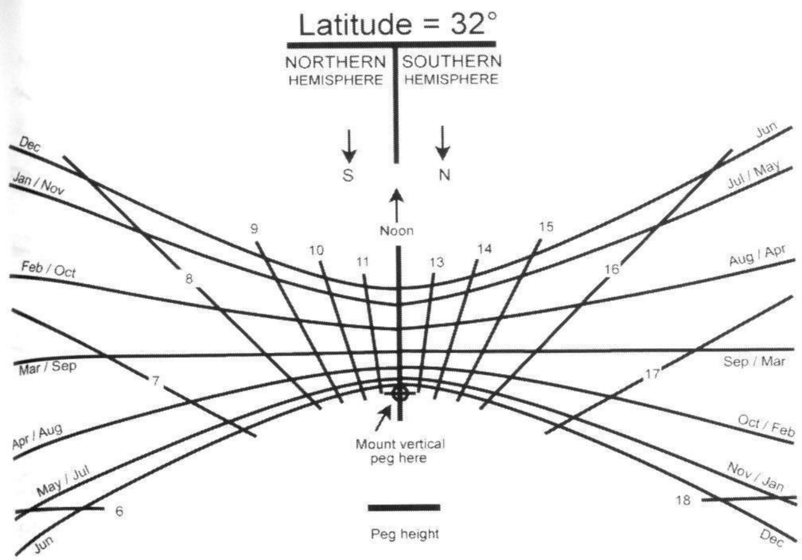
$$h = \frac{D \times \tan(\text{solar altitude})}{\cos(\text{solar azimuth} - \text{window azimuth})}$$

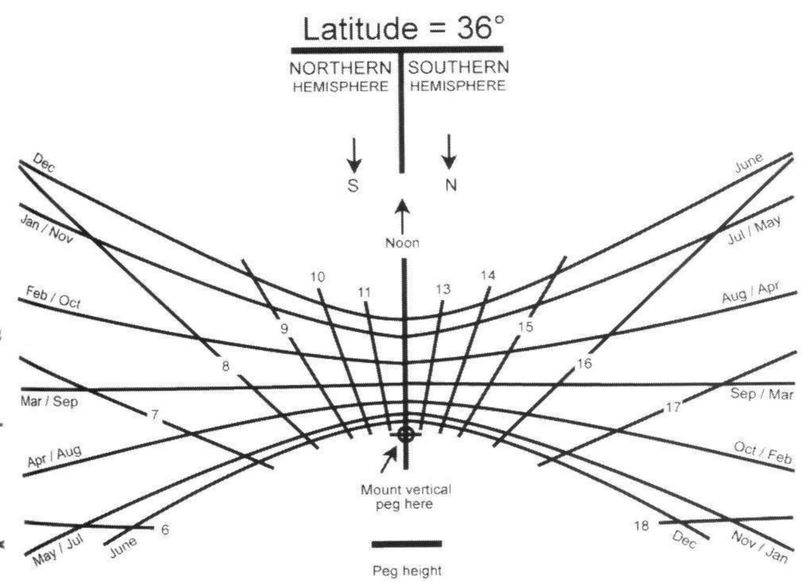
For fin shading:

$$w = D \times \tan(\text{solar azimuth} - \text{window azimuth})$$

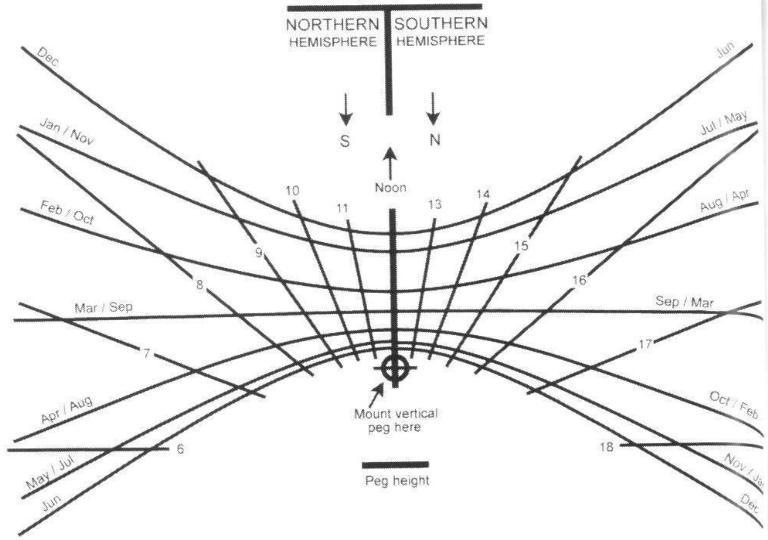
Then tilt the model until the shadow of the peg points toward the intersection of the chosen time's line and the chosen date's curve. When the end of the peg's shadow touches this intersection, your model will show the same sun-shadow patterns as would occur on the time and date of the intersection you chose. [46]



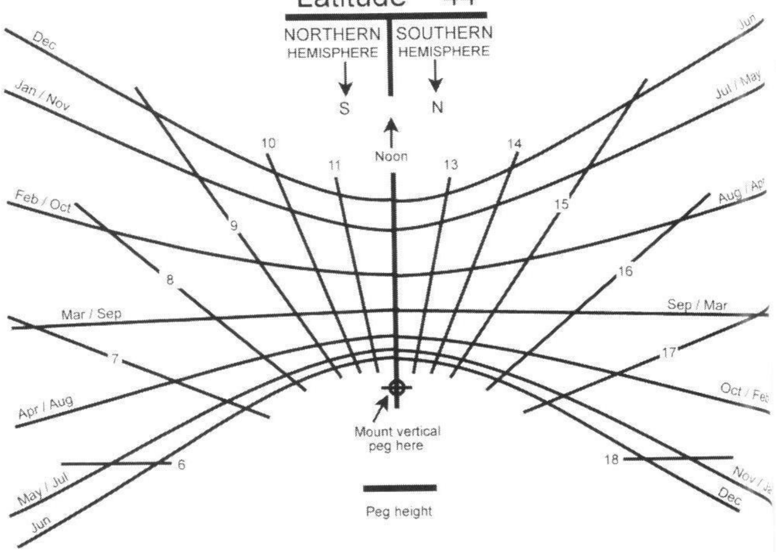




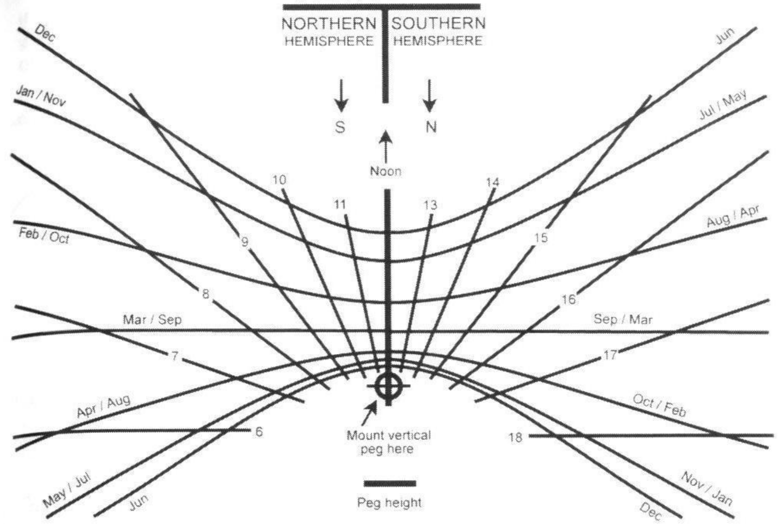
Latitude = 40°



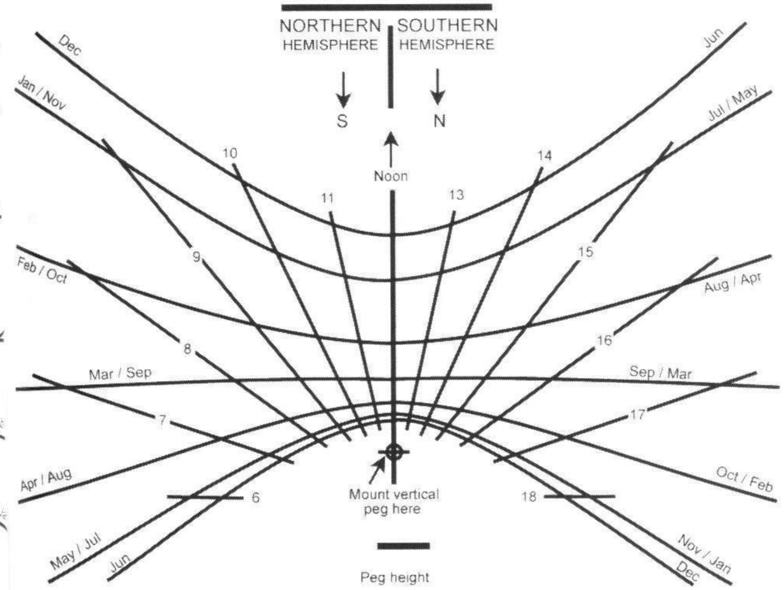
Latitude = 44°



Latitude = 48°

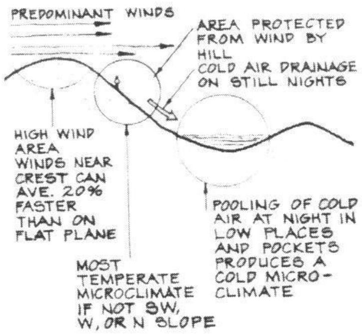


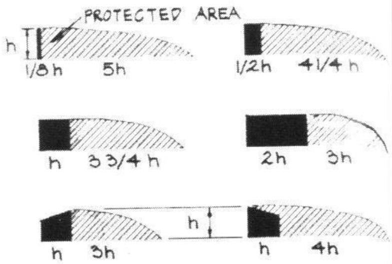
Latitude = 52°



Air-Flow Relationships [70]

SITE SELECTION

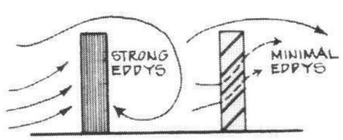




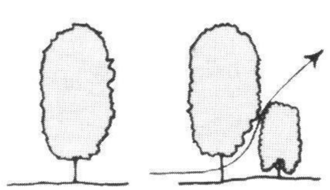
Besides site selection, wind protection may be provided by adjacent buildings, walls or vegetation. Generally, the thinner the adjacent element, the larger the protected area down wind.

For a typical house, heat loss by air infiltration can be 2 ½ times as great in a 2.2 m/s [5 mph] wind verses no wind. Since infiltration may account for up to half of the building's heating load, protection from wind can produce a considerable reduction in heating requirements.

WIND BREAKS



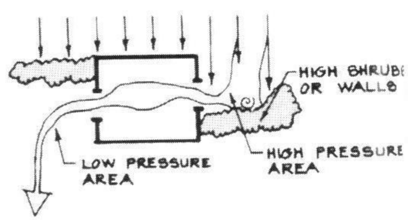
Solid windbreaks produce strong eddy currents which negate much of their effectiveness. A slatted fence prevents this.

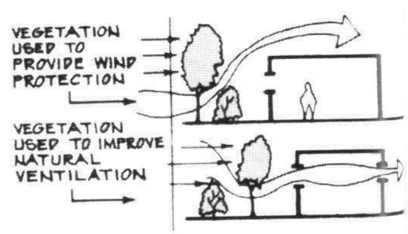


Thick vegetation is highly effective, especially a combination of trees and shrubs as shown.

LANDSCAPE ELEMENTS

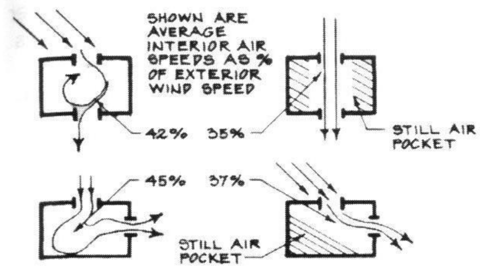
Trees, shrubs, walls, etc. can often be used to improve natural ventilation even if the building cannot be optimally oriented to the wind.

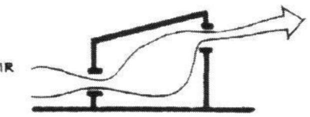




ROOM AND WINDOW ORIENTATION

If windows are on opposite sides, the room should be oriented askew to the wind direction. If the windows are on adjacent walls, the room should be oriented to face directly into the wind.



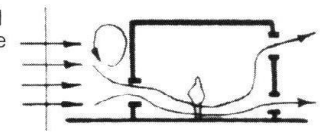


Height difference between inlet and outlet helps induce natural ventilation during still times.

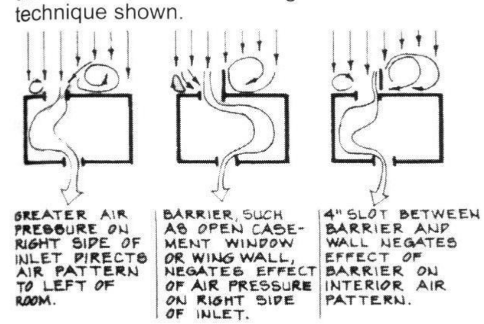
INLET TREATMENT

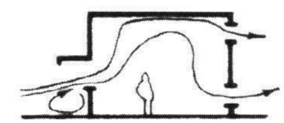
Air patterns in a room are largely determined by the inlet location and its relationship to the exterior surfaces of the building.

It is important for night vent cooling to wash thermal masses with cool night air via the technique shown.



The same principles apply to the vertical dimension.

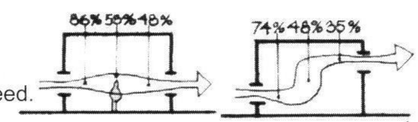


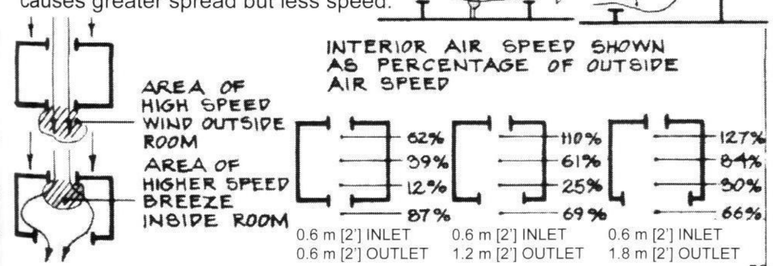


Overhangs can have the same effect as wing walls and other barriers in the horizontal dimension.

OUTLET TREATMENT

Outlet size in relation to inlet size largely determines the speed of interior airflow. Change in direction causes greater spread but less speed.





Simulation Modeling

Solar architecture/ passive solar building simulation programs

Since their inception there has been a rapid increase in the number of available building energy simulation programs. Their capabilities have been improving in pace with available computer speed and capacity, allowing ever more detailed aspects of the buildings and their environmental driving forces to be incorporated in the programs. In turn, causing a flourishing of building research to better understand and characterize the important physical processes involved. Focused mainly on residential and small commercial applications, the general capabilities of available programs are listed below.

General purpose programs

These are characterized by their accuracy and extent of options and level of detail, and are generally engineering research oriented. They are mainly used by architects and engineers experienced in simulation and building science. These programs have the following capabilities:

- Transient heat flow in lightweight and heavy mass buildings, usually with a one-dimensional time-domain analysis. Most have transient slab-on-grade heat transfer algorithms, but frequently of limited sophistication.
- Weather tape driven state-of-the-art solar and environmental algorithms.
- Determine heating and cooling loads, and building and environment temperature and heat flow histories.
- State-of-the-art window analysis algorithms, incorporating long-wave and short-wave and convective window heat transfers algorithms. Shading and internal solar distribution algorithms are of varied sophistication.
- Separate radiant and convection heat transfer algorithms, although some are limited to a combined coefficient analysis.
- Infiltration and natural ventilation algorithms, with a large variation is algorithm sophistication, a few incorporating inter-zone air flow analysis.
- HVAC system model sophistication varies from simple residential system models to a multitude of commercial building HVAC variants.
- Most have multi-zone modeling capabilities.
- Building geometry is typically specified with text input, but in some cases can be defined using CAD tools.

- Daylight utilization analysis algorithms are common, usually for a limited range of geometries.
- Graphical input and output interfaces are common but not universal.
- Many programs incorporate photovoltaic and life cycle cost analysis.

Variants of programs in this category of programs are frequently used for confirming building compliance with performance based energy standards, in which case some inputs and features are constrained to inputs and features allowed by the standards.

Architectural design oriented programs

Although the general purpose programs are frequently used for architectural design, they have the reputation of being difficult to learn and interpret, time consuming in their detail, and as a result have had a relatively small penetration into the architectural design arena. The more designer friendly architectural design oriented programs are characterized by ease of use, fast running speeds, extensive libraries, easily interpretable graphical input and output, and the ability to integrate simulation into the various phases of the recursive design process. Since many of these are modified versions of general purpose programs, they tend to show their engineering roots.

Educational variants of the architectural design programs are designed to quickly and instructively show the effects of the main factors influencing building energy performance. To simplify the input they are usually limited to simple building geometries, and many of the algorithms are simplified. The simplicity of course comes at some cost of accuracy and generality.

Trends in program development

Despite the fact that the simulation programs are continually getting more accurate and easy to use, the current programs can hardly be said to be mature, either in capability or their penetration into the design studio. Some of the trends in program development are: easy-to-use interfaces for the general purpose programs, full CAD input, and the interoperability of building energy programs with other building programs such as duct design programs and computation fluid dynamics (CFD) programs.

Directories of available programs can be found at:
http://apps1.eere.energy.gov/buildings/tools_directory/

Economics - Life Cycle Cost [37]

Life Cycle Cost (LCC): All costs adjusted to present value including: investment cost + replacement cost + operation/ maintenance/ repair cost (energy cost + water cost) - residual value. LCC is a linear pocket book expression of internal costs over time.

Life Cycle Analysis (LCA): A tool for quantifying alternative investment opportunities by looking at the LCC of all the components and weighing the trade-offs which may be increased maintenance for one system or more costly replacement parts for another. [57]

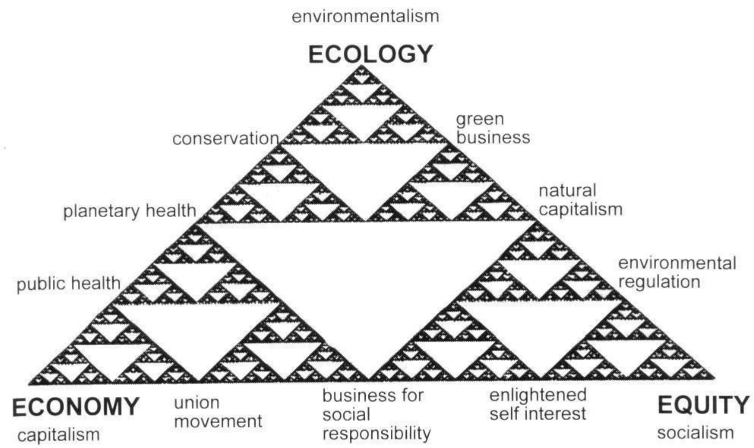
True Life Cycle Cost: Includes the internal cost (LCC) plus external costs (environmental, health, financial) and subsidies. [55]

As illustrated below, when the ratio of true cost to internal cost is analyzed for various energy sources, only passive solar architecture has a ratio of less than 1; internal costs are less than the true costs. [53,54,56,58,59,60,61,62,63]

	Energy Sources	**A. Internal cost** (cents per kwh)	**B. True Cost** = internal cost + environmental + health + financial + subsidies (cents per kwh)	**Ratio** of True cost/ Internal Cost **(B/A)**
Fossil Fuels	Coal	7	21 +	3.0
	Oil	7	20	2.9
	Natural Gas	6	14	2.3
	Nuclear	10	22 +	2.2
Traditional Renewable	Large Hydro	4	14	3.5
	Small Hydro	6	9	1.5
	Geothermal	7	9	1.3
Newer Renewable	Biomass	8	10	1.3
	Solar thermal	8	10	1.3
	Wind	5	6	1.2
	Photovoltaic	15	17	1.1
	Passive solar architecture	5	0-3 We treat electricity saved by these design techniques as electricity produced that we would have to pay for otherwise without green design.	0.6

Life Cycle Design

Triple Bottom Line Accounting is a term coined by the British business consultant John Elkington in 1997 that refers to environmental, societal and financial accounting.



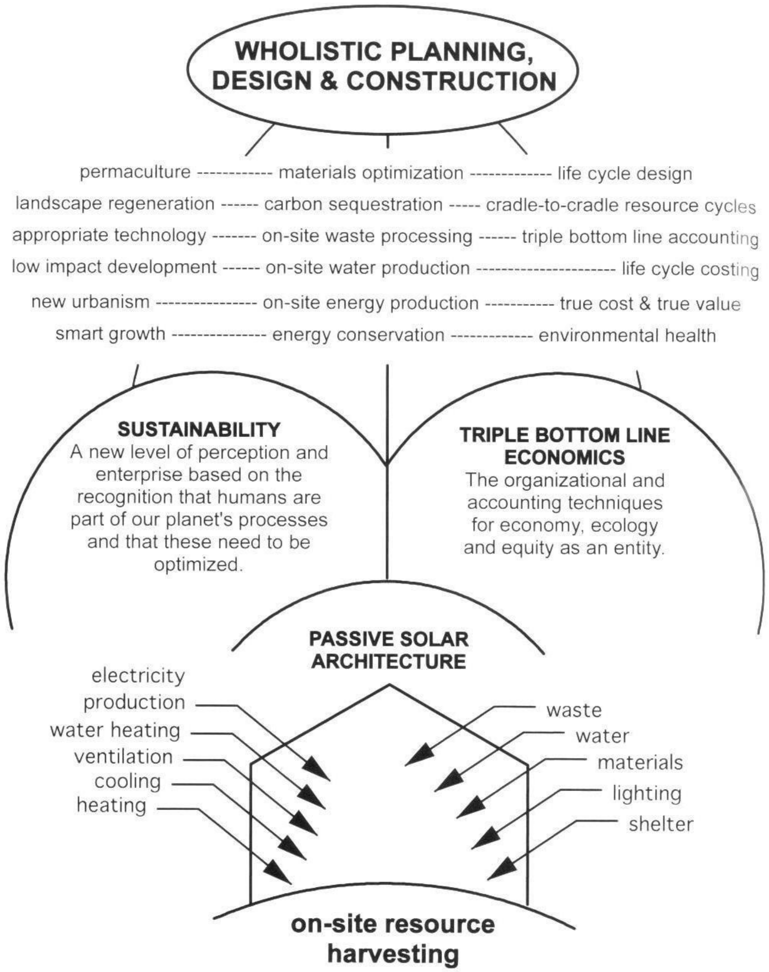
This ***fractal triangle***, developed by McDonough and Braungart, is a tool that helps you identify and understand triple bottom line accounting. Each point of the triangle is one of the triple bottom line elements, and points between each illustrate the different combinations of points on each side. Being a fractal, there are infinite combinations possible, just as in human social behavior. [43]

Life Cycle Design (LCD): Where true cost accounting and cradle-to-cradle material cycles become a part of the design process.

More exploration needs to be done to improve the life-cycle sustainability of building materials. Retrofitting existing buildings with local, sustainable materials rather than high-tech, high-environmental cost materials. [96-104]

SECTION 5: SPECIFIC FUNCTIONS

Sections 1,2,3 and 4 have covered the specifics of history, context, components and tools. This section focuses on putting it all together.

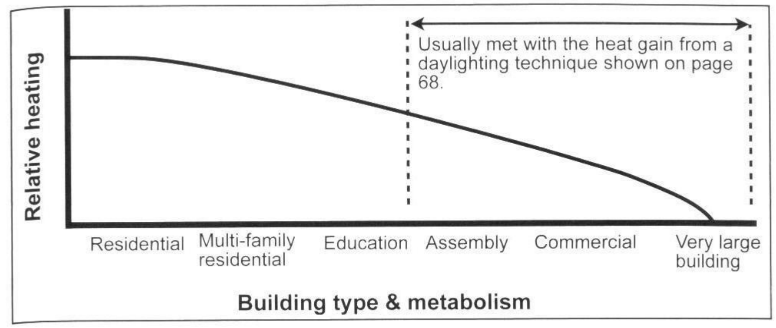


Passive solar architecture functions are at the core of a triad of efforts to make human activity more a part of our planet and provide resources for future generations.

Passive Heating

There are two primary considerations in regard to passive heating.

1. **Metabolism:** Buildings at the residential end of the scale are explored in this section because the heating demand of buildings at the other end of the spectrum is usually met with heat gain from a daylighting strategy as discussed on pages 63-68.



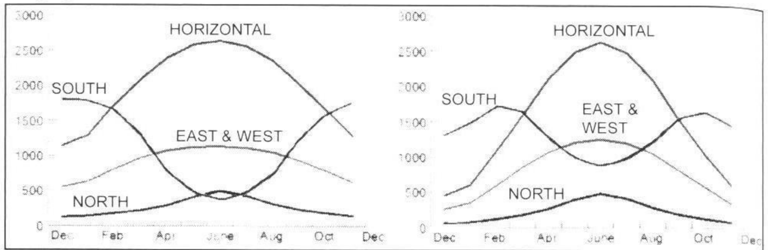
2. **Scale of heating and cooling needs:** Most buildings require both heating and cooling, and most passive designs can use the same components to do both. Cooling is covered here with cooling specifics in the cooling section on pages 60-62.

Climate	Thermal Load	% Area of equator facing glass/ floor area (1)	Area of thermal mass/ area of equator facing glass	
			Water (2)	Masonry (2)
Very cold (3)	Heating only	10-20	4-6	5-10
Cold (4)(5)(6)	Heating only	10-25	4-6	6-11
Temperate	Heating & some cooling	14-20	3-5	8-12
	Balanced heating & cooling	9-15	2-4	5-9
	Cooling with some heating	8-13	2-3	8-12
Tropical-dry	Cooling with small amounts of heating	6-11	0.5-1	10-14
Tropical-wet	Cooling only	0	0	0

Notes: (1)(2)(3)(4)(5)(6) are on the following page.

Passive Heating Notes

(1) Solar apertures facing the equator (shown as south in the figure) are in the only orientation that maximizes winter gain and minimizes summer radiation. Small variations in azimuth angles from the equatorial direction are negligible in effect, up to 20° is negligible, but 30° and above is not recommended.



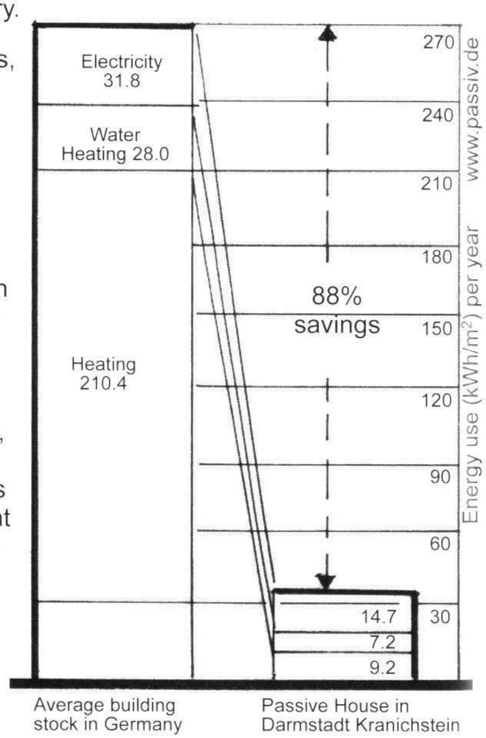
Thermal gain by window orientation in BTUs/ ft^2 of glass/ day at 35° (left) and 48° (right) north latitude. [45]

(2) Masses are assumed to be 0.23 m [9"] for a water wall, or 0.3 m [12"] thick for tubular water columns and 0.05 m [2"] thick for distributed mass masonry.

(3) For very cold climates, a super-insulated shell with air-to-air heat exchanger and movable insulation on all fenestration is assumed.

(4) For cold climates, a super-insulated shell with air-to-air heat exchanger is assumed.

(5) Passive solar is applicable to all climates, not just mild temperate areas. Northern Europe's passive house movement has been successful in a cold climate. If all of Germany's housing was passive, the reduction in their energy demand would be immense.

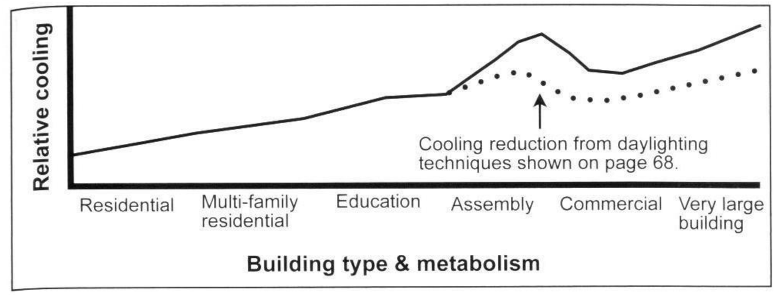


Passive Cooling & Ventilation

Cooling and ventilation have been combined because they are integrally connected in passive design. The first rule of passive cooling is not to passively heat when you need to passively cool. Keep the heat out before it enters the building with radiation control methods as described on page 24.

There are two primary considerations in regard to passive cooling.

1. **Metabolism:** Unlike passive heating, passive cooling and ventilation increase as the size and complexity of the building increase with the exception of assembly spaces.



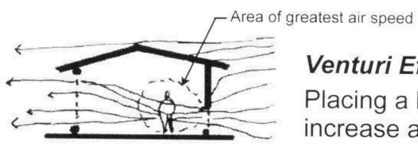
2. **Scale of cooling and heating needs:** Passive cooling varies distinctly with humidity. In hot-dry climates, clear night skies allow night radiation and convective cooling with cool night air. In hot-wet climates, the only thermal sinks available are wet surfaces that can cool through evaporation.

Climate	Thermal Load	Cooling Strategy	See page
Tropical-wet	Cooling only	First, protection from solar radiation, then maximum cross ventilation supplemented with ceiling fans	61
Tropical- dry	Cooling only	Night sky radiation from concentrated thermal mass or Night ventilation over distributed thermal mass	11
Subtropical-wet	Cooling with some heating	Protection from solar radiation, maximum cross ventilation supplemented with ceiling fans	61, 58
Subtropical-dry	Cooling with some heating	Night sky radiation from concentrated thermal mass or Night ventilation over distributed thermal mass	61, 11, 58
Temperate	Balanced cooling and heating	See passive heating section pages 58-59.	58

Tropical and subtropical hot-wet climates are considered the most difficult passive cooling situations. However, there are many passively cooled, successful buildings in these climates.

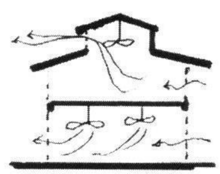
The main thermal sinks in this climate are wet surfaces. The human skin is admirably designed for this purpose if enough air-flow over its surface is provided. Thus, strategies for passive cooling include minimizing solar and thermal loads while maximizing ventilation during the day and night. Thermal mass is not much help in these climates.

Air-flow is critical, so an ACH of 30 is desired. Buildings are large enough to create considerable differential pressure from the windward to the leeward side. This can be used to our advantage if the building is sited correctly and cross ventilation is planned. The limiting condition is when there is little or no breeze; however, there are ways air-flow can be enhanced under these conditions.



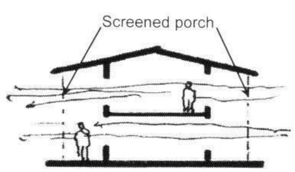
Venturi Effect

Placing a larger exit than entrance will increase air speed in the room.



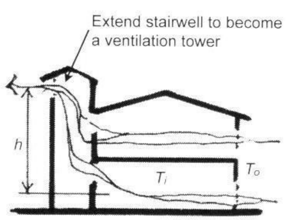
Ceiling Fans

Newer optimized ceiling fans are quiet, reversible and inexpensive. They should be placed in every room in a hot- humid climate. If operated by photovoltaics, the power production is highest during the peak cooling period.



Enhanced Side Effect of Openings

Insect screens can reduce air flow by 60% at 0.7 m/s [1.5 mph] or 28% at 2.7 m/s [6 mph], so large screened areas or porches are more beneficial than smaller windows for screened air-flow.

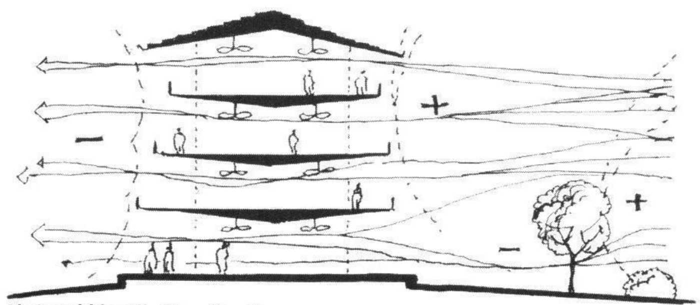


Stack Ventilation

Utilizing the difference in air temperature between incoming and outgoing air as described below:

$$v = 60(0.65)\Delta\sqrt{gh\left(Ti - \frac{To}{Ti}\right)}$$

V = m^3/s [cfm]
Δ = cross sectional area of stack m^2 [ft^2]
g = gravitational constant 9.8 m/s^2 [32.2 ft/s^2]

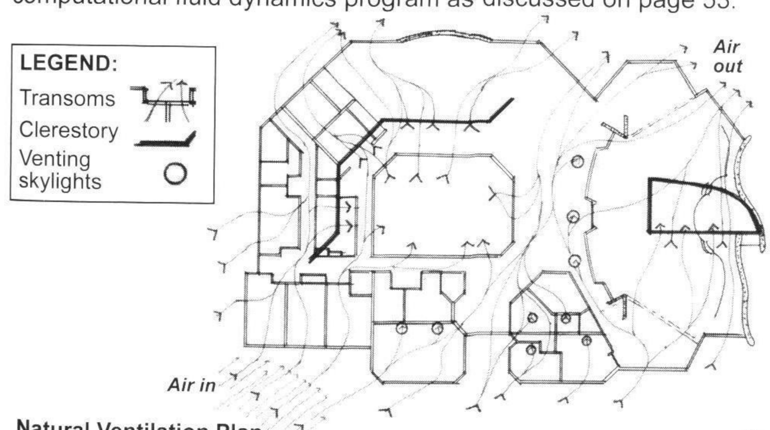


Natural Ventilation Section

In hot-humid climates, tall buildings can access higher velocity breezes, and circulation can take the form of balcony halls which can double as shading devices. Interior air-flow rates can be increased by the shape of the ceiling, adjustable air openings and exits and with supplemental ceiling fans. Landscape elements can also be designed to enhance ventilation at the lower levels, as illustrated above. Evaporative cooling can be encouraged with misters, fountains and other water elements.

There has been a revived interest in natural ventilation for buildings in temperate zones as well for the following reasons: more personal control, noise and cost reductions and night ventilation cooling opportunities. Site wind data is even more variable than insolation data and should be developed for each site. [105,106,107,108]

Conceptual and schematic designs resulting in a natural ventilation plan can be developed using the principles stated on pages 51-52. For large buildings, schematic design should be evaluated by a computational fluid dynamics program as discussed on page 53.

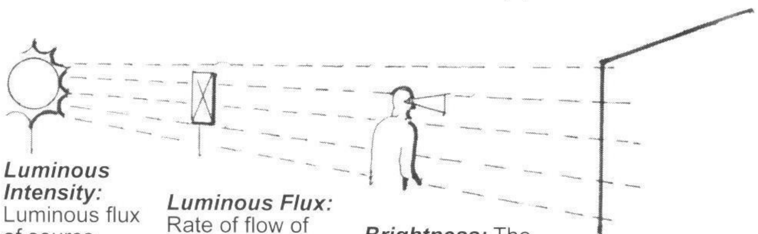


Natural Ventilation Plan

Natural Lighting [13,15,16,17,18,19,20,22]

In relation to all passive functions, natural lighting often yields the greatest payback in commercial and industrial buildings.

- Generally, the largest energy use in non-residential buildings is for lighting (40%). In addition, electric lighting adds to the cooling load of a load dominated building.
- In many areas, the maximum demand for electricity occurs in the hot summer when daylight is plentiful.
- Payroll costs exceed energy costs by several orders of magnitude. The proven advantages of natural lighting in regard to health and productivity make its economic advantages compelling.
- Natural lighting is one of the easiest strategies for reducing carbon emissions associated with electricity production.



Luminous Intensity: Luminous flux of source

Luminous Flux: Rate of flow of visible light

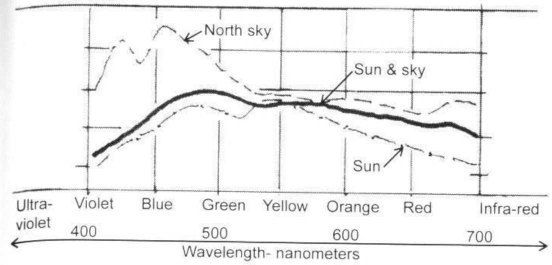
Brightness: The sensation by which an observer is able to distinguish between differences of luminance

Illuminance: Intensity of light falling on a surface per unit area

Units used in natural lighting

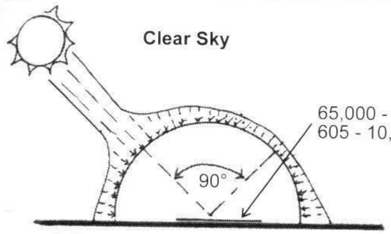
Term/ Units	SI	US	Conversion Factor
Luminous intensity	Candela (cd) = 1/683 watt/steradian	Candela (cd) = 1/683 watt/steradian	1
Luminous flux	Lumen (lm)	Lumen (lm)	1
Brightness	Lambert (L) = $(1/\pi \text{candela})/\text{cm}^2$	Foot-lambert (fL) = $(1/\pi \text{candela})/\text{ft}^2$	1 L = 929.03 fL 1 fL = 0.001 L
Illuminance	Lux (lx) = lm/m^2	Foot candle (fc) = lm/ft^2	1 lx = 0.093 fc 1 fc = 10.764 lx

Sources of Daylight [22]



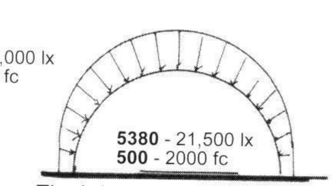
Spectral energy distribution diagram illustrates the color difference between light available for daylighting.

Clear Sky

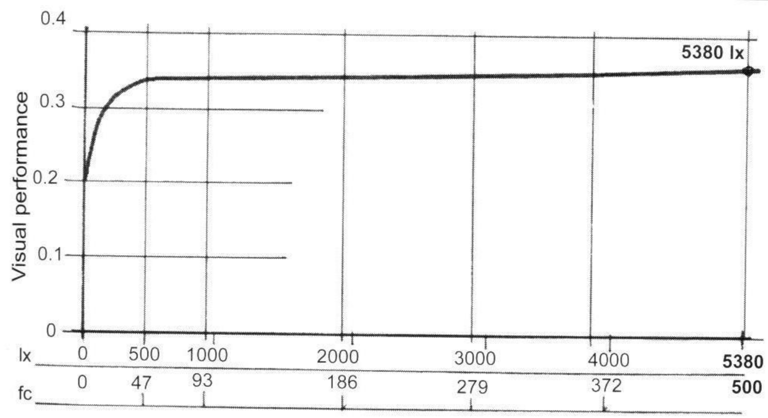


The brightness distribution is typically about ten times greater near the sun than at the darkest part of the sky which is 90° in the other direction.

Overcast Sky



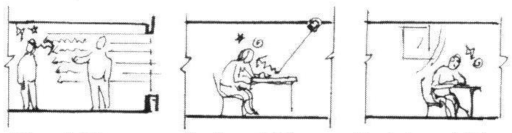
The brightness distribution is typically about three times greater at the zenith than the horizon.



In the 1950's, electrical engineers increased the use of electric lighting in buildings dramatically in order to enhance visual performance. This chart illustrates the limits of only increasing the intensity level of light and the abundance of natural light available, even under an overcast sky. Designing for natural light is not an availability problem, the solution is one of architectural planning (page 66) and geometric manipulation (pages 67-68).

Nature of Daylighting [21,22]

Daylighting is environmental in nature because it involves the immediate spatial context, different visual tasks, complex workings of the eye and brain and compositional aspects like figure ground relationships, brightness ratios and avoidance of glare. Even with sophisticated daylighting software programs, the most common tool for daylight analysis is a 3-D physical model large enough for measurements to be taken. These allow the designer to work directly with the spatial composition of daylighting.



Here, a bright spot at the periphery will cause the iris to adjust improperly for the task involved.

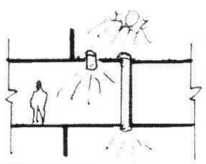
Direct Glare *Indirect Glare* *Peripheral Glare*

Glare: Unwanted light interferes with visual tasks and is best controlled by reflecting light from large surfaces or providing light from several directions.

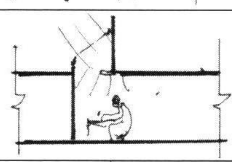
There are two basic approaches to daylighting.

1. ***Side-lighting:*** Has a limited reach horizontally, but with great effort can be extended to 12m [40'], see page 67.

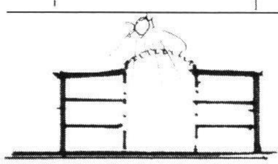
2. ***Top-lighting:*** Listed in order of size below.



Tubular skylights are good for up to two stories, are inexpensive and do not have a high solar heat gain because of their small size.



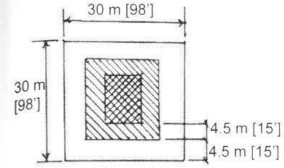
In larger scale applications, wall washing and light monitors work well, see page 68.



Atria type spaces are good for even larger scale applications as seen on page 66.

To achieve optimal daylighting in most situations, a mixture of these approaches should be used.

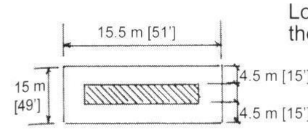
Planning for Daylight [14,21,22]



If we use the standard window arrangement for side-lighting on a 3000 m^2 [32,292 ft^2] square building, available daylight is limited by its reach.

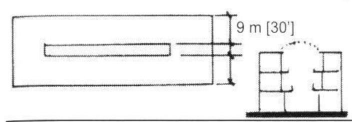
In this example:
51% of the area is in full daylight
33% of the area is in partial daylight
16% of the area has no daylight.

In this case, only half get good light and only half of that light that has good orientation. This loss of day-lighting is even worse for larger buildings.



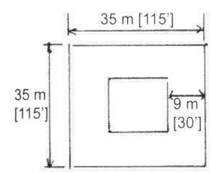
Longer, thinner buildings are better, especially if they run along an east-west axis.

In this example:
59% of the area is in full daylight
41% of the area is in partial daylight



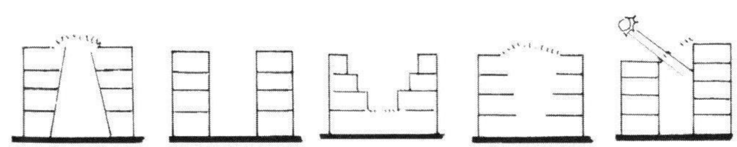
Further improvement could be made by adding a hall/ light gallery down the center of the building.

In this example:
100% of the area can be daylit



Adding a central open space to the square building would also give 100% full daylight. For this reason, we often see atria in large buildings.

Variations of Central Spaces for Daylighting

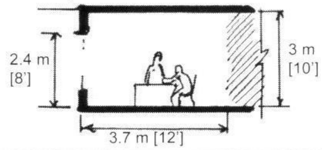


Enclosed glazed atrium *Courtyard* *Light Court* *Atrium facing the sky* *Atrium facing the equator*

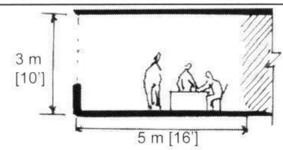
In addition to adding a central space, there are ways to increase the effective reach of side-lighting as shown on page 67.

Side-lighting [21]

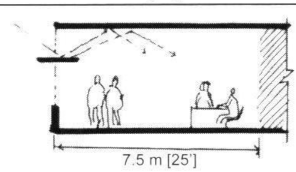
Side-lighting is the most common method of day-lighting, but it is severely limited by its depth of reach. Glare and too much contrast become problematic as the depth of the room increases.



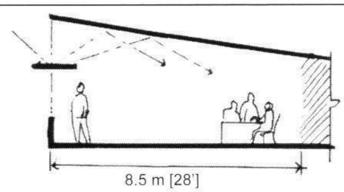
Daylight depth of reach with a standard window configuration.



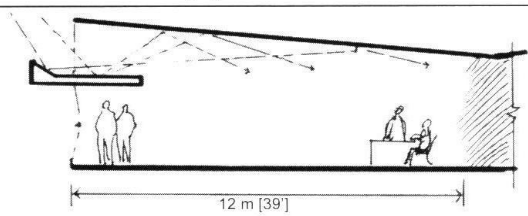
Daylight depth of reach can be increased by raising the ceiling and window height.



Adding a light-shelf on the equator facing side as described on page 24 will extend the depth of reach even further. There are many variations of light-shelfs.



Sloping the ceiling so that it becomes lower further away from the windows can reflect more light and increase the reach.



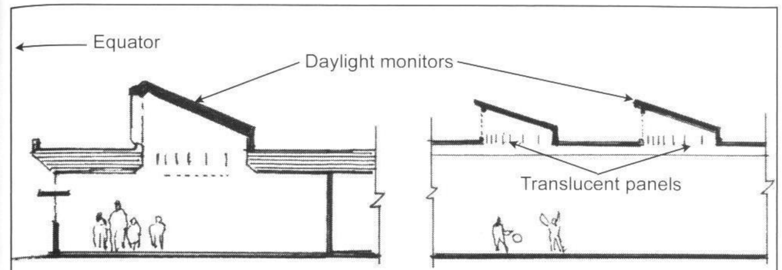
The upper limit of side-lighting includes the following strategies:

1. High ceiling 4.5 m [15']
2. Slope ceiling to rear 4 m [13']
3. Deep light shelf 4 m [13'] with reflective sloped edge

This illustrates the limits to side-lighting and illustrates why it is often used in conjunction with top-lighting as described on page 68.

Top-lighting [45]

For low-rise buildings or in conjunction with atria, top-lighting has many advantages. One of the most effective approaches is the use of monitors facing the equator combined with side-lighting.



Classroom scale space

Gymnasium scale space

The advantages of this orientation and configuration are:

- Greater daylighting resource that is easily controlled, see page 24.
- Cooling load reduction (daylighting can produce lumens with half the heat of fluorescent fixtures).
- Maintenance cost of electric lighting reduced.
- Solar gain for heating season.
- As effective as other strategies with less glazing.

Percent of floor area needed for day-lighting	Small to mid-size space	Large volume Spaces
Equator facing roof monitor	8-11%	5-8%
Equator facing light shelf	8-11%	
Equator light shelf w/ blinds between glazing	10-18%	
Opposite of equator facing roof monitor	12-15%	7-10%
High, opposite of equator facing transom glazing	15-20%	

In summary, equator facing top-lighting and side-lighting should be done first, then spatially supplemented with daylight from other orientations if necessary.

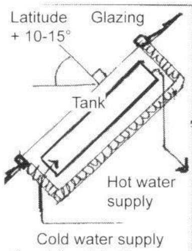
Water Heating [109,110,111]

Solar water heating has been used since the late 19th century and the technology of many of the components is mature. Many of the system designs have still been quite primitive, but we can expect that competition in the market will deliver systems with higher solar fractions. Most systems now use back-up heating to insure hot water all the time.

Most hot water systems don't circulate the water through the collector directly. This can lead to calcium carbonate deposits in the collector tubes, corrosion of the tube, or damage to the collector during freezing weather. Instead, a heat exchanger is used and this can be a coil in the storage tank or a heat exchanger outside of the tank in which one fluid loop goes to the collector, and one goes to the tank. Typically, these fluid loops have circulation pumps operated by a controller.

Most variations in hot water systems occur in the tank configurations. There is the batch system, example 1, where the tank is also the collector. This can be used for mild-sunny climates where freezes are not too severe.

Another passive system is the thermosiphon system, example 2, where the buoyancy of heated water operates the system rather than a pump. There are several variations on this approach shown in examples 2a and 2b.

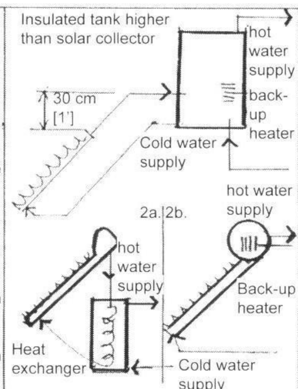


A well-insulated box integrated in the attic, roof or ground; glazed on the equatorial side lined with reflective foil- tank/ collector flat black or with selective surface.

Ex. 1: Batch Passive Water Heater

Solar heating fraction 50-65%

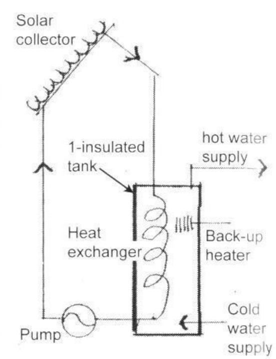
Advantages: Simplicity, long life, no power needed
Disadvantage: Weight is 227 kg [500 lbs.], so reinforcing of roof structure may be necessary.



Ex. 2: Thermosiphon Passive Water Heater & Variations

Solar heating fraction 60-70%

Advantages: Long life and no power needed
Disadvantages: Complexity of freeze protection.
Variation 2a: A percolation system using an alcohol water loop to drive hot water down to a separate tank.
Variation 2b: Integral collection-tank configuration with back-up heater.



Ex. 3: One-tank Active Water Heater

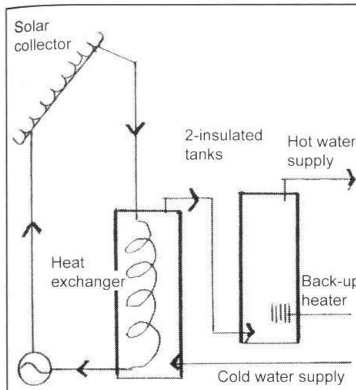
Solar heating fraction 60-70%

Advantages: Tank is on the building's interior where it is protected from the elements and is not a visual factor.

A one tank system with a pump is shown in example 3. The disadvantage of ex. 3 is that heat tends to migrate down quite rapidly, so more back-up heat than necessary is used. The two-tank system in example 4 is the most common. It has one disadvantage, solar heat only goes to the back-up tank when hot water is used, so if one goes on vacation one might as well not have a solar water heater.

Improvement is possible in the tank system configuration as in example 5. Here a double set of tanks is used, one mounted above the other. A double set of passive natural convection chimneys between the tanks exchange hot and cold water between the tanks whenever the solar tank is hotter than the back-up tank and during periods of less use such as a vacation no back-up heat is needed. This set of chimneys act as a thermal diode where heat can flow up but not down.

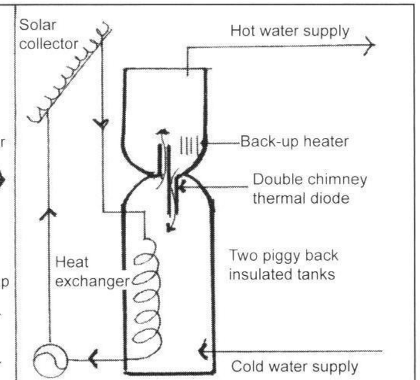
Water consumption varies greatly from day to day, although most systems assume that it is always the same. To account for the consumption variability the total volume of the tanks should be 40% larger that the average daily hot water consumption.



Ex. 4: Two-tank Active Water Heater

Solar heating fraction 60-70%

Separate solar heating system from back-up system.
Disadvantage:
Solar hot water only flows to the back-up tank when hot water is used, so when no water is used, the solar water heater is useless.

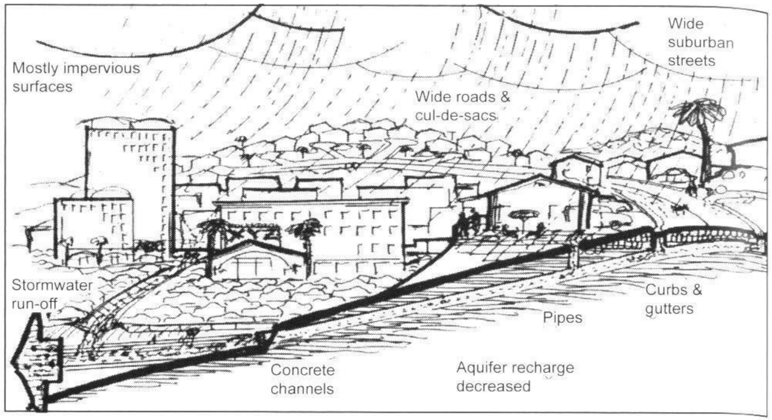


Ex. 5: Optimized Two-tank Water Heater

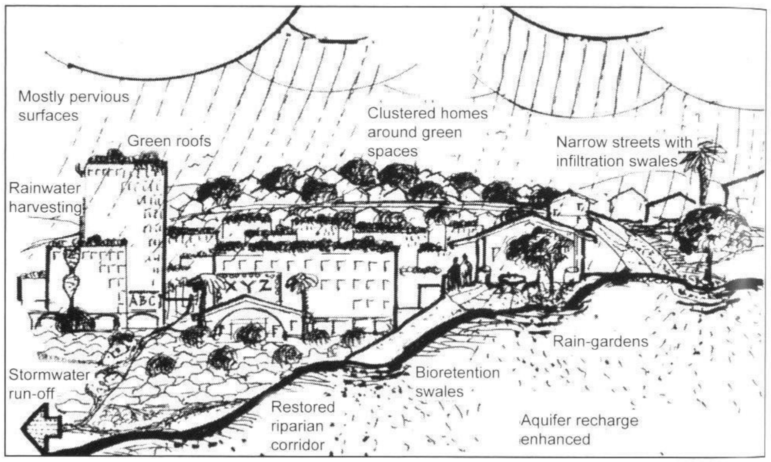
Solar heating fraction 80-90%

This optimized configuration combines the best of all the active systems.

Notes:
1. PV powered pumps are a great match for water heaters.
2. Evacuated tube collectors can work well even in cold climates.These can be thermosiphon or active systems.



***HIGH IMPACT DEVELOPMENT* (*HID*)** is characterized by having:
- High percentages of impervious surfaces
- Landscaping that is mostly decorative
- Storm-water issues & pollution which have typically been handled by concrete curbs, pipes, and canals



***LOW IMPACT DEVELOPMENT* (*LID*)** is characterized by having:
- A high percentage of pervious surfaces
- Regenerative, native or edible landscaping
- Water infiltration and filtration of on-site pollutants
- Surface drainage recharges the local aquifer or is harvested for use

Rainwater Harvesting

Rainwater harvesting is a method of capturing high quality water locally which reduces the energy and transportation fuels used to transport water to a site. Harvested rainwater can reduce the storm-water run-off from a site and the associated pollutants that it would carry with it.

Many communities throughout the world harvest rainwater as their sole source of water, while in more regulated urban areas, there are restrictions on the collection of rainwater. Draught conditions and storm-water managers encourage the catchment of rainwater.

There are a variety of storage methods from below grade cisterns to above-ground tanks. Storing the water high enough above the point of use allows gravity to create enough pressure for dispersing the water.

Typical rainwater catchment systems include:

- Catchment area (roof or drainage area on the ground).
- First flush diverter (to remove the debris & pollutants that may have accumulated during the dry season).
- Storage tank or cistern
- Filter (depending on end use may range from sand and charcoal with UV sterilization to more complex filtration and treatment)
- Pump (if necessary to elevate the water for use)

Calculating catchment area:

Water collection = (Collection Area) x (Rainfall) x (Run-off Coefficient)

For example, a roof of 200 m^2 with annual rainfall of 500 mm [20"] and a run-off coefficient of 0.8 will be able to collect 80m^3 [21,136 gallons] annually.

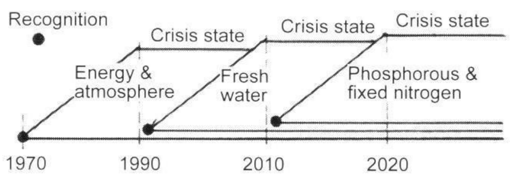
$$(200\ m^2) \times (500\ mm) \times (0.8) = 80\ m^3\ [21{,}136\ \text{gallons}]$$

In areas where rainfall is scarce and it is needed to provide drinking water, the storage capacity may need to be 40-110 m^3 [10,000-30,000 gallons]. Whereas areas of greater more frequent rainfall may utilize a system of 10 m^3 [2640 gallons] of storage or less.

www.harvestingrainwater.com

Waste Systems

The 21st century faces a series of resource crises, as serious as our energy and atmospheric crises. They are all related to our consumption patterns and our built environment. Using passive approaches which combine use, production, and efficiency at the scale of buildings can help relieve this crisis.



Resource Crises of the 21st Century

All five of these resources are essential to agriculture.

Phosphorous deposits that are easily exploitable are diminishing. As a result phosphate costs have risen by 500% during the last 10 years. As with oil, many nations have depleted phosphate mines and now must rely on imports. [52]

One of the best sources of phosphate now available is in human waste. One half of that is available in urine which is easy to recover if separated from solid waste. Modifying toilets and toilet habits to collect urine is a passive approach to tapping into this resource which is also rich in fixed nitrogen.

Doing the same with solid waste is harder due to contamination of lead and cadmium leached from old pipes. Making agriculture sustainable over the long term begins with efforts to phase out toxic metals from our plumbing.

Source control of waste

Waste streams include waste-water, both graywater and blackwater, trash from consumer goods, yard and plant trimmings, food scraps and a number of hazardous chemicals, from cleaning products to hobby materials like paints. The most effective management of waste is source control.

Blackwater can be avoided with the use of composting toilets. Composting toilets and waterless urinals do not require any water at the point of use. They have been successfully used on university campuses as well as residences. Composted waste can be used as fertilizer on tree and non-edible landscape applications. Maintenance for composting toilets usually requires a space below the toilets for collection via gravity. Urine sequestration is also becoming important as mentioned above.

Biological waste treatment systems which utilize aquatic systems and greenhouses or ponds can successfully treat blackwater to a drinking water quality. A living machine has been used to describe this type of system and depending on the design, tilapia (fish), mushrooms, flowers, etc. can be harvested from the biological processes in a waste-to-nutrient cycle.

Non-processed foods that do not contain meat scraps and oils can be composted several ways. In large cities, a bin for compost is often provided which takes the compost off-site for processing. Compost is a resource. One of the best ways of processing it is with worm bins. The excrement or castings from the worms are water-soluble nutrients and bacteria which make a rich organic fertilizer and soil conditioner. Vermiculturists recommend Red Wigglers (Eisenia foetida or Eisenia andrei), European nightcrawlers (Eisenia hortensis) and in the tropics, blueworms (Perionyx excavatus).

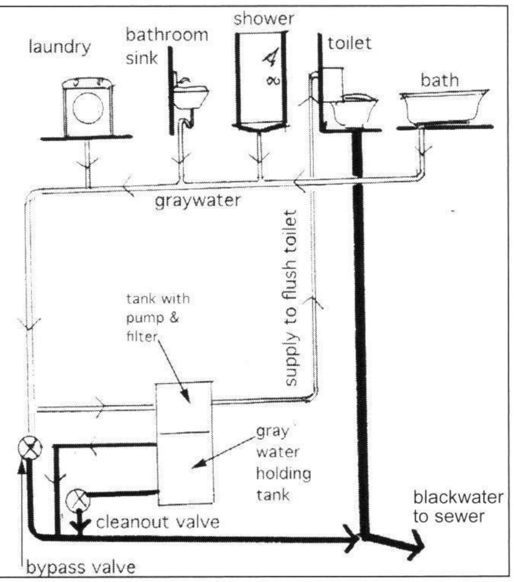
Graywater Systems [41]

Graywater: Waste-water that has come from bathroom sinks, washing machines, and showers or tubs that has not come into contact with human waste such as urine or fecal matter. Kitchen sink water is often considered blackwater because it often contains oils, grease and other food waste.

Black-water is the waste-water from toilets, kitchen sinks and washing machines used to clean soiled diapers. It is very important to keep black-water and graywater separate. Graywater may be used for landscape irrigation and toilet flushing depending on local regulations. Some areas will even allow kitchen sink water to feed into the graywater system, but this usually only occurs when there is treatment of the graywater before it is reused or sent into irrigation pipes.

Graywater has been integrated into some innovative toilets which utilize a faucet and wash basin on the top of the toilet's holding tank. When the toilet is flushed, the water used to refill the tank prior to the next flush is directed through the faucet for hand-washing, then it drains via the washbasin into the toilet's holding tank. This type of integrated graywater system is popular in Japan and is one of the only systems that does not require dual plumbing.

The graywater system illustrated here uses a pump, holding tank and filtration to reuse large quantities of graywater for toilet flushing. Excess graywater must be able to be directed to the septic or sewer system via a bypass valve. Plumbers are usually able to deal with graywater plumbing inside a building and landscape installers are able to distribute the graywater into the landscape.



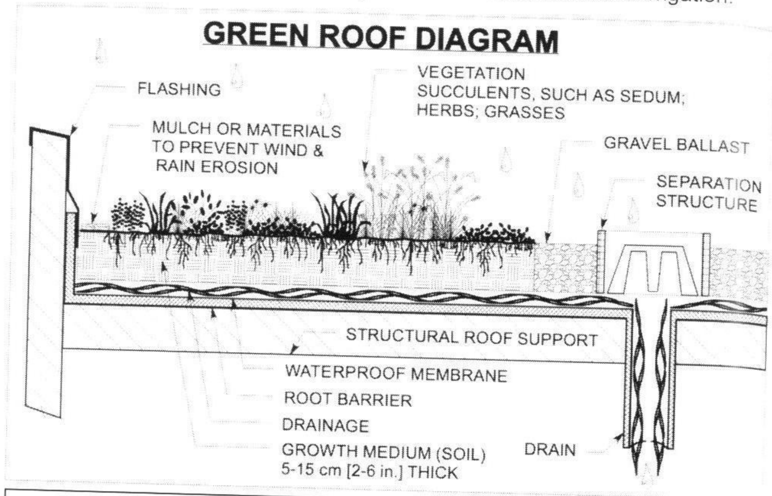
Typical graywater systems include a collection system, surge capacity, filtration, a distribution system and an end use. Storing large quantities of graywater is not recommended because it can turn into blackwater if not treated first. Treatment can take the form of sand filters or chemical, UV or ozone disinfection for graywater that will be held for toilet flushing.

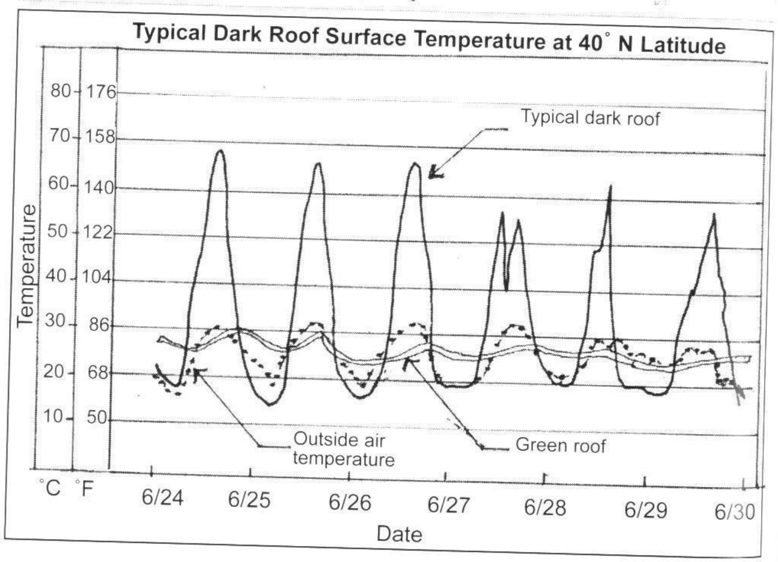
If graywater is used for irrigation, it should be distributed subsurface and not sprayed overhead. It is also not recommended for use on certain edible plants, but this will vary depending on local code.

Green Roofs [39]

A green roof is a roof that is partially or completely covered with vegetation and soil; or a growing medium, planted over a waterproof membrane. Also known as Living Roofs, Eco-Roofs, Oikosteges, or vegetated roofs.

Green roofs can be categorized as intensive or extensive, depending on the depth of planting medium and the amount of maintenance required. Intensive roofs typically have deeper soil, require more maintenance and irrigation.





Roof gardens used for food production are considered intensive. Extensive green roofs, by contrast, are designed to be virtually self-sustaining, require minimal maintenance, and can be established on a very thin layer of planting medium.

Advantages of green roofs include:

Food Production: Growth of fruits, vegetables and flowers, turning an otherwise hostile environment of concrete and asphalt into viable agricultural land.

Reduced Energy Use: Green roofs reduce insolation, absorb heat and act as insulators, reducing heat transfer through the roof and improving indoor comfort. Studies have shown that green roofs can reduce summer heat gains by as much as 95% and winter heat losses by an average of 26%. [42]

Reduced Heat Island Effect: Green roofs provide shade and remove heat from the air through evaportranspiration, reducing the temperature of the roof surface and the surrounding air. On a hot summer day the surface temperatures of a green roof can be up to 50°C [122°F], cooler than that of a conventional roof. [50]

Reduced Air Pollution: and greenhouse gas emissions- by lowering air conditioning demand. Vegetation can also remove air pollutants and greenhouse gas emissions through dry particle deposition and carbon sequestration and storage.

Enhanced Storm-water Management & Water Quality: Green roofs can reduce the overall volume of storm-water from 64%-94% and slow the peak flow rate of runoff in the urban environment; they also help filter pollutants from rainfall and can be used for water purification and treatment. [47]

Improved Quality of Life: Green roofs can provide aesthetic relief in urban centers, provide valuable habitat for a variety of animal and insect species and for the building's occupants, can help to reduce sound transmission and increase comfort.

Longevity of Materials: Green roofs are expected to increase a roof's life-span by two to three times due to the reduction in extremes in temperature and exposure. [] Over the life cycle of the building this can be a substantial savings.

Living Walls: Living walls, also known as green facades, bio-walls or vertical gardens, have many of the same advantages as green roofs. In urban areas, with large amounts of available vertical surfaces, living walls may also be a means of water re-use, graywater treatment, air purification, and urban agriculture. [51] In arid climates it is particularly advantageous, as water circulated on a vertical surface is less likely to evaporate than in horizontal gardens.

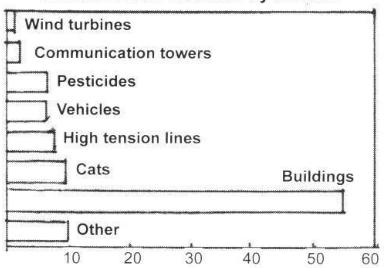
Plant Species: Final plant selection depends on many factors: type of assembly, depth of soil/medium, climate specifics, intended use, species ability to handle seasonal variation, available native plants species, etc.

Habitat: Green roofs can provide a refuge for birds, butterflies and other wildlife.

Wildlife Protection [112-128]

Another attribute of passive design is the lesser known but important issue, the conservation of wildlife. Ecological traps can be created by buildings. Many species rely on light polarization for location and many building materials can polarize light and confuse behavior. Buildings can also be barriers.

Annual Bird Fatalities by Source



Percent per 10,000 Bird Fatalities

Glass can be invisible to birds and if it reflects trees, shrubs or sky where they normally take refuge chances are they'll fly into it.

Conservative estimates are that 100 million birds die as a result of hitting glass in the U.S. every year, comparable to a major oil spill every day. World wide bird fatalities in regard to buildings are estimated to be one billion per year.

Site

- The lowest two levels of the building are the most dangerous to birds.
- Avoid landscape glazing; glass sound barriers, glazed connections, etc.
- Landscape close to the wall reduces flight momentum, 1m [3'] is optimal.

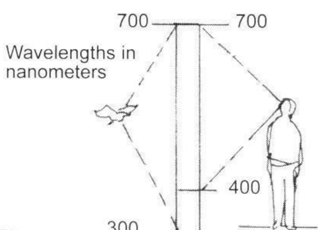
Glazing

- Avoid see-through, monolithic, indistinguishable expanses of glass. (*)
- Glass reflectivity should be 10% or less.
- Use screens, trellises, grills or light shelves to reduce the unbroken glass area, the optimal spacing for birds is 11.25 cm [4.5"]. (*)
- Angled glass on lowest floor will reflect the ground rather than the sky (20 degrees off vertical is optimal).

Lighting

- Design to eliminate light trespass from the interior of the building.
- Use light colored curtains or blinds if evening illumination is utilized.
- Good daylighting techniques such as smaller lighting zones, use of task lighting, etc. produce safe bird conditions.(*)
- For high rise buildings that need to meet aviation safety night standards use white strobe with 3 second flash interval rather than continuous flood lighting, rotating lights or red lights.
- Outdoor lighting on or around the building should be kept to a minimum.
- Utilize motion detectors as lighting controls whenever possible.(*)

(*) indicates passive solar objectives for other reasons as well.



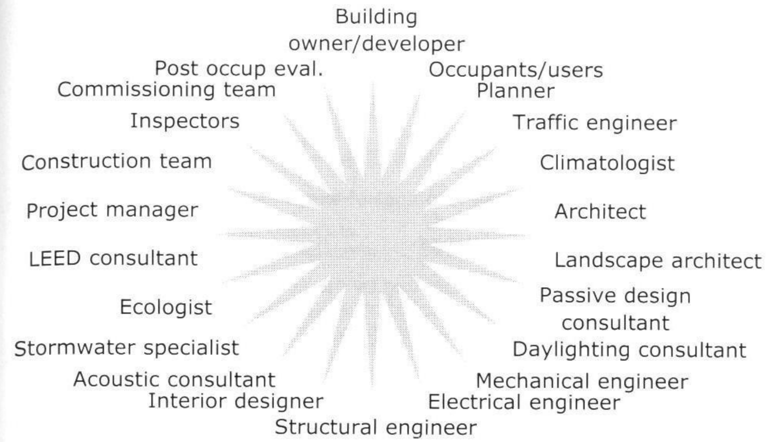
Birds see a wider spectrum of light than humans at the UV end of the spectrum.

Currently, glass is being developed that creates a pattern in this zone that is visible only to birds.

Passive designers should encourage this effort. More information at: http://www.glaswerke.arnold.de

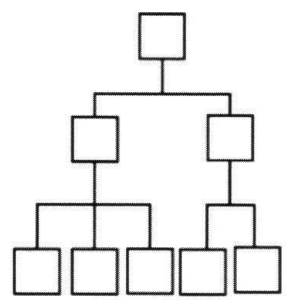
Integrated Design [32,37,38,40,44,48]

The power of passive solar design is the power that comes from integration of separate components to achieve the efficiency of synergy. This kind of effort, especially for large buildings, requires many specialties, all which must to work together in an integrative fashion.



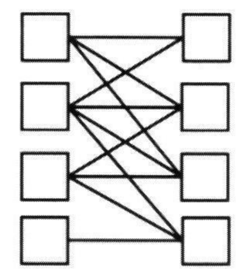
Organizing the design and construction team to accomplish this level of integration requires a transition from the traditional organization of generalists and specialists as shown below, to an organization where design and specialization take place at each step in the process from conception, to construction, to occupancy and operation.

Reductionism, compartmentization, specialization



Hierarchical Organization of Single Specializations

Systematic, integration, specialist/generalist networking



Network Organization of Multidisciplinary Teams

Aesthetics [37]

Passive solar design is architecture and architecture is involved with aesthetics. The question of what is aesthetics has been asked for a long time from Plato to Tolstoy to Wright to Hundertwasser. So the question continues what are the aesthetics of *passive solar architecture*? Historically, architectural aesthetics have dealt with three qualities: harmony, proportion and scale. These three have been used to create architecture composed of:

sequence - the movement of things

rhythm - the repetition of things

order - the constructive nature of things

form - the shape of things

theme - the primary story told by the composition

feeling - the emotion conveyed by the story

clarity - the clear communication of any or all of the above

The aesthetic goal in any composition is to achieve synergy, where all the elements are so well composed that the whole exceeds the sum of its parts, giving the composition a transcendent quality. This quality has been achieved by all great architecture.

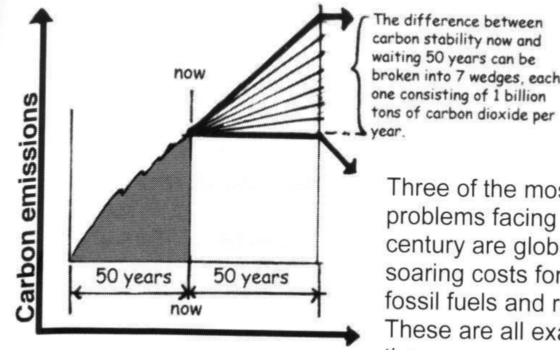
The theme for passive solar architecture could be comfort, which has been discussed through out this manual. However, the next level of comfort would be health; personal health, community health and planetary health.

With comfort and health comes the feeling of rightness, rightness that supports health and comfort. Successful passive solar architecture can create comfort and contribute to health. In addition to being successful aesthetically, it must be clear in its communication of these qualities through its feeling of rightness.

Aesthetically successful passive buildings have an intense but peaceful feeling of this rightness that is communicated by the building itself without words or description.

Modern architecture using the theme of industrial progress became the architecture of the twentieth century. Passive solar architecture using the theme of comfort, health and sustainability is becoming the architecture of the twenty-first century.

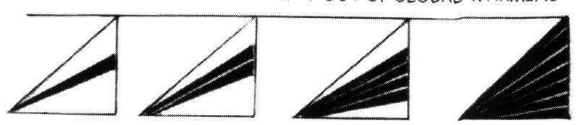
Summary [36]



Source: A Plan to Keep Carbon in Check, Socolow & Pacala Scientific American 2004.

Three of the most critical problems facing us in our new century are global warming, soaring costs for post-peak fossil fuels and resource wars. These are all exacerbated by the way we use energy. We can help to mitigate these through wide application of passive design. Recent quantification of global warming gives us some inkling of what our best strategies for carbon mitigation could be. Some of these mitigations are reactive and require big changes in behavior. Some are proactive and easier to accomplish. Passive design is part of this proactive approach. For example, 48% of the greenhouse gases discharged from the United States originate in buildings, and these could have been cut by 80% with passive design. We have an obligation to design buildings in a way that can help reduce global warming. With sustainable planning, passive solar architecture and appropriate technology, we can start to build our way out of these predicaments.

BUILDING OUR WAY OUT OF GLOBAL WARMING



ONE CARBON REDUCTION WEDGE	LIGHT GREEN	BRIGHT GREEN	DEEP GREEN
Each of the following would yield one wedge of carbon reduction: - 2 billion cars with 60 mpg v. 30 mpg - Reduce worldwide population - Stopping deforestation worldwide - Reduce buildings electricity use by 25% Given the effort to achieve one reduction wedge, passive buildings are the easiest path. Zero energy buildings can yield 4 wedges.	Reduce buildings electrical use by 50% Gives us 2 wedges	Zero Energy Building Gives us 4 wedges	Integrated planning & building techniques Yield more wedges Net energy producing passive buildings New urbanist planning Optimizing building materials Integrating passive approaches to water & waste functions

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Climate Data

http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm
http://www.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html
http://www.ncdc.noaa.gov/oa/mpp/freedata.html
http://www.nws.noaa.gov/om/coop/standard.htm
http://www.wcc.nrcs.usda.gov/climate/windrose.html
http://www.wmo.int/pages/prog/gcos/documents/GSN_Stations_by_Region.pdfhttp://www.ncdc.noaa.gov/oa/wdc/index.php

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Daylighting

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