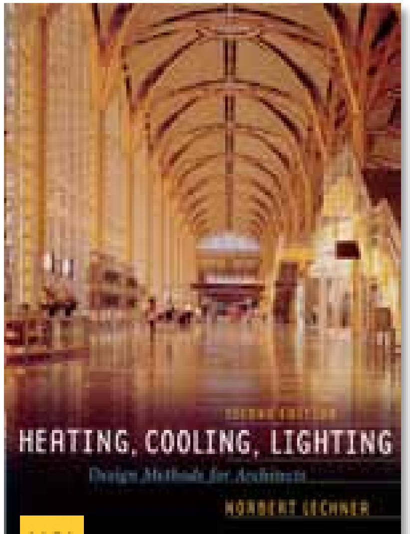
Arch 125: Environmental Building Design

Passive Solar Design (Heating)



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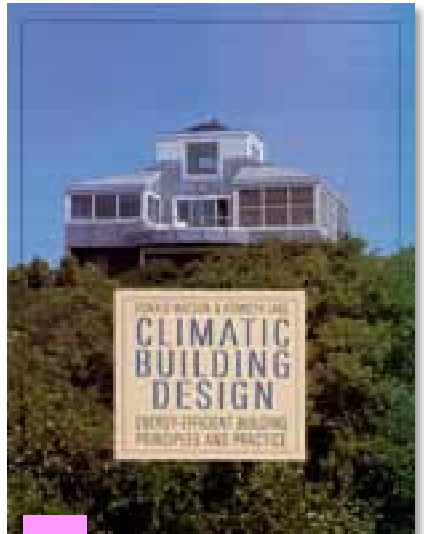

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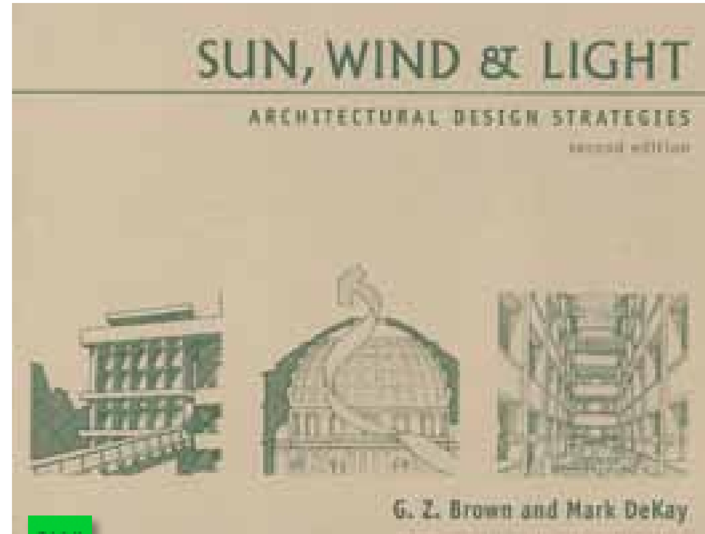
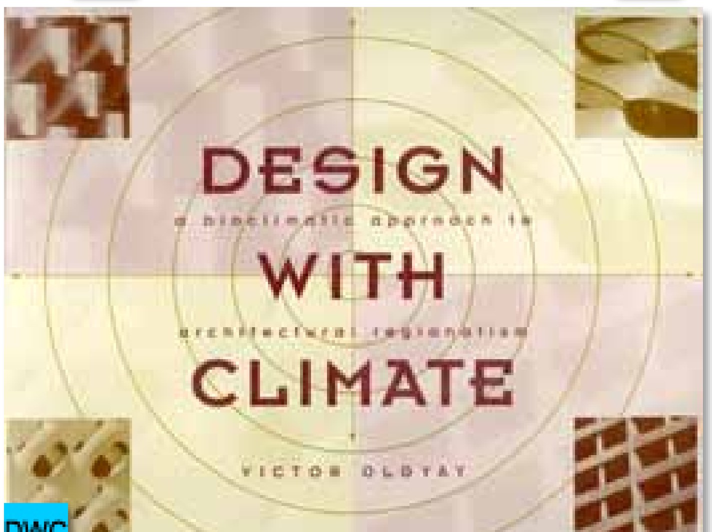


SWL



DWC

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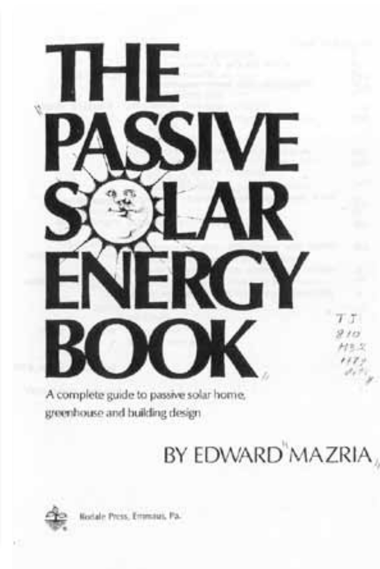


Texts used in the preparation of this presentation.

What is PASSIVE Design?

- is based upon **climate considerations**
- attempts to control comfort (heating and cooling) **without consuming fuels**
- uses the **orientation of the building** to control heat gain and heat loss
- uses the **shape of the building** (plan, section) to control air flow
- uses **materials** to control heat
- maximizes use of **free solar energy** for heating and lighting
- maximizes use of **free ventilation** for cooling
- uses **shade** (natural or architectural) to control heat gain

How do Passive and Sustainable Design relate?

Passive solar heating and passive ventilation for cooling assist in creating sustainable building by reducing dependency on fossil fuels for heating and cooling buildings, as well as reducing the need for electricity to support lighting by using practices of daylighting in buildings.

In LEED, Passive Design assists in gaining points in the Energy and Atmosphere category, as well as in Indoor Air Quality as Passive Design promotes natural ventilation and daylighting strategies.

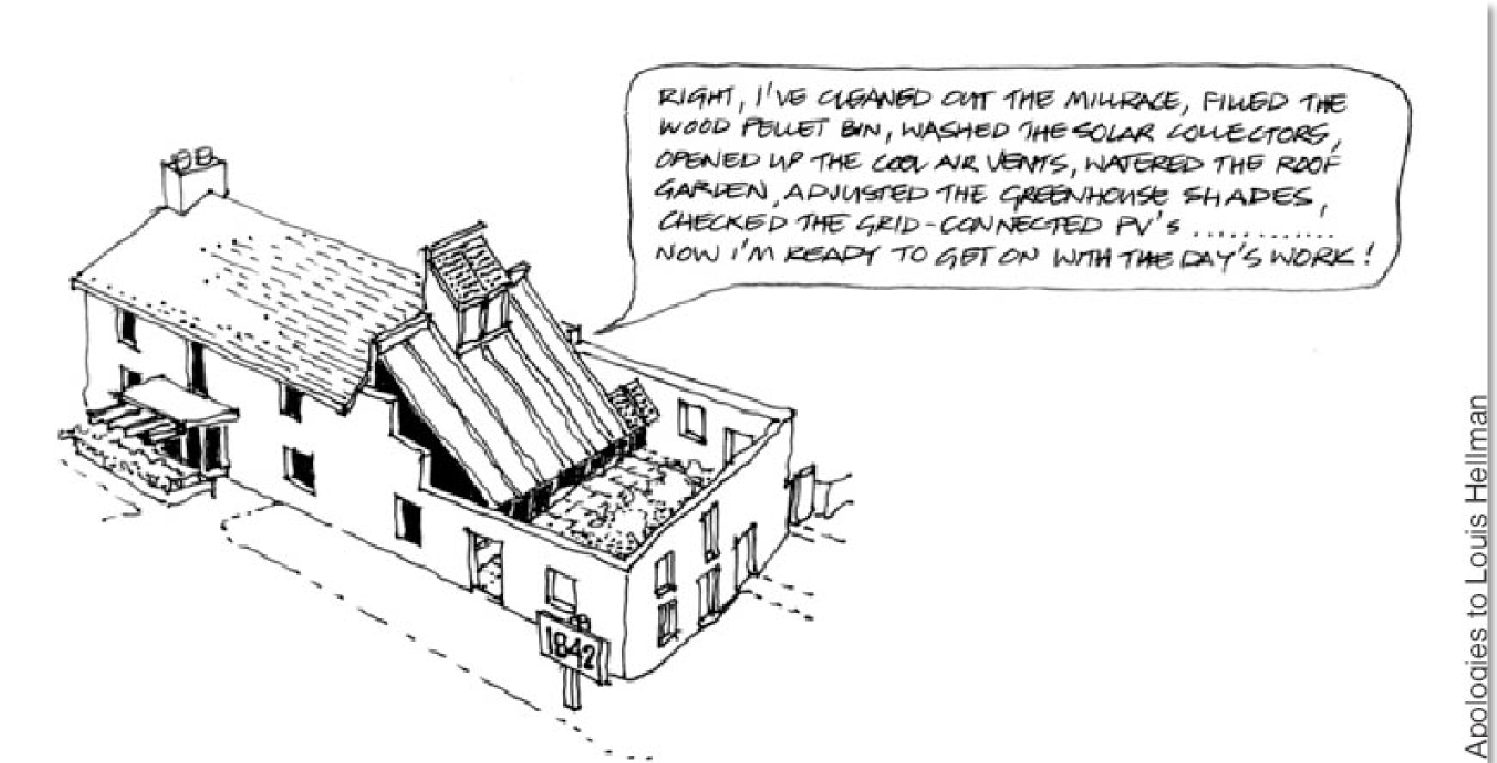
However, not all Sustainably Designed buildings are strongly Passive, and not all Passively Designed buildings are by default strongly sustainable (although this is more likely than the reverse.)

Passive Buildings Require Active Users…

Unlike most contemporarily designed buildings that rely on "Thermostat" control to regulate the temperature and relative humidity (comfort) in buildings, Passive Buildings require occupant involvement to ensure their success.

Occupants need to be EDUCATED as to when to open and close windows, raise and lower shades, and otherwise control some of the non automated means of controlling the effects of the sun and wind on the interior environments of the building.

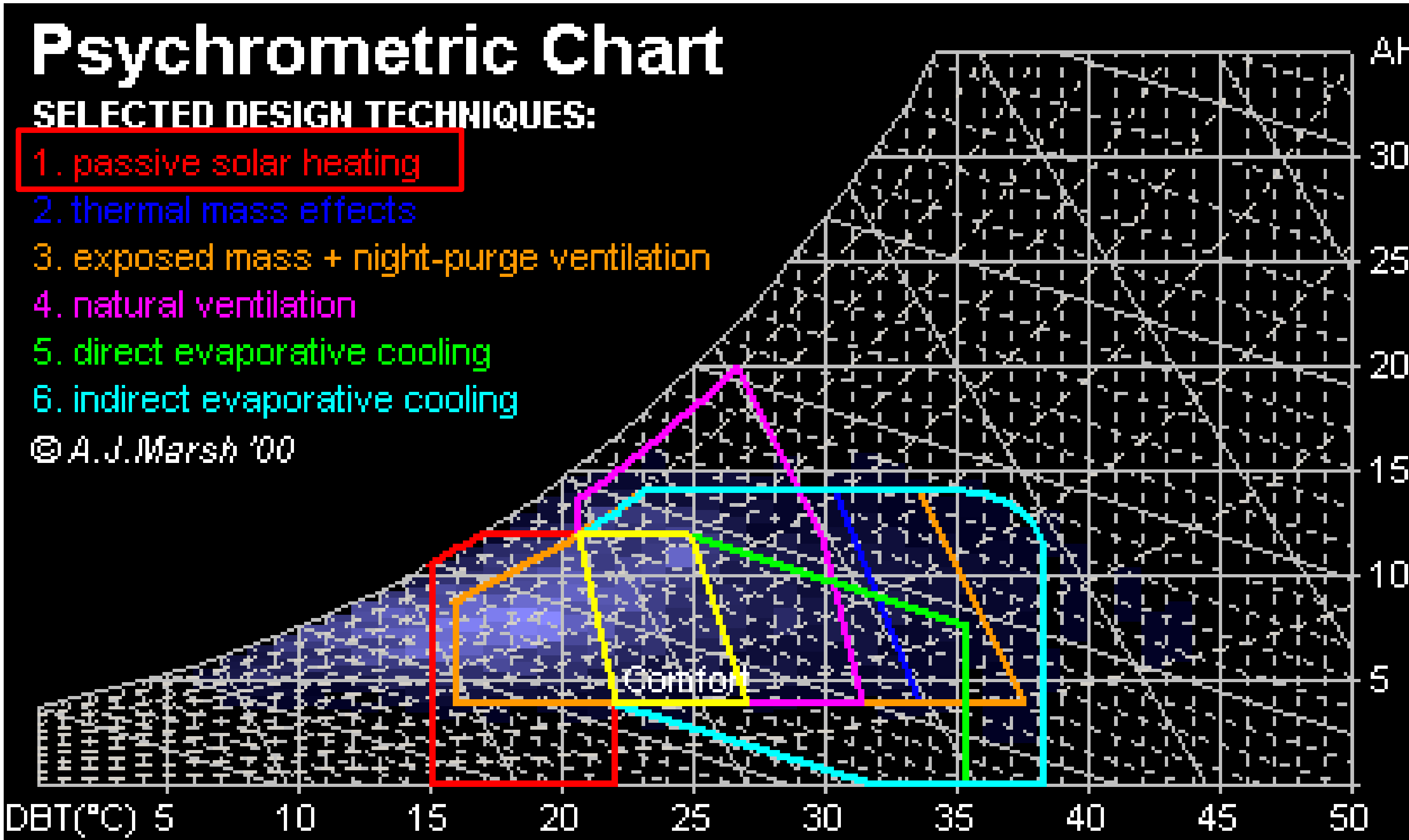
Sometimes Passive Buildings, due to limitations in achieving an interior climate that falls in the middle of the "comfort zone", will require occupants to accept a wider range of acceptable temperature and relative humidity values.



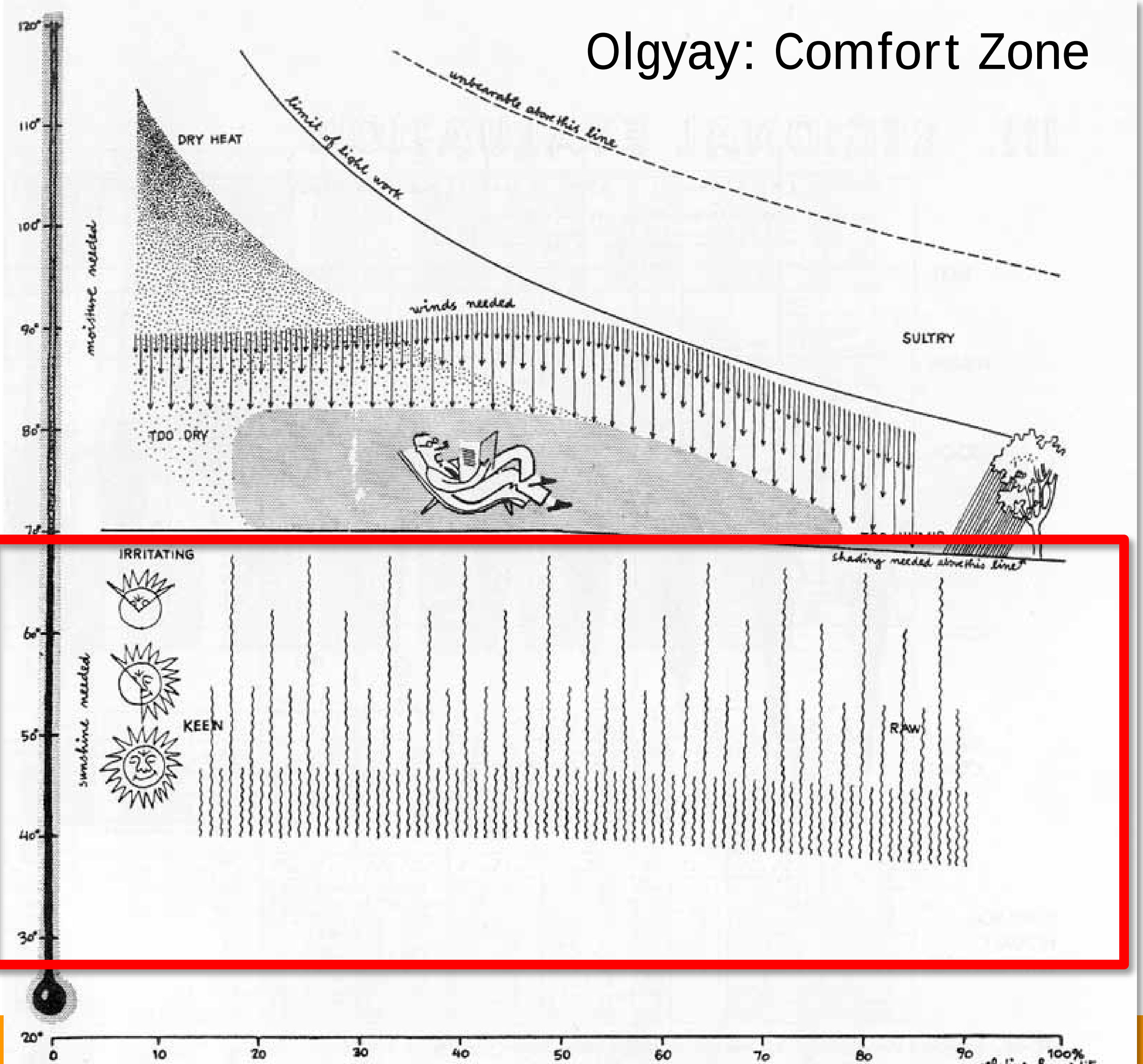
"RIGHT, I'VE CLEANED OUT THE MILLRACE, FILLED THE WOOD PELLET BIN, WASHED THE SOLAR COLLECTORS, OPENED UP THE COOL AIR VENTS, WATERED THE ROOF GARDEN, ADJUSTED THE GREENHOUSE SHADES, CHECKED THE GRID-CONNECTED PVs……….. NOW I'M READY TO GET ON WITH THE DAY'S WORK!"

(Louis Hellman writing abut **The Mill, Eden Mills** home and office of Charles Simon.)

6 main strategy modes for PASSIVE design



Olgyay: Comfort Zone



46. Schematic bioclimatic index.

DWC

Strategies for Winter Climate Control

CONTROL STRATEGIES		CONDUCTION	CONVECTION	RADIATION	EVAPORATION
WINTER (HEATING)	PROMOTE GAIN			Promote solar gain	
WINTER (HEATING)	RESIST LOSS	Minimize conductive heat flow	Minimize external air flow; Minimize infiltration		
SUMMER (COOLING)	RESIST GAIN	Minimize conductive heat flow	Minimize infiltration	Minimize solar gain	
SUMMER (COOLING)	PROMOTE LOSS	Promote earth cooling	Promote ventilation	Promote radiant cooling	Promote evaporative cooling
	HEAT SOURCES		Atmosphere	Sun	
	HEAT SINKS	Earth	Atmosphere	Sky	Atmosphere

Strategies of Climate Control

(chart modeled after Watson "Climatic Building Design")

Solar Savings

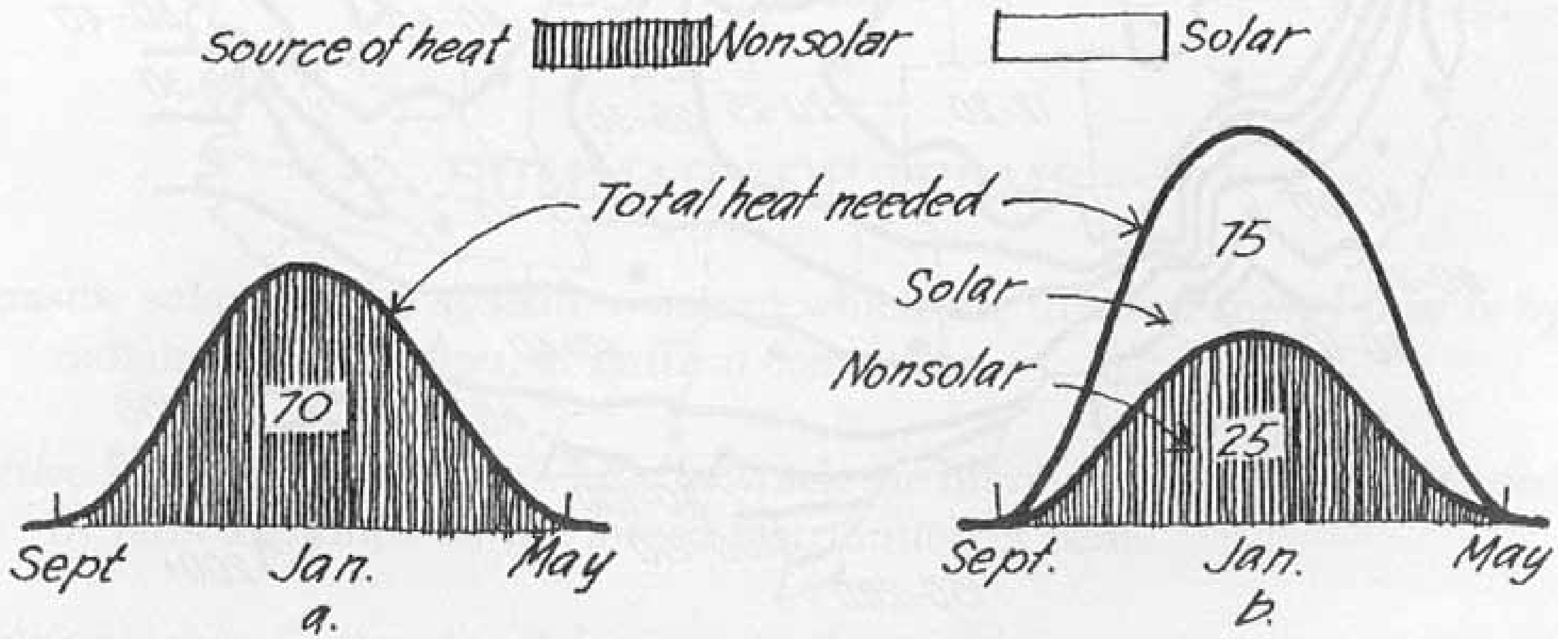
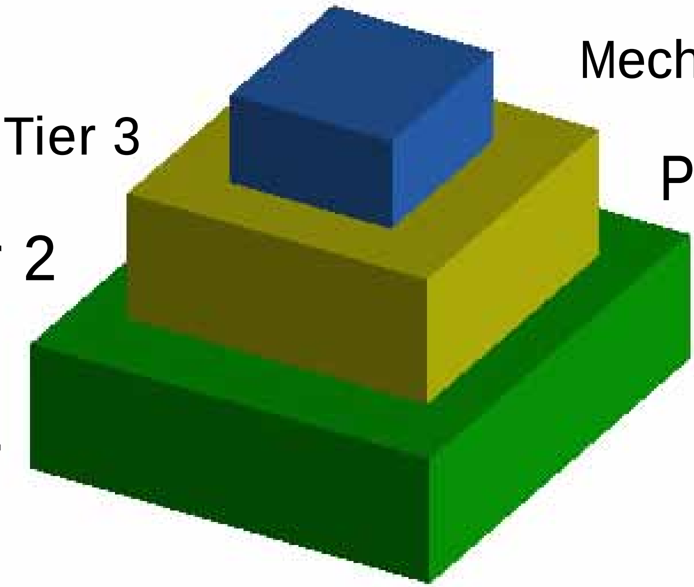


Figure 7.4: Performance comparison of: (a) "reference" non-solar building and (b) passive solar building. *(Redrawn from Stein et al., 1986, by permission.)*

Reduce loads: Passive Strategies

The tiered approach to reducing carbon for HEATING:



Maximize the amount of energy required for mechanical heating that comes from renewable sources.

- **Source:** Lechner. Heating, Cooling, Lighting.

Passive SOLAR Heating Strategies:

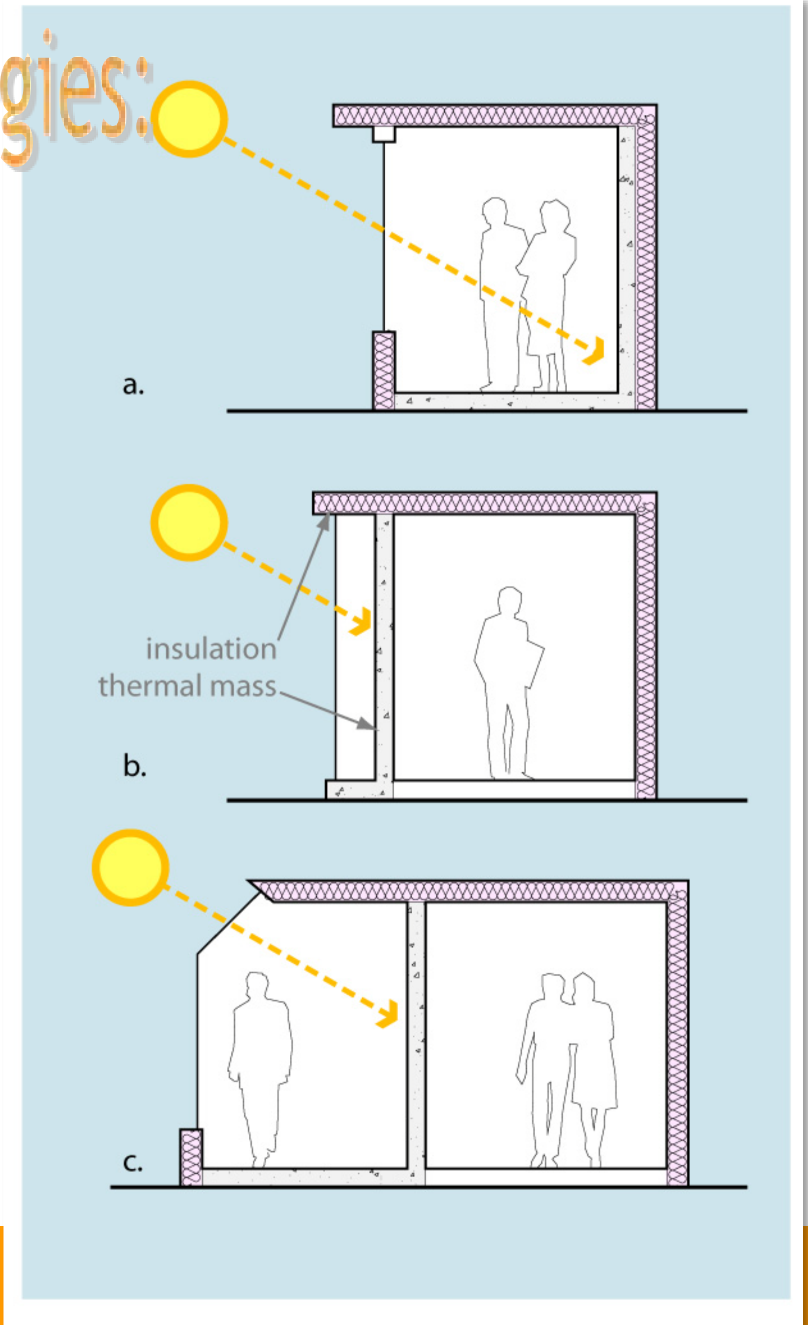
1. primarily south facing windows
2. proportion windows to suit thermal mass and size of room(s)

3 MAIN STRATEGIES:

Direct Gain

Thermal Storage Wall (trombe)

Sunspace



General Rules:

ECS

1. **Conservation Levels**: Higher than normal levels of insulation and airtightness (maybe 2X)

2. **Distribution of Solar Glazing**: distributed throughout the building proportional to the heat loss of each zone

3. **Orientation**: Optimum within 5 degrees of true south

4. **Glazing Tilt**: Looking for perpendicular to sun angle in winter, although vertical efficient where lots of reflective snow cover

5. **Number of glazing layers**: 3 to 4 for severe climates, less otherwise

6. **Night insulation and Low-E glazing**: Greatly improves reduction of night heat losses

7. Mixing passive systems can increase comfort levels.

General Rules:

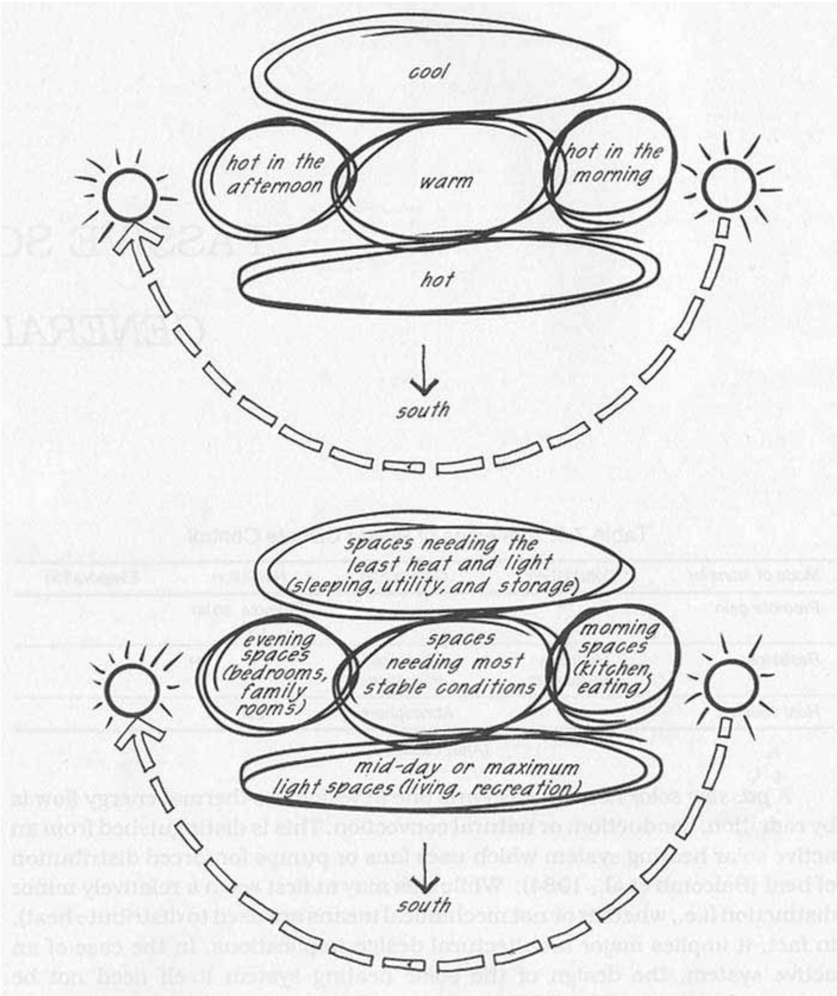


Figure 7.2: Designing for the sun: (a) horizontal temperature zones of building interiors, and (b) potential design response. *(After AIA, 1981.)*

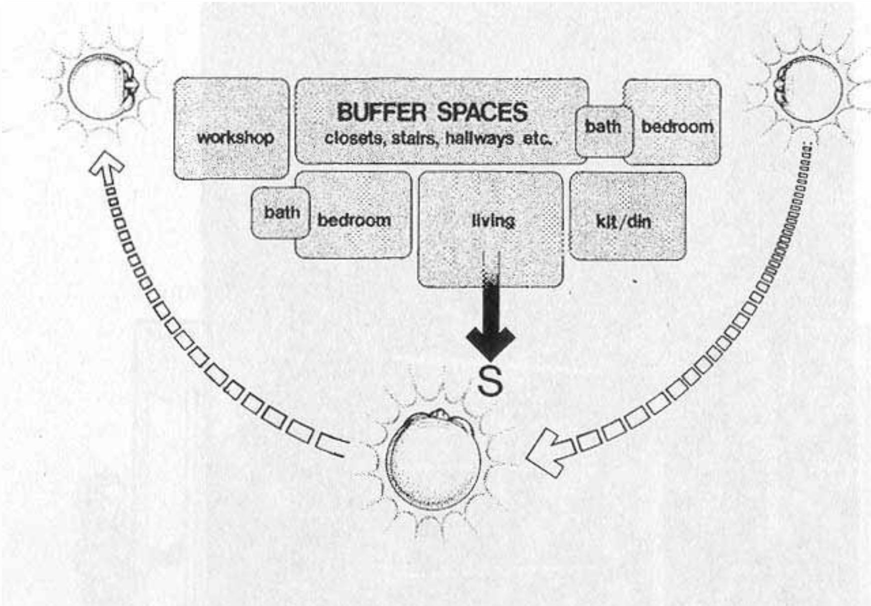


Fig. IV–4a

Locate openings to admit sunlight and provide for ventilation—WINDOW LOCATION(6)—while at the same time choosing the most appropriate heating system for each space—CHOOSING THE SYSTEM(7). If a greenhouse is integrated into the building—SIZING THE GREENHOUSE(15)—place it along the south face of the building for maximum exposure to the winter sun.

Louisiana's 2009 Solar Decathlon House:

South face, designed for solar energy – heating and electricity

North face has small openings to minimize heat loss.

Insulating Bead Storage for Windows:

Insulating Bead Storage for Windows:

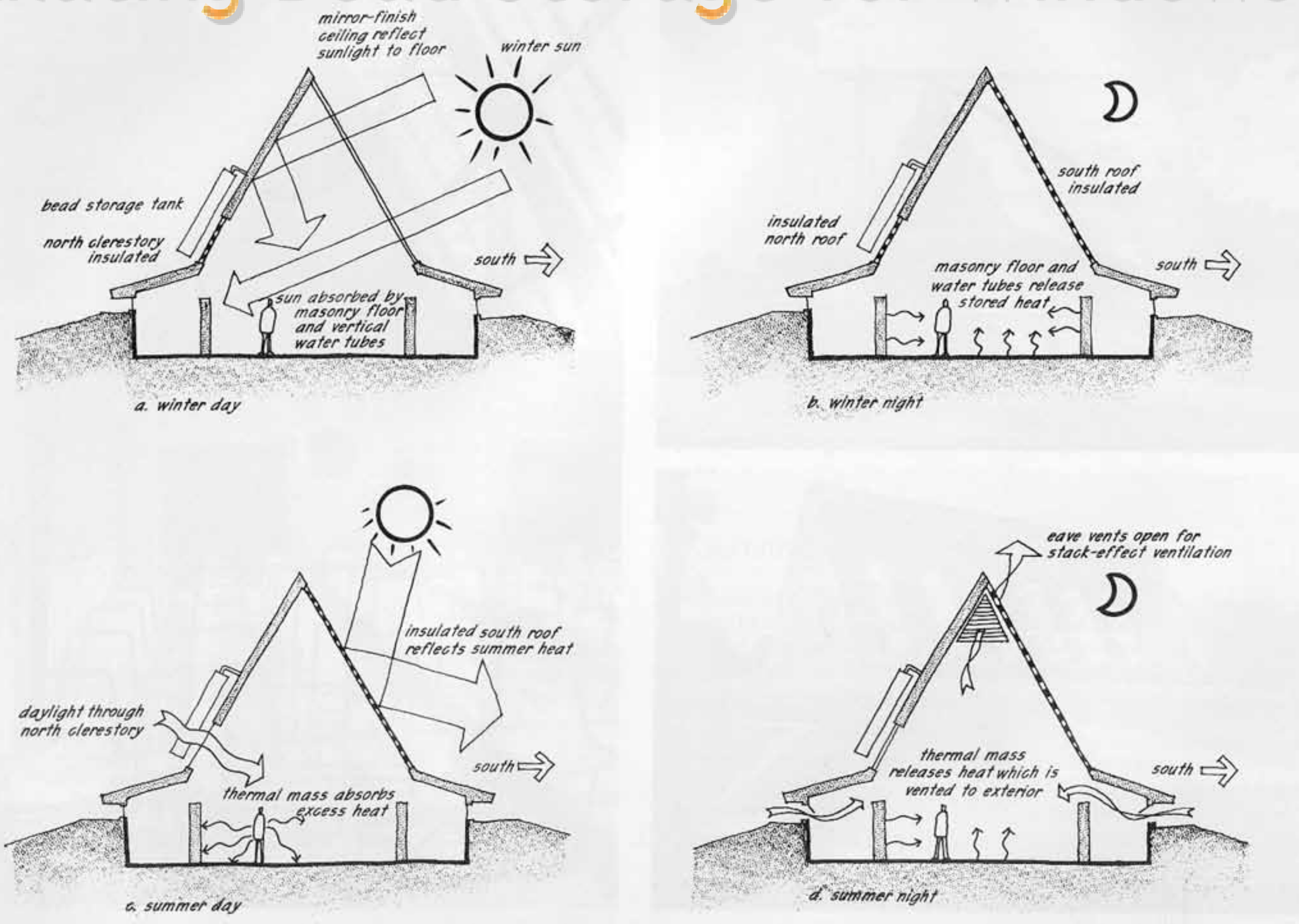
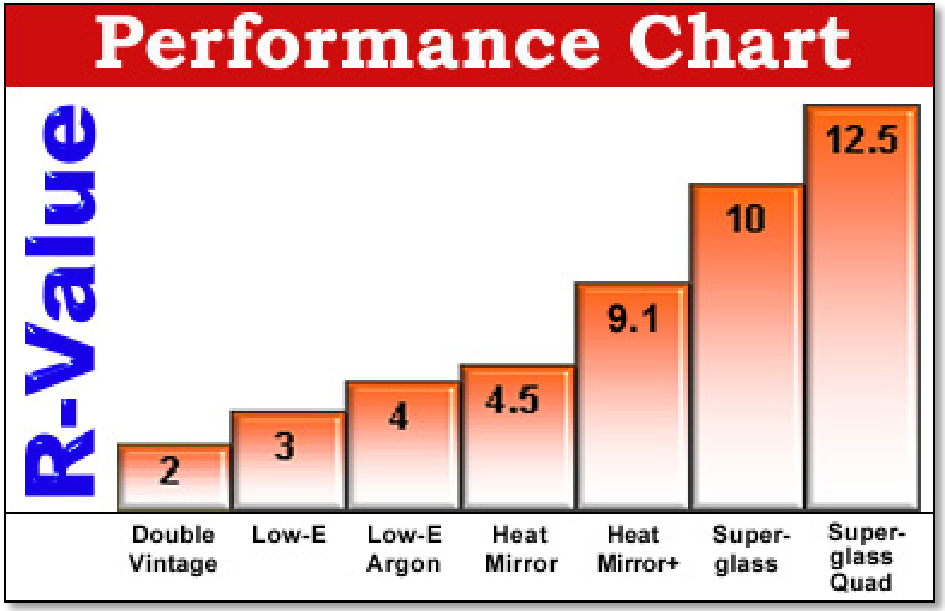


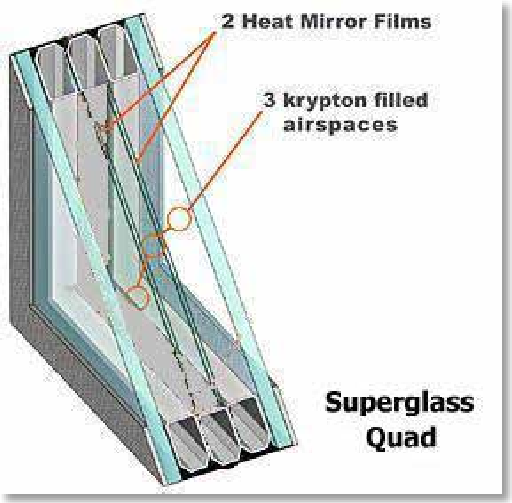
Figure 8.8: Patoka Nature Center modes of operation: (a) winter day, (b) winter night, (c) summer day, and (d) summer night. The building uses "night flushing" as a summer ventilation cooling strategy. Sixteen small awning windows over the exhibit booths admit air while large louvered exhaust eave vents are very effective in inducing stack effect night ventilation during the summer.

ECS

New Technology: Super Windows

Heat Mirror Superglass-88 provides a U-Value of .11 (R-Value of 9.1) and Superglass-66 provides a U-Value of .10 (R-10). With R-values as high as 13.5, Superglass Quad exceeds the energy savings and year-round comfort of any glass on the market





Heat Capacity of Materials

TABLE 19a

Thermal admittance expresses the "acceptability" a material has towards heat absorption and storage. Materials of high admittance quickly store and release heat (metals, for example) while materials of low admittance are relatively "indifferent" to heat presence—they respond slowly and hold little heat.

$$\text{THERMAL ADMITTANCE} = \sqrt{\text{CONDUCTIVITY} \times \text{HEAT CAPACITY}}$$

Material Description	Heat Capacity BTU/cu.ft (°F)	Conductivity BTU /hr (ft)°F	T. Admittance BTU/ft²(°F) √hr
Acoustic tile	5.8	.033	.44
Adobe	19.6	.37	2.7
Aluminum	35.9	128.	67.8
Brick, common (120 pcf)	24.	.42	3.2
Brick, face (130 pcf)	26.	.75	4.4
Concrete	29.4	1.0	5.4
Copper	51.	227	108.
Corkboard	24.6	.023	.27
Glass (Pyrex)	26.8	.59	4.1
Gypsum	51.3	.25	2.2
Iron, cast	54.	27.6	38.6
Limestone	34.7	.54	3.5
Marble	18.	1.5	7.1
Paraffin	18.6	.14	2.3
Particleboard (160 pcf)	27.7	.1	1.36
Plasterboard	22.4	.43	3.1
Plywood	9.9	.067	.81
Polystyrene (Beadboard)	.3	.023	.083
Sand	18	.19	1.85
Soil, light & dry (80 pcf)	18.	.2	1.9
Soil, average (damp, 131 pcf)	30.1	.75	4.75
Soil, wet (117 pcf)	35.1	1.4	7.0
Wood, hardwood	18.7	.09	1.3
Wood, white oak	26.8	.1	1.6
Wood, softwood	10.6	.067	.84
Wood, white pine	18.1	.063	1.07
Water, still*	62.4	.35 *	4.67 *
Glass, cellular insulation	2.2	.033	.27
Lead	21.8	20.1	20.9
Ice	27.	1.35	6.04
Bakelite	20.4	9.7	16.6
Steel (mild)	58.7	26.2	39.2
Granite	31.7	1.40	6.6

*The "apparent" admittance of stirred water is much higher, due to increase in heat transfer (apparent conduction) by convection; it may range from 8 to 400 times greater than still water.

Imperial

Passive heating requires buildings be able to store free solar heat in their materials – need to have THERMAL MASS

Material	Density(Kg/m3)	Specific heat(kJ/kg.K)	Thermal mass (kJ/m3.K)
Water	1000	4.186	4186
Concrete	2240	0.920	2060
AAC	500	1.100	550
Brick	1700	0.920	1360
Stone (Sandstone)	2000	0.900	1800
FC Sheet (compressed)	1700	0.900	1530
Earth Wall (Adobe)	1550	0.837	1300
Rammed Earth	2000	0.837	1673
Compressed Earth Blocks	2080	0.837	1740

Metric

What is Direct Gain??

Direct Gain: A passive solar heating system type consisting of

•south-facing windows that admit winter sunshine directly into the building's interior where it is absorbed by thermally massive materials.

•glazing is protected from the summer sun by an overhang.

•Some means of reducing night heat loss through the glazing (such as night insulation or low-e glass) is recommended in all but the mildest climates.

What are Sun Tempered Buildings??

Sun tempered buildings: direct gain buildings with NO intentional thermal mass (for example, a conventionally constructed wood frame with 1/2" gyp bd walls and ceiling and a wood floor over a crawl space). South facing glazing should be less than 7% of floor area to prevent overheating.

Direct Gain:

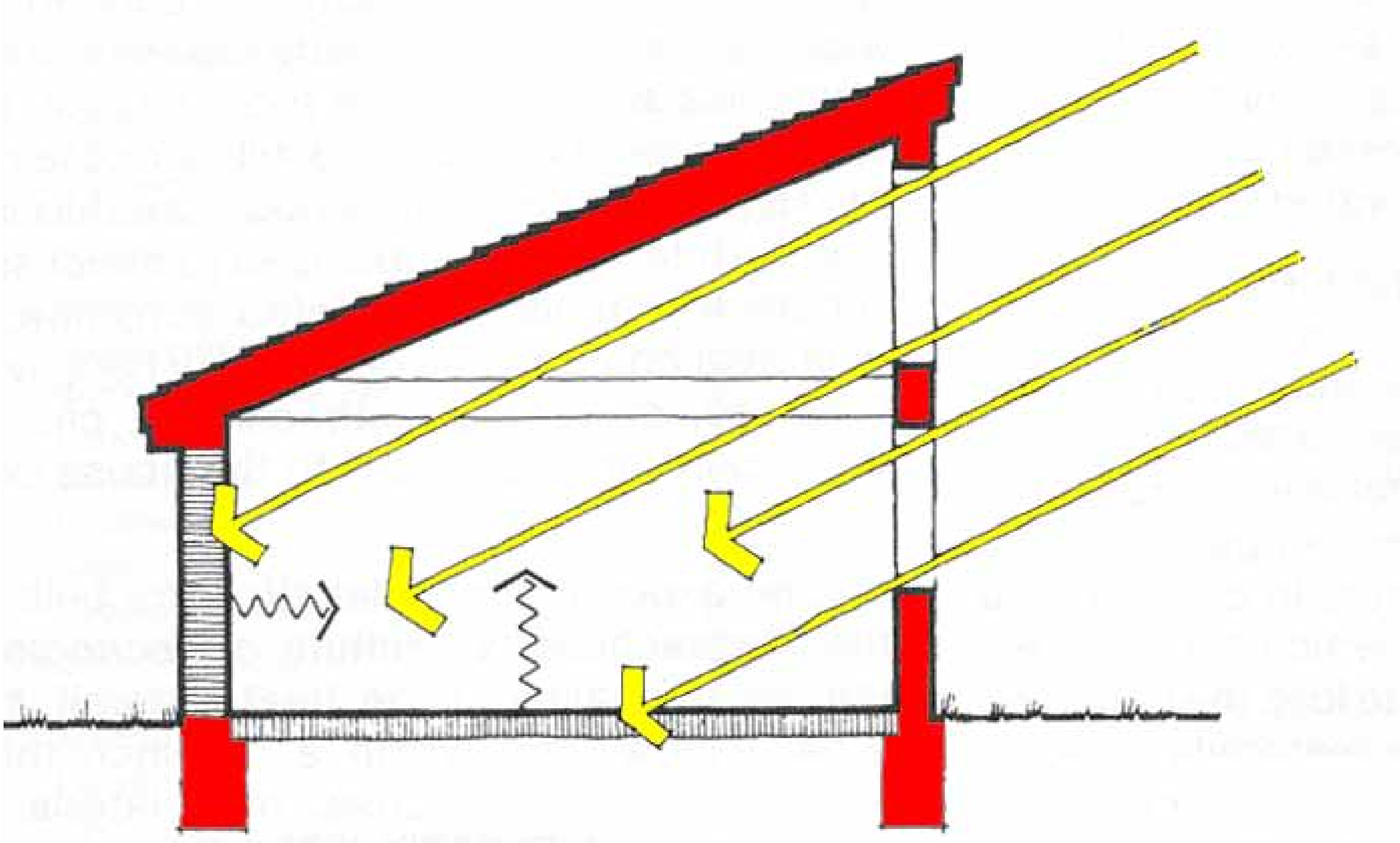
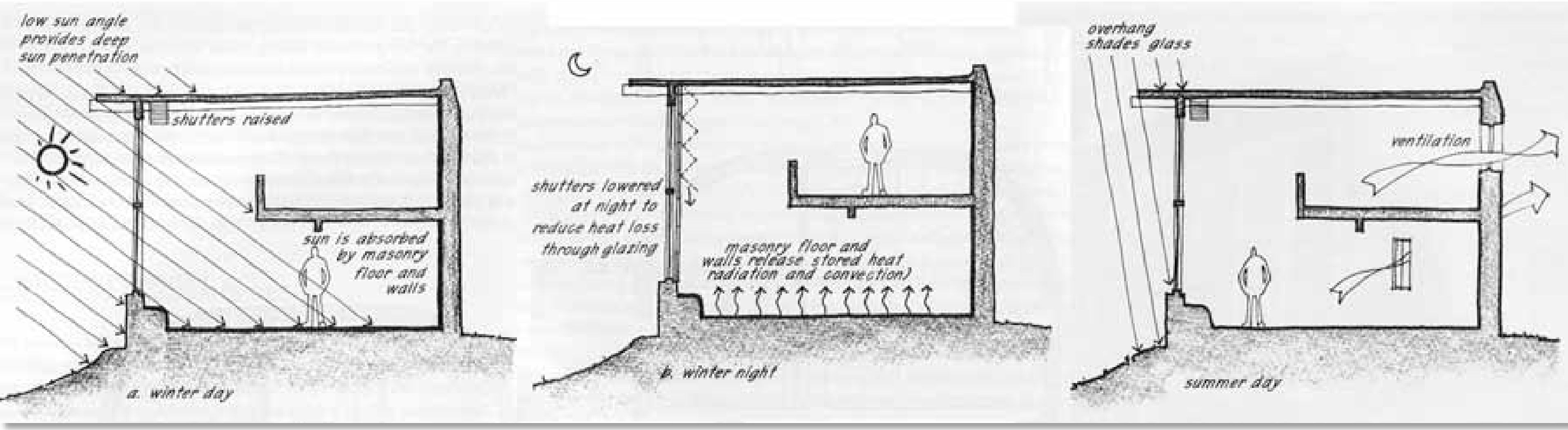


FIG. 19a. Direct Gain

Direct Gain:



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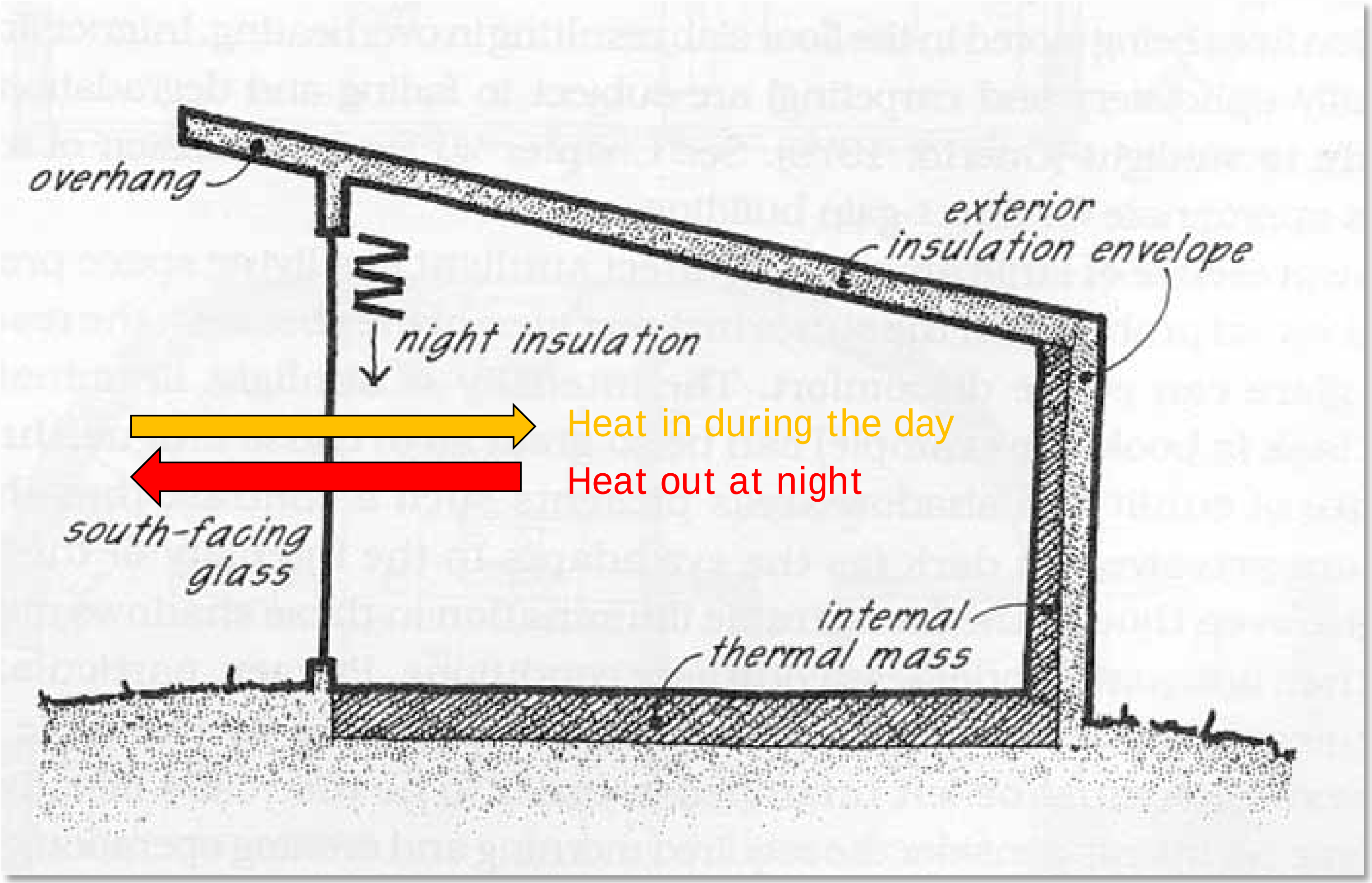
The direct gain system makes overt use of solar geometry to ensure that sun reaches the thermal mass in the winter, and that shading devices prevent solar access during the months where cooling is the dominant issue.

Direct Gain - night insulation:



Night insulation

Most devices that you might employ to keep heat in at night are custom designed.

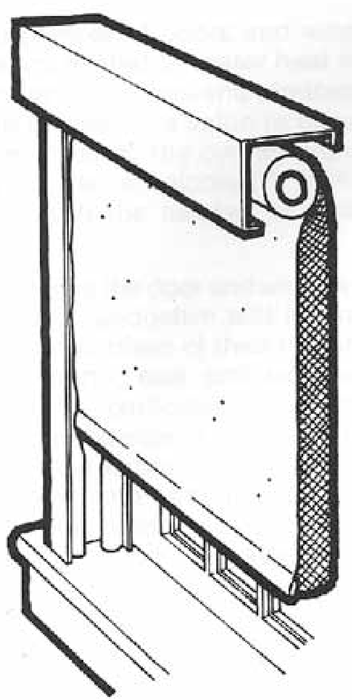


FIG. 39b. An insulating shade is designed to minimize conductive & radiative heat transmission, as well as a seal against infiltration.

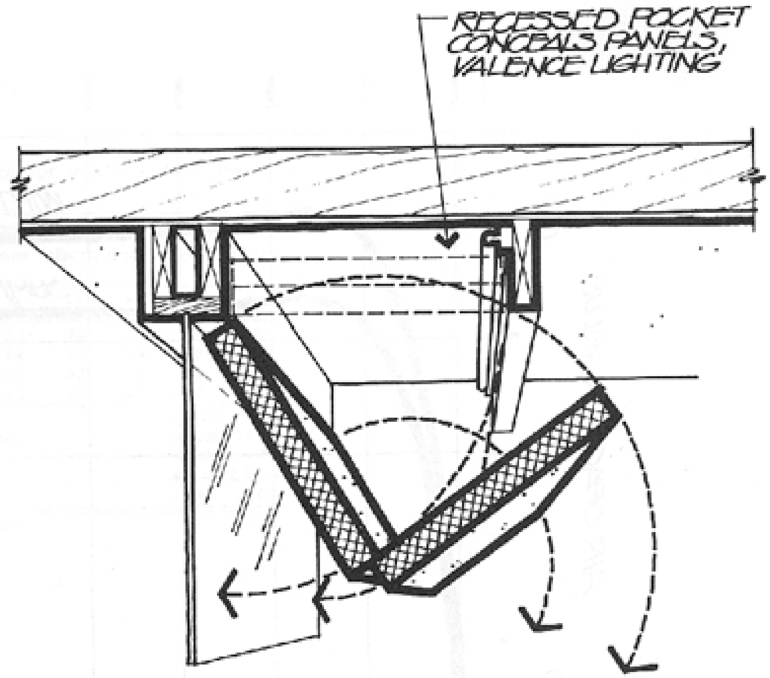


FIG. 39c. Hinged and fold-down panels offer large additional resistances to window units, can be made from aluminum-faced urethane or polystyrene sandwich panels, or insulation board w/laminated facings.

Direct Gain:

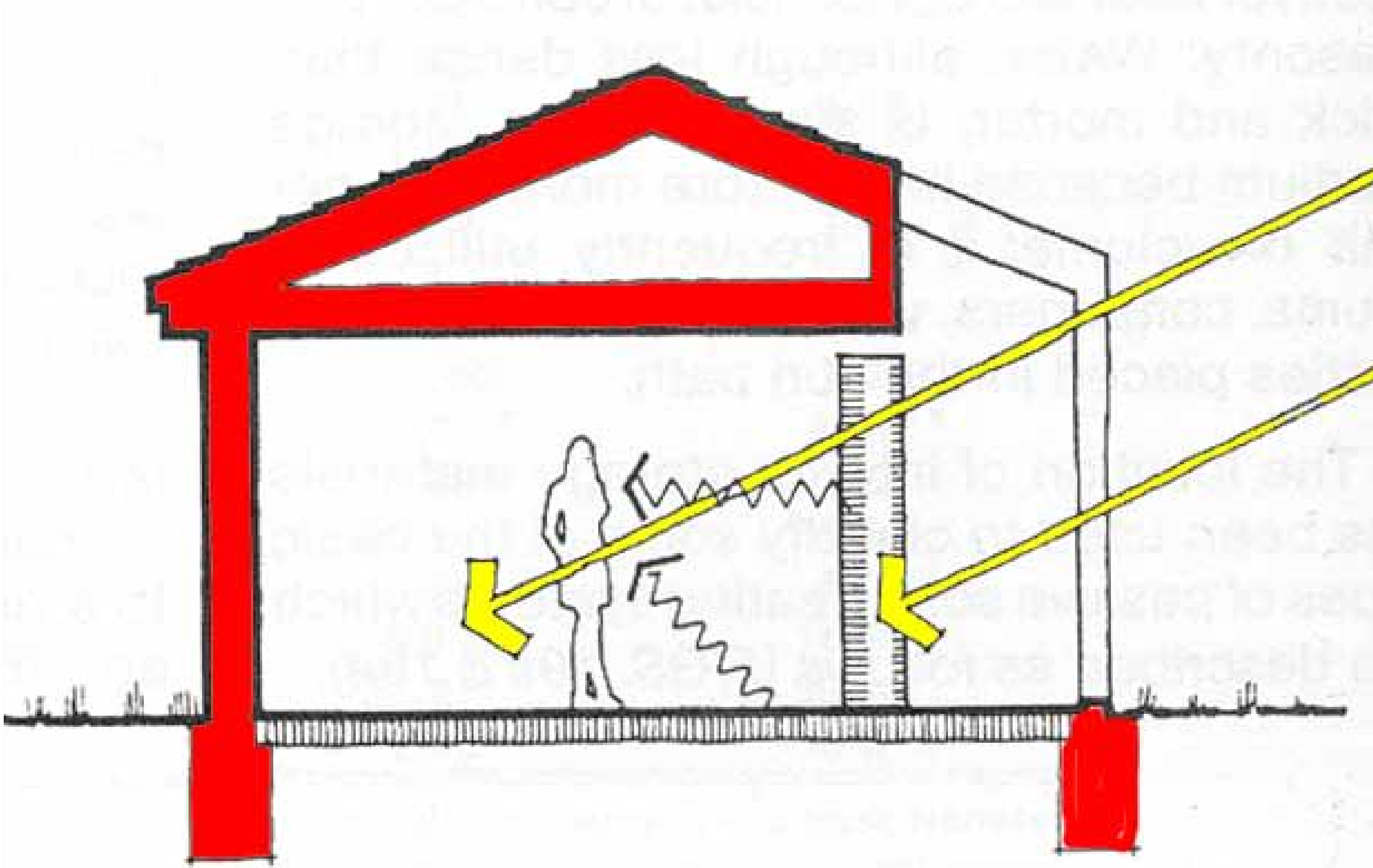


FIG. 19b. Direct and Indirect Gain

Direct Gain Rules:

ECS 8. **Mass Distribution**: spread it around evenly; 6 times glazing area (3X minimum)

9. **Mass Thickness**: thin and spread out better than thick. More than 4” for masonry or concrete not useful

10. **Colour**: Floors dark to absorb more heat, walls and ceilings lighter to reflect light.

11. **Surface Covering**: insulative coverings (ie. Rugs) greatly decrease performance of thermal mass

12. **Concrete Block Masonry**: If used, a high density with cores filled with grout

Direct Gain Rules, cont'd:

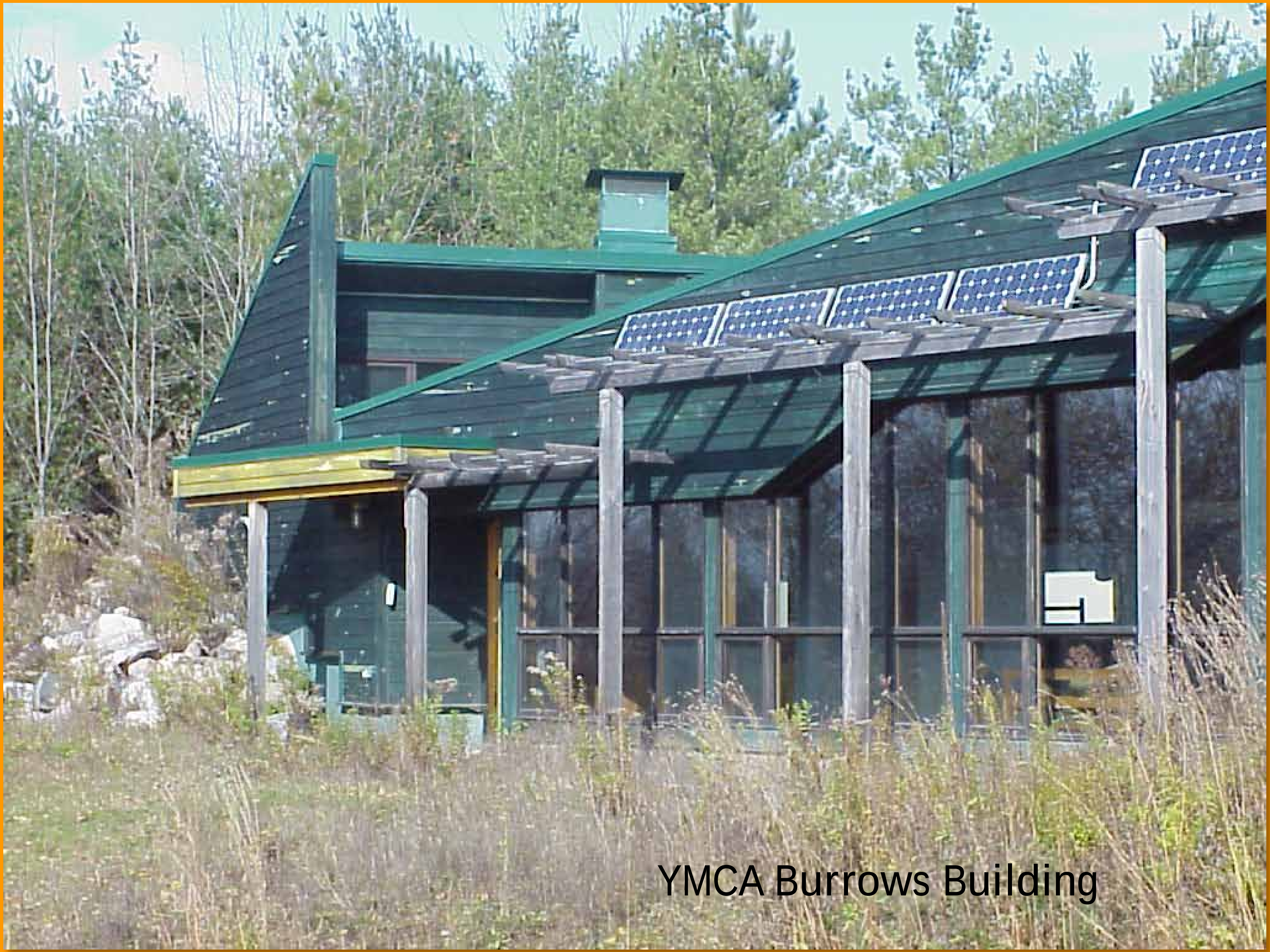
ECS 13. **Floor Materials**: Concrete or brick preferred. If insulating under, at least 4” thick (100mm). More than 6” (150mm) not useful.

14. **Limits on Direct Gain Glazing Area**: South facing glazing limited to prevent large temperature swings. 7% of floor area for low mass buildings, 13% of floor area for high mass buildings.

15. **Glazing orientation**: Vertical facing due south preferred. Vertical easiest to build, and easiest to shade in summer. Performance penalty for 15degrees off due south is 10% and for 30 degrees is 20% loss; so within 15 degrees recommended.

16. **Night insulation**: Really helpful but can be very costly.

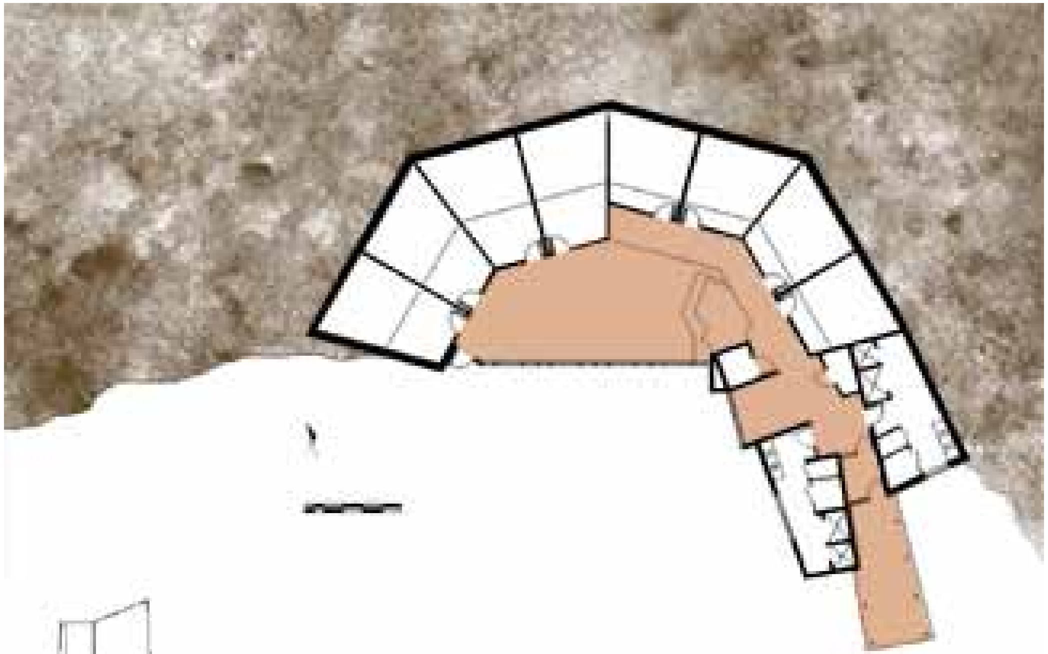
17. **Thermal Insulation**: Insulation located OUTSIDE the thermal mass.

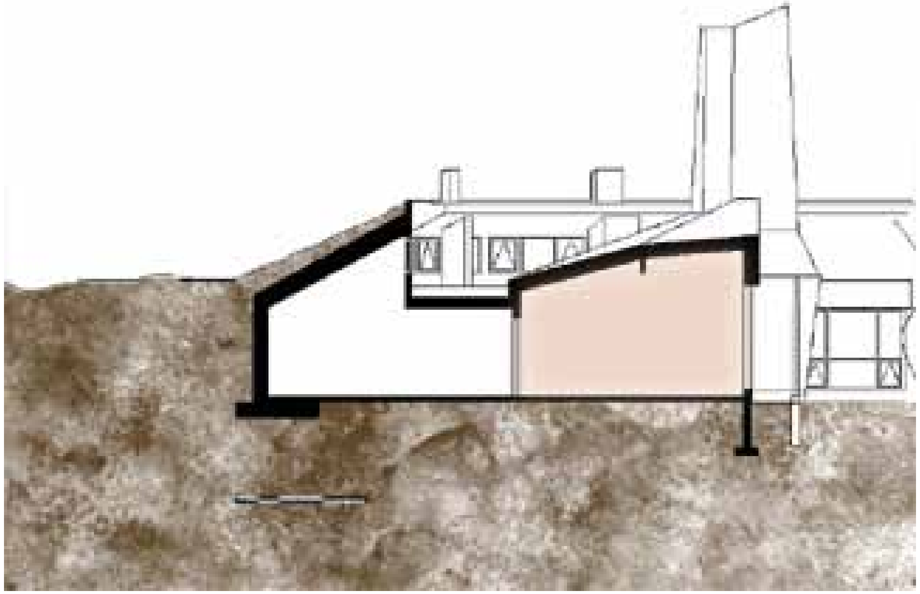

YMCA Burrows Building

The white brick wall in the YMCA Burrows building is used to hold the heat that comes into the building through the windows. This is done in this wall, rather than in the floor (more usual), as the kids will be walking around in stocking feet.

YMCA Burrows:

Rear wall and mid wall are used for heat storage. North side is built into the earth. Mostly linear organization with spaces facing south.





For North House, there was a phase change material underneath the wood floor that would absorb solar energy when the shades were up (and it was determined that heat was needed).

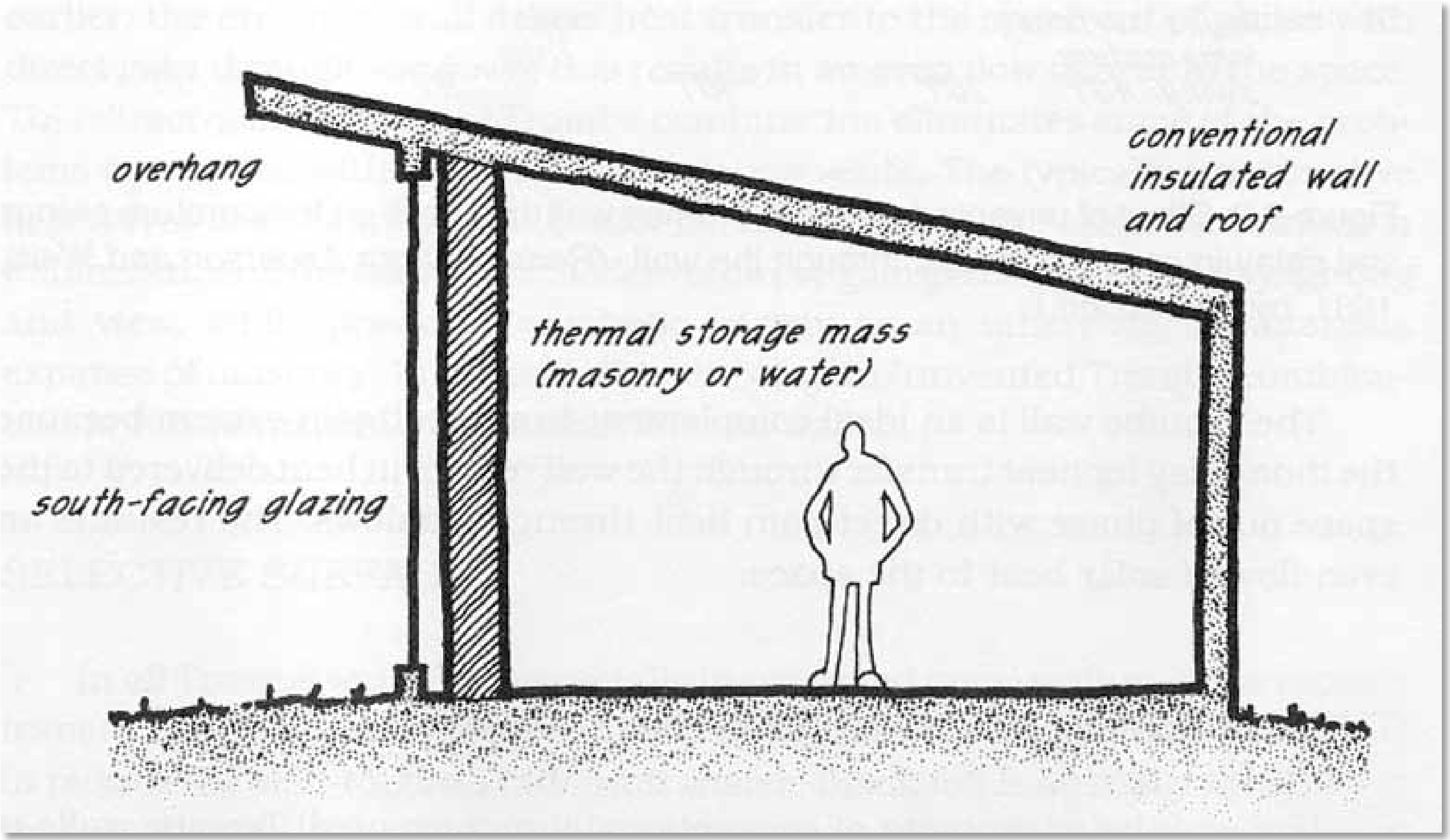
What is a Thermal Storage Wall??

Thermal Storage Wall -- a passive solar heating system consisting of a south facing wall constructed of heavy masonry (Trombe Wall) or water filled containers (water wall). The outside south facing surface is glazed to admit sunlight and reduce heat losses.

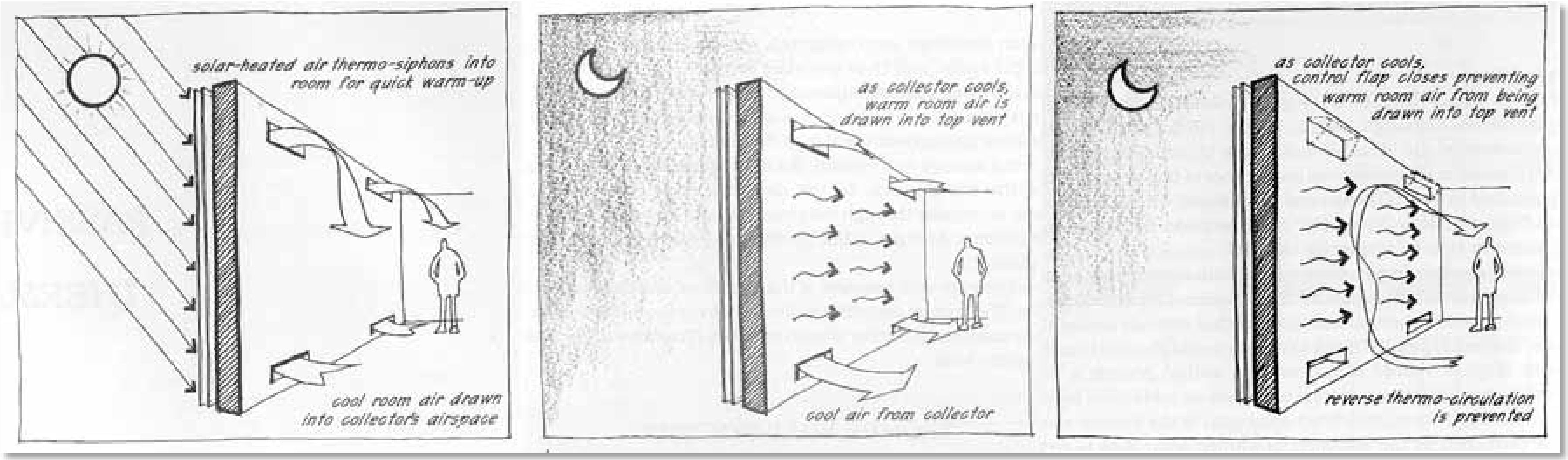
Trombe Wall -- a thermal storage wall system consisting of a dark, south facing masonry wall covered with vertical glazing.

Water Wall -- a thermal storage wall system consisting of water filled containers located behind a south facing glazing.

Trombe Walls:



Trombe Walls:



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Whether or not a wall has flaps, and flaps that automatically close off when the air direction reverses, becomes a critical issue in making sure that preheating of the room occurs in the morning hours.

Trombe Walls:

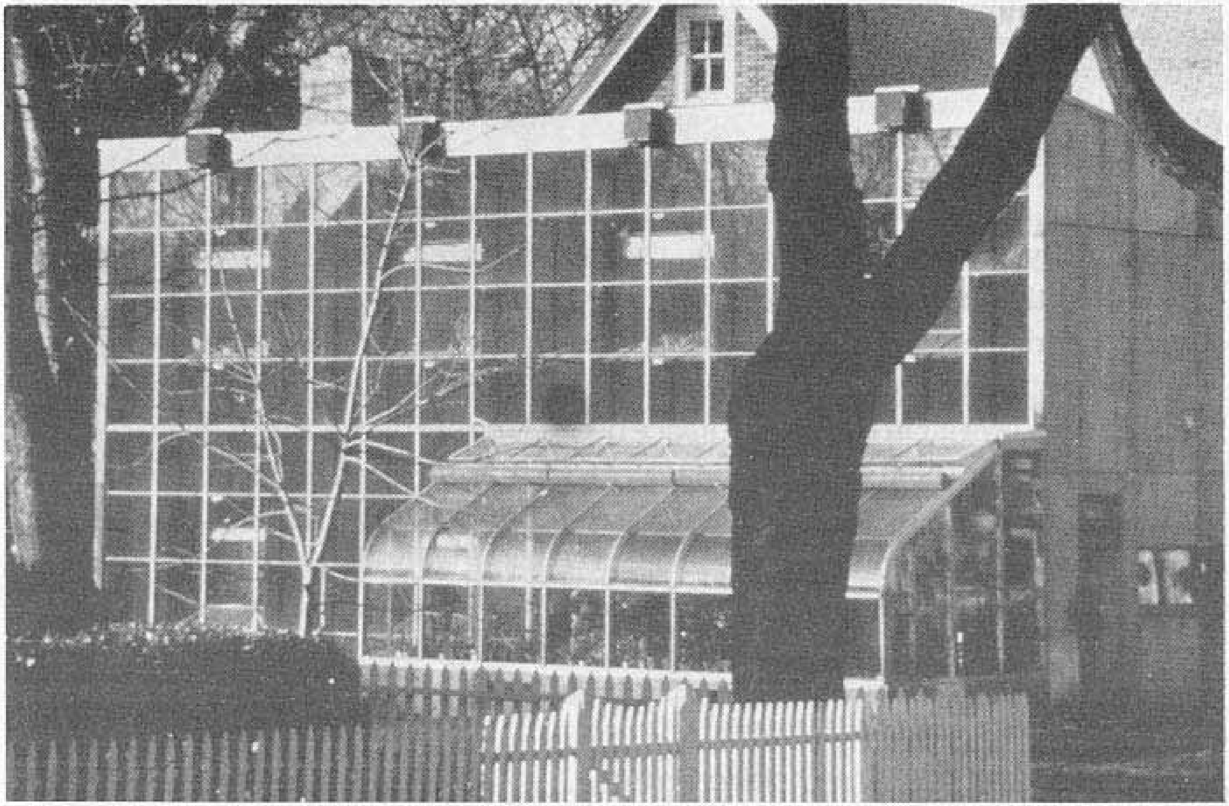

Figure 9.5: Kelbaugh house showing south facade with Trombe wall. *(Photo courtesy of D. Kelbaugh.)*

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Trombe Walls:

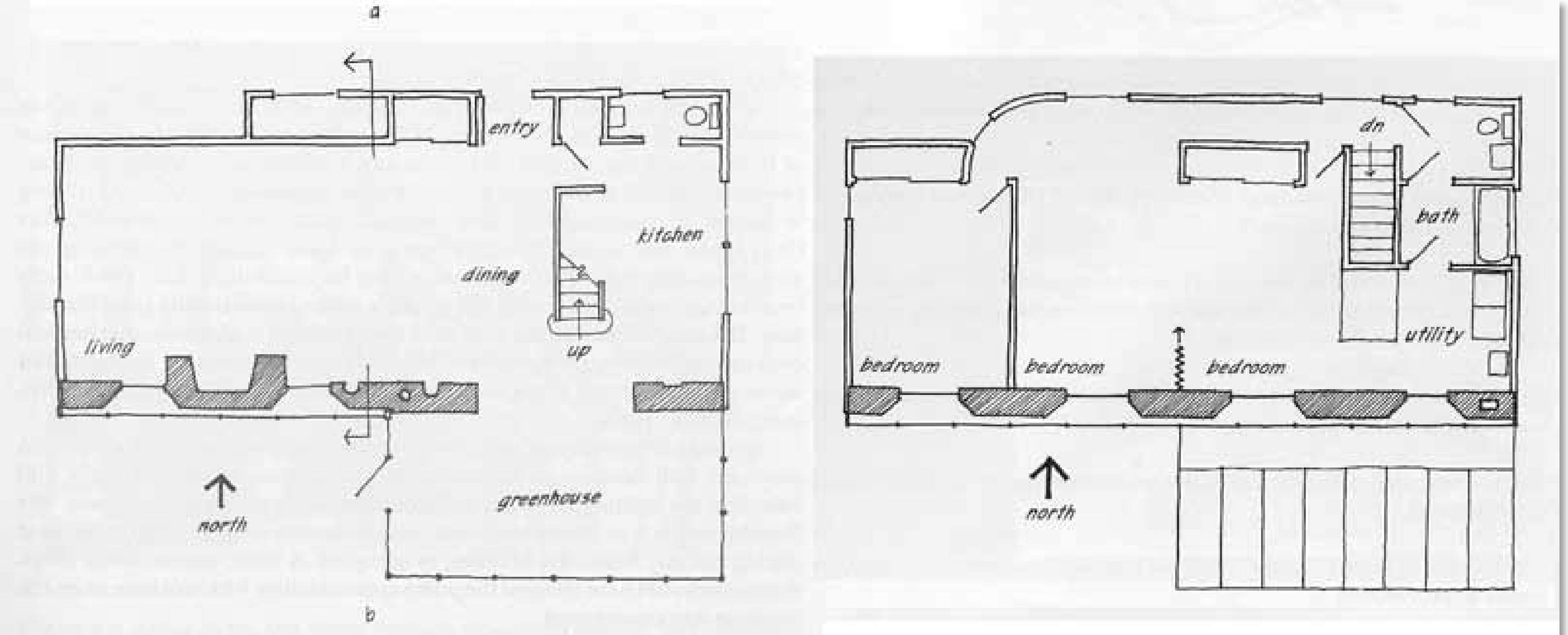

Figure 9.6: Kelbaugh house: (a) upper and (b) lower floor plans. *(After Kelbaugh, 1976.)*

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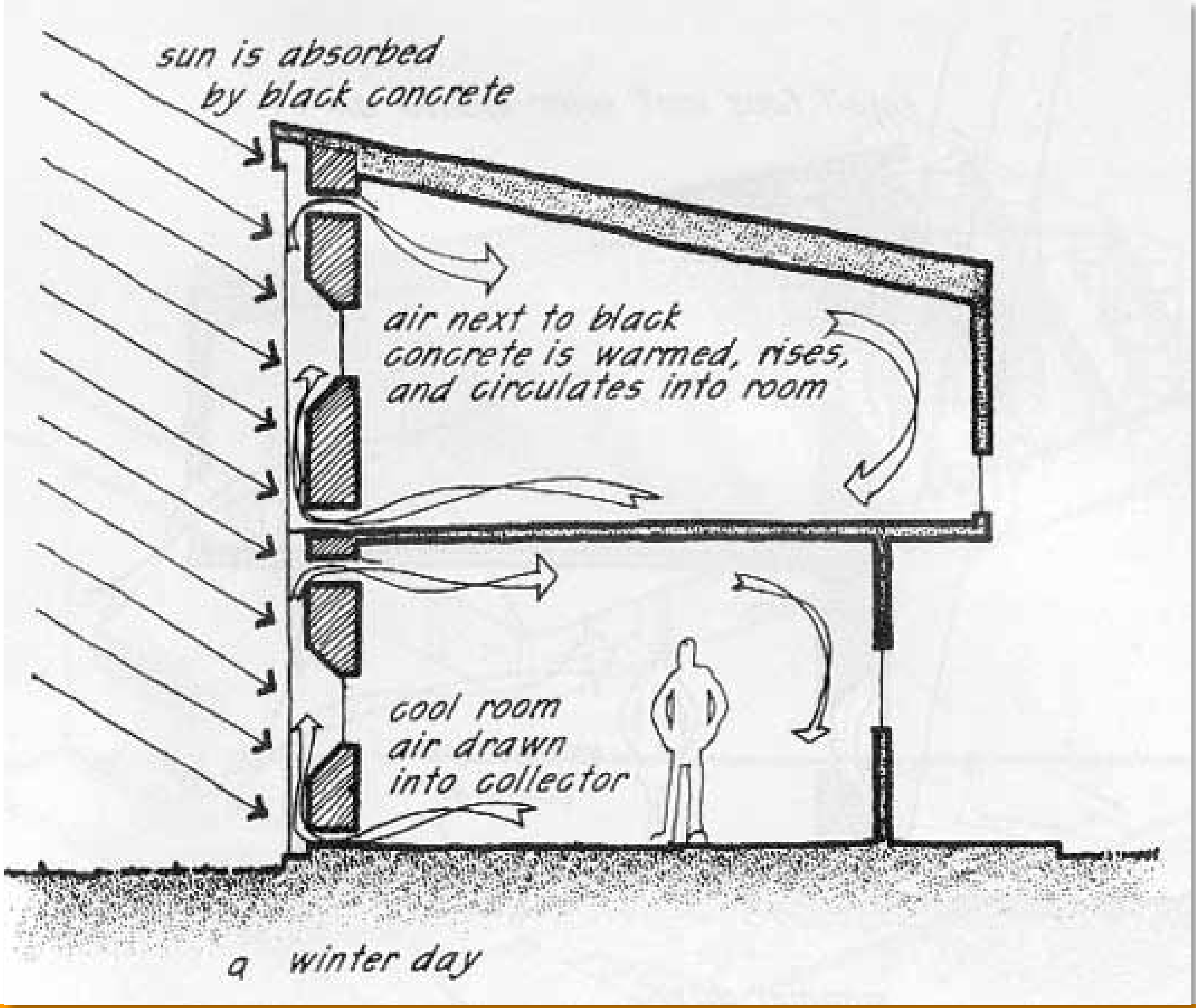
Trombe Walls:



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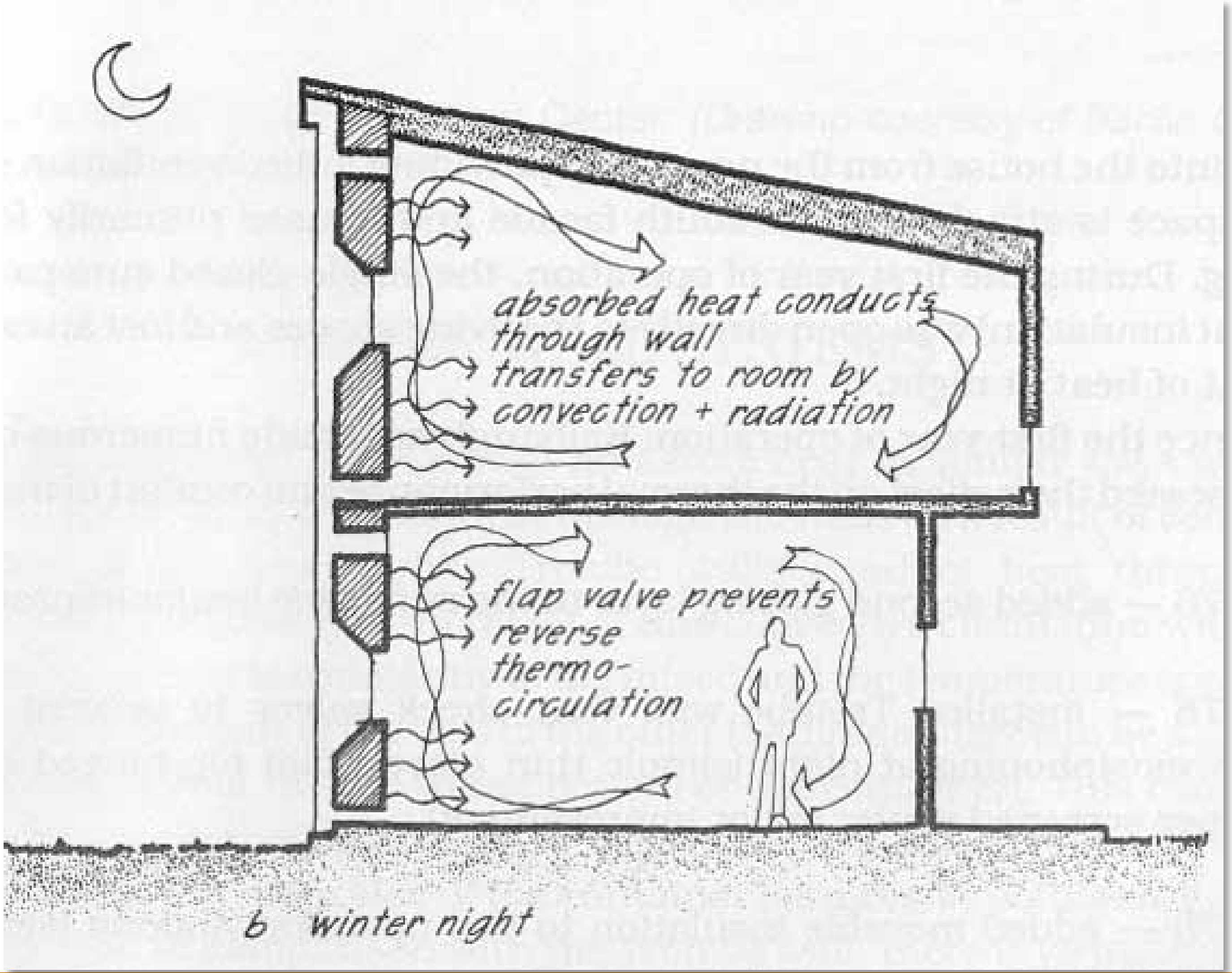
Trombe Walls:



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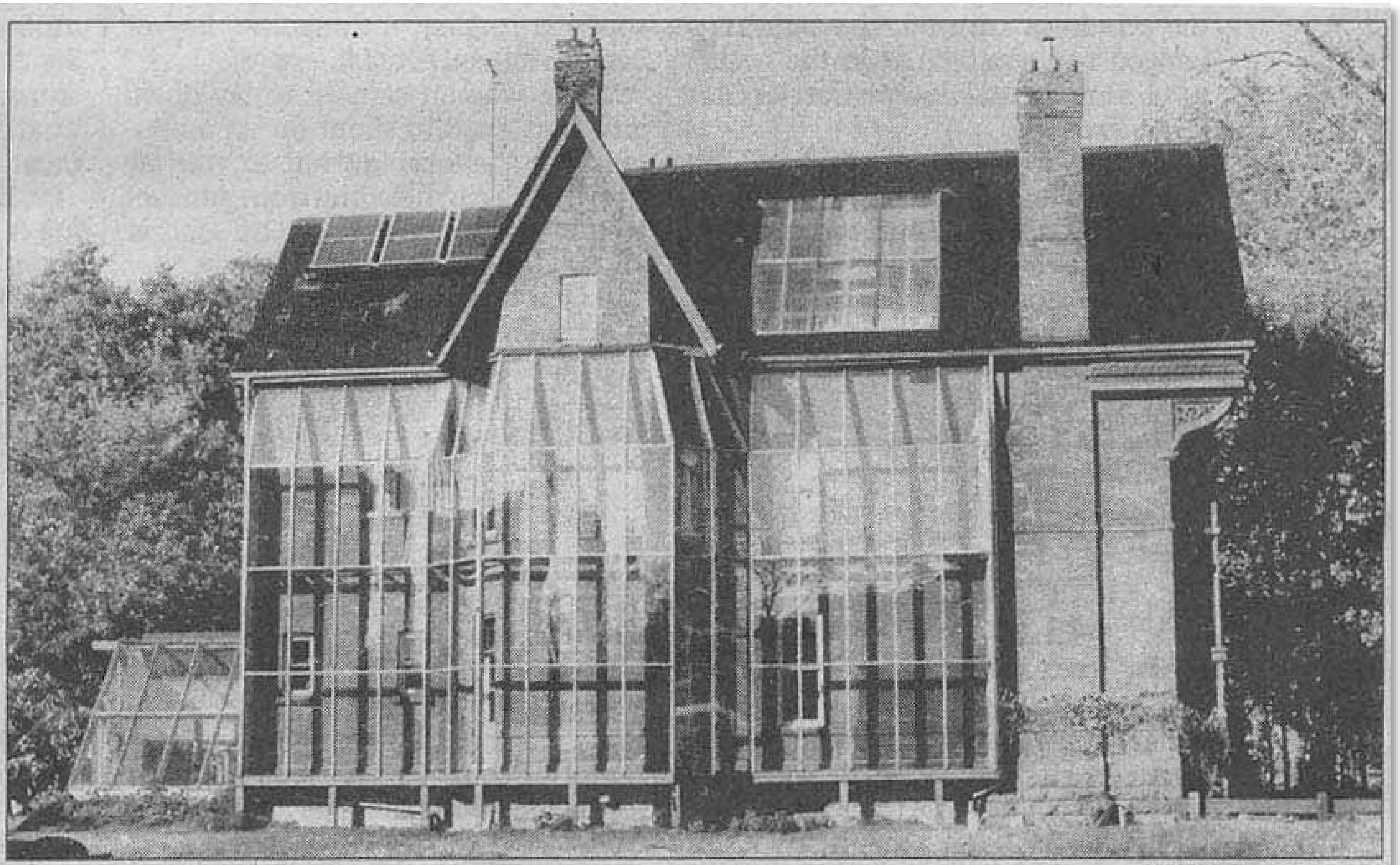
Trombe Walls:



POLLUTION PROBE PHOTO

A Trombe wall was installed on Ecology House in Toronto, following the energy crunch of the 1970s. The three-storey, glass wall, since removed, trapped solar energy for heating. With this year's oil price hikes, the concept of green buildings may be undergoing a revival. In the top photo, a worker at a housing site in Caledon runs his saw from the electricity generated by the solar panel next to him.

Trombe Walls:

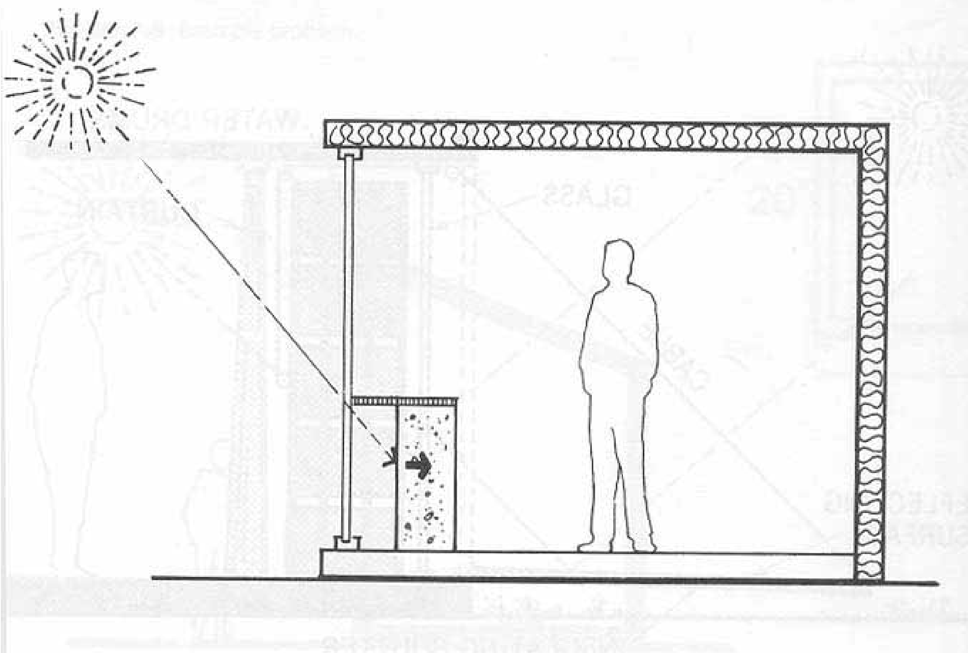


Figure 7.9e A half-height wall allows controlled direct gain for daytime heating and daylighting while also storing heat for the night.

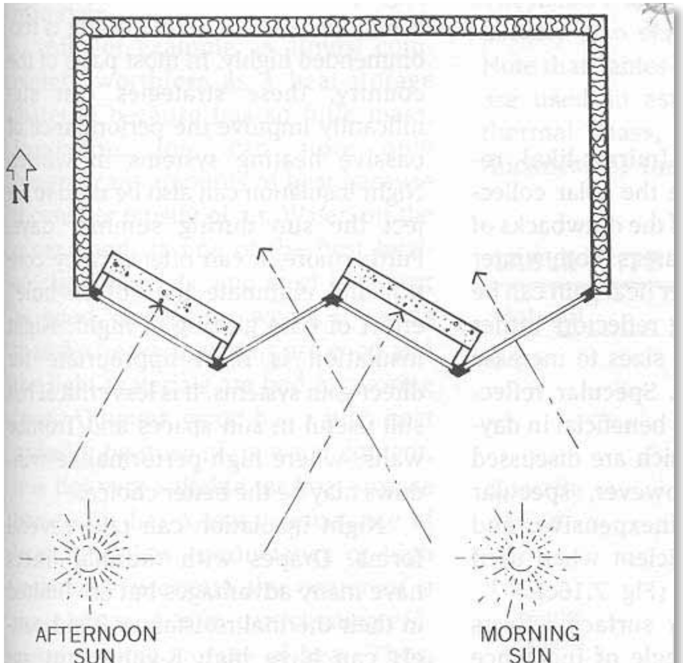


Figure 7.16b Plan view of a combined system of direct gain and Trombe walls to get quick morning heating and to prevent afternoon overheating.

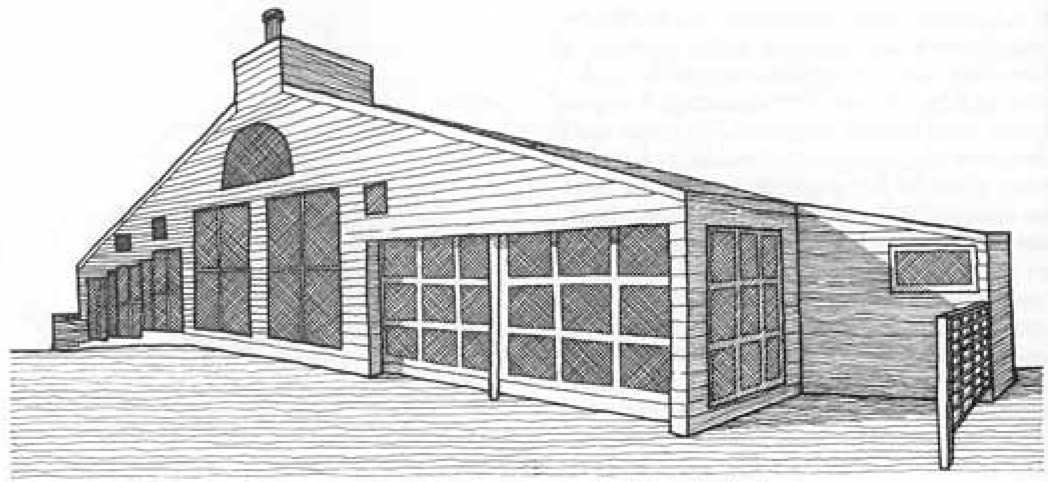
HCL

Trombe Walls:

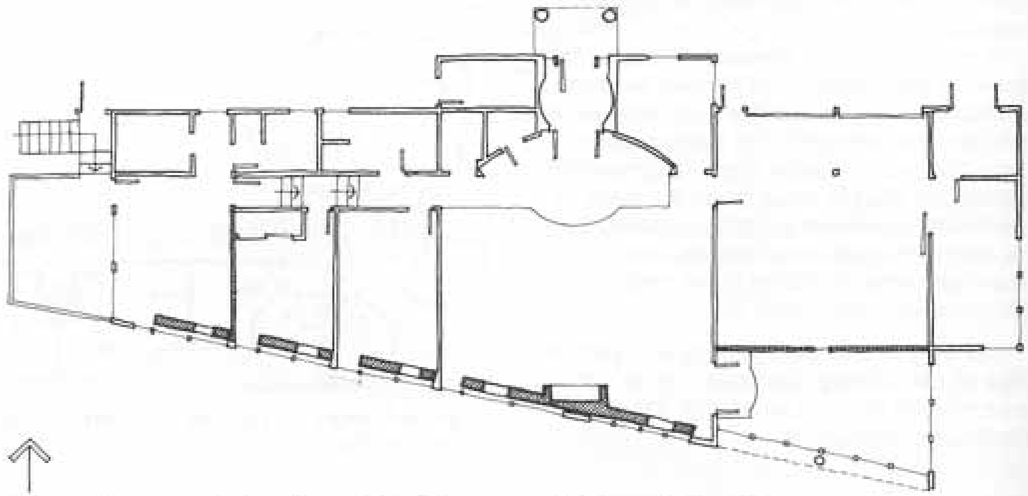
Figure 7.9d A Trombe wall can consist of vertical tubes filled with water. The tubes can be opaque, translucent, or transparent. (Courtesy of and © Solar Components Corporation.)

HCL

Trombe Walls:



Sisko House Metuchen, New Jersey Kelbaugh & Lee



Sisko House Metuchen, New Jersey Kelbaugh & Lee

SWL

Arizona’s house at the 2009 Solar Decathlon used a trombe wall made from water. Water has a high thermal storage capacity and is very “portable”.

Thermal Storage Wall Rules:

ECS 18. **Glazing azimuth**: directional orientation preferred is due south. Within 30degrees of due south only a 4% penalty.

19. **Vents**: generally used in larger applications but omitted in residential. In larger applications can be beneficial.

20. **Glazing distance**: *Unvented*, 1"is enough. *Vented*, 6" or more is better.

21. **Trombe Wall Thickness**: between 10 and 16". 12" recommended.

22. **Water Walls and Phase Change Materials**: more effective than concrete so smaller volume necessary.

Thermal Storage Wall Rules, cont'd:

ECS 23. **Selective Surfaces**: on outside face of thermal mass part of wall can greatly increase performance. No venting.

24. **Absorber colour**: for solid materials, use black. Applicable to solid colour containers for water walls too. Transparent or fiberglass water containers will allow some visible light through the container which will be absorbed by direct gain means beyond, so OK too.

What is a Sunspace??

Sunspace -- a passive solar heating system type consisting of a glassed-in room like a greenhouse, atrium or conservatory, located on the south side of a building and separated from other building spaces by a common wall.

Common Wall -- a wall separating a sunspace from other living spaces.

Greenhouse -- a sunspace used primarily for growing plants

Projected Glazing Area -- net glazing projected onto a single vertical wall.

Sunspaces:

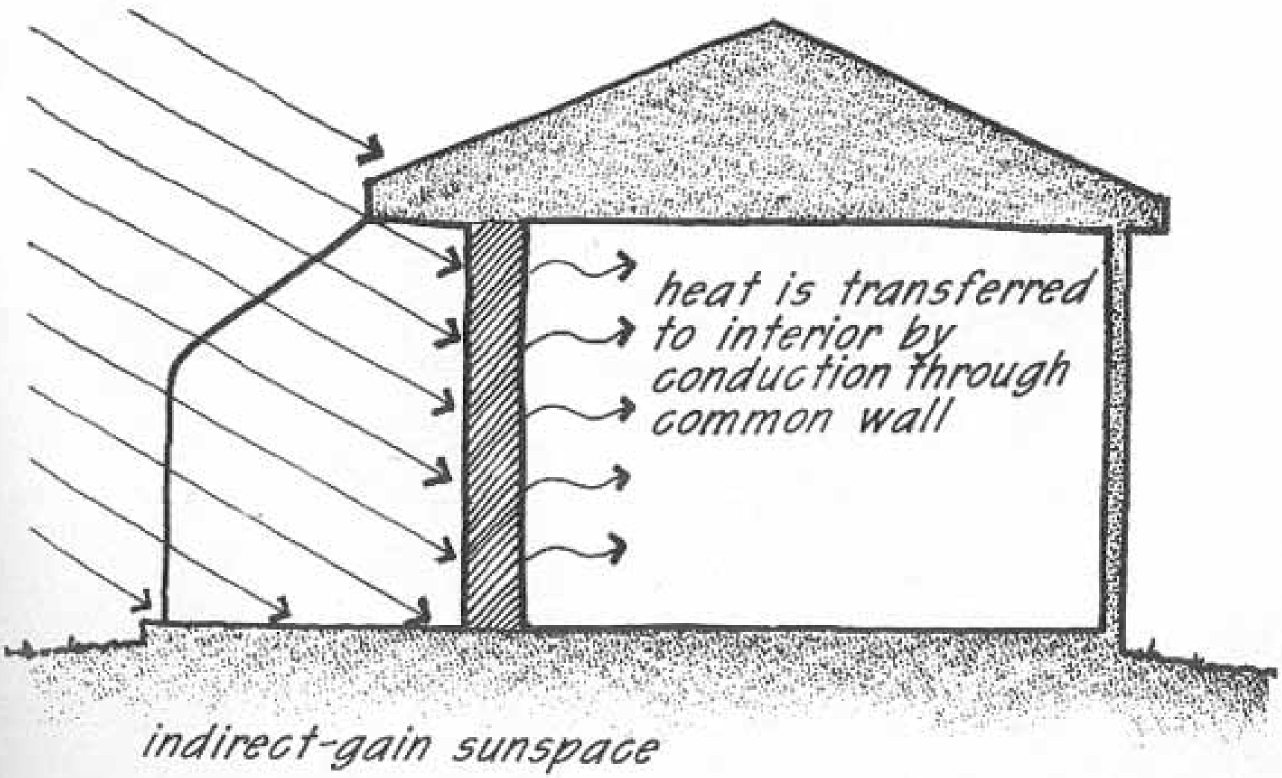


Figure 10.1: Indirect-gain sunspace building with common thermal storage wall. Conduction through the common wall is the primary means of heat transfer to living space.

ECS

Sunspaces:

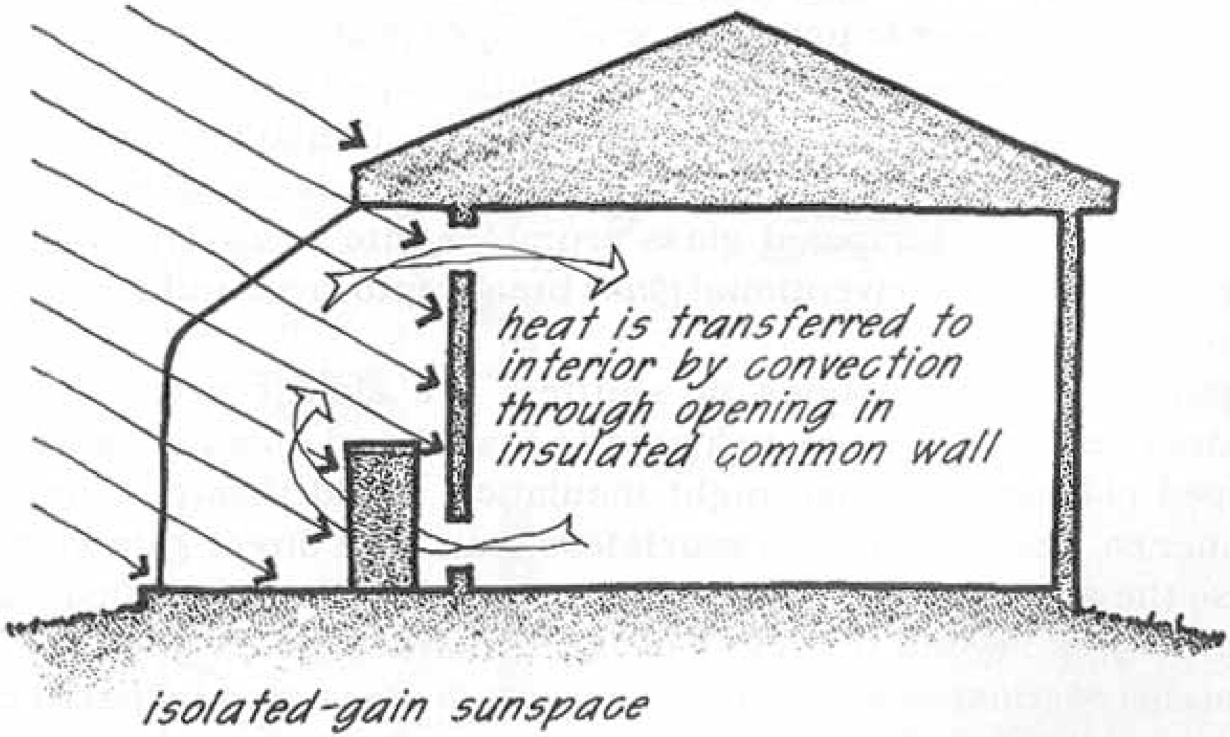


Figure 10.2: Isolated-gain sunspace building with free-standing thermal storage mass and insulated common wall. Convection (either fan-forced or natural) is the primary means of heat transfer to living space.

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The glass doors at the center of Iowa’s Solar Decathlon 2009 entry enclose a sun space.

The floor of the sun space has thermal mass. Windows in the adjacent walls can be opened to allow the heat to enter.

Sunspaces:

HCL

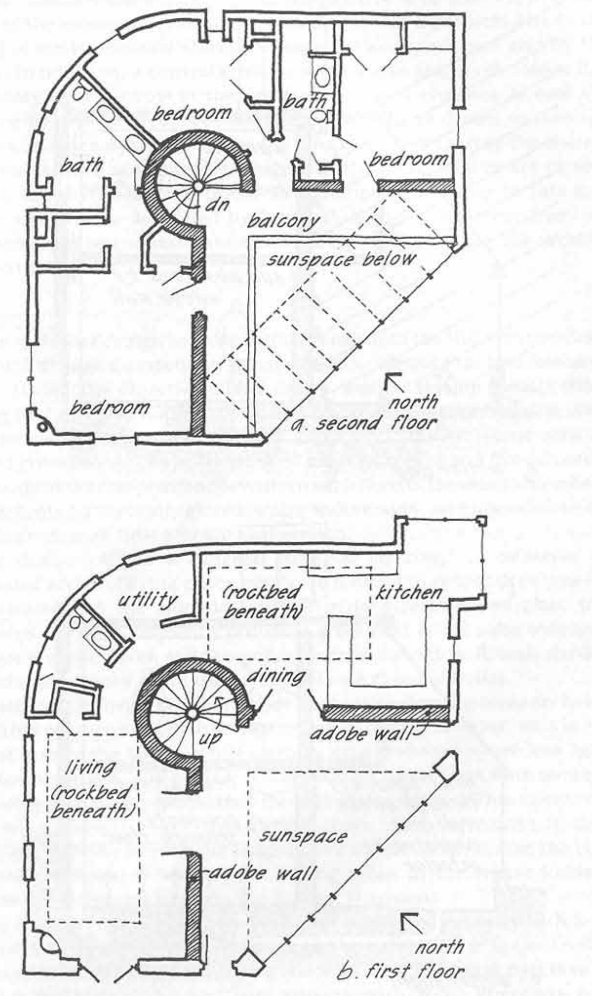

Figure 10.4: “Unit One” — First Village (a) upper, and (b) lower floor plans. *(Redrawn from Howard and Fraker, 1990, by permission.)*

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Sunspaces:

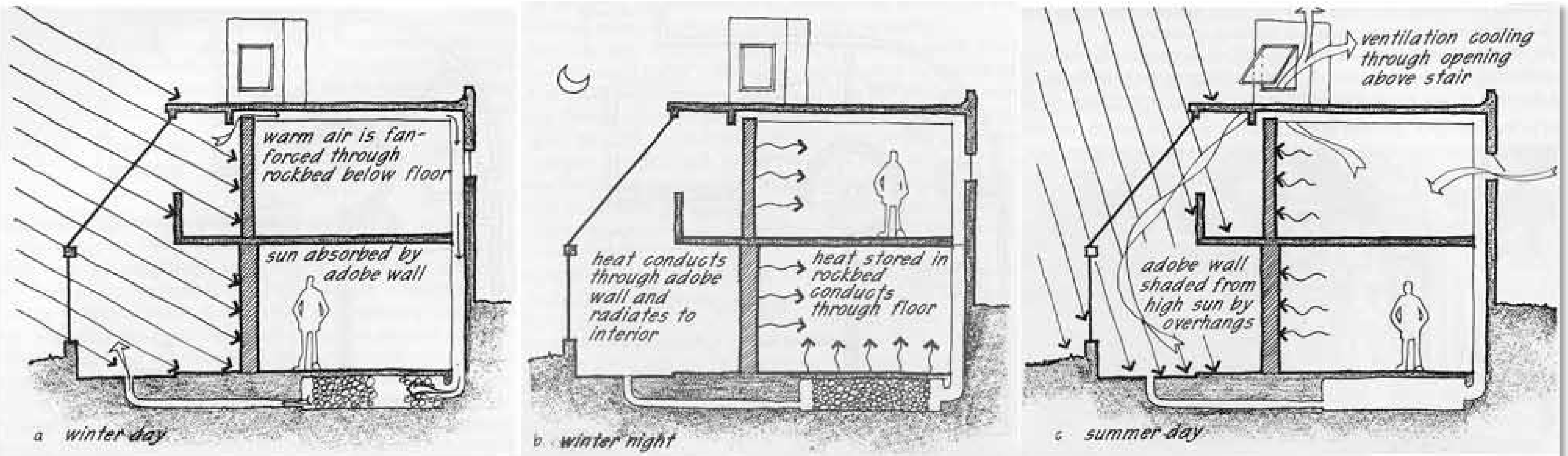

Figure 10.5: "Unit One" passive operation: (a) winter day, and (b) winter night. *(Redrawn from Howard and Fraker, 1990, by permission.)*

Figure 10.5 (continued): "Unit One" passive operation: (c) summer day. *(Redrawn from Howard and Fraker, 1990, by permission.)*

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Sunspace Rules:

25. **Effect of orientation**: optimum due south. Penalties about 5% for 30 degrees off due south. More summer overheating for off south directions.

26. **Use of Mass**: increases space's livability. Reduces overheating. Optimum thickness for masonry walls between 8 and 12".

27. **Area of Mass**: direct gain rules apply 3 mass to 1 glazing. If water used, $0.5ft^3/f^2$ of glass. Water containers dark coloured and located in the sun.

28. **Water Container Shape**: The one that allows the greatest volume to be placed. Size not too important.

29. **Do not glaze end walls**: for both summer and winter performance.

Sunspace Rules, cont'd:

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30. **Roof:** Need to be able to shade it in the summer to avoid overheating. Curtain, awnings or internal shades, OK.

31. **Common Wall**: Needs to be able to be closed off from main living space to avoid overheating. Preferably masonry (like trombe wall).

32. **Common wall vents**: required as one of the ways heat is transferred to the living space.

a. doorways, 15% of glazing area

b. window openings, 20% of glazing area

c. high and low vent pairs, 10% of glazing area

Iowa's sun space can be closed off.

Sunspace Rules, cont'd:

ECS 33. **Summer Venting**: needs to be vented during summer especially if not well shaded.

34. **Wall Colour**: Direct gain rules apply, except:

a. use darker colours in general as light colours tend to reflect light and heat out of the space

b. if used as a green house, surfaces in corners need to be light to improve plant performance/life.

35. **Sunspace width**: 15 to 20 feet works well.

36. **Colour:** dark colours work better to absorb heat.

37. **Plants and other lightweight objects**: Limit.

At the YMCA Solarium Building, the sunspace is used to house the Living Machine, and the heat caught in this space pumped to other portions of the building to heat them.

What is a Convective Air Loop??

Convective Air Loop -- a passive solar heating system that consists of a solar collector and a thermal storage mass (usually a rockbed) isolated from the living spaces. Air is used to transfer heat from the collector to the storage and the living spaces.

Hybrid System -- A predominantly passive solar heating system which utilizes an active component, such as a fan, to force heat from one location to another.

Rockbed -- a heat storage component consisting of an enclosed volute of rocks (fist-sized) with a plenum at each end. During the charging cycle, warm air from the solar collector is circulated through the rocks, warming them. During the discharge cycle, cool room air is circulated through the rocks where it is heated and returned to the room.

Rockbeds:

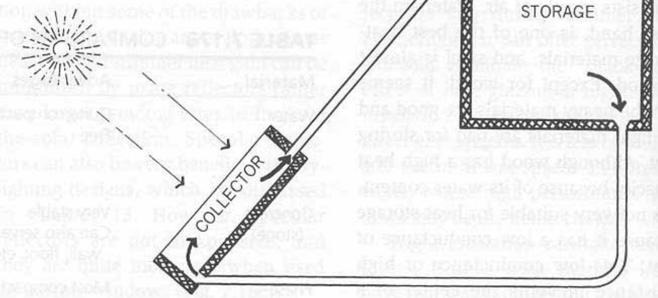

Figure 7.18a The convective loop (thermosiphon) system requires the storage to be above the collector.

HCL

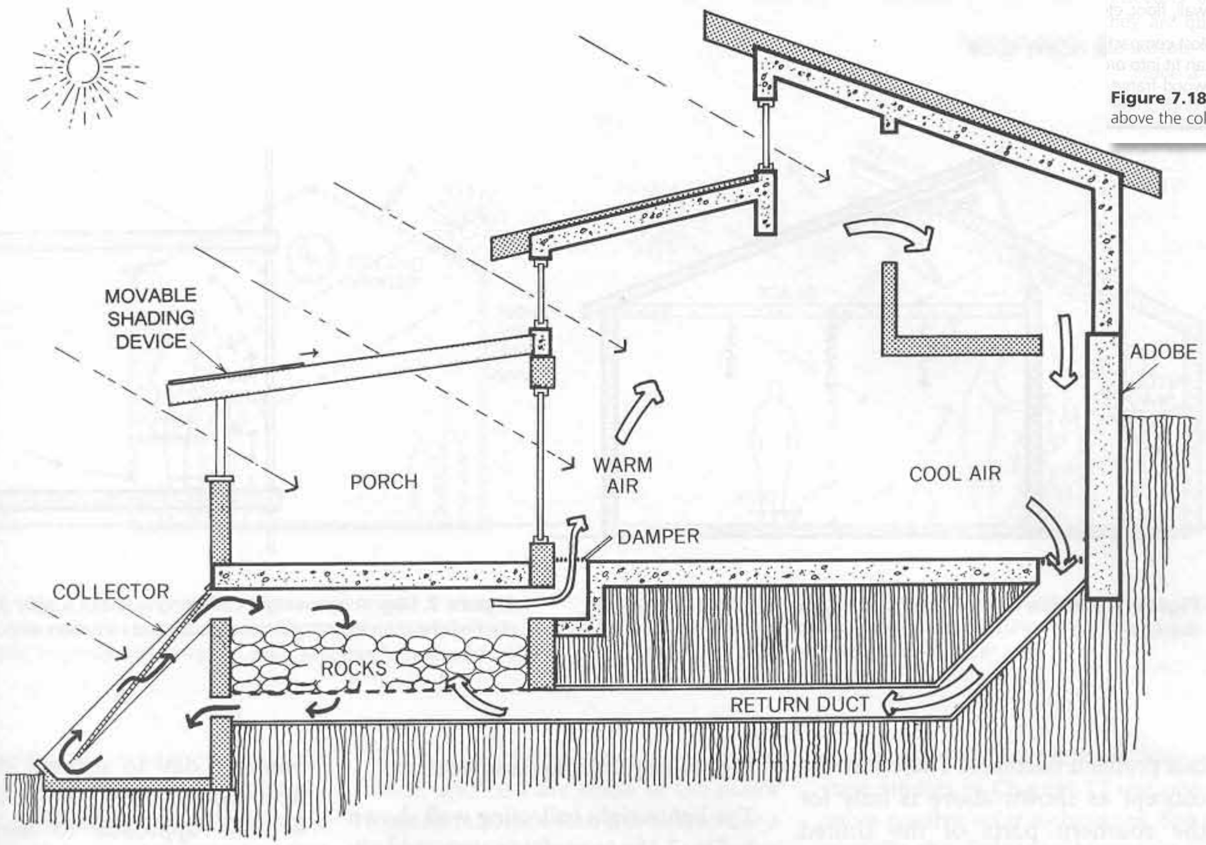

Figure 7.18b A convective loop heats the rock bed in the Davis house, New Mexico, designed by Steve Baer.

Rockbeds:

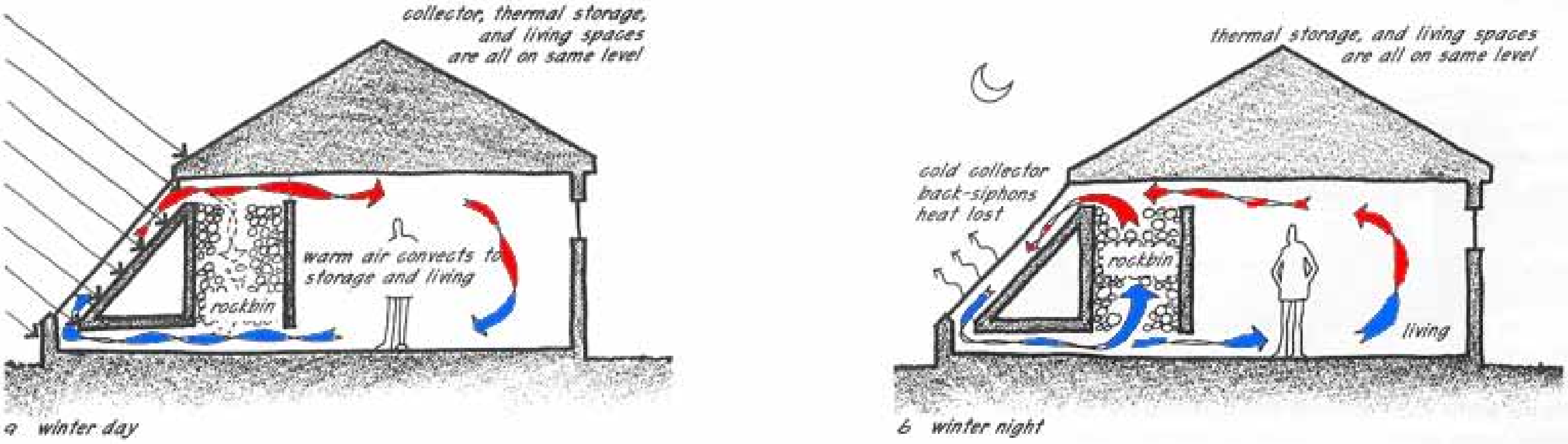

Figure 11.1: Positioning the collector, storage, and living areas at the same level in a convective air loop system: (a) winter day operation — level arrangement allows convective heating to occur during the day; (b) winter night operation — this "level" positioning of components permits unwanted back-siphoning, effectively cooling the system.

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Rockbeds:

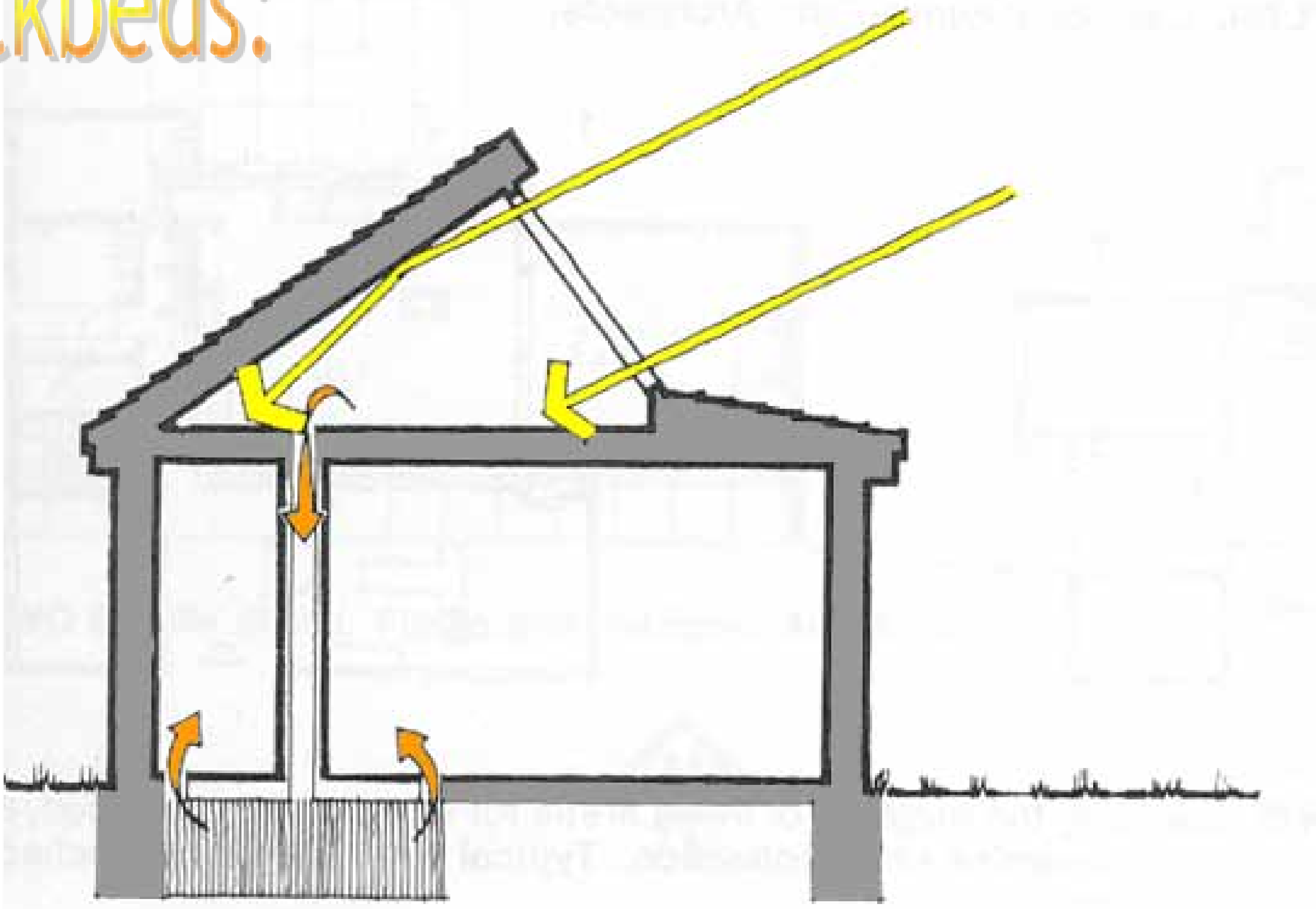
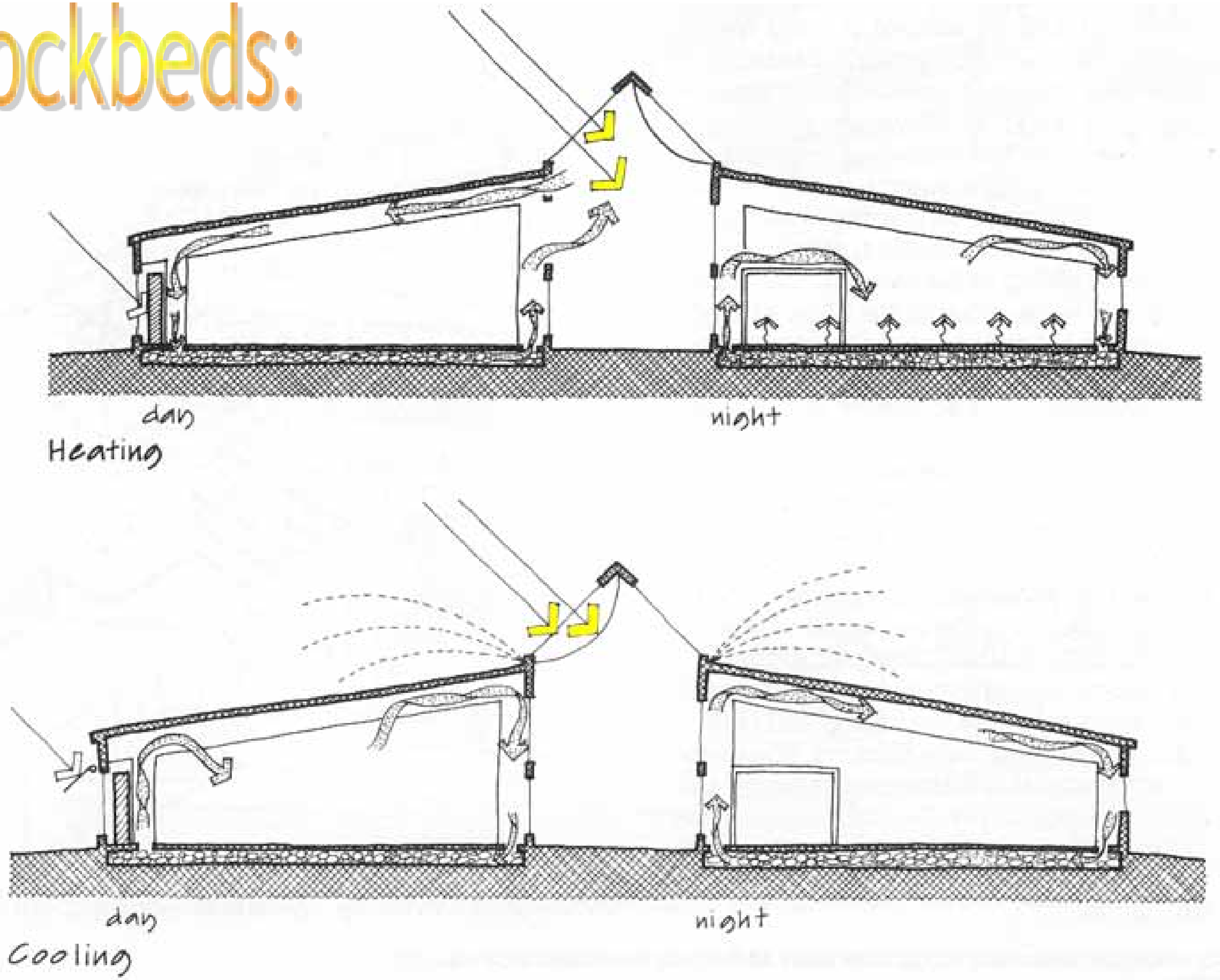


FIG. 19e. **Remote Gain and Storage**

Rockbeds:



SWL

Rockbeds:

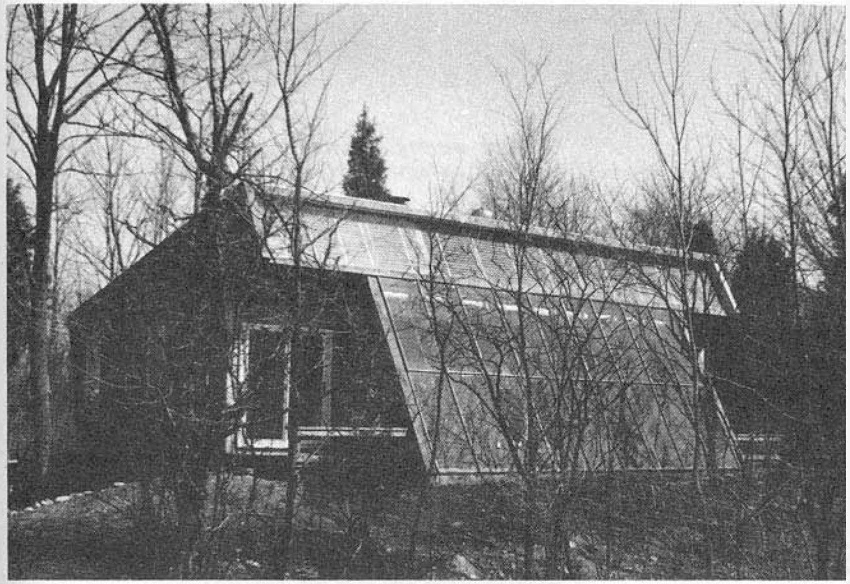


Figure 10.6: Solargreen exterior showing south-facing sunspace.

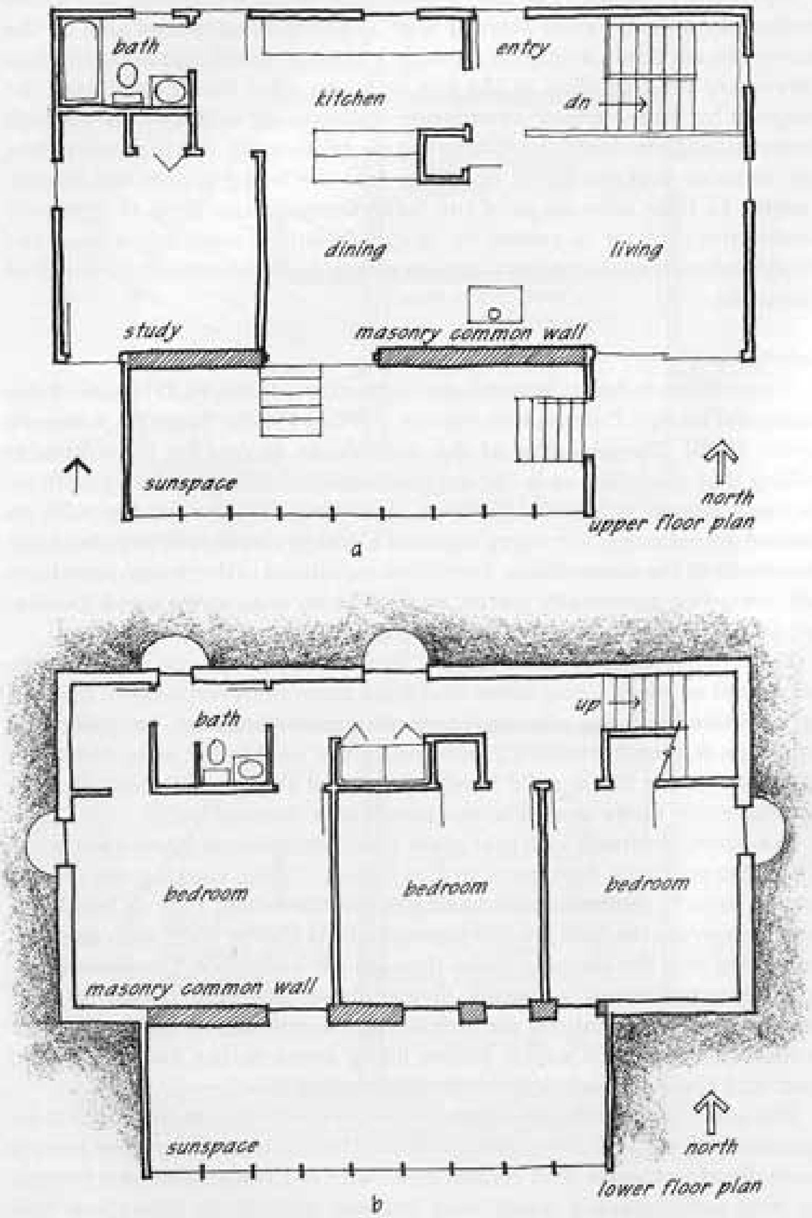


Figure 10.8: Solargreen floor plans: (a) upper level, and (b) lower level.

ECS

Rockbeds:

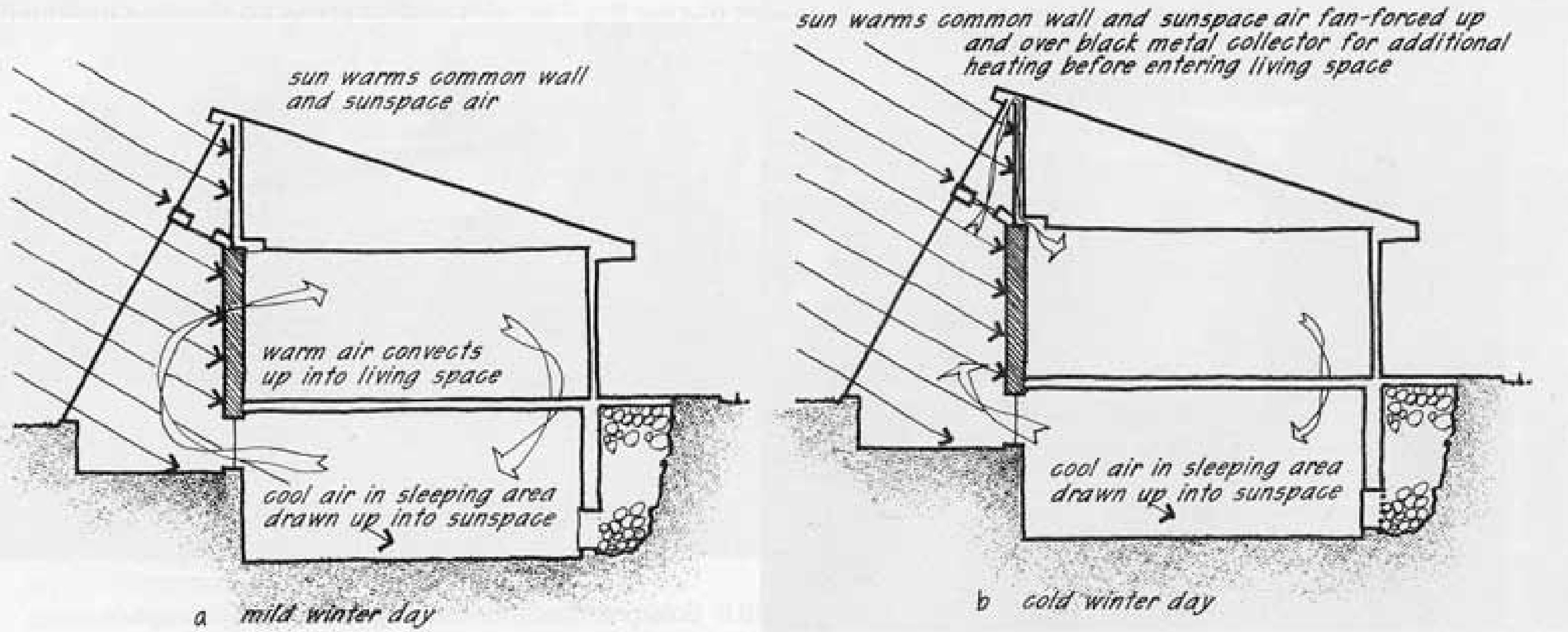


Figure 10.9: Solargreen passive operation: (a) winter day — passive heating only, and (b) winter day — with hybrid collector added.

ECS

Rockbeds:

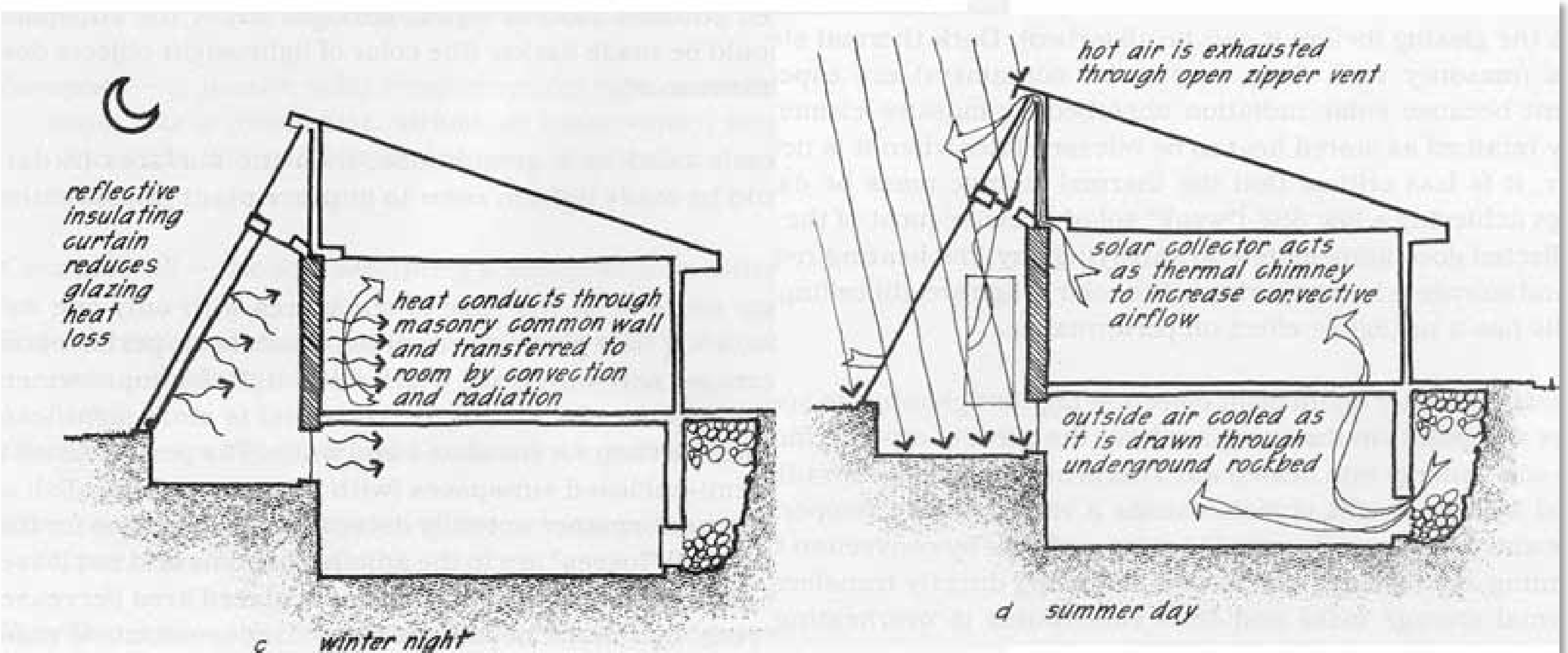


Figure 10.9 (continued): Solargreen passive operation: (c) winter night, and (d) summer day.

ECS