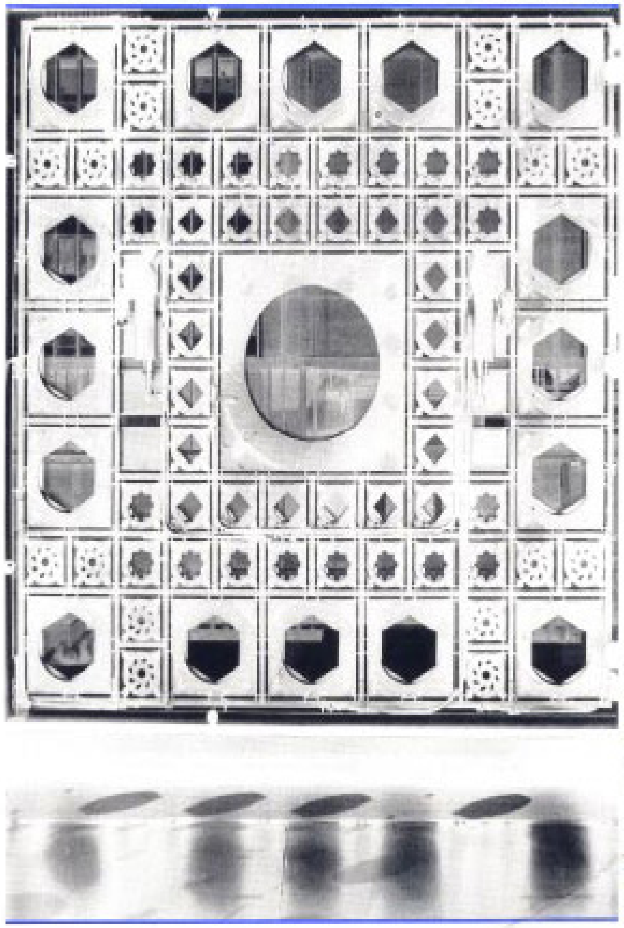
INSIDE Out

Second Edition



DESIGN PROCEDURES FOR PASSIVE ENVIRONMENTAL TECHNOLOGIES

C1 - D1 Thermal

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C1 THERMAL

PROGRAM ANALYSIS

INTRODUCTION

Goal

Determine whether the building has an internally dominated load (IDL) or a skin dominated load (SDL) in order to establish appropriate thermal design strategies.

Discussion

The load on a building refers to the heat imbalance between the inside and the outside that makes the building skin a necessary barrier between the two. Buildings with a heating load need to be heated; buildings with a cooling load need to be cooled. Your building may require both heating and cooling over the course of the day or year, and it may have zones with heating loads, while the rest of the building requires cooling. The customary unit for measuring thermal loads (in English units) is British thermal units per hour or Btuh (a few references abbreviate Btuh as Btu/hr or Btu/h). When comparing the intensity of thermal loads in similar buildings or in zones of a single building, thermal load density (Btuh/ft^2) is used.

For an IDL building the major thermal problem over the year is caused by thermal forces generated within the building—heat from people, lights, and equipment. IDL buildings have a cooling load most of the year because they generate heat faster than they can dissipate it to their surroundings.

For an SDL building the major thermal problem over the year is caused by thermal forces acting on the skin of the building—convective, conductive, and radiant heat flows through the building skin as well as infiltration of outside air. SDL buildings are more strongly affected by these external loads than by their internal loads: They need to be cooled when it's hot and heated when it's cool.

In this section you will:

1. Analyze the programmed use of each space in your building.
2. Divide the building into a few zones according to anticipated thermal performance.
3. Estimate the heat gains and heat losses for each zone.
4. Calculate balance point temperatures for each zone to establish heating and cooling requirements.
5. Adopt appropriate, energy-conservation strategies for each zone.

C1 THERMAL

PROGRAM ANALYSIS

USE SCHEDULES—PEOPLE, LIGHTS, AND EQUIPMENT

Discussion

Your building program identifies a number of discrete spaces with characteristics that change over the course of a day. The number of occupants will vary from space to space, and each space may be heavily occupied at certain times (peak hours) and sparsely occupied at others (off-peak hours). Each space may have different types of equipment in operation and different lighting requirements. Since people, lights, and equipment are heat sources, the internal heat gains will vary from space to space, and each space will have different thermal needs. Analyzing the programmatic use of each space is a first step toward a design that will address those needs.

Procedure

For each space identified in your building program:

1. Calculate the approximate area of the space according to occupancy [Table C1.1.1] or other design considerations (such as your design intuition or *Architectural Graphic Standards*).
2. Determine when the space is in use, then identify the hours of heavy use or higher occupancy (peak hours) and the hours of light use or lower occupancy (off-peak hours). You may want to add a third use category, unoccupied, to distinguish between sparsely occupied and completely unoccupied times.
3. Record the number of people during peak and off-peak hours.
4. Determine whether the lighting use level is high, moderate, or low at peak and off-peak hours. Display spaces and visually demanding tasks such as sewing, drafting, or hazardous work require high light levels. Circulation spaces require only low light levels. Most program spaces require moderate light levels. [For general lighting levels by task, see *Heating, Cooling, Lighting* Table 12.9 p.381. For general lighting power density values see *MEEB* Table 15.1, p.675.]
5. Determine whether equipment use in the space is high, moderate, or low during peak and off-peak hours. For example, circulation spaces have minimal equipment and low use rates, office spaces generally have moderate use rates, and commercial kitchens have high use rates.

Use Schedule [suggested format]

Space	Area (ft^2)	Peak Hours	Off-Peak Hours	Number of Occupants	Light Level	Equipment Use
kitchen	*240*	*6a.m.–1p.m., 5p.m.–8p.m.*		*6*	*moderate*	*high*
	240		*1p.m.–5p.m., 8p.m.–midnight*	*1*	*moderate*	*moderate*

USE SCHEDULES (continued)

Table C1.1.1 Occupancy

	Use	Floor Area per Occupant (ft^2)
1.	Aircraft Hangars (no repair)	500
2.	Auction Rooms	7
3.	Assembly Areas, Concentrated Use	7
	(without fixed seats)	
	auditoria	
	churches and chapels	
	dance floors	
	lodge rooms	
	reviewing stands	
	stadia	
4.	Assembly Areas, Less Concentrated Use	15
	conference rooms	
	dining rooms	
	drinking establishments	
	exhibit rooms	
	gymnasia	
	lounges	
5.	Bowling Alleys	5 people per alley
6.	Children's Homes and Homes for the Elderly	80
7.	Classrooms	20
8.	Congregate Residences	
	10 or fewer occupants, less than 3,000 ft^2	300
	10 or more occupants, more than 3,000 ft^2	200
9.	Dormitories	50
10.	Dwellings	300
11.	Exercise Rooms	50
12.	Garages, Parking	200
13.	Hospitals and Sanitaria, Nursing Homes	80
14.	Hotels and Apartments	200
15.	Kitchens (commercial)	200
16.	Library Reading Rooms	50
17.	Locker Rooms	50
18.	Manufacturing Areas	200
19.	Mechanical Equipment Rooms	300
20.	Nurseries for Children (daycare)	35
21.	Offices	100
22.	School Shops and Vocational Rooms	50
23.	Storage and Stock Rooms	300
24.	Stores, Retail Sales	30
25.	Warehouses	500
26.	All Others	100

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C1 THERMAL

PROGRAM ANALYSIS

THERMAL ZONING

C1
C1.2

Discussion

If thermal efficiency were your sole design criterion, it would be simpler to meet thermal needs if you grouped the building spaces into two or three major thermal zones, rather than dealing with each space individually. Each thermal zone should contain spaces with similar thermal needs. By identifying similar or compensating use levels (similar hours of use and density of internal loads from people, lights, and equipment), you can easily group spaces into thermal zones. When this grouping is done, an appropriate thermal design strategy can be developed for each zone.

Procedure

1. Evaluate the data you compiled in C1.1. Group those spaces with similar peak and off-peak hours. Then group the spaces with similar or compensating levels of use by people, lights, and equipment.
2. Work with both lists until you have identified two or three zones with relatively consistent thermal characteristics. (More than three zones should not be necessary for your small building.)
3. Develop a schematic design drawing indicating the spatial layout of each zone and the placement of zones relative to each other on your site. Annotate this drawing to explain your rationale. Label the zones A, B, or C in the order of thermal load density (e.g., from lowest [A] to moderate [B], to highest [C]).

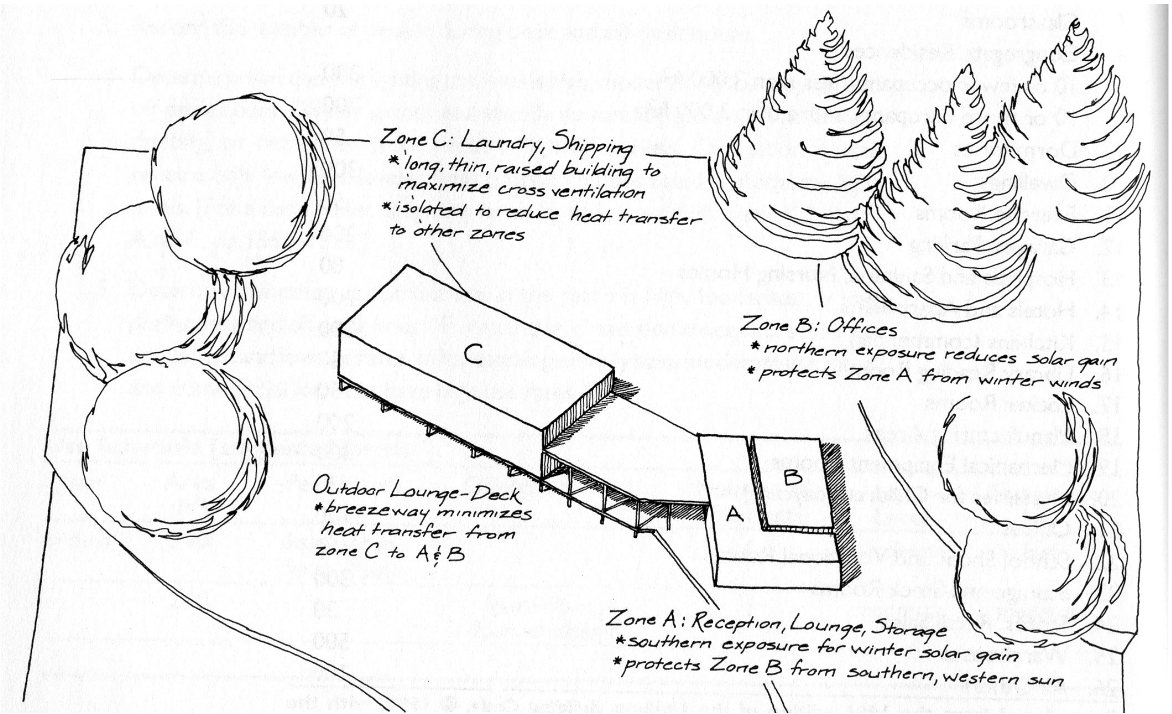


Figure C1.2.1 Thermal Zoning Proposal. Linen supply, Charleston, South Carolina.

C1 THERMAL

PROGRAM ANALYSIS

HEAT GAINS

C1

C1.3

DISCUSSION

There are two basic components of your building's heat gain: The gain from internal thermal forces (people, lights, and equipment) and the gain from external thermal forces (primarily solar gain). You can estimate the people–lights–equipment gains of each thermal zone according to its characteristic functions. Solar gains can be roughly estimated within a narrow seasonal range. More precise heat gain estimates will be developed in E1.3.

PROCEDURE

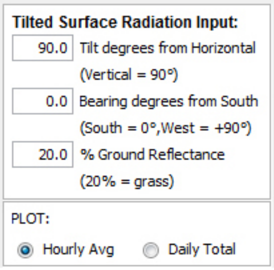
For each zone:

1. List the peak and off-peak hours.
2. Select the function that is most representative [Table C1.3.1 or *SWL*, pp. E.351-E.352], and use the corresponding heat gain from people, lights, and equipment. If your zone is a composite of two or more functions, calculate or estimate the average intensity of heat gain. Since the table represents heat gains for moderate to high use, you may use a reduced heat gain when estimating off-peak gains. In most cases you will have to make an educated guess, and the results will be only as accurate as your estimate. This estimation **IS** precise enough for this stage of the design process.

Heat Gains: People, Lights, Equipment [suggested format]

Zone	Peak Hours	Off-Peak Hours	Function	Heat Gain (Btuh/ft^2)
A	*8a.m.–6p.m.*		*office*	*11*
A		*6p.m.–8a.m.*	*office*	*6*
B	*6a.m.–8a.m.,* *noon–2p.m.*		*cafeteria*	*19.5*
B		*8a.m.–noon*	*cafeteria*	*6.5*

3. Assume that the sunny day peak solar heat gain is through your south aperture at noon and is at zero at sunrise and sunset. Use *Climate Consultant*, Radiation Range plot {set the Tilt to 90º, see Fig C1.3.1) to approximate your seasonal peak solar gains. Use the Total Surface Average High values for January, April, July and October. If the window is shaded, reduce the gain by 50%. Divide the peak gain from each aperture by the floor area of the zone.



Tilted Surface Radiation Input:

90.0 Tilt degrees from Horizontal (Vertical = 90°)

0.0 Bearing degrees from South (South = 0°,West = +90°)

20.0 % Ground Reflectance (20% = grass)

PLOT:

● Hourly Avg ○ Daily Total

Figure C1.3.1 Tilt setting.

Heat Gains: Solar (for each zone) [suggested format]

Zone ________		January Heat Gain (Btuh/ft^2)	April Heat Gain (Btuh/ft^2)	July Heat Gain (Btuh/ft^2)	October Heat Gain (Btuh/ft^2)
Time:	Sunrise	0	0	0	0
	noon				
	Sunset	0	0	0	0

PROGRAM ANALYSIS

HEAT GAINS (continued)

SENSIBLE HEAT GAIN (Btu/h, ft2 of Floor Area)

BUILDING TYPE	People (occup.)	Equipment (eff.-ave.)	Lights Daylighted	Lights Not Daylighted
Assembly	5	3 to 5	1.2 to 2.1	2.8 to 4.8
Auditoria	28	1		
Standing space	32	0.5		
Conference rooms	11	3 to 5		
Education	3 to 8	4 to 7	1.7 to 2.8	4 to 6.5
Classroom	13	3 to 4		
Laboratory	8	4 to 7		
Libraries	5	3 to 4		
Grocery Stores	2 to 5	8 to 13	1.6 to 3.4	3.8 to 7.8
Lodging	1	3 to 5	1.2 to 1.8	2.9 to 4.1
Healthcare			2.9 to 4	6.8 to 9.2
Sleeping (hospital)	1 to 2	1 to 2		
In-patient (clinic)	2	2 to 4		
Office	1 to 2	3 to 5	1.9 to 2.2	4.4 to 5.1
Recreation			2.3 to 5.7	5.5 to 13.3
Spectator areas	34	0		
Gymnasium	19	1 to 2		
Ballroom	31	1 to 2		
Residential	1 to 2	1 to 2	0.3 to 1.8	0.7 to 4.1
Dormitory sleeping	5	1 to 2		
Apartments	1 to 2	1 to 2		
Restaurant			1 to 2.1	2.4 to 4.8
Fast food, dining	23	3 to 5		
kitchen, refrigeration	6	17		
Sit-down	16	4 to 6		
kitchen, refrigeration	6	7		
Retail	2 to 8	3 to 5	1.5 to 4.8	3.4 to 11.3
Warehouse	0 to 2	2 to 4	0.1 to 1.3	0.3 to 3.1

Table C1.3.1 Sensible Heat Gain from People and Equipment plus Lights.

4. Make a total heat gain schedule for your building by combining the heat gains from people, lights, and equipment with the solar heat gains. Include enough data to represent the operations of your building during peak and off-peak periods. You will need these schedules to estimate the balance point temperature in C1.5.

Heat Gain Schedule (for each zone) **[suggested format]**

Zone__*A* Month/Season *October/Fall*

Time	People, Lights, Equipment (Btuh/ft^2)	Solar (Btuh/ft^2)	**TOTAL** (Btuh/ft^2)
7a.m.	*7*	*0*	*7*

HEAT LOSS

Discussion

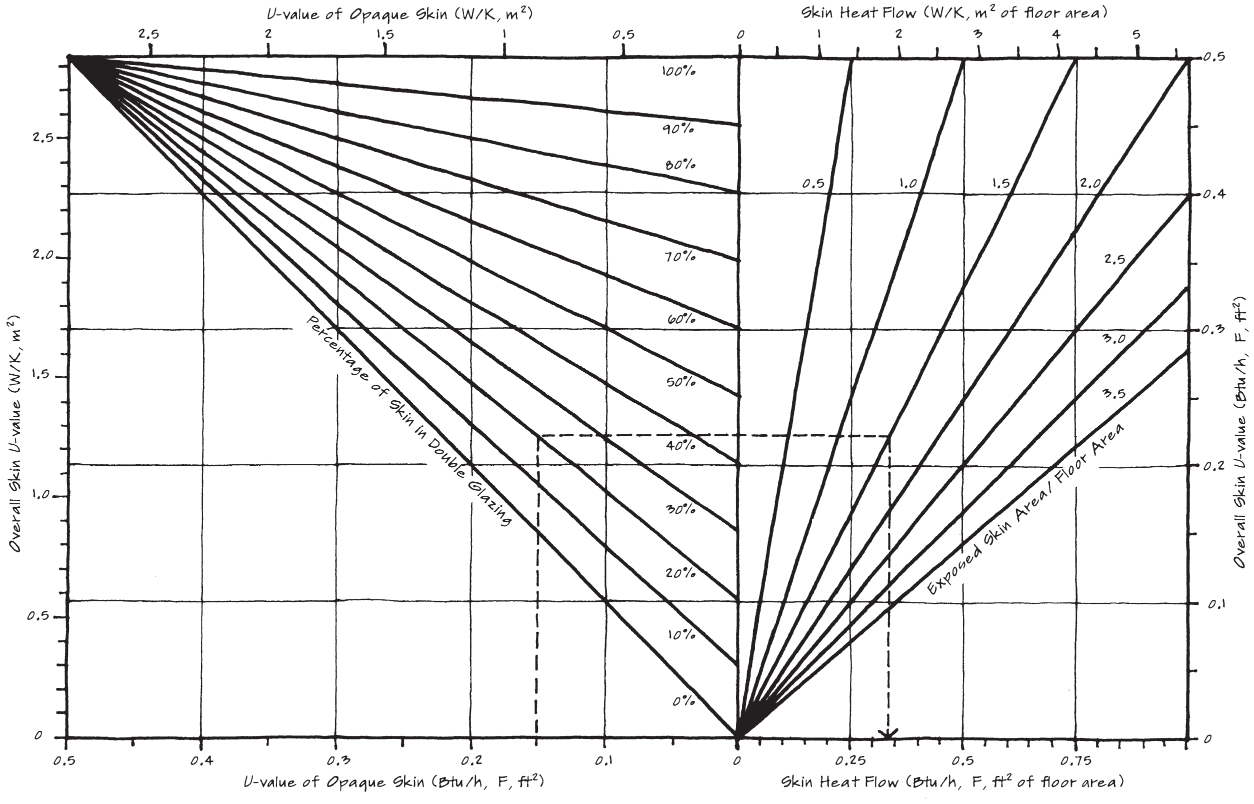
Building heat gains vary daily and seasonally according to operating schedule and sun intensity. Heat loss—through the building skin and ventilation or infiltration—is defined solely by the temperature difference between inside and outside. In fact, heat loss is constant for each degree of temperature difference (in other words, Btuh/ft^2°F is constant). Both types of heat loss can be estimated according to function.

Procedure

For each zone, use the nomograph below, Fig. C1.4.1, to calculate Skin Heat Flow and Table C1.4.1 on the next page to estimate Ventilation Heat Gain/Loss. For the nomograph, you'll need to estimate the U-value of the opaque skin [0.05 for built-to-code or 0.03 for well-insulated], percentage of skin area in glass, and exposed skin to floor area ratio of each zone.

Heat Loss Schedule [suggested format]

Zone	Area (ft^2)	Heat Loss through Skin (Btuh/ft^2°F)	Heat Loss by Ventilation/Infiltration (Btuh/ft^2°F)	**TOTAL** (Btuh/ft^2°F)
A	*1,200*	*0.7*	*1.0*	*1.7*



Estimating Heat Flow Through the Skin

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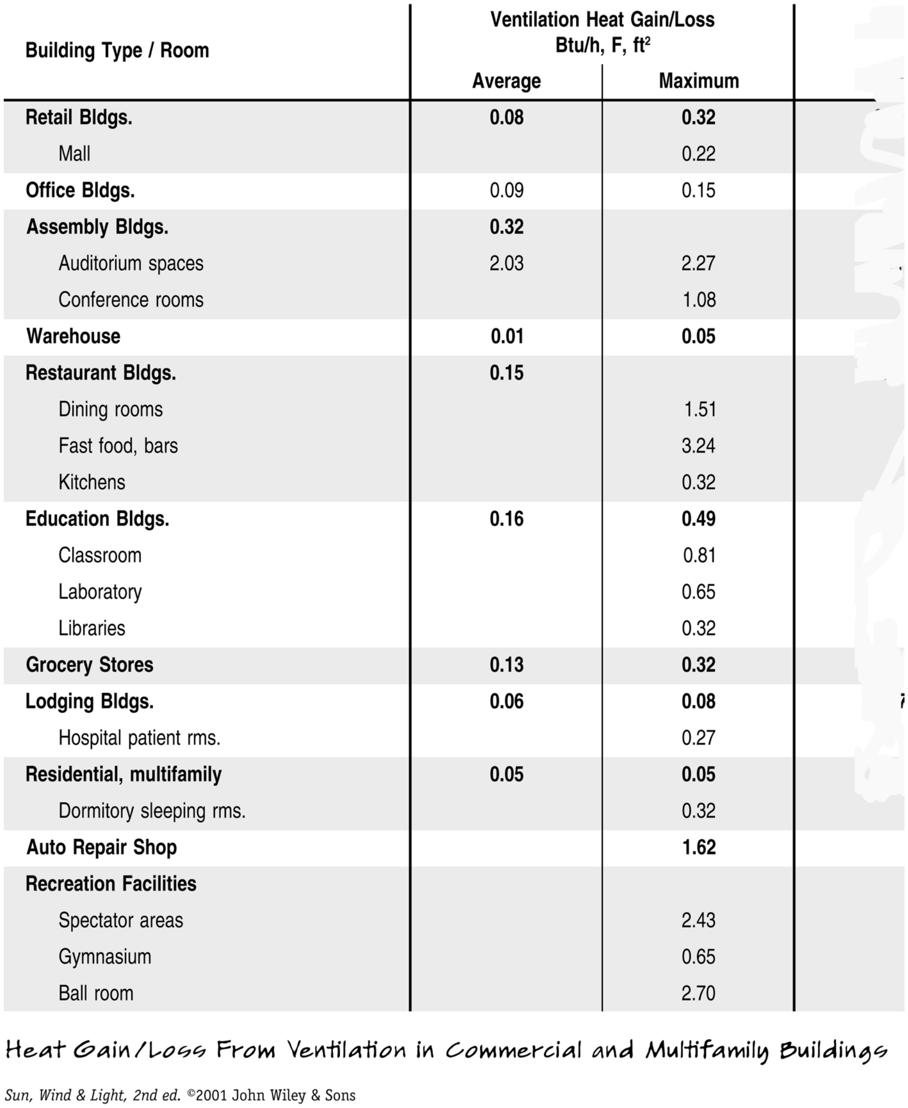
Figure C1.4.1 Sensible Heat Gain from People and Equipment plus Lights.

HEAT LOSS (continued)



Building Type / Room	Ventilation Heat Gain/Loss Btu/h, F, ft^2 Average	Maximum
Retail Bldgs.	**0.08**	**0.32**
Mall		0.22
Office Bldgs.	0.09	0.15
Assembly Bldgs.	**0.32**	
Auditorium spaces	2.03	2.27
Conference rooms		1.08
Warehouse	**0.01**	**0.05**
Restaurant Bldgs.	**0.15**	
Dining rooms		1.51
Fast food, bars		3.24
Kitchens		0.32
Education Bldgs.	**0.16**	**0.49**
Classroom		0.81
Laboratory		0.65
Libraries		0.32
Grocery Stores	**0.13**	**0.32**
Lodging Bldgs.	**0.06**	**0.08**
Hospital patient rms.		0.27
Residential, multifamily	**0.05**	**0.05**
Dormitory sleeping rms.		0.32
Auto Repair Shop		**1.62**
Recreation Facilities		
Spectator areas		2.43
Gymnasium		0.65
Ball room		2.70

Heat Gain/Loss From Ventilation in Commercial and Multifamily Buildings

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Table C1.4.1 Ventilation Heat Gain/Loss by building type.

BALANCE POINT TEMPERATURE ESTIMATE C1.5

Discussion

By comparing the external temperature data for your climate with the heat gain and heat loss data for your thermal zones, you can determine the daily and seasonal heating and cooling requirements of your building. The balance point temperature is the outdoor temperature at which a zone loses heat at the same rate it generates heat. For example, a balance point temperature of 40°F indicates cooling is required when the external temperature is above 40°F, and heating is required when it is below 40°F. Since your heat gain and loss rates change daily and seasonally, your balance point temperatures will also fluctuate.

For more information

SWL, A28, pp.E.356–363.

Procedure

For each thermal zone:

1. Assign minimum and maximum seasonal temperatures for your climate [*Climate Consultant* Temperature Range plot] to the times of day on the chart below. (These are the typical times when minima and maxima occur—just before sunrise and halfway between noon and sunset.) You may substitute data from months that better represent your climate's seasons.

Month	Time	Min Temp	Time	Max Temp
January	7a.m.		2p.m.	
April	5a.m.		3p.m.	
July	4a.m.		6p.m.	
October	6a.m.		3p.m.	

2. Plot the time–temperature points for each season on the corresponding balance point temperature chart [Figure C1.5.3], and connect the points with a straight line. Then make a copy of the chart for each zone.

3. Calculate the temperature differential (ΔT) between the inside and the balance point temperature using the nomograph in Figure C1.5.1 on the next page. For the rate of heat gain, use the data from C1.3; for the heat loss rate, use the data from C1.4. For each season you will need to find ΔT for peak and off-peak hours throughout the day. Alternately, you may use the formula below to calculate ΔT.

   ΔT = (rate of heat gain) **/** (rate of heat loss)

4. Set an internal temperature, T_{in}, or thermostat setting for each season, and plot it as a straight line across the balance point temperature charts. Choose temperature settings according to the season. For example, 65°F in winter when occupied (day), 50°F in winter when unoccupied (night), and 80°F in summer.

BALANCE POINT TEMPERATURE ESTIMATE (continued)

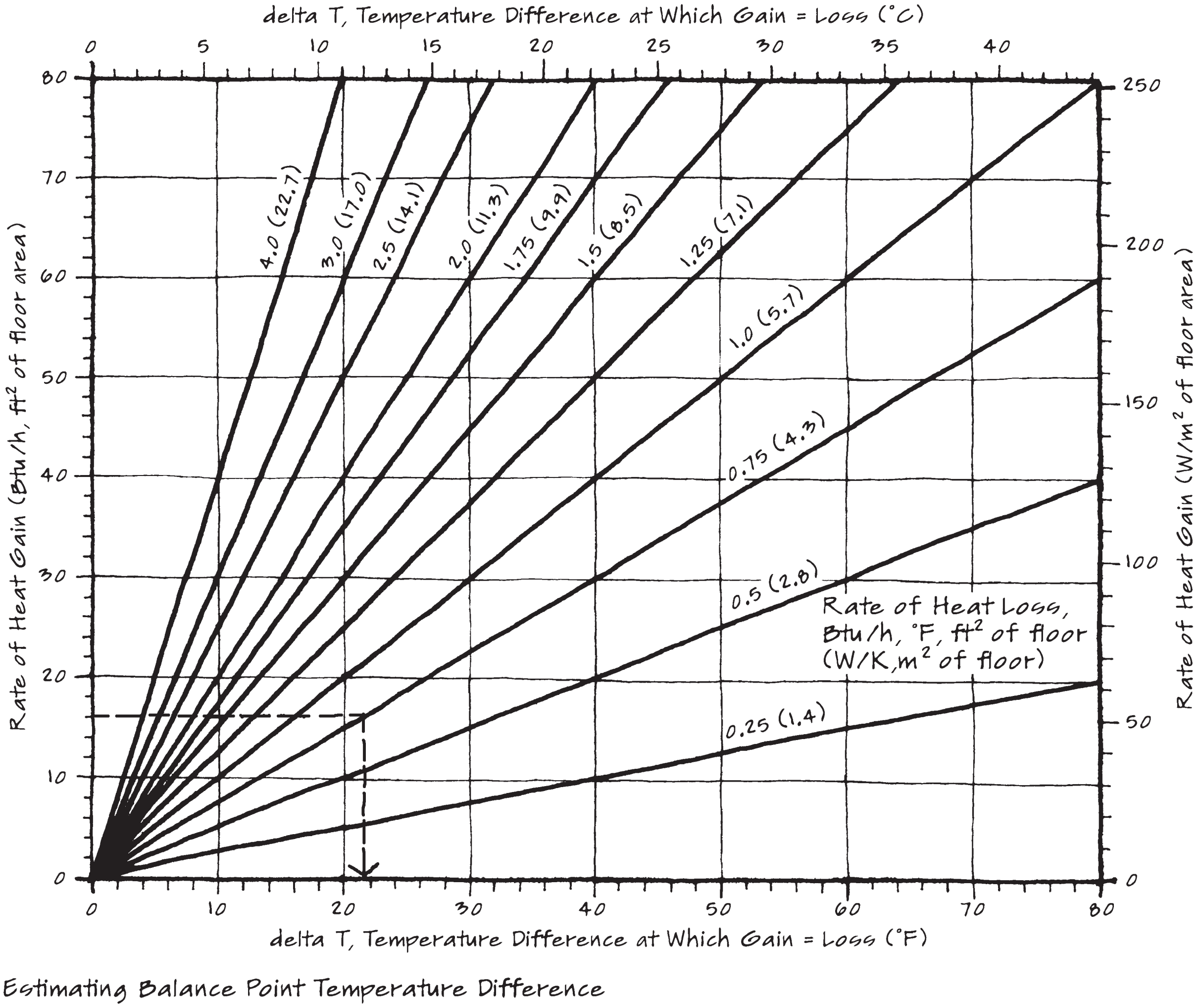

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Figure C1.5.1 **Balance Point Temperature Nomograph for Rates of Heat Gain. Adapted, by permission, from Brown, *Sun, Wind, and Light*, copyright © 2001, John Wiley & Sons, Inc.**

BALANCE POINT TEMPERATURE ESTIMATE (continued)

5. Using T_{in} and ΔT, calculate the balance point temperatures for sunrise, noon, sunset, peak hours, and off-peak hours in each season.

   balance point temperature = $T_{in} - \Delta T$

Balance Point Temperature Data (for each season for each zone) [suggested format]

Zone *A* Season *Winter*

Time	T_{in} (°F)	ΔT (°F)	Balance Point Temperature (°F)
6a.m.	*50*	*15*	*35*
noon	*65*		

6. Plot the balance point temperatures for each season by time of day on the corresponding balance point temperature chart. Blank charts areprovided on the following pages [Figure C1.5.3]. Reproduce it for each zone of your building. Use the midpoints of peak and off-peak time spans for plotting. Connect the balance point temperatures with a dashed line.

7. Color the area between the external temperature level and the balance point temperature level **RED** if heating is required (external temperature is below the balance point temperature) and **BLUE** if cooling is required (external temperature is above the balance point temperature).

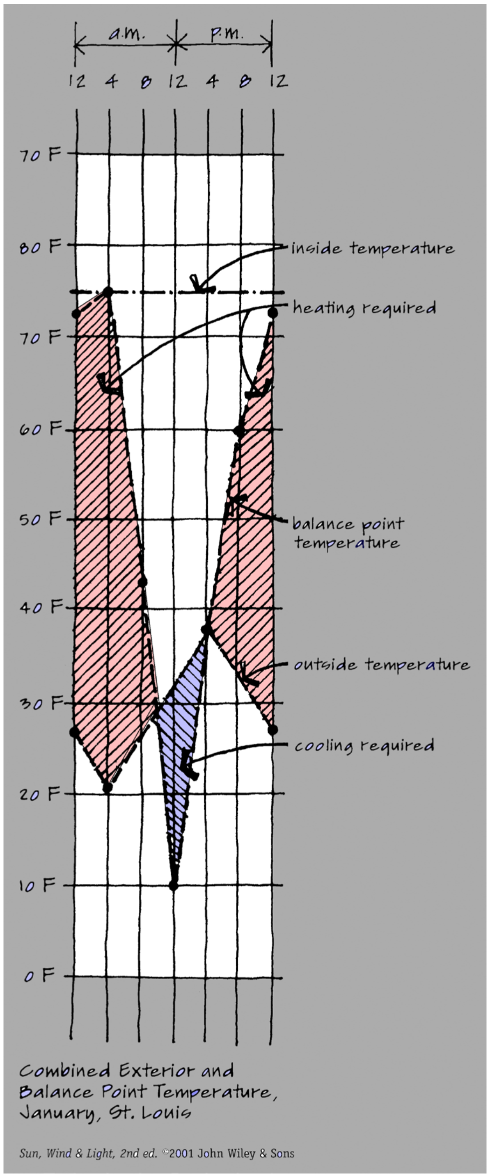

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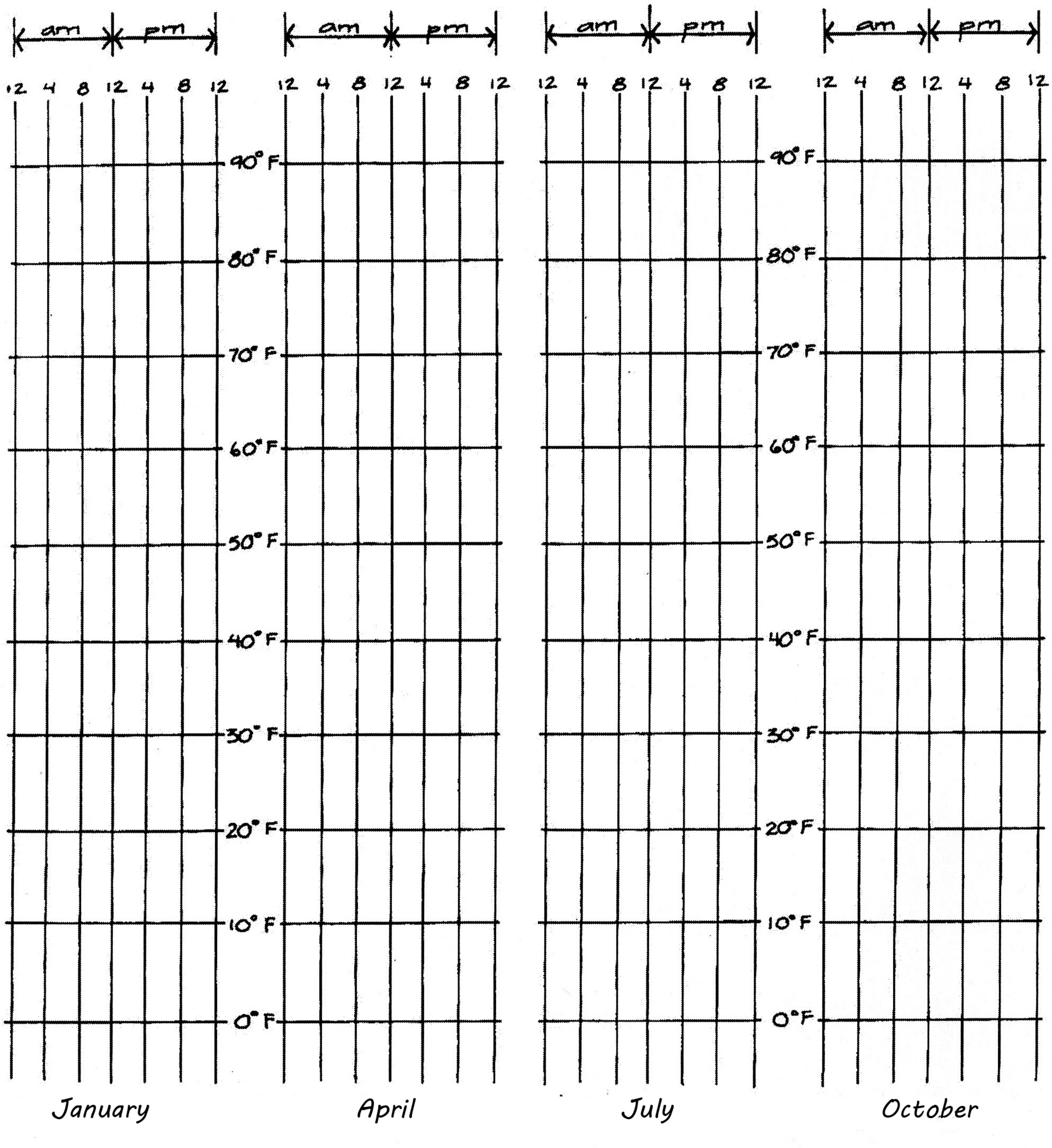
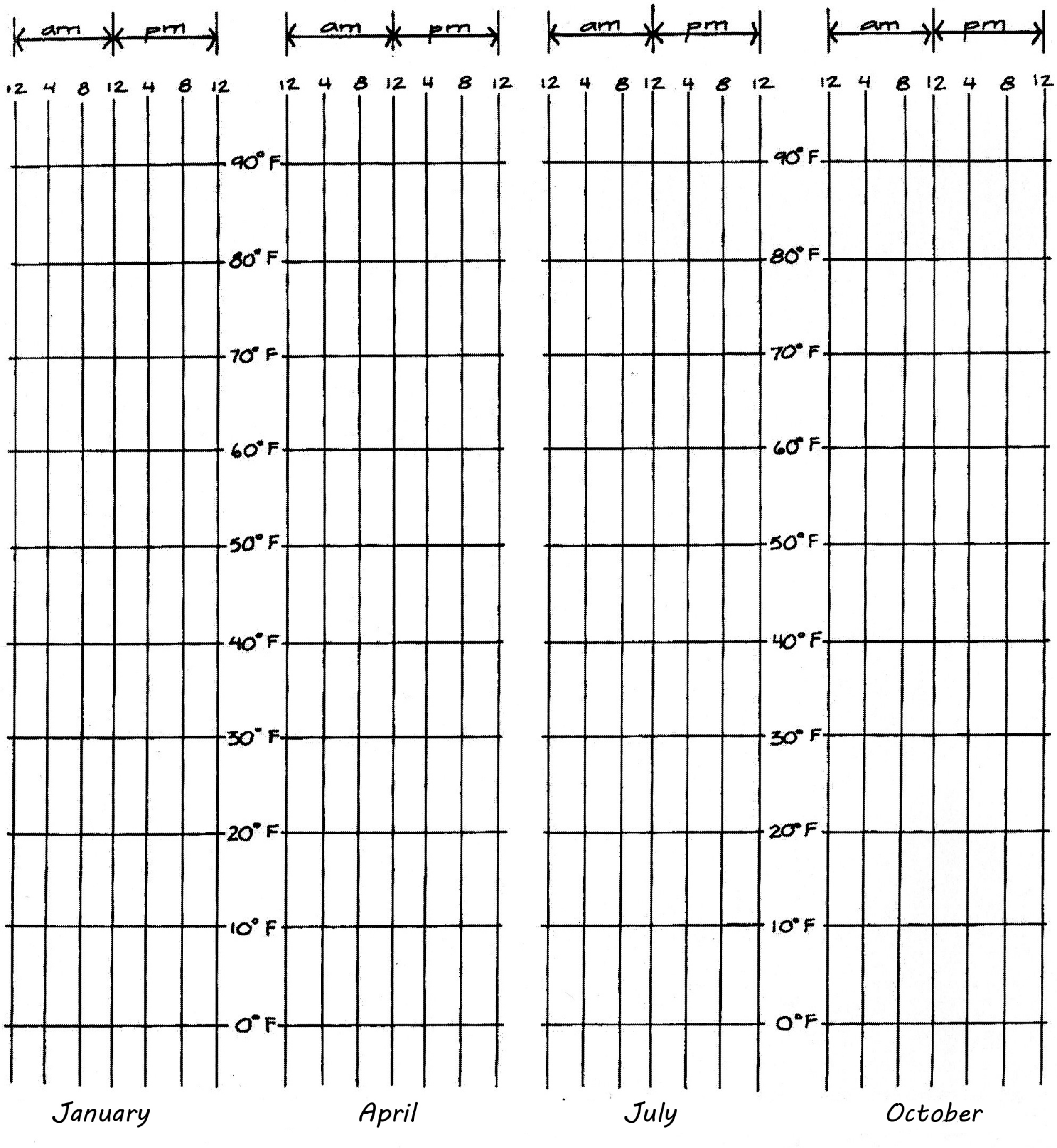
Figure C1.5.2 January Balance Point Temperature Plot. For 1,500 ft² building in St. Louis, MO.

BALANCE POINT TEMPERATURE ESTIMATE (continued)



Zone ____________________

Figure C1.5.3 **Balance Point Temperature Charts**



Zone ______________________

Figure C1.5.3 Balance Point Temperature Charts

ENERGY CONSERVATION

C1.6

Discussion

The balance point temperatures indicate the thermal needs of your zones. IDL zones require cooling year-round, while SDL zones require summer cooling and winter heating. Since the balance point temperature charts show the thermal profile of a typical day, you can make subtle determinations, such as whether morning warm-up or all-day heating is necessary.

Procedure

1. Consult the table of energy conservation strategies [Table C1.6.1] to help choose appropriate thermal strategies for each zone.
2. Illustrate your energy-conservation choices with an annotated, schematic diagram of your proposed thermal zoning.

Table C1.6.1 Energy Conservation Strategies

Characteristic Balance Point Temperature Chart		Strategies											
		interior temperature setting		internal heat generation		solar heat gain		rate of heat gain or loss through envelope		rate of heat gain or loss by ventilation		thermal storage	
		increase	decrease	increase	decrease	increase	decrease	increase	decrease	increase	decrease	store heat	store cool
heating always required			X	X		X			X		X		
heating and cooling required	heating		X	X		X			X		X		X
	cooling--outside warmer than inside	X			X		X		X		X	X	
	cooling--outside cooler than inside	X			X		X	X		X		X	
cooling always required	outside warmer than inside	X			X		X		X		X		
	outside cooler than inside	X			X		X	X		X			X

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D1 THERMAL

SCHEMATIC DESIGN

INTRODUCTION

Goal

Design a building that synthesizes the information you have acquired through the study of precedents; the analyses of your site, climate, and program requirements; and the application of thermal design strategies for heating and cooling.

Thermal Schematic Design Goals

A. The thermal strategies chosen will work in your climate.
B. Buildings are located so shadows are not cast off the site.
C. The buildings are clustered and sited to create optimal microclimates for heating when you need heat and for cooling when you need to cool.
D. Sufficient aperture is provided to ventilate the building.
E. Ventilation removes heat without leaving hot, dead-air areas.
F. The building is exposed to the south in proportion to the heat needed.
G. The winter sun can reach all the south-facing apertures provided for the collection of heat.
H. Glazing is shaded from the sun during overheated months.

Discussion

Sections D1, E1, F1, and G1 are concerned with design for heating and cooling. We have devoted a large portion of this workbook to thermal considerations because of their significant impacts on building form and energy use.

It is helpful to make an analogy between the ways organisms and buildings respond to their thermal environments (Knowles 1974). Organisms respond in three ways—migration, form, and metabolism. When migrating, they move from an environment that is too cold or too hot to one that is just right. This movement may happen seasonally or diurnally. The ratio of an animal's skin or surface area to its volume determines its ability to lose heat to the environment. For example, the form of an elephant's ear is primarily described by its large surface area that maximizes the elephant's potential to cool. Metabolism refers to the internal chemical conversion of food energy to heat. Those animals with a high heat loss must eat large amounts of food to produce heat within their bodies to balance their heat loss (Thompson 1952 and Stevens 1974).

These three forms of thermal response have their analogies in buildings. Migration in the built world is as commonplace as migration in the natural world. Occupants may move from one area of a building to another or the building may be moved to a thermally different area. For example, to better cope with hot, summer evenings, residents move from bedrooms to sleeping porches. Form—which can include size, shape, skin area, orientation, proportion, volume, openings, articulation—can also be dependent on thermal response. An igloo's compact form (an example of the smallest possible skin area to enclosed volume ratio) minimizes the rate of heat loss and offers a small profile to heat-robbing winds. Metabolism, the fuel-sustained component

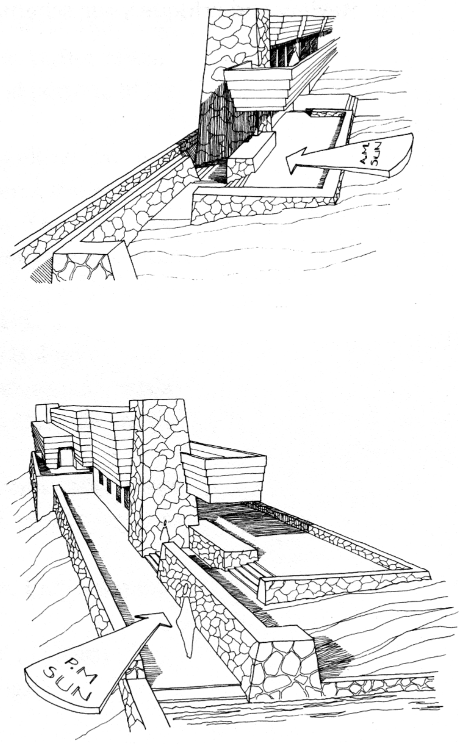

Figure D1.0.1 ***Above,*** **Morning Terrace;** ***below,*** **Evening Terrace. Pauson House, Phoenix, Arizona, Frank Lloyd Wright (architect), 1941.**

INTRODUCTION (continued)

of the building, seeks to maintain thermal equilibrium. The more heat-producing people, lights, and equipment that occupy a building, the more cooling is required.

Current design practice usually separates form from metabolism in order to simplify preliminary design development. They are not recombined until later in the process when a building's form must be used as the basis for determining its metabolic rate. Even though form and metabolism are dependent on different sets of variables, they are intrinsically linked. If thermal needs are not taken into consideration when determining form, the cost required for the building to obtain metabolic equilibrium can be enormous.

IN THIS SECTION YOU WILL:

1. Employ appropriate thermal design strategies.
2. Complete your thermal schematic design.
3. Use a variety of analysis techniques to test the performance of your schematic design and to alter it, where appropriate.
4. Review and critique your schematic design.

DESIGN

THERMAL SCHEMATIC DESIGN STRATEGIES

Site-Scale Strategies

- Schedule building use periods to avoid the hottest times of the day.
- Use wind breaks to protect building clusters without shading them in winter.
- Use trees for shading during the building's overheated months, particularly on the east and west building façades, and for outdoor spaces during the months when it is hot outside.
- Pre-cool ventilation air by allowing the wind to pass over damp vegetation, through shaded areas, or over bodies of water.
- Design for wind—wind tends to keep moving in one direction and flows from high pressure to low pressure areas; hot air rises while cool air falls.

Cluster-Scale Strategies

- Arrange buildings so the winter wind is blocked from sunny exterior spaces.
- Provide courtyards that are open to the night sky for summer cooling.
- Shape the building so that it does not block the neighbor's access to the sun for heating and/or daylighting.

Building-Scale Strategies

- Place the zones with higher internal gains on the cooler side of the building.
- Use spaces that can tolerate greater temperature variations as buffer areas.
- Provide alternative cool places for activities during the hottest periods of the day or the hottest season.
- Use apertures for natural ventilation. Building codes generally allow commercial buildings to be built without mechanical ventilation systems if at least 5% of the floor area is provided as fully operable window area. The more you depend on natural ventilation for cooling, the larger these window openings should be.
- Keep a clear path through buildings for unobstructed ventilation.
- Adopt a "closed," "open," or "mixed" building ventilation strategy.
    - ❖ "Open" buildings have large openings that provide continuous ventilation. These buildings have little thermal mass to increase the effect of the cooling exterior air.
    - ❖ "Closed" buildings use high mass without simultaneous ventilation. These may use evaporative cooling, desiccant cooling, roof ponds, and/or mechanical refrigeration.
    - ❖ "Mixed" buildings can be "closed" during very hot hours, then "opened" for night ventilation to remove stored heat.
- Orient the solar glazing for heating between 20°E and 32°W of South.
- Exclude direct sun when using daylight instead of electric light.

Component-Scale Strategies

- Minimize or fully shade from direct sun glass areas in the hottest summer exposures (east- and west-facing walls and roofs).
- Provide clerestories with protection from direct sun. They are sources of daylight as well as effective ventilators, especially if they open on the leeward side of the building.

DESIGN (continued)

PROCEDURE

Propose a schematic design for your building based on analyses of precedent [A1], site and climate [B1], and program [C1]. Use the appropriate thermal design strategies for your design.

DOCUMENT YOUR DESIGN AS FOLLOWS:

1. Site plan, including parking and access drives.
2. Cluster plan, including outdoor spaces.
3. Floor plans.
4. Roof plan and elevations, or axonometrics, illustrating all building sides and roof.
5. Sections.
6. Design diagram, annotated to identify design strategies and thermal zones.

BIOCLIMATIC CHART THERMAL STRATEGIES

Discussion

The bioclimatic chart of thermal strategies [Figure D1.2.1] can be used to identify appropriate thermal responses for your climate. It separates cooling strategies into "open" (cross-hatched pochet) and "closed" (diagonal pochet). In the comfort zone (no pochet), both strategies are applicable. Below the comfort zone (vertical pochet), passive solar heating strategies are applicable. In extremely dry climates, only evaporative cooling is effective. In hot, dry southern climates (less than 30% relative humidity and south of 36°N latitude), roof ponds can be used for cooling and heating. In warm, wet climates (greater than 50% relative humidity), desiccant radiators can be used for cooling. In climates that have characteristically moist soil, earthtube cooling can be effective. Further discussion of desiccant, roof-pond, evaporative, and earthtube cooling can be found in E1.9–E1.12. Programmatic considerations may suggest different strategies for different thermal zones in your building.

Procedure

Evaluate how well your design attains Thermal Schematic Design Goal A—**The thermal strategies chosen will work in your climate**.

1. For each thermal zone use the balance point temperature estimates [C1.5] to determine which seasons require heating, cooling, or both.
2. Make a separate bioclimatic plot for each zone. Plot the monthly climatic data on the bioclimatic chart [Figure D1.2.1]. Use the data from B1.1. Represent months that need cooling with a **BLUE** line, months that need heating with a **RED** line, and months that need both cooling and heating with a **BLUE** line that turns **RED**.
3. Identify the appropriate thermal strategies for your climate. Note that when your building requires cooling and outdoor temperatures are below the comfort zone, ventilation is the most effective cooling strategy.
4. Explain how your design employs the appropriate strategies or how you must change your design to meet Goal A.

BIOCLIMATIC CHART THERMAL STRATEGIES (continued)

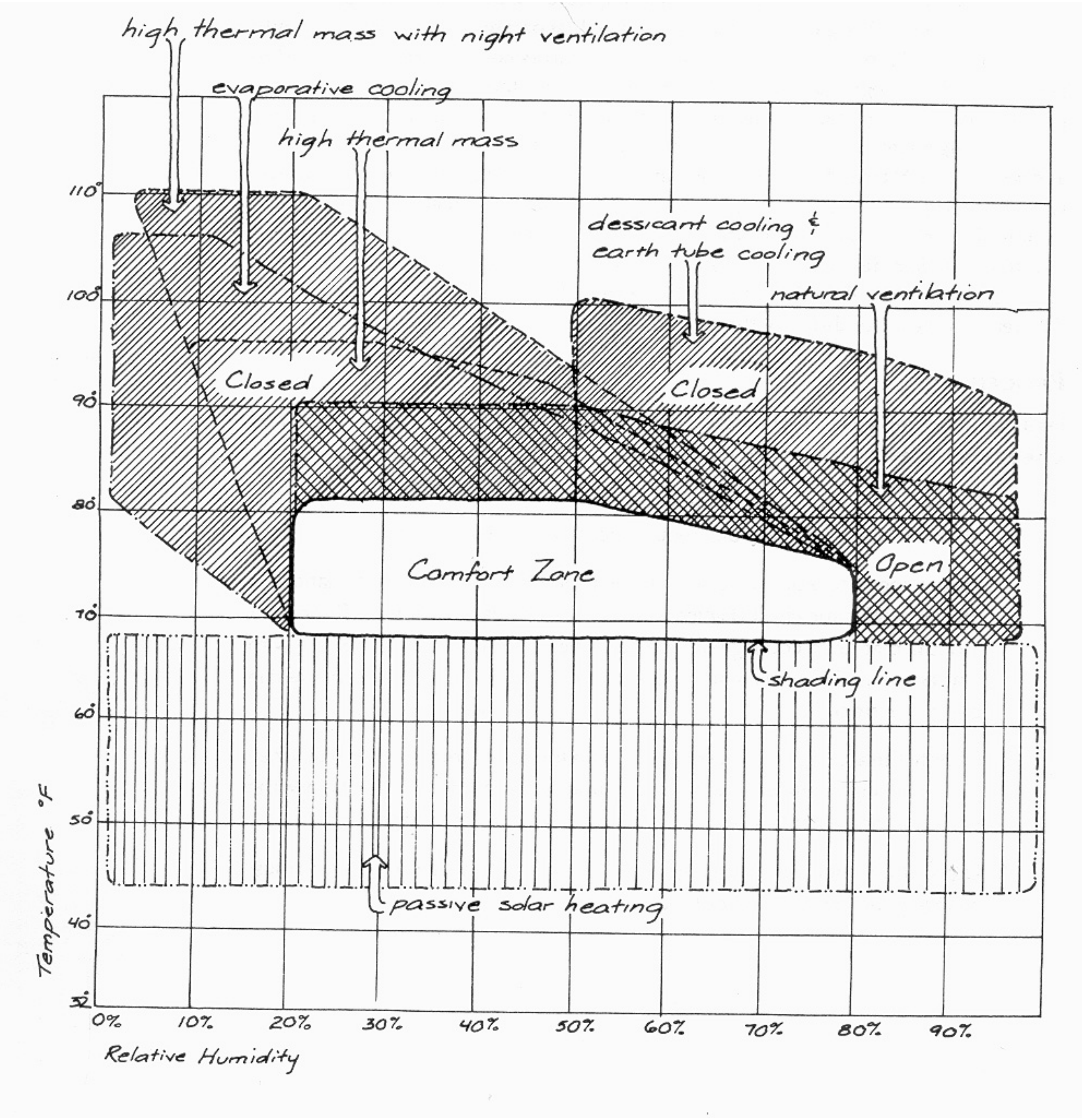

Figure D1.2.1 Bioclimatic Chart of Thermal Strategies

SOLAR ENVELOPE

D1.3

DISCUSSION

To be a good solar neighbor, to ensure that your building and the buildings on adjacent sites have full access to the sun at the peak of the heating season, your building must be placed within the solar envelope of the site [*MEEB,* Section 3.6(b), pp.73–74]. The solar envelope is a "roof" over your site that is based on the sun's position at 9 a.m. and 3 p.m. on December 21, the lowest sun path during the heating season in the Northern Hemisphere. To fit within the solar envelope, your building must not penetrate the planes of this "roof" (Knowles 1974).

FOR MORE INFORMATION

SWL, #15, pp.E40–48 (this discussion is based on a flat site).

PROCEDURE

Evaluate how well your design attains Thermal Schematic Design Goal B—**Buildings are located so shadows are not cast off the site**.

1. Make a clay or cardboard model of your building and site improvements (scale: 1" = 40'). Place this model on your site model [B1.3]. The building model must be accurate in size and massing as well as in its location on the site.

   > NOTE: You may want to draw your proposed windows, which you will need for D1.8, on the model before you assemble it.

2. Construct a wire-frame or cardboard solar envelope for your site.
   a. Find the sun's azimuth and altitude for 9 a.m. and 3 p.m. on December 21 [*MEEB,* Tables C.11–C.14, pp.1600–1607, or use the Libbey-Owens-Ford sun angle calculator].
   b. Build "roof envelope hips" from the site's NE corner (at the 3 p.m. azimuth and altitude) and the NW corner (at the 9 a.m. azimuth and altitude). If these "hips" cross the south property line before they intersect, construct an E–W "ridge" above the south property line. If these "hips" intersect on the site, construct a N–S "ridge" from the point of intersection southward. If the site is sloped and the two "hips" intersect at different elevations, build the N–S "ridge" at the lower elevation.
3. Discuss whether or not your building and site improvements are within the solar envelope and meet Goal B. Describe how your design must be altered if the goal has not been met.

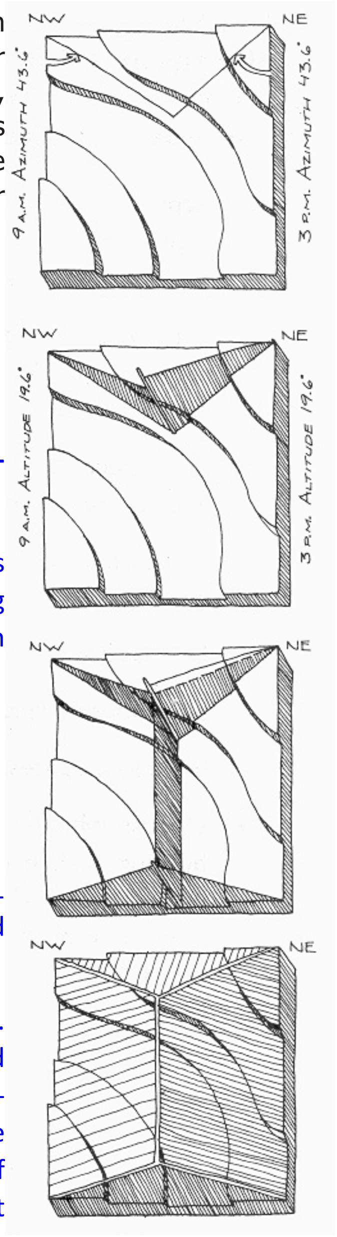

Figure D1.3.1 Typical Solar Envelope Construction. *Top, down*: Draw azimuths; construct altitude angle; construct north–south ridge; build roof planes.

SITE MICROCLIMATE

Procedure

Evaluate how well your design attains Thermal Schematic Design Goal C—**The buildings are clustered and sited to create optimal microclimates for heating when you need heat and for cooling when you need to cool.**

1. Reproduce the windflow diagram [B1.2], and draw your building and site improvements on the site. Show seasonal changes in wind patterns that are caused by your proposed building placement and site development.
2. With your building and site model [D1.3], use the sun peg shadow plot technique [B1.3] to study the yearly cycle of shadows. On a copy of your site plan draw the shadows cast at 9 a.m., noon, and 3 p.m.
3. Reproduce the sun peg shadow plot [B1.3], and draw your building and site improvements on the site plan, including the new shadow patterns.
4. Based on the changes in wind and shadow patterns caused by your proposed building, plot a new set of climatic response matrices [B1.4].
5. Discuss how well you have manipulated the microclimates created for:
   a. outdoor spaces
   b. indoor spaces.
6. Discuss whether or not your building and site improvements have met Goal C, and describe how your design must be altered if the goal has not been met.

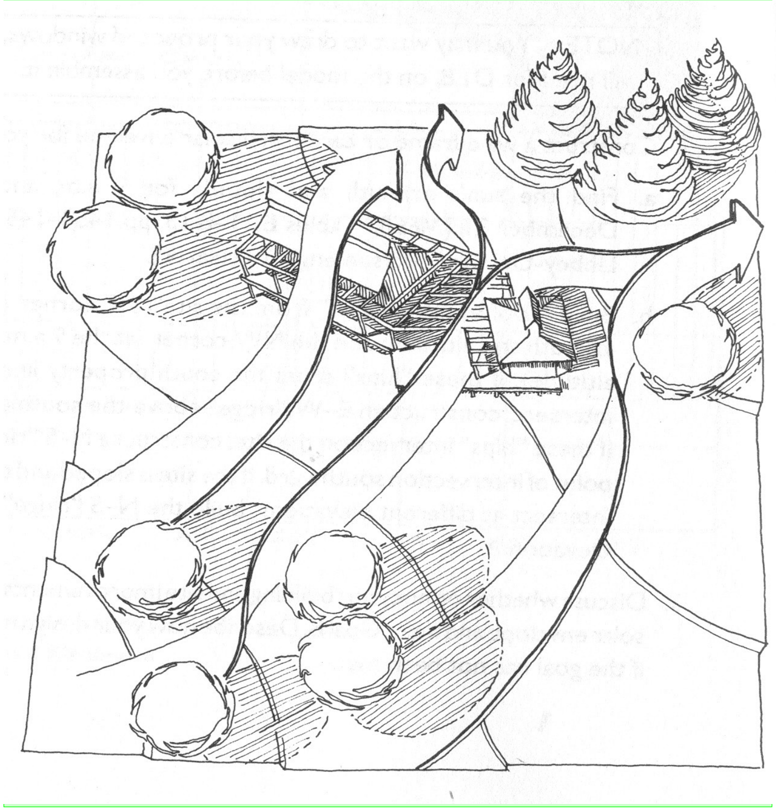

Figure D1.4.1 **Site Wind Flow and Shadows. Linen supply complex, Charleston, South Carolina.**

VENTILATION APERTURE

Discussion

Explore the use of either an "open" or "mixed" ventilation scheme for your building, even if you have selected a "closed" scheme. In climates where a "closed" scheme is appropriate for the overheated months, a "mixed" scheme is often appropriate for the cooler months. This "mixed" scheme is especially appropriate for an internally dominated load building.

"Open" buildings use primarily natural ventilation and depend on thermally or wind-induced internal air flow for cooling. This cooling strategy works only if the inside air temperature is higher than the outside temperature. For some climates, natural ventilation can be used even in the hottest month. In drier climates, cooling can be accomplished near the upper limit of the comfort zone by moving air as warm as 87°F. This temperature has to be significantly lower in more humid climates.

"Closed" buildings use high mass without simultaneous ventilation. These buildings may also use evaporative cooling, desiccant cooling, earthtube cooling, roof ponds, and/or mechanical refrigeration.

"Mixed" buildings can be "closed" during very hot hours, then "opened" for night ventilation to remove stored heat.

The significant difference between "open" and "mixed" ventilation strategies is that "open" ventilation removes heat as it is generated, while "mixed" strategies remove the entire day's heat gain during a short ventilation period.

There are two basic ways to passively ventilate a building.

- Cross-ventilation (wind-induced) depends on the force of the wind to expel hot air from the leeward side of the building to be replaced by cooler air forced in the windward side.
- Stack ventilation (thermally induced) depends on hot air rising to expel heat from openings high in the building. This hot air is then replaced by cooler air drawn in through much lower openings in the building envelope. This strategy is particularly useful if you have calm wind conditions during overheated months. It can also be effective with earth-tube cooling.

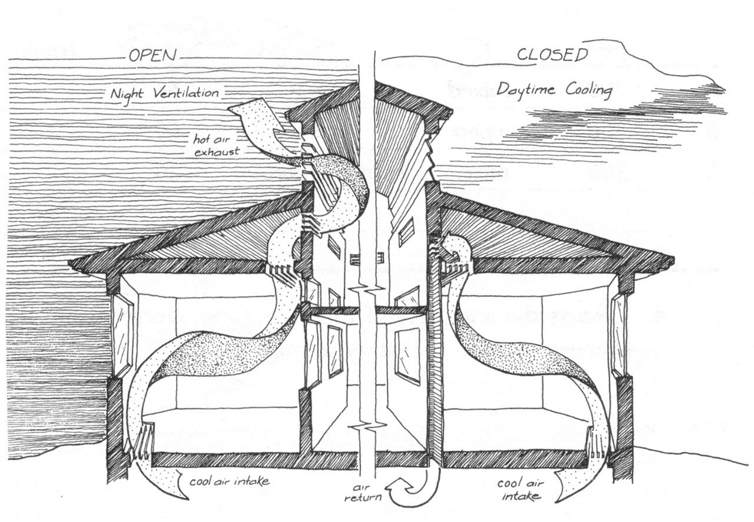

Figure D1.5.1 "Mixed" Cooling Strategy. Linen supply office, Charleston, South Carolina.

VENTILATION APERTURE (continued)

PROCEDURE

Evaluate how well your design attains Thermal Schematic Design Goal D—**Sufficient aperture is provided to ventilate the building.**

1. Calculate the internal heat gain density (Btuh/ft^2) for each thermal zone using data from C1.3.

   If the zone uses a “mixed” strategy, the heat for an entire day must be removed during a short period. Estimate the heat to be removed during this ventilation period by doubling the Btuh/ft^2 calculated in C1.3.

2. Tabulate the following information about your ventilation strategy:
   a. strategy used
   b. ventilation method (cross-, stack, or both)
   c. internal heat density
   d. wind speed [*Climate Consultant,* Wind Velocity Range plot] and/or stack height (the measurement from the horizontal centerline of the upper window to the horizontal centerline of the lower window)
   e. recommended ventilation aperture [*Green Studio Handbook* pp.167–172 (cross-ventilation) and pp.173–176 (stack ventilation)].

3. If you are using earthtube cooling, estimate the length and diameter of the tube required [*Green Studio Handbook,* pp.191–194].

Ventilation Aperture [suggested format]

Zone	Area (ft^2)	Ventilation Strategy	Ventilation Method	Internal Heat Density (Btuh/ft^2)	Wind Speed (mph)	Stack Height (ft)	Tube Size (diam,length)	Recommended Ventilation Aperture (ft^2)
A	*1,200*	*mixed*	*cross-*	*65*	*6*			*96*
B	*400*	*open*	*stack*	*50*		*25*		*80*
C	*200*	*mixed*	*earthtube(forced)*	*20*			*2@12"ϕ, 50'*	

4. Discuss the adequacy of the ventilation aperture, and indicate any design changes that are necessary to meet Goal D.

VENTILATION AIR FLOW

PROCEDURE

Evaluate how well your design attains Thermal Schematic Design Goal E—**Ventilation removes heat without leaving hot, dead-air areas.**

1. For "open" and "mixed" buildings, show the airflow ventilation path.

   On your site plan, floor plans, and sections draw the flow of ventilating air around and through your building for the months you need to cool. In drawing these flows, remember that wind flows from positive to negative pressure areas, hot air rises, and cool air falls.

2. For "closed" and "mixed" buildings, show the radiation or airflow paths.
   a. On your floor plans and sections indicate the locations of thermal mass. In order for mass cooling strategies to be successful, the mass must have a large amount of surface area as compared to its volume.
   b. If the mass will be cooled primarily by radiation, draw the path of radiant transfer from thermal mass to heat sink, and specify the type of heat sink (night sky, body of water, or the earth).
   c. If your building relies on night ventilation, where the mass is cooled by conduction/convection, draw the path of air currents over the surface of the mass.

3. Discuss the effectiveness of your ventilation or radiation strategies. Indicate any design changes that are necessary to accomplish Goal E.

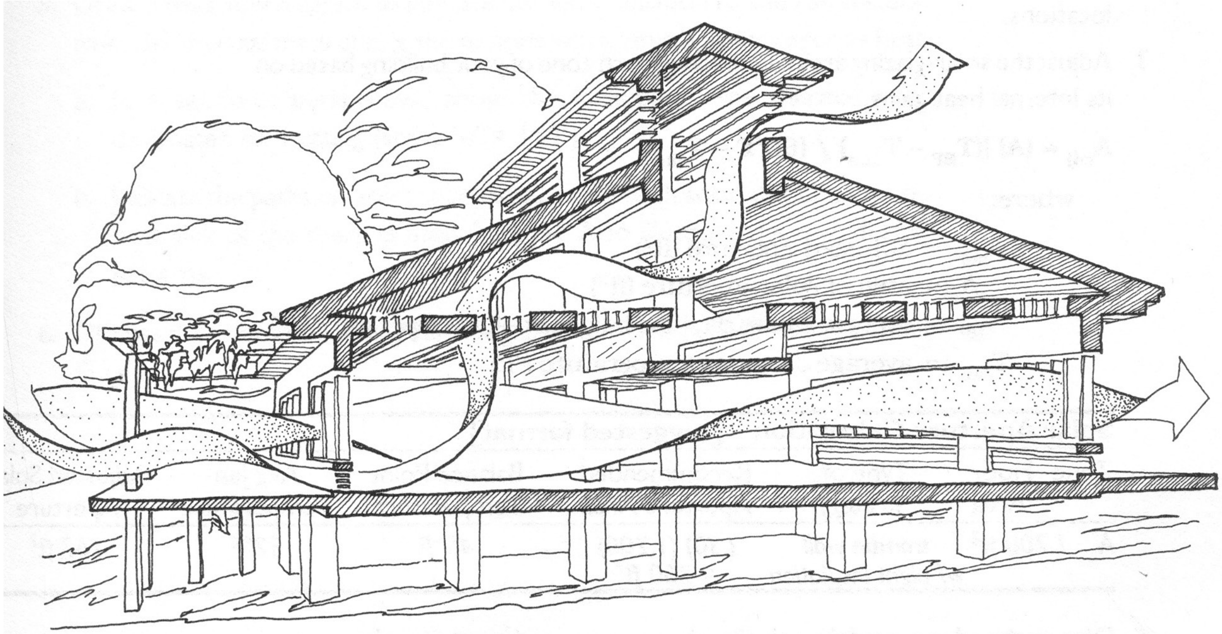

Figure D1.6.1 Cross-Ventilation Flow. Linen supply laundry, Charleston, South Carolina.

SOLAR-GLAZING APERTURE

DISCUSSION

Adequate solar aperture and its required thermal mass can be estimated based on the direct gain or indirect gain strategy used. This aperture must be adjusted to account for internal heat gains that reduce the need for solar heating. The adjustment is based on a building's or thermal zone's balance point temperature during the daytime in the winter.

PROCEDURE

Evaluate how well your design attains Thermal Schematic Design Goal F—**The building is exposed to the south in proportion to the heat needed.**

1. Determine the Heating Degree Days (HDD65ºF)for your climate [*MEEB* Table B1, pp.1565–1573].
2. Estimate the amount (or range) of solar glazing and the thermal mass required to heat each thermal zone [*Green Studio Handbook*, pp.131–135 (direct gain) or pp.137–143 (indirect gain)].
3. Determine the target net load coefficient (NLC) based on your HDD65ºF as set out in *Green Studio Handbook Table* 4.10 or 4.11 (p. 132 or 134).
4. Use the NLC for each thermal zone that you calculated in C1.4 (total heat loss via skin and ventilation/infiltration) to compare with the target NCL. If your NCL is greater than the target, the mass and glass is not adequate to fully passively heat the thermal zone.

Solar Aperture Calculation [suggested format]

Zone	Floor Area	Type of Strategy	Recommended Areas Glass/Mass	Heating Degree Days	Target NCL	Estimated NCL (C1.4)
A	*1,200 ft²*	*trombe wall w/ night insul.*	*Glass= 480 ft²* *Mass= 1,520 ft²*	*3467*	*5.6 btu/DDFft²*	*3.5 btu/DDFft²*

5. Discuss the adequacy of the solar heating aperture and any design changes you deem necessary to meet Goal F.

SOLAR GLAZING AND THERMAL MASS

Discussion

Solar apertures must be coupled to thermal mass to provide effective passive solar heating. A very large ratio of thermal mass surface area to volume is required. This surface area should be directly exposed to the sun's rays. The thermal mass must be located within about 20 feet of the occupants to effectively re-radiate heat to them. Remember, the total volume of the mass is less significant than the total surface area that is exposed to the sun.

Procedure

Evaluate how well your design attains Thermal Schematic Design Goal G—**The winter sun can reach all the south-facing apertures you have provided for the collection of heat.**

1. Determine which months to use the sun to heat [B1.1 and C1.5]:
    a. outdoor spaces
    b. building interiors in each zone.
2. Clearly identify the areas of solar aperture on your 1" = 40' scale model. Remember, the roof pond is an effective heating device and should be identified as a solar aperture for heating.
3. Use the sun peg and model to see if the sun reaches these areas between 10 a.m. and 2 p.m. during the months when your building needs heat.
4. Draw the shadows on your matrix site plan [Appendix B] and your south elevation, or include photographs of the study. Indicate the time and month shown.
5. Draw a heat flow diagram to indicate the sun's radiation to and re-radiation from the thermal mass during the periods when your building requires heat.
    a. In a sectional perspective, show the location of the thermal mass designated for heating.
    b. Indicate the paths of direct solar radiation through solar apertures to the heat sink of the thermal mass [step 3]. Also illustrate the re-radiation patterns.
6. Discuss the effectiveness of your design and any changes necessary to meet Goal G.

WINDOW SHADING

D1.9

DISCUSSION

Your building must be cooled when the outdoor temperature exceeds the balance point temperature [C1.5]. When outdoor conditions fall below 68°F—indicated by the shading line on the bioclimatic chart of thermal strategies [Figure D1.2.1]—cooling can easily be accomplished solely through ventilation. When conditions as plotted on this bioclimatic chart are above the shading line, it is also necessary to shade glazing on all façades of your building for effective cooling.

PROCEDURE

Evaluate how well your design attains Thermal Schematic Design Goal H—**Glazing is shaded from the sun during overheated months.**

1. Record the months that your building requires shading [Figure D1.2.1]. These months occur when the average daily high outdoor temperature is plotted above the shading line.
2. Use the sun peg with your 1" = 40' scale model to evaluate the building aperture shading at site and cluster scales. (Component-scale shading will be evaluated in E1.2.)
   a. Evaluate whether all glazed apertures are shaded at 9 a.m., noon, and 3 p.m. during the building's overheated months.
   b. Document this shading using either photos of your model or drawings (elevations, plans, or axonometrics).
3. If you intend to use desiccant cooling or a roof pond, verify that the roof is exposed to the sky and not shaded by overhanging trees or buildings.
4. Discuss the success of your shading strategies and any design changes needed to accomplish Goal H.

DESIGN REVIEW

DISCUSSION

You have formulated a schematic design for your building and site, chosen appropriate thermal strategies, and ensured access to appropriate environmental forces. Each step has been accomplished independently and conflicting decisions may have been made. This design review affords you the opportunity to synthesize your cumulative design decisions.

PROCEDURE

Review how well your design accomplishes Thermal Schematic Design Goals A–H.

1. Discuss the tradeoffs between the heating and cooling strategies that your design required.
2. Discuss situations where your heating and cooling strategies worked effectively together.
3. Make a schematic design sketch that combines all your thermal design strategies. Indicate how and why your design has evolved in response to meeting D1.0 goals.