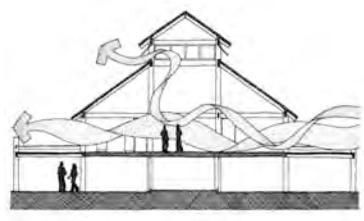


ARCHITECTURE 331/431

Environmental Control Systems

A5: Passive Heating & Cooling

INTRODUCTION

In this exercise you'll use longhand analysis methods to estimate the energy performance of passive heating and cooling strategies applied to an existing building design. Working in pairs, you'll propose, investigate and analyze design strategies for an existing building located in a city in the western US.

OBJECTIVES

To identify, apply, and analyze appropriate climate response strategies for a small house in a particular climate aimed at improving its energy performance.

PROBLEM STATEMENT

This assignment begins with the building described in assignment A3 for which you've determined the whole building UA_{ref}. Everyone will start with the same UA_{ref} and area take-offs, rather than those you previously determined, in order to make more meaningful comparisons of the resulting designs and analysis in different climates.

Imagine that a client has come to you with this plan (building and information from assignment A3) for a second home that they are building, and has asked you to evaluate this design with the aim of optimizing its solar heating and cooling potential. The clients are happy with the spatial organization of the plan and do not want this changed. Also, the building's foundations have been poured, so you must maintain the building footprint. Currently, the building is designed with a simple flat roof resulting in a 9'-0" ceiling (per information in assignment A3). You may however, change the wall and roof section (to increase insulation levels) and window sizes and locations.

PROJECT INFORMATION

Most of the information, tables and charts needed to complete this assignment is provided with this document (attached) or in the Digital Appendix 5 on the course website. You will need to download the climate summary for your location from the Western Regional Climate Center (WRCC) website, and find the design temperatures and heating degree-days for your location from the weather data in MEEB 10th ed., Appendix B.

METHODOLOGY

Use the following procedure to analyze the existing design, and make appropriate revisions to the walls, windows and roof of the building to optimize its thermal performance. For the purposes of this assignment, you'll be assigned a location (in the western US) by your section instructor from one of the cities listed in Table F.1 (Digital Appendix 5), with climate data available on the Western Regional Climate Center's website.

1. **CLIMATE ANALYSIS** (refer to http://www.wrcc.dri.edu/summary/lcd.html)

   - **WRCC**: For your climate, print the summary from the western regional climate center. You may want to convert this into an Excel spreadsheet so that you can easily cut-and-paste data into a 2-hour temperature chart.
   - **PSYCHROMETRIC CHART**: For your climate, plot the normal daily high and low temperatures, and corresponding relative humidity for every other month on a psychrometric chart.
   - **TABLE B1**: For your climate, determine the number of annual heating degree-days (HDD65), the winter design temperature, and the summer design temperatures (wet bulb and dry bulb). You can find this information in MEEB 10th ed., Appendix B, TABLE B1.
   - **2-HOUR TEMPERATURES**: Create a 2-hour temperature chart for your climate and color it according to the "closed" heating, "open", and "closed" cooling periods, using 55°F as the Balance Point Temperature, and 75°F as the "change-over" temperature.
   - **PRIORITIES**: Identify three to six *climate design priorities*, in order of their importance.
   - **STRATEGIES**: For each design priority, identify two or more *architectural design strategies*.

2. **PASSIVE HEATING** - Direct Gain (refer to MEEB 10th, 8.4-5, pp. 223 – 236)

- **INSULATION**: Next check to see if the current design satisfies the "whole-building heat loss criteria" (as described in section 8.4 of MEEB). Starting with the assumption that this is a "passively solar-heated building," determine the building **"heat loss coefficient"** using the relationship (given on page 227 of MEEB):

  $$\frac{\text{(UA ref w/o south windows*) x 24 hours/day}}{\text{total heated floor area (ft}^2\text{)}} = \underline{\hspace{3cm}} \text{ BTU/°F Day-ft}^2$$

  **subtract all south facing windows and doors for this exercise*

  Using Table 8.3 (attached), is this value equal to or less than the value "allowed" for your climate (given the number of annual heating degree days for your climate)? If not, you will need to either add insulation to your walls, reduce the area of non-south facing windows or both.

  Once you've made the necessary revisions to the building's envelope and have revised your UA_{value} accordingly so that your heat loss coefficient complies with the values in Table 8.3:

- **GLASS**: Determine the area of south-facing windows for this house to maximize the solar savings fraction (SSF) for a building in your climate (Digital Appendix 5, Table F.1)

- **MASS**: For this area of south facing glass (or "collector area"), and your anticipated SSF, determine the quantity of thermal mass recommended (Table F.2, attached).

- Describe the revisions you've made to the building envelope by *either* creating a new window schedule and wall section for this building, or drawing building elevations. Describe where you've located the thermal mass needed to achieve your predicted SSF.

3. **PASSIVE COOLING:** Cross and Stack Ventilation (refer to sections 8.5 and 8.6 in MEEB10th pgs. 234–252):

- **HEAT GAINS:** Estimate the typical internal heat gains caused by people and equipment, electric lights and heat gain through the building envelope for your building during a typical warm or overheated period (Digital Appendix 5,Table F.3). Residential internal gains are often assumed at 230 BTU/hr per occupant plus 1200 to 1600 BTU/hr from appliances.

  For people and equipment, assume 2 persons plus 1400 BTU/hr for equipment/appliances; for electric lights, assume a daylight factor greater than 4% (DF > 4); for heat gains through the envelope, use Table F.3 Part C, using the summer design temperature for your climate.

- **CROSS VENTILATION:** Use the cross ventilation rule-of-thumb chart (attached) to determine if the size of operable windows on the north, east, south and west are sufficient for "open" strategy cooling. You must consider the direction of prevailing winds during the "shoulder seasons" when the building is in "open" mode and cross ventilation is appropriate.

- **STACK VENTILATION**: Explore the possibilities for stack ventilation (stack ventilation rule-of-them chart attached). Does stack ventilation make sense in your climate? What modification(s) would be necessary to the house design in order to accommodate stack ventilation?

NOTE:
*Windows should be 100% shaded during **closed cooling** periods, and ideally 100% unshaded during **closed heating** periods. For this exercise you will not be required to demonstrate/design that this has been accomplished, unless you choose to do the extra credit portion of this assignment.*

DELIVERABLES

Use the following checklist to summarize the results of your investigation. Make sure you highlight and annotate your report so that it is easy to follow your process. Package your results in a simple and concise manner.

1. **Climate Analysis**:
   - Climate Summary (WWRC)
   - Psychrometric Chart
   - 2-Hour Temperature Chart
   - Climate Priorities and Architectural Strategies; provide a very brief narrative explaining (to your client) explaining your recommended design strategies for making the building more climate responsive and energy efficient.

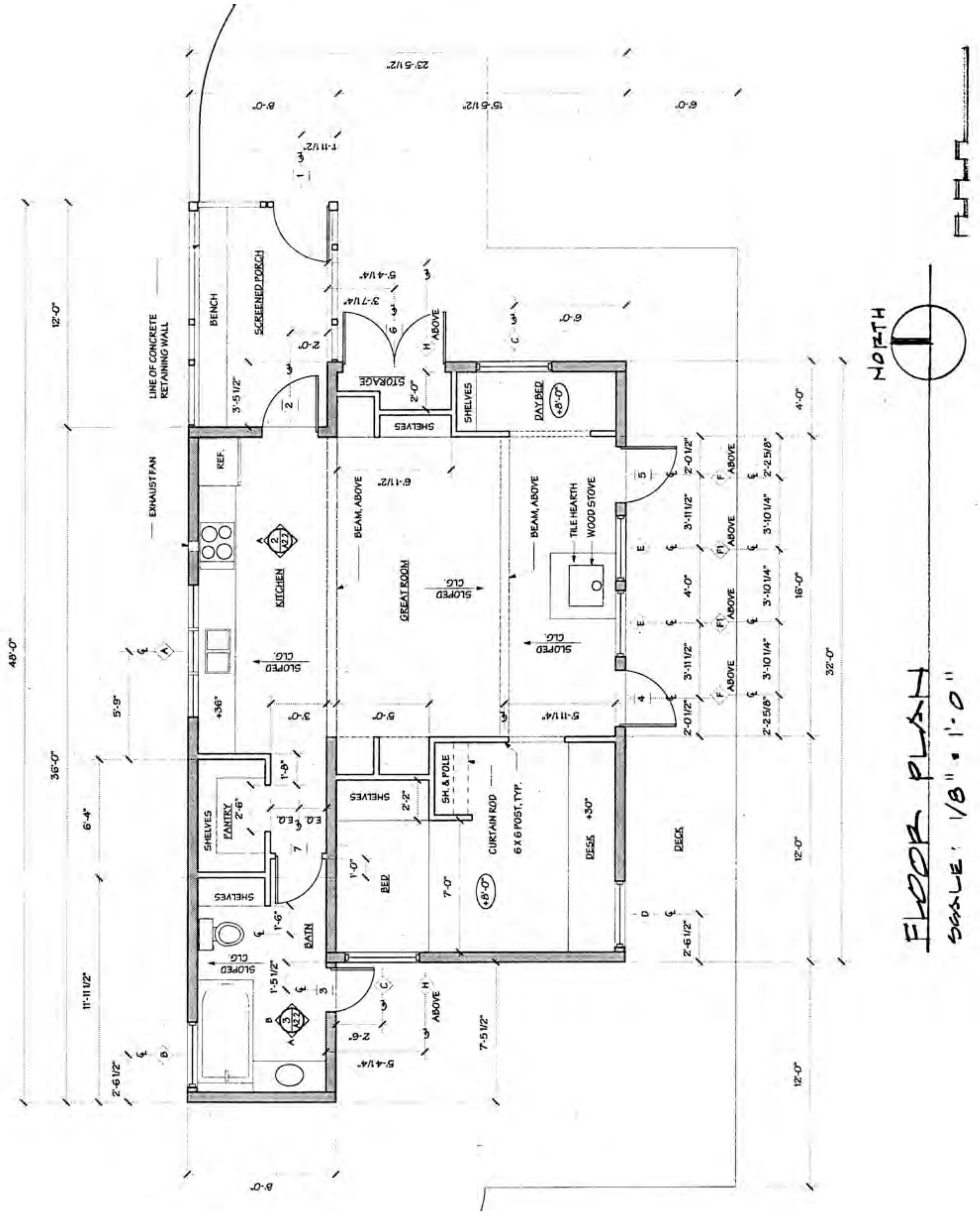
2. **Passive Heating**:
   - Submit revised spreadsheets showing any modifications you've made to the building's envelope; highlight changes in R-Value and area (windows, walls).
   - Write a very brief narrative explaining (to your client) your recommended modifications to their house design.

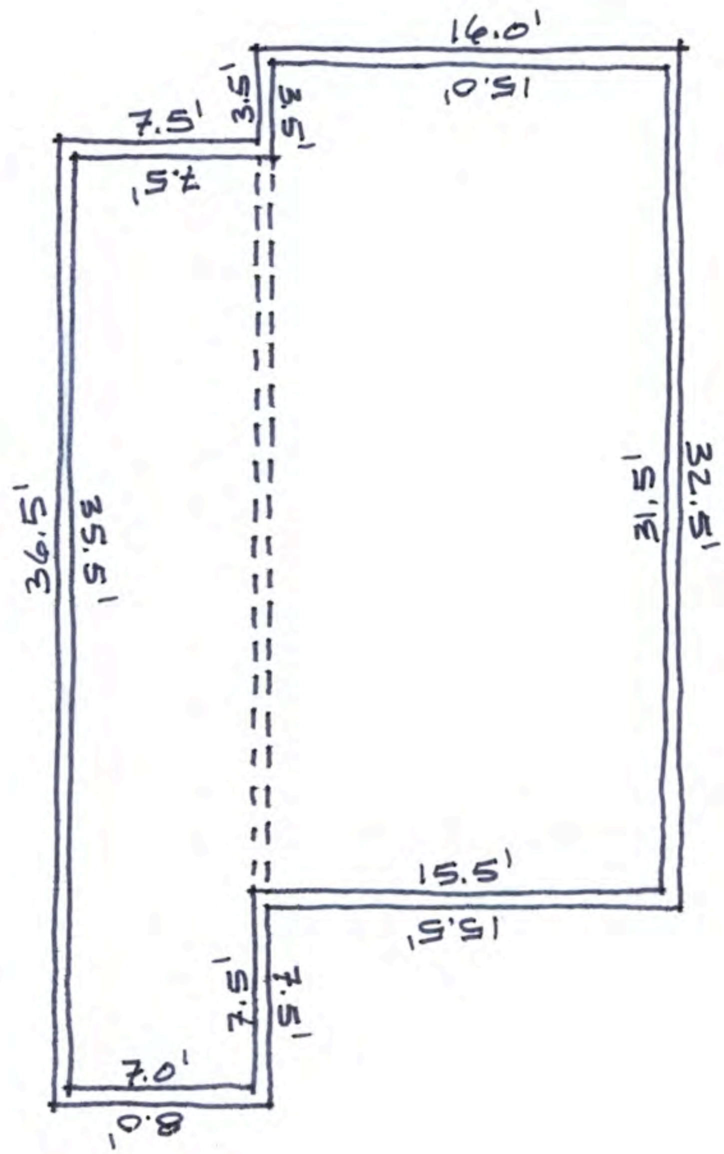
3. **Climate Analysis**:
   - Note or highlight changes to window areas in a revised spreadsheet.
   - Write a very brief narrative describing the results of your passive cooling investigation and your recommendations for your client.

EXTRA CREDIT

Apply the changes you've recommended and articulate these in drawing(s) of the revised building design. This can be done with a **digital model,** or could be done with elevations and building sections. You will need to resolve the roof design, giving architectural form to the current flat-roof proposal (e.g. overhangs, fascia, soffit, etc.), or you may propose a roof resolution of your own. Remember, the plan and building organization is not to be changed, but openings will be modified and you can add windows/clerestories/dormers in your proposed roof. In addition, you must show any shading devices used, and these should address the need for both summer shade and winter heat gain.

Submit your rendered revisions in both digital form and hard copy (8-1/2" x 11" or 11" x 17"). You will be evaluated on how clearly and comprehensively it demonstrates your proposed design renovations. **Credit equivalent to one assignment** will be given to submissions that fulfill the criteria above. The grade for this extra credit submission **will be substituted** for your lowest grade on a previous assignment.


FLOOR PLAN
SCALE: 1/8" = 1'-0"
NORTH
SCREENED PORCH
BENCH
LINE OF CONCRETE RETAINING WALL
STORAGE
SHELVES
DAY BED
KITCHEN
REF.
EXHAUST FAN
GREAT ROOM
SLOPED CLG.
BEAM, ABOVE
TILE HEARTH
WOOD STOVE
PANTRY
BATH
BED
SH. & POLE
CURTAIN ROD
6 X 6 POST, TYP.
DESK +30"
DECK
ABOVE
48'-0"
36'-0"
32'-0"
16'-0"
12'-0"
23'-5 1/2"
15'-5 1/2"
8'-0"
6'-0"



Gross Wall Areas

Wall areas are measured from the inside; corners are counted, but only once. Gross wall areas do not include openings.

South: (32.5' x 9.0') + (7.5' x 9.0') = 360.0' ft^2

East: (15.0' x 9.0') + (7.5' x 9.0') = 202.5' ft^2

North: (36.5' x 9.0') + (3.5' x 9.0') = 360.0' ft^2

West: (15.5' x 9.0') + (7.0' x 9.0') = 202.5' ft^2

Windows

Use the following window schedule to determine the area of all the windows in the house. Windows are indicated on the plans with a **letter** in a **square** adjacent to each door. The doors are **double-glazed, clear, wood** windows (Table E.14).

Window	Dimensions	Area (ft^2)
A	2'-0" x 4'-0"	8
B	3'-0" x 4'-0"	12
C	3'-6" x 3'-6"	12.25
D	3'-0" x 3'-0"	9
E	3'-0" x 5'-0"	15

Doors

Use the following door schedule to determine the area for all the doors in the house. Doors are indicated on the plans with a **number** in a diamond adjacent to each window. The doors are wood (or wood slab in wood frame), some with glazing and others unglazed (MEEB 10, Table E.10).

Door	Dimensions	Area (ft^2)	Description
1	3'-0" x 6'-8"	20	Screen Door (not applicable)
2	3'-0" x 6'-8"	20	Glazed Door, 25% glazing
3	2'-4" x 6'-8"	15.56	Glazed Door, 6% glazing
4	3'-0" x 6'-8"	20	Glazed Door, 45% glazing
5	3'-0" x 6'-8"	20	Glazed Door, 45% glazing
6	2'-8" x 6'-8"	17.78	Unglazed Door, 1-3/8" solid core flush

Roof

This building has a flat, built-up roof with a 5/8" plywood deck, 2" x 8" rafters @ 24" O.C. and R—19 blanket insulation with non-reflective air space, gypsum board, and acoustic tile. The ceiling height is nominally 9'-0".

Walls

Framing consists of 2" x 6" studs at 16" o.c. resulting in 15% of the wall area having framing and 85% of the wall area having insulation.

Building Envelope Summary

Building Element		U-value	Area	U x Area
Orientation	Element	BTU/hr ft^2 ^{o}F	ft^2	BTU/hr ^{o}F
South	Door 3	0.280	15.56	4.36
	Window D	0.510	9.00	4.59
	Door 4	0.370	20.00	7.40
	Windows E (2)	0.510	30.00	15.30
	Door 5	0.370	20.00	7.40
	Walls (360.0 ft^2)	0.044	265.44	11.68
East	Window C	0.510	12.25	6.25
	Doors 6 (2)	0.260	35.56	9.25
	Door 2	0.280	20.00	5.60
	Walls (202.5 ft^2)	0.044	134.69	5.93
North	Windows A (3)	0.510	24.00	12.24
	Window B	0.510	12.00	6.12
	Walls (360.0 ft^2)	0.044	324.00	14.26
West	Window C	0.510	12.25	6.25
	Walls (202.5 ft^2)	0.044	190.25	8.37
				0.00
	Ceiling/Roof	0.046	735.00	33.81
			UA conduction	158.79

Volumetric Heat Capacity (Air)	0.018	BTU/ft^3 ^{o}F
Building Volume (ft^3)	6615.00	ft^3
Air Changes per Hour (ACH)	0.45	ACH
"UA" infiltration = VHC x Volume x ACH	53.58	BTU/hr ^{o}F
Heat loss coefficient (F)	0.36	BTU/hr ^{o}F ft
Length of building perimeter (P)	127.00	ft^3
"UA" perimeter = F x P	45.72	BTU/hr ^{o}F
Total Heat loss coefficient (UA_{ref})	**258.09**	**BTU/hr ^{o}F ft**

Wall U-value Summary

	k conductivity BTU - in / hr ft² °F	C Conductance BTU / hr ft² °F	R Resistance hr ft² °F / BTU	Path 1 (insulation) hr ft² °F / BTU	Path 2 (framing) hr ft² °F / BTU
outside air film			0.17	0.17	0.17
1/2" wood siding		1.240	0.81	0.81	0.81
1/2" medium density particleboard			1.32	1.32	1.32
5-1/2" fiberglass batt insulation	0.25	0.045	22.00	22.00	
5-1/2" wood framing (Douglas Fir)	1.00	0.182	5.50		5.50
1/2" gypsum board			0.45	0.45	0.45
Inside Air Film			0.68	0.68	0.68
			R total	25.43	8.93
				x 85%	x 15%
			Paths 1 & 2	21.61	1.34
			Overall R-value of Walls & Ceiling	22.95	
			Overall U-value of Walls & Ceiling	0.044	

Roof U-value Summary

	k conductivity $\frac{BTU - in}{hr\ ft^2\ ^oF}$	C Conductance $\frac{BTU}{hr\ ft^2\ ^oF}$	R Resistance $\frac{hr\ ft^2\ ^oF}{BTU}$	Path 1 (insulation) $\frac{hr\ ft^2\ ^oF}{BTU}$	Path 2 (framing) $\frac{hr\ ft^2\ ^oF}{BTU}$
outside air film			0.17	0.17	0.17
Built-up roof		3.000	0.33	0.33	0.33
5/8" plywood deck			0.78	0.78	0.78
6" R-19 blanket insulation			19.00	19.00	
1-1/2" non-reflective air space			1.05	1.05	
7-1/2" wood framing (Douglas Fir)	1.00	0.133	7.50		7.50
1/2" gypsum board			0.45	0.45	0.45
Acoustic tile			1.25	1.25	1.89
Inside Air Film			0.61	0.61	0.61
			R total	23.64	11.73
				x 85%	x 15%
			Paths 1 & 2	20.09	1.76
			Overall R-value of Walls & Ceiling	21.85	
			Overall U-value of Walls & Ceiling	0.046	

TABLE 8.3 Overall Heat Loss Criteria for Solar Guidelines

Maximum Overall Heat Loss					
		Btu/DDF ft²		***W/DDK m²***	
Annual Heating Degree Days (Base 65°F)	**(Base 18°C)**	**Conventional Buildings**	**Passively Solar-Heated Buildings, Excluding Solar Wall[a]**	**Conventional Buildings**	**Passively Solar-Heated Buildings, Excluding Solar Wall[a]**
Less than 1000	Less than 556	9	7.6	51	43
1000–3000	556–1667	8	6.6	45	37
3000–5000	1667–2778	7	5.6	40	32
5000–7000	2778–3889	6	4.6	34	26
Over 7000	Over 3889	5	3.6	28	20

Source: Balcomb et al. (1980). SI conversions approximated by the author.

[a]The guidelines in Table F.1 assume a solar building that meets this criterion.

F.2 THERMAL MASS FOR PASSIVE SOLAR BUILDINGS

TABLE F.2 Design Guidelines for Passive Solar Thermal Mass

Expected Solar Savings Fraction (SSF), %	***Thermal Storage by Weight/Collector Area***				***Recommended Effective[a] Thermal Storage Area Per Unit Area of Solar Collection Area***	
	Water		***Masonry***		***Water Surface Area[b]***	***Masonry Surface Area[c]***
	lb/ft²	**kg/m²**	**lb/ft²**	**kg/m²**	**Collector Surface Area**	**Collector Surface Area**
10	6	29	30	147	0.1	0.7
20	12	59	60	293	0.2	1.5
30	18	88	90	440	0.3	2.2
40	24	117	120	586	0.4	2.9
50	30	147	150	733	0.5	3.7
60	36	176	180	879	0.6	4.4
70	42	205	210	1026	0.7	5.1
80	48	234	240	1172	0.8	5.9
90	54	264	270	1319	0.9	6.6

Source: Adapted from J. D. Balcomb et al. (1980). *Passive Solar Design Handbook,* Vol. 2 (Passive Solar Design Analysis), U.S. Department of Energy, Washington, DC.

[a]Effective area is that area exposed at some point to direct sun during a clear winter day.

[b]For a water container 12 in. (300 mm) thick.

[c]For a 4-in. (100-mm)-thick brick, density 123 lb/ft³ (1970 kg/m³).

PASSIVE COOLING • Cross Ventilation
MEEB 9th: Fig. 5.14a
MEEB 10th: Fig. 8.14a

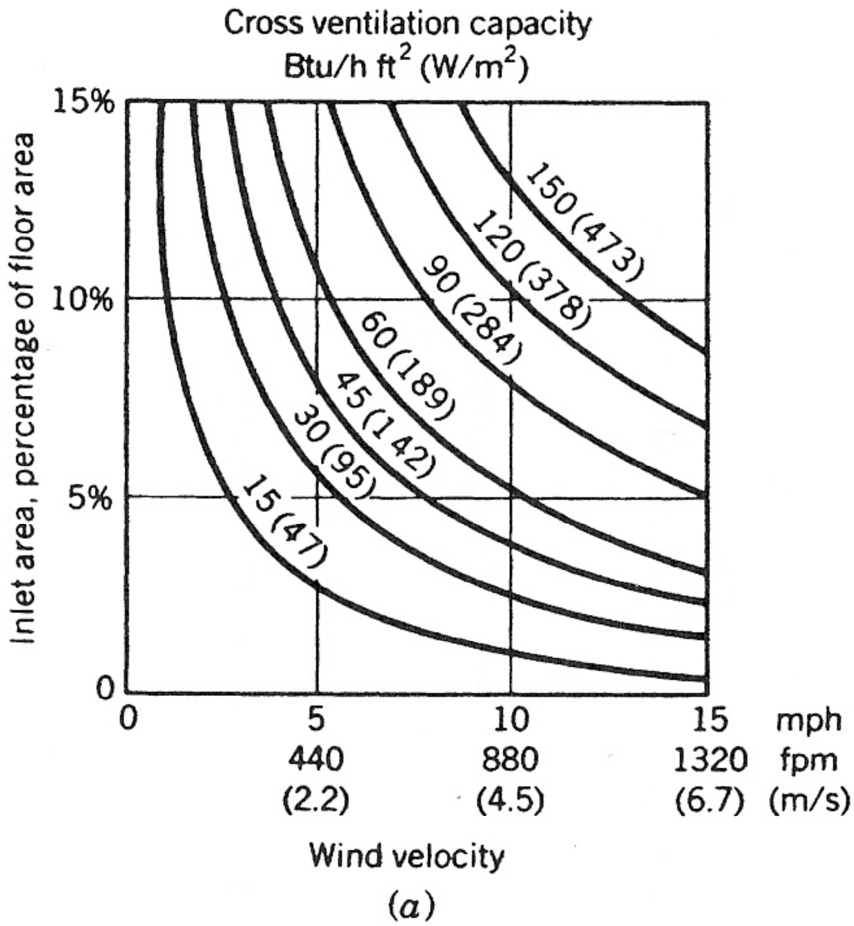


Fig. 5.14 (a) *Cross-ventilation design guidelines for heat removed per unit floor area and relationship of inlet openings and wind speed. Total inlet opening area is expressed as a percent of total floor area served by cross ventilation. Note: Outlet areas must also be at least equal to inlet areas. This graph is based on an internal temperature 3F° (1.7C°)* above *the exterior temperature, and assuming that the wind is not quite perpendicular to the window openings, for a wind effectiveness factor of 0.4 (see Section 5.14).*

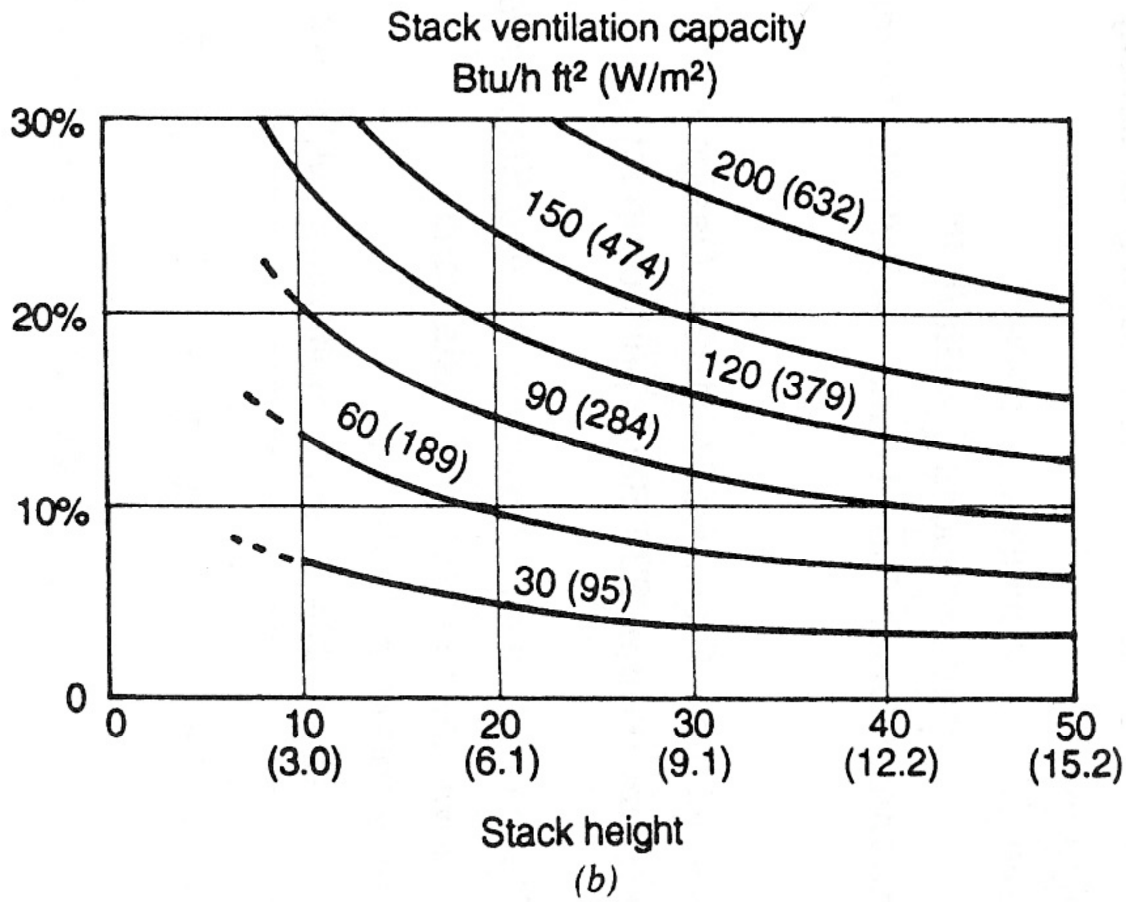


Fig. 5.14 (b) *Stack-ventilation design guidelines for heat removed per unit floor area and relationship of stack height and inlet openings. Area of stack inlet/throat/outlet is expressed as a percentage of total floor area served by stack ventilation. Note: Outlet areas and stack throat area must also be at least equal to inlet areas. This graph is based on an internal temperature of 83°F, exterior temperature 80°F, for a 3F° differential (28.3°C internal, 26.7°C internal, for a 1.6C° differential).*