The band of Sun

- At three times of year (each solstice and equinox), the noon solar altitude is determined.
- Solar altitude at solar noon:
  - Altitude (ß)=90°-latitude°(Lat.)±Δ
  - Δ=23.5° for summer and winter solstice (for spring and autumn equinox, Δ=0°)
  - Seoul: Latitude: 37°34'N. Longitude: 126°57'E
  - 76°16'(summer solstice), 29°16'(winter solstice)
- Good for analyzing the portion of available solar radiation.

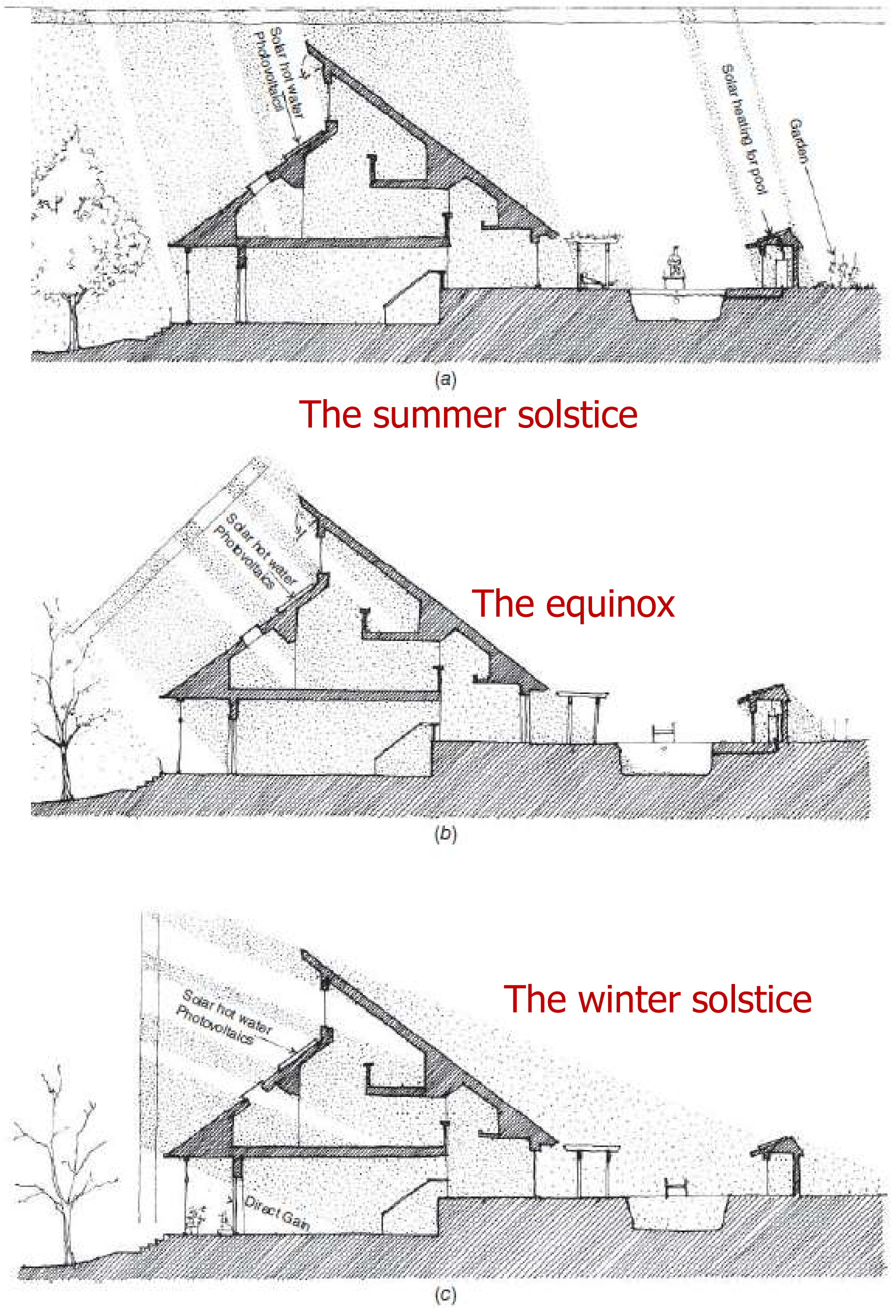


Fig. 3.14 The band of sun available to a proposed building at solar noon is charted on a north-south section. (a) The summer solstice, where optimum collecting surfaces are at near-horizontal tilt angles. (b) The equinox. (c) The winter solstice, where optimum collecting surfaces are at near-vertical south-facing tilt angles.

Zion canyon visitor center

- Passive solar: the band of Sun

Skyline

- The skyline is what is actually seen from a given location.
- Good for obstruction analysis.
- Time slot of interest: 9 A.M.-3 P.M. ('best' solar collection hours)

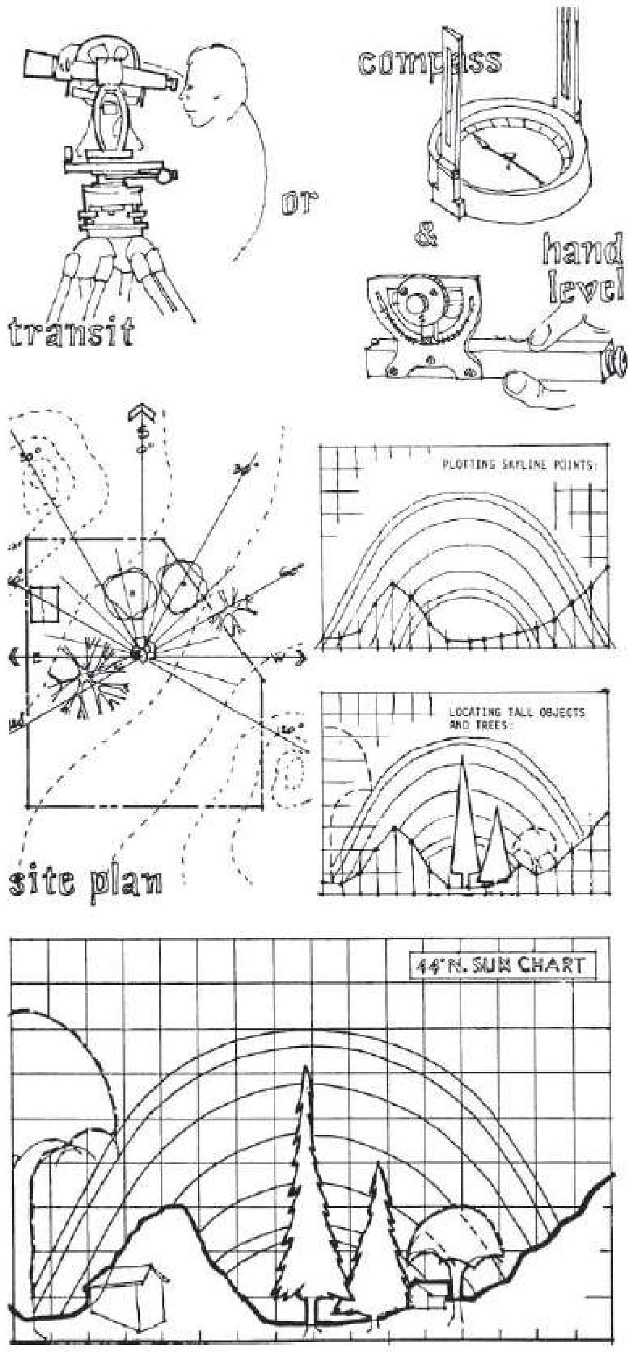
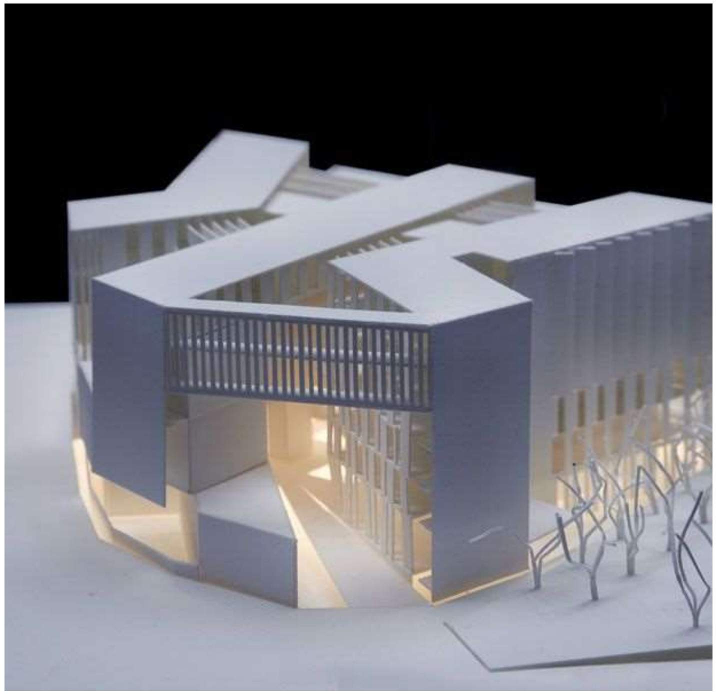


Fig. 3.15 Charting the skyline from a specific site position. (From Edward Mazria and David Winitsky. 1976. Solar Guide and Calculator. Center for Environmental Research, University of Oregon.)

Sun and shadows: model techniques

- Time consuming & expensive to build
- Can reduce analysis time
- Good for studying multiple locations, generating multiple views, allowing real 3-D views, comparing alternatives

Fig. 3.16 *A model of a small building with a glazed open-frame circulation space on the south side is observed at the sun's position at 3:00 p.m. on December 21 through the use of a sunpeg chart. (Photo by Tyler Mavichien; © Alison Kwok; all rights reserved.)*



Controlling solar reflections

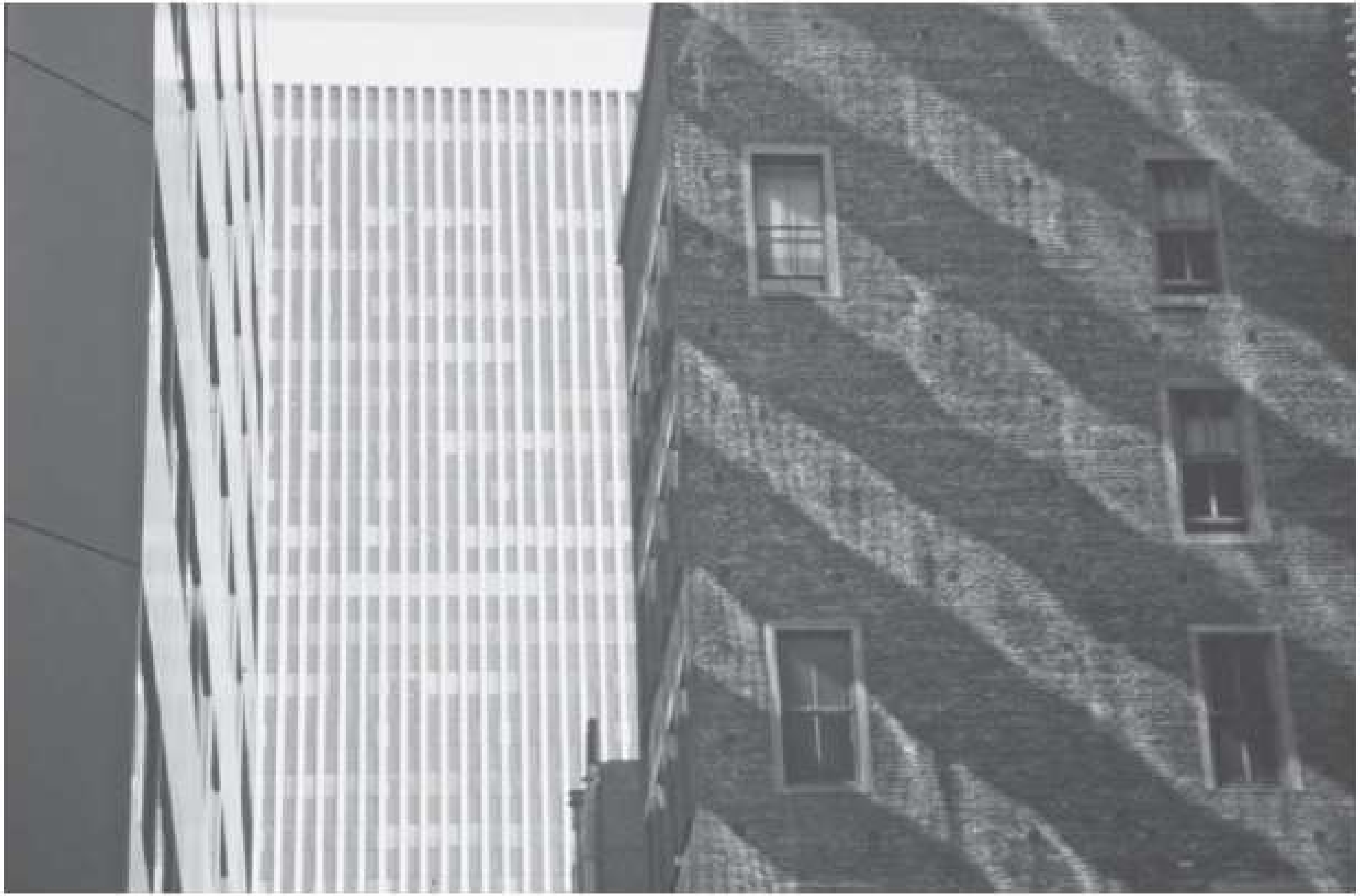


Fig. 3.17 *Mirror-glass windows in a newer office building (left) in San Francisco, California, cast strong reflections on the north- and west-facing walls of an older building next door. Although this reflected radiation/heat might occasionally be welcome in winter, the resulting glare can be intense. In summer, the older building is particularly disadvantaged by additional thermal loads on its envelope. (© Alison Kwok; all rights reserved.)*

Selective protection

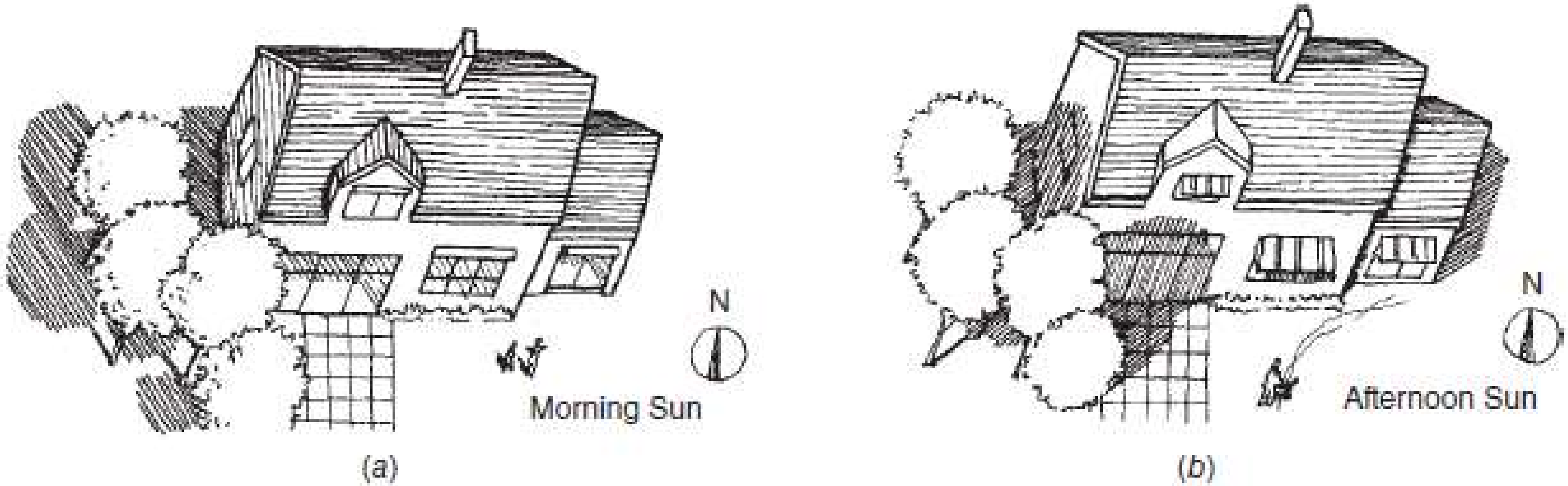


Fig. 3.18 *Selective protection from reflections. (a) The trees standing west of this south window wall do not interfere with solar access during the best hours for solar collection (around noon), nor do they prevent early morning sun from entering the windows. Any reflections of the early morning sun are intercepted by the trees before they can annoy those in nearby buildings. (b) The late afternoon sun is blocked by the trees before either solar gain or reflections can occur.*

Controlling solar reflections

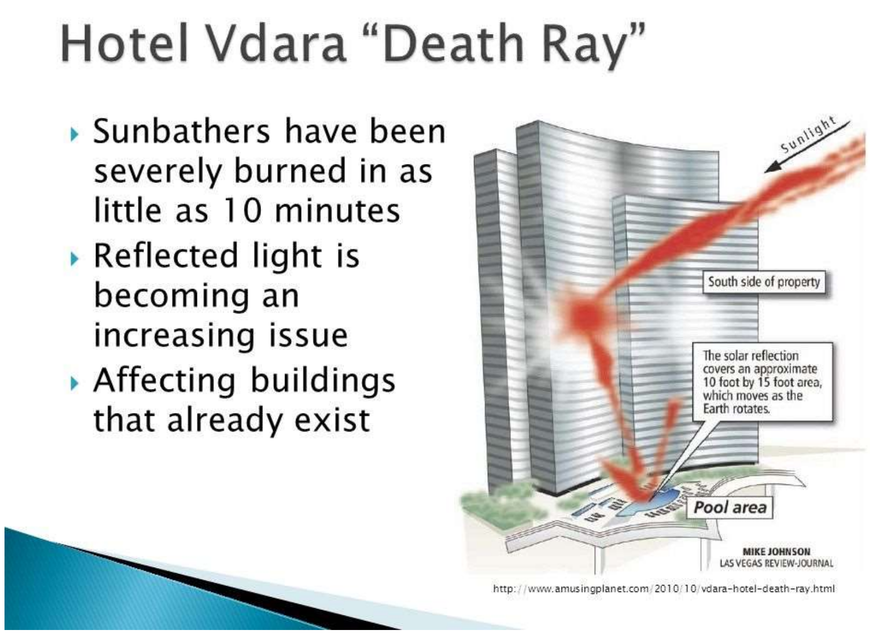
The Walt Disney concert hall shoots heat rays: The five most embarrassing architectural failures ever!!

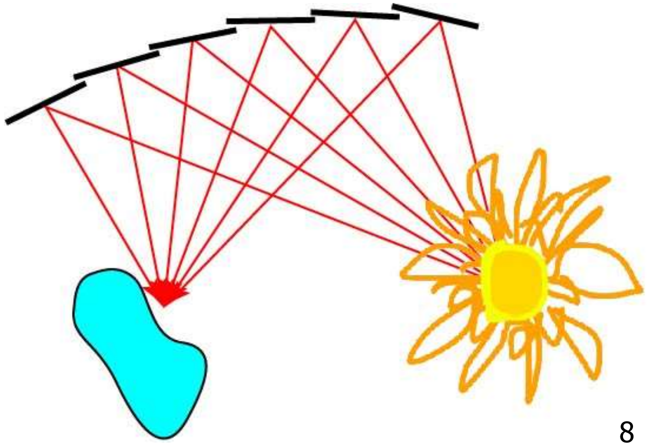
http://www.cracked.com/article_19682_5-most-embarrassing-architectural-failures.html

Fig. 3.20 *After construction, modifications were made to the highly polished stainless steel exterior of the Walt Disney Concert Hall in Los Angeles, California (by Frank Gehry), to reduce reflections impacting the neighboring condominiums; surfaces now have a matte finish. (© Karen Tse; used with permission.)*

Vdara hotel, Las Vegas

Las Vegas hotel deals with so-called "Death Ray"





Images: https://gnarlyarchitecture.wordpress.com/2011/11/30/a-visit-to-the-vdara-death-ray-2/
http://slideplayer.com/slide/5849837/
https://www.nbclosangeles.com/news/weird/Las-Vegas-Vdara-Hotel-Death-Ray-104041383.html

Airflow: air pollution

- Greenhouse effect is being amplified because greenhouse gases that block the outgoing flow of long-wave radiation (heat) from the Earth surface are accumulating in the atmosphere (Fig. 3.24)
- Energy production and use are contributing heavily to these greenhouse gases, which include CO_2, methane, nitrous oxide, CFCs, etc.
- Buildings are substantial contributors to the aforementioned threats.
  - 1/3 energy consumed
  - Chlorofluorocarbons (CFCs) used as refrigerant in building refrigeration equipment

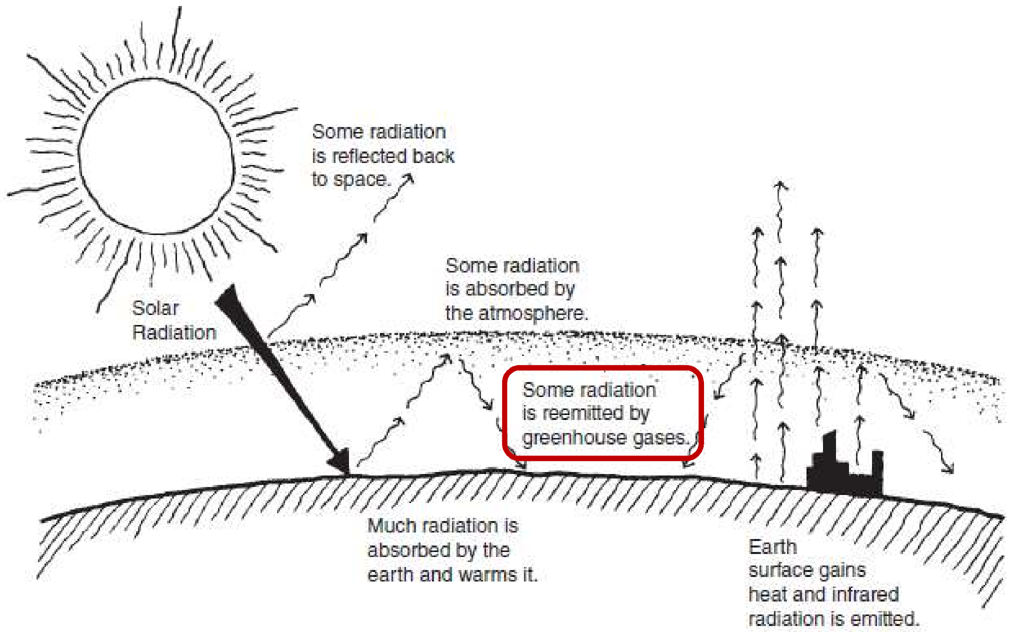
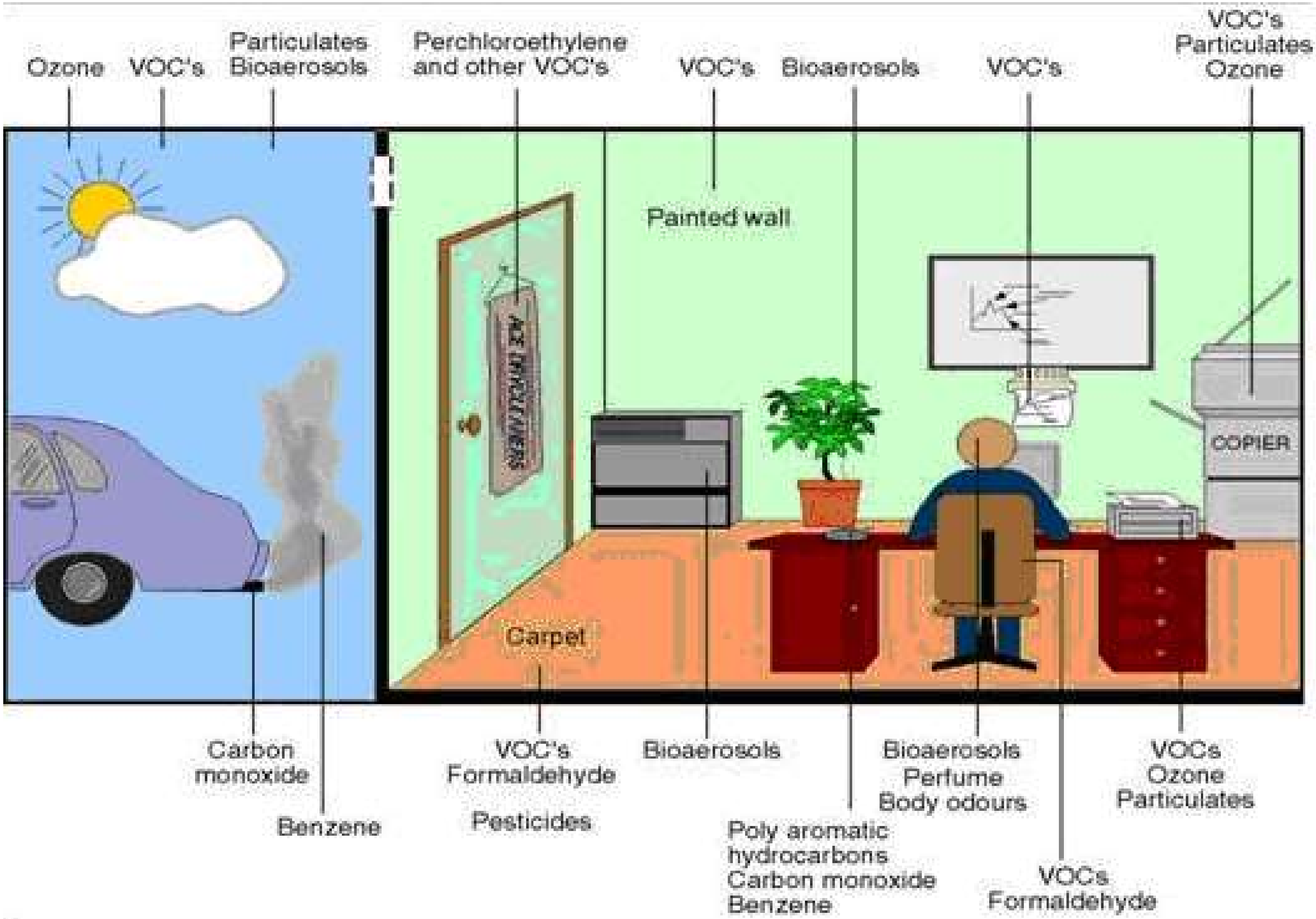


Fig. 3.24 *The greenhouse effect traps heat in the Earth's upper atmosphere. Clouds and particles in the atmosphere reflect about one-fourth of incoming solar radiation while blocking about two-thirds of the heat that the Earth would otherwise lose to outer space. Historically, the atmosphere kept the Earth about 33°C (60°F) warmer than it would be without this heat-trapping process. Increases in greenhouse gas concentrations will reflect more incoming solar radiation but block even more outgoing radiation, resulting in global warming and regional changes in climate. (Drawing by Amanda Clegg.)*

TABLE 3.3 Air Pollution: Sources and Effects

Gas or Pollutant	Sources	Effects
Carbon monoxide (CO)	Gasoline-powered vehicles, industry using oil and gas, building heating using oil and gas, biomass combustion	Enters human bloodstream rapidly, causing nervous system dysfunction and death at high concentrations; interferes with self-cleansing of atmosphere
Carbon dioxide (CO_2)	Fossil-fuel combustion, deforestation	Contributes to greenhouse effect
Methane (CH_4)	Rice fields, cattle, landfills, fossil-fuel production	Contributes to greenhouse effect
Sulfur oxides such as sulfur dioxide (SO_2) and sulfur trioxide	Industry using coal and oil; heating using coal and oil; power plants using coal, oil, and gas; ore smelting	Acid rain, damaging plants and attacking building skin materials; irritates human respiratory tract and complicates cardiovascular disease; decreases visibility in atmosphere
Nitrogen oxides (NO_X) such as nitric oxide (NO) and nitrogen dioxide (NO_2)	Gasoline-powered vehicles, building heating using oil and gas, industry and power plants, biomass burning	Acid rain, damaging plants and attacking building skin materials; irritates human eyes, nose, and upper respiratory tract; triggers development of smog; decreases visibility in atmosphere
Nitrous oxide (N_2O)	Nitrogenous fertilizers, deforestation, biomass burning	Contributes to greenhouse effect
Hydrocarbons (compounds of hydrogen and carbon)	Petroleum-powered vehicles, petroleum refineries, general burning	Promotes smog; toxic to human beings at high concentrations
Chlorofluorocarbons	Aerosol sprays, refrigerants, foams	Contributes to greenhouse effect and to stratospheric ozone depletion
Particulates (liquid or solid particles smaller than 500 micrometers)	Vehicle exhausts, industry, building heating, general burning, spore- and pollen-bearing vegetation	Promotes precipitation formation; some are toxic to human beings; some pollens and spores cause allergic reactions in human beings

Sources: Adapted from Marsh (1991) and Graedel and Crutzen (1989).



http://www.yourbuilding.org

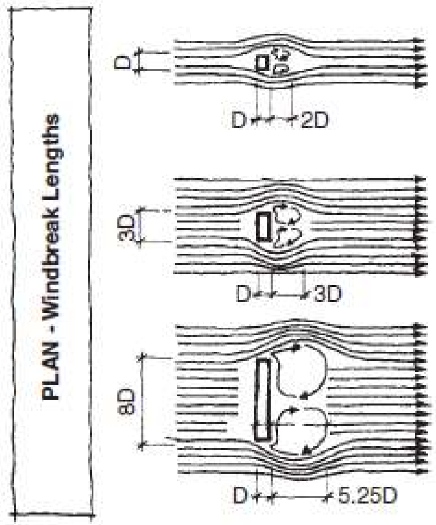
Local sources of pollution

- must be minimized or isolated (Fig 3.25)

Fig. 3.25 *Reactive protection of an outdoor air intake. A loading dock near an intake was a source of indoor air pollution from truck motor fumes, prompting the installation of a warning sign.*

Wind control

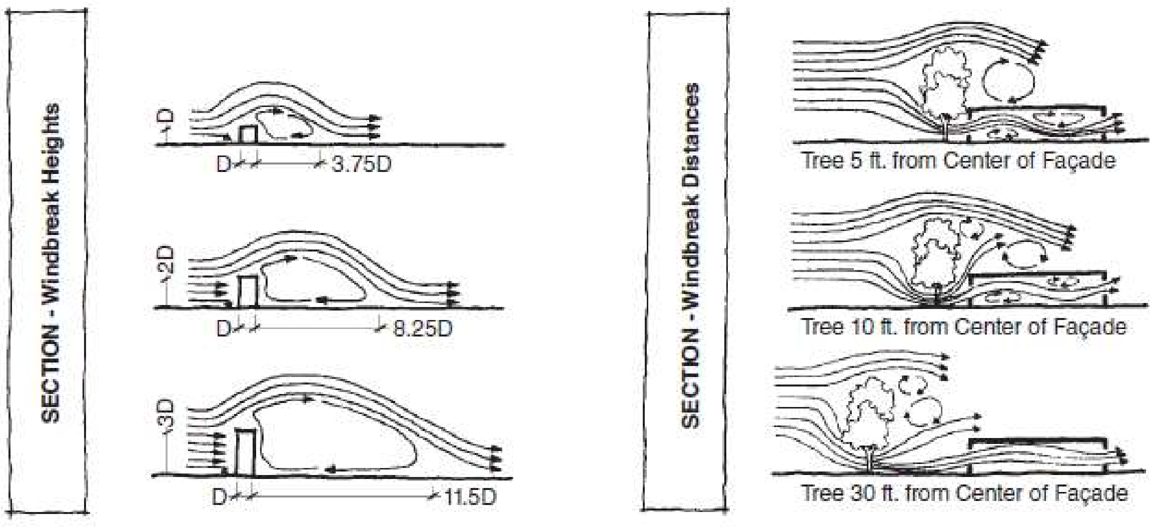
- Wind changes from resources to detriment with the diurnal and seasonal changes.
- The general patterns of wind flow: Fig. 3.26
- For detailed analyses, wind tunnel tests using scale-models are employed.



(a)

Wind Speed Reduction (%)				
Density of Belt	Average Over First: 50 Yd	100 Yd	150 Yd	300 Yd
Very Open	18	24	25	18
Open	54	46	37	20
Medium	60	56	48	28
Dense	66	55	44	25
Very Dense	66	48	37	20

(b)



(c) (d)

Fig. 3.26 *Approximate patterns of wind around objects. (a) Effects of different barrier lengths (widths). (b) Reduction in wind speed due to windbreak density. (c) Effects of different barrier heights. (d) Wind flow through trees and buildings. (Reproduced with the permission of the American Institute of Architects; © 1981, AIA. Redrawn by Jonathan Meendering.)*

*detriment: a harmful thing

Windbreak

- Windbreaks are commonly used to protect outdoor areas; these can be fences or plants.
- Before wind reaches an obstacle, it slows, builds positive pressure, turns upward or sideways, passes the obstacle, increases its speed.

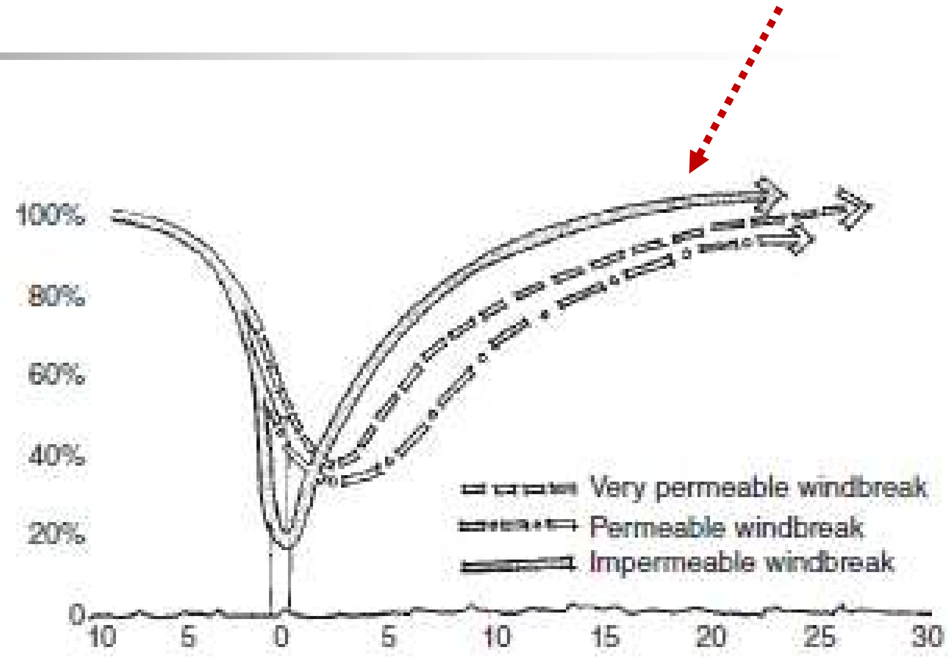


Fig. 3.28 *Wind speed reduction behind windbreaks of varying permeability. Solid (impermeable) barriers produce the lowest wind speeds, but these are effective for the shortest distance beyond the windbreak. Units of distance = heights of windbreak. (Brown and Gillespie, 1995. Redrawn by Erik Winter.)*

Wind behavior expected from typical building arrangements:

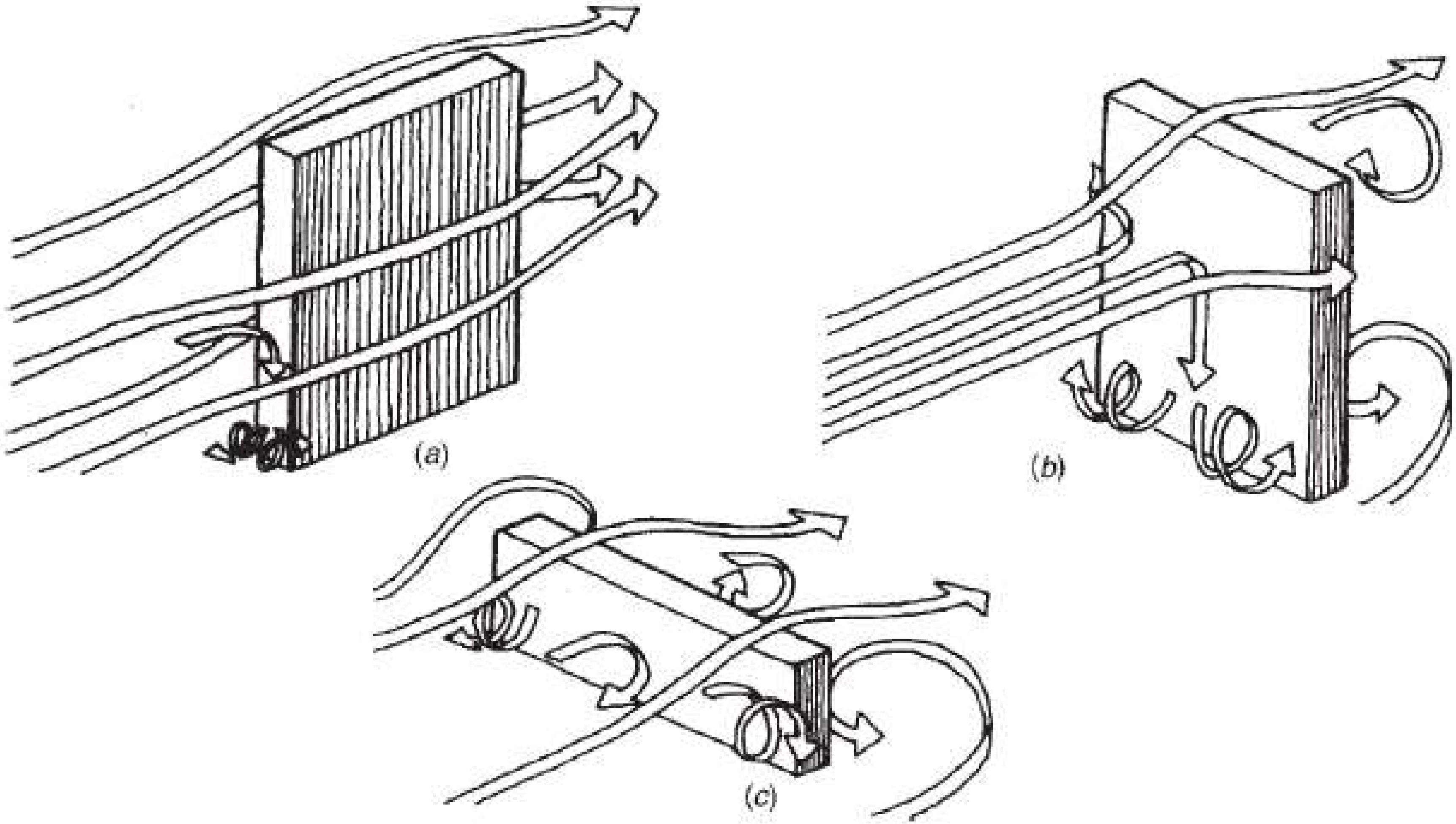


Fig. 3.31 Wind patterns around single buildings. (a) Tall, slender buildings: height greater than 2.5 times the width. (b) Tall, rather wide buildings; height between 2.5 and 0.6 times the width. (c) Long buildings; height less than 0.6 times the width. (From Beranek, W. J. "General Rules of the Determination of Wind Environment," in Wind Engineering, J. E. Cermak [ed.], Vol. 1; © 1980, Pergamon Press Ltd. Reprinted by permission.)

Wind patterns

Wind behavior expected from typical building arrangements

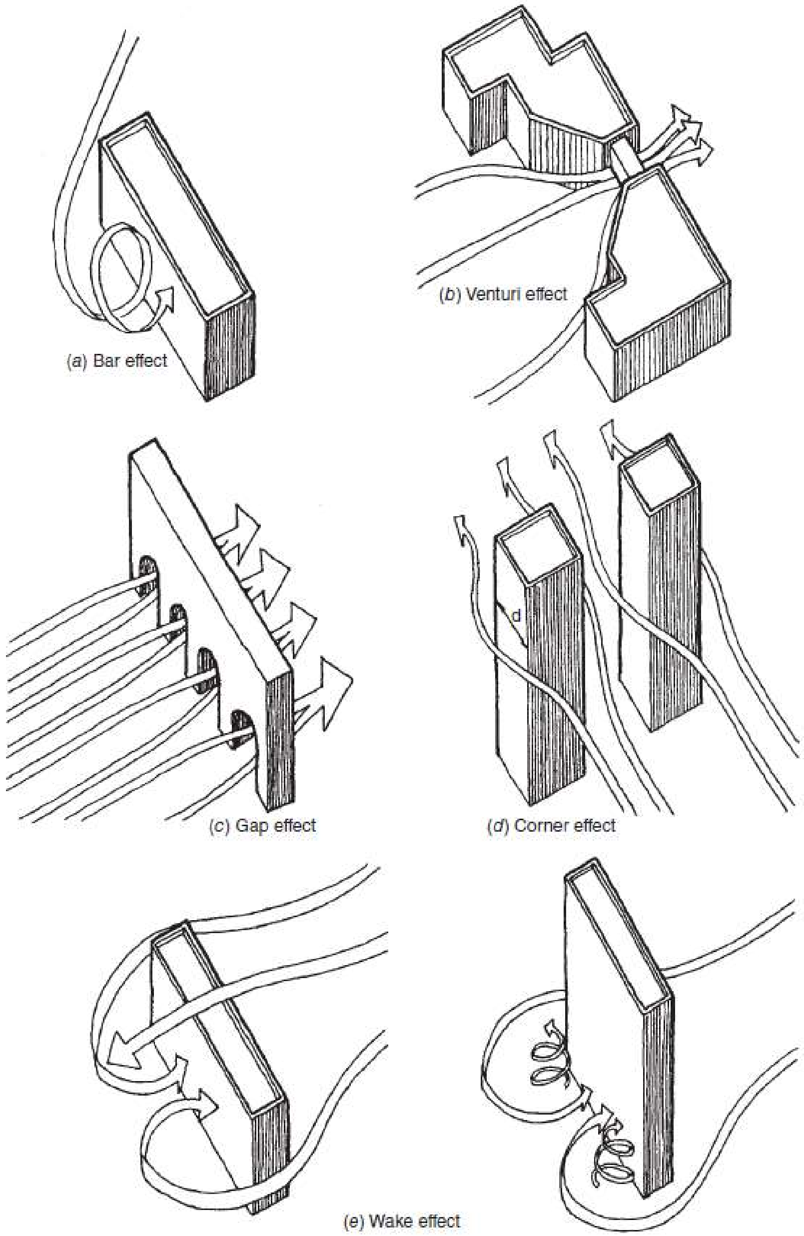


Fig. 3.32 *Wind patterns among building clusters (see text for quantification). (From J. Gandemer, "Wind Environments Around Buildings: Aerodynamic Concepts," in* Wind Effects on Buildings and Structures, *K. J. Eaton [ed.]; © 1977, Cambridge University Press. Reprinted by permission.)*

Ventilation w/ or wo/ cooling

- Ventilation is the delivery of fresh air to provide oxygen and carry away CO_2, body odors, indoor pollutants, etc.
- Recommended rates:
  - USA: Tables F.1- F.2
  - Korea: 0.7 ACH (Air Changes per Hour) → prescriptive approach
- Passive cooling: Fig. 3.33

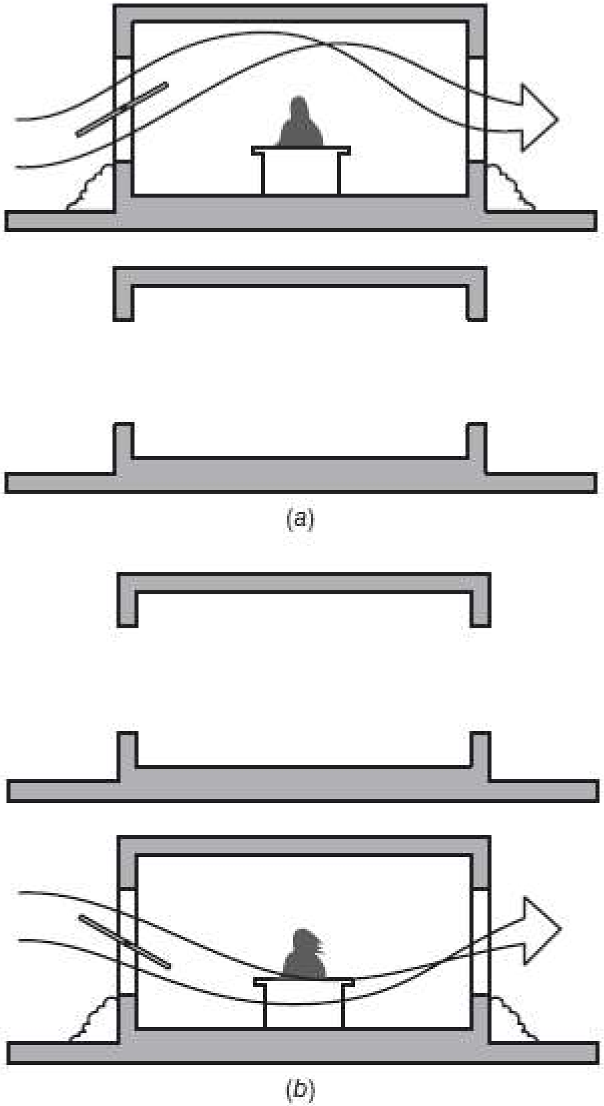


Fig. 3.33 *Ventilation with and without occupant cooling. The size and position of a window will influence the flow of air within a space. (a) Ventilation: the window directs breezes upward, removing hot air at the ceiling. Airflow has minimum contact with occupants. (b) Space ventilation and people cooling: the window directs breezes toward the floor and across occupants and provides a direct people-cooling effect from air motion and fresh air for the space. (Drawn by Alisa Kwok.)*

This rate is based on the default occupant density.

This shall be used when actual occupant density is not known.

Table F.1 Minimum Ventilation Rates in Breathing Zone (for Buildings Except Low-Rise Residential)

	People Outdoor Air Rate		*Area Outdoor Air Rate*			*Default Values*			
	R_p		R_A		Notes	Occupant Density	Combined Outdoor Air Rate		Air Class
Occupancy Category	I-P: cfm/Person	SI: L/s Person	I-P: cfm/ft2	SI: L/s m2		#/1000 ft2 (#/100 m2)	I-P: cfm/Person	SI: L/s Person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25 (26.9)	10	4.9	2
Day room	5	2.5	0.06	0.3		30 (32.3)	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15 (16.1)	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50 (53.8)	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25 (26.9)	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25 (26.9)	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25 (26.9)	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35 (37.7)	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3	H	65 (70.0)	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3	H	150 (161)	8	4.0	1
Art classroom	10	5	0.18	0.9		20 (21.5)	19	9.5	2
Science laboratories	10	5	0.18	0.9		25 (26.9)	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25 (26.9)	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20 (21.5)	19	9.5	2
Computer lab	10	5	0.12	0.6		25 (26.9)	15	7.4	1
Media center	10	5	0.12	0.6	A	25 (26.9)	15	7.4	1
Music/theater/dance	10	5	0.06	0.3	H	35 (37.7)	12	5.9	1
Multi-use assembly	7.5	3.8	0.06	0.3	H	100 (108)	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70 (75.3)	10	5.1	2
Cafeteria/fast food dining	7.5	3.8	0.18	0.9		100 (108)	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100 (108)	9	4.7	2
Kitchen (cooking)	7.5	3.8	0.12	0.6		20 (21.5)	14	7.0	2
General									
Break rooms	5	2.5	0.06	0.3	H	25 (26.9)	7	3.5	1
Coffee stations	5	2.5	0.06	0.3	H	20 (21.5)	8	4	1
Conference/meeting	5	2.5	0.06	0.3	H	50 (53.8)	6	3.1	1
Corridors	—	—	0.06	0.3	H	—			1
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3	H	10 (10.8)	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3	H	20 (21.5)	8	4	1

Lobbies/prefunction	7.5	3.8	0.06	0.3		30 (32.3)	10	4.8
Multi-purpose assembly	5	2.5	0.06	0.3		120 (129)	6	2.8
Office Buildings								
Office space	5	2.5	0.06	0.3		5 (5.4)	17	8.5
Reception areas	5	2.5	0.06	0.3		30 (32.3)	7	3.5
Telephone/data entry	5	2.5	0.06	0.3		60 (64.6)	6	3
Main entry lobbies	5	2.5	0.06	0.3		10 (10.8)	11	5.5
Miscellaneous Spaces								
Bank vaults/safe deposit	5	2.5	0.06	0.3		5 (5.4)	17	8.5
Computer (not printing)	5	2.5	0.06	0.3		4 (4.3)	20	10
Pharmacy (prep. area)	5	2.5	0.18	0.9		10 (10.8)	23	11.5
Photo studios	5	2.5	0.12	0.6		10 (10.8)	17	8.5
Shipping/receiving	10	5	0.12	0.6	B	2	70	
Transportation waiting	7.5	3.8	0.06	0.3		100 (108)	8	4.1
Warehouses	10	5	0.06	0.3	B	—		
Public Assembly Spaces								
Auditorium seating area	5.0	2.5	0.06	0.3		150 (161)	5	2.7
Places of religious worship	5.0	2.5	0.06	0.3		120 (129)	6	2.8
Courtrooms	5.0	2.5	0.06	0.3		70 (75.3)	6	2.9
Legislative chambers	5.0	2.5	0.06	0.3		50 (53.8)	6	3.1
Libraries	5.0	2.5	0.12	0.6		10 (10.8)	17	8.5
Lobbies	5.0	2.5	0.06	0.3		150 (161)	5	2.7
Museums (children's)	7.5	3.8	0.12	0.6		40 (43.0)	11	5.3
Museums/galleries	7.5	3.8	0.06	0.3		40 (43.0)	9	4.6
Retail								
Sales (except as below)	7.5	3.8	0.12	0.6		15 (16.1)	16	7.8
Mall common areas	7.5	3.8	0.06	0.3		40 (43.0)	9	4.6
Barber shop	7.5	3.8	0.06	0.3		25 (26.9)	10	5
Beauty and nail salons	20	10	0.12	0.6		25 (26.9)	25	12.4
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10 (10.8)	26	12.8
Supermarket	7.5	3.8	0.06	0.3		8 (8.6)	15	7.6
Coin-operated laundries	7.5	3.8	0.06	0.3		20 (21.5)	11	5.3

Table F.2 Recommended Ventilation and Exhaust Air Requirements—Low-Rise Residential

Part A: Ventilation Air cfm (L/s)					
Floor Area ft^2 (m^2)	1 Bedroom	2 Bedrooms	3 Bedrooms	4 Bedrooms	5 Bedrooms
<500 (<47)	30 (14)	38 (18)	45 (21)	53 (25)	60 (28)
501–1000 (47–93)	45 (21)	53 (24)	60 (28)	68 (31)	75 (35)
1001–1500 (93–139)	60 (28)	68 (31)	75 (35)	83 (38)	90 (42)
1501–2000 (140–186)	75 (35)	83 (38)	90 (42)	98 (45)	105 (49)
2001–2500 (186–232)	90 (42)	98 (45)	105 (49)	113 (52)	120 (56)
2501–3000 (232–279)	105 (50)	113 (52)	120 (56)	128 (59)	135 (63)
3001–3500 (279–325)	120 (56)	128 (59)	135 (63)	143 (66)	150 (70)
3501–4000 (325–372)	135 (63)	143 (66)	150 (70)	158 (73)	165 (77)
4001–4500 (372–418)	150 (70)	158 (73)	165 (77)	173 (80)	180 (84)
4501–5000 (418–465)	165 (77)	173 (80)	180 (84)	188 (87)	195 (91)

Part B: Exhaust Air

If *continuous*—local ventilation exhaust air flow rates:

- Kitchen: 5 air changes per hour (based upon kitchen volume)
- Bathroom: 20 cfm [10 L/s]

If *intermittent*—local ventilation exhaust air flow rates:

- Kitchen: 100 cfm (50 L/s) (vented range hood required if exhaust fan flow rate is less than 5 kitchen air changes per hour)
- Bathroom: 50 cfm (25 L/s)

Source: Reprinted with permission; ©ASHRAE, www.ashrae.org. ANSI/ASHRAE Standard 62.2-2016, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. See Standard 62.2 for definitions, assumptions, implementation, and exceptions.

Design decision regarding a clerestory: prevailing wind

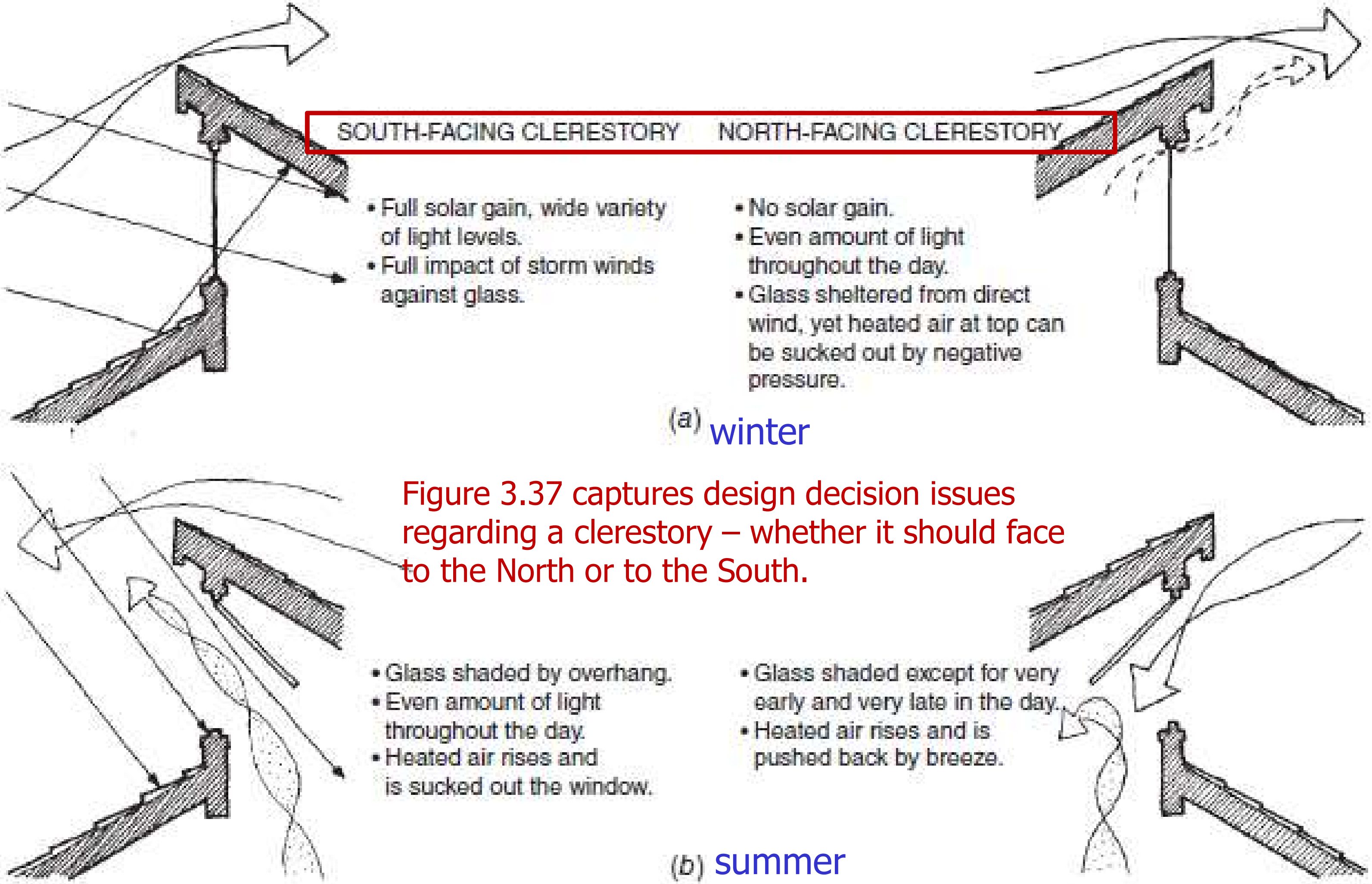


Figure 3.37 captures design decision issues regarding a clerestory – whether it should face to the North or to the South.

Fig. 3.37 *Some relative advantages of north versus south orientation for a clerestory window/shed roof combination. (a) Winter, with low sun and southerly storm winds. (b) Summer, with high sun and northerly breezes. (These wind directions are prevalent in the Pacific Northwest.)*

Please note that prevailing wind directions change with the seasons.

Weather data file

SAREK.TXT - 메모장

파일(F) 편집(E) 서식(O) 보기(V) 도움말(H)

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DB temperature: (X-500)*0.1
Humidity ratio (0.1g/kg)
Direct solar irradiance (kcal/hm^2)
Diffuse solar irradiance (kcal/hm^2)
Cloud cover (0-10)
Wind direction (1-16)
Wind speed (0.1m/s)

Calendar (month, day, day of the week)

94814.TM2 - 워드패드

파일(F) 편집(E) 보기(V) 삽입(I) 서식(O) 도움말(H)

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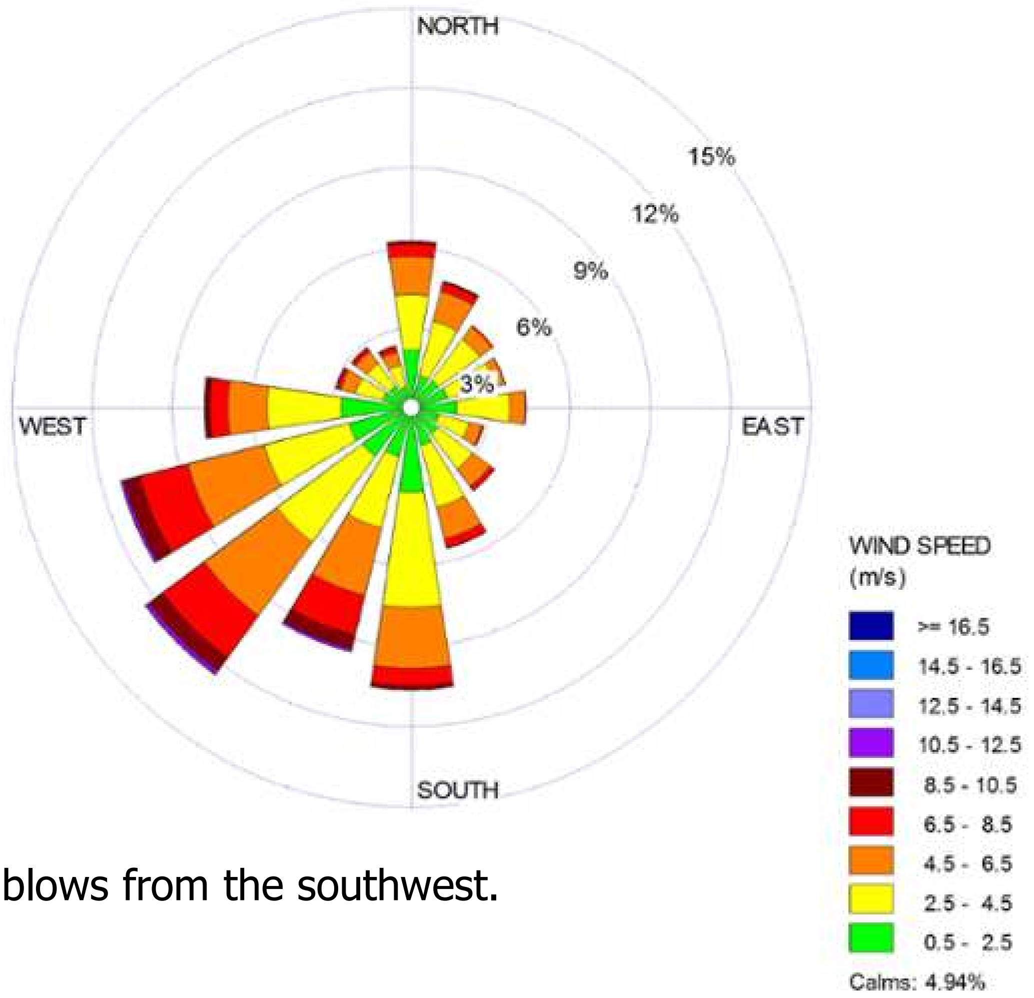
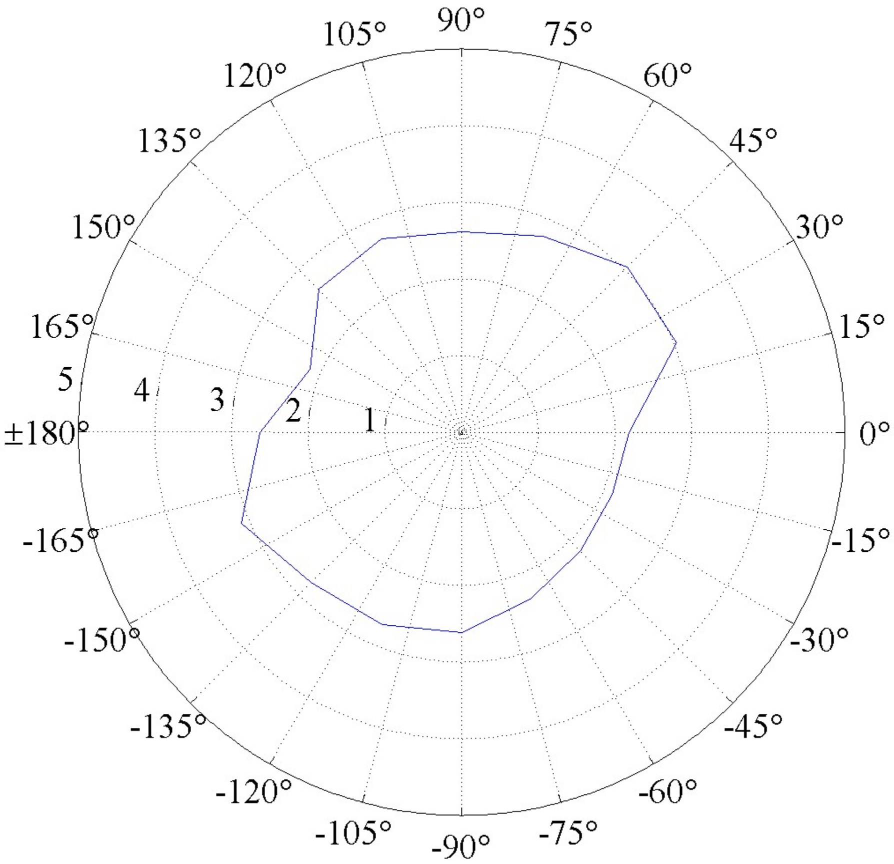
Wind roses for local wind analysis



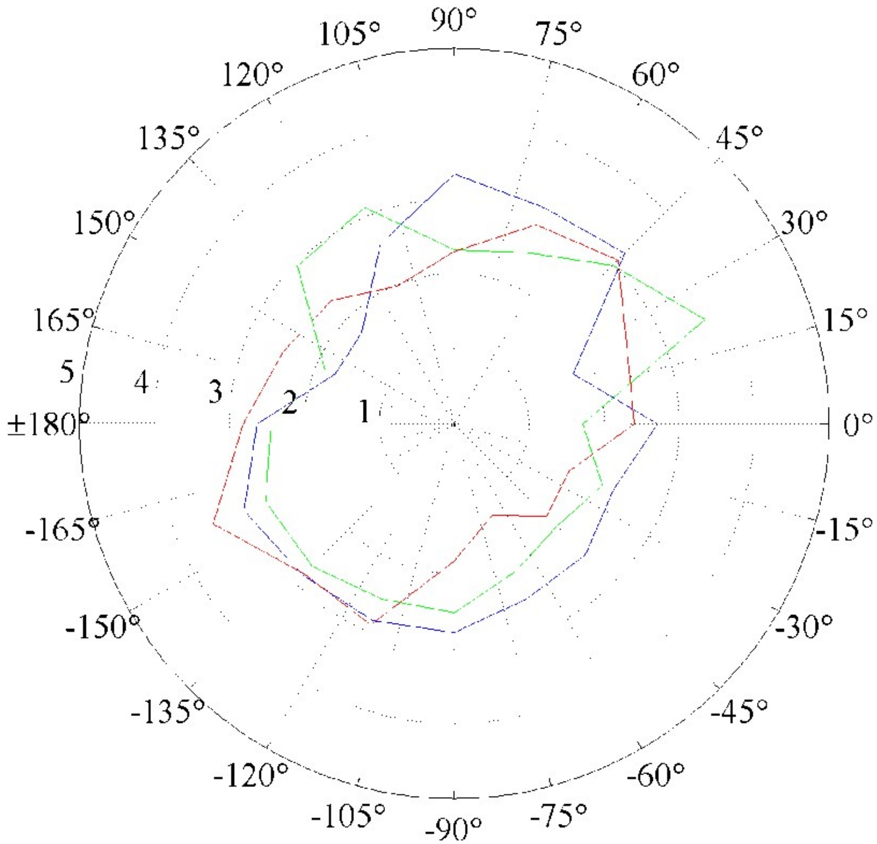
The prevailing wind blows from the southwest.

Image source: https://www.smhi.se/en/services/professional-services/data-and-statistics/wind-roses-for-analysis-of-local-wind-conditions-1.124512

Analysis of prevailing wind



Over a year



Seasonal (red: summer, green: spring/fall, blue: winter)

Windroses of mean wind speed (m/s) and direction (Seoul, Korea)

Hyun, S.H., Park, C.S. and Augenbroe, G. (2008), Analysis of uncertainty in natural ventilation predictions of high-rise apart ment buildings, Building Services Engineering Research and Technology, vol.29, no.4, pp.311-326

Air velocity and comfort

- Wind can cool people in hot weather, yet it can become annoying at higher speeds.
- Manual controls for openings are a necessary part of a natural ventilation design.
- Proper sized and placed openings must be provided.

TABLE 3.4 Beaufort Scale (Lower Speeds Only)

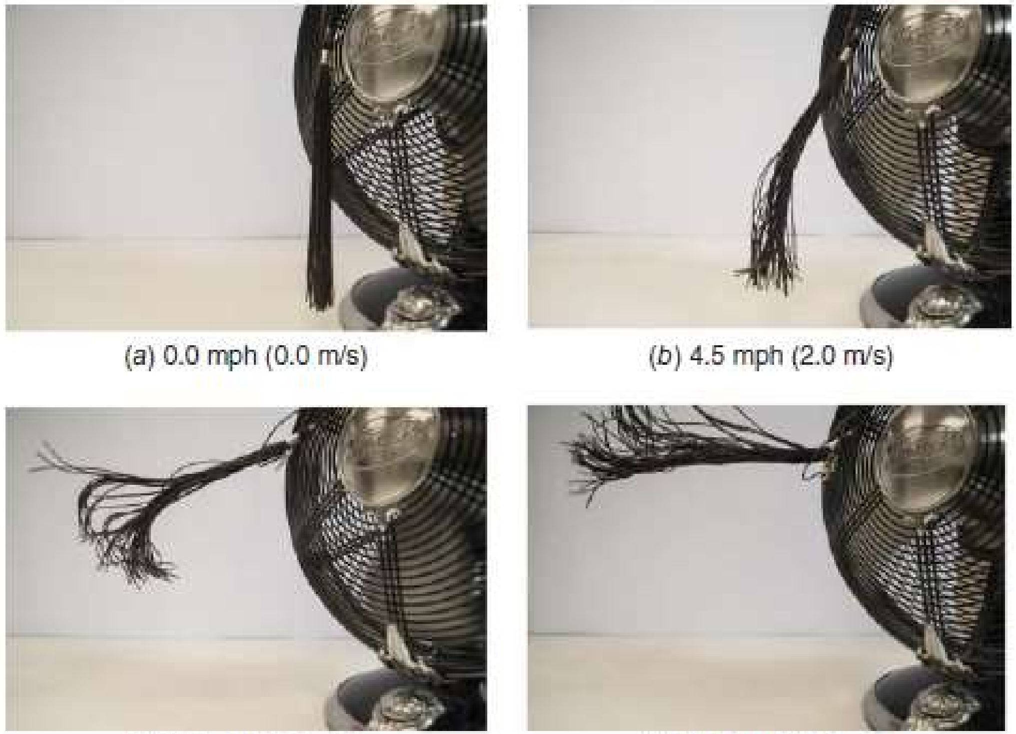
Beaufort Number	Speed 6 m (19.7 ft) Above Ground			Description of Effects Outdoors	
	m/s	fpm	mph	On Land	Over Water
0	0.3	<88	<1	Smoke rises; no perceptible movement	Smooth sea
1	0.3–1.5	88–264	1–3	Smoke drift shows wind direction; tree leaves barely move	Scale-like ripples
2	1.6–3.3	352–616	4–7	Wind felt on face; leaves rustle	Small wavelets
3	3.4–5.5	704–1056	8–12	Leaves, twigs in constant motion; hair is disturbed; wind extends light flag	Large wavelets; occasional white foam crests
4	5.5–7.9	1144–1496	13–18	Small branches move; dust rises; hair disarranged	Small waves become longer

Source: https://en.wikipedia.org/wiki/Beaufort_scale; accessed August 2018.

TABLE 4.6 Air Velocity and Comfort

Air Velocity	Possible Lower-Temperature Comfort Sensation (between 80°F and 90°F; Larger Numbers Correspond to High-Humidity Areas)	Probable Impact
Up to 50 fpm (0.25 m/s)	No change in comfort sensation	Unnoticed
50–100 fpm (0.25–0.51 m/s)	2–3F° lower (1.1–1.7C°)	Pleasant
100–200 fpm (0.51–1.02 m/s)	4–5F° lower (2.2–2.8C°)	Generally pleasant but causing a constant awareness of air movement
200–300 fpm (1.02–1.52 m/s)	5–7F° lower (2.8–3.9C°)	From slightly to annoyingly drafty
Above 300 fpm (1.52 m/s)	More than 5–7F° lower (2.8–3.9C°)	Requires corrective measures if work is to be efficient and health secured

Source: Adapted from Victor Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism*, Copyright © 1963, Princeton University Press. Reprinted by permission.



(*a*) 0.0 mph (0.0 m/s)

(*b*) 4.5 mph (2.0 m/s)

(*c*) 7.8 mph (3.5 m/s)

(*d*) 11.2 mph (5.0 m/s)

Fig. 4.18 *a-d Various air speed rates are shown using a fan and graduation tassel.*

Wind, daylight, and Sun

- The design constraints of both daylighting and cross-ventilation tend to limit building width → Fig. 3.36(a)
- Increasing urban density and reliance on electric lighting and mechanical cooling have changed design responses. → Fig. 3.36(b)
- Trend back to arranging office spaces close to daylighting is occurring. Buildings are slowly trending toward operable windows.
- (a) → (b) → (a), especially in Europe.

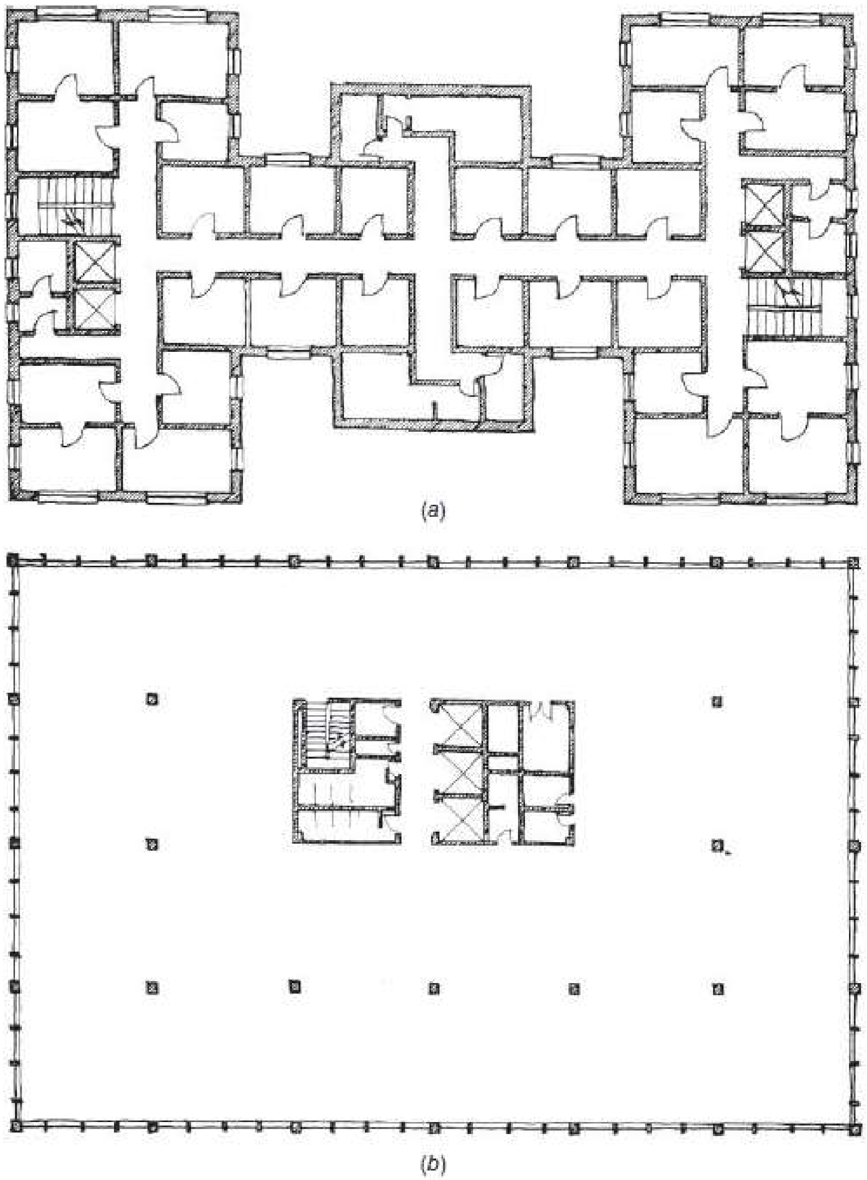


Fig. 3.36 In contrast to office building plan (a), which provides daylight and natural ventilation in each office, office building plan (b) receives mechanically cooled and filtered air, is less subject to exterior noise, typically provides constant light and temperature throughout, and provides for more rentable floor space on its site. Plan b also allows less daylight to reach the street level, consumes much more electricity (though probably less heating fuel), and thus contributes more waste heat (and possibly noise from mechanical equipment) to its surroundings year-round.

Plants can do several roles

- A typical approach to fixed sunscreen design in U.S. temperate zones:
  - to shade a half of the south window in a residence from Mar. 21 to Sep. 21.
  - to shade all of a window in an internal load dominated building from Mar. 21 to Sep. 21.
- For sun position is identical at Mar. 21 and Sep. 21, the monthly average temperatures are different. March is a colder month than September. Average temperatures for June and September are quite similar.
- Full solar radiation is more welcome in early spring than in early fall.

(a) (b)

Fig. 3.40 Educational solar angles displayed (a) for a roof overhang at Springs Preserve, Las Vegas, Nevada. (b) Detail displaying the shade provided during the summer solstice. (© Alison Kwok; all rights reserved.)

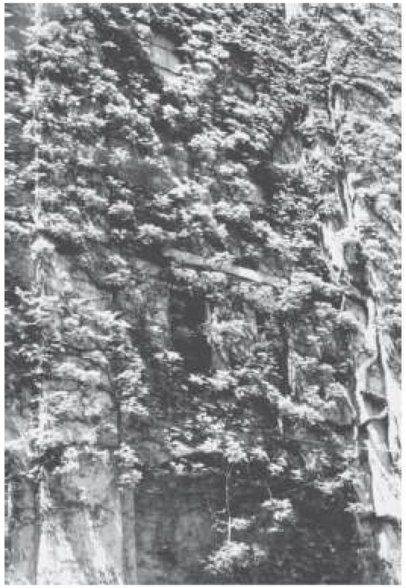
In contrast to fixed sunscreens/overhangs (Fig.3.40), deciduous trees(plants) do most of their shading from the middle of June to early October.

March – June - September

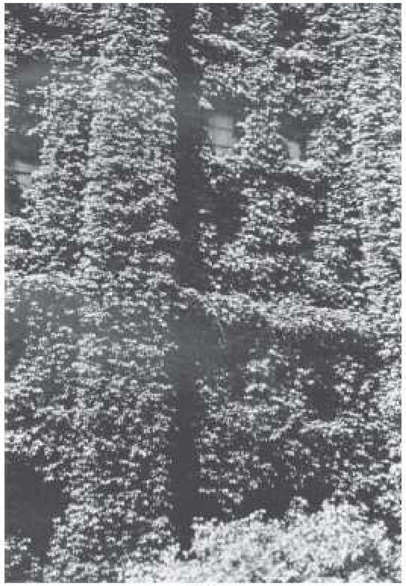
Smart shading device

Note that the sun's path is identical in late May and late July.

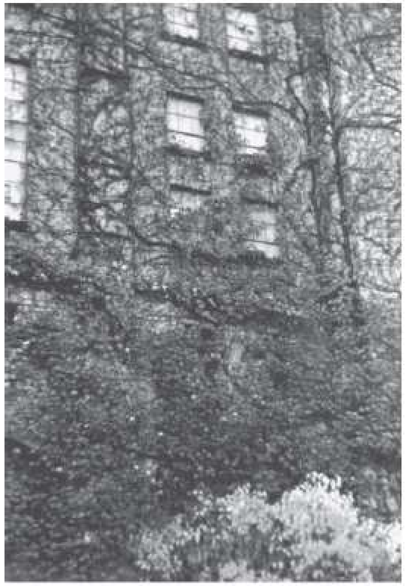
The sun's path is identical in late November and late January.



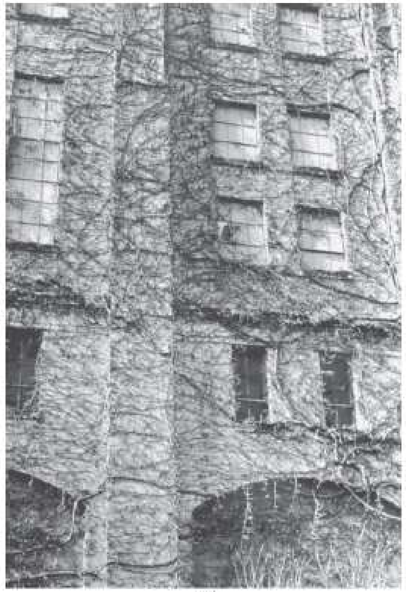
(a) May



(b) July



(c) November



(d) January

Fig. 3.42 Deciduous vines, temperature, and sun position. The sun's path through the sky is identical in late May (a) and late July (b). Similarly paired—but lower—sun paths occur in late November (c) and late January (d). This deciduous vine responds more to the temperature of its Oregon climate than to the sun's position, which makes it particularly useful as a sun control device. For pest control and wall longevity, it is best to keep vines on a trellis rather than on the wall surface. (From Reynolds, 1976.)

Smart shading device

Plants can enhance privacy, slow the winter wind, reduce glare from strong sunlight, and/or prevent summer sun from entering and overheating buildings.

Deciduous plants do most of their shading (because of their leaves) from the middle of June to early October, giving windows access to solar radiation throughout much of the spring months.

Fig. 3.41 A deciduous tree as a naturally "smart" shading device. (Courtesy Tyler Mavichien.)

For internal load dominated large buildings, a tree that foliates early in spring, defoliates late in fall, and has low transmissivity is advantageous.

TABLE 3.5 Deciduous Trees for Summer Shading and Winter Solar Collection

		Transmissivity[a] Range %				Mature Height	
Botanical Name	**Common Name**	**Summer**	**Winter**	**Foliation[b]**	**Defoliation[c]**	**m**	**ft**
Acer platanoides	Norway maple	5–14	60–75	E	M	15–25	50–82
Acer rubrum	Red maple	8–22	63–82	M	E	20–35	65–115
Acer saccharinum	Silver maple	10–28	60–87	M	M	20–35	65–115
Acer saccharum	Sugar maple	16–27	60–80	M	E	20–35	65–115
Aesculus hippocastanum	Horse chestnut	8–27	73	M	L	22–30	72–98
Amelanchier canadensis	Serviceberry	20–25	57	L	M		
Betula pendula	European birch	14–24	48–88	M	M–L	15–30	50–98
Cercis canadensis[d]	Red bud	62	74	L	M	12	40
Carya ovata	Shagbark hickory	15–28	66			24–30	78–98
Catalpa speciosa	Western catalpa	24–30	52–83	L		18–30	60–98
Cornus florida[d]	Dogwood	43	53	L	E	11	36
Fagus sylvatica	European birch	7–15	83	L	L	18–30	60–98
Fraxinus pennsylvanica	Green ash	10–29	70–71	M–L	M	18–25	60–82
Gleditsia tricanthos inermis	Honey locust	25–50	50–85	M	E	20–30	65–98
Juglans nigra	Black walnut	9	55–72	L	E–M	23–45	75–148
Liquidambar styraciflua[d]	Sweet gum	33	47	M	L	24	78
Liriodendron tulipifera	Tulip tree	10	69–78	M–L	M	27–45	88–148
Platanus acerifolia	London plane tree	11–17	46–64	M–L		30–35	98–115
Populus detoides	Cottonwood	10–20	68	E	M	23–30	75–98
Populus tremuloides	Trembling aspen	20–33		E		12–15	40–50
Quercus alba	White oak	13–38					
Quercus palustris[d]	Pin oak	45	47	L	L	23	75
Quercus rubra	Red oak	12–23	70–81		M	23–30	75–98
Robinia pseudoacacia[d]	Black locust	38	40	L	E	21	69
Tilia cordata	Littleleaf linden	7–22	46–70	L	E	18–21	60–69
Ulmus americana	American elm	13	63–89	M	M	18–24	60–78

Source: Brown and Gillespie (1995), except as noted.

[a]Transmissivity to solar radiation; estimates vary with instruments used by various researchers.

[b]Foliation: E = early (before April 30); M = middle (May 1–15); L = late (after May 15).

[c]Defoliation: E = early (before November 1); M = middle (November 1–30); L = late (after November 30).

[d]From Montgomery (1987). Transmissivity % = (100% – blockage %).

Case study: Aldo Leopold Legacy center

EXHIBIT P

ALDO LEOPOLD LEGACY CENTER
Interpretive Exhibit Hall

Daylighting to reduce the use of artificial lighting

Case study: Aldo Leopold Legacy center

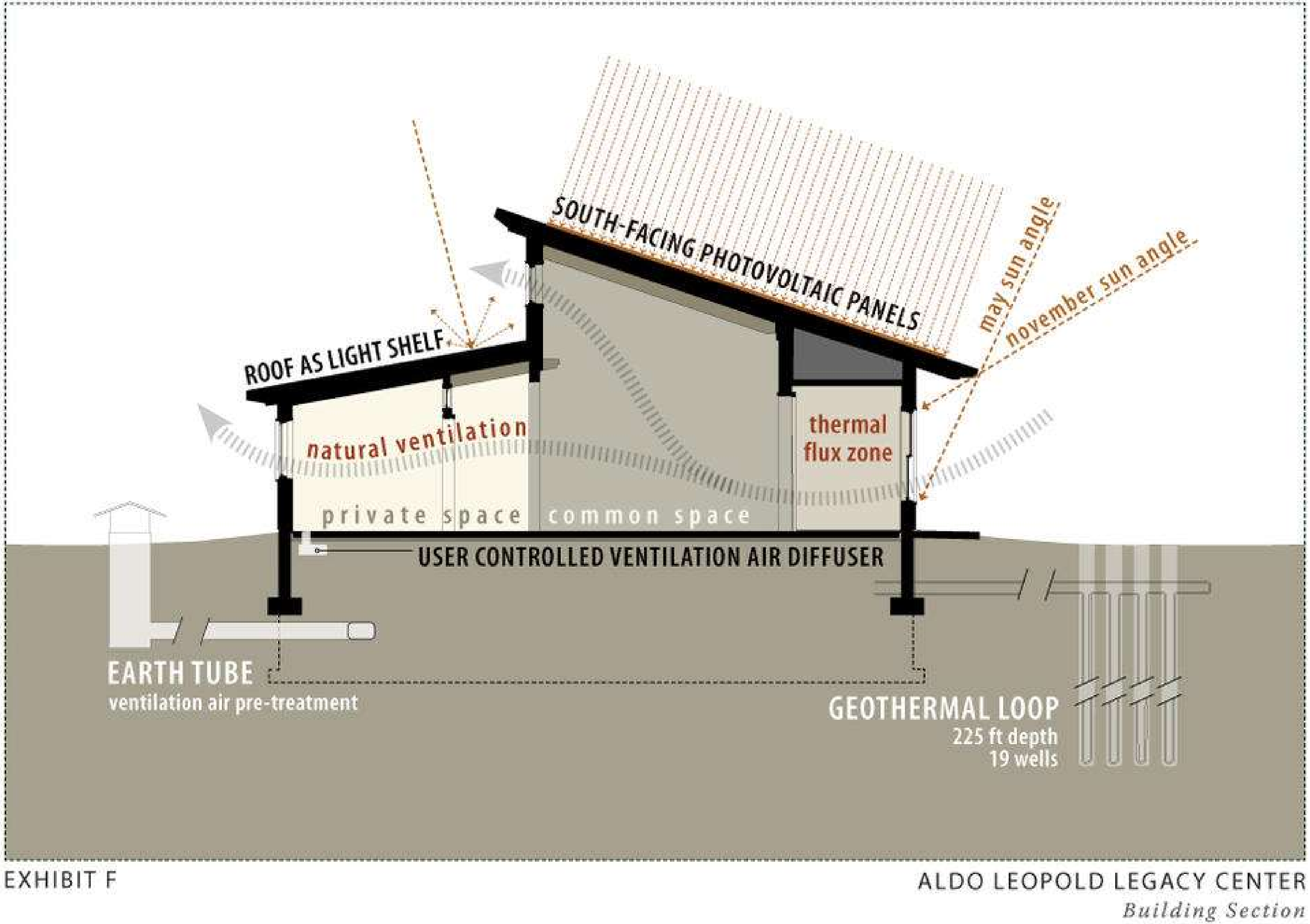


Fig. 3.47 building section showing strategies for lighting, heating, cooling and ventilation