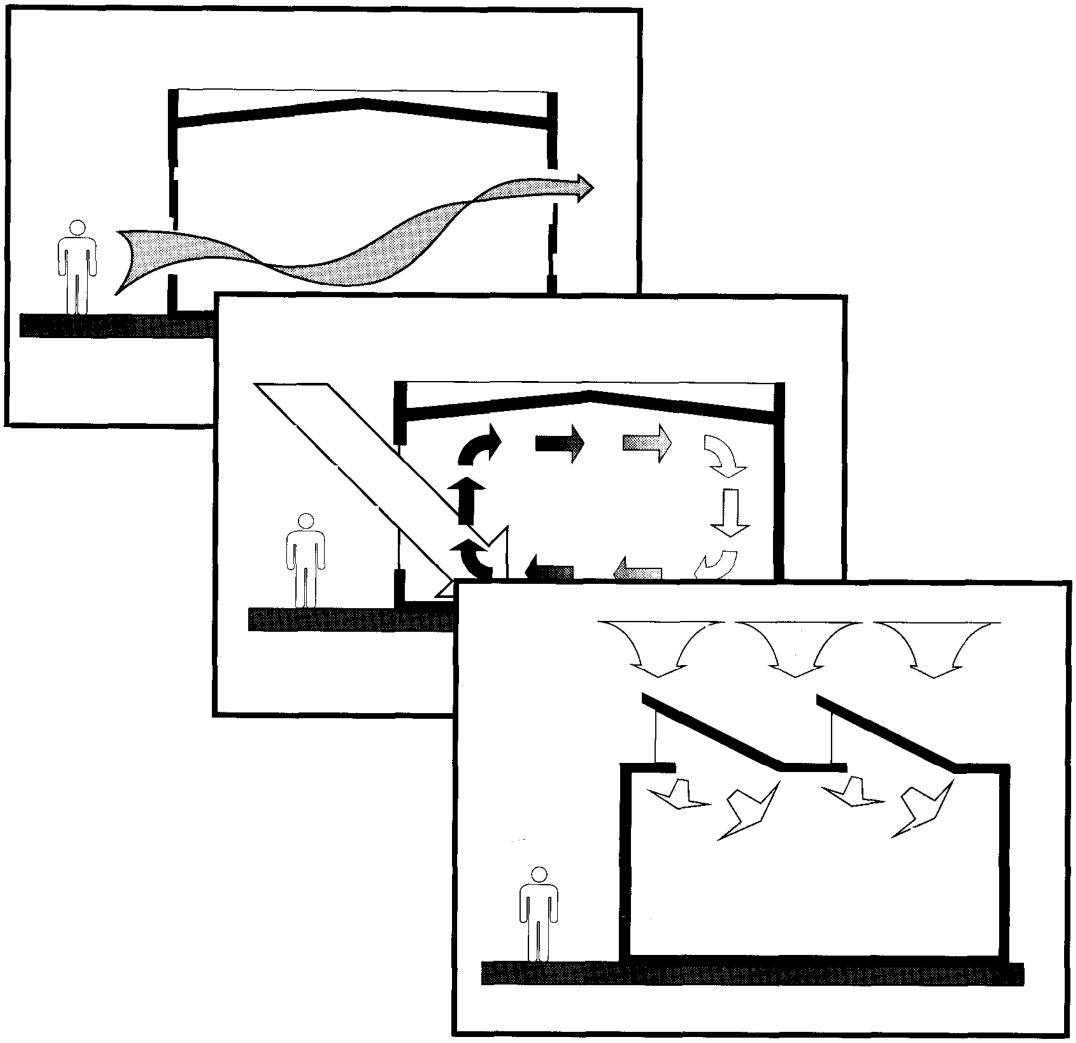
United States Air Force

Passive Solar Handbook

Introduction To Passive Solar Concepts



Volume I

Foreword

The United States Air Force is committed to energy efficiency and the use of renewable forms of energy in all of its facilities when shown to be reliable and cost effective. In its response to the Military Construction Codification Act of 10 USC 2801, Executive Order 12003 and Office of the Secretary of Defense directives, the Air Force has implemented numerous policies and procedures to significantly reduce the usage of fossil fuel derived energy. Since the oil embargo of the early 1970's, the Air Force has encouraged and demonstrated the integration of a variety of energy conserving features, including solar applications, in its facilities. Passive solar systems represent one type of solar application that can be used in almost all facilities to improve their energy efficiency and to lower their energy costs.

The audience for this five-volume passive solar handbook is the numerous Air Force personnel and others responsible for programming, planning, designing, supervising construction, commissioning, and operating and maintaining Air Force commercial-type facilities worldwide. This handbook was developed in response to MAJCOM and base needs for information on the integration of passive solar systems into new Air Force commercial-type facilities.

The goal of the Air Force Passive Solar Handbook series is to integrate passive solar concepts into the Air Force planning, programming, design, construction, and operation processes for commercial-type facilities.

The five volumes of the Passive Solar Handbook are as follows:

Volume I: Introduction To Passive Solar Concepts
Volume II: Comprehensive Planning Guide
Volume III: Programming Guide
Volume IV Passive Solar Design (proposed)
Volume V: Construction Inspection (proposed)

This is the first volume of the series.

Joseph A. Ahearn, Major General, USAF
Director of Engineering and Services

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Passive Solar Concepts

Introduction

Passive solar systems use the energy from the sun to heat, cool, and illuminate buildings. The Air Force has used passive solar concepts in buildings since it was established in 1947 and will continue to do so whenever possible. Figure 1-1 illustrates a passive solar strategy used by the Air Force in 1947. Although this form of passive heating system is no longer in use, it illustrates the Air Force's early commitment to the use of passive solar systems in commercial-type buildings.

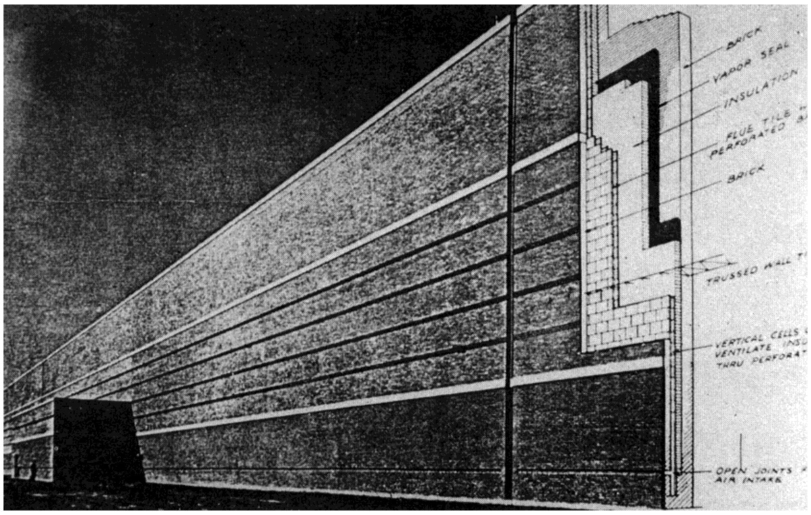


Figure 1-1: Breathing Wall. Tinker AFB, Oklahoma

The breathing wall, built in 1947, is a double layer mass wall acting as an indirect gain solar heating system.

Solar Thermal Concepts
Daylighting Concepts

Solar concepts described in this handbook fall into two broad categories: (1) those that use the energy from the sun to directly or indirectly impact the thermal needs (heating and cooling energy use) of the building, and (2) those that use the energy from the sun to directly impact the lighting needs of the building. Solar systems that heat or cool the building will be called *solar thermal systems;* ones that light the building will be called *daylighting systems.*

It is not anticipated that a properly designed passive solar commercial-type building will completely eliminate the need for the auxiliary energy systems used to heat, cool, or light the building. Because of the size of the buildings, large internal loads, and their diverse use patterns, it is anticipated that passive solar systems will supplement the energy systems of the building. However, it is possible for a combination of passive solar concepts to reduce total energy costs by as much as 40% and have savings-to-investment ratios (SIR) that should make them cost effective.

Glossary

Technical and solar terms used throughout all of the volumes of the handbook are defined in Chapter 5 of this volume.

Solar Concepts

A total of eleven different passive concepts will be considered in this handbook. Many other possible solar concepts were evaluated. The ones listed below are appropriate in a wide range of climates and building types.

(H) Direct gain with storage
(H) Indirect gain
(H) Direct gain (without storage)
(H) Sunspaces
(C) Night Mechanical Ventilation
(C) Natural Ventilation
(L) Windows
(L) Skylights
(L) Sawtooth Apertures
(L) Monitor Apertures
(L) Atria

The letters (H), (C), and (L) stand for heating, cooling, and lighting, respectively, and are used to remind you of the purpose for each passive solar system concept.

Passive Solar System Components

Solar thermal concepts use the energy from the sun to heat or cool the building and usually consist of four separate components:

(1) collection
(2) storage
(3) distribution
(4) control

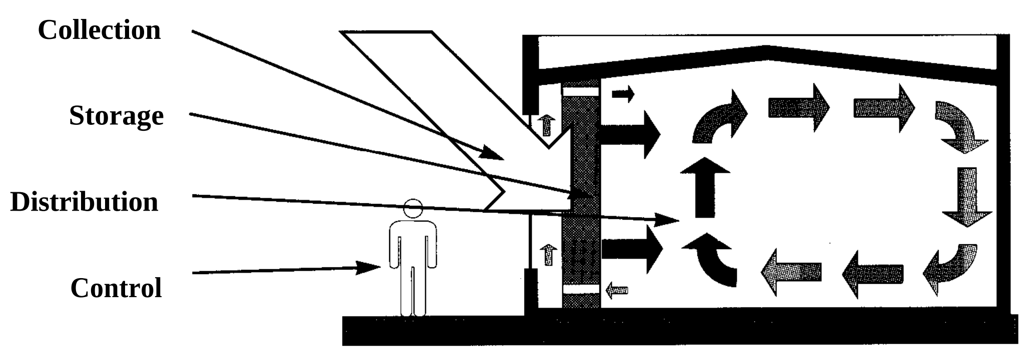


Figure 1-2: Components of a Passive Solar Thermal System

Daylighting concepts use the sun to light the building and usually consist of only three components:

(1) collection
(2) distribution
(3) control

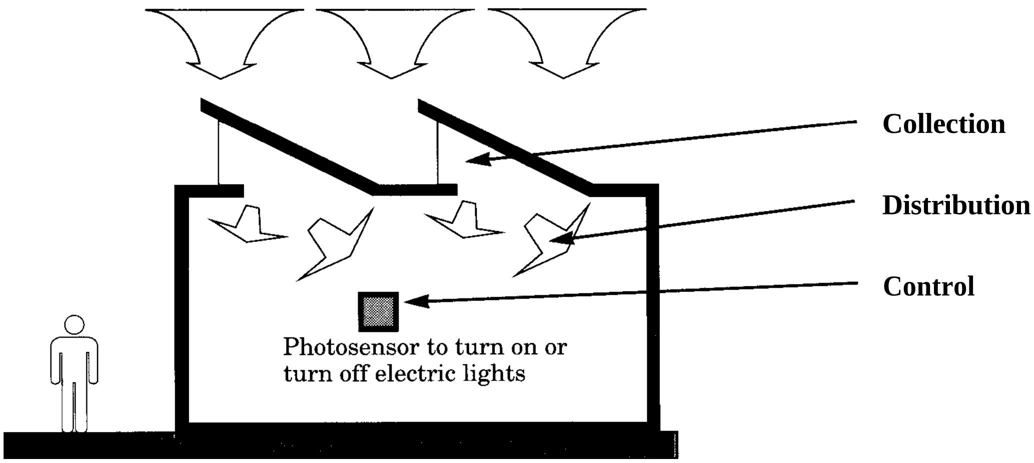


Figure 1-3: Components of a Daylighting System

In a passive solar building, the solar components are parts of the building itself rather than separate subsystems. Therefore, the collection component may be windows or some other type of solar aperture; the storage component is usually the structural mass of the building; and the distribution component is formed by the shape, size, and location of the rooms of the building.

It is virtually impossible to separate the passive features of a building from the building as a whole. In this regard, a passive solar building is nonconventional; one must learn to think of such a building as a totality rather than as a collection of separate parts that are interchangeable depending upon economic need. In a conventional (nonsolar) building, if a particular heating, cooling, or lighting system is not economically viable, it can usually be changed without impacting any other aspect of the building design.

To change the passive features of a solar building may require a complete redesign of the building. Therefore, it is important to correctly identify, during the comprehensive planning stage, the appropriate passive solar concepts that will be used in the building.

Passive Heating

Collection

Passive heating concepts use heat from the sun to offset winter heating needs. The collection subsystem may include windows, skylights, or some other type of solar aperture. *The purpose of the collection subsystem is to allow sunlight into the building to heat the space and, if appropriate, to heat the storage mass.* The storage subsystem usually includes parts of the floor or interior walls of the building.

Storage

The purpose of the storage subsystem is to store the collected solar heat until it is needed by the occupants in the building. In most cases, heat is collected during the daytime and used at night. Stored energy is released from the storage mass and distributed throughout the building to offset heating energy use.

Distribution

Distribution is accomplished by arranging the functional spaces of the building such that those that need heat are closest to the storage subsystem.

The size and shape of the solar apertures (collection subsystem) affects the quantity of heating energy available to offset auxiliary heating energy needs. The size of the storage subsystem affects the quantity of heat stored and the time delay between initial collection and final use of energy. The size, shape, and location of rooms in the building impact the optimum distribution of the heat throughout the building.

Heat distribution is accomplished by a combination of radiation and convection. Heat is *radiated* from the storage subsystem into the rooms being heated after the collected solar energy has passed through the storage system. Heat is *convected* through the air, warming it, and thereby warming the people in the room.

Control

Control of the passive heating system might be quite different from control of an HV or HVAC system. In many passive buildings, control is achieved through the use of shading devices, or some other means to regulate the sunlight entering the building. More complex passive buildings may also have thermostats to control fans and motors that regulate the air flow or control vents. In many passive buildings, the control mechanisms are manual; that is, people control the building.

A balance between the size, shape, and location of each subsystem must be achieved to ensure optimal system performance and efficiency. If the collection subsystem is too large or too small, then either too much energy is collected and the building is overheated or not enough energy is collected to be effective. Similarly, if the storage subsystem is improperly sized, then it either holds the energy in storage too long (oversized) or not long enough (undersized) to provide heat to the building when it is needed. Finally, if the spaces of the building are not correctly organized, the heat cannot be distributed in a manner that ensures optimal auxiliary heating energy savings and comfort. In developing this handbook, extensive analysis was done to determine the -optimal size of different subsystems for various climate zones and building types.

When developing a knowledge of the optimal performance characteristics of a passive heating system, it is usually the storage component that is least understood. When a storage surface is illuminated by sunlight, the energy enters the mass and is stored as heat. The type of material used, its thermal storage capacity, thermal conductance, thickness, and the room's temperature dictate the quantity of energy stored and the length of time it stays in storage. For example, a 4-inch concrete wall might store energy for 4 hours before completely releasing it as heat. Similarly, 24 inches of concrete might store energy for 18 to 20 hours before completely releasing it. *By varying the type of building material used, and its thickness, it is possible to substantially vary the performance characteristics of a passive heating system.* The most commonly used materials in storage systems are concrete and masonry products.

Prompt Systems

Extended Systems

Passive heating systems that collect and distribute the heat in 4 hours or less are called *prompt* systems. Ones that perform this process and take more than 12 hours to release the heat are called *extended* systems. *Most passive solar heating systems are designed to release their heat between 4 and 12 hours.* This is especially true of passive heating systems used in commercial-type buildings, such as administration buildings, which are not occupied for more than 10 to 12 hours a day.

Passive solar heating systems are often categorized by the relationship between the solar system and the building, that is, whether or not the solar system is part of a room being heated, part of the building, or totally separate from the building. Using this reasoning, there are three categories of passive solar heating systems:

(1) direct gain systems
(2) indirect gain systems
(3) isolated gain systems

This terminology will be used to describe the four passive heating concepts described in this handbook:

- *Direct gain (without storage) (DG)*
- *Direct gain plus storage (D+S)*
- *Indirect gain (with storage)(IND)*
- *Sunspace (isolated gain with storage) (SUN)*

Direct Gain (DG)

Direct Gain plus Storage (D+S)

There are two types of direct gain heating systems. *A direct gain without storage, abbreviated DG,* is a prompt system that does not include any additional interior mass in the building (other than what would normally be available in structural members, walls, ceilings, and floors). A direct gain system is schematically illustrated in Figure 1-4. Figure 1-5 contains a photograph of a direct gain system used in an airport facility. Both of these figures are on the following page. *A direct gain plus storage, abbreviated D+S,* includes additional internal mass to extend the storage capacity to approximately 8 hours. This system is schematically illustrated in Figure 1-6, and a photograph of one is shown in Figure l-7. Both figures are on page 7.

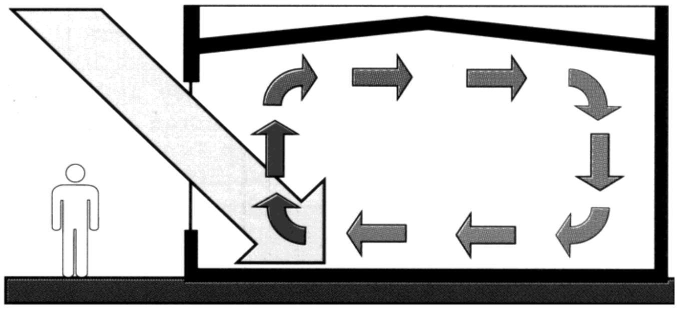


Figure 1-4: Direct Gain (DG) Schematic

Figure 1-5: Direct Gain. Walker Field Terminal, Grand Junction, Colorado

The roof apertures are used to provide both heating and daylighting. They were primarily designed to be a direct gain heating system.

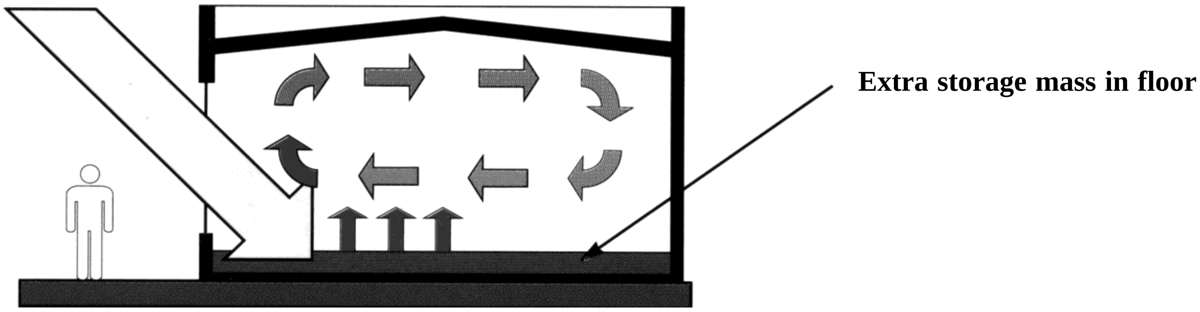


Figure 1-6: Direct Gain plus Storage (D+S) Schematic

Figure l-7: Direct Gain plus Storage. Air National Guard Composite Operations and Training Facility, Bangor, Maine

Note the illuminated mass wall on the left of the picture and the sloped direct gain apertures in the roof.

Indirect Gain (IND)

Indirect gain (IND) concepts place the collection and storage components of the solar thermal system very close to each other as part of the same wall. Heat is collected and stored in an exterior wall or on the roof of a building, and distributed to the building by passing all the way through the storage mass. For some applications, air that passes between the aperture and the storage mass (which are only 4 to 6 in. apart) is heated and circulated to rooms to offset immediate heating energy needs. Indirect gain systems are often used when extended storage capacity is needed in a building because it is possible to make the storage component very thick (12+ inches). *In commercial-type buildings, there were no cases where walls in excess of 8 inches thick were needed or useful.* See Figure 1-8 and 1-9.

Vents may not be recommended for some applications
(see Volume IV)

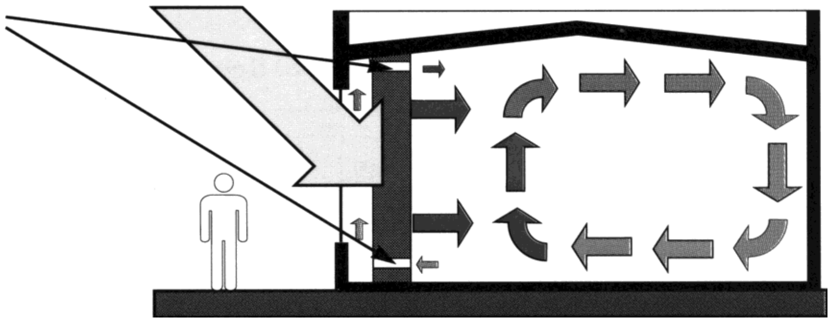


Figure 1-8: Indirect Gain (IND) Schematic

Figure 1-9: Indirect Gain. Shelly Ridge Girl Scout Center, Philadelphia Area Council

Note the masonry wall construction behind the glazing. This is the indirect gain heating system. The apertures above the wall are used for daylighting as well as direct gain heating.

Sunspaces (SUN)

Isolated gain passive solar heating systems isolate the collection and storage subsystems from the building. One special category of an isolated gain system is a sunspace. A *sunspace (SUN)* combines some features of direct gain systems with features of indirect gain systems. A sunspace is a room attached to or integrated with the exterior of a building in which the room temperature is allowed to rise and fall outside the thermal comfort zone. The space can be inhabited, thus acting like a direct gain system. However, the walls and floor of a sunspace are used as storage. The back walls of the sunspace allow the heat to pass through them, much like an indirect gain system, to heat the room adjacent to the sunspace. See Figure 1-10 and 1-11.

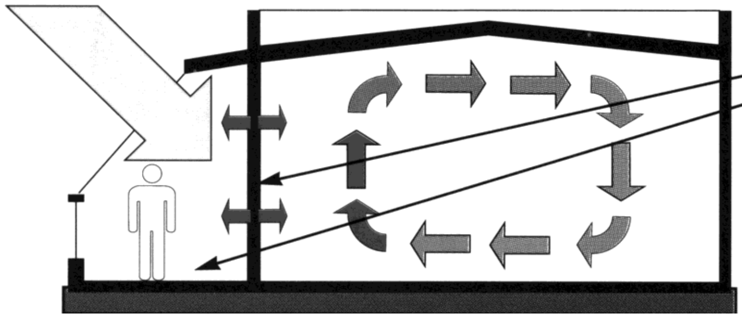


Figure 1-10: Sunspace (SUN) Schematic

Figure 1-11: Sunspace. Commissary, McGuire AFB, New Jersey

The attached sunspace can be seen on the right of the picture.

Different types of passive heating systems have been considered to allow for design variation and to recognize the fact that some concepts work better in some building types. In general, passive heating systems work best in buildings: *(1) with low levels of continuous internal load* (less than 1.5 w/sf), *(2) that are occupied for extended periods* (more than 8 hours), and (3) *are located in climates with heating seasons in excess of 1,000 HDD.* The severity and length of the heating season are not as critical as the internal load and occupancy schedule of the building.

Passive Cooling

Passive cooling systems have the same basic components as passive heating systems, but work in a different manner. *Whereas the purpose of passive heating systems is to draw heat into the building, the purpose of a passive cooling strategy is to remove or reject heat from the building, and thereby cool it.* Because the mechanisms that drive passive cooling strategies are not fully understood, many cooling concepts are difficult to fully evaluate during the comprehensive planning process. Therefore, the number of cooling concepts advocated in this volume of the handbook is limited. A more detailed discussion of passive cooling concepts can be found in Volume IV: Passive Solar Design.

Peak Cooling

Passive cooling benefits are achieved by avoidance of the cooling load in the building. In many commercial-type buildings, the *peak cooling* requirement is directly associated with solar gains. By avoiding solar gains, a portion of the cooling load is avoided. This can be accomplished by shading the apertures of the building.

Shading

Shading can be achieved using the shape and form of the facade, using low transmission glazing, or using devices inside of the building. From a passive solar viewpoint, the most effective method of shading is on the outside of the building using

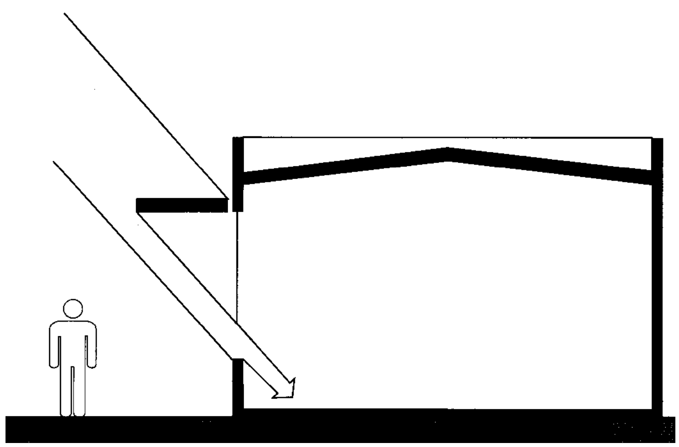


Figure 1-12: Shading Schematic

overhangs, fins, or louvers, as illustrated in Figures 1-12 and 1-13. *A less effective method is to use glazing with a low shading coefficient.*

Shading devices must be carefully designed. For passive heating systems, shading devices should block the sun during the summer months hut allow sunlight to enter the building during winter. For daylighting systems, the sun is usually blocked during the swing seasons (spring and autumn) as well as the summer. In either case, there will be variations depending upon the building type and internal loads.

Figure 1-13: Shading. Military Personnel Support Center, Grissom AFB, Indiana

In this building, note how the vertical structural elements and roof overhangs are used to shade the windows.

The analysis of passive cooling systems done for this handbook *assumed that all glazing facing south (in the Northern Hemisphere; north in the Southern Hemisphere) is shaded from the sun from spring through autumn.*

The most successful cooling strategies reduce the internal loads of the building. This can be achieved during the daytime by designing for natural ventilation and at night by mechanically ventilating (night mechanical ventilation) the building. These two strategies have proven to be most successful in the commercial-type buildings analyzed.

Natural Ventilation (NVN)

Natural ventilation (NVN) relies on the natural airflow and breezes to reduce the need for mechanical cooling when the building is occupied. See Figure 1-14 on the following page. In most cases, natural ventilation occurs simply by opening windows when the outside air temperature is lower than the inside air temperature. This strategy is effective primarily during the spring and autumn (the swing seasons), thus avoiding the intermittent use of mechanical heating and cooling equipment. *The Air Force recommends that commercial-type buildings have operable windows when climatic conditions offer the potential for significant energy savings. This strategy is a no-cost change in building design and operation.* It should be noted that inappropriately opening windows as a heating control strategy during the heating season may offset any gains achieved by using them for natural ventilation.

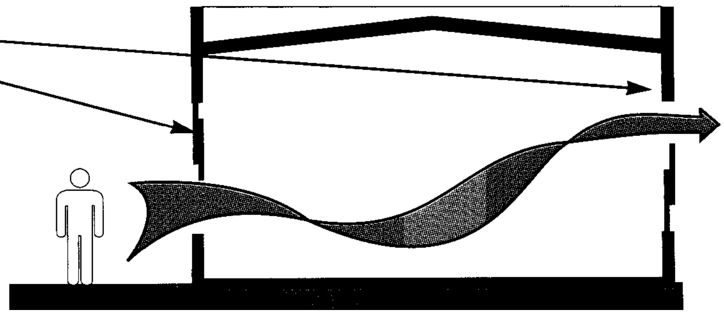


Figure 1-14: Natural Ventilation (NVN) Schematic

Night Mechanical Ventilation (NMV)

Night mechanical ventilation (NMV) reduces the temperature of the internal mass of the building at night so that the mass will absorb heat during the day See Figures 1-15 and l-16. The mass temperature is reduced by "flushing" the building with cool (low humidity) night air. The air reduces the temperature of the internal mass sufficiently to keep the building cool during much of the day. *This type of system uses the fan and duct components of the HVAC or HV system to distribute the cool night air throughout the building.*

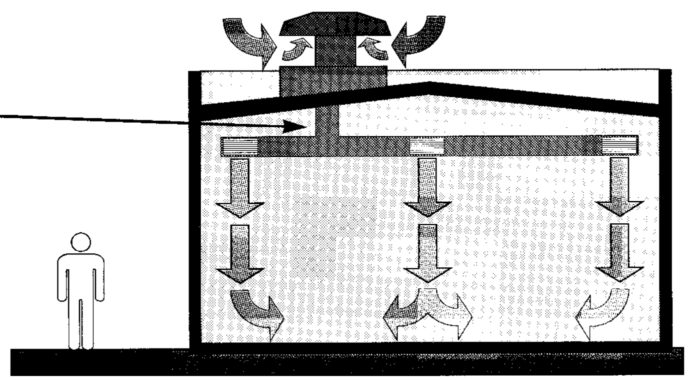


Figure 1-15: Night Mechanical Ventilation (NMV) Schematic

Figure 1-16: Night Mechanical Ventilation. Colorado Mountain College, Glenwood Springs, Colorado

The vertical duct system on the right hand side of the picture is part of the night mechanical ventilation system.

Daylighting

Daylighting is the use of natural light from the sky as a supplement for electric lighting in buildings. Traditional daylighting systems differ in one major respect from passive heating systems: they use the sky as a source of light and avoid letting direct sunlight into a building. Since light from the sky is used in lieu of direct sunlight, daylighting systems function quite well on overcast, partly cloudy, or clear days.

Daylighting is an instantaneous use of the light from the sky. Therefore, daylighting systems consist of collection and distribution components and do not include a storage component like passive heating systems. However, much like solar thermal strategies, daylighting systems are categorized according to the type of collection system used. Thus, there are three basic types of daylighting systems:

(1) sidelighting
(2) toplighting
(3) core daylighting

Daylighting is the most effective passive solar strategy in almost all commercial building types because it reduces two major energy uses in these buildings: electric lighting and cooling.

Obviously, if daylighting is being used, the electric lighting must be turned off. This reduces electricity consumption for lighting. In many large buildings, the largest single component of the cooling load is the energy needed to remove heat generated by the electric lighting system. Therefore, turning off the electric lighting, reduces, by as much as 40%, the energy used to mechanically cool the building.

A total of five different daylighting systems were analyzed for this handbook. These were:

- *Windows (sidelighting) (WIN)*
- *Skylights (toplighting) (SKY)*
- *Sawtooth apertures (toplighting)* (SAW)
- *Monitor apertures (toplighting) (MON)*
- *Atria (core daylighting) (ATR)*

Windows (WIN)

In this volume of the handbook, sidelighting systems are limited to *windows (WIN)* to illuminate the interior of a building. See Figures 1-17 and 1-18. Additional sidelighting concepts are discussed in Volume IV Passive Solar Design.

It is not necessary to add extensive amounts of glazing to sidelight a building. However, there are limitations to the depth that daylight can penetrate into a building from a window. *In most cases, 30 feet is the maximum depth of daylight penetration for a typical office, though a greater depth can be assumed for tall hangars, depending on their geometry.* The layout of interior walls and furnishings can reduce this depth of daylight penetration. Beyond this distance, either toplighting or core daylighting systems must be used.

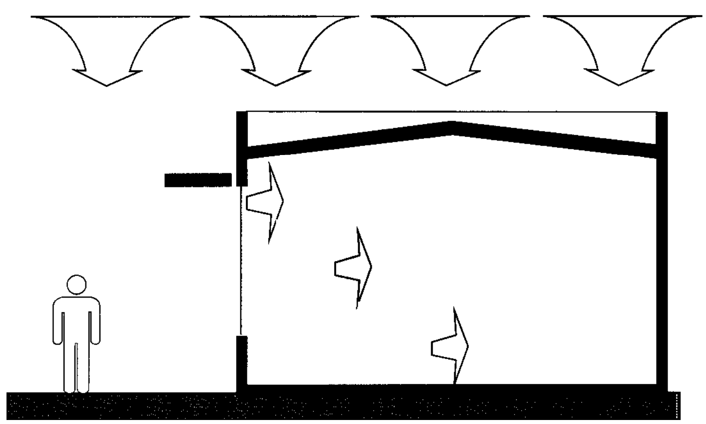


Figure 1-17: Window (WIN) Schematic

Figure 1-18: Windows. Standard Brands Research Center, Wilton, Connecticut

Windows are excellent daylighting apertures. Glare is being controlled by a set of operable, blinds.

Toplighting

Toplighting systems bring light through the roof of the building to illuminate interior spaces. These systems are most effective in one-story buildings. Three different types of toplighting systems are considered in this handbook: (1) skylights, (2) sawtooth apertures, and (3) monitor apertures.

Skylights (SKY)

Skylights (SKY), as illustrated in Figure 1-19, are horizontal apertures cut through the roof of a building. See Figure 1-20 for an application of skylights in a base exchange.

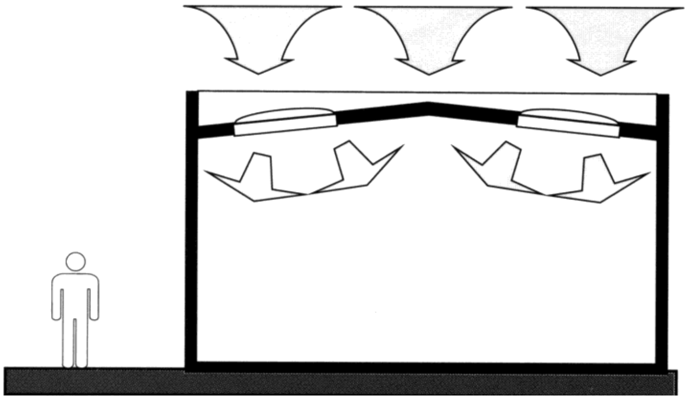


Figure 1-19: Skylight (SKY) Schematic

Figure 1-20: Skylights. Base Exchange Mall, McChord AFB, Washington

Sawtooth Apertures (SAW)

Sawtooth apertures (SAW), as schematically illustrated in Figure 1-21, are a toplighting system that includes a glazed vertical surface and a sloped roof. The name comes from the fact that a series of these apertures look like the teeth of a handsaw. In some literature, this type of aperture is called *a roof clerestory*. Figure 1-22 illustrates sawtooth apertures in a fire station.

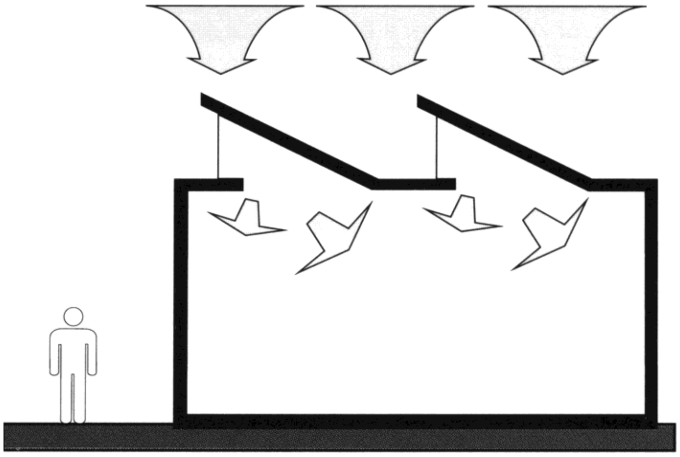


Figure 1-21: Sawtooth Aperture (SAW) Schematic

Figure 1-22: Sawtooth Apertures. Fire Station, McEntire A.N.G. Base, South Carolina

A series of sawtooth apertures are on the roof of the building. They are used to provide daylight in both the equipment room and dormitory areas of the building.

Monitor Apertures (MON)

Monitor apertures (MON) were initially developed during the 19th century for use in industrial facilities that had high- and low-bay areas side by side. See Figures 1-23 and 1-24. The high-bay is extended beyond the roof line and glazed on two opposing sides that extend above the roof. *Both sawtooth and monitor apertures are appropriate in almost all one-story buildings that have large open areas, such as industrial facilities, maintenance facilities, and warehouses.*

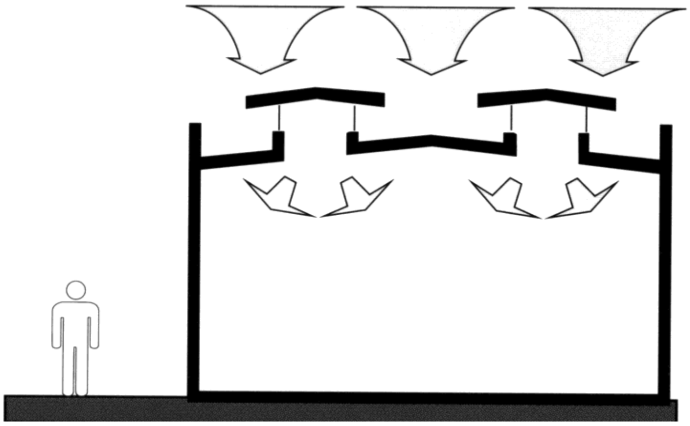


Figure 1-23: Monitor Aperture (MON) Schematic

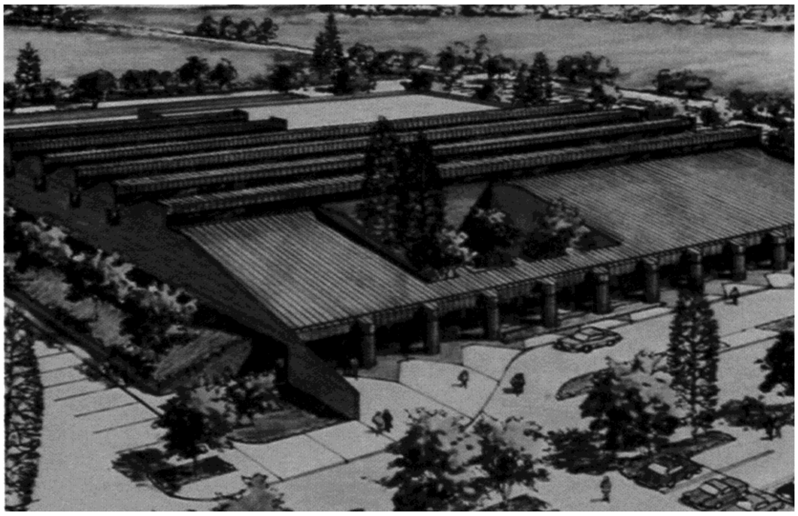


Figure 1-24: Monitor Apertures. Commissary, Vandenberg AFB, California

The monitor apertures extend above the roof line of this building, allowing daylight to be used throughout the facility. Note the extended overhang and courtyard on the front of the building, also passive features that shade and daylight the building.

Atrium (ATR)

In multistory commercial-type buildings, the most difficult location to daylight is the center of the building, called the building core. An *atrium (ATR)* is a *core daylighting* concept that opens up the center of the building so that it can he daylit. See Figures 1-25 and 1-26. *An atrium works best when the perimeter of the building, within 15 ft of the exterior walls, is daylighted using sidelighting techniques.* An atrium can be capped with any of the roof aperture systems previously discussed.

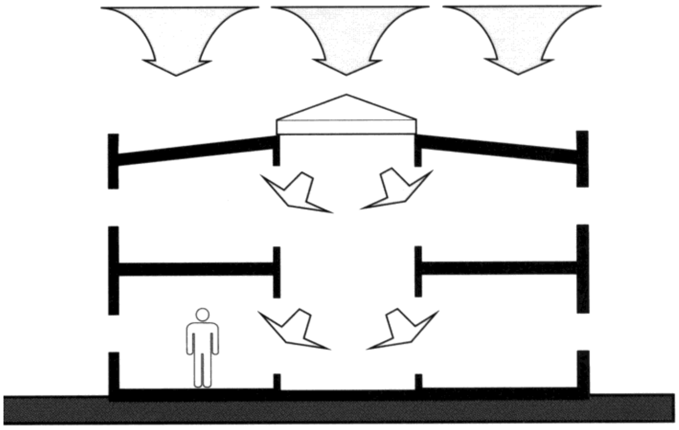


Figure 1-25: Atrium (ATR) Schematic

Figure 1-26: Atrium. Personnel Services Building, Robins AFB, Georgia

The center bays of this building have been raised above the roof line to create a large atrium that allows daylight to he used to offset electric lighting usage.

Automated Electric Lighting Control

To save energy by using daylight, the electric lighting must be turned off when daylight can *be used.* This is accomplished by an automated electric lighting control system. Different control strategies are discussed in more detail in Volume IV: Passive Solar Design.

If automated electric lighting control is not planned for a particular building, it is not appropriate to assume that energy savings will result from daylighting the building.

Conclusions

A large number of passive solar concepts can be applied to commercial-type buildings. The ones presented in this chapter are appropriate for most cases. However, other passive solar systems may be appropriate under special circumstances, for particular building types, or for a particular climate region. During the comprehensive planning process, it may he enough to know that passive solar heating and/or cooling, and/or daylighting, are appropriate in a building. When more detailed analysis is needed during the design process, it can be done following the procedures found in Volume IV: Passive Solar Design.

Additional Reading

For those interested in learning more about passive solar systems, additional reading material is listed in Chapter 4.

Introduction

Base Comprehensive Plan

Energy-conserving planning and passive solar design begins with site selection. If the base has implemented a *Base Comprehensive Plan (BCP)*, then energy requirements are specified in the plan, Section II-J. The BCP may require certain building types and functions to occur in specific interrelationships with other existing buildings. These restrictions are critical to good base planning and have minimal adverse impact on site planning for solar buildings. Frequently, their impact is supportive of solar planning techniques and objectives. See Figure 2-1.

Solar buildings should be located and designed so that they interact with climate in a positive manner. To do this, it is necessary to understand which aspects of climate are important to a particular passive solar system and building type.

Site planning requirements are slightly different depending upon whether the building is using a passive heating, cooling, or daylighting strategy, or a combination of these. The decision to site plan for one strategy over another is dependent upon the primary energy uses in the proposed building and the most effective passive solar system. Site planning is an interactive process, beginning with defining the overall goal for energy use and cost in the proposed building, determining the most effective solar concepts to achieve this goal, and using that information to determine how to site plan for the building.

Areas where passive solar consideration impacts the site selection process

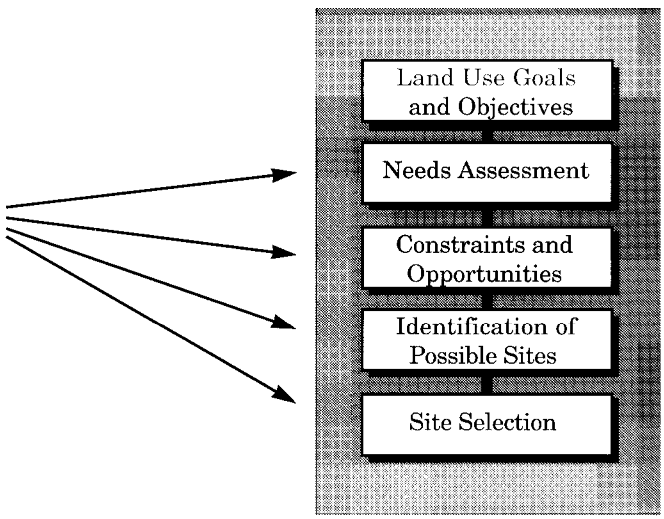


Figure 2-1: Site Selection Process

The site selection process must follow the guidelines set down by the Base Comprehensive Plan (BCP) in terms of working within the overall land use goals and objectives for the base. Based upon the needs, constraints, and opportunities afforded by the

BCP, it is possible to identify several possible sites appropriate for the proposed building. From these sites, it is possible to pick a site that achieves all or most of the needs and goals of the project, including any site planning constraints caused by the use of passive solar systems. Energy issues will typically not be the dominant factor in site selection. *However, all other things being equal, if a site has better access to the sun and sky, then it should be given some priority over other sites.*

Site Planning For Passive Heating

Site planning for passively heated buildings involves ensuring that the solar collection facades of the building have access to the sun. Since not all facades of any building have ‘access’ to the sun, site planning for solar access typically involves consideration of one, or possibly two, key facades. The most important facade usually is the south facade (north facade in the Southern Hemisphere). Next, usually, is the east facade, although protecting the solar access of this facade is not as critical as it is with the primary solar facade.

Solar Envelope

The primary method of site planning for passive heating in commercial-type buildings is a concept called the *solar envelope*. A solar envelope is defined as the boundaries of a three-dimensional volume, on the site, having unobstructed access to the sun during a certain time period over the year, as shown in Figure 2-2. The method for delineating the solar envelope is presented in Volume IV: Passive Solar Design.

It is not the purpose of this volume of the handbook to teach how to generate solar envelopes, which are discussed in Volume IV, but to demonstrate the underlying principles of the process, so that when site selection is being made, you can quickly judge if a site has a reasonable solar access. *The underlying principle of the solar envelope concept is to ensure that a portion of the site, as represented by a three-dimensional volume, has access to the sun so that passive heating systems can function properly.* In addition, a solar envelope helps to ensure that adjacent buildings are not shaded from the sun.

The solar envelope establishes a volume on a site that has unobstructed access to the sun during a certain time period over the year. An appropriate envelope can be constructed for any site and any time frame. The final envelope does not represent the shape of the proposed building, but the three-dimensional volume within which the building should be constructed. Solar envelopes can be simple or complex depending upon the surrounding buildings, topography, and the ingenuity of the planner. Figure 2-2, on the following page, illustrates a typical site which looks fairly constrained. Figure 2-3 illustrates the solar envelope for that site. The final building form may be different than the solar envelope, but must fit within the boundaries established by it to obtain proper solar access.

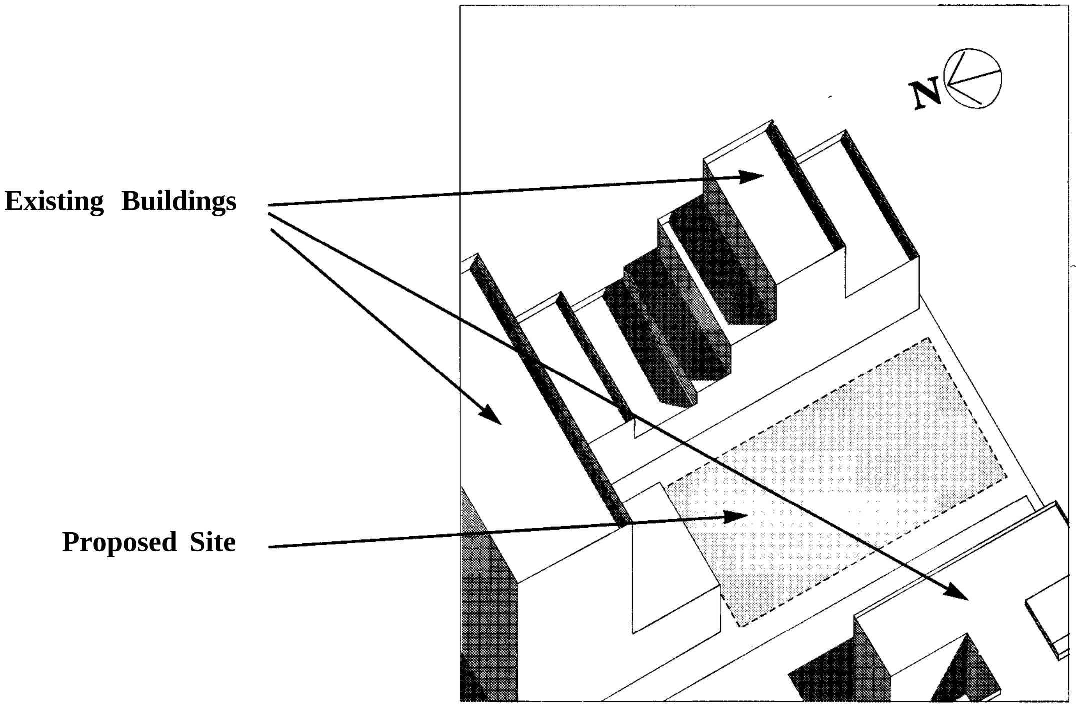


Figure 2-2: Constrained Site

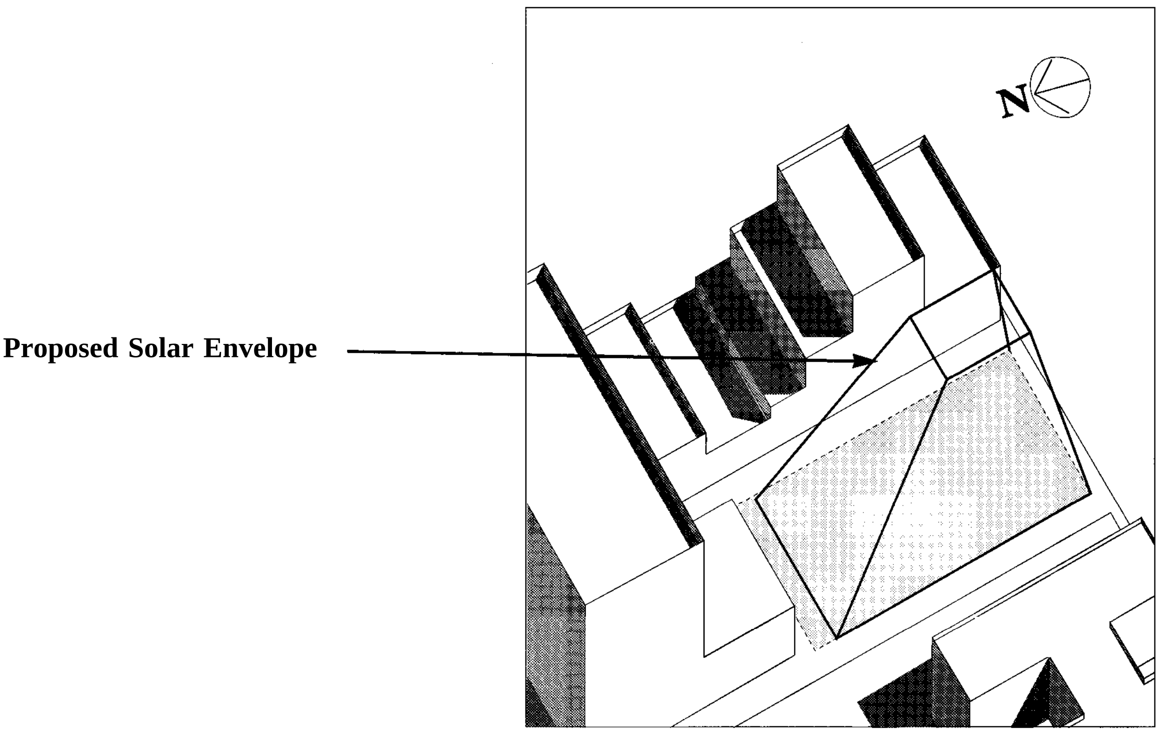


Figure 2-3: Solar Envelope For Constrained Site

The solar envelope is determined from the volume created by the range of sun movement during the operating schedule of a building over the year. For example, suppose a building has an operating schedule of 0800 to 1700h year-round, and the site constraints allow the sun in during the winter between 0900h and 1500h, and in the summer between 0700h and 1700h. The sun locations in winter (December 21st) and summer (June 21st) can be plotted for these times and converted to a three dimensional volume, as in Figures 2-4 and 2-5. *This establishes the solar envelope within which the building is designed.*

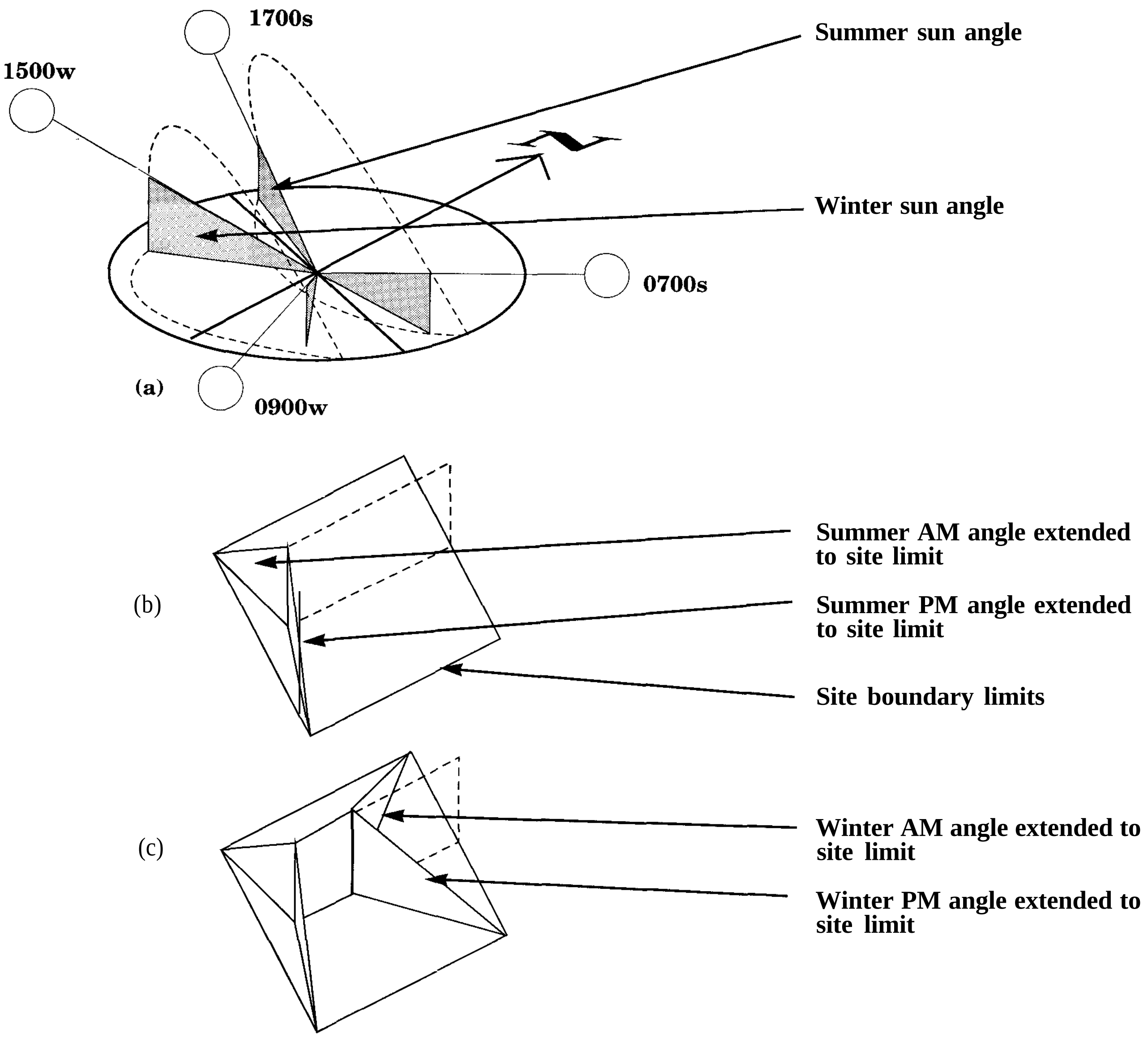


Figure 2-4: Establishing Solar Envelope Boundaries
(a) time constraints, (b) setting summer limits, (c) setting winter limits

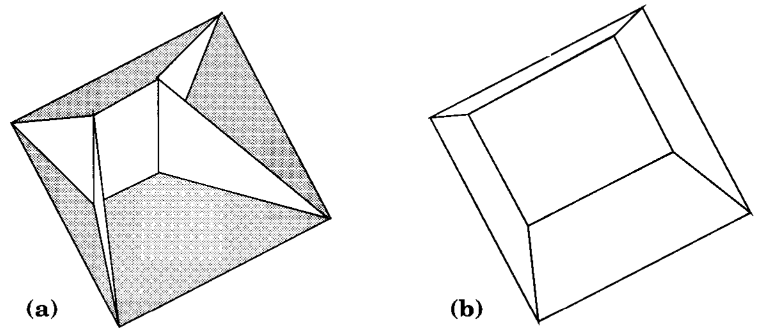


Figure 2-5: The Final Solar Envelope
(a) final boundaries, (b) solar envelope within boundaries

A solar envelope can be established for a parcel of land even if the entire parcel is not going to be developed at one time. Each phase of construction is designed to fit within the confines of the overall solar envelope. This is illustrated in Figure 2-6.

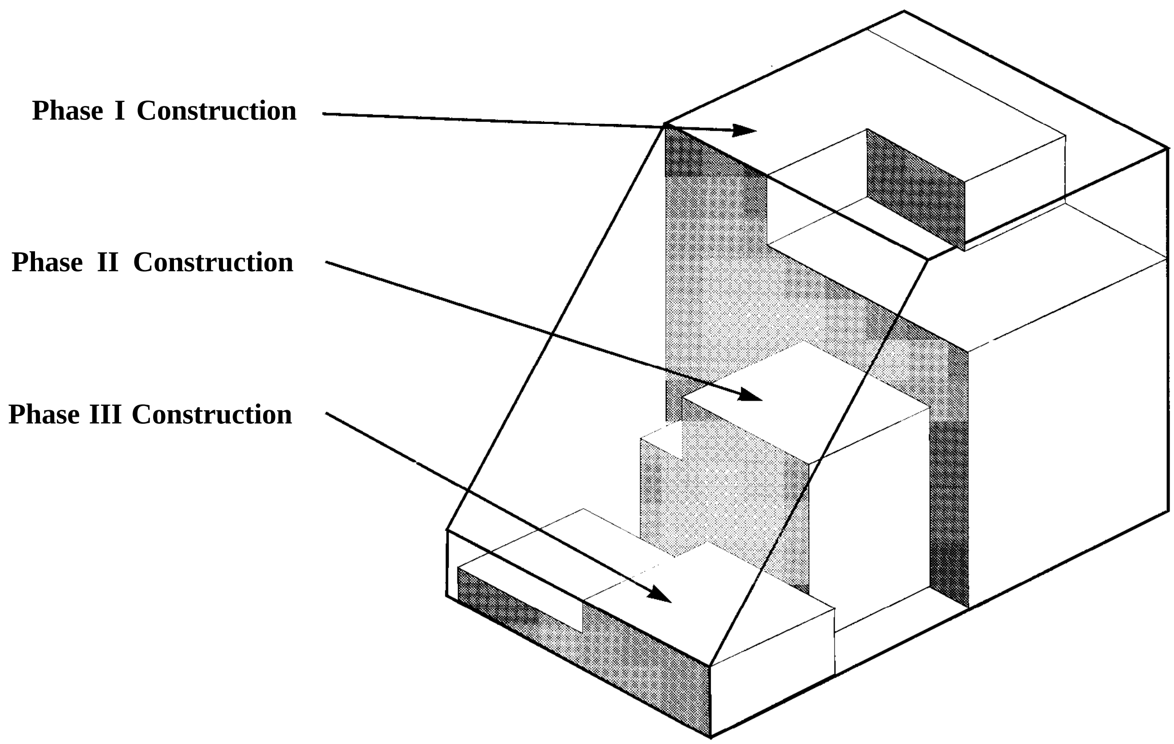


Figure 2-6: Phased Development Within A Single Solar Envelope

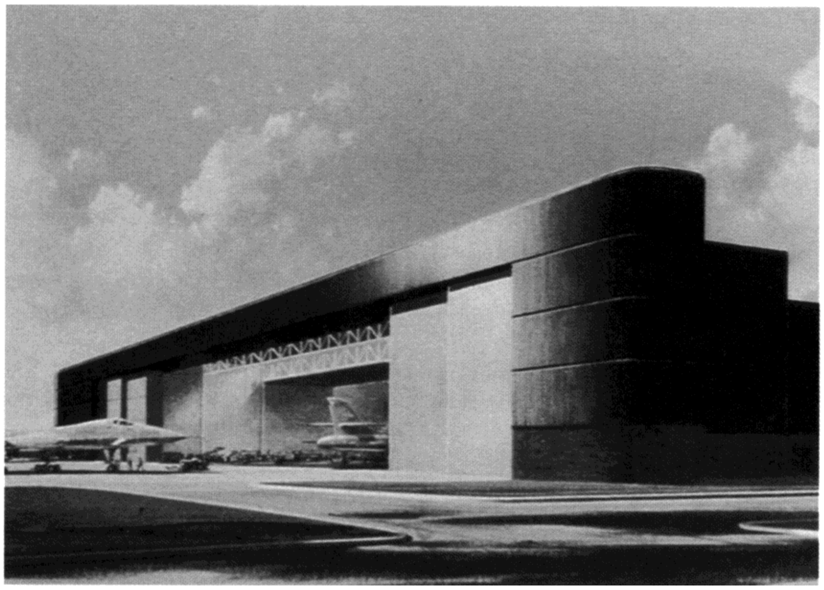


Figure 2-7: Solar Envelope. B-1B Bomber Hangar, Dyess AFB, Texas

Note how the shape of the roof conforms to the solar envelope used to design the building.

Buildings designed within the solar envelope may sometimes be different from current architectural practice. See Figure 2-7. Commercial-type buildings will be lower, where possible, and fill more of the site than do present day buildings. However, the inability to "fit" a solar envelope to a site, or to fit the functional spatial needs of a building to the solar envelope, does not negate the possible use of passive solar systems in the building. Buildings larger than the solar envelope still have access to the sun; however, they block access to surrounding buildings or undeveloped sites.

Site Planning For Passive Cooling

Passive cooling of commercial-type buildings relies on cooling load avoidance and ventilation to reduce dependency on mechanical cooling energy. Site planning for passive cooling should only be done for building types in which cooling is an important requirement and in climates where passive cooling strategies can be effective.

If no passive cooling strategies are appropriate, there is no need to go through a detailed site planning process for passive cooling. In addition, none of the cooling strategies are as effective as either the heating or daylighting strategies. Therefore, site planning for passive cooling may be a secondary consideration.

The most important factors to be considered when planning for a passive cooling system are:

(1) high humidity (60%+) levels
(2) air movement over and through the site
(3) solar gains through glazing

Solar gains (through glazing) and air movement can be handled through a combination of site planning and building design. *High humidity (60% +) levels during occupied hours are a given in many locations that ma.y limit the effective use of passive cooling.*

High Humidity

Humidity is a critical consideration for two reasons. First, high humidity levels can create physical discomfort even if the air temperature is comfortable. One of the purposes of mechanical cooling systems is to maintain a reasonable humidity level inside a building so that it is a comfortable work environment. The second reason that humidity is a critical design element has to do with the energy needed by a mechanical cooling system to remove humidity and moisture from a building. In warm and humid climates, opening a window for an hour may require a constant 24 hours of mechanical cooling to remove the moisture from the building that enters through the window and permeates the structure. Obviously, trading off 1 hour of "free" natural cooling for 24 hours of mechanical cooling is not cost effective.

Keep in mind that the site planning process and the building comprehensive planning process are interactive. For a given building type in a given climate region, one may have already determined that all, some, or none of the recommended cooling strategies are appropriate.

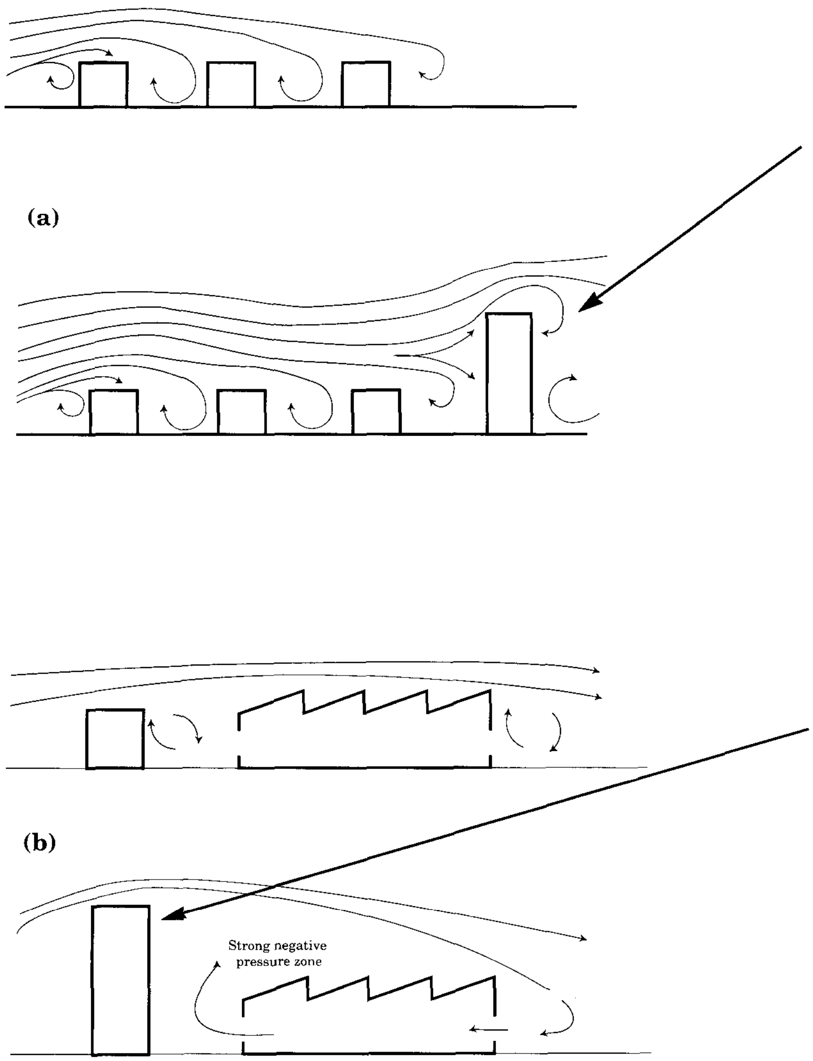
Air Movement

Air movement, in the form of adequate ventilation, is perhaps the most important aspect of passive cooling. Air movement as low as 2.3 miles per hour can reduce the effective air temperature in a building by as much as 5°F.

Site planning for natural ventilation requires knowledge of the prevailing wind directions and speeds, and being able to determine what parts of a site are most favorable for ventilation. Rapid changes in slope, dense vegetation, and tall surrounding buildings can effectively block the prevailing breezes, even though they may be useful to shade the sun from the building. See Figure 2-8 on the following page.

Solar Gains

Solar gains represent an important part of the cooling load of a large building. Reducing solar gains reduces energy use, peak demand, and mechanical cooling equipment size. *When considering a site and trying to judge what the implications of site planning are on solar gains, you should be looking for trees and surrounding buildings that can shade the proposed building.*



Impact of tall buildings on air movement (negative impact)

Impact of tall buildings on air movement (positive impact)

Figure 2-8: Site Considerations For Natural Ventilation

Of the two cooling strategies recommended in this handbook, only one of them, natural ventilation (NVN), requires special site planning consideration. The second, night mechanical ventilation (NMV), is not usually affected by most normal site conditions.

Planning For Daylighting

Site planning for daylighting is different from site planning for solar thermal systems. Daylighting systems use the light from a clear or overcast sky to illuminate the interior of buildings. In most cases, direct sunlight is avoided. Therefore, it is not necessary to protect a specific facade (such as the south or east facade) as in a passive thermal system. *In general, any facade can be used to daylight the interior of a building.* When site planning for daylight, the following simple rules can be applied:

Protect any two opposite facades of a building.

Protect any facade and the roof of the building.

Site planning to "protect" a facade of a building means to keep it free of major obstructions, such as adjacent buildings and large trees. For a daylighted building, this means a space adjacent to the daylighted facade(s) equal to one-half of the building height must be left relatively free of obstructions to ensure that light from the sky can reach the facade(s). This type of daylight access requirement is far less constraining than most requirements for passive heating systems.

For example, if the north and south facades of a building are being used to daylight the building and the building is 40 feet tall, then a space 20 feet wide must be left clear adjacent to the daylighted facades of the building. See Figure 2-9. Similarly, if the site already has a building 60 feet tall, no new buildings should be built within 30 feet of it, assuming the new buildings are less than 60 feet tall. All of the values used in these examples represent minimum protection zones. Good design sense and the scale of the building will also help determine the size and shape of the protected zone. Daylight planning tools are explained in more detail in Volume IV: Passive Solar Design.

Protected Zones:
A) Single Aperture
B) Entire Wall
Dependent upon building height or height of the surrounding buildings.

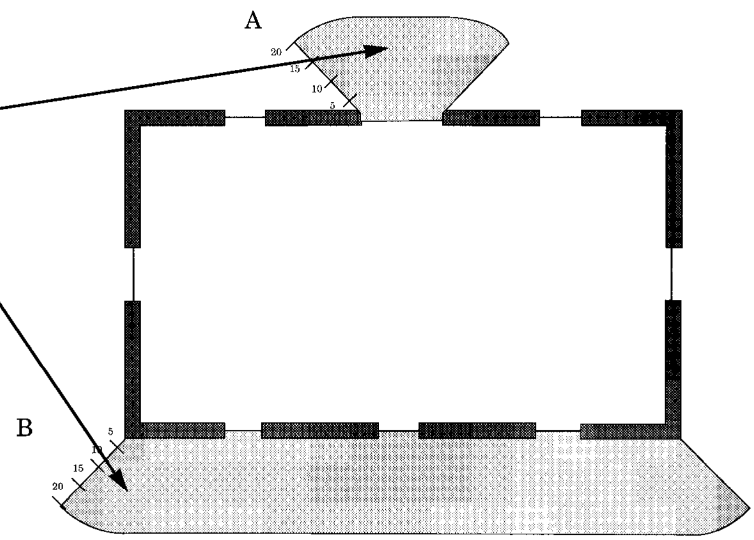


Figure 2-9: Site Planning For Daylighting

No special protection or site planning is needed for toplighting and core daylighting concepts because they typically have an unobstructed view of the sky.

When looking at possible building sites and attempting to determine whether a site is appropriate for a daylit building, it is helpful to have some sense of the proposed building's overall size and volume so that an estimate of the space needed to protect the daylighting facades can be made. If the building is also going to use a passive heating system, the space surrounding the solar envelope must be protected.

Most building sites are adjacent to streets or alleyways. Facades facing these are usually relatively easy to protect. Sites used for low (one-story, low-bay) buildings that are surrounded by tall high-bay buildings should consider the use of toplighting concepts, assuming these concepts are appropriate for the building type and climate.

Daylighting is the most appropriate passive system for all building types in all climate regions. Therefore, site planning for daylighting will be a routine part of the comprehensive building planning process. Fortunately, it is also the easiest system to accommodate.

Building Orientation and Shape

In general, *passive solar buildings which take advantage of the climate are less tolerant to changes in orientation and shape than are climate rejecting buildings.* However, sites do not have to be ideal for passive solar strategies to be appropriate. This does not negate the need for site planning; it just helps keep the site planning process, as applied to large passive solar commercial-type buildings, in its proper perspective. The impact of building orientation on site selection is discussed in more detail in Volume IV: Passive Solar Design.

Internal loads (people, equipment, lighting, and so forth) have a major impact upon the importance of orientation and shape in site planning. The importance of internal loads and their impact on site planning can best be illustrated by looking at several examples. The first is a large administration building located in the northeastern United States. This example building is three stories tall with 10,000 sf of floor area per story. The annual energy costs (1987) are $36,900 per year, or about $1.23 per square foot per year. The building is oriented such that the four facades face north, south, east, and west. The building site plan is illustrated in Figure 2-10 and energy costs are shown in Table 2-l. Both of these are on the following page.

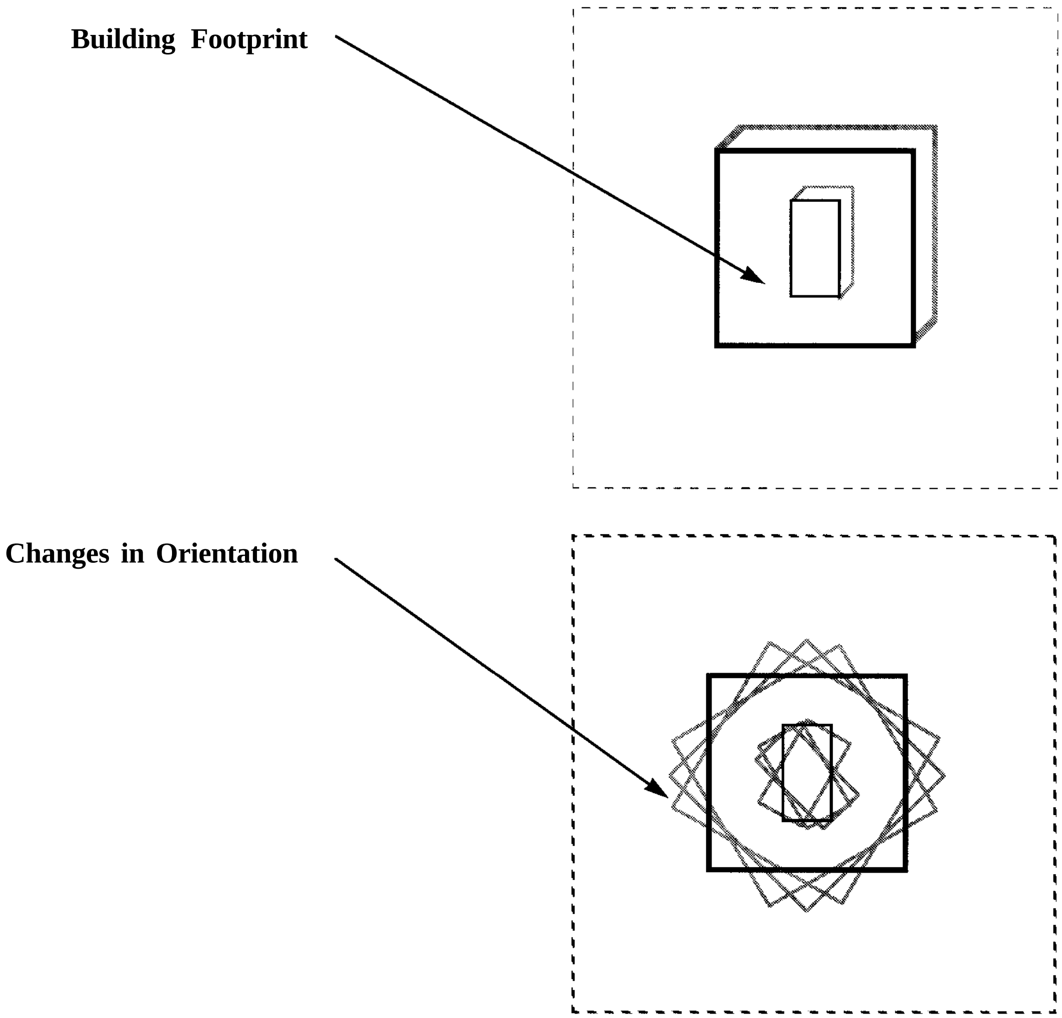


Figure 2-10: Building Used In Orientation Analysis

Energy Savings	Change in Orientation, from South 30° ($/yr)	45° ($/yr)	60° ($/yr)
Heating	29	26	36
Cooling	58	15	0
Lighting	0	0	0
HVAC	53	38	23
Total	**140**	**79**	**59**

Table 2-1: Energy Cost Impact of Changing Orientation

If the building is reoriented such that the primary facades are rotated 30°, 45°, and 60° east of due south, the greatest savings occur when the building is rotated 30°. This results in a $140 per year savings, considerably less than one-half of 1% of the annual energy costs. Rotating the building 45° or 60° results in even smaller savings of $79.00 per year or $59.00 per year, respectively. Clearly, the orientation of this building has little effect on the energy consumption. It is not sensitive to climate, and its energy use is determined by internal loads.

Elongated Shapes

Elongated shapes, such as (b) and (c) in Figure 2-11, are beneficial for all kinds of passive solar buildings, but especially daylighted buildings. *An elongated building can have as much as a 15-25% reduction in energy use over a compact building of the same size, due to its greater ability to use daylight.*

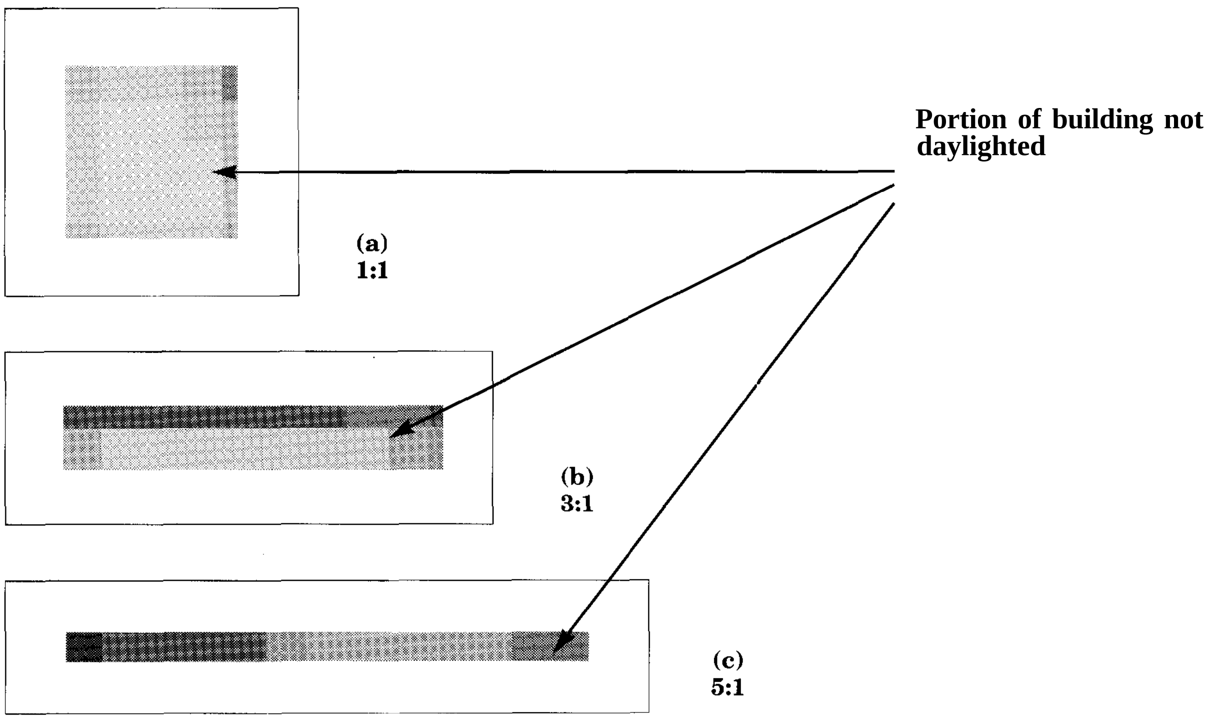


Figure 2-11: Changes in Building Shape (Aspect Ratio)

The buildings in Figure 2-11 are assumed to have the same floor area, occupancy, and internal loads. The building with the 1:1 aspect ratio has a total energy use of 62,000 Btu per square foot per year (Btu/sf-yr). The building with the 3:1 aspect ratio has an energy use of 50,000 Btu/sf-yr and the building with the 5:1 aspect ratio has an energy use of 46,000 Btu/sf-yr. The shape of these buildings has a major impact on energy use. This example is for Denver, Colorado. In most cases it will be easier to daylight a building that is 45 feet deep (5:1 aspect ratio) as opposed to one that is 100 feet deep (1:1 aspect ratio). Energy savings can vary from site to site, depending upon the climate region and the building type.

3.0 Energy and Buildings

Introduction

A total of 18 different commercial-type buildings were analyzed for this handbook. A listing of these building types, in the order they appear in various charts and appendices throughout the handbook, is as follows:

A. *ADMIN, <5000 SF*
B. *ADMIN, >5000 SF*
C. *ADMIN, MULTISTORY*
D. *ADMIN, COMPUTER FACILITY*
E. *DINING FACILITY*
F. *DORMITORY*
G. *FIRE STATION*
H. *INDUSTRIAL FACILITY*
I. *MAINTENANCE, <5000 SF*
J. *MAINTENANCE, HIGH-BAY*
K. *MAINTENANCE, AIR CONDITIONED*
L. *MAINTENANCE, LOW -BAY*
M. *TRAINING, AUDITORIUM*
N. *TRAINING, <5000 SF*
O. *TRAINING, >5000 SF*
P. *TRAINING, MULTISTORY*
Q. *TRAINING, GYMNASIUM*
R. *WAREHOUSE*

< = less than
> = greater than

These building types represent general categories of commercial-type buildings and do not describe specific buildings as found in the USAF building type category codes. For example, a law office, building code 610-112, would be an administrative building, but it could be <5000 sf, >5000 sf, or multistory.

Appendix B lists all of the USAF building-type category codes and the building type they represent. An example of Appendix B is shown in Table 3-1.

Building-Type Code Used In This Handbook

A. ADMIN, <5000 SF
B. ADMIN, >5000 SF
C. ADMIN, MULTISTORY
D. ADMIN, COMPUTER FACILITY
E. DINING FACILITY
F. DORMITORY
G. FIRE STATION
H. INDUSTRIAL FACILITY
I. MAINTENANCE, <5000 SF
J. MAINTENANCE, HIGH-BAY
K. MAINTENANCE, HVAC
L. MAINTENANCE, LOW-BAY
M. TRAINING, AUDITORIUM
N. TRAINING, <5000 SF
O. TRAINING, >5000 SF
P. TRAINING, MULTISTORY
Q. TRAINING, GYMNASIUM
R. WAREHOUSE
NC. NO CURRENT BUILDING TYPE

BUILDING-TYPE CATEGORY CODES — Appendix B

Building Code	USAF Category Code	Building Description
A,B,C,D	100-000	C31 FACILITY
I,J,K,L	111-000	ACFT OPS/MAINT FACILITY
A,B,C	120-000	POL OPS FACILITY
NC	121-111	PETROLEUM OPS BUILDING
NC	121-120	QUICK-TURN FACILITY
G	130-142	FIRE STATION
A,B,C	130-833	CENTRAL SECURITY CONTROL
A,B,C	130-835	SP OPERATIONS
D	131-111	TELECOMM CENTER
D	131-118	DIGITAL FACILITY
D	131-132	SATCOM GROUND TERMINAL
D	131-134	AIR COMM FACILITY
D	131-136	AIR COMM RELAY FACILITY
D	131-138	RECEIVER/TRANSMITTER FACILITY
D	131-139	MICROWAVE RELAY STATION
D	131-143	RADAR FACILITY
NC	134-XXX	REMOTE CONTROL AND GROUND CONTROL FAC
NC	134-375	RAPCON
A,B,C	140-000	COMMAND POST

Table 3-1: Appendix B: Building Type Category Codes

Climate and Buildings

Climates are typically characterized as rainy, sunny, hot, cloudy, humid, cold, and so forth. However, subjective characterizations such as these are inadequate when concerned with building energy performance because: (1) they may not be an indicator of building energy use, and (2) comparing subjective characterizations often leads to error. For example, the following statement would widely be considered true: "It rains more in Seattle than in Boston." Two questions should be asked: (1) is rainfall usually an indicator of building energy use?, and (2) does it really rain more in Seattle than Boston? The answer to both questions is no.

Weather

Climate

Weather represents the momentary condition of the atmosphere with respect to temperature (hot or cold), moisture (wet or dry), wind (calm or storm), sky (clear or cloudy), and pressure (high or low). *Climate* represents the average long-term condition of the atmosphere. Therefore, climate variables are often used to categorize regions that have similar characteristics. In general, different climate variables are used to analyze the energy use of a building depending upon whether the building is residential or nonresidential.

The climate variables that usually influence commercial-type building energy use are:

- *outside air temperature*
- *humidity*
- *solar radiation*

Climate Regions

Climate regions group different geographic locations according to specific sets of climate variables. Climate regions that are indicators of building energy use commonly use heating degree days (HDD) and cooling degree days (CDD) as a way to establish regional boundaries. These have previously been used by the Air Force to establish building climate regions and are discussed in Engineering Technical Letter (ETL): *Energy Budget Figures.*

Engineering Technical Letter (ETL): *Energy Budget Figures*

Heating and cooling degree days are not sufficient to analyze complex commercial-type passive solar buildings for two basic reasons: (1) they do not encompass the latent cooling load (that is, the moisture load) common in nonresidential buildings, caused by a high occupancy density, and (2) they do not include some form of solar (or daylighting) variable to properly analyze passive solar commercial-type buildings.

To determine the energy use in this handbook, four climate variables were used to establish climate regions:

Climate Variables Used to Establish Climate Regions

(1) Heating Degree Days (HDD)
(2) Cooling Degree Days (CDD)
(3) Latent Enthalpy Hours (LEH)
(4) Cloudiness Index (RAD)

Heating Degree Days (HDD)

The number of *Heating Degree Days (HDD)* in a single day is determined by subtracting the average (maximum - minimum) temperature for that day from a reference temperature: 65°F in the United States and 60°F in the United Kingdom. The average temperature must be less than 65°F for heating degree days to occur. Heating is assumed to be required under these conditions. For days when the average temperature is greater than 65°F, see the discussion on Cooling Degree Days (CDD) beginning on the next page.

The number of heating degree days for a month or year is determined by summing all of the daily values for a month or year, respectively. Heating Degree Days (HDD) are considered a good indicator of heating energy use and are often used to determine the total climate related heating energy use of a building located on a given air base or in a given climate region. Cold climates have HDD values for a year in excess of 6,000; extremely cold climates have HDD values greater than 10,000. Warm climates may have HDD values for a year less than 2,000, while tropical climates may have no heating degree days, that is, HDD equals 0. The range of HDD annual values for the free world is from 20,264 (Barrow, Alaska) to 0 (several locales, including such places as Honolulu and Wake Island).

As you might suspect, a wide range of HDD values exists in a country as large as the United States. For example, for air bases located near Fort Wayne, Indiana, Sacramento, California, or Apalachicola, Florida, the HDDs would be 6208, 2842, and 1361, respectively. Each of these locales would have a different need for heating and the appropriate passive solar system to meet a part of this need would therefore be quite different in concept and capacity.

AFM 88-29 Facility Design and Planning: Engineering Weather Data

Information about specific HDDs characteristics of any air base can be found in AFM 88-29 (TM 5-784, NAVFAC P-89) Facility Design and Planning: Engineering Weather Data.

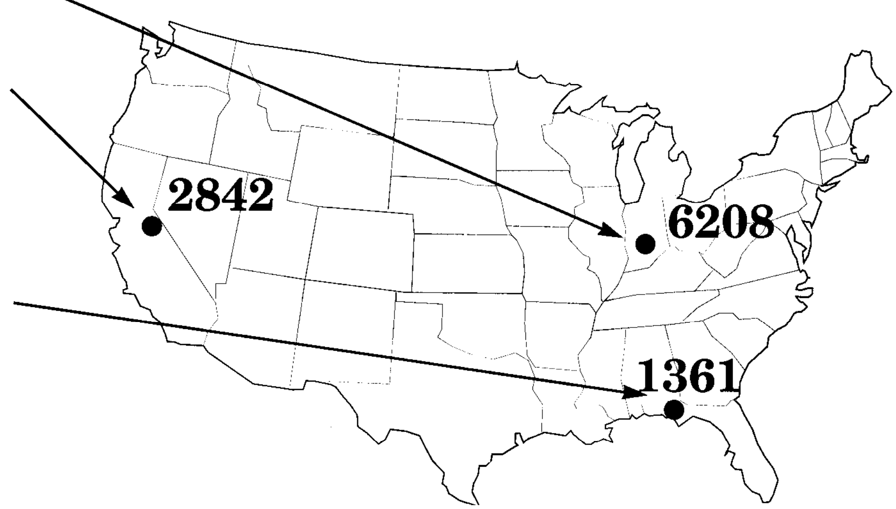


Figure 3-2: Heating Degree Day (HDD) Example

Cooling Degree Days (HDD)

Cooling Degree Days (CDDs) are quite similar to HDDs except they represent a cooling condition rather than a heating condition. Therefore, the number of Cooling Degree Days in a single day is determined by subtracting the reference temperature from the average temperature for the day. Since this is a cooling condition, it is assumed that the average temperature is greater than the reference temperature (65°F).

If an air conditioning system is used to cool a building, then CDDs provide some information about the climate related cooling load. Since the CDD is an indicator of cooling needs, values are low in cold climates, which have little cooling, and high in climates which are warm. The range of CDD annual values for the free world is from 0 (several locales, such as Barrow, Alaska) to 7576 in Khartoum in the Sudan. Fort Wayne, Sacramento, and Apalachicola have values of 747, 1157, and 2662, respectively.

Information about specific CDDs characteristics of any air base can be found in AFM 88-29 (TM 5-784, NAVFAC P-89) Facility Design and Planning: Engineering Weather Data.

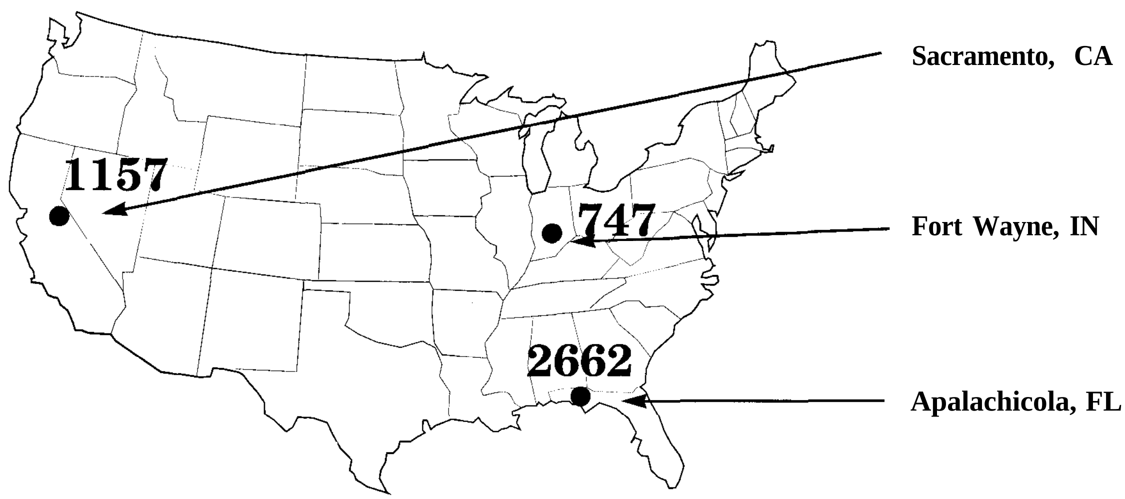


Figure 3-3: Cooling Degree Day (CDD) Example

Latent Enthalpy Hours (LEH)

In commercial-type buildings, or even large residences such as dormitories or apartments, a great deal of energy is expended removing moisture from the building during the cooling season. This type of energy use is more important in large buildings than in detached houses. To determine the impact of this type of energy use, called latent energy use, on buildings, a new climate measure has been developed called a Latent Enthalpy Hour (LEH).

Latent Enthalpy Hours (LEH)

Latent Enthalpy Hours are a measure similar in format to a degree-day. An LEH is defined as the number of hours in which the energy requirement for removing moisture from the air is greater than the energy requirements to maintain the moisture content of the air equal to the upper extremes of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) thermal comfort zone. Arid, high altitude climates (such as Denver, Colorado) may have LEH values less than 100 and tropical climates (such as Honolulu, Hawaii) may have LEH values in excess of 25,000. Because this is a new climate measure, little worldwide data exists to establish the upper boundary For the cities of Fort Wayne, Sacramento, and Apalachicola the LEH values are 4156, 50, and 11052, respectively.

Information about the specific LEH characteristics of a particular air base cannot be found in any current AFM. The concept of an LEH is new and not currently published for USAF locales.

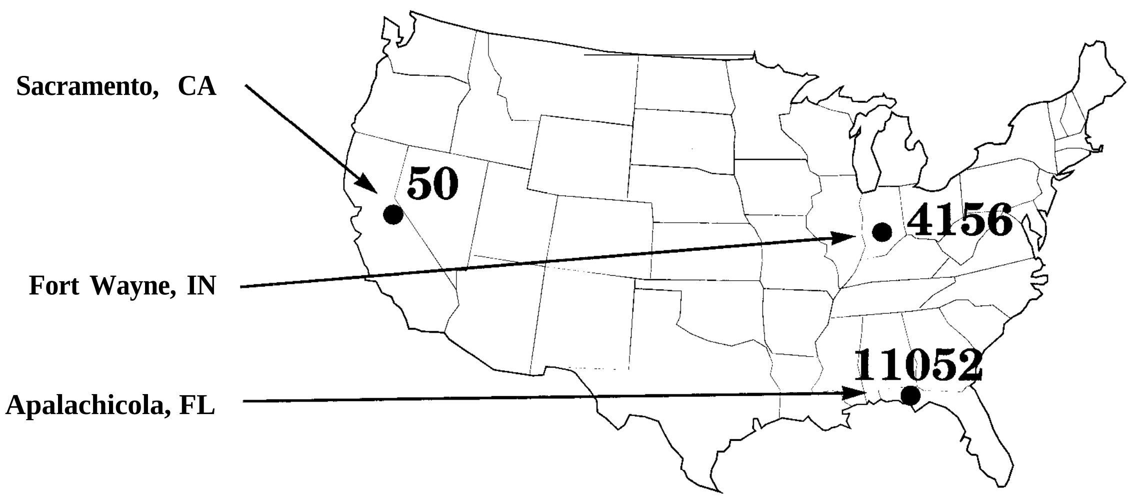


Figure 3-4: Latent Enthalpy Hour (LEH) Example

Radiation and Daylight (RAD) Index

Daylighting and passive solar heating potential are considered through a cloudiness index, also known as a radiation and daylight (RAD) index. The RAD index varies from 0.0 to 1.0 and is defined as the ratio of monthly mean values of daily global horizontal radiation divided by the available radiation at the edge of the atmosphere (called the extraterrestrial radiation constant). The RAD value is a term commonly used to express solar radiation in combination with cloud cover. Knowing something about radiation is critical for the passive thermal strategies, while knowing something about cloud cover is important for analyzing the performance characteristics of daylighting systems.

Although RAD values can range from 0.0 to 1.0, the lowest recorded value is 0.339 in Adak, Alaska, while the highest is 0.713 in Lovelock, Nevada. In Fort Wayne, Sacramento, and Apalachicola, the values are 0.45, 0.64, and 0.52, respectively. Clear locales have values of 0.6 or higher, while cloudy locales have values less than 0.5.

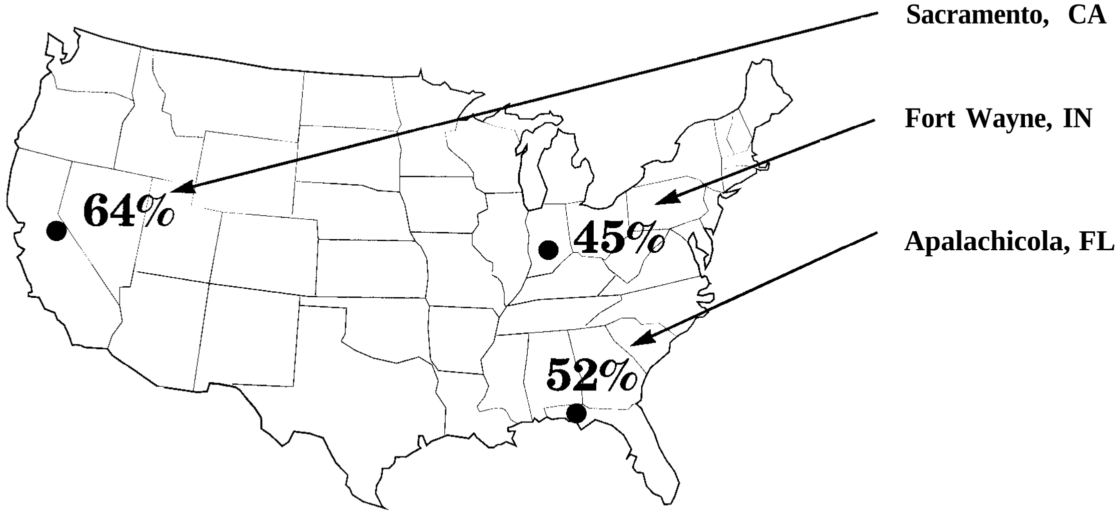


Figure 3-5: Radiation and Daylight (RAD) Example

Information about specific RAD characteristics of any air base cannot currently be found in any Air Force manual. However, data for major cities in the United States can be found in the Insolation Data Manual, published by the Solar Energy Research Institute (SERI), SERI/SP-755-789.

Climate Regions

Using these four climate variables results in 12 climate regions, worldwide, for use in planning commercial-type buildings. These regions are illustrated by the data in Table 3-2 on the following page.

Appendix A: USAF Commercial-Type Building Climate Regions, Worldwide

A set of maps showing each climate region and the air bases in the region can be found in Appendix A.

Energy Responsive Buildings

For the most part, buildings do not use energy, people do. Heating, cooling, lighting, and ventilation adjustments are made in response to people's needs and desires. Those needs vary depending upon the activity being performed and the climate in which the building is located.

Region	HDD (range)	CDD (range)	LEH (range)	RAD (range)	Example (Air Force Base)
1	7,000 to 21,000	0 to 50	0 to 100	0.35 to 0.50	Eielson, AK
2	4,750 to 11,000	500 to 1,250	2,500 to 10,000	0.40 to 0.60	Grissom, IN
3	1,250 to 6,000	0 to 2,250	0 to 3,000	0.40 to 0.70	McChord, WA
4	4,500 to 10,000	0 to 1,500	0 to 1,000	0.50 to 0.70	USAF Academy, CO
5	1,000 to 6,000	250 to 2,250	5,000 to 15,000	0.60 to 0.75	Kirtland, NM
6	1,750 to 5,000	650 to 2,500	10,000 to 20,000	0.45 to 0.60	Arnold, TN
7	1,500 to 4,000	1,750 to 3,500	15,000 to 27,500	0.45 to 0.60	Lackland, TX
8	0	2,500 to 5,000	17,500 to 30,000	0.40 to 0.60	Hickam, HI
9	1,500 to 4,000	0 to 500	0 to 500	0.40 to 0.55	Croughton, UK
10	4,000 to 7,500	0 to 1,000	500 to 2,000	0.40 to 0.55	Ramstein, FRG
11	2,000 to 6,500	1,000 to 2,500	1,000 to 7,500	0.45 to 0.60	Comiso, IT
12	0 to 1,750	2,250 to 4,500	15,000 to 27,500	0.45 to 0.55	Tyndall, FL

Table 3-2: USAF Commercial-Type Building Climate Regions, Worldwide

Energy End Use Categories

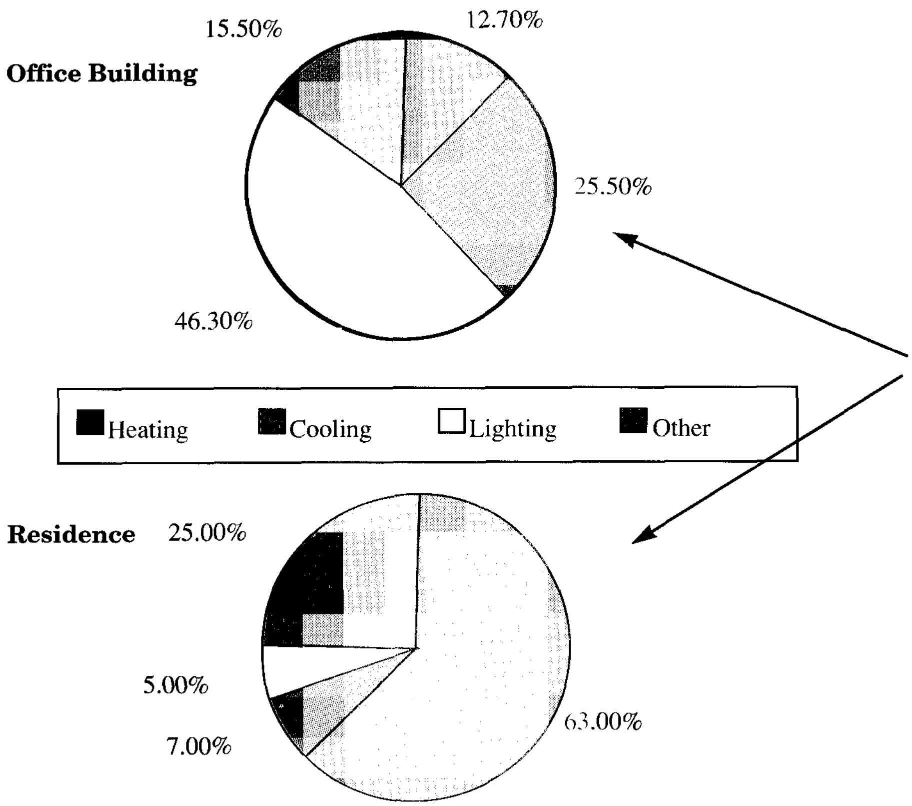
Energy use is usually divided into several energy end use components for detailed analysis. In this handbook, energy end use is divided into the following categories:

(1) *heating*
(2) *cooling*
(3) *lighting*
(4) *ventilation*
(5) *process loads*

Energy Use Per Unit Of Floor Area: Btu/sf-yr

Energy use by each end use category can be measured in terms of *total energy,* such as 450,000,000 Btu's per year, or it can be considered in terms of *energy use per unit of floor area,* such as 45,000 Btu's per square foot per year. Throughout this handbook, energy use per unit of area will be used as a measure of energy use in different building types, sizes, and climate regions.

For a passive solar system to be effective in a commercial-type building, it must address an actual energy need of the building. Actual energy needs may vary considerably from preconceived notions about how buildings use energy. Figure 3-6 illustrates a comparison of the energy use for a house and an administration building, each about 2,000 square feet in size, located in Denver, Colorado (Climate Region 4). The differences are quite striking; note the differences in heating and lighting energy use.



Compare Heating and Lighting Energy Use

Figure 3-6: Commercial vs. Residential Building Energy Use, Denver, CO

An appropriate passive solar system for the house will be quite different from the appropriate passive solar solutions for the administration building of the same size.

Commercial-type buildings range in size from small (1,000 sf) to quite large (100,000 sf) and range in use from administration facilities to warehouses, from dormitories to fire stations. Therefore, it is not surprising that the range of possible solutions to the energy needs of these different building types will also be quite varied. In buildings of such varied size and use, the application of solar technologies is termed "making the building climate adapted," that is, making the building more responsive to the energy savings associated with using the climate to best advantage. *Climate adapting a building can include such diverse concepts as shading the building from the sun, using the sun for heat and light, or using the prevailing breezes to cool the building.* Any or all of these solutions might be appropriate depending upon the building type, its size, and climate region.

Climate Adapted Buildings

Climate Rejecting Buildings

This handbook encourages the planning, design, and construction of *climate adapted* commercial-type buildings and discourages the development of *climate rejecting* buildings. A climate rejecting building isolates the building energy use from interaction with the surrounding environment. It uses mechanical systems to heat, cool, and light the building, regardless of the possibilities of using the environmental conditions to best advantage.

The concepts of climate adapted or climate rejecting buildings represent the extremes of possible solutions: one uses the climate, while the other isolates the building from it. In reality, solutions to real building energy problems lie somewhere

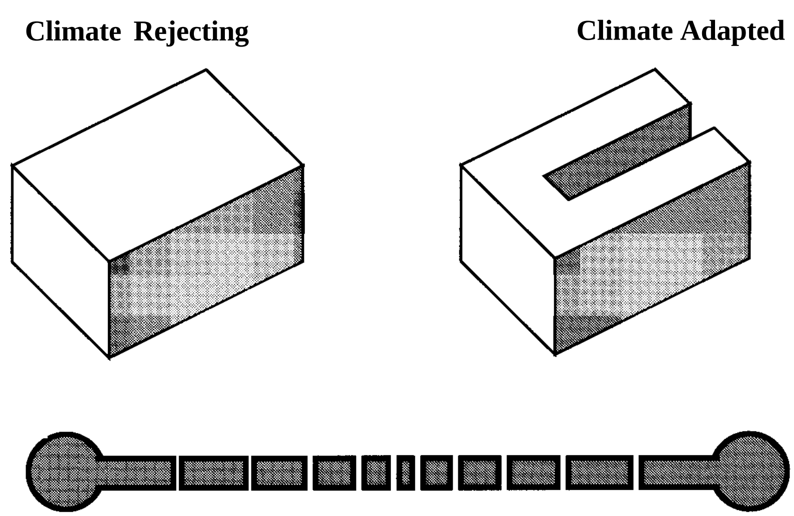


Figure 3-7: Climate Rejecting vs. Climate Adapted

Energy use and energy economics may make some passive concepts attractive and others impractical when considered within the constraints of a project's needs, fuel availability, and budgetary requirements. Therefore, some compromise is expected, and the planner or designer should keep in mind that the final solution may be a combination of climate adapted and rejecting concepts.

Two primary characteristics of each building type have a major impact upon the overall energy use:

(1) envelope loads
(2) internal loads

Envelope Loads

Envelope loads are associated with energy transfer through the building shell. In some building types, such as single family detached housing or a warehouse, envelope loads are the single dominant energy transfer.

Internal Loads

Internal loads can be divided into two subcategories: (1) those due to occupancy, and (2) those due to lighting and process energy use. *It is primarily the variation in internal load characteristics that determines which passive solar systems will be most effective in commercial-type buildings.*

Each building type has specific occupancy characteristics that can be expressed in terms of people loads, period of operation, hours of operation, and schedules. The people load is an estimate of the number of people in the building. This varies considerably from one building type to another. For example, an administration building is assumed to house one person per 65 square feet, while a warehouse typically has one person per 4,000 square feet. The period of operation is a designation of whether the building is open during the daytime, at night, or both. An administration building is usually open only during the day, while a warehouse may be used day and night. The hours of operation are the average number of hours per day that the building is occupied, while the schedule is the number of days per week the building is occupied. An administration building is typically occupied 10 hours a day, 5 days a week, while a warehouse may be occupied 24 hours a day, 7 days a week.

Energy use associated with lighting and process loads (coffee pots, vending machines, etc.) make up the second major internal load category. In most commercial-type buildings, these loads are assumed to be continuous during the occupied period of each day. For example, a continuous lighting load is one in which the electric lights are turned on in the morning and off at night and stay on all day long. It is the continuous nature of these internal loads that make them so critical to the overall energy use and costs of the building.

A fair amount of variation exists in these internal load characteristics; however, each of the building types typically functions within a particular range of occupancy and schedule. Those commonly found in Air Force commercial-type buildings are shown in Table 3-3.

		Operational Characteristics Day-Night	Hr/Day	Days/Week	Internal Load Light (w/sf)	Process (w/sf)	Thermal System
A.	ADMIN, <5000 SF	D	10	5	2.5	0.5	HVAC
B.	ADMIN, >5000 SF	D	10	5	2.5	0.5	HVAC
C.	ADMIN, MULTISTORY	D	10	5	2.5	0.5	HVAC
D.	ADMIN, COMPUTER FACILITY	D	10	5	2.5	2.0	HVAC
E.	DINING FACILITY	D+N	14	7	1.3	2.8	HVAC
F.	DORMITORY	D+N	24	7	1.3	0.5	HVAC
G.	FIRE STATION	D+N	24	7	1.3	0.5	HVAC
H.	INDUSTRIAL FACILITY	D	10	5	1.7	2.0	HV
I.	MAINTENANCE, <5000 SF	D	10	5	1.0	0.5	HV
J.	MAINTENANCE, HIGH-BAY	D	10	5	2.1	1.0	HV
K.	MAINTENANCE, AIR COND	D	10	5	1.7	1.0	HVAC
L.	MAINTENANCE, LOW-BAY	D	10	5	1.7	1.0	HV
M.	TRAINING, AUDITORIUM	D+N	8	7	1.3	0.5	HVAC
N.	TRAINING, <5000 SF	D	10	5	2.5	0.5	HVAC
O.	TRAINING, >5000 SF	D	10	5	2.5	0.5	HVAC
P.	TRAINING, MULTISTORY	D	10	5	2.5	0.5	HVAC
Q.	TRAINING, GYMNASIUM	D	10	7	1.7	0.0	HV
R.	WAREHOUSE	D	10	7	1.7	0.0	HV

Table 3-3: Internal Load Variables For Each Building Type

The interrelationship between envelope and internal loads is critical to understanding which passive concepts are appropriate for a particular building type and climate region. Figure 3-8 illustrates the importance of envelope or internal loads, as a fraction of total energy use, for the different climate regions. Figure 3-8 shows that as internal loads increase, there is a corresponding decrease in the importance of envelope loads.

When the envelope load is a larger fraction of the total energy use than the internal loads, the building is usually dominated by heating energy use. When the internal load is larger than the envelope load, the building is typically dominated by lighting and cooling energy use. See Figure 3-8 on the following page.

Buildings that are clearly envelope dominated can use passive heating concepts to best advantage. Buildings that are clearly internal load dominated can use daylighting strategies to best advantage. Buildings in which the envelope and internal loads are close to each other are very complex to analyze and may be able to use heating, cooling, and daylighting strategies to advantage.

None of the commercial-type buildings analyzed for this handbook are clearly envelope dominated. Some, such as warehouses or dormitories, have an almost equal balance between envelope and internal loads. Others, such as administration buildings and dining facilities, are dominated by their internal loads. This means that many of the traditional passive heating concepts associated with the phrase “passive solar” are not going to be effective in these buildings. Recognizing that commercial-type buildings are complex and respond differently to the environment than do more simple buildings (such as houses), makes it easier to find the appropriate passive solution to the energy needs of the building.

Envelope vs. Internal Loads

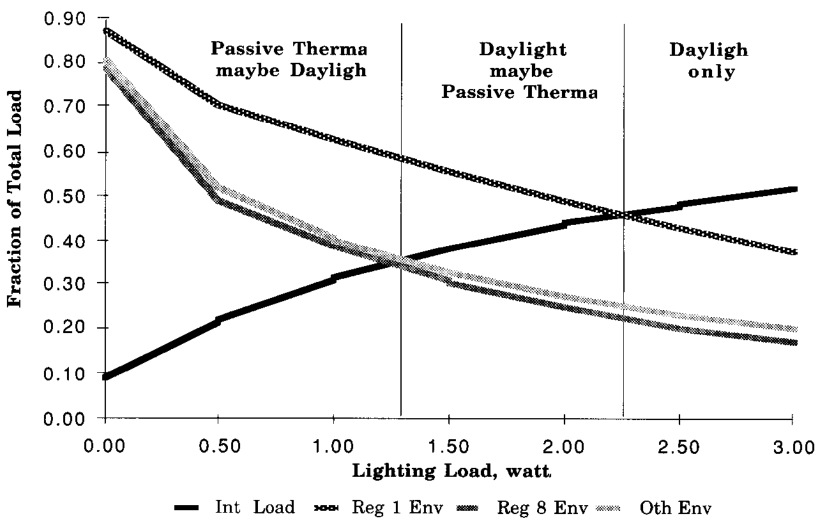


Figure 3-8: Internal vs. Envelope Loads

Energy Costs

Energy costs represent another way to consider the impact of energy use in buildings. The impact of different fuels used for heating (such as electricity, natural gas, or fuel oil) as well as the costs of electricity for cooling and lighting a building can provide another important clue as to what kinds of passive concepts are most effective in commercial-type buildings.

In this handbook, energy costs are considered in terms of costs (in dollars) per square foot of building area per year. Thus, an energy cost of $1.00/sf-yr in a 10,000 sf building would mean that the building costs $10,000 per year to heat, cool, light, and so forth. Using a cost per unit of area measure allows one to compare the energy costs of different building types or different sizes of the same building type.

In large nonresidential buildings, no direct link between energy use and energy costs exists. Put another way, saving energy is not directly proportional to saving energy costs. This is a startling revelation to many people who are not familiar with energy costs in commercial-type buildings. For example, Figure 3-9 illustrates the energy use and energy cost for a 2,000 square foot administration building in Climate Region 4. Although heating is 13% of the energy use, it is only 4% of the costs. Cooling, which was 26% of the energy use, is 44% of the energy costs.

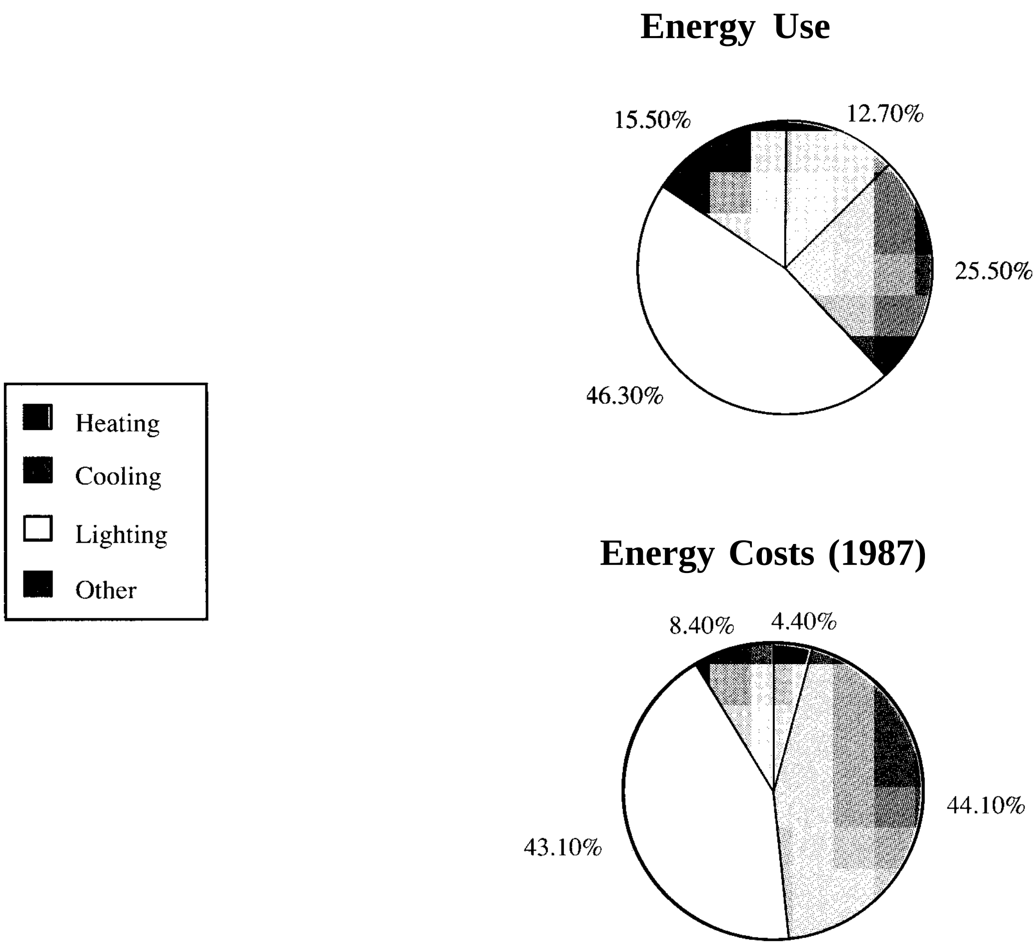


Figure 3-9: Energy Use vs. Energy Costs in a 2,000 SF Administration Building, Climate Region 4

In general, no direct link exists between energy use and energy costs because of the way different fuels are priced. Fuels that are predominantly used for heating, such as natural gas, fuel oil, or diesel oil, are priced on a consumption basis; fuel used is fuel paid for. Electricity, on the other hand, is priced on a consumption and demand basis; that is, electricity costs are based upon use (consumption) and the rate of use (demand). A charge for the rate of use, more commonly called peak demand charges, adds another dimension to the overall energy cost of a building.

Peak demand charges can be found in more than 80% of all utility company rate schedules in the United States, and close to 100% of all utilities outside the United States. Peak demand charges represent the costs associated with building and maintaining generation plants, distribution networks, and transformers used by utilities to provide electricity.

The impact of peak demand charges varies greatly from one utility to another. For example, Table 3-4 illustrates the energy use and cost (1987) for a 60,000 sf administration building located near Denver, Colorado. Based upon the local utility rate structure, it can be seen that peak demand represents $0.89 per square foot of the total $1.21 per square foot energy costs. Ignoring the impact of peak demand on costs would be overlooking 74% of the total energy costs of the building.

	Consumption		Demand	Total
Energy End Use Category	Elec ($sf-yr)	Gas ($/sf-yr)	($/sf-yr)	($/sf-yr)
Heating		0.0070		0.0070
Cooling	0.0501		0.2791	0.3291
Lighting	0.2374		0.5708	0.8082
Other	0.0138	0.0047	0.0425	0.0655
TOTAL	0.03015	0.0117	0.8924	1.2055

Table 3-4: Annual Energy Costs (1987) For A 60,000 SF Administration Building, Climate Region 4

A good analogy for understanding the importance of peak demand charges is to consider the costs of owning a car. There are two types of costs associated with owning a car: variable costs and fixed costs. Variable costs include gasoline, oil, tires, and so forth, and vary depending upon the amount of usage the car gets. Fixed costs include such things as insurance and loan payments. These costs occur regardless of whether the car is driven or not. Costs associated with producing electricity can vary from month to month for a utility and are reflected in the cost per kWh of electricity purchased. The fixed costs of providing electricity service associated with electricity production are billed to the customer as demand or capacity charges.

How the peak demand for a building is determined can also vary from one utility to another, but, in general, it is based upon the largest need for electricity during a billing period. Thus, peak demand represents the maximum rate of energy use, and peak demand costs, in dollars per kW, represent a charge for the largest (peak) rate of energy use.

The rate of electrical energy use, in kW, is different than the consumption of electricity, in kWh. An analogy for understanding the concept of peak demand as representative of the rate of energy use is to consider using either a fire hose or a garden hose to fill a 5-gallon water bucket. Using either hose, the total quantity of water in the bucket is eventually 5 gallons, that is, the water "consumed" is 5 gallons. However, the "rate of consumption" for a $^3/_4$-inch garden hose is quite a bit less than the rate for a 3-inch fire hose. Thus, for either hose, the total quantity of water in the bucket is 5 gallons, however, the fire hose fills the bucket much faster than the garden hose.

Suppose two identical buildings consume 20,000 kWh of electricity in a month. However, one building has a peak demand of 5 kW and the other a peak demand of 500 kW. It is clear that the utility has to be able to maintain a power plant that has the capacity to produce 505 kW of electricity to be able to meet the needs of the two buildings, regardless of the fact that they are both consuming 20,000 kWh. If the utility rate structure is $0.10 per kWh for electricity and $10.00 per kW for peak demand, then the building with a 5 kW peak demand has a monthly utility bill of $2,050. The building with the 500 kW peak demand has a utility bill of $7,000. Although the two buildings consume the same quantity of energy (20,000 kWh), their monthly bills are quite different.

Save energy and energy cost

A properly designed passive solar building is one that saves both energy use and energy costs. However, a primary purpose of this handbook is to save energy costs. The possibility of saving energy costs without reducing energy use or by increasing energy use will also be considered. Saving energy costs without reducing energy use can occur if the peak demand for a building can be reduced. For example, in the previous example, suppose the demand were reduced from 500 kW to 250 kW. Then the energy costs would be reduced from $7,000 to $4,500 even if there is no reduction in energy usage (it is still 20,000 kWh).

Saving energy costs by increasing energy use can occur in two ways. First, by decreasing the peak demand but simultaneously increasing the consumption of electricity, it is possible to reduce the overall cost of energy in a building. For example, suppose the 500 kW building could have the peak demand reduced to 100 kW if it "costs" an additional 10,000 kWh. Thus, the total electricity costs would be based upon 30,000 kWh and 100 kW. Total electricity costs would be $4,000, down from $7,000.

The second way to reduce energy costs by increasing energy use is to switch fuel, that is, change from a more costly fuel to a less expensive fuel. A good example of this is to use natural gas instead of electricity to heat a building. Even though natural gas heating is less efficient than electric heating, the cost differential associated with the two fuels usually makes it cheaper to use natural gas rather than electricity. Although special circumstances may make it difficult or impossible to trade off one fuel for another, it is a viable alternative that should be considered during the comprehensive planning process.

Suggested Additional Reading 4.0

Introduction

The following are a selection of books and Air Force documents that are suggested as additional reading to better understand passive solar energy systems. The books range from nontechnical to engineering texts.

Daylighting and Lighting

Concepts and Practice of Architectural Daylighting, Fuller Moore, New York: Van Nostrand Reinhold, 1985. ISBN 0-442-26439-9.

Daylighting Design and Analysis, Claude L. Robbins, New York: Van Nostrand Reinhold, 1986. ISBN 0-442-27949-3.

Illuminating Engineering Society Handbook, Volumes 1 and 2, Editor: J. Kaufman, New York: Illuminating Engineering Society, 1985.

Illumination Engineering: From Edison's Lamp to the Laser, Joseph B. Murdoch, New York: Macmillan, 1985. ISBN 0-02-948580-0.

Interior Lighting for Environmental Designers, James L. Nuckolls, New York: Wiley-Interscience, 1976. ISBN 0-471-65163-X.

The Lighting of Buildings, Hopkinson and Kay, London: Faber and Faber. 1972.

Recommended Practice of Daylighting, Illuminating Engineering Society, New York: Illuminating Engineering Society, 1979. PR-5.

Sunlight as Formgiver for Architecture, William Lam, New York: Van Nostrand Reinhold. 1986. ISBN 0-442-25941-7.

Passive Solar Thermal

The Passive Solar Energy Book (Expanded Professional Edition), Edward Mazria, Emmaus, PA: Rodale Press, 1979. ISBN 0-87857-238-4.

Passive Solar Heating Analysis, American Society of Heating, Refrigerating and Air Conditioning Engineers, New York: ASHRAE, 1985.

The Solar Cooling Handbook, Editor: Harry Miller, Proceedings of the Passive Cooling Workshop, Amherst MA, 1981.

Solar Envelope Concepts: Moderate Density Building Applications, Knowles and Berry, U.S. Department of Energy, Golden, CO: Solar Energy Research Institute, 1980. SERI/SP-98155-1.

Buildings and Energy

ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, New York: ASHRAE. 1985.

ASHRAE Systems Handbook, American Society of Heating, Refrigerating and Air Conditioning Engineers, New York: ASHRAE, 1984.

The Design of Energy Responsive Commercial Buildings, Ternoey, Bickle, Robbins, Busch, and McCord, New York: Wiley and Sons, 1985. ISBN 0-471-80463-0.

Mechanical and Electrical Equipment For Buildings, 7th Edition, McGuinness, Stein, and Reynolds, New York: Wiley and Sons, 1985. ISBN 0-471-58432-0.

Small Office Building Handbook, Burt-Hill-Kosar-Rittelmann Associates, New York: Van Nostrand Reinhold, 1985. ISBN 0-442-21126-0.

Sun, Wind, and Light: Architectural Design Strategies, G. Brown, New York: Wiley and Sons, 1985. ISBN 0-471-82063-6.

United States Air Force Documents

Base Comprehensive Planning, *Land Use Planning Bulletin:* HQ USAF/LEEVX.

Engineering Weather Data, AFM 88-29.

Engineering Technical Letter (ETL): *Energy Efficient Equipment.*

Engineering Technical Letter (ETL): *Normal Passive Solar Applications.*

Engineering Technical Letter (ETL): *Unique Passive Solar Applications.*

Engineering Technical Letter (ETL): *Solar Applications in Medical Facilities.*

Engineering Technical Letter (ETL): *Computer Energy Analysis.*

Engineering Technical Letter (ETL): *Energy Budget Figures.*

Engineering Technical Letter (ETL): *Energy Management and Control Systems* (EMCS).

Engineering Technical Letter (ETL): *Solar Applications.*

Installation Design, AFM 88-43.

Other Sources of Information

Insolation Data Manual, Knapp, Stoffel, and Whitaker. U.S. Department of Energy, Golden, CO: Solar Energy Research Institute, 1981. SERI/SP-755-789.

Renewable Energy Technology Handbook for Military Engineers, Golden CO: Solar Energy Research Institute, 1981.

Solar Energy Dictionary, V. Hunt, New York: Industrial Press, 1982. ISBN 0-8311-1139-9.

5.0 Glossary of Terms

A

Altitude (solar). One of two angles used to specify the sun's position at any given time; altitude is the angle of the sun above the horizon. It is measured positively from the horizon to the zenith, from 0 to 90 degrees. See also *azimuth (solar)* and *zenith.*

Ambient. The surrounding atmosphere; encompassing on all sides. The environment surrounding a building. See also *ambient air, ambient lighting,* and *ambient temperature.*

Ambient air. The outdoor air in the vicinity of a building.

Ambient lighting. Interior light, natural or man made, throughout an area that produces general illumination. See also *task lighting.*

Ambient temperature. The natural temperature of the atmosphere surrounding a particular location or building.

Aperture. The rough opening in the surface of a building that admits heat, air, and light. The aperture opening may or may not account for framing or glazing.

ASHRAE. Acronym for the American Society of Heating, Refrigerating and Air Conditioning Engineers.

Aspect ratio. The ratio of the length to width of a building.

Atrium (pl. atria) (ATR). An interior, covered, open area in the center of a building that can be used for passive solar heating, cooling, and daylighting. One of five daylighting strategies analyzed in the handbook. See also *monitor aperture, sawtooth aperture, skylight,* and *windows.*

Auxiliary energy. Purchased energy to operate heating, cooling, and lighting systems plus the energy required to operate blowers, pumps, and other devices.

Auxiliary energy (sub)system. Equipment using conventional energy to supplement the output of the passive heating, cooling, or daylighting system.

Azimuth (solar). One of two angles used to specify the sun's position at any given time; azimuth is the angle between south and the point on the horizon directly below the sun. South is 0 degrees and the angles east or west of due south are described as 0 to 180 degrees (-0 to -180° if west). See also *altitude.*

B

Base load. The minimum amount of electrical power that a utility must supply in a 24-hour period. See also *peak load* and *peak demand.*

Beam daylighting. The intentional use of the direct (sunlight) component of daylight to illuminate a building.

Billing demand. The peak electrical demand, measured by a utility, on which peak demand charges are based. See *metered demand.*

Btu. See *British thermal unit.*

British thermal unit (Btu). The amount of heat required to raise the temperature of one pound of water one degree F under standard conditions of pressure and temperature.

C

CBD. See *Commerce Business Daily.*

CDD. See *Cooling Degree Day.*

Clear sky (daylighting). A reference cloudless sky condition used in daylighting calculations. See also *overcast sky.*

Clear sky (weather). A sky that has less than 30% cloud cover; the sun is unobstructed. See also *cloudy sky, partly cloudy sky,* and *overcast sky.*

Clerestory. An aperture in a wall above one's line of vision (7 feet) used for light, heat gain, and ventilation. Used in the Handbook to describe a daylighting aperture.

Climate. Prevailing or average weather conditions of a geographic region or city, as shown by meteorological changes over a period of years.

Climate adapted building. A building that makes use of the natural environment, as much as possible, for heating, cooling, and lighting, to help reduce auxiliary energy usage. See also *climate rejecting building.*

Climate rejecting building. A building that relies totally on mechanical means for heating, cooling, and lighting. There is no use of the natural environment to help reduce auxiliary energy use. See also *climate adapted building.*

Cloudiness index (RAD). The fraction of horizontal incoming solar radiation transmitted through the atmosphere. It is a measure of cloudiness and other atmospheric conditions which attenuate solar radiation at a given location.

Cloudy sky (weather). A sky having between 30 and 70% cloud cover, with the sun obstructed.

Coincident peak demand. The largest peak demand, occurring simultaneously, from all electrical uses in a building. Often used to determine the billing demand for a building.

Collection. The process of trapping energy for use as heat (passive solar thermal system) or light (daylighting system).

Commerce Business Daily. A daily publication of the U.S. Department of Commerce listing all goods and services to be purchased by the U.S. government.

Commercial-type buildings. A term used by the United States Air Force to describe all nonresidential, institutional, and industrial buildings.

Control. That part of a passive solar thermal or daylighting system used to manage temperatures, air movement, or the quantity of light in a space.

Conventional building. The name given a building that does not use any passive solar strategies to reduce energy use and energy costs.

Cooling Degree Day (CDD). A measure of the need for cooling. The number of cooling degree days in a single day is determined by subtracting the reference temperature from the average temperature for the day. See *Heating Degree Day.*

D

D+S. See *direct gain plus storage.*

Daylight. The light from the sun and (clear or overcast) sky used to illuminate the interior of buildings.

Daylighting. The use of natural lighting from the sun and (clear or overcast) sky as a supplement to electric lighting in buildings.

DD Form 1391. The form used by the Department of Defense entitled "Military Construction Project Data" to specify a facility requirement, including estimated costs.

Degree Day. See *heating degree day* and *cooling degree day.*

Design Instructions (DIs). Provide authority to the design manager, through the AFRCE, to initiate the facility design process.

DG. See *direct gain.*

DI's. See *design instructions.*

Direct gain (DG). A passive system where the sun heats the floor or walls of the building directly, through appropriately placed apertures. The building does not have any additional internal mass beyond normal construction practices. One of four passive heating strategies analyzed in the handbook. See *direct gain plus storage, indirect gain,* and *sunspace.*

Direct gain plus storage (D+S). A passive system where the sun heats the floor or walls of the building directly through appropriately placed apertures. The building has additional internal mass beyond normal construction practices for a given building type. One of four passive heating strategies analyzed in the handbook. See *direct gain*, *indirect gain*, and *sunspace*.

Distribution. Moving heat, air, and daylight to where they are needed in a building.

E

Energy budget. The quantity of energy, usually in Btu's per square-foot per year (Btu/sf-yr), allocated to a building or end use category.

Energy end use. The amount of energy used by a specific end use category of the building. In this handbook, end use categories are heating, cooling, lighting, process, and ventilation.

Envelope loads. The heating and cooling energy use associated with the energy gains and losses through the shell (envelope) of the building.

Erg. The CGS (centimeter-gram-second) unit of work equal to the work done by a force of one dyne acting through a distance of one centimeter. Equal to approximately 1,050 Btu's.

F

Facade. The front of a building; any face of a building given special architectural consideration.

fc. See *footcandle.*

Fenestration. Arrangements, proportions, and design of windows in a building.

Footcandle (fc). The non-SI unit of measure of illuminance. One footcandle is equal to one lumen per square foot. See *illuminance* and *lux*.

Form 254 (Standard Form 254). U.S. government form entitled "Architect-Engineer and Related Services Questionnaire" used to record the experience and capabilities of architectural and engineering firms.

Form 255 (Standard Form 255). U.S. government form entitled "Architect-Engineer and Related Services Questionnaire for Specific Project" used to record the experience and capabilities of architectural and engineering firms on a specific project.

G

Glare. The sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort, or loss of visual performance and visibility.

Greenhouse. See *sunspace*.

H

HDD. See *Heating Degree Day*.

Heat storage. See *storage*.

Heating Degree Day (HDD). A measure of the need for heating. The number of heating degree days in a single day is determined by subtracting the average temperature from the reference temperature for the day.

Heating-Ventilating system (HV). A mechanical system designed for heating and ventilating only; no mechanical cooling capability. This type of system is commonly used in industrial and maintenance facilities.

Heating-Ventilating-Air Conditioning system (HVAC). A mechanical system designed for heating, ventilating, and air conditioning a building. For example, this type of system is commonly used in administration facilities.

HV. See *heating-ventilating system.*

HVAC. See *heating-ventilating-air conditioning system.*

I

IES. Acronym for the Illuminating Engineering Society.

Illuminance. The density of the luminous flux incident on a surface, in lumens per unit of area. See *footcandle* and *lux*.

Illumination. The act of being illuminated.

IND. See *indirect gain solar system.*

Indirect gain (IND) solar system. Passive heating system in which the collection and storage components are part of the same building element, wall or roof. The sunlight passes through the collector aperture to heat the storage component. Conduction through the storage component brings the heat to the inside surface where it is distributed to the space by radiation and convection. One of four passive heating strategies analyzed in the handbook. See also *direct gain, direct gain plus storage,* and *sunspace.*

Internal gains. Combined heat release from all heat sources (including lighting, people, and process loads) in a building other than its heating system.

Internal loads. The heating, cooling, lighting, ventilation, and process loads of a building associated with the interior spaces. See *envelope loads* and *internal gains.*

Irradiance. The density of the radiant flux incident on a surface, in Btu's per square foot or watts per square meter.

Isolated solar system. See *sunspace.*

J

Joule (J). The absolute SI unit of work or energy that equals 10^7 ergs. See *erg.*

K

Kilowatt (kW). A unit of power equal to 1,000 watts. The rate of flow of energy into a building. See *peak demand.*

Kilowatt-hour (kWh). The time rate of flow of electricity in one hour. Equal to 3,413 Btu's.

kW. See *kilowatt.*

kWh. See *kilowatt-hour.*

L

Latent Enthalpy Hour (LEH). The number of hours in which the energy requirement for removing moisture from the air is greater than that for the upper extremes of the ASHRAE thermal comfort zone.

LEH. See *Latent Enthalpy Hour.*

Light. Radiant energy that is capable of exciting the retina of the eye and producing visual sensation. Radiation in the spectrum of 380 nanometers to 780 nanometers, where a nanometer is 10^{-9} meters.

Light court. An uncovered, interior, open area in the center of a building. See also *atrium.*

lm. See *Lumen*

Lumen (lm). The SI and non-S1 unit of luminous flux, that is, the visible energy exitant a light source.

Lux (lx). The SI unit of measure of illuminance. One lux is equal to one lumen per square meter. See *illuminance* and *footcandle.*

lx. See *lux.*

M

Metered demand. The measured total coincident electrical demand in a building. See also *billing demand.*

MON. See *monitor aperture.*

Monitor aperture (MON). A raised portion of the roof of a building which has apertures on opposing surfaces. Commonly used in passive heating and daylighting systems. One of five daylighting strategies analyzed in the handbook. See also *atrium, sawtooth aperture, skylight,* and *windows.*

N

Natural light. See *daylight.*

Natural ventilation (NVN). The unassisted movement of air through a building. Can be caused by pressure or temperature differences between the outside and inside air. One of two passive cooling strategies analyzed in the handbook. See also *night mechanical ventilation.*

Night mechanical ventilation (NMV). The mechanical ventilation of the mass of the building at night to help reduce daytime cooling loads and cooling peak demand. One of two passive cooling strategies analyzed in the handbook. See also *natural ventilation.*

NMV. See *night mechanical ventilation.*

NVN. See *natural ventilation.*

O

Operating schedule. The portion of the workday that a building is typically occupied.

Orientation. The relationship of a building surface with respect to compass heading. Usually expressed as either a compass heading or a degree heading.

Overcast sky (daylighting). A sky with 100% cloud cover. The sun is obstructed and clouds extend to the horizon in all directions. See also *clear sky, cloudy sky,* and *partly cloudy sky.*

P

Partly cloudy sky (weather). A sky that has intermittent clouds in which the sun is alternately obstructed and unobstructed. See also *clear sky, cloudy sky,* and *overcast sky.*

Passive solar system. A heating, cooling, or daylighting system that operates without mechanical devices to collect, store, and distribute energy in a building.

Peak cooling. The peak cooling load in a building; measured in Btu's or kW's. See *peak demand.*

Peak demand. The maximum rate of electricity usage by a utility customer during a 15 or 30 minute time period. See also *billing demand.*

Project book. A document containing data, criteria, functional requirements, and cost information to support programming and design of Air Force facilities.

Q, R

RAD. See *Cloudiness Index.*

S

Savings-to-investment ratio (SIR). Used by the Air Force to determine the economic viability of passive solar energy systems.

SAW. See *sawtooth aperture.*

Sawtooth aperture (SAW). A roof aperture system in which the glazing is placed on the short, usually vertical, surface of a series of roof serrations. One of five daylighting strategies analyzed in the handbook. See also *atrium, monitor aperture, skylight,* and *windows.*

Shading. An effective way to keep a building comfortable through cooling load avoidance. Shading is primarily used on apertures to avoid excessive solar gains, but can also be used on facades to keep walls from being exposed to the sun.

Shading coefficient. The ratio of the solar heat gain through a specific glazing system under a given set of conditions, to the total solar heat gain through a single layer of clear, l/S-inch thick, double-strength glass under the same conditions.

Sidelighting. The use of daylight apertures in the walls of a building. See *windows* and *clerestories.*

SIR. See *savings-to-investment ratio.*

SKY. See *skylight.*

Skylight (SKY). A roof aperture, typically horizontal, used to illuminate the interior zones of low-rise buildings. One of five daylighting strategies analyzed in the handbook. See also *atrium, monitor aperture, sawtooth aperture,* and *windows.*

Solar envelope. A solar envelope is a three-dimensional volume, covering that part of a site that is buildable, within which a building has access to the sun without blocking direct sunlight to adjacent buildings or property.

Standard Form 254. See *Form 254*

Standard Form 255. See *Form 255*

Storage. Using the mass in the walls or floor of a building to collect heat during the day for use at night or on cloudy days.

Sunspace. A usable space attached to a building that has glazing on two or more sides. Air temperatures are allowed to vary more than in the building proper. Sometimes called a solarium, winter garden, or greenhouse. One of four passive heating strategies analyzed in the handbook. See also *direct gain, direct gain plus storage,* and *indirect gain.*

T, U

Toplighting. The use of daylight apertures on the roof of a building. See *monitor apertures, sawtooth apertures,* and *skylight.*

V

Ventilation. The atmospheric air that is purposely allowed to enter an interior space to cool or freshen it.

W

Watt (W). The absolute SI unit of power that equals one (1) absolute joule per second.

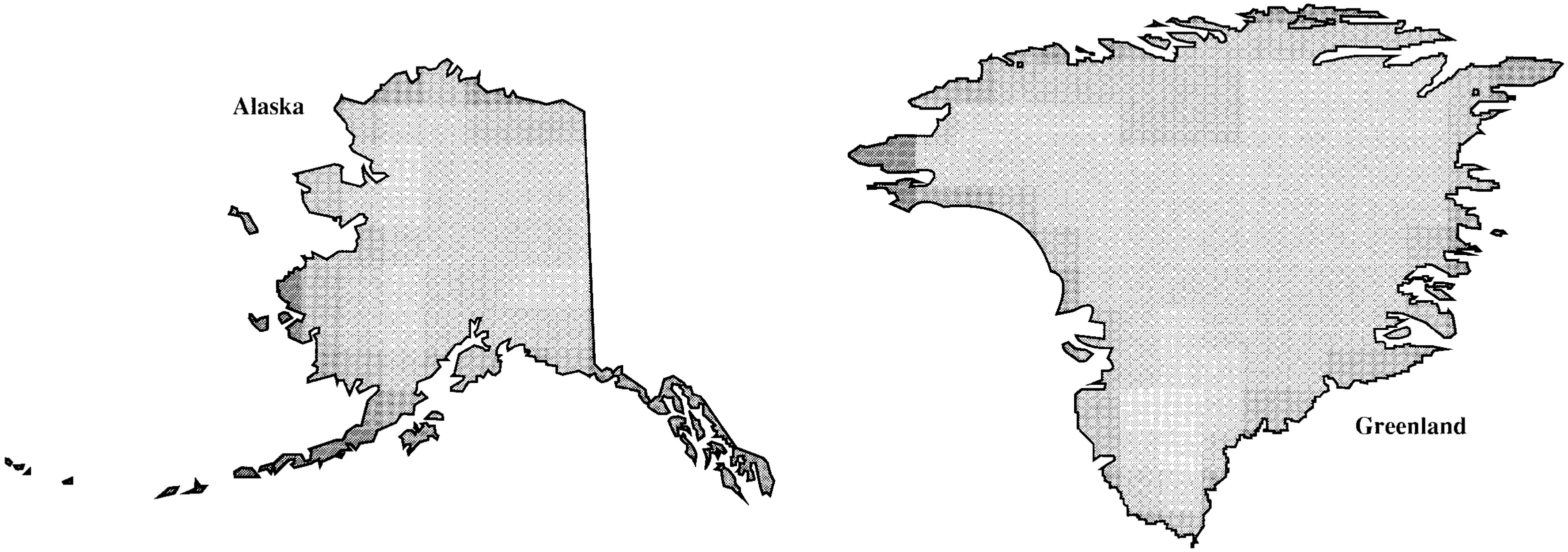
WIN. See *window aperture.*

Window aperture (WIN). An aperture in a wall of a building. One of five daylighting strategies analyzed in the handbook. See also *atrium, monitor aperture, skylight,* and *sawtooth aperture.*

X, Y, Z

Zenith. The point at the top of a hemispheric sky dome.

CLIMATE REGION 1

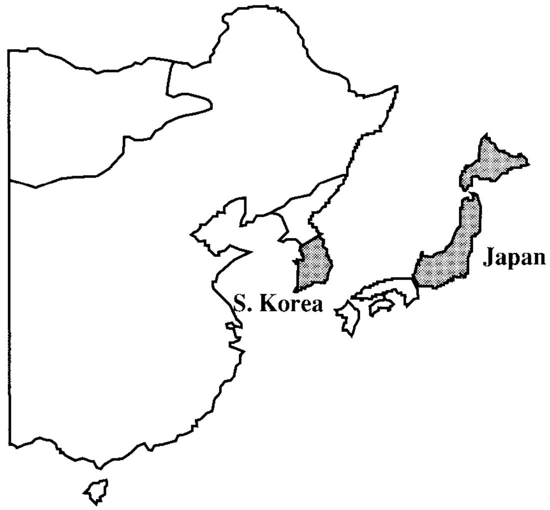


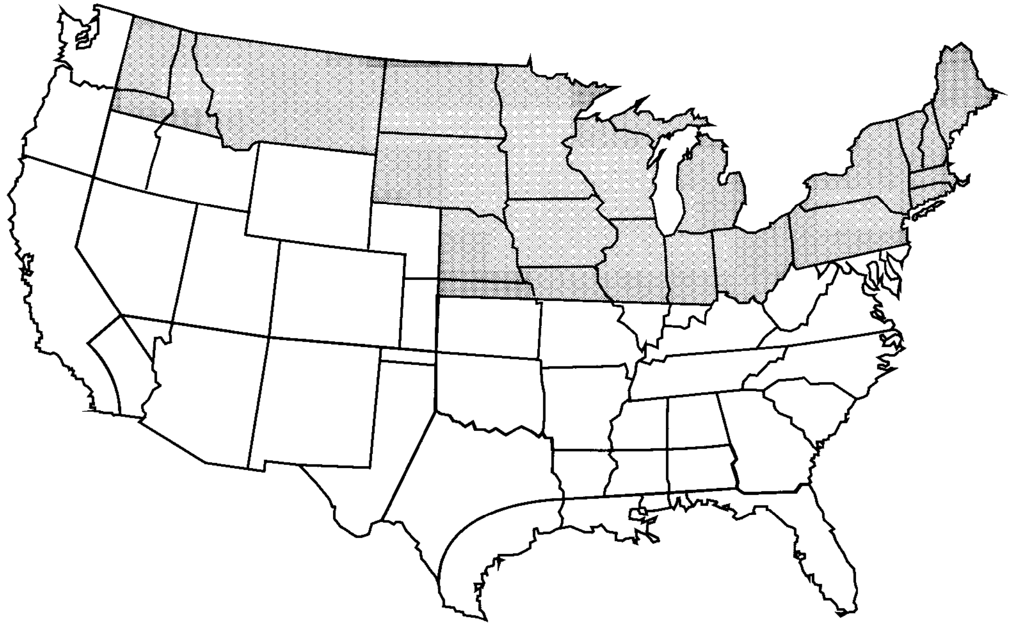
Climate Characteristics	
HDD (Range)	7,000 to 21,000
CDD (Range)	0 to 50
LEH (Range)	0 to 100
RAD (Range)	0.35 to 0.50

U.S. Air Force Bases

CLEAR
EIELSON
ELMENDORF
KING SALMON
SHEMYA
SONDRESTROM
THULE

CLIMATE REGION 2 — Appendix A





Climate Characteristics	
HDD (Range)	4,750 to 11,000
CDD (Range)	500 to 1250
LEH (Range)	2,500 to 10,000
RAD (Range)	0.40 to 0.60

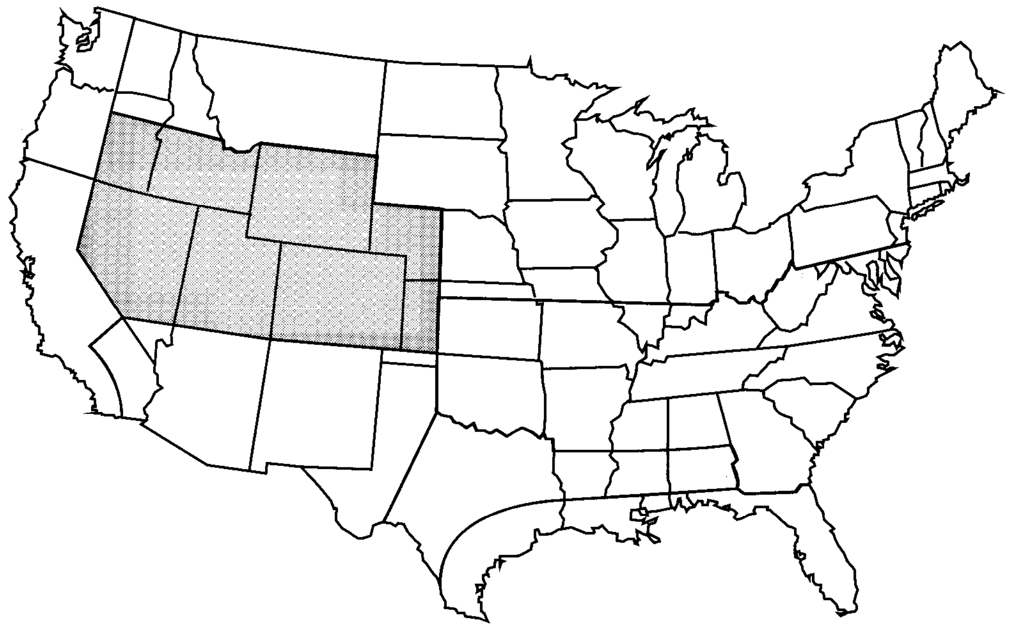
U.S. Air Force Bases		
CHANUTE	KUNSAN	OTIS
ELLSWORTH	LORING	PEASE
FAIRCHILD	MALMSTROM	PLATTSBURGH
GRAND FORKS	MCGUIRE	WILLOW GROVE
GRIFFISS	MINOT	WRIGHT- PATTERSON
GRISSOM	MISAWA	WURTSMITH
HANSCOM	OFFUTT	YOKOTA
K. I. SAWYER	OSAN	

CLIMATE REGION 3

Climate Characteristics	
HDD (Range)	1,250 to 6,000
CDD (Range)	0 to 2,250
LEH (Range)	0 to 3,000
RAD (Range)	0.40 to 0.70

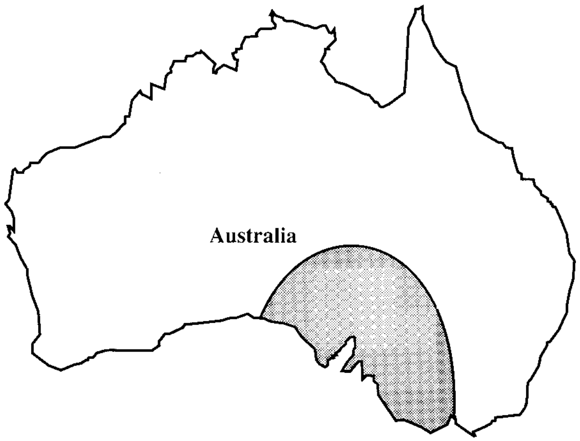
U.S. Air Force Bases	
BEALE	NORTON
CASTLE	ONIZUKA
GEORGE	TRAVIS
MARCH	VANDENBERG
MATHER	
MCCLELLAN	
MCCHORD	

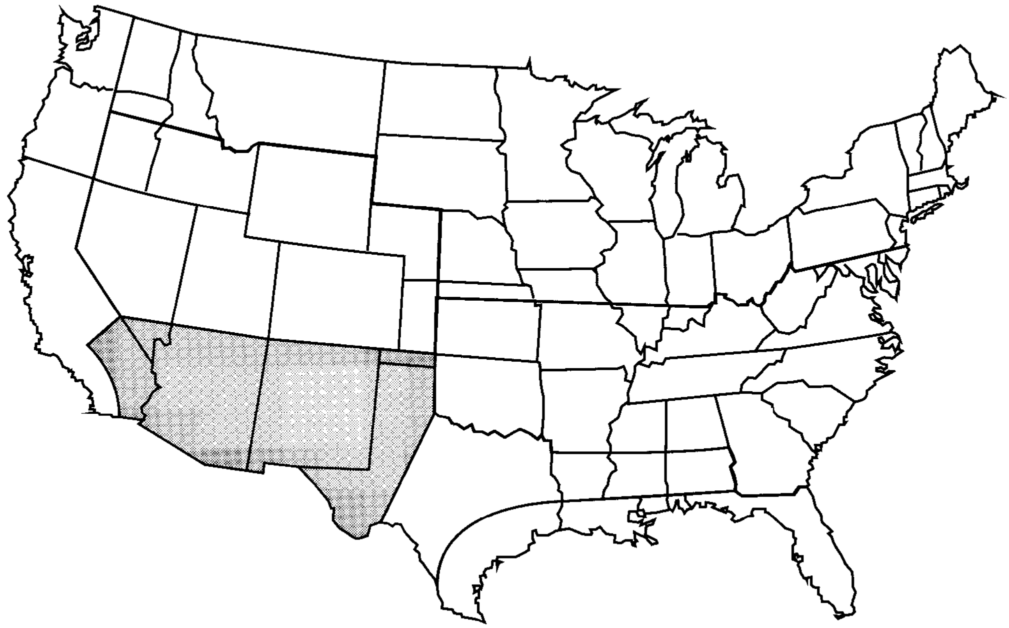
CLIMATE REGION 4 — Appendix A



Climate Characteristics		U.S. Air Force Bases	
HDD (Range)	4,500 to 10,000	FALCON	PETERSEN
		F.E. WARREN	USAF ACADEMY
CDD (Range)	0 to 1,500	HILL	
		INDIAN SPRINGS	
LEH (Range)	0 to 1,000	LOWRY	
		MOUNTAIN HOME	
RAD (Range)	0.50 to 0.70	NELLIS	

CLIMATE REGION 5 — Appendix A

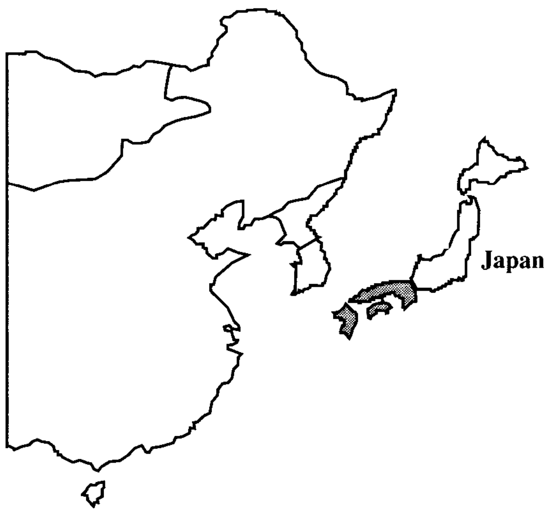


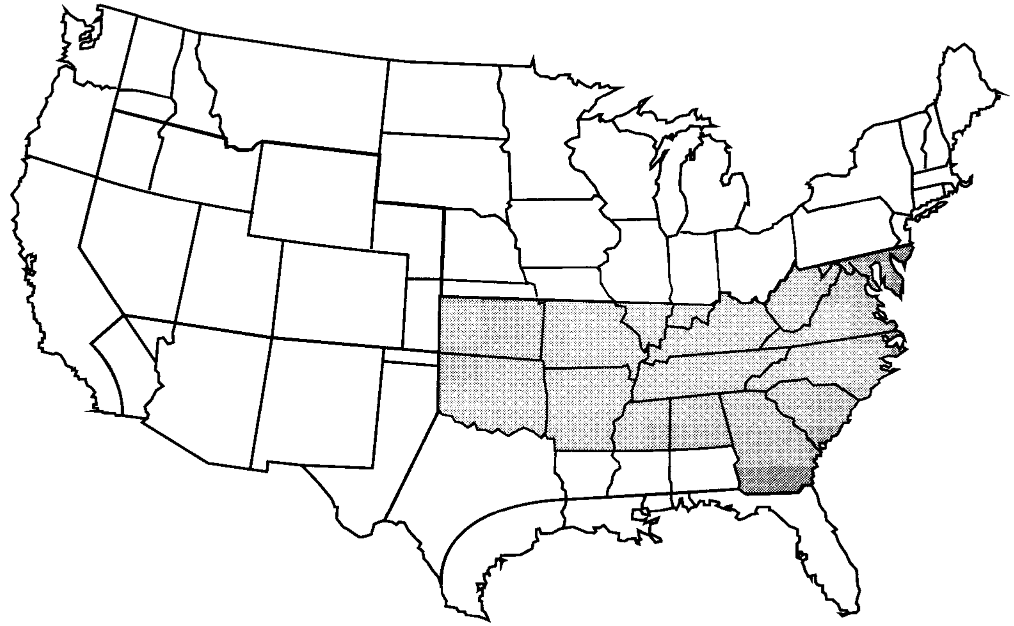


Climate Characteristics		U.S. Air Force Bases	
HDD (Range)	1,000 to 6,000	CANNON	WILLIAMS
		DAVIS-MONTHAN	WOOMERA
CDD (Range)	250 to 2,250	EDWARDS	
		HOLLOMAN	
LEH (Range)	5,000 to 15,000	KIRTLAND	
		LUKE	
RAD (Range)	0.60 to 0.75	REESE	

CLIMATE REGION 6

Appendix A



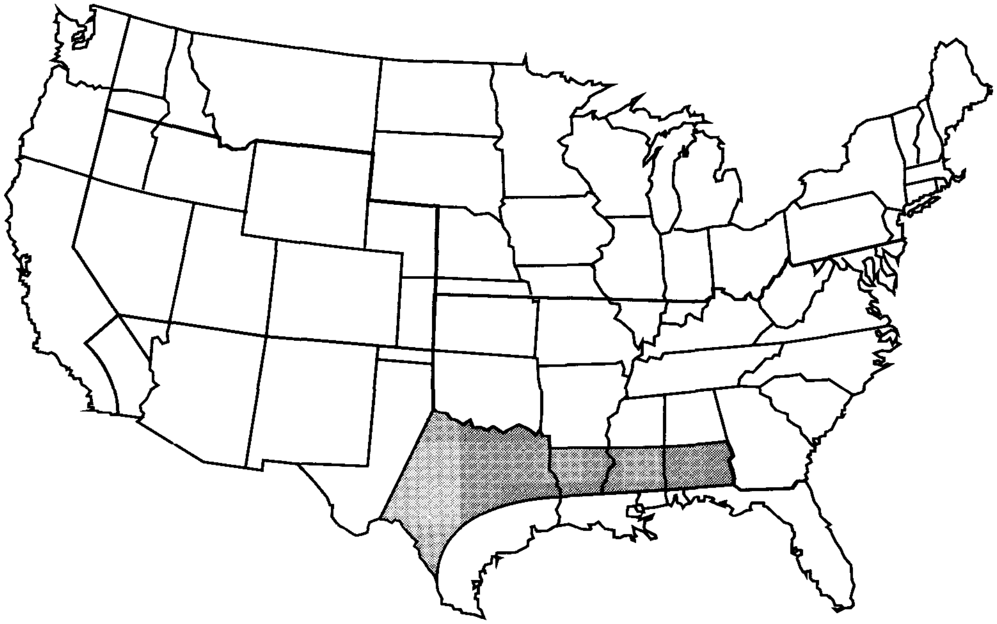


Climate Characteristics	
HDD (Range)	1,750 to 5,000
CDD (Range)	650 to 2,500
LEH (Range)	10,000 to 20,000
RAD (Range)	0.45 to 0.60

U.S. Air Force Bases		
ALTUS	EAKER	SEYMOUR JOHNSON
ANDREWS	LANGLEY	SHAW
ARNOLD	LITTLE ROCK	TINKER
BOLLING	MCCONNELL	WHITEMAN
CHARLESTON	POPE	WHITEMAN
DOBBINS	ROBINS	SHAW
DOVER	SCOTT	WHITEMAN

CLIMATE REGION 7

Appendix A

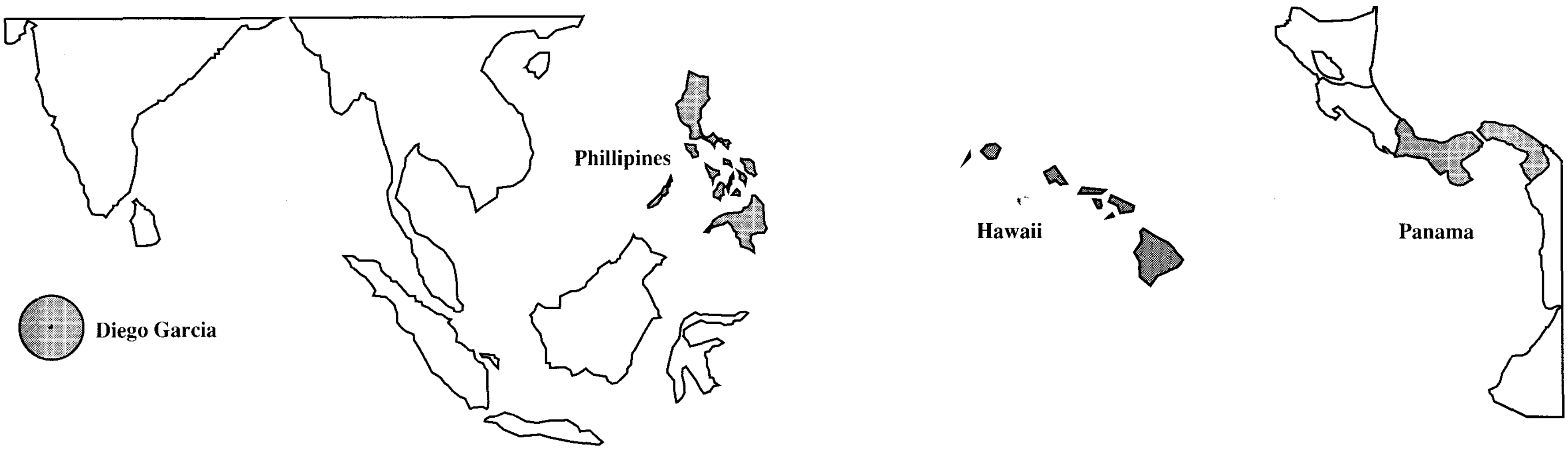


Climate Characteristics	
HDD (Range)	1,500 to 4,000
CDD (Range)	1,750 to 3,500
LEH (Range)	15,000 to 27,500
RAD (Range)	0.45 to 0.60

U.S. Air Force Bases	
BERGSTROM	KELLY
BROOKS	LACKLAND
CARSWELL	LAUGHLIN
COLUMBUS	MAXWELL
DYESS	RANDOLPH
GOODFELLOW	SHEPPARD
GUNTER	VANCE

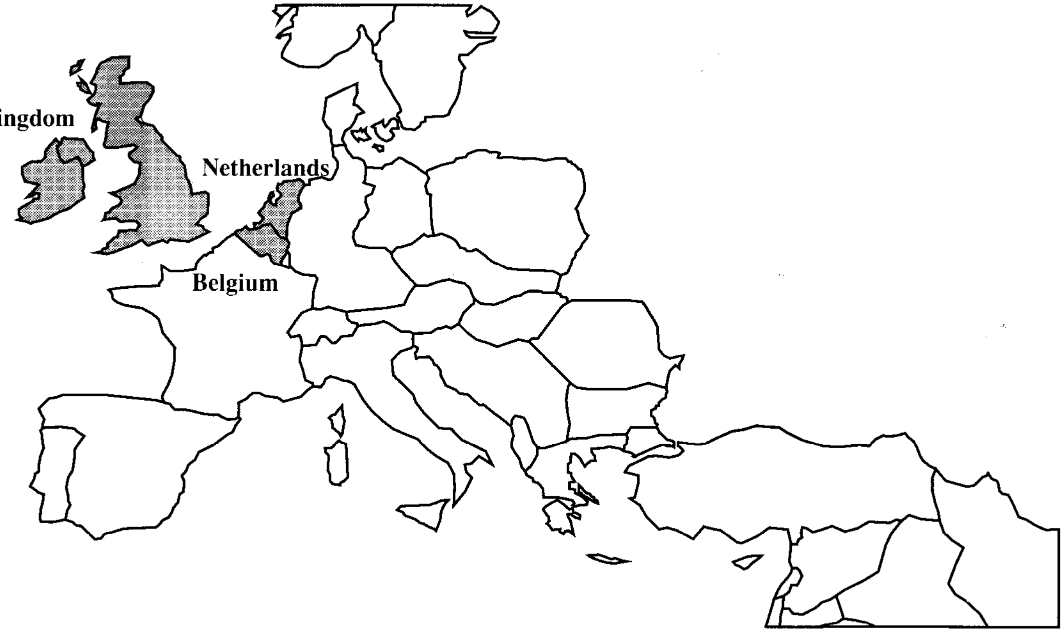
CLIMATE REGION 8

Appendix A



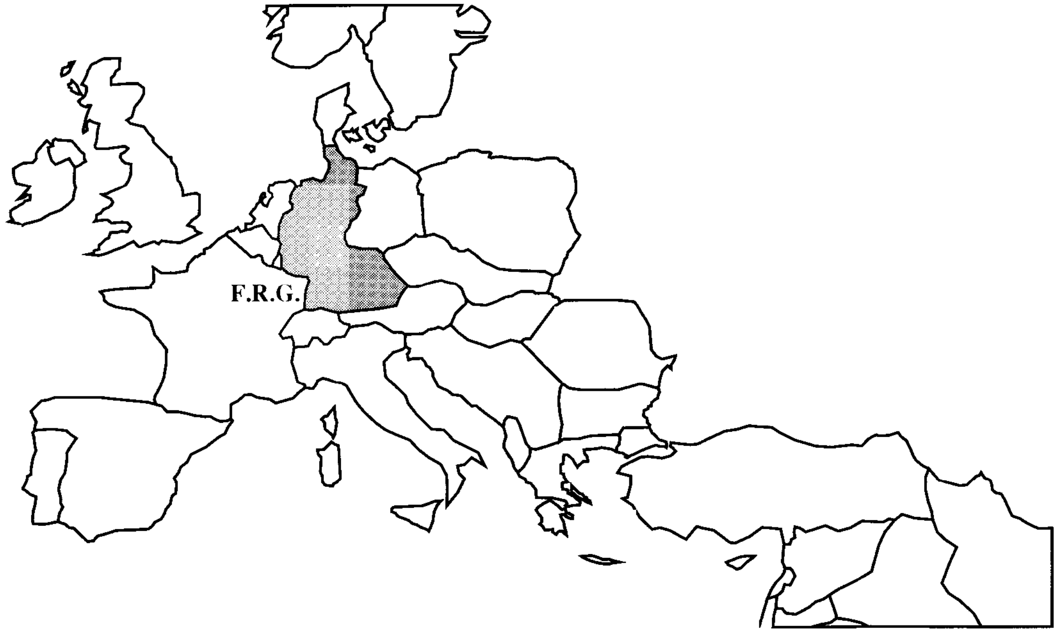
Climate Characteristics		U.S. Air Force Bases
HDD (Range)	0	ANDERSON
		ASCENSION (EQUATORIAL ATLANTIC OCEAN - Not Shown)
CDD (Range)	2,500 to 5,000	CLARK
		DIEGO GARCIA
LEH (Range)	17,500 to 30,000	HICKAM
		HOWARD
RAD (Range)	0.40 to 0.60	WHEELER

CLIMATE REGION 9 Appendix A



Climate Characteristics		U.S. Air Force Bases		
HDD (Range)	1,500 to 4,000	ABINGDON	GREENHAM COMMON	WETHERSFIELD
CDD (Range)	0 to 500	ALCONBURY	HIGH WYCOMBE	WOODBRIDGE
LEH (Range)	0 to 500	BENTWATERS	LAKENHEATH	
RAD (Range)	0.40 to 0.55	CHICKSANDS	MILDENHALL	
		C.N.A. (SOESTERBURG)	MOLESWORTH	
		CROUGHTON	SCULTHORPE	
		FLORENNES	UPPER HEYFORD	

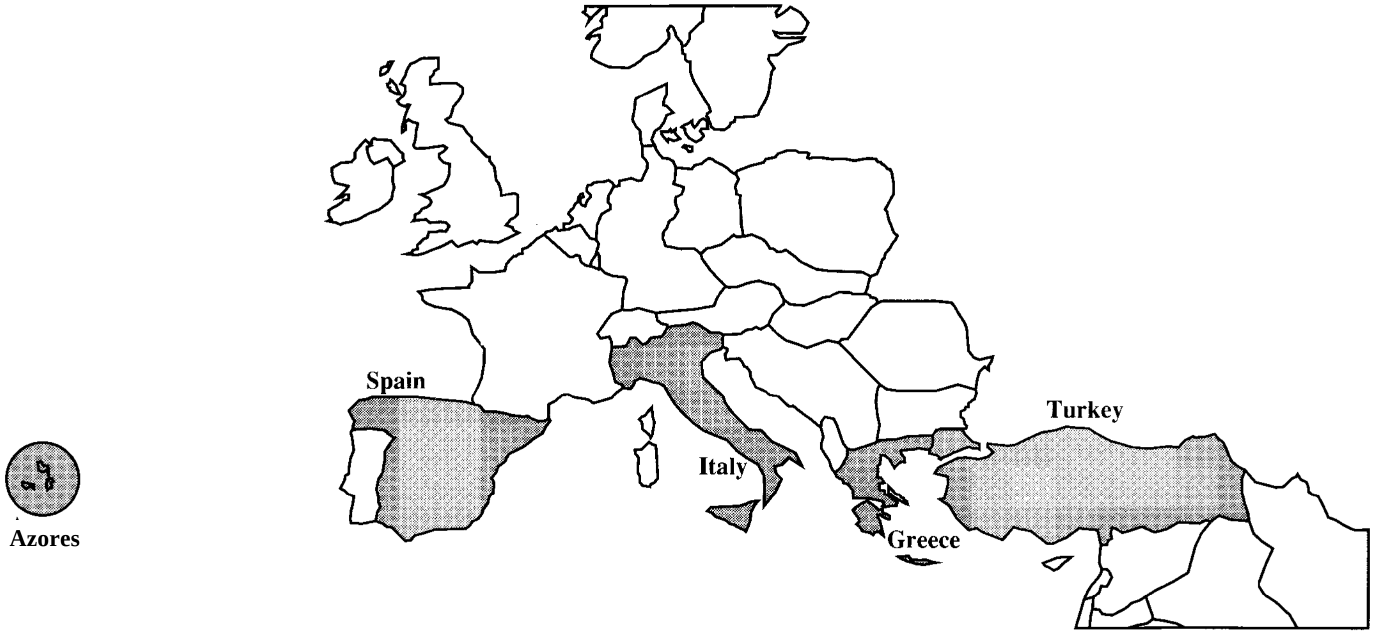
CLIMATE REGION 10 Appendix A



Climate Characteristics	
HDD (Range)	4,000 to 7,500
CDD (Range)	0 to 1,000
LEH (Range)	500 to 2,000
RAD (Range)	0.40 to 0.55

U.S. Air Force Bases	
BITBURG	RHINE ORDINANCE
HAHN	SEMBACH
HESSISCH-OLDENDORF	SPANGDAHLEM
KAPAUN	VOGELWEH
LANDSTUHL	WERSCHEIM
RAMSTEIN	
RHEIN MAIN	

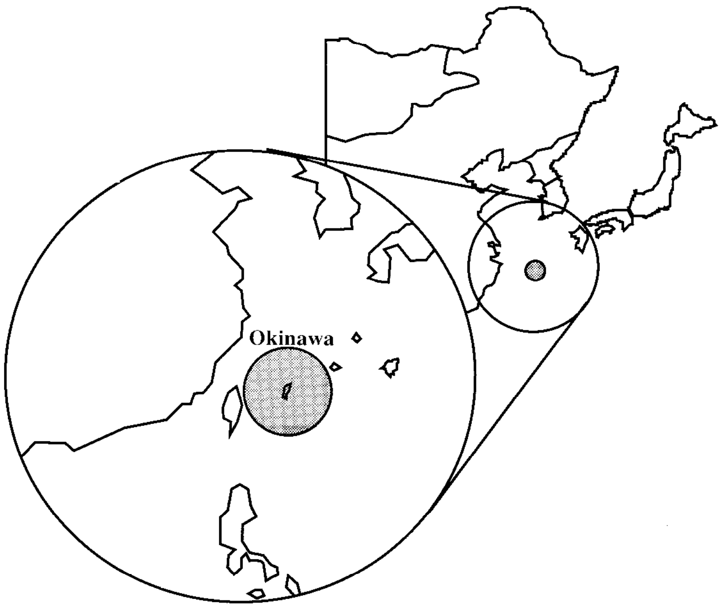
CLIMATE REGION 11

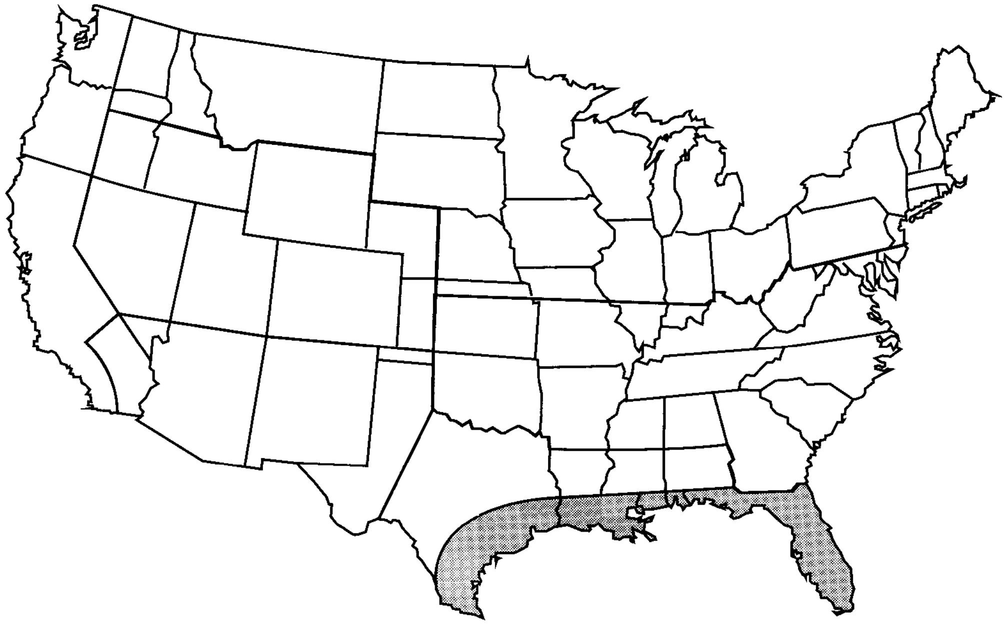


Climate Characteristics	
HDD (Range)	2,000 to 6,500
CDD (Range)	1,000 to 2,500
LEH (Range)	1,000 to 7,500
RAD (Range)	0.45 to 0.60

U.S. Air Force Bases	
ANKARA	IZMIR
AVIANO	LAJES FIELD
COMISO	SAN VITO
CRETONE	TORREJON
HELLENIKON	ZARAGOZA
INCIRLIK	
IRAKLION	

CLIMATE REGION 12	Appendix A





Climate Characteristics		U.S. Air Force Bases	
HDD (Range)	0 to 1,750	BARKSDALE	MACDILL
CDD (Range)	2,250 to 4,500	EGLIN	MOODY
LEH (Range)	15,000 to 27,500	ENGLAND	PATRICK
RAD (Range)	0.45 to 0.55	HOMESTEAD	TYNDALL
		HURLBURT	
		KADENA	
		KEESLER	

BUILDING-TYPE CATEGORY CODES

Appendix B

Building Code	USAF Category Code	Building Description
A,B,C,D	100-000	C31 FACILITY
I,J,K,L	111-000	ACFT OPS/MAINT FACILITY
A,B,C	120-000	POL OPS FACILITY
A,B	121-111	PETROLEUM OPS BUILDING
NC	121-120	QUICK-TURN FACILITY
G	130-142	FIRE STATION
A,B,C	130-833	CENTRAL SECURITY CONTROL
A,B,C	130-835	SP OPERATIONS
D	131-111	TELECOMM CENTER
D	131-118	DIGITAL FACILITY
D	131-132	SATCOM GROUND TERMINAL
D	131-134	AIR COMM FACILITY
D	131-136	AIR COMM RELAY FACILITY
D	131-138	RECEIVER/TRANSMITTER FACILITY
D	131-139	MICROWAVE RELAY STATION
D	131-143	RADAR FACILITY
NC	134-XXX	REMOTE CONTROL AND GROUND CONTROL FAC
NC	134-375	RAPCON
A,B,C	140-000	COMMAND POST
A,B,C	140-453	MOBILITY READINESS FACILITY
A,B,C	140-454	ORDINANCE CONTROL
NC	140-459	CREW READINESS/COMBAT CONTROL FAC
A,B,C	140-461	USAF COMMAND POST
A,B,C	140-753	SQ OPERATIONS
A,B,C	140-763	INTEGRATION SUP FAC
A,B,C	140-764	INTEGRATION SUP FAC
A,B	141-000	COMMAND POST
R	141-132	STORAGE FACILITY
G	141-165	EXPLOSIVE ORDINANCE DISPOSAL
J	141-181	AIRCRAFT SHELTER
J	141-182	AIRCRAFT SHELTER
R	141-185	STORAGE FACILITY
D	141-383	AUDIO-VISUAL FACILITY
NC	141-389	TV PRODUCTION FACILITY
A,B	141-451	COMPUTER FACILITY
A,B,C	141-453	BASE OPERATIONS

BUILDING TYPE CATEGORY LIST

A	Administration, < 5000 SF	**J**	Maintenance Facility, High-Bay
B	Administration, > 5000 SF	**K**	Maintenance Facility, with HVAC
C	Administration, Multistory	**L**	Maintenance Facility, Low-Bay
D	Administration, Computer Facility	**M**	Auditorium, Cinema, Theatre
E	Dining or Food Service Facility	**N**	Training Facility, School, < 5000 SF
F	Dormitory	**O**	Training Facility, School, > 5000 SF
G	Fire Station	**P**	Training Facility, Multistory
H	Industrial Facility	**Q**	Gymnasium
I	Maintenance Facility, < 5000 SF	**R**	Warehouse, Storage Facility
		NC	No current building type category

BUILDING-TYPE CATEGORY CODES

Appendix B

Building Code	USAF Category Code	Building Description
D	141-454	MOBILITY READINESS FACILITY
A,B	141-455	ORDINANCE CONTROL
NC	141-626	CONTROL TOWER
NC	141-629	WEATHER OBSERVATION FACILITY
NC	141-743	BASE PHOTO LAB
NC	141-745	COMBAT TARGET CTR
NC	141-747	PPIF FACILITY
NC	141-748	PASSENGER TERMINALS
A,B,C,D	141-750	TECH OPERATIONS FAC
NC	141-766	CHEMICAL LABORATORY
R	141-782	AIR FREIGHT TERMINAL
R	141-783	AIR FREIGHT TERMINAL PART (ONLY)
NC	141-784	AIR PASSENGER TERMINALS
NC	149-962	TRAFFIC CONTROL TOWER
D	171-152	COMBAT MANEUV INSTRU FACILITY
N,O,P	171-158	BAND CTR
N,O,P	171-211	FLYING TRAINING CLASSROOM
D	171-212	FLIGHT SIMULATOR TRAINING
N,O,P	171-213	FLIGHT TRAINING UNIT
N,O,P	171-214	PHYSIOLOGICAL TRAINING
A,B,C	171-356	HISTORICAL RESEARCH CENTER
A,B,C	171-445	SQUAD OPS FACILITY
R	171-472	RANGE SUPPLY AND EQUIPMENT STORAGE
L,R	171-473	RANGE TARGET STORAGE AND REPAIR
NC	171-475	INDOOR SMALL-ARMS RANGE
NC	171-476	SMALL-ARMS MARKSMANSHIP TRAINING
D	171-611	SCIENTIFIC FACILITY
N,O,P	171-618	FIELD TRAINING FACILITY
A,B,C,D	171-620	COMBAT LOGISTICS SUPPORT FACILITY
D	171-621	TECH TRAINING FACILITY
N,O,P	171-623	TECH TRAINING LAB/SHOP
N,O,P	171-623	AVIONICS ACADEMIC CLASSROOMS
NC	171-625	LIQ FUELS TRAINING FAC
J	171-625	HIGH-BAY TECH TRAINING FAC
N,O,P	171-712	TARGET INTELLIGENCE TRAINING
D	171-810	RADAR BOMB-SCORE FACILITY

BUILDING TYPE CATEGORY LIST

A	Administration, < 5000 SF
B	Administration, > 5000 SF
C	Administration, Multistory
D	Administration, Computer Facility
E	Dining or Food Service Facility
F	Dormitory
G	Fire Station
H	Industrial Facility
I	Maintenance Facility, < 5000 SF
J	Maintenance Facility, High-Bay
K	Maintenance Facility, with HVAC
L	Maintenance Facility, Low-Bay
M	Auditorium, Cinema, Theatre
N	Training Facility, School, < 5000 SF
O	Training Facility, School, > 5000 SF
P	Training Facility, Multistory
Q	Gymnasium
R	Warehouse, Storage Facility
NC	No current building type category

BUILDING-TYPE CATEGORY CODES

Appendix B

Building Code	USAF Category Code	Building Description
N,O,P	171-813	SAFETY EDUCATION FACILITY
N,O,P	171-815	NCO PME CENTER
N,O,P	171-851	LEADERSHIP DEV COMPLEX
N,O,P	171-873	AERIAL PORT
N,O,P	171-875	MUNITIONS LOAD-REW TRAINING FAC
NC	179-475	SMALL ARMS TRAINING
I,J,K,L	200-000	ACFT MAINTENANCE & MGMT FAC
I,J,K,L,R	210-000	MUNI MAINTENANCE/STORAGE FAC
I,K,L	210-000	MUNITIONS MAINT FAC
L	211-XXX	LOW-BAY INSTRU/ELECT EQUIP MAINT SHOP
I,J,K,L	211-000	MAINTENANCE COMPLEX
J	211-111	HANGAR
NC	211-111	FUEL SYSTEMS MAINT DOCK
NC	211-133	FUEL ACCESSORIES TEST FACILITY
I,K,L,R	211-147	AIRCRAFT WEAPONS CAL SHELTER
I,J,L	211-152	ACFT MAINTENANCE
NC	211-152	LOW-BAY
J	211-152	MAINTENANCE HANGAR
NC	211-153	NDI LAB
I,J,K,L	211-154	MAINTENANCE COMPLEX
J	211-154	HIGH-BAY FACILITY
I,J,K,L	211-157	GENERAL PURPOSE/NDI/ACFT ORG MAINT SHOP
J	211-159	CORROSION CONTROL FAC
J	211-159	CORROSION CONTROL FACILITY
I,J,K	211-179	FUEL SYSTEMS MAINT FACILITY
NC	211-179	FUEL SYST MAINT FACILITY
NC	211-183	SOUND-SUPPRESSOR SUP FAC
NC	211-193	SOUND-SUPPRESSOR SUP FAC
NC	211-254	CONSOLIDATED FUEL CONTROL FACILITY
NC	211-271	DEPOT INSTRUMENT OH SHOP
I,J,K,L	211-271	DEPOT INSTN OVERHAUL SHOP
R	212-213	MUNITIONS MAINT AND STORAGE
L,R	212-213	MUNITIONS MAINTENANCE/STORAGE
I,J,K,L	212-216	MISSILE MAINTENANCE SHOP
I,J,K,L	213-XXX	TACTICAL MISSILE/GUIDE WEAPON MAINT SHOP
I,J,K,L	213-636	MARINE MAINT SHOP
N C	214-425	VEHICLE MAINTENANCE FACILITY

BUILDING TYPE CATEGORY LIST

A	Administration, < 5000 SF
B	Administration, > 5000 SF
C	Administration, Multistory
D	Administration, Computer Facility
E	Dining or Food Service Facility
F	Dormitory
G	Fire Station
H	Industrial Facility
I	Maintenance Facility, < 5000 SF
J	Maintenance Facility, High-Bay
K	Maintenance Facility, with HVAC
L	Maintenance Facility, Low-Bay
M	Auditorium, Cinema, Theatre
N	Training Facility, School, < 5000 SF
0	Training Facility, School, > 5000 SF
P	Training Facility, Multistory
Q	Gymnasium
R	Warehouse, Storage Facility
NC	No current building type category

BUILDING-TYPE CATEGORY CODES

Appendix B

Building Code	USAF Category Code	Building Description
I,J,K,L	214-425	VEHICLE MAINT SHOP
R	214-425	VEHICLE OPERATION HEATED-PARKING SHED
R	214-426	VEHICLE OPERATION HEATED-PARKING SHED
R	214-428	VEHICLE OPERATION HEATED-PARKING SHED
I,J,K,L	214-467	VEHICLE MAINT SHOP
I,J,K,L	215-XXX	WEAPONS & MUNITIONS MAINT SHOP
I,J,K,L	216-642	AMMO MAINT SHOP
I,J,K,L	217-000	VEHICLE MAINT FAC
NC	217-000	MAINT/STORAGE AND VEH PARKING FAC
K	217-712	AVIONICS REPAIR FAC
I,J,K,L	217-713	AIRCRAFT EQM POD SHOP
I,J,L,R	217-713	POD SHOP AND STORAGE
K	217-713	HAVAIDS COMM MAINT SHOP
I,J,K,L	217-735	ENGINEERING TEST FAC
I,J,K,L	217-812	EW MAINT FAC
I,J,K,L	218-712	SPECIAL EQUIPMENT SHOP
A,B,C,D	218-712	ACFT SUP EQUIP FAC
L	217-762	HVACAIDS COMM MAINT SHOP
I,J,K,L	218-852	PARACHUTE-EGRESS FACILITY
NC	218-868	PRECISION MEASUREMENT LAB
I,J,K,L	219-000	BCE COMPLEX
R	219-422	STORAGE FACILITY
I,J,K,L	219-900	BCE MAINT COMPLEX
I,J,K,L	219-940	BCE MAINT COMPLEX
I,J,K,L	219-943	BCE MAINT SHOP
I,J,K,L	219-944	BCE MAINT SHOP
R	219-946	STORAGE FACILITY
R	219-947	STORAGE FACILITY
H	220-XXX	PRODUCTION
D	310-916	COMPUTER SERVICE CTR
NC	310-921	BIOCOMMUNICATIONS LAB
NC	310-922	OPTICAL SYS LAB
NC	310-926	MICROWAVE LAB
A,B,C,D	311-173	ACFT SYS ENG FAC
I,J,K,L	311-174	TEST & EVALUATION FAC
I,J,K,L	315-236	GUIDED WEAPON & EVAL FAC

BUILDING TYPE CATEGORY LIST

A	Administration, < 5000 SF
B	Administration, > 5000 SF
C	Administration, Multistory
D	Administration, Computer Facility
E	Dining or Food Service Facility
F	Dormitory
G	Fire Station
H	Industrial Facility
I	Maintenance Facility, < 5000 SF
J	Maintenance Facility, High-Bay
K	Maintenance Facility, with HVAC
L	Maintenance Facility, Low-Bay
M	Auditorium, Cinema, Theatre
N	Training Facility, School, < 5000 SF
O	Training Facility, School, > 5000 SF
P	Training Facility, Multistory
Q	Gymnasium
R	Warehouse, Storage Facility
NC	No current building type category

BUILDING-TYPE CATEGORY CODES

Appendix B

Building Code	USAF Category Code	Building Description
I,J,K,L	317-311	ELECT TEC/RESEARCH LAB
I,J,K,L	317-315	SYS MGT ENG FAC
I,J,K,L	317-932	AVIONICS RESEARCH LAB
I,J,K,L	318-612	ACFT FIRE PROT/EXPL RES FAC
R	318-612	PROPANE LAB STORAGE
I,J,K,L	319-946	HAZARDOUS-MATTER EVAL FAC
NC	319-951	TEST TRACK FACILITY
A,B,C	400-000	COMMAND POST, SUPPORT
NC	411-135	HYDRANT FUEL SYSTEM AND STORAGE
R	411-628	TOOLING SHED
R	422-250	OPS/MUNITIONS STORAGE FAC
R	422-258	MUNITIONS STORAGE FACILITY
R	422-264	MUNITIONS STORAGE IGLOOS
R	422-275	MUNITIONS PRELOAD COMPLEX
R	441-758	DEPOT WAREHOUSE
R	442-000	RRR EQUIPMENT STORAGE
NC	442-257	BASE HAZARDOUS-MATERIAL STORAGE
NC	442-275	ANCILLARY EXPLOSIVE COMPLEX
NC	442-515	MEDICAL STORAGE
NC	442-628	BASE HAZARDOUS-MATERIAL STORAGE
NC	442-750	RESOURCE MANAGEMENT COMPLEX
J,R	442-758	AIRCRAFT WAREHOUSE/RRR EQUIP STORAGE
R	442-765	TROOP SUBSISTENCE WAREHOUSE
R	442-768	FORMS/PUBLICATIONS WAREHOUSE
R	442-769	HOUSING SUPPLY/STORAGE FACILITY
NC	510-XXX	HOSPITAL BUILDING
NC	510-001	DENTAL CLINIC
NC	510-411	DISPENSARIES
NC	510-713	MEDICAL LOGISTICS FACILITY
NC	530-XXX	LABORATORIES
NC	540-243	DENTAL CLINIC
NC	550-XXX	DISPENSARIES
A,B,C	610-000	CONSOLIDATED SUPPORT CENTER/LOG FAC
A,B,C,I	610-100	ACFT MAINTENANCE MGMT FAC
A,B,C	610-111	AREA DEFENSE OFFICE
A,B,C	610-112	LAW OFFICE

BUILDING TYPE CATEGORY LIST

A	Administration, < 5000 SF
B	Administration, > 5000 SF
C	Administration, Multistory
D	Administration, Computer Facility
E	Dining or Food Service Facility
F	Dormitory
G	Fire Station
H	Industrial Facility
I	Maintenance Facility, < 5000 SF
J	Maintenance Facility, High-Bay
K	Maintenance Facility, with HVAC
L	Maintenance Facility, Low-Bay
M	Auditorium, Cinema, Theatre
N	Training Facility, School, < 5000 SF
O	Training Facility, School, > 5000 SF
P	Training Facility, Multistory
Q	Gymnasium
R	Warehouse, Storage Facility
NC	No current building type category

BUILDING-TYPE CATEGORY CODES

Appendix B

Building Code	USAF Category Code	Building Description
A,B,C	610-119	FAMILY-HOUSING MGMT OFFICE
A,B,C	610-121	VOA
A,B,C	610-122	BSA
A,B,C	610-127	BASE ENGINEERING ADMIN
A,B,C	610-128	BASE PERSONNEL OFFICE
A,B,C	610-129	WEAPONS SYS MUNITIONS MGMT FAC
A,B,C	610-142	TRAFFIC MGMT FAC
A,B,C	610-144	MUNITIONS MAINT ADMIN
A,B,C	610-200	CONSOLIDATED SUP FAC
F	610-241	ORDERLY ROOM, DORMATORY
A,B,C	610-243	AEROMED EVAC AIRLIFT SQ/ACB FAC
A,B,C	610-249	WING HEADQUARTERS
D	610-281	COMPUTER FACILITY
A,B,C	610-282	SUPPORT OFFICE
A,B,C	610-284	RECRUITING GROUP FAC
A,B,C	610-285	COMBAT CONTROL OFFICE
A,B,C	610-286	AIR DIV HEADQUARTERS
N,O,P	610-287	INSTRUCTIONAL FAC
A,B,C	610-675	SUPPORT CENTER
D	610-711	COMPUTER FACILITY
A,B,C	610-915	OSA BUILDING
F	720-000	UPH
E,F	721-215	DINING HALL IN DORMITORY
F	721-311	RECRUITS DORMITORY
F	721-312	AIRMEN PERMANENT PARTY/PCS-STUDENT DORM
F	721-315	VISITING AIRMEN QUARTERS DORM
E	722-351	AIRMEN DETACHED DINING HALL
E	722-356	OFFICERS DINING HALL
NC	723-XXX	KITCHEN
F	724-415	UOPH
F	724-417	TRANSIENT BILLETING
F	730-xXx	CONFINEMENT FACILITY (STOCKADE)
G	730-142	FIRE STATION/CRASH RESCUE OFFICE
NC	730-182	BREAD BAKERY
NC	730-186	PASTRY BAKERY
N,O,P	730-441	EDUCATION CENTER

BUILDING TYPE CATEGORY LIST

A	Administration, < 5000 SF	**J**	Maintenance Facility, High-Bay
B	Administration, > 5000 SF	**K**	Maintenance Facility, with HVAC
C	Administration, Multistory	**L**	Maintenance Facility, Low-Bay
D	Administration, Computer Facility	**M**	Auditorium, Cinema, Theatre
E	Dining or Food Service Facility	**N**	Training Facility, School, < 5000 SF
F	Dormitory	**O**	Training Facility, School, > 5000 SF
G	Fire Station	**P**	Training Facility, Multistory
H	Industrial Facility	**Q**	Gymnasium
I	Maintenance Facility, < 5000 SF	**R**	Warehouse, Storage Facility
		NC	No current building type category

BUILDING-TYPE CATEGORY CODES

Appendix B

Building Code	USAF Category Code	Building Description
NC	730-443	POST OFFICE
NC	730-717	CLOTHING STORE
NC	730-771	CHAPEL
N,O,P	730-772	RELIGIOUS EDUCATION CENTER
N,O	730-772	CHAPEL CENTER
N,O	730-773	CHAPEL CENTER
N,O	730-774	HOSPITAL CHAPEL
E	730-781	DEPENDENT BOARDING SCHOOL DINING HALL
NC	730-782	DEPENDENT ELEMENTARY SCHOOL
F	730-782	DEPENDENT BOARDING FACILITY
NC	730-785	DEPENDENT HIGH SCHOOL
NC	730-821	MATERIAL PROCESSING DEPOT
A,B,C	730-832	SECURITY POLICE CONTROL & IDENT
A,B,C	730-833	SP CENTRAL CONTROL
A,B,C	730-835	SP CENTRAL OP
NC	730-836	RESERVE FIRE TRAINING FAC
D	730-838	MASTER SURVEILLANCE & CONTROL FAC
A	730-839	GUARD HOUSE
NC	730-842	SECURITY POLICE KENNEL SUPPORT
A,B,C	740-000	CONSOLIDATED PERSONNEL SUP CTR
A,B,C	740-155	CREDIT UNIONS
A,B,C	740-153	BRANCH BANKS
A,B,C	740-171	RED CROSS OFFICE
A,B,C	740-253	FAMILY SERVICES CENTER
NC	740-255	THRIFT SHOP
NC	740-266	STORE
K	740-266	COMMISSARY STORE
K	740-269	BASE PACKAGE STORE
E	740-315	ROD AND GUN CLUB
E	740-316	RECREATION CENTER
E	740-317	AERO CLUB
NC	740-379	BX AMUSEMENT TR
E	740-381	BX CAFETERIA AND SNACK BAR
NC	740-382	BRANCH BASE EXCHANGE
I,J,K,L	740-385	BX MAINT SHOP
A,B,C	740-386	BX ADMIN

BUILDING TYPE CATEGORY LIST

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BUILDING-TYPE CATEGORY CODES

Appendix B

Building Code	USAF Category Code	Building Description
NC	740-388	BASE EXCHANGE
K	740-389	SERVICE OUTLET
F	740-443	TLF
E	740-615	CONSOLIDATED OPEN MESS
E	740-617	OFFICERS CLUB
E	740-618	NCO CLUB
E	740-62X	AIRMEN OPEN MESS
E	740-732	RESTAURANT
E	740-735	BASE RESTAURANT
N,O	740-644	ARTS & CRAFTS CTR
L	740-665	AUTO HOBBY SHOP
F	740-666	RECREATION SITE LODGING
NC	740-668	MISCELLANEOUS RECREATION BLDG
A,B,C	740-669	COMPOSITE RECREATION BLDG
Q	740-673	FIELD HOUSE
Q	740-674	GYMNASIUM
A,B,C	740-675	LIBRARY
NC	740-677	INDOOR SWIMMING POOL
R	740-733	STORAGE FACILITY
M	740-873	BASE THEATRE
NC	740-883	YOUTH CLUB
N,O,P	740-884	CHILD CARE CENTER
NC	760-XXX	MUSEUMS AND MEMORIALS
H	890-XXX	OTHER

BUILDING TYPE CATEGORY LIST

A	Administration, < 5000 SF
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Index

This index is a cross-reference for the information in the first three volumes of the Passive Solar Handbook. For each entry, the volume number is shown in parentheses, followed by the page number in that volume upon which the information is located. If the information is found in more than one volume, semicolons are used to separate volumes. For instance, for the entry **Air movement: (I) 26; (II) 5,** information about air movement is contained in Volume I on page 26 and in Volume II on page 5.

A

B

C

E

F, G

H

R

S

V

W, X, Y, Z