
Introduction to Cooling Buildings by Natural Ventilation

Course No: A02-007

Credit: 2 PDH

J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI



Continuing Education and Development, Inc.
22 Stonewall Court
Woodcliff Lake, NJ 07677

P: (877) 322-5800
info@cedengineering.com

An Introduction To Cooling Buildings By Natural Ventilation



Guyer Partners
44240 Clubhouse Drive
El Macero, CA 95618
(530)758-6637
jpguyer@pacbell.net

J. Paul Guyer, P.E., R.A.

Paul Guyer is a registered civil engineer, mechanical engineer, fire protection engineer, and architect with over 35 years experience in the design of buildings and related infrastructure. For an additional 9 years he was a senior advisor to the California Legislature on infrastructure and capital outlay issues. He is a graduate of Stanford University and has held numerous national, state and local positions with the American Society of Civil Engineers and National Society of Professional Engineers.

CONTENTS

1. INTRODUCTION
2. COOLING BY NATURAL VENTILATION
3. DESIGN CRITERIA

This course is adapted from the *Unified Facilities Criteria* of the United States government, which is in the public domain, is authorized for unlimited distribution, and is not copyrighted.

The Figures, Tables and Symbols in this document are in some cases a little difficult to read, but they are the best available. **DO NOT PURCHASE THIS COURSE IF THE FIGURES, TABLES AND SYMBOLS ARE NOT ACCEPTABLE TO YOU.**

1. INTRODUCTION

1.1 SCOPE. This course provides guidance and criteria for the design of buildings to be totally or partially cooled by natural ventilation. This course describes a variety of natural cooling techniques and the climatic conditions under which they may be considered. Comfort criteria and design considerations for determining and implementing appropriate cooling strategies are described. Building design features and practices are presented for the designer's information. Special considerations related to the integration of mechanical systems and other design issues that will influence comfort and safety are noted.

1.2 PURPOSE. When natural ventilation can supplant some or all of a building's mechanical cooling requirements, two types of cost savings may result:

- The energy costs of operating the air conditioning system.
- The first cost of unnecessary mechanical equipment.

1.3 OBJECTIVE. This course provides information on natural ventilation for the design of buildings. Its use will facilitate the design of buildings that save energy by substituting natural ventilation for mechanical cooling. Although "natural ventilation" strictly refers to ventilation induced by external wind or interior thermal buoyancy, the meaning usually includes ventilation from low-powered equipment such as whole-house fans and ceiling fans.

1.3.1 NATURALLY VENTILATED BUILDINGS AND CLIMATE. The external climate (temperature, radiation, humidity, and wind) determines the heating and cooling requirements of the building. Since the building envelope acts as a mediator between the external and internal environment, its design and composition affect the interior conditions of the building, as well as its energy consumption and life-cycle cost. The design of naturally ventilated buildings attempts to adjust to the regional and site-

specific sun and wind patterns on a daily and annual basis to maximize occupant comfort at minimum energy cost.

1.3.2 CONSIDERATION OF NATURAL VENTILATION IN THE DESIGN PROCESS.

Because the building site has a strong influence on how well natural ventilation will function, it is important that such ventilation be a primary design parameter from the very beginning of the design process. The siting of the building will influence the ease or difficulty with which solar shading may be achieved, how much insulation is required, etc. Ventilation should also be considered throughout the design of the building. This course provides guidelines and suggested practices at both of these scales.

1.4 PRIMARY CRITERIA. This course provides a procedure to evaluate the success or failure of a building design by examining the expected percentage of time that human thermal comfort will be achieved. The choice of building cooling strategy (i.e. natural ventilation, evaporative cooling, thermal mass, nocturnal ventilation, or mechanical air conditioning) is determined from the climate data for the site and an evaluation of what strategies work in different climates. Methods are given for determining and achieving the interior ventilation rates required for comfort. When wind or buoyancy-driven ventilation alone cannot provide adequate interior wind speeds for comfort, mechanical fan backup systems shall be used. Because naturally ventilated buildings respond to the site conditions and microclimate, there is no one set of specific criteria applicable to every naturally ventilated building. However, general building design criteria are included whenever possible.

2. COOLING BY NATURAL VENTILATION

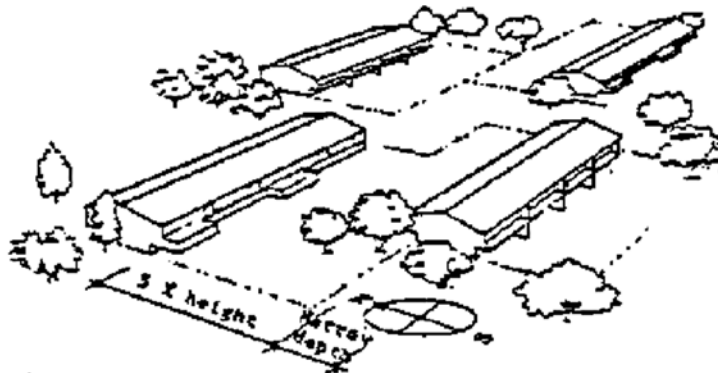
2.1 THE CAUSES OF NATURAL VENTILATION. Natural ventilation in buildings is produced by pressure differences between the inside and the outside of the building. The magnitude of the pressure difference and the resistance to flow across the openings in the envelope will determine the rate of airflow through the openings. The two main forces producing pressure differences are the wind force and the thermal force or stack effect. The amount of pressure induced by thermal differences in a building is directly proportional to the vertical height of the enclosed volume of heated or cooled air. Tall room volumes will have strong stack effects, while short room volumes will have little or no stack effects. For low-rise buildings or in medium to high wind conditions, the stack effect may be considered negligible in comparison to wind pressure forces. The stack effect rarely creates enough air movement to cool the occupants directly, but it can provide enough ventilation for fresh air and health requirements. In high-rise buildings, the stack effect may cause strong air movement through elevator shafts and stair towers, but the individual floors are usually separated from other floors so that the stack effect within the floors will be small. This course emphasizes the use of wind-induced ventilation.

2.2 THE COOLING PROCESS. Although there are many strategies for naturally cooling a building, the primary ones are:

- Convective Cooling--cooling of the occupants and/or of the structural mass by air movement,
- Radiant Cooling--heat in the building's structure is discharged by long wave radiation to the night sky,
- Evaporative Cooling--water is evaporated to cool the interior air or building structure, and
- Earth Cooling--soil is used as a heat sink and heat is transferred by direct contact with the soil or through air or water pipes.

Natural ventilation, a form of convective cooling, has the potential to cool the human body directly through convection and evaporation, or indirectly by cooling the structure of the building surrounding the occupants. The choice of cooling strategy is dependent on the climatic factors, the type of building, and the indoor climate desired.

2.2.1 BODILY COOLING. Bodily cooling is effective during overheated periods when the temperature and humidity of the air are above the still air comfort range. Bodily cooling is especially useful in hot-humid climates where high humidity suppresses the range of daily temperature fluctuation making structural cooling difficult to achieve. When bodily cooling is desired, buildings should allow maximum airflow across the occupied area and provide protection from the sun and rain.



Main Design Features

1. Main habitable rooms facing north-south
2. Wide spacing between dwellings to ensure good air movement
3. Narrow depth of dwelling to allow good air movement in all rooms
4. Overhanging roof to the north and south to provide protection from sun and rain and glare from the bright overcast sky
5. Trees to provide shade in the east and west walls without blocking air movement

Figure 1

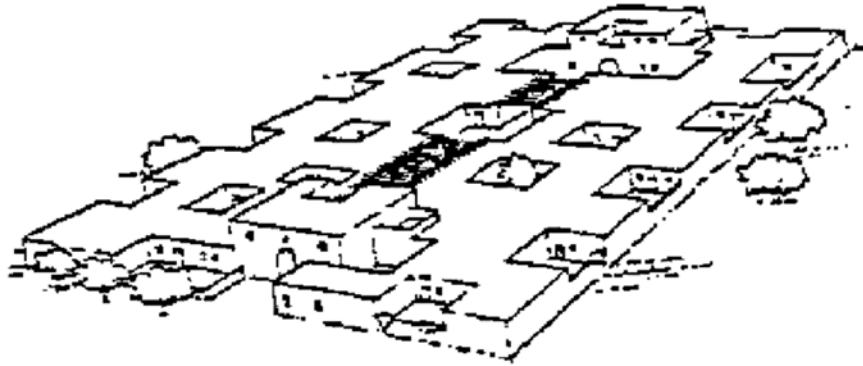
Typical Layout for Body Cooling in a Warm-Humid Climate

Lightweight structures which respond quickly to lower night temperatures are desirable. In the extreme case, the best "structure" consists of only an insulated roof-canopy to

provide shade and protection from the rain while allowing maximum ventilation. In practice, careful siting and orientation, narrow elevated buildings, open plans, and use of exterior wingwalls, overhanging eaves, verandahs, and large windows are prevalent elements of naturally ventilated buildings in warm-humid climates (see Figure 1).

2.2.2 STRUCTURAL COOLING. Structural cooling, in which the building mass smooths out the daily temperature variation, is effective in climates which have large daily temperature variations (i.e., hot-arid climates). During the day, the building interior is unventilated and the high thermal capacity of the building structure serves as a heat sink for the interior gains. At night, the mass is cooled by longwave radiation to the sky. Cooling may be enhanced by "flushing" the building with cool night air removing the stored structural heat and prechilling the mass for the next day. Night air must be cool enough to receive the stored heat (i.e., the nighttime outdoor air temperatures must be lower than indoor air temperatures, and dip into or below the comfort zone). Traditional architecture has achieved structural cooling through natural ventilation by means of small closable windows and various forms of wind scoops or wind towers. Ventilation is often enhanced by using pools of water or evaporative screens to cool the incoming air (see Figure 2). Nocturnal ventilation can lower daytime indoor temperatures below that of similarly thermally massive but unventilated buildings by an amount equal to 15 percent of the outdoor temperature range. Therefore if the outdoor temperature range is 59deg.F (15deg.C), an additional 8 to 9deg.F (2 to 3deg.C) indoor daytime temperature reduction can be expected in the nocturnally ventilated, thermally massive building as compared to an unventilated building.

2.2.3 COMBINATIONS OF BODILY AND STRUCTURAL COOLING. For bodily cooling, ventilation is used both day and night to dissipate the solar heat absorbed by the lightweight building envelope and to cool the building's occupants. Nocturnal structural cooling does not allow daytime wind-induced bodily cooling. In order to take advantage of the night coolness stored in a structural mass, the building must be unventilated during the day. Thus, structural cooling and daytime bodily cooling by natural ventilation are mutually exclusive.



Main Design Features

1. Compact planning with minimal external surface area
2. Windows of habitable rooms oriented to the north and south
3. Most windows facing onto patios, rather than the exterior of the group
4. Shaded pedestrian circulation
5. Small patios to provide sheltered outdoor living space
6. Very limited planting

Figure 2

Typical Layout for Structural Cooling

Daytime air movement for body cooling may be achieved by mechanically stirring the air with ceiling fans or some other mechanical equipment. Natural ventilation can be used for bodily cooling during the night when the structure is being ventilated. However, there may be limits to the rate at which cold night air can be introduced to occupied spaces. This depends on the air temperature and the use of the space.

2.2.4 EVAPORATIVE COOLING. Evaporative cooling may be used in hot-arid climates where water is available and is most effective in regions with high dry bulb temperatures (greater than 80deg.F or 26.7deg.C) and wet bulb temperatures of 65deg.F (18.3deg.C) or less. Evaporative cooling functions through absorption of sensible heat by water from the air in the phase change of liquid to vapor. Evaporative cooling may be achieved by mechanical or passive (wind induced) means. Two types of evaporative cooling exist: direct, in which the building supply air is humidified, and indirect, in which it is not. A combination indirect and direct evaporative cooling can create cooler temperatures than

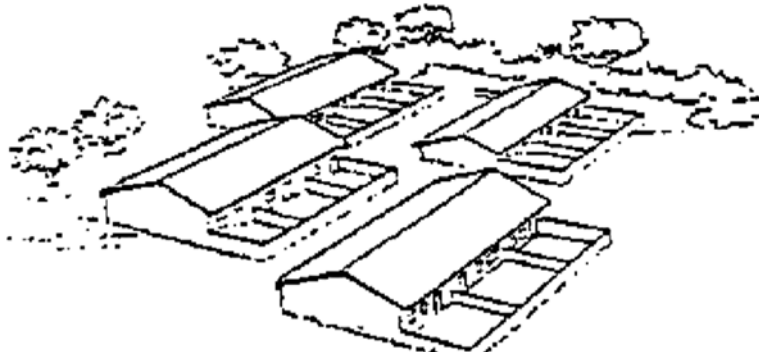
that of either type alone. A passive direct evaporative cooling system can reduce dry bulb temperature by 40 to 50 percent of the difference between dry bulb and wet bulb temperatures, whereas a mechanical direct evaporative cooling system can reduce dry bulb temperature by 60 to 80 percent. Evaporative cooling is not covered further in this course.

2.2.5 EARTH COOLING. The earth may be used as a heat sink wherever the below grade soil temperature is lower than the ambient interior temperature. The ground is the only heat sink to which a building can continuously lose heat by means of conduction during the overheated season. There are no simple analytical techniques for predicting the cooling potential of the ground.

2.2.6 COMBINATIONS OF NATURAL COOLING STRATEGIES. It is possible to combine the natural cooling strategies, or to use a natural cooling strategy with mechanical air conditioning or heating. Combinations may be achieved on a seasonal basis (such as winter mechanical heating with natural ventilation in the summer for cooling) or by spatial zoning in buildings (partly air conditioned and partly naturally ventilated). Combining the strategies with mechanical systems are especially useful in composite climates where seasonal variations complicate the design of the building (see Figure 3).

2.3 COMFORT CRITERIA. The acceptable comfort zone shall be that prescribed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 55, Thermal Environmental Conditions for Human Occupancy. Eighty percent or more of the building occupants will find this zone thermally acceptable in still air and shade conditions. Figure 4 shows the acceptable range of temperature and humidity conditions for persons in typical summer and winter clothing at near sedentary activity levels.

2.3.1 THE EFFECT OF AIR MOVEMENT. Air movement influences the bodily heat balance by affecting the rate of convective heat transfer between the skin and air, and



Main Design Features

1. Main habitable rooms facing north and south
2. Controlled space between dwellings for air movement in the humid season
3. Planting and layout provide protection from hot-dry and cold winds
4. Walls to provide some shade to external spaces
5. Medium depth of building to allow temporary cross ventilation in the humid season

Figure 3

Typical Layout in a Composite Climate

the rate of bodily cooling through evaporation of skin moisture. The air velocity lines indicated on Figure 4 show the extent to which increased air movement can increase the range of temperatures and humidities in which people will feel comfortable.

2.3.2 REQUIRED AIR VELOCITIES FOR HUMAN COMFORT. Minimum rates of ventilation are based on requirements for health (oxygen supply and removal of contaminants). Ventilation, natural or mechanical, is required at all times. Refer to ASHRAE publications for minimum rates by occupancy and building type. The maximum rates of interior air velocity are defined by factors other than human physiological comfort alone. The upper limit of indoor velocity depends on building type and use. For offices and commercial spaces, the limit is 160 fpm (0.8 m/sec), the point at which loose paper, hair and other light objects may be blown about.

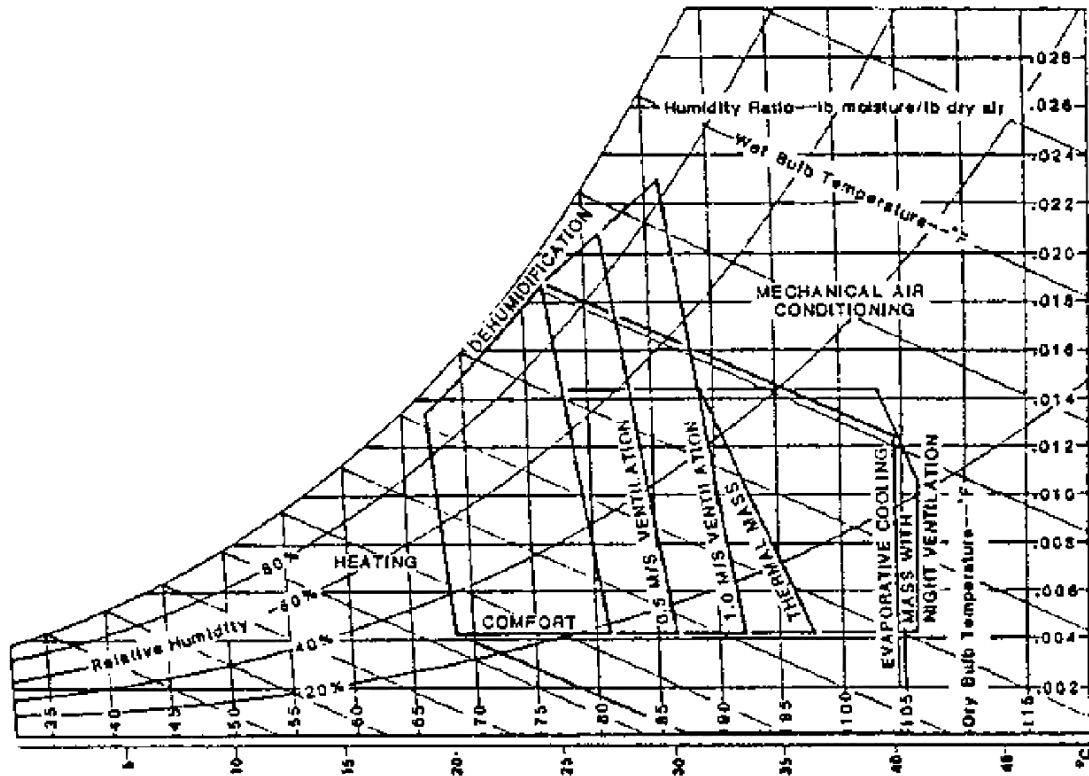


Figure 4

Bioclimatic Chart with Base Comfort Zone

In heavy industrial spaces, this limit is not as important as the removal of toxic fumes, heat or other deleterious conditions; and therefore, higher indoor velocities (up to 300 fpm or 1.5 m/sec) are acceptable. Maximum indoor air velocities for residential buildings are between these extremes. A practical upper limit is 197 fpm (1.0 m/sec).

3. DESIGN CRITERIA

3.1 BUILDING DESIGN FOR NATURAL VENTILATION

3.1.1 INTRODUCTION. Continuous ventilative cooling is suitable in hot-humid climates such as Hawaii where the high atmospheric humidity limits the daily swing of temperature. In such climates, buildings cannot cool off sufficiently at night to reduce daytime internal temperatures substantially below the outdoor daytime temperature. The best buildings for such zones have continuous ventilation day and night, both for cooling the occupants directly and for dissipating any internal gains. The indoor temperatures remain close to the outdoor temperatures. These buildings are usually open, relying on their connection to the outside wind environment to achieve the most comfortable interior conditions. The primary comfort requirements for buildings using natural ventilation are to protect occupants from the sun and rain without obstructing the airflow that cools both the occupants and the building structure. Minimizing heat gain and promoting maximum ventilation are of primary importance.

3.1.2 REQUIREMENTS AND RECOMMENDATIONS

3.1.2.1 CLIMATE ANALYSIS. Perform a Climate Analysis to determine the number of months that natural ventilation will provide comfort and the air velocity required to achieve comfort in the given climate.

3.1.2.2 REQUIRED AIR CHANGES. An outside air exchange rate sufficient to remove internal heat gain must be provided to prevent a rise in interior temperature. Calculate the required air changes to keep the building's interior temperature below the top of the comfort zone at the 98 fpm (0.5 m/sec) internal air movement boundary.

3.1.2.3 SITE SELECTION. Sites in which the slope, elevation, orientation, vegetation and wind pattern act to increase summer and winter cooling by wind and decrease radiation effects by shading should be used. Locations near large bodies of water may

be preferable if cooling breezes can be directed into the building(s). To minimize heat gains from solar radiation, south, south-southeasterly and northern slopes are preferable. West and east facing slopes should be avoided due to the difficulty of providing adequate shading. The most desirable wooded sites have high tree canopies and open trunk areas, permitting air movement while providing shade. Avoid sites with dense low canopy trees which block breezes and trap humidity in dead air pockets.

3.1.2.4 SITE PLANNING AND LANDSCAPING. Buildings must be spaced to allow winds to reach the ventilation openings. In general, it is not desirable to site buildings within the wake of surrounding structures or landscaping. In most cases dense development should be avoided. The terrain, surrounding vegetation and other nearby structures may be used positively to "channel" or redirect breezes into the building. On sloping sites, locations near the crest of the hill on the windward side are desirable. Valley bottoms should be avoided since they may have reduced air movement. Street layouts can be used to channel airflow in higher density site planning. If buildings are grouped, airflow principles should be used to determine the most suitable arrangement. Minimize unshaded paving to reduce the amount of solar heat absorbed and stored near the building. Organic ground covers are preferable to man-made surfaces since they are able to reject solar heat by evaporation.

3.1.2.5 BUILDING ENVELOPE AND STRUCTURE. The roof and walls exposed to the sun shall be well-insulated to keep solar gains to a minimum. Light colored, reflective exterior surfaces shall be used. Solid outer walls shall be reduced to a minimum to permit maximum ventilation. The roof becomes the dominant building feature providing protection from the sun and rain. There is an advantage to using lightweight envelopes that will not store daytime heat into the evening hours. The building envelope shall be designed and constructed to maximize natural ventilation of the interior spaces. The building's orientation and shape are important concerns. One- or two-room-deep plans elongated along the east-west axis are preferable. Window placement, size, type, and position will influence ventilation effectiveness. Elevating the building may also be desirable.

3.1.2.6 SOLAR SHADING. Shading of the glazing is required at all times of the year when cooling is required (both natural and mechanical) from 8 am to 6 pm solar time. The shading should be exterior to the glazing to provide maximum protection from radiant solar heat gain. External shading of building surfaces, outdoor living areas and parking lots is also recommended. If the proposed design does not meet these shading requirements, the designer should provide heat gain/loss calculations to show that effective solar control will be provided by alternative means and that thermal comfort will be maintained.

3.1.2.7 THERMAL INSULATION. The ceiling should be insulated if an attic is required. Roofs above inhabited spaces, and walls exposed to direct sunlight should also be insulated.

3.1.2.8 INTERIOR SPACES. Interior occupied spaces shall be shaded and well ventilated. Minimum interior walls, partitions and other obstructions to airflow are desirable. Light, reflective colors are preferable. Heat, moisture, and odor-producing areas should be separated from the rest of the occupied spaces and separately ventilated.

3.1.2.9 BACK-UP MECHANICAL SYSTEMS. It may be necessary or desirable to include backup ventilation using a whole-house fan, ceiling fans in the interior spaces, or a mechanical ventilation system to ensure comfort when wind-driven ventilation is inadequate. Ceiling fans are required in all major occupied spaces of naturally ventilated buildings when comfort cannot be achieved by natural ventilation alone.

3.1.3 SPECIAL CONSIDERATIONS

3.1.3.1 MECHANICAL SYSTEM INTEGRATION. Naturally ventilated buildings may not be completely compatible with conventional mechanical systems. Care shall be exercised so that neither cooling strategy undermines the effectiveness of the other. Automatic sensors to detect open windows or doors and to shut down mechanically-

conditioned air supply are recommended in naturally ventilated buildings with backup air conditioning or closed-loop ventilating systems. Natural ventilation of buildings with large openings in the building envelope is inappropriate during months when appreciable heating or air conditioning is required unless the openings can be closed to thermal and infiltrative losses. In such cases, movable insulation shall be considered.

3.1.3.2 CONDENSATION. Condensation may be a problem in buildings combining natural ventilation with mechanical air conditioning. Note that planning and design to minimize mechanical air conditioning loads does not always coincide with planning for natural ventilation. If a combined (zoned) system is desired, each shall be designed for maximum efficiency and the connection between the zones should be carefully detailed.

3.1.3.3 OTHER ISSUES. Due to the "open" nature of naturally ventilated buildings, special consideration shall be given to possible problems with noise, privacy, and rain protection.

3.1.3.4 BUILDING TYPE CONSIDERATIONS. High ventilation rates may not be suitable for offices (where papers may be blown about) or for uses requiring high security, or rigid environmental standards (such as computer and other sensitive instrument rooms, toxic producing processes, hospitals, clinics, etc). In general, natural ventilation may be considered for all residential projects, recreation facilities, religious buildings, industrial buildings and general purpose warehouses when climate analysis indicates that natural ventilation is an acceptable strategy. Storerooms for hazardous materials or for materials requiring humidity control are not addressed by this course. In buildings where natural ventilation is indicated as an acceptable strategy, mechanical cooling may still be necessary for critical areas, but the natural ventilation may be used to reduce energy and mechanical equipment costs in less critical areas.

3.1.4 OPTIMAL CONFIGURATION TO ENCOURAGE VENTILATION. Each building project and site will have a unique set of opportunities and constraints, and should be

considered on a case-by-case basis. The following "ideal" set of design conditions would produce one optimal configuration for ventilation.

- **Site Selection and Planning.** The optimal site is an open site near the crest of a south-facing hill with a minimum of five building heights between buildings. Nearby solid enclosure walls or fences that might block the wind should be avoided.
- **Building Shape.** Buildings shall be elongated along the east-west axis, with the long faces to the south and north, elevated on columns or north-south walls.
- **Landscaping.** Nearby ground surfaces should be covered with grass rather than asphalt. Trees and hedges that shade the ground, building surfaces, open outdoor areas and parking lots should be selected.
- **Building Envelope.** Design should provide for adequate insulation and shading to minimize internal heat gains from solar radiation. Large openings in positive and negative pressure zones shall be on the north and south walls for ventilation. If insect screens are necessary, they shall be placed at the balcony walls rather than directly over the windows, to increase the screen area and reduce its resistance to incoming airflow.
- **Interior Planning.** For maximum ventilation, the building should be planned with a single loaded corridor and minimal interior partitions in the naturally ventilated rooms. Separate ventilation of odor, heat or humidity producing spaces such as bathrooms should be provided, and these spaces should be placed on the lee side of the building. Provide ceiling fans in all major occupied spaces for use when outside wind speeds are too low.

3.1.5 ANALYSIS AND TESTING PROCEDURE. Every building design shall be evaluated to determine if the required comfort levels are achieved. When evaluating the quality of ventilation from a human comfort standpoint, it is important to consider the interior air distribution as well as the total amount of airflow. One or more of the following five analysis methods shall be undertaken as early in the design process as possible to facilitate any necessary design changes.

3.1.5.1 METHOD 1. Perform a window sizing procedure for the worst two naturally ventilated months. If the proposed building design meets or exceeds the required window square footage, then acceptable levels of comfort can be expected.

3.1.5.2 METHOD 2. The ASHRAE formulae may be used to determine interior air movement rates in relatively simple buildings. Examine the two worst naturally ventilated months. If the proposed building design achieves greater or equal air movement than that required from the climate analysis, then acceptable comfort levels can be expected.

3.1.5.3 METHOD 3. For complex building shapes or buildings taller than six stories, use a wind tunnel test to obtain direct interior velocity measurements or to obtain surface pressure coefficients for use in the window sizing method. For buildings that are complex or house critically important functions, computer analysis using a typical hourly weather tape to estimate indoor thermal conditions is also recommended.

3.1.5.4 METHOD 4. For one-story buildings, field modeling may be substituted for wind tunnel testing. The results can be plotted on the bioclimatic chart or input into a computer program to determine comfort levels.

3.1.5.5 METHOD 5. A thermo-physiological model may be used to determine the percentage of time that the building will be comfortable, based on a computer-generated hourly simulation of human thermal comfort. Predictions of the interior air velocity rates (determined by one of the methods listed above) and hourly indoor thermal conditions (from computer thermal analysis) are required as input. For important or complex buildings, this method will provide the most accurate estimate of thermal comfort.

3.2 BUILDING DESIGN FOR ZONED AND SEASONAL COMBINATIONS

3.2.1 INTRODUCTION. Natural ventilation is commonly combined with Heating-Ventilation and Air Conditioning (HVAC) systems in zoned buildings and seasonally adjustable buildings.

3.2.1.1 ZONED BUILDINGS. The zoning approach combines natural ventilation (or other passive cooling strategies) and HVAC systems spatially within the building. In one form, zoning involves migration of occupants by providing a variety of thermal zones, each of which is comfortable under a different set of climatic conditions. Because each thermal zone is tuned to a limited set of environmental conditions, its design is simpler. The zone approach may exploit a particular site characteristic such as orientation or placement near water, a particular material characteristic such as thermal capacity, a particular climate characteristic such as nighttime downslope winds, or a particular cultural or social pattern such as sleeping outdoors. Traditional examples of such zones are the verandas/porches of the southern U.S. and the rooftop sleeping areas of Middle Eastern buildings.

3.2.1.2 SEASONALLY ADJUSTABLE BUILDINGS. These are suitable for variable climates in which natural ventilation applies for only part of the year. Seasonally adjustable buildings aim at balancing the differing requirements of the various seasons. The characteristics of the building envelope and siting will vary depending upon the length and severity of the seasons. They commonly employ seasonally adjustable features such as storm windows, insulated shutters and solar shading devices such as awnings and vegetated trellises.

3.2.2 REQUIREMENTS AND RECOMMENDATIONS. Perform a Climate Analysis to determine the percentage of time that natural ventilation will provide comfort and the air velocity required to achieve comfort in the given climate. This method also examines possible seasonal variations which may affect the building design.

3.2.2.1 EARLY STAGES OF DESIGN. The designer should consider zoned or seasonally adjustable envelope configurations during the early stages of design in order to maximize their effectiveness.

3.2.2.2 CONSIDERATIONS FOR ZONED BUILDINGS. To determine the potential for a zoned building, examine the programmed uses of the building. Uses requiring differing environmental conditions suggest a zoned building system.

3.2.2.3 CONSIDERATIONS FOR SEASONABLY VARIABLE BUILDINGS. To determine the acceptability of designing a seasonally variable building, determine the number and months when natural ventilation and mechanical systems should be used.

3.2.2.4 COMPUTER APPLICATIONS. Review the cooling strategies and design features that could be applicable for different parts of the building and for different times of the year to determine whether combinations of natural ventilation and HVAC systems will work more efficiently than natural ventilation or HVAC alone. For simple buildings, this may not require detailed analysis. In more complex cases, where computer simulation is desirable, the computer program needs to have multi-zoned or attached-sunspace capabilities in order to simulate a zoned building configuration.

3.2.2.5 SEASONAL ADJUSTMENTS. The naturally ventilated part(s) of the building may require seasonal adjustment in some climates to extend the period of its use. Examples of this seasonal adjustment include screened porches which are enclosed with glass "storm windows" to become useful as sun spaces during the winter. Movable insulation panels may also be used either seasonally or on a night-day cycle to maintain habitability.

3.2.3 SPECIAL CONSIDERATIONS

3.2.3.1 MECHANICAL SYSTEMS INTEGRATION. In zoned or combination buildings, the connection between the zones must be carefully detailed so that neither side

creates a negative thermal impact on the effectiveness of the other side. The naturally ventilated portion of the building should be separated from the mechanically-cooled portion by insulated partitions (a minimum of R-6 insulation for walls, single glazing for windows between zones). Exfiltration from the mechanically cooled zone should not exceed 1 air change per hour during the period when mechanical cooling is in operation.

3.2.3.2 HEAT LOSS THROUGH GLAZED AREAS. During the heating season, glazed areas are the most vulnerable component of the building envelope to unwanted heat loss by radiation and convection. Movable insulation can substantially reduce both heat loss through glazed components at night and undesirable solar heat admission during the day.

3.2.4 ANALYSIS AND TESTING PROCEDURE. In complex or important buildings, computer simulation may be necessary or desirable. The computer program must have multizoned or attached sunspace capabilities in order to simulate a zoned building configuration. A single-zone model cannot provide a useful analysis of building energy use, or of the hourly thermal conditions expected in the various zones. At a minimum, hourly runs should be performed for peak four-day periods in each season.