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Authors

Arens, Edward A
Watanabe, N.

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A METHOD FOR DESIGNING NATURALLY COOLED BUILDINGS USING BIN CLIMATE DATA

E.A. Arens, Ph.D. **N.S. Watanabe**

ASHRAE Member

ABSTRACT

A manual method for determining the effectiveness of cooling strategies and for sizing ventilative openings in buildings is described. It allows for a fairly rapid assessment of the natural cooling potential of the climate, and assists with the determination of: the most appropriate design for the building envelope, whether heating or mechanical cooling systems are required, and whether a mechanical ventilation system is required as a backup to natural ventilation.

In the case of ventilative cooling, the method also assists the designer with the design of the building's orientation, shape, and ventilative openings.

The method uses binned weather data contained in the Summary of Meteorological Observations, Surface (SMOS) and Revised Uniform Summary of Surface Weather Observations (RUSSWO).

Many new criteria on acceptable comfort conditions needed to be assembled for the described procedure. For some of these there was little published precedent and further work is indicated.

INTRODUCTION

In naturally cooled buildings, the building envelope acts as a mediator between the interior environment and the exterior climate providing cooling at little or no energy cost. When natural cooling techniques can supplant some or all of a building's mechanical cooling requirements, two types of cost savings may result: (1) the energy costs of operating the air-conditioning system and (2) the first cost of unnecessary mechanical equipment. As a result it is useful to examine whether natural cooling can be successfully used in a building to replace mechanical cooling either wholly or in part. Partial uses might be seasonal, such as extending the periods of the year in which mechanical cooling is not needed, or spatial, such as zoning the building to mechanically condition only the parts that cannot be cooled naturally. It is also useful to determine whether low-powered ceiling or ventilating fans are needed to supplement the natural cooling.

BACKGROUND

In naturally cooled buildings, the interior environment is closely linked to the exterior climate. The interior conditions are not as closely controlled as is usual with mechanical systems. The building acts as a filter, allowing some part of the varying exterior climate to be transmitted to the interior. Thus, to quantify the performance of such buildings in providing comfortable conditions for their occupants, one must be able to characterize in some detail both the exterior climate and the building's effects on the climate.

Edward A. Arens, Associate Professor, Department of Architecture, College of Environmental Design, University of California, Berkeley; and Nora S. Watanabe, Research Manager, Center for Environmental Design Research, College of Environmental Design, University of California, Berkeley.

Natural cooling analysis lends itself to hour-by-hour simulation because the complexities of climate, such as the coincidental occurrence of several climatic variables, are fully maintained on the computerized climatic record. The building's influence on the climate can thus be modeled in some detail. Hourly simulation is now routine in the design of passively heated and cooled buildings and is quite sophisticated in determining the effects of evaporative cooling and thermal mass elements on heating or cooling. Although the simulation of wind-driven ventilative cooling is in its infancy, it shows promise provided a human thermal comfort model sensitive to interior air movement is incorporated into the simulation (Arens, Blyholder, and Schiller 1984).

There are very few noncomputerized methods for predicting the performance of naturally cooled buildings. One exception is a technique originally developed by Givoni (1976) for evaluating the cooling potential of a climate using the psychrometric chart. This technique was used by Watson and Labs (1985) to produce an analysis of passive heating and cooling potential for selected locations in the U.S. They processed hourly weather data for 29 stations to produce summaries of the number of hours per year during which different passive strategies were capable of providing comfort. They then referred the designer to a list of design techniques that were appropriate for achieving the various passive strategies.

STATEMENT OF THE PROBLEM

Building designers and owners are faced with the difficult problem of determining whether natural cooling techniques can be substituted for mechanical cooling in order to save energy. One solution, which would be particularly useful in the early stages of planning and design, is a manual procedure for quickly determining the potential of various cooling strategies in different climates. The procedure should be based on accepted criteria for occupant comfort and should indicate the success of possible cooling strategies in terms of the percentage of time that they are able to (or fail to) maintain human thermal comfort in the building.

In developing this procedure, the method of Watson and Labs (1985) served as a useful model. However, there were four principal technical problems to be solved:

1. Modifying the comfort zone boundaries on the building bioclimatic chart to reflect the most current comfort criteria and the special requirements of naturally cooled buildings.
2. Finding summarized climatic data for assessing the natural cooling potential for many climates worldwide, so that the designer need not obtain and process hourly weather data.
3. Extending and amplifying Watson and Labs' method, from a graphic analysis of climatic potential, to a stepwise decision-making process for determining the cooling requirements of the building design. This process should be based on quantified design criteria.
4. Including a procedure for sizing windows to meet the ventilative cooling requirements determined in the climatic analysis.

BUILDING BIOCLIMATIC CHART

The "Building Bioclimatic Chart" is used as the basis for this procedure. This chart combines human comfort requirements with the possible climatic modifications achieved by effectively executed natural cooling strategies. When superimposed on a location's climatic data, the Building Bioclimatic Chart can be used to determine whether the various cooling strategies are appropriate for a given climate.

Its underlying basis is the "Bioclimatic Chart" in which the ASHRAE 55-1981 comfort zone is extended for a variety of combinations of temperature, humidity, wind, and radiation (Arens, Gonzalez, and Berglund 1986). (see Figure 1). On the chart the contour lines represent the same level of comfort as the boundaries of the comfort zone. For example, at point A (78 F or 25°C and 50% relative humidity), one is comfortable in still air and shade and no corrective measures are required. At point B (90 F or 32°C and 35% relative humidity), air movement

equivalent to 200 fpm or 1.0 m/s is required to achieve comfort. At point C (86 F or 30°C and 20% relative humidity), increasing the relative humidity to 30% or providing 100 fpm or 0.5 m/s air movement would achieve comfort.

For natural cooling, it was necessary to modify the upper humidity limit given in ASHRAE Standard 55-1981. This limit, 0.012 moisture ratio, is based on avoiding condensation and mold growth in the ducts of centrally air-conditioned buildings rather than on human thermal comfort requirements. There seems to be little consensus on the upper limit to humidity as it affects human thermal comfort. Experience in warm climates such as Hawaii indicates that humidities of 95% relative humidity can be acceptable in naturally ventilated buildings as long as there is a small amount of air movement.

This leaves the consideration of condensation and mold growth on building surfaces. Since the surface temperatures in most naturally cooled buildings tend to be close to the ambient air temperature, condensation will not occur until relative humidities are very high. One might note that surface temperatures in thermally massive buildings in climates with large diurnal temperature swings can fall considerably below the ambient air temperature in the daytime, but this effect occurs only in climates with low humidities where surface condensation is not a problem. These considerations allowed the upper humidity limit to be raised. Ninety five percent relative humidity was used within the comfort zone, tapering to 85% at 85 F (30°C) at the 2.2 mph (1 m/s) velocity line.

When the climatic limits for each climate control strategy are plotted on the revised bioclimatic chart, the "Building Bioclimatic Chart" is produced (see Figure 2). The building bioclimatic chart indicates that whenever ambient outdoor temperature and humidity conditions fall within the designated limits of a control strategy, then the interior of a building designed to effectively execute that strategy will remain comfortable. The boundaries indicated on Figure 2 are appropriate for residences and other buildings with small internal gains. For buildings with larger internal gains, such as offices and factories, the boundaries would need to be shifted to the left. The strategies may be used alone or in conjunction with air conditioning and conventional heating. They are:

1. solar heating,
2. solar gain controls,
3. ventilation at 1.1 and 2.2 mph (0.5 and 1 m/s),
4. thermal mass (low levels of ventilation),
5. thermal mass with nocturnal ventilation (low ventilation in daytime, high ventilation at night), and
6. evaporative cooling.

The natural ventilation strategy boundary is based on the assumption that indoor air temperature and vapor pressure are identical, indoors and out, and that the mean radiant temperature of the building interior is approximately the same as that of the air. Both assumptions are sufficiently valid if the interior is exposed to high rates of ventilation, the building envelope is well insulated and well shaded, and the exterior is light colored to restrict solar heat gain.

The thermal mass strategy boundary is based on the daily outdoor temperature swing. Since a massive building acts to average out the outdoor temperature swing, the upper temperature limit to this zone is set at one-half of a very high daily temperature range. The half-range is 18 F or 10°C. This maximum is reduced at higher humidities because the daily temperature swing is typically reduced in humid climates. The linear humidity-to-temperature-range relationship is described on page 314 of Givoni (1976). This causes the sloped right-hand margin to the zone. The upper humidity limit of .0144 humidity ratio is based on condensation control on building walls. This value is rather tentative and warrants research.

In the thermal mass with nocturnal ventilation strategy, the upper temperature limit is higher because the building is operated as a thermal diode, "flushed" with cool night air to pre-chill the mass for the next day, and then closed during the daytime to reduce the entry of unwanted heat. This moves the interior temperature swing toward the lower end of the outdoor diurnal temperature range, by an amount found to be equal to 15% (Givoni 1976). In other words, if the outdoor diurnal temperature range is 27 F (15°C), then an additional 4 F (2.3°C) indoor temperature reduction can be obtained by nocturnally ventilating a thermally massive building.

The evaporative cooling boundary refers only to direct evaporative cooling. Its upper boundary is based on the maximum wet-bulb temperature acceptable for comfort in the still air comfort zone. The right-hand boundary is based on experience which suggests that a 25 F (14°C) temperature reduction is the limit of what can be achieved at reasonable indoor air velocities. Greater cooling effectiveness can be obtained in very arid regions by nighttime operation or by combinations of direct and indirect evaporative cooling systems.

SOURCES OF INFORMATION ON CLIMATE

The climatic elements important to natural cooling in buildings are temperature, wind, humidity, and radiation. They act in conjunction to influence comfort and building performance and must be analyzed coincidentally. Hourly data files preserve a full record of these climatic coincidences. However, a computer is needed to process hourly data, which may limit its application in design. Summaries with bins of occurrences of coincident variables offer the next best level of detail.

Such climatic records exist in many forms. ASHRAE, for example, has recently funded the development of bin data for 51 U.S. locations (Degelman 1985). The data are intended for simplified energy calculation purposes, which use bins of dry-bulb temperatures paired with their mean coincident wet-bulb temperatures, and vice versa. This data format is not sufficient for determining the amount of time to be expected within the various boundaries shown on the Building Bioclimatic Chart. For this, the bins must contain fully coincident observations.

The most comprehensive sets of such data available both for the U.S. and worldwide are the Air Force's RUSSWO (Revised Uniform Summary of Surface Weather Observations) and the Navy's SMOS (Summary of Meteorological Observations, Surface). Their almost identical "Part C" (surface winds) and "Part E" (temperature and humidity) summaries are available from the National Climatic Center in Asheville, NC 28801. These summaries are generated from long-term hourly records taken from weather bureau and military weather stations. The worldwide availability of these records is summarized in the NAVAIR Guide (1980), which is also available from the National Climatic Center.

Unfortunately the RUSSWO and SMOS summaries are not produced in psychrometric format. They present the climatic data in bins of dry-bulb temperature vs. wet-bulb depression. Thus the building bioclimatic chart cannot be simply superimposed on the climatic data but must be translated from the more familiar psychrometric format to the weather data format as shown in Figure 3.

CLIMATE ANALYSIS METHOD

Overview

The user superimposes the building bioclimatic chart overlays on the psychrometric summaries and transfers the results onto a formatted climate-analysis worksheet. The method is outlined in the flowchart presented in Figure 4.

Building Bioclimatic Chart Transferred onto Three Overlays. The overlays, represented in Figure 5, plot the range of temperatures and humidities for which the natural cooling strategies should be used in building design. They are printed on mylar at the same scale as the climatic data summary sheets.

Climatic Data from the National Climatic Center. Obtain the RUSSWO or SMOS "Part E": "psychrometric summary" (annual and monthly) and "means and standard deviations of dry-bulb temperature" (annual) from National Climatic Center (704-259-0682) for the weather station most similar to the building site. This is usually the closest station, but in rough terrain there may be large climatic changes over small distances.

Climate-Analysis Summary Worksheet. The user follows the step-by-step method outlined on the worksheet. A completed example worksheet is given in Figure 6.

Step 1: Determining the Appropriate Cooling Strategy

The user inspects the frequency of hours within the natural cooling strategy boundaries on the overlay (see Figure 5) to determine the percentage of time that the natural cooling strategy will apply. This step may be used to determine the most appropriate cooling strategy(ies) for the climate or to determine if a zoned building is appropriate.

Annual Summary. Using the annual psychrometric summary and the overlays, sum the percentage of time within the boundary for each strategy and the comfort zone. For 2.2 mph (1.0 m/s) ventilation, this is zones 1-3. When summing the percentages, count four 0.0% as equivalent to one 0.1% throughout the method. This is necessary because percentages less than 0.05 are rounded to 0.0 in the climatic summaries. The average of such rounded values is assumed to be 0.025.

In general, hot-humid climates require provisions for ventilation for bodily comfort, and hot-arid climates require either high thermal mass or evaporative cooling for bodily cooling, with nocturnal ventilation for structural cooling.

Monthly Summaries. Follow the same procedure using the monthly psychrometric summaries to observe what periods of the year that the natural cooling strategy will apply. If more than one cooling strategy is indicated, then a zoned or seasonally adjustable envelope may be desirable.

Step 2: Determining Whether Mechanical Air Conditioning is Required

Annual Summary. Using the overlay and the annual psychrometric chart, sum the percentage frequency of hours hotter or more humid than the natural cooling strategy(ies). On the overlay, this is the area above the boundary for the strategy (zone 7). See the shaded area shown in Figure 7, "Determining the air-conditioning requirement."

If the total hours above the boundary exceeds 5% annually, an air-conditioning system will be needed and the building envelope must be capable of restricting air infiltration to less than 0.5 air changes per hour. This eliminates porous wall constructions, such as louvered walls and jalousie windows, which cannot be tightly shut.

The 5% value is used for military housing, in which the occupants are rarely expected during the hottest period of the day. This value, and the 10% monthly value used below, were obtained by looking at diurnal temperature swings and by working the method backward in climates and seasons of known ventilative acceptability. The user may select other acceptability criteria. For example, one would expect more stringent criteria for office spaces.

An alternative way to define the acceptability criteria would be to use a small percentage of the time that the boundaries can be exceeded (say 2.5%) during the hours of day when occupants are expected to be present and not in bed (say from 6 to 9 a.m. and 6 to 12 p.m.). This is quite possible, since RUSSWO and SMOS summaries are available for three-hour time intervals throughout the day. There is a small amount of added complexity in that the user has to add up the exceedence percentages under the overlays on several (in the above example, three) summary sheets rather than one. For demonstrating the method here, the all-hours summaries (annual and monthly) are the simplest.

Monthly Summaries. For seasonal requirements, repeat the same procedure using the monthly charts to determine which months will require mechanical air conditioning for more than 10% of the time.

If mechanical air conditioning is required for less than 10% of the time during the month, the natural cooling strategy is viable for that month and the air-conditioning system can be turned off. In zoned buildings, naturally ventilated spaces will be comfortable for that month.

If mechanical air conditioning is required, an infiltration-resistant envelope is required. Skip Step 3 and go to Step 4.

Step 3: Determining Whether an Infiltration-Resistant Envelope is Required

Skip this step if an air-conditioning system is utilized; infiltration must be limited to 0.5 air changes per hour.

Annual Summary. Using the annual psychrometric chart, determine the percentage of time below 67 F (19°C) (see Figure 8, "Determining open or infiltration-resistant envelope requirement"). If more than 10% of the annual hours are less than 67 F, then an insulated building capable of holding infiltration to under one air change per hour is required. This eliminates porous wall constructions, such as louvered walls that cannot be shut. Operable louver windows such as jalousies are acceptable, but fixed open louvers should be avoided.

The upper limit of the climatic data bin directly below the comfort zone is 67 F (19°C). The 10% exceedence criterion may seem high, but the coldest periods of the day occur when the occupants are in bed under blankets. The insulation of blankets extends the comfort zone to lower temperatures, so the amount of time that discomfort is experienced is considerably less than 10%.

An alternative way to define the lower exceedence criterion would be to use 67 F exceeded a small percentage of the time (e.g., 2.5%) during the hours of day when occupants are present and not in bed (e.g., from 6 to 9 a.m. and 6 to 12 p.m.).

Monthly Summaries. If an infiltration-resistant envelope is required, then this procedure may be examined using the monthly psychrometric summaries to determine possible seasonal variations.

Step 4: Determining Whether Heating Equipment is Required

Annual Summary. Using the annual psychrometric chart, determine the percentage of time below 61 F (16°C) (see Figure 9, "Determining heating requirement"). If more than 10% of the annual hours are less than 61 F, auxiliary heating will be required. In addition the building envelope must be capable of holding infiltration to less than 0.5 air changes per hour, eliminating jalousie windows and other openings that cannot be tightly shut.

The 61 F (16°C) value corresponds to the upper limit of the bin below a typical balance point of a free-floating residential building with roof and wall insulation and air exchanges restricted to 0.5 ACH.

Monthly Summaries. For seasonal heating requirements, repeat the same procedure using the monthly psychrometric charts. If heating is required for more than 25% of the time during the month, then the natural cooling strategy will not be applicable and the auxiliary heating system will be used during that month.

Any cooling strategy involving large openings in the building envelope will not be appropriate during months when appreciable heating is required unless the openings can be closed to thermal and infiltrative losses. The 25% heating figure rather loosely defines months too cold to require cooling.

Using Thermal Mass for Heating. The cooling strategy thermal mass might also act to reduce auxiliary heating requirements if the heat losses occur during the daily minimum temperatures and are relieved the same day by a substantial temperature rise.

Step 5: Determining the Monthly Feasibility of the Chosen Cooling Strategy

If the chosen natural cooling strategy is applicable for four months or more (i.e., heating and air conditioning are required for less than eight months), then the strategy is effective and should be used in the building design.

If the most suitable strategy is natural ventilation, then go to Step 6 to determine whether ceiling fans are required.

If the number of months when air conditioning and heating are required is greater than eight, then using the natural cooling strategy seasonally or zonally to reduce loads on the required mechanical systems may be economical.

Step 6: Determining Whether Ceiling or Whole-House Fans are Required

It may be necessary to include backup ventilation using a ceiling or whole-house fan to ensure comfort when wind-driven ventilation is inadequate. Fans are required in all major occupied spaces of naturally ventilated buildings when comfort cannot be achieved by natural ventilation alone. The requirement is determined from the climatic data by the following procedure:

1. If an SMOS summary is available, use Part E, "Percentage Frequency of Air Temperature vs. Wind Directions," for the two hottest months of the year as determined in Step 2. If the total percent time that is calm and above 81 F (27°C) is greater than 10% for either month, then fans should be installed. This percentage limit is the same as that used in Step 2 to determine whether mechanical cooling is required.
2. If only a RUSSWO summary is available, use the two hottest months of the year as determined in Step 2. From Part C, "Surface Winds," determine the total percent calm for these months. Add the percentage of time within the natural ventilation boundary (determined in Step 1) and the percent above the boundary (determined in Step 2) for each of the two months to determine the total time above the comfort zone upper boundary. Multiply the percent time calm by the total time above the comfort zone boundary for the month and divide by 100. If this is greater than 10% for either month, then fans should be installed.
3. If the natural ventilation strategy is indicated, follow the window sizing procedure described below.

After following these procedures, schematic design can begin. The user should refer to published collections of design features and concepts, such as those presented in Watson and Labs (1985) or Koenigsberger et al. (1973), for architectural examples.

WINDOW SIZING PROCEDURE

Required Total Window Areas. A stepwise procedure to size ventilative openings is presented in the Appendix. The procedure is used to determine required total window inlet and outlet areas based on a required interior air velocity. It is valid for rooms with only one interior partition, or open rooms in one- to six-story buildings without large interior gains.

The procedure is based on work published by Chandra et. al. (1983). We have added only the periods over which the analysis is performed, the use of RUSSWO and SMOS data in the method, the pressure coefficients for tall buildings, and the resistance factors for interior partitions.

Care should be taken in using this procedure out of context. For elaborate and complex buildings, wind tunnel or field tests might be necessary. In addition, there is some indication that this type of method may apply only under fairly strong (over 6 mph) winds with relatively low turbulence.

CONCLUSION

A manual method of climatic analysis is described for determining the effectiveness of cooling strategies and for sizing ventilative openings in buildings. It provides designers:

1. A fairly rapid assessment of the natural cooling potential of the climate,
2. A determination of the most appropriate nature for the building envelope,
3. A determination of whether heating or mechanical cooling systems are required, and
4. A determination of whether a mechanical ventilating system is required as a backup to natural ventilation.

In the case of ventilative cooling, a design method is included for sizing ventilative openings in response to the requirements determined in the climatic analysis. The method also assists with building orientation and shape. The opportunity for developing similar procedures to aid in the design of the other natural cooling strategies remains to be explored.

Both the climatic analysis and design methods employ a readily available resource underutilized by the building design community: the SMOS and RUSSWO bin data summaries. The summaries include climatic bins providing information on the occurrence of combinations of climatic variables very useful to building design, such as wind direction vs. temperature, temperature vs. humidity, and wind speed vs. direction. The various climatic summaries are available in hourly, three-hourly, monthly, and annual tabulations.

Many new criteria on acceptable comfort conditions are included in the described method. For most of these, there is little published precedent. The new criteria include: the upper humidity limit on the bioclimatic chart, the upper levels of acceptable air movement under ventilative cooling, adjustments to the boundaries of the Building Bioclimatic Chart, and the percentages of time that discomfort is acceptable on a monthly and annual basis. Several of the criteria values in the method were selected by testing the method in climates for which the natural cooling potential was known and adjusting the criteria to fit. Further research is needed to better define such criteria.

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APPENDIX

Window Sizing Procedure

The user must first obtain the following climatic data:

SMOS "Part E": Temperature vs. Wind Direction (annual and monthly), and
 RUSSWO "Part C," Surface Winds (annual and monthly).

The user then performs the following steps to determine the size of the ventilation openings.

- (1) Required air velocity rate, V
 From the Climatic Analysis V = _____ fpm

- (2) Cross-sectional area of the room, CS
 Height of room, H H = _____ ft
 Width of room across flow, W W = _____ ft
 See Figure A-1, "Examples of Room
 Width for Window Sizing Procedure"

 $CS = H * W$ CS = _____ ft²

- (3) Required airflow rate, CFM.
 $CFM = V * CS$ CFM = _____ cfm

- (4) Building location = _____ (city)
 Weather Station location = _____
 Design months = _____ = _____
 From: Climatic Analysis--examine worst
 two naturally ventilated months separately.

- (5) Prevailing wind direction for month, WD. WD = _____ = _____
 (a) OPTION 1: SMOS Part E--Temperature vs.
 Wind Direction. Pick predominant wind
 direction associated with the 82-86 F band
 for the month; 82-86 F roughly corresponds
 to the conditions when ventilation is effective.

 (b) OPTION 2: If no SMOS exists for the location,
 use RUSSWO Part C--Surface Winds
 Pick predominant wind direction for month.

- (6) Wind speed for month, WS. WS = _____ knts = _____ knts
 From: SMOS or RUSSWO Part C--Surface Winds
 Pick mean wind speed corresponding to
 direction chosen in Step 5 for the month.

- (7) Incidence angle on windward face, α $\alpha =$ _____ deg = _____ deg
 (From site plan and prevailing wind
 direction, see Figure A-2).

- (8) From Table A-1 or A-2 determine:
 (a) Windward pressure coefficient, WPC WPC = _____ = _____
 (b) Leeward pressure coefficient, LPC LPC = _____ = _____

- (9) Pressure coefficient differential, PCD.
 $PCD = WPC - LPC$ PCD = _____ = _____

- (10) For the surrounding neighborhood and
 the proposed building type, determine
 from Table A-3 the pressure coefficient
 correction factor, PCCF. PCCF = _____ = _____

- (11) Calculate the revised pressure coefficient differential, PD.

$$PD = PCD * PCCF$$

$$PD = \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$$

- (12) Obtain terrain correction factor, TCF.
From Table A-4.

$$TCF = \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$$

- (13) Compute revised meteorological wind speed in feet per minute, W.

$$W = WS * TCF * 101.2$$

$$W = \underline{\hspace{2cm}} \text{ fpm} = \underline{\hspace{2cm}} \text{ fpm}$$

- (14) Calculate required open effective window area, A.

$$A = \frac{1.56 \text{ CFM}}{W * (PD)^{0.5}}$$

$$A = \underline{\hspace{2cm}} \text{ ft}^2 = \underline{\hspace{2cm}} \text{ ft}^2$$

- (15) Select an open inlet area, $A_i > A$.
Note: if equal inlet and outlet area are desired, $A_i = 1.41 A$.

$$A_i = \underline{\hspace{2cm}} \text{ ft}^2 = \underline{\hspace{2cm}} \text{ ft}^2$$

- (16) Calculate open outlet area, A_o .

$$A_o = A * A_i / (A_i^2 - A^2)^{0.5}$$

$$A_o = \underline{\hspace{2cm}} \text{ ft}^2 = \underline{\hspace{2cm}} \text{ ft}^2$$

- (17) Increase open areas calculated above for resistance due to insect screens, partially open windows, partitions, etc.

Find Resistance Factor (RF) from Table A-5.

$$RF = \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$$

- (18) Calculate TOTAL (not open) inlet and outlet window areas, TA_i , TA_o .

$$TA_i = A_i / RF \quad TA_i = \frac{\underline{\hspace{2cm}} \text{ ft}^2}{\text{Total Req'd Inlet Area for worst month.}}$$

$$TA_i = \frac{\underline{\hspace{2cm}} \text{ ft}^2}{\text{Total Req'd Inlet Area for second worst month.}}$$

$$TA_o = A_o / RF \quad TA_o = \frac{\underline{\hspace{2cm}} \text{ ft}^2}{\text{Total Req'd Outlet Area for worst month.}}$$

$$TA_o = \frac{\underline{\hspace{2cm}} \text{ ft}^2}{\text{Total Req'd Outlet Area for second worst month.}}$$

SUMMARY:

Required velocity, $V = \underline{\hspace{2cm}}$ Weather Station =

Worst month = Second worst month =

Windspeed, $WS = \underline{\hspace{2cm}}$ Windspeed, $WS = \underline{\hspace{2cm}}$

Wind direction, $WD = \underline{\hspace{2cm}}$ Wind direction, $WD = \underline{\hspace{2cm}}$

Open inlet req'd, $TA_i = \underline{\hspace{2cm}}$ Open inlet req'd, $TA_i = \underline{\hspace{2cm}}$

Open outlet req'd, $TA_o = \underline{\hspace{2cm}}$ Open outlet req'd, $TA_o = \underline{\hspace{2cm}}$

TABLE A-1

Typical Average Surface Pressure Coefficients on the Walls of
a Residential Scale (1-2 Story) Building

Wind Angle Figure A-2 α	Building Wall Surface Pressure Coefficients* WPC	LPC		
		a	b	c
0	+0.40	-0.40	-0.25	-0.40
22.5	+0.40	-0.06	-0.40	-0.60
45.0	+0.25	+0.25	-0.45	-0.45
67.5	-0.06	+0.30	-0.55	-0.40

Notes: Recommended Pressure Coefficient values for other apertures are:

1. Inlet with wingwall, PC = +0.40
2. Outlet with wingwall, PC = -0.25
3. Roof outlets (e.g. Venturi Type), PC = -0.30

*Source: Colorado State University wind tunnel tests on a 1:25 scale model of the Florida Solar Energy Center Passive Cooling Laboratory. (Chandra et. al. 1983).

TABLE A-2

Typical Average Surface Pressure Coefficients for 2-6 Story Buildings

FOR BUILDINGS WITH SQUARE FLOORPLANS:

Wind Angle Figure A-2 α	Building Wall Surface Pressure Coefficients# WPC	LPC		
		a	b	c
0	+0.80	-0.70	-0.30	-0.70
15	+0.80	-0.90	-0.50	-0.60
45	+0.50	+0.50	-0.50	-0.50

FOR BUILDINGS WITH RECTANGULAR FLOORPLANS:

Wind Angle Figure A-2	Building Wall Surface Pressure Coefficients#			
	a	b	c	d
0	-0.70	-0.40	-0.70	+0.70
45	+0.40	-0.50	-0.40	+0.60
90	+0.80	-0.50	-0.20	-0.50

#Sources: "The Assessment of Wind Loads," British Research Station Digest #119 (July 1970), and "Wind Forces on Structures," ASCE Task Report, Vol 126 Part 2 (1961).

TABLE A-3

Pressure Coefficient Correction Factor, PCCF

- 1) Wall height of typical upwind buildings, h = _____ ft
 2) Gap between proposed building and adjacent upwind building, g = _____ ft
 3) Ratio, g/h = _____

Ratio g/h	PCCF for Building Types				
	1*	2*	3*	4*	5#
0	0.00	0.00	0.00	0.00	0.00
1	0.17	0.24	0.23	0.31	0.17
2	0.40	0.57	0.54	0.72	0.39
3	0.59	0.83	0.79	1.06	0.61
4	0.73	1.03	0.98	1.32	0.74
5	0.87	1.23	1.17	1.57	0.87
6 or more	1.00	1.41	1.34	1.80	1.00

1. Common one-story building on ground, or lower floor of two-story building.
2. One-story building with extended eaves and wingwalls.
3. Building elevated on stilts or second floor of common building.
4. Type 2 building elevated on stilts or second floor with extended eaves and wingwalls.
5. For first floor of a common two- to six-story building.

Note that pressure coefficients for buildings taller than six stories must be obtained from an appropriate wind tunnel test.

Source *: Florida Solar Energy Center (Chandra et. al. 1983).

#: Lee, Hussain and Soliman, "Predicting Natural Ventilation Forces Upon Low-Rise Buildings," ASHRAE Journal, February 1980, pp 35-39.

TABLE A-4

Terrain Correction Factor, TCF

Terrain Type	24 Hr. Ventilation	Night Ventilation Only
1. Oceanfront or > 3 miles water in front	1.30	0.98
2. Flatlands with isolated wall separated buildings (e.g. farmland)	1.00	0.75
3. Rural or suburban	0.85	0.64
4. Urban or industrial	0.67	0.50
5. Center of large city	0.47	0.35

TABLE A-5

Resistance Factors, RF

Resistance Factor: $RF = IPF \times WPF \times PF$

1. Insect Screening, IPF

Screen Type	Typical IPF
a. No screen	1.00
b. Bronze, 14 wires/inch	0.80
c. Fiberglass, 18 wires/inch	0.60

2. Window Porosity, WPF

Window Type	Typical WPF
a. Single or double hung	0.40
b. Awning, Hopper, Jalousie, or Projections which swivel open on horizontal pivot	0.60-0.80
c. Casement	0.50-0.90

Note: the WPF factors above assume that interior drapes or shades will not block any wind.

3. Interior Partition Factor, PF.

From Figure A-3, choose the factor for the situation which is most similar to the building design. Connections between the rooms are as open as possible (i.e. floor to ceiling openings) which models configurations such as transoms above open doors. Note that the factors on the Figure are averages for the room and that some areas in the room will have much higher or lower velocities.

Figure 2. Building bioclimatic chart

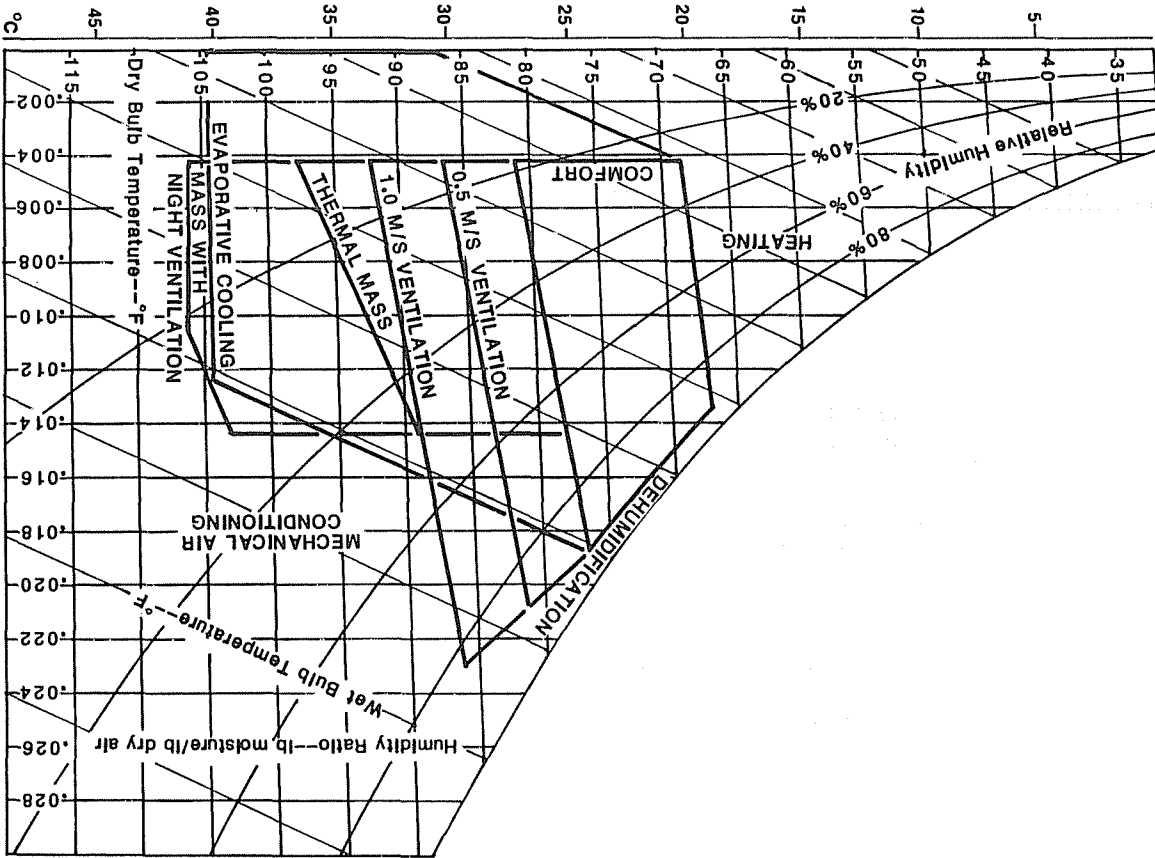
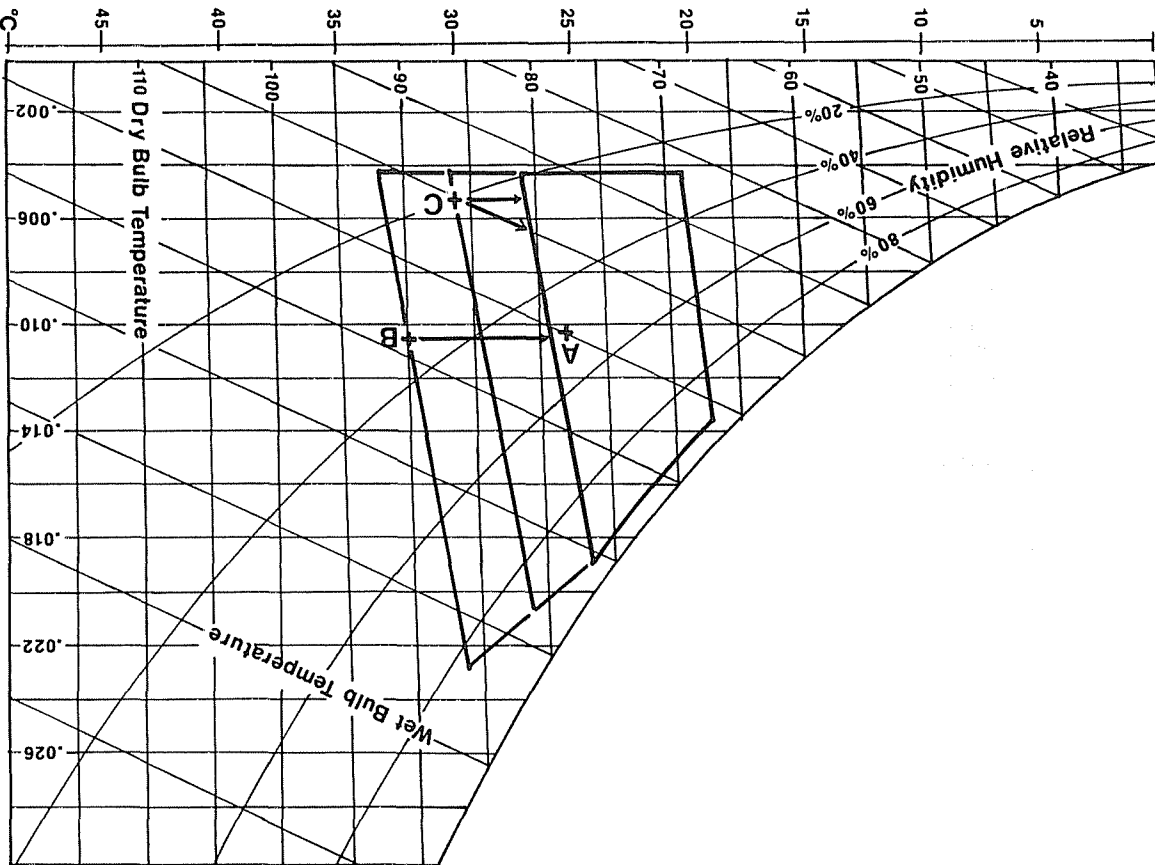


Figure 1. Abbreviated bioclimatic chart and example points



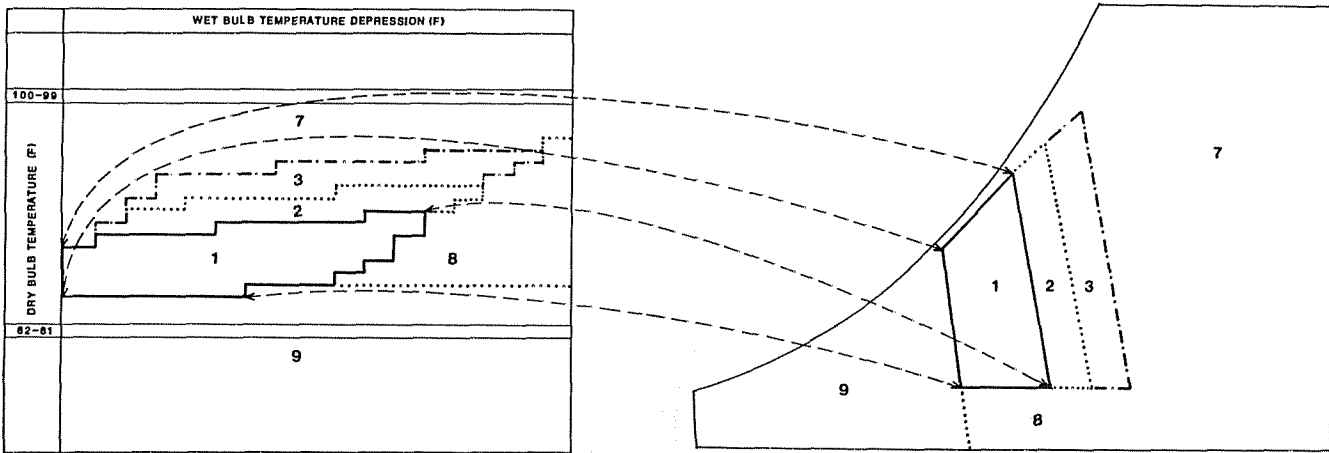


Figure 3. Relationship between the psychrometric and RUSSWO/SMOS format

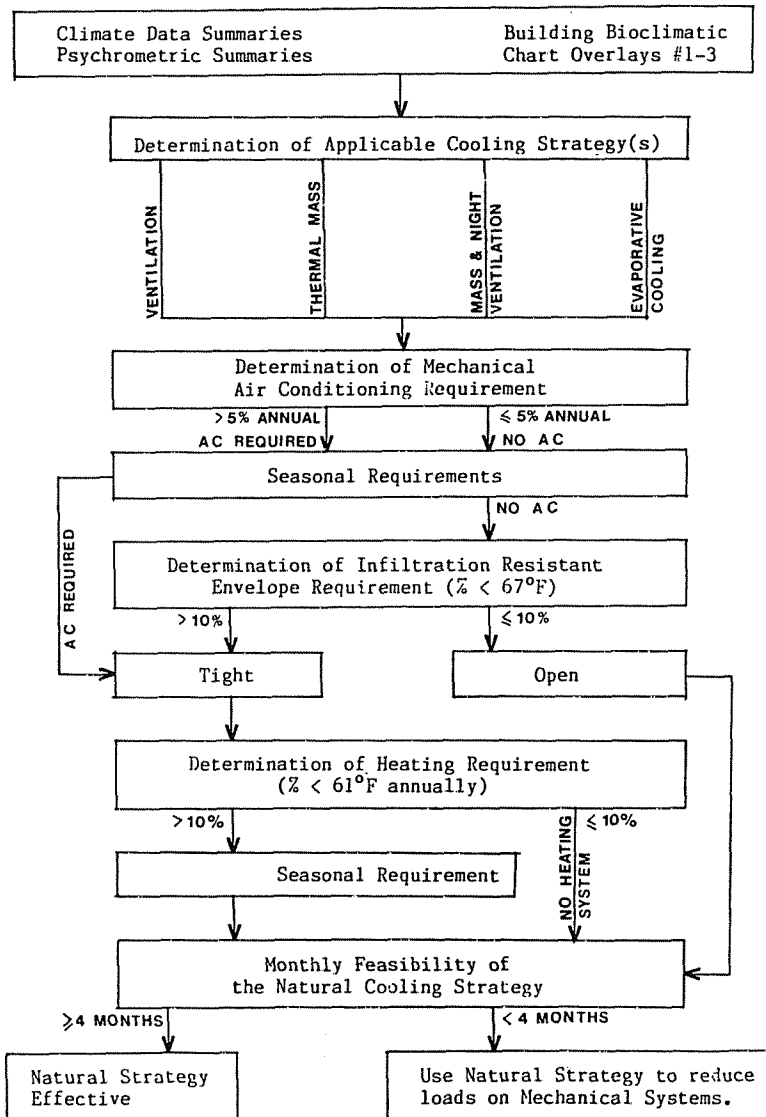
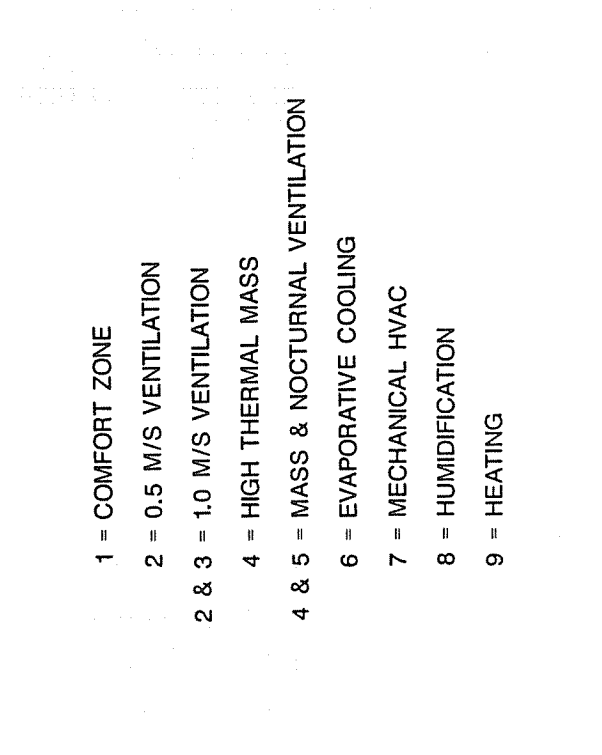
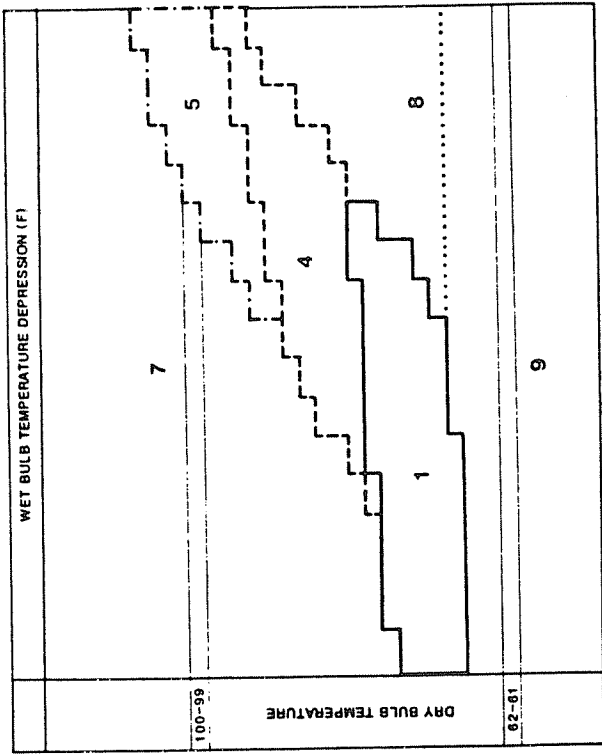


Figure 4. Climate analysis flowchart



- 1 = COMFORT ZONE
- 2 = 0.5 M/S VENTILATION
- 3 = 1.0 M/S VENTILATION
- 4 = HIGH THERMAL MASS
- 5 = MASS & NOCTURNAL VENTILATION
- 6 = EVAPORATIVE COOLING
- 7 = MECHANICAL HVAC
- 8 = HUMIDIFICATION
- 9 = HEATING

Figure 5. Cooling strategy boundaries in RUSSWO/SMOS format

CLIMATE ANALYSIS SUMMARY WORKSHEET

STEP 1: Station Name: KANEHOE BAY, HAWAII Prepared By: N. WATANABE
 Data Years: 73-77 SMOS Date Prepared: 1/86

STEP 2: Determination of Natural Cooling Strategy.

	Annual %	Monthly % of Best Two Strategies:											
		JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Comfort (zone 1).....	63.8	98.5	94.3	92.7	92.0	99.6	96.3	96.8	90.8	85.6	92.7	96.6	97.0
Ventilation 0.5m/s (zones 1 & 2).....	96.6	99.6	94.8	98.1	98.1	100	100	99.8	99.5	99.1	99.7	99.8	97.5
1.0m/s (zones 1, 2 & 3).....	99.9												
Thermal Mass (zones 1 & 4).....	75.5												
Mass + Night Ventilation (z 1, 4 & 5).....	75.5												
Evaporative Cooling (zones 1 & 6).....	74.9												

STEP 3: Determination of Mechanical Air Conditioning Requirement.

	Annual %	Monthly % Above Strategy Boundary (zone 7):											
		JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Best Strategy: <u>1.0M/S VENTILATION</u>	0.1	0.1	0	0	0.1	0	0	0.2	0.5	0.9	0.3	0.2	0
2nd Best Strategy: <u>0.5M/S</u>	3.4	1.2	0.5	0.4	0.4	0.4	1.7	3.2	9.2	17.3	3.4	0.5	

If annual % < 5%, then a.c. is not required.
 If monthly % > 10%, place an "X" in the monthly square above.
 If annual % > 5% then a.c. is required, and the building must have TIGHT ENVELOPE. Go to Step 5.

STEP 4: Determination of Infiltration-Resistant Envelope Requirement.

	Annual %	Can be Examined Monthly to Determine Possible Seasonal Variations:											
		JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
% Below 67°F:.....	0.95												
% Below 67°F:.....													

If < 10%, Open Envelope O.K. Go To Step 6.
 If > 10%, Infiltration-Resistant Envelope Required.

STEP 5: Determination of Heating Requirement

	Annual %	Can be Examined Monthly to Determine Possible Seasonal Variations:											
		JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
% Below 61°F:.....	0												
% Below 61°F:.....													

If < 10%, No Auxiliary Heating System. Go to Step 6.
 If > 10%, Heating Required. Examine Monthly %:
 If Monthly % > 25%, place an "X" in the monthly square above.

STEP 6: Monthly Feasibility of Natural Strategy

	Best Strategy:	Can be Examined Monthly to Determine Possible Seasonal Variations:											
		JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Best Strategy:										X			
2nd Best Strategy:													

If the natural cooling strategy works for > 4 months (i.e. 4 or more open squares), include the natural cooling strategy in design. See Sections 3 and 4 for design requirements and recommendations.
 If the natural cooling strategy works for < 4 months (i.e. 9 or more X's), optional use of the strategy seasonally and/or zonally to reduce loads on mechanical system is recommended.

STEP 7: Determination of Fan Ventilation Requirement. 0.54/s VENT.

	Hottest month	SEPT.	2nd hottest month	AUG.
1. If using SMOS: total time calm and > 81°F:.....		85.6		90.8
2. If using RUSSWO: a. Time within ventilation boundary (from STEP 2):.....		14.4		9.2
b. Time above ventilation boundary (from STEP 3):.....		5.4		2.2
c. Time calm (from Part C, Surface Winds):.....		5.4		2.2
d. (% calm) X (within boundary + above boundary):... e * (a x b)		5.4		2.2

If % time in line 1 or 2d is greater than 10%, then ceiling or whole-house fans must be installed.

Figure 6. Climate analysis summary worksheet

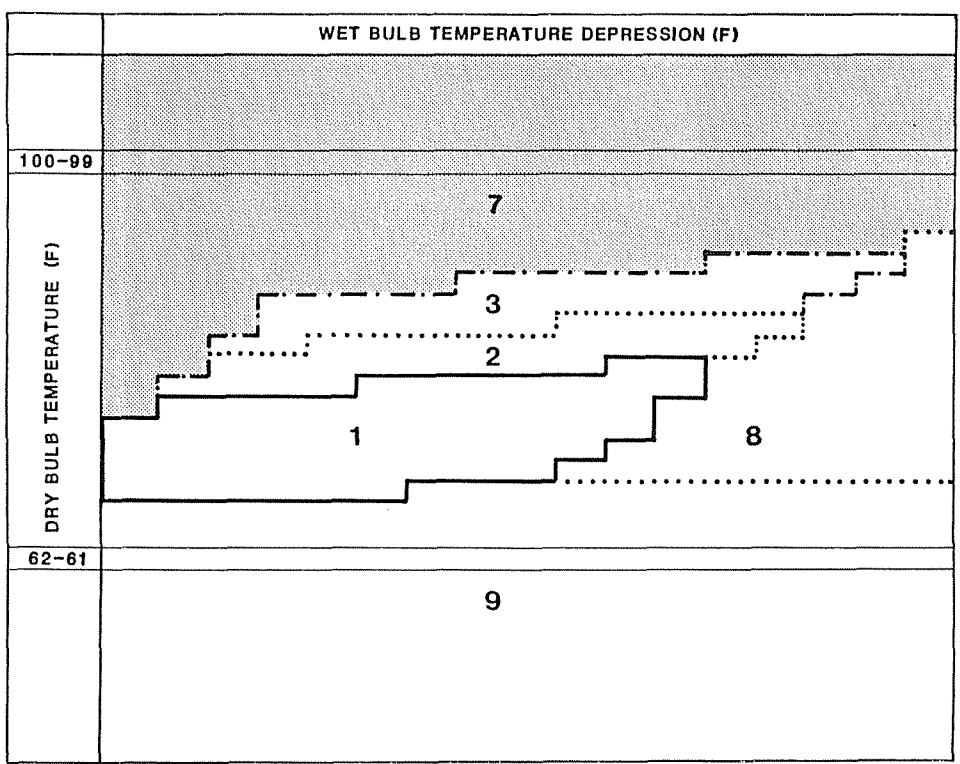


Figure 7. Determining whether mechanical air conditioning is required

PSYCHROMETRIC SUMMARY

22519 STATION KANEHOE BAY, HAWAII STATION NAME 73-77 YEARS ALL MONTH PAGE 1 HOURS (L & F)

NAVWEASERVCOM

Temp (F)	WET BULB TEMPERATURE DEPRESSION (F)																															TOTAL D.B./W.B.	TOTAL		
	0	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-24	25-26	27-28	29-30	≥31	Dry Bulb	Wet Bulb	Dew Point															
90/ 89								.0	.0	.0								2	2																
88/ 87						.0	.0	.0	.0	.0								20	20																
86/ 85			.0			.0	.2	.2	.1	.0								83	83																
84/ 83			.0	.1	.4	.9	.5	.1	.0									293	293																
82/ 81			.1	.6	2.1	1.9	.7	.1										794	794	1															
80/ 79	.0	.1	.5	3.1	4.6	2.4	.4	.1	.0									1619	1619	8															
78/ 77		.3	2.8	6.3	7.2	1.7	.3	.1										2717	2717	63															
76/ 75	.0	1.4	5.3	8.9	4.4	1.2	.3	.1										3146	3146	426															
74/ 73	.1	2.4	6.3	7.4	2.1	.9	.3	.1										2831	2831	2244															
72/ 71	.3	2.7	4.6	3.2	1.0	.5	.2	.0										1823	1823	3417															
70/ 69	.1	2.1	2.1	.8	.3	.1	.0	.0										820	820	4050															
68/ 67	.1	.9	.8	.3	.1	.1	.0	.0										321	321	2529															
66/ 65	.1	.2	.2	.1	.1	.0												95	95	1104															
64/ 63	.0	.1	.0	.0														20	20	465															
62/ 61		.0			.0													4	4	186															
60/ 59																			69	390															
58/ 57																			22	176															
56/ 55																			3	125															
54/ 53																			1	71															
52/ 51																				42															
50/ 49																				15															
48/ 47																				5															
46/ 45																				1															
44/ 43																				1															
TOTAL	.8	10.2	22.7	30.7	22.3	9.7	2.9	.7	.0									14588	14588	14589															
Element (X)	Σx²		Σx		X	σx	No. Obs.	Mean No. of Hours with Temperature											Total																
Rel. Hum.	85042368		1103748		75.7	10.264	14589	≥ 0 F	≥ 32 F	≥ 67 F	≥ 73 F	≥ 80 F	≥ 93 F	Total	8760.0																				
Dry Bulb	83076123		1099581		75.4	3.650	14588			8688.8	6910.6	1139.0		8760.0																					
Wet Bulb	71167763		1017975		69.8	3.005	14588			7650.1	1648.1	1.2		8769.0																					
Dew Point	65442842		975528		66.9	3.810	14589			5224.3	763.4	2.4		8760.0																					

Figure 8. Determining whether an infiltration-resistant envelope is required

PSYCHROMETRIC SUMMARY

22519 STATION KANEHOE BAY, HAWAII STATION NAME 73-77 YEARS ALL MONTH PAGE 1 HOURS (L & F)

NAVWEASERVCOM

Temp (F)	WET BULB TEMPERATURE DEPRESSION (F)																															TOTAL D.B./W.B.	TOTAL		
	0	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-24	25-26	27-28	29-30	≥31	Dry Bulb	Wet Bulb	Dew Point															
90/ 89								.0	.0	.0								2	2																
88/ 87						.0	.0	.0	.0	.0								20	20																
86/ 85			.0			.0	.2	.2	.1	.0								83	83																
84/ 83			.0	.1	.4	.9	.5	.1	.0									293	293																
82/ 81			.1	.6	2.1	1.9	.7	.1										794	794	1															
80/ 79	.0	.1	.5	3.1	4.6	2.4	.4	.1	.0									1619	1619	8															
78/ 77		.3	2.8	6.3	7.2	1.7	.3	.1										2717	2717	63															
76/ 75	.0	1.4	5.3	8.9	4.4	1.2	.3	.1										3146	3146	426															
74/ 73	.1	2.4	6.3	7.4	2.1	.9	.3	.1										2831	2831	2244															
72/ 71	.3	2.7	4.6	3.2	1.0	.5	.2	.0										1823	1823	3417															
70/ 69	.1	2.1	2.1	.8	.3	.1	.0	.0										820	820	4050															
68/ 67	.1	.9	.8	.3	.1	.1	.0	.0										321	321	2529															
66/ 65	.1	.2	.2	.1	.1	.0												95	95	1104															
64/ 63	.0	.1	.0	.0														20	20	465															
62/ 61		.0			.0													4	4	186															
60/ 59																			69	390															
58/ 57																			22	176															
56/ 55																			3	125															
54/ 53																			1	71															
52/ 51																				42															
50/ 49																				15															
48/ 47																				5															
46/ 45																				1															
44/ 43																				1															
TOTAL	.8	10.2	22.7	30.7	22.3	9.7	2.9	.7	.0									14588	14588	14589															
Element (X)	Σx²		Σx		X	σx	No. Obs.	Mean No. of Hours with Temperature											Total																
Rel. Hum.	85042368		1103748		75.7	10.264	14589	≥ 0 F	≥ 32 F	≥ 67 F	≥ 73 F	≥ 80 F	≥ 93 F	Total	8760.0																				
Dry Bulb	83076123		1099581		75.4	3.650	14588			8688.8	6910.6	1139.0		8760.0																					
Wet Bulb	71167763		1017975		69.8	3.005	14588			7650.1	1648.1	1.2		8769.0																					
Dew Point	65442842		975528		66.9	3.810	14589			5224.3	763.4	2.4		8760.0																					

Figure 9. Determining whether heating equipment is required

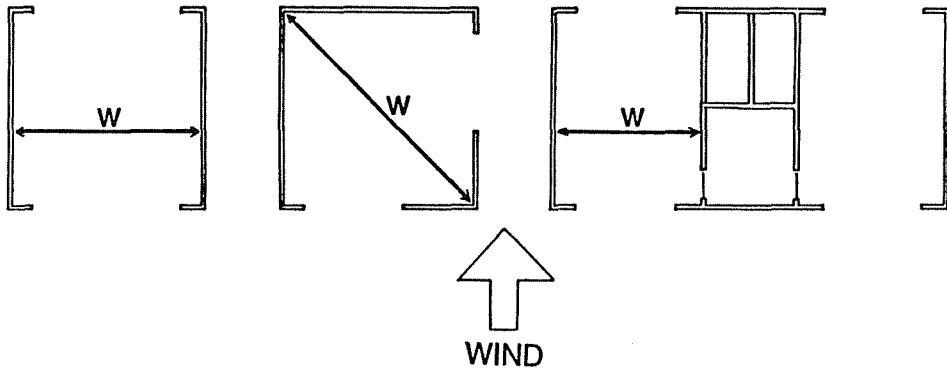


Figure A-1. Examples of room width for window sizing procedure

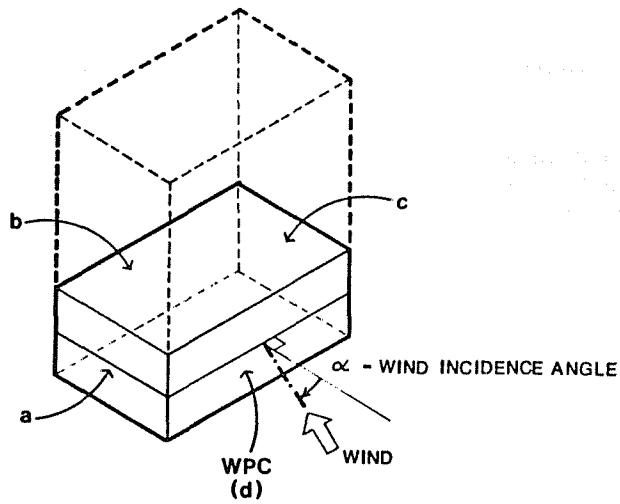


Figure A-2. Pressure coefficient planes and wind incidence angles

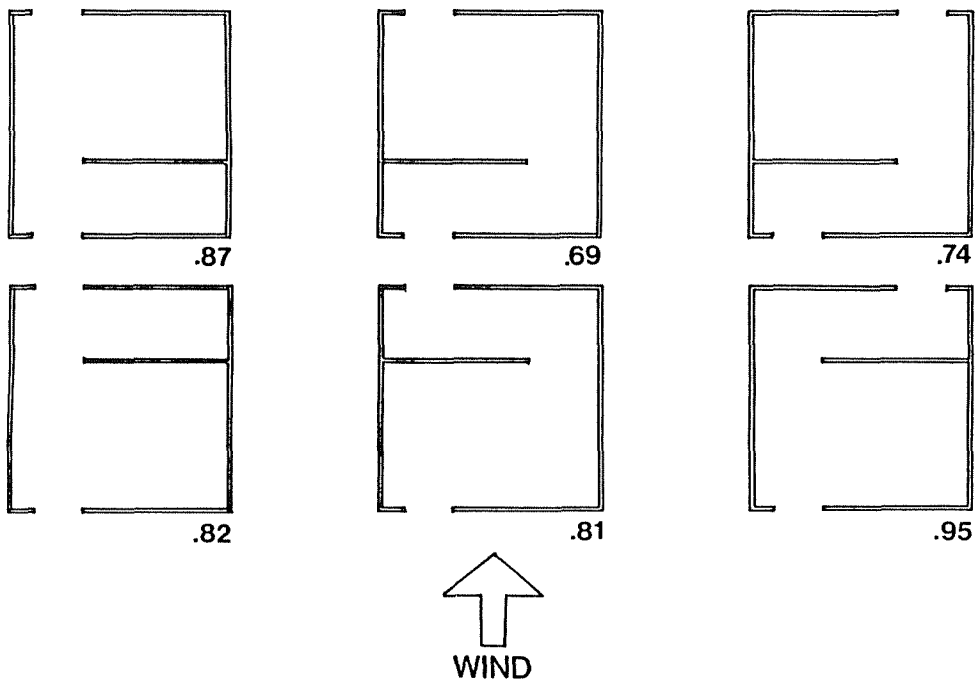


Figure A-3. Interior partition factors

Discussion

L. CROW, Denver, CO: Isn't the data set of reference used identified as the "E Summary" set?

E.A. ARENS: The method we are using is based on either the Air Force's RUSSWO (Revised Uniform Summary of Surface Weather Observations) or the Navy's SMOS (Summary of Meteorological Observations, Surface). We are using "part C" for wind data and "Part E" for temperature and humidity information. "Part E" is also known as the "E Summary."