Credits

Authors
J. B. Jones, AIA
Stephen F. Lander, AIA
H. Mark Ruth, AIA

AIA Guam & Micronesia Chapter
Steering Committee
Frederick Sun, AIA
Stephen F. Lander, AIA
H. Mark Ruth, AIA
J. B. Jones, AIA
William A. McAlister, FAIA

Editorial Assistance
Sheila M. Stevens

Publication Assistance
Glimpses of Guam

Illustrations
J. B. Jones, AIA

This publication was funded under a grant from the U.S. Department of Energy, Energy Extension Service, Administered by the Guam Energy Office.

All rights reserved. No material may be reprinted or reproduced, in whole or in part without prior written permission.

Information contained in the book is based on public record, visual observation and descriptive material received from project designers. All reasonable attempts have been made to assure the accuracy of the facts and opinions contained herein. However, inaccuracies may occur and the authors suggest that all facts and opinions be verified before the reader relies on them in any manner.
Acknowledgements

Energy Conscious Design for a Tropical Isle is a project of the American Institute of Architects, Guam and Micronesia Chapter under the direction of the authors. Project plans, photographs, project descriptions, research and technical support were obtained from the chapter steering committee, executive board and general membership.

Gratitude goes to the staff of the Guam Energy Office for their assistance in obtaining funding and for their guidance and encouragement.

Additional thanks are extended to Conrado G. Vales, P.E. and Victorio Reyes, Jr., P.E. for their technical assistance.
Contents

1. INTRODUCTION
2. DESIGN CRITERIA - PART 2
   - Building Envelope
   - Heat Gain
   - Metabolism
   - Climate
   - Human Comfort
3. DESIGN CRITERIA - PART 1
4. AIR-CONDITIONED HOUSES
5. PARTIALLY AIR-CONDITIONED HOUSES
6. OTHER TECHNOLOGIES
7. APPENDIX
Introduction

Tropical isles can be idyllic and casual, yet present problems in developing truly comfortable and energy-efficient living conditions. Islands have the potential of being marvelous places to live. With sea breezes, moderate temperatures and plenty of sunshine, comfort depends upon the designer's ability to use these assets while carefully handling high humidity, heat gain and frequent rain.

This book is developed as a reference for energy-efficient design in residences. As a planning and design tool, it provides homeowners, builders and members of the housing community with an understanding of the conditions that affect buildings in the tropics; it provides basic background on the design factors necessary to construct comfortable energy-efficient homes.

The presentation is for three levels of review: the quick overview, general reading and detailed exploration of formulas and techniques. A quick review of photos, plans and sketches will provide a sense of the tropics along with several appropriate design ideas. A general reading will bring an appreciation and understanding of the interrelationship of human comfort design factors and how they apply to the island environment. The potential of good, appropriate design will become clear, and the individual house concepts can be studied, discussed and compared. Finally, an indepth review of the formulas and calculations will present firsthand the intricacies of the refined application of detailed techniques.

The book is divided into six sections. The first two sections provide design criteria affecting all construction such as climate factors, site characteristics, heat gain concepts, daylighting principles and window and shading comparisons. These principles apply to each type of construction, whether naturally ventilated, air-conditioned or partially air-conditioned.

The specific application and principles of natural ventilation and air conditioning are discussed in the third and fourth sections. The fifth section deals with partial air conditioning by integration of air-condi-
Human Comfort

Four major properties of the environment influence human comfort: air temperature, humidity, air velocity and radiant temperature.

Temperature: The degree of heat in a body or substance, such as air, expressed in degrees Fahrenheit (F) or Centigrade (C).

Relative Humidity (RH): The amount of moisture in air compared to the maximum amount that can exist at a given temperature without condensation, expressed in percentage.

Air Velocity: Movement of air through space, expressed in feet per minute (fpm) or miles per hour (mph). Ten feet per minute is considered stagnant and above 2.3 miles per hour (175-265 feet per minute) the breeze starts to become drafty and disrupting.

Radiant Temperature: Temperature of a solid object which emits or accepts radiant energy. Human skin temperature is about 92°F (33.3°C) when comfortable and radiates heat to cooler objects and receives heat from warmer objects.

When only air temperature and humidity are considered, the main part of the human comfort zone is between 72°F (22.2°C) and 78°F (20°C) with a relative humidity (RH) of 40 percent to 50 percent.

**AIR MOVEMENT AT 1.7 MILES PER HOUR (150 FEET PER MINUTE)**

<table>
<thead>
<tr>
<th>Air Temperature</th>
<th>Effective Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>87</td>
</tr>
<tr>
<td>86</td>
<td>85</td>
</tr>
<tr>
<td>84</td>
<td>83</td>
</tr>
<tr>
<td>82</td>
<td>81</td>
</tr>
<tr>
<td>80</td>
<td>79</td>
</tr>
<tr>
<td>78</td>
<td>77</td>
</tr>
</tbody>
</table>

**AIR MOVEMENT AT 4.5 MILES PER HOUR (400 FEET PER MINUTE)**

<table>
<thead>
<tr>
<th>Air Temperature</th>
<th>Effective Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>83</td>
</tr>
<tr>
<td>86</td>
<td>81</td>
</tr>
<tr>
<td>84</td>
<td>79</td>
</tr>
<tr>
<td>82</td>
<td>77</td>
</tr>
<tr>
<td>80</td>
<td>75</td>
</tr>
<tr>
<td>78</td>
<td>72.5</td>
</tr>
<tr>
<td>76</td>
<td>70</td>
</tr>
</tbody>
</table>

**EFFECTIVE TEMPERATURES RESULTING FROM AIR MOVEMENT**
The peripheral portions of the comfort zone include other combinations of relative humidities and temperatures. In general, if the RH increases, the temperature should decrease and if the temperature increases the RH should decrease.

The perception of temperature and humidity is affected by what is often referred to as the wind chill factor, a passage of air over the skin causing increased evaporation and making a person feel cooler. Thus, a person in a slight breeze feels comfortable in a higher combination of both RH and temperature.

Climate

A tropical island environment is warm, humid, and has a reasonably constant climate. The main climatic periods are the dry and wet seasons while the seasonal variations of temperate climates, winter, spring, summer and fall, are much less pronounced. For islands the surrounding ocean moderates the temperature. The tradewinds temper the impact of the relative humidity making the climate generally pleasant.

For an architect or someone planning a home, the key aspects of a climate are those which affect human comfort and the use of buildings. These include the averages, changes and extremes of temperature, humidity, winds, rainfall, solar radiation, sky conditions and specific site characteristics.

Wherever one lives in the tropics, local weather charts, along with sun data should be reviewed when designing a house. The weather information is usually available at regional weather facilities, airports and educational facilities. Sun charts depend directly on the latitude and are available from reference books.

The specific climatological data for our island, Guam, is included in the appendices.

Temperature

The overall temperature range in the tropics is generally at or above the upper part of the comfort zone. Islands in general benefit from the moderating effect of the surrounding water and both the overall daily temperature variation and seasonal variation will be less extreme than most larger land masses.

The location within the equatorial belt also affects the temperature range with less seasonal variation and slightly higher temperatures occurring closer to the equator.

Changes in temperature can actually be experienced on the same island. The higher elevations, particularly on the windward side of the island, high coastal plateaus and mountain crests are frequently cooler than inland and river locations where the temperature and RH are both higher. Low-lying and sheltered areas will also benefit less from the pleasant tropical breeze.
Relative Humidity

For many tropical locations, the high relative humidity is more of a nuisance than the temperature.

The concept of "relative humidity" provides a direct indication of evaporation potential. The warmer the air, the greater the potential for the air to hold moisture. Humidity is highest in the early morning, when the temperature is the lowest and the potential for the air to hold moisture the lowest, and decreases to its lowest point in the afternoon when air temperatures and moisture capacities are the highest. The afternoon values are much more characteristic and are often used alone as a brief indication of humidity conditions.

During the dry season the relative humidities are lower and approach those of more temperate islands such as Hawaii. Throughout the Pacific Basin these climatic conditions vary with the islands closest to the equator being slightly warmer and more humid.

Wind

Location in the trade-wind zone provides predictable wind throughout the year although there are noticeable shifts in the pattern of daily and seasonal velocities. Higher velocity winds occur during the dry season. During the wet season and storm periods, winds may shift from the predominant direction for short periods of time.

The Sun

Sun angles and paths are directly dependent upon a location's latitude. Within the equatorial belt the sun is predominantly overhead. The exact time of sunrise and sunset may vary slightly depending upon a site's location within a time zone.

Sun charts will help determine the effect of shadows cast by sunlight falling into a building and the position of the sun at different times of the day and year. In the tropics, it is good design to reflect away, baffle, intercept or absorb the extremes of heat and light to produce a livable interior. The desirable orientation of structures can be predicted based on the inclination of the sun at particular times of the year and throughout the day.

Direct sunlight causes heat load on house walls, heavy on the east and particularly heavy on the west. Overhangs and other protective devices and landscaping should be used to cut down on this direct sunlight. The radiation and a location's temperature are also affected by cloud cover.
Rainfall

Precipitation is a major climatic condition in the tropics. The yearly rainfall is heavy due to the constant availability of moisture-laden air. Rainfall will vary widely from island to island and from year to year. There is a definite local variation due to location and topography with the windward shores and valleys receiving more rainfall and the leeward side of mountains and cliffs receiving considerably less. It is quite common to experience intense rains associated with strong winds at any time of the year. Minimizing the entry of driven rain is important when considering exposure of openings and outdoor living areas.

During the course of the year, shifts in the wind direction, temperature and rainfall are experienced as a result of shifts in the Intertropical Convergence Zone. This shift follows the zenith of the sun with about a month delay.

For each general climate there are many specific climatic conditions classed as microclimates. The microclimate is the local deviation due to topography, orientation, elevation, ground surface, vegetation and the presence of three-dimensional objects such as structures, trees, fences and walls that influence air movement and create shades and shadows.

An initial task of the designer is to identify the distinct factors of the site and identify the favorable conditions, constraints and adverse characteristics of the site and its climatic features. The effect of the microclimate is the key for proper selection and planning of a site.

Air temperature is affected by surrounding areas. At any point near the ground air temperature is dependent upon the amount of heat gained or lost by the earth's surface or other surfaces. Additionally, heat exchange near the surface varies from day to night and includes a lag time. An example of lag time occurs when a previously heated surface gradually cools off.
but continues to emit heat while it cools. During calm days warm air stratifies near the ground surface. At night the ground loses heat by radiation until its temperature is lower than the air and the direction of heat flow is reversed (from air to ground).

The thermal effects of incident radiation depend on nearby surfaces. For ground surface, vegetation is preferable to concrete because the plants diffuse and minimize solar reflections and reradiation. Dark asphalt paving may reach temperatures considerably higher than the surrounding air temperature and reflect or re-radiate this heat to persons and structures nearby. With vegetation the surface contact with solar radiation is transferred to a higher layer, thereby allowing the ground to have a cooler layer of air and avoiding the ground build-up of solar heat to be reradiated. Large trees can provide a shade coefficient of 0.20, blocking 80 percent of the sun's radiation to a building or the ground.

Topography affects air temperature and humidity, resulting in a blanket of cool air near the ground. Cool air behaves as a liquid flowing downhill and settles in the deepest depressions. Moist air tends to be heavier so it will seek lower levels, thus creating the cool, damp feeling of a valley. When the moisture-laden air and surrounding damp areas are heated by the early morning sun, the same area often becomes a "steam bath."
Dew also tends to form more frequently in valleys. As the lower level of air warms during the day, the ability to hold moisture increases and therefore the RH decreases and the evaporation potential increases. At night the situation is reversed, as air cools, its RH increases and when the point of saturation (100 percent RH) is reached, the excess moisture condenses in the form of dew.

Air movement is affected by ground cover and topography. Wind speed is reduced by horizontal barriers such as tree clusters or walls. Also, wind speed increases with the height above the surrounding ground. For hilly sites, the greater wind speed occurs at the crest. In moderately humid areas, valleys are generally cooler than hill crests, but in humid areas, hill crests are usually cooler because of the effect of increased air movement. Valleys and depressions experience low velocities except where the direction of the valley corresponds with the direction of the wind. The more pronounced the valley's form the more the valley's floor will be sheltered from crosswinds and will funnel parallel wind. The effect of nearby buildings is similar to trees as buildings cast shadows, and channel winds with localized increases in velocity and altering of wind direction.

Precipitation is affected by topography and the direction of prevailing breezes. The effect of hills on rainfall patterns can be pronounced, especially where the prevailing tradewinds occur. Where ground level changes significantly, the windward slope will receive more rainfall than the regional average and the leeward will receive correspondingly less. As the hill forces the air mass to rise, the air cools and can no longer support the moisture it carries. Conversely, a descending air mass increases in temperature and can therefore absorb more moisture. This phenomenon is more pronounced with increase in the steepness of the hill formation.

The influence of solar radiation is affected by nearby hills, buildings or trees and surrounding surfaces.

Vegetation affects the microclimate. An open surface of water or rich vegetation will provide an abundant supply of water vapor and therefore will raise the RH. Dense surrounding vegetation will restrict air movement causing stagnant air pockets. High tree foliage provides shade for an area without restricting air flow. Lack of vegetation and an increase in hard surfaces, such as encountered in urban areas, increases the temperature.
These surroundings affect both the shades and shadows cast upon the site and affect the incident radiation. The orientation of surrounding hills and site objects affects the location and direction of shadows. Trees and other structures immediately adjacent to the east and west sides of a site particularly cast long early morning or late afternoon shadows.

Open flatlands can be quite breezy, but need additional shade elements.

**Heat Gain**

Heat loads in a space generally come from the outside climate, occupants and equipment or processes (lights, refrigerator, cooking, etc.). The heat is transferred according to physical laws of nature. Heat is generally measured in British Thermal Units (BTU), the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit.

There are four principal ways a body will gain or lose heat: conduction, convection, radiation and evaporation. Loss of heat by the first three can only occur when the air, surroundings or both are at less than body temperature. The heat that is transferred by direct change in temperature is referred to as sensible heat. Loss by evaporation can occur if the air is dry enough to absorb further moisture; the rate heat loss takes place depends on the humidity of the air and the rate the air passes over the body. The transfer of heat is due to a change in state, i.e., from a liquid to a gas, and is referred to as latent heat.
Conduction

Conduction is the transfer of heat through a solid or liquid material, and is dependent upon the temperature differential and the heat flow rate or conductance of the material. Heat transfer through metals is faster than through wood; water stores more heat than wood, etc. Conduction will generally transfer heat much faster than convection. Conduction of heat occurs through contact with cool surfaces such as hard tile floors or waterbeds.

Convection

Convection is heat flow through open air and is dependent on the rate of ventilation and temperature differential.

As a particle of air bumps into another particle of air, heat is transferred. The hotter the air becomes, the more active the particles and the more they expand. The more they expand the lighter the air becomes and it floats upward. Conversely, the colder the air becomes, the less active the particles are and the less space they take; the air becomes denser and sinks downward.

Radiation

Radiation occurs through space from a heat source to another object. Radiation travels by various waves with some waves of a visible wave length (light) while others, such as ultraviolet, are invisible. Radiation is a form of energy and often this energy is transformed into heat. In a climate that is already too warm, heat becomes a constant adversary to be managed and controlled in order for people to be comfortable.
A body will give up heat to cool walls or a ceiling even if the air temperature is high. This cooling has a 40 percent greater effect on comfort than air temperature, so lowering the surface temperature 10°F (5.5°C) would give the equivalent cooling of lowering the air temperature 14°F (7.8°C).

With a mean radiant temperature of 65°F (18.3°C) and the air temperature of 85°F (29.4°C), the effective temperature would be 74°F (41°C).

The mean radiant temperature is a weighted average of the various influences in a space as estimated by the following formula:

$$\text{MRT} = \frac{\sum t \theta}{360} = \frac{t_1 \theta_1 + t_2 \theta_2 + \ldots}{360}$$

MRT = mean radiant temperature

$\theta$ = surface temperature in °F

$\theta$ = surface exposure angle in degrees.

For example:

$$\text{MRT} = \frac{(72°F \times 300°) + (80°F \times 60°)}{360} = 73°F$$

With a mean radiant temperature of 73°F (22.8°C), air velocity of 20 feet per minute, wearing light clothing and resting an average person can feel comfortable at 80°F (26.7°C).

For comparison, other examples are listed:

With a mean radiant temperature of 70°F (21.1°C) and 60 percent RH a person can feel comfortable at 83°F (28.3°C) air temperature even with minimal breeze.

With a mean radiant temperature of 75°F (23.9°C) under similar circumstances, a person can feel comfortable at 81 to 86°F (27.2 to 30°C) depending upon a breeze up to 3.4 miles per hour.

With a mean radiant temperature of 80°F (26.7°C) and similar circumstances, a person can feel comfortable from 77 to 84°F (25 to 28.9°C) depending upon a breeze up to 3.4 miles per hour.
At higher radiant temperatures the breeze becomes even more important. With either heavier clothing or more activity the maximum comfortable temperature becomes lower and the breeze even more important. For medium activity, 50 percent RH and a mean radiant temperature of 70°F (21.1°C) the comfortable maximum is 75 to 76°F (23.9 to 24.4°C) with a 2.3 to 3.4 mile per hour breeze (200 to 300 feet per minute).

Dense materials like concrete, quarry tile or marble can absorb and store more heat, thus they should be shaded as much as possible. Dense floor materials like marble will absorb more energy and thus retain a cool feeling longer.

**Evaporation**

A large amount of energy is absorbed in the physical change of a substance from liquid to gas. This is the basis for almost all mechanical air-conditioning systems, and the built-in human air-conditioning system, perspiration and evaporation.

A moist surface will have greater evaporation if additional air (wind) is moved across it. Thus a person feels cooler in a breeze. Evaporation takes place more readily at low relative humidities rather than high relative humidities when the air is already packed with moisture.

**Combined Heat Transfer**

For heat transfer the heat moves from the warmer object toward the cooler object via conduction, convection or radiation. The transfer through building walls will combine these various forms. The heat on the exterior surface will come from radiation and convection. The transfer through the wall will be via conduction and sometimes convection, depending upon the wall configuration and air spaces. From the inside face of the wall, heat is again transferred by radiation and convection.
Building Envelope

The roof, outside walls and floor of an elevated structure are collectively called the building envelope. To determine the heat gain and other thermal effects on a structure, the individual parts of the building envelope are evaluated.

The roof component of the building envelope has the greatest exposure to the sun. Great heat is generated during the day making it necessary to decrease the heat build-up, reduce penetration of the heat to the interior and prevent further radiation of heat to the interior during the night. An unprotected solid roof such as concrete heats up during the day, stores the heat and gets rid of it by radiation or convection at night. An unshaded mass will store four times more heat energy than a shaded mass. With an air temperature of 80F (26.7C), an unprotected concrete slab will show a daytime upper surface temperature of 120F (48.9C) and a lower surface temperature of 115F (50.5C). The better insulated a roof the longer it takes for heat to pass through, and the less heat eventually passes through, as some is reradiated up to the sky. The same principle holds true for walls that are unshaded.

The outside walls form a major area of the building envelope. The insulative values of these walls become very important, especially when the house is to be air conditioned or the walls are exposed to solar radiation. For an elevated floor slab heat transfer is similar to a shaded wall with slightly different factors from the adjacent air films.

In order to compute heat gain for the building envelope, heat transfer values are added for the various materials in a wall or roof. The values depend on the material thickness. Values for the inside and outside air films are also added. Insulating quality of building assemblies is expressed in “R” values. The “R” value is the resistance to the flow of heat measured in time. With an R=20 roof, it will take 20 hours for one British Thermal Unit (BTU) to flow through one square foot of that roof assembly if there is a 1F (.56C) temperature difference between the inside and outside. The appendix provides R values for many typical materials and building assembly calculations.

The inverse of the R value is the “U” value (1/R = U). It is the per hour expression of viewing the same heat flow rate. In the case of the R=20 roof, one-twentieth of a BTU will flow through one square foot of roof in one hour if there is a 1F (.56C) temperature difference. Therefore, the U value of a R=20 roof is .05. Brief calculations for heat gain are indicated below and included in the chapter, Air-Conditioned Houses.

Another heat gain characteristic is thermal lag time; the building’s temperature lags behind the outdoor temperature timewise: this is why a west wall feels hot at 10:00 p.m., long after sunset. For example, the interval of lag between the upper and lower surface of a standard 6-inch concrete roof slab is about four hours. Building materials that are dense and heavyweight have
longer lag times than thinner, lighter materials. Thermal lag time can be beneficial because it helps even out the interior heat loading and lessens the heat flow since the heat flow is reversed in the evening when the exterior temperature is less than the material temperature.

This is the amount of BTUs per square foot per degree of temperature change (in Fahrenheit) between inside and outside wall temperature per hour.

A 10-foot by 10-foot wall (100 square feet) with a 15 degree temperature change will transmit in one hour:

\[
\text{Heat Load} = U \times Hrs \times \text{Ft}^2 \times F
\]

\[
= 0.25 \times 1 \times 100 \times 15 = 375 \text{ BTU}
\]

Note that the exterior surface temperature may be significantly higher than the exterior air temperature because of radiation.

Lag time is usually not figured into simple heat gain calculations, but is nevertheless an important phenomenon to understand.

To evaluate the transmission through a wall the R values for the various materials along with the R values for the appropriate type of air films are added together. For example:

Concrete block wall without insulation:

- outside surface (15 miles per hour wind) 0.17
- 3/4-inch cement stucco 0.15
- 8-inch concrete block with cells filled 2.98
- inside surface (still air) 0.68

\[
U = 1/R = \text{BTU/hr/ft}^2/\text{F} = 1/3.98 = 0.25
\]
Chapter 2
Design Criteria Part 2
Windows
Shading
General Lighting
Daylighting
Psychological Cooling
Windows

Windows are an important part of the building envelope and their proper design is critical to the livability of a house. Windows have profound psychological influence on occupants and affect the amount of interior light and sense of enclosure. They are vital tools in developing proper ventilation and strategic window placement provides privacy for the interior while offering a variety of views of the exterior.

For proper location, window functions should be divided into three main uses:

Ventilating
Daylighting
Viewing

These uses may be combined but often are more effective with windows that satisfy only one or two functions at a time.

Several other factors are also important to consider:

Safety egress
Minimum heat gain
Rain protection
Security
Maintenance cost
Initial expense
Air infiltration when closed

For minimum heat gain through windows a number of techniques may be used:

Provide reflective glazing, tinted glass or reflective coating.
Control direct sunlight striking or reflecting onto the window.
Locate landscaping for maximum shading.

Use minimum ratio of window to wall area.
Provide double glazing, insulated glass or heat absorbing glass.
Face windows north or south, allowing for easier shading.
Reduce air infiltration.
Avoid thermal bridges (seal window frames with gaskets).

The strategies for selection and placement of windows depend upon whether the house is to be naturally ventilated, air conditioned or partially air conditioned. Further explanation of window needs for each type of house is discussed in the individual chapters.

Of all elements, openings give perhaps the most complicated and difficult design task. A well-planned window system will have several types of windows performing several tasks, either individually or interrelated. All types require protection from direct solar radiation, rain, burglars and insects.

The cost of selecting the correct type for each application may be more expensive, but is a very small part of the overall building cost and yet is of great importance to successful ventilation.

Selection of opening types should be based on the importance of each of the window’s energy functions, considering climate, orientation, time of day the building is most used and the environmental requirements of activities being housed. The following presents guidelines for choosing the correct type, size and placement of windows. Final selection should be based on consideration of the total opening system, in combination.
AWNING

1. 85 to 90%
2. Medium Perimeter

*Should not be installed in traffic areas without side protection. Sometimes hard to seal for security alarm.

PROJECTING

1. Minimum Sealing
2. 40%

*Good for Clerestory windows.

OPERABLE LOUVER (JALOUSIE)

1. 85 to 95%
2. Large sealing perimeter

*Glass louvers inexpensive—aluminum louvers expensive. Louver blades can be glass, frosted glass, aluminum, redwood.

FIXED LOUVER

1. 85 to 95%

*Totally incompatible with air conditioning without additional window covering.

HORIZONTAL SLIDER

1. Minimum sealing
2. 45%

*Horizontal windows are often more difficult to seal against water infiltration from wind-driven rain.

VERTICAL SLIDER

1. Minimum sealing
2. 45%
Shading

Shading of windows is an easy and often attractive way to protect openings from direct and indirect sunlight. Shading may be achieved by using exterior appendages. These appendages may be either a part of a window system or part of the adjacent wall system.

In the tropics maximum shade is desired year round, so a simple method of determining necessary dimensions for shading devices is to calculate the minimum angles of shade. If a window is shaded at the time of least angle, then it is amply shaded the rest of the year. These angles vary with the latitude and are different throughout the year. For example, the lowest angle on a southern exposure (in the northern hemisphere) occurs on December 21. Therefore, for December 21, the lowest angle occurring during the main part of the day, 10:00 a.m. to 3:00 p.m., is the governing factor.

This is an easier approach to shading than employed in temperate climates where part of the year (winter) it may be desirable to have unshaded light for warming purposes.

The following formula determines the amount of shade from horizontal projections where “s” values are derived from the sun angles. The amount of shade from horizontal projections can be approximated using minimum values through the year for the 5 hours of maximum solar exposure, 10:00 a.m. to 3:00 p.m. for a given wall orientation. “s” values for our island are:

- E and W wall orientation: 0.95
- SE and SW wall orientation: 0.91
- NW and NE wall orientation: 3.4
- N wall orientation: 12.6
- S wall orientation: 1.13

Fixing the window sill at “d” would mean the window would be shaded year round from 10:00 a.m. to 3:00 p.m.

For east and west walls the critical heat gain periods may be before 10:00 a.m. for east walls and after 3:00 p.m. for west walls. There is a practical limit that horizontal projecting elements can shade these sides and
other shading devices listed later on in the section should be considered along with landscaping.

\[ d = sx \]
\[ x = d/s \]

The following illustrations compare various shading devices in terms of shading value, ventilation, view, maintenance, cost, initial expense and potential typhoon resistance.

The shading coefficient is the factor that the sky brightness values are reduced due to shading.

"A" indicates aluminum construction.
"W" indicates wood construction.

*SOLID SCREEN\]
* 0.10

*AWNING\]
* 0.15

*VERTICAL FINS\]
* 0.30 to 0.50

*SOLID OVERHANG\]
* 0.25
Very effective for south elevations

*VERTICAL ANGLED FINS\]
* 0.30
General Lighting

Proper lighting considerations can save energy and avoid some heat load by optimizing the use of natural daylight and effectively using artificial light. Light hitting a surface is measured or expressed in footcandles.

For general lighting, 10 to 30 footcandles are satisfactory. Goals at specific areas should be:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Average Footcandles</th>
<th>Range Footcandles</th>
</tr>
</thead>
<tbody>
<tr>
<td>sink</td>
<td>75</td>
<td>50 to 100</td>
</tr>
<tr>
<td>range and work</td>
<td>75</td>
<td>50 to 100</td>
</tr>
<tr>
<td>surface</td>
<td>75</td>
<td>50 to 100</td>
</tr>
<tr>
<td>reading</td>
<td>75</td>
<td>50 to 100</td>
</tr>
<tr>
<td>shaving and makeup</td>
<td>30</td>
<td>20 to 50</td>
</tr>
<tr>
<td>sewing</td>
<td>150</td>
<td>100 to 200</td>
</tr>
<tr>
<td>desk</td>
<td>75</td>
<td>50 to 100</td>
</tr>
<tr>
<td>table games</td>
<td>30</td>
<td>20 to 50</td>
</tr>
</tbody>
</table>

Lighting to the eye is relative to other factors such as brightness (amount of light emitted or reflected from the viewed object), and contrast with the surroundings.

The preferred task lighting levels will vary slightly between individuals. Use of artificial light can be conserved by tailoring it to the specific need. Dimmers, baffles, diffuser, reflectors and many small lamps allow customizing of the illumination of the task, rather than flooding the whole room with light.
When selecting new fixtures fluorescent lamps should be considered. These operate considerably cheaper and generate less heat than standard incandescent, although their very white light may be unacceptable in some situations, such as make-up mirrors. There are certain disadvantages from using fluorescent fixtures, including relatively high initial costs and dimmers generally not being economically feasible. Incandescent is still the most popular lighting for social areas where mood is a consideration.

An indirect or diffused light usually feels more comfortable than a direct light source as the high intensity or glare is not seen by the eye. Glare can also be reduced by proper selection of light diffusers. Eye strain can also be minimized by raising the background brightness until the task and background areas are of equal brightness. A single light fixture may combine task lighting and general lighting needs depending upon location.

Contrast lighting can draw attention to an object, produce shadows and display textures. It is helpful in delineating outline, size and detail; however for extended viewing contrast creates eye strain, as the eye adjusts to the average brightness and still receives some light at high brightness; contrast ratios of up to 3 to 1 are generally acceptable.

Other useful tools in maximizing the energy efficiency of general lighting are to include photocells, timers and dimmers. Photo-cells on exterior lights such as entrance lights or carport lights prevent forgetting to turn lights off during the day. Timers are valuable where lights are planned that will only be used for certain hours of the evening. Dimmers allow the adjusting of the artificial light intensity to the task. They are not only good energy savers but allow a variety of lighting changes within a space without altering light fixtures. Dimmers also augment task lighting plans.

Daylighting

Daylighting is the age-old use of natural sunlight to light interior surroundings. Before the dependence upon artificial light, the science of daylighting was well defined and well used. More recently, prior to the energy crisis, its use had greatly diminished and been almost forgotten.

In the tropics there is an abundance of sunshine all year. People seek the shade rather than the direct light, but indirect daylight brightens an interior, adds life and makes it more pleasant.

Daylighting must be designed carefully to avoid adding too much heat load to the interior spaces. This generally means the use of indirect sunlight and avoidance of direct sunlight.
Daylight generally enters a space through windows, either in the wall, the roof (skylight) or at a second level wall (clerestory). Doors and other openings may also provide lighting.

Proper placement of windows involves careful planning to eliminate glare and contrast. Windows near adjacent walks or ceilings can use those surfaces to reflect light throughout the room spreading the light more evenly. This also reduces glare since the view from such windows is very indirect from most of the room. A window in the middle of a wall would cause high contrast and glare between the brightness of the window and the indirectly lighted wall. Such excessive contrast can be somewhat reduced by keeping the wall with the opening in a light or bright color.

Glare at windows can be reduced by the positioning of shading devices to limit the view of the sky to about 15 degrees above the horizon, or the use of low shrubs to block reflected light from water or other surfaces. Lighting levels drop off drastically as you move away from a source (window, skylight or light fixture) as the light is dispersed by a factor of volume.

Light levels from more than one source can simply be added to find the footcandles at the specific position. The problem is how to distribute the lighting from the perimeter back into the rooms. One of the more effective ways is to use reflective surfaces to bounce the extra light concentrated at a window back up to the ceiling and down again further inside the space. This can be done by a light shelf seven or eight feet above the floor or with venetian blinds. At skylights this can be done by a curved reflector suspended below the opening.

The level of daylight is dependent upon the reflectance level of various surfaces. Exterior ground or water surfaces, or nearby walls or vegetation affect the light hitting the window. The reflectance level of walls, louvers or blinds, ceilings or floor effect the interior distribution.

The level of natural lighting can be estimated, but is subject to many variables. To demonstrate the approach formulas are indicated below. For more detailed study, reference books on daylighting design and professionals familiar with the references should be consulted.

For a window in a wall the amount of light received at a point inside a room measured in footcandles is dependent upon the availability and intensity of exterior light and estimated by the following:

$$\text{Footcandles at a point} = \frac{10 \times W \times H^2}{D (D^2 + H^2)} \times \frac{4AgR}{Af (1-R)} \times \text{(shading coefficient)} \times \text{(reflectance factor of exterior surface - if reflected light involved)}$$
Where

A_f is the number of square feet in the floor area

H is the number of feet the top of the window is above the reference plane.

W is the number of feet of the window width.

D is the number of feet in the perpendicular horizontal distance of the reference point from the window.

A_g is the number of square feet in the actual area of glass.

R is the average reflectance of the wall (i.e., 50 percent for light or 20 percent for dark).

For a skylight or clerestory light at a point inside is estimated as follows:

Footcandles $F \times U \times A_g/A_f \times (\text{exterior intensities}) \times (\text{shading } \times (\text{reflectance factor of exterior surfaces if coefficient reflected light is involved})

F is percentage of skylight (the hemispherical shaped dome of visible sky) exposed to the skylight or clerestory.

U is a general coefficient of utilization:

<table>
<thead>
<tr>
<th></th>
<th>dark colored walls</th>
<th>light colored walls</th>
</tr>
</thead>
<tbody>
<tr>
<td>skylight horizontal</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>60 degrees angle from horizontal skylight</td>
<td>0.2</td>
<td>0.25</td>
</tr>
<tr>
<td>vertical clerestory</td>
<td>0.15</td>
<td>0.2</td>
</tr>
</tbody>
</table>

A_g is area of glass

A_f is area of the floor we expect to light

These factors are multiplied by the amount of footcandles expected at various times of the day to see the amount of footcandles at the point of concern. If a shading element is involved, the figure will be multiplied by the appropriate shading coefficient indicated on the shading device charts.

Average figures for our island for the number of footcandles delivered by the sky, based on the average 55 percent of possible sunshine and March 21 and September 21 intensities are:

- 8:00 a.m. and 4:00 p.m.: 3940
- 10:00 a.m. and 2:00 p.m.: 5115
- noon: 5300

Minimum average expected values may also be useful, based on December 21 and December average possible sunshine of 52 percent these are:

- 8:00 a.m. and 4:00 p.m.: 2450
- 10:00 a.m. and 2:00 p.m.: 4080
- noon: 4485

The figures are dependent upon a location's latitude. The amount of daylighting footcandles available can be increased by the reflective percentage if a reflective material is used on an exterior surface of a projected distance equal to the height to the top of the window. For example, a concrete driveway or patio will reflect considerably increased light to a sliding glass door.

<table>
<thead>
<tr>
<th>Reflectance Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>concrete</td>
</tr>
<tr>
<td>white</td>
</tr>
<tr>
<td>asphalt</td>
</tr>
<tr>
<td>grass</td>
</tr>
<tr>
<td>ground cover</td>
</tr>
</tbody>
</table>
One helpful way to study daylighting is to build a model. Light is a physical phenomenon that does not have a spatial scale; therefore a building can be scaled down and still permit accurate measurements of lighting levels. The model’s surfaces will need to be approximately the same reflectance as the actual building. Use of a light meter that measures footcandles can establish ratios of light experienced at a position versus the light available outside. Preferably, the model should be tested at the proposed building site so that it can model such local conditions as reflections from landscaping or adjacent buildings. Passage of seasons can be simulated by tilting the model to the proper relationship.

For those who wish general guidelines without detailed calculations, the following items can be expected to improve the quality and quantity of daylighting:

- Daylighting may be more important in daily general activity areas than in resting spaces or spaces that require electric lighting anyway.
- Take extra care when using morning and afternoon sun for daylighting due to their low angle and heat gain problem.
- Use light colored ceilings and walls to increase reflection of light.
- Use light colored gravel immediately in front of windows to reflect light from the ground outside to the ceiling inside.
- Place windows close to areas desired to be lighted, i.e., sinks and desks.
- Windows off courtyards or alcoves often give good indirect lighting.
- Clerestory windows or skylights introduce light deep into rooms; care must be used to handle the direct sun and to waterproof these window assemblies.
- Combine skylights with electric lighting to provide a consistent light source over an activity area.
- Translucent materials such as glass blocks offer a diffused light source while blocking some of the heat gain that comes through transparent glass. This is especially effective against early morning and late afternoon sun.
- Provide adequate shading of the window, both top and sides to block direct sun and glare.
- Use low landscaping to reduce glare reflected from nearby ocean or other highly reflective surfaces.
- Canvas, fiberglass roof panels or other translucent materials will soften the direct sunlight for a patio or general activity area.

Psychological Cooling

Cooling affects physical and psychological comfort and must be coordinated by the designer. Effective use of color will increase a person’s sense of comfort in a space.

Dark colors exposed to direct sun will absorb more solar radiation than highly reflective colors, thus exterior building surfaces exposed to direct sun should be highly reflective such as white or light yellow. Surfaces oriented to reflect light onto the building or into windows (such as fins or louvers) might be painted dark to avoid glare to the interior.

Some colors are considered psychologically cool (restful) since their long wave length is less stressful to the eye; such colors are greens, blues and violets. Whites, browns and blacks are considered neutral. “Hot” (stimulating) colors—yellows, oranges and reds—should be used sparingly. While most of the impact is psychological, excited individuals burn up more energy (and consequently give off slightly more heat) than more relaxed people.

The tropics worldwide are renowned for bright colors that abound both throughout nature and the manmade environment. Such colors should also be considered in various aspects of residential design. Thus any color scheme should consider many design factors including psychological affects prior to the selection of materials and colors.
Naturally Ventilated Houses

A major approach to providing comfort in residences while achieving energy efficiency is to employ the techniques of natural ventilation. Choice of ventilation methods will be based on the interrelated comfort principles, climatic conditions, specific site conditions and lifestyle.

The conditions identified in the standard comfort zone generally apply to slightly active people clothed for a temperate climate zone and with an air velocity below 10 feet per minute (essentially still air). This condition does not consider comfort when the air motion relative to occupants is "lively" or "breezy"—which is a nontechnical description of a comfortable environment in hot weather. People in summer clothing, with 85°F (29.4°C), 70 percent RH can be quite comfortable where there is a 2-3 mile per hour breeze. Psychologically, in warm weather, the movement of air relative to people is a pleasant sensation and greatly increases the feeling of comfort.

When there is a perceptible air velocity as little as 2-3 miles per hour there is striking change in conditions for thermal environmental comfort. An average person would normally require 73°F (22.8°C) for 90 percent RH, whereas, 78°F (25.6°C) becomes comfortable with the breeze. Thus proper ventilation may make people feel 5°F (2.8°C) cooler even with relatively slow air motion.

If people can be comfortable in what is normally considered a hot, humid condition because of a steady breeze, this principle should be adapted to design. An average velocity of 2-3 miles per hour can be easily tolerated by occupants. It does not rustle papers or give a feeling of draft to most people. A 5-8 mile per hour breeze is still gentle, will flutter papers and mess hair and may be nearer the upper limit for comfort. With 80 percent RH, 85°F (29.4°C) and a wind of 2-3 miles per hour there would be an effective temperate of 78°F, (25.6°C) which is acceptable to most people.

Natural ventilation provides for three distinct functions — for air supply, for convective and evaporative cooling and for psychological cooling.

Ventilation is necessary to keep interior temperature and humidity from increasing due to heat output associated with human activity. Exhaus.ts such as range hoods and bathroom exhaust fans aid ventilation. House plants add to the humidity and increase the need for ventilation.

Buildings with louvered, vented and windowed walls that are planned for natural ventilation should be orientated to fully take advantage of prevailing breezes. The orientation of a building and the location of windows must also consider sun angles to minimize heat gain. Skillful use of building elements such as screen walls, projecting canopies and landscaping can help induce ventilation and provide sun protection.

Air exerts a pressure as it strikes a building. The greatest pressure occurs on the windward side when the wall is at a right angle to the wind direction. As the air blows over and around the building a low pressure area is created on the leeward side.

Air moves from high pressure to low pressure. With openings in both the windward and leeward sides, an airflow is created within the building. Maximum velocity will occur when small openings are on the windward side where the pressure is the greatest and large openings on the leeward side, the optimum ratio being 1:2.

The next task is to use the basic principles of air flow to develop good natural ventilation. How can a building be planned to take advantage of the movement of air, alleviate influences of the sun and humidity and provide for comfortable and safe living? Factors to be considered in the proper planning of such a building are:

- Building configuration.
- Location of interior spaces and outdoor spaces.
- Roof shapes.
- Windows and openings.
- Shade and sun control.
- Landscaping and vegetation.
- Induced ventilation.
- Traditional architectural solutions.
Building Configurations

Generally, the shape of a building should be elongated with the longest side facing toward the wind. Ideally, the long sides should be away from the east and west sun, but this is not always possible because the prevailing breezes often come from these directions. Recommended building proportions are 1:1.5 to 1:2 for the short side compared to the long side facing the wind. For our island, this will result in a relatively long narrow building directed east-northeast.

For two-story structures, the air flow through the first floor is good although slowed somewhat by ground friction. Because of the pressure build-up, wind will be forced over the structure and therefore a provision such as an overhang or canopy will help to redirect the wind horizontally into the structure.

Elevating a structure on stilts minimizes the resistance near ground level and in fact greatly improves air distribution by allowing air to circulate freely on all sides, including under a structure. Raising the building also gets away from the humidity of the heavier low air and elevates the structure above the level of low bushes that block or slow the breezes down. This concept was well understood in early stilt houses. With later design the lower bodegas, or store rooms, were enclosed by thick coral stone and mortar walls which blocked wind under the structure.

Two-story structures provide other advantages such as reduction of roof area and the solar insulation effect of upper floors. Also, a stronger wind occurs at 20-40 feet above the ground.

Transition spaces such as gardens, lanais, porches, verandas, terraces and breezeways can serve to direct the breeze while providing added protection from the sun's direct heat.

Location of Interior and Exterior Spaces

The planning of functions and spaces to take advantage and to promote natural ventilation is of great importance, since the occupants of a building will seek those spaces where their comfort can be satisfied.

During the daylight hours, the living room, dining, patio areas, kitchen, recreation and work rooms receive the most use. These areas should be located for the best exposure to ventilation and natural light. A transition space such as a hallway can be utilized as a means of channeling air movement to areas not directly exposed to the wind.

Spaces may be stacked such as bedrooms over living room to gain better exposure for more rooms or to take advantage of the fact that air rises as it is warmed, and thereby induces ventilation.
The kitchen, bath and other utility areas should be on the leeward side of incoming breezes so heat, humidity and smell can be dissipated without contaminating adjacent areas. Water heaters, freezers, washers and some other heat and humidity generators can be located outside the general living spaces.

Bedrooms are occupied generally during night hours when breezes and air movement are slow or non-existent. Still, the bedrooms should be located to receive the cooler outside air whose temperature has dropped approximately 10 degrees.

Where bedrooms are clustered in one general area, efforts should be made to provide for the free movement of air through them.

Naturally ventilated spaces appear larger because sound does not reverberate as much as in a totally closed room, thus some rooms can be smaller, and more economical to construct.

Closets and storerooms can be located along unshaded exterior walls to buffer the heat load to major living spaces.

A patio, screened-in porch or courtyard can serve as a secondary activity area for some functions and be economically naturally ventilated and lighted. Thus construction may be less expensive by allowing the basic house structure to be smaller since it doesn't need to accommodate the patio functions. The design of the exterior space must still consider its effect on natural ventilation and sunlight just as described for the interior spaces.

Roof Shapes

The roof is a major building element that can greatly influence natural ventilation.

A roof generally will not produce temperatures cooler than the outdoor air, but if well designed, it can prevent indoor temperature from increasing above outdoor air temperature, thus keep the ceiling temperature about the same level as the surrounding surfaces.

A major consideration is to have roofs constructed of low thermal capacity, using materials of lightweight construction or providing good heat resistance. Insulation is desirable in cases where a heavy concrete or tile roof is necessary or preferred.

Another consideration is the shape of the roof. The roof shape can provide a natural method for moving air through a building. As air gets warmer, it expands, becomes lighter and rises to the highest point in the space. A sloped roof will direct the movement of hot air up and out through vents provided at the top. A roof shape that effectively promotes natural ventilation in tropical climates is the hip type roof, with gable vents and long overhangs. This allows hot air to rise and escape while providing protection from direct sunlight and rain.

In addition, the roof construction space itself should be vented at the top and bottom so air flows between the roofing and ceiling. Natural air currents will keep the space cooler and carry away the radiant heat gain coming through the roof. Openings to this air cavity must be a minimum of 1/150 of the ceiling area.

A roof configuration can evolve into an upper and lower roof. The upper roof could be only a shade element or a roof trellis.

Conversely, the upper roof could be the major element and the lower roof element of minimum material allowing heat to transfer out of the space when the interior is warmer than the exterior air.

Common but often inappropriate for the tropics, a typical low flat roof tends to collect warm air inside its construction and radiate heat down to the occupants.
Ceiling height is an important consideration. In an air-conditioned space this is decreased to minimize the volume of air to be conditioned, whereas in other structures this should be high to decrease radiation of heat from the ceiling materials.

Induced ventilation will occur with a solar chimney that uses rising hot air to draw fresh air into the building, even when the roof is flat.

The chimney has a clear material on one side to admit the sun's heat and dark solid material on the other three sides. The sun heats the air in the chimney which then rises, drawing new air in, preferably from low vents near shady outside areas. A 2-foot square chimney 6-foot high over a 10-foot by 12-foot by 8-foot high room can easily create a better than 2 mile per hour breeze.

Windows and Openings

Ventilation occurs through windows, doors and other openings such as exhaust ports. While windows serve various functions including daylighting and viewing, the primary concern for a naturally ventilated house is the ventilation capability. The windows for such a structure should be plentiful. The orientation depends upon the direction of prevailing breezes as previously discussed.

Windows should be located at a variety of heights to permit air movement at various levels. This minimizes stagnant air pockets. Proper circulation may also be achieved by having the intake openings at a low level on the windward side and at both low and high levels on the leeward walls. Low windows encourage
air flow at a level where human activity normally occurs. High windows on the leeward side assist in exhausting hot air and induce ventilation by natural convection.

Windows are a potential source of large heat gain into the interior and require careful placement and shading to minimize the heat transfer. They are also a potential problem area for water infiltration. The strong winds and heavy rains common to the tropics make watertight windows a necessity. Proper sealing of joints, placement of gaskets and continued maintenance of the entire window assembly is important.

Shade and Sun Control

In addition to air movement or ventilation, solar heat gain is the other element in a warm humid island climate than can be easily controlled to maintain physical comfort.

Control of the effects of the sun on a building will influence the inside temperature. A decrease in the radiant heat gain will consequently reduce the amount of heat that must be removed. By providing devices for shading, the solar heat gain can be drastically reduced and shaded surfaces can be of a lower R value, which are usually less expensive. Surfaces are not required by building codes to be insulated to any particular R value when the building is not air conditioned.

Landscaping and Vegetation

Landscaping can have a significant cooling effect, and can be an energy saver through proper site planning and the selection of plant materials. Proper landscaping design will help control solar heat gain, humidity, direct breezes and augment rain protection.

Two facts stand out as illustrations of the importance of landscape and vegetation. First, the rough dark leaf texture and volume of a tree or shrub diffuse and absorbs solar radiation and provides shade.

Second, the temperature of grassed areas on sunny days are 10 to 15 degrees cooler than those over bare ground or paved surfaces. Ground cover and low growing vegetation absorb the heat that would be reflected into the air, or onto walls and into windows.

Selection of plant types and locations must also consider what effect a particular plant or tree will have on the prevailing breezes as well as what effects it will have on shading and humidity.

Dense plant material on a trellis will provide shade which will be cooler than a space exposed to full sun. But such dense material on a vertical trellis will also restrict welcome breezes and will increase humidity. Some trees provide daytime shade but close leaflets in the evening, decreasing their resistance to wind and minimizing humidity build-up (i.e., flame tree, yellow poinciana and monkey pod).
In other cases, dense vegetation can be arranged around a building to funnel and direct breezes through the building or along the surface of a building.

With our island’s breezes normally coming from the east, planting on this side should be either below or high above building openings. The low planting will not hinder the breeze, however, a tall tree has the benefit of providing shade from the morning sun and a funneling effect on the breeze under it.

Plants on the north and south need to be taller or closer to building walls to have a shading effect. These can also be used to direct airflow along walls or at windows.

To shade structures trees need to be high when located on the south side.
High trees on the leeward side, if too close to a building, will tend to reduce wind speed through a building. Therefore, a careful balance must be achieved because shade is needed on this exposure. Leeward trees with foliage centered at the roof line will increase the low pressure area on this side of the house, increasing interior ventilation.

**Induced Ventilation**

Interior wind induced ventilation velocity can be estimated through the following calculations:

\[ M = EAV \]

- **M** is air flow in cubic feet per minute.
- **E** is effectiveness of the opening (0.5 for openings perpendicular to the wind)
- **A** is the actual open area of windows (use the smaller of either the inlet or outlet, and reduce to 80 percent to account for screens and mullions)
- **V** is the wind velocity in feet per minute (miles per hour figure multiplied by 88)

We can compare the estimated ventilation with the flow required to get the number of air changes desired. The residential minimum number of air changes is one half the volume per hour.

The rate of air movement inside the building can be estimated from the above results as follows: We take the cross-sectional area of the incoming air and approximate the size of the air stream. After the air comes through the window it spreads out a bit, so a 3 feet x 4 feet window might have an estimated air stream of 5 feet x 6 feet. The interior velocity is:

\[ V_I = \frac{M}{A_s} \]

- **V_I** is interior velocity in feet per minute.
- **A_s** is the area of the air stream in square feet.
- **M** is air flow in cubic feet per minute.

This result can be used in evaluating the effective temperature of the space, assuming the occupants are in the air flow, as previously discussed.

The amount of ventilation induced thermally can be calculated. This is the ventilation that occurs when no wind is present; it results from the inside warm air rising and going out upper openings, and cooler air coming in the lower openings to replace the exhausted air.

\[ M = 9.4A \sqrt{h} (\Delta t) \]

- **M** is air flow thermally induced, in cubic feet per minute.
- **A** is area of opening (smallest of either upper or lower openings in square feet).
- **h** is average height difference between inlet and outlet in feet.
- **\( \Delta t \)** is the numerical difference between exterior and interior temperature in F.

The temperature difference can be assumed to be at least 1/2F per foot of the average height difference. This thermally induced ventilation can be increased by raising the height of the outlet opening, increasing the area of the windows or creating a further temperature rise at the outlet.
Normally induced ventilation would be designed to complement the wind ventilation, so for our island the high outlets would face west, or within 45 degrees angle of the west. Facing to the southwest would allow the use of the afternoon sun to increase the temperature at the outlets and thereby induce more ventilation. Calculations are done to find the effect of the wind ventilation combined with the induced ventilation, as they cannot simply be added.

is combined air flow; cubic feet per minute.

is largest component, either wind or thermal induced; cubic feet per minute.

is smallest component; cubic feet per minute.

Where ventilation cannot be easily induced it may be desirable to reduce relative humidity by increasing the temperature. This is done by localized heating elements in closets, closed bookshelves or pianos. If heating elements are not used, venting should be provided for closets and cabinets to avoid humidity build-up. The air should be allowed to enter at the top and exit at the bottom, after absorbing moisture and thus weight.

Traditional Architectural Solutions

Traditional architecture has some particular techniques and concepts that are good examples of energy conscious designs. These concepts can be applied in today's structures.

Early island residences had high ceilings which allowed hot air to rise away from the occupants, and provided a greater distance from heat reradiating from the ceiling. The traditional wood framing and roof form economically provided the higher space; present concrete construction could effectively use the same concept.

Full height windows were frequently used to gain ventilation. Sometimes these had open balustrades or balconies to provide privacy or safety, yet allow breezes for good ventilation.
A detached kitchen has long been a part of the island's architecture. This separated the kitchen heat and smoke from the other areas of the house and allowed for easier, more open ventilation of the kitchen. This has been passed down to today's barbecue and occasional outside party kitchens.

New residences could beneficially reconsider the concept of a kitchen separated from the rest of the house by a breezeway.

Balconies, entrance porches and verandas are common throughout the region, especially in areas of previous Spanish influence. These provided raised, breezy, comfortable spaces away from the enclosed interior spaces, and made use of areas under long overhangs that shade the walls. These served as meeting and conversation spaces at the front of houses for evening relaxation.
Naturally Ventilated Residences

The following tropical residences have been designed and constructed using the concepts and principles previously reviewed:

- Franke House
- McCully - Cadmus House
- Winkler Residence
- Wiseman Residence
- Batcheller House
- Hawaii Energy House
Franke House

The Franke House is designed to take maximum advantage of the naturalness of a beachside property on the leeward coast of Guam.

The house is naturally ventilated throughout. Windows encircle the residence providing vistas of the surrounding areas: the ocean to the southeast and northeast, an island directly to the west and a backdrop of mountains to the east. The windows are especially concentrated on the windward and leeward sides for good cross ventilation. The recessed entry is angled into the wind and combines to further induce the air through the house.

The first floor is elevated on concrete columns 4-5 feet above grade with the adjacent ground bermed up at various redwood decks and stairs. By elevating the structure the building's wind resistance is reduced and the living levels are further elevated above the surrounding ground cover. The additional height also offers further protection from storm inundation and provides boat storage.

The two-story interior is organized around an open central core that in turn opens to ocean side balconies at two different levels. Open spaces above beams and louvered doors throughout add further to the interior air circulation, especially at the upper level where the open center is bound by bedrooms on both sides. Relatively high ceilings at both levels permit ceiling fans for all major rooms.

The structure combines a concrete exterior building envelope with a wood second floor and exterior decks. The walls and roof are polyurethane waffle construction with cement plaster on the interior and concrete on the exterior. The roof and walls (other than windows) have a "U" value of approximately 20.

The interior plaster surfaces and ceramic tile and marble first floor offer cool surrounding surfaces throughout.

The windows are primarily horizontal sliders. These are protected from rain and direct sun by projecting sunscreens which further provide security and typhoon protection when closed.

A thermo syphon hot water system is used. Overall, many of the energy-conscious features are simply an adaptation of traditional island details that have been used for centuries. These details include the elevated floors, high ceilings and tilt-down sunscreen shutters.

Project: Residence for Mr. & Mrs. Milt Franke
Architect: J.B. Jones, Architect, AIA
Contractor: Self-constructed
Construction Date: Under construction

1. House sited to take maximum advantage of prevailing winds.
2. Existing tall palm trees preserved.
3. First floor is elevated providing increased ventilation and boat storage beneath structure.
1. House orientated toward prevailing breeze.
2. Large quantity of windows especially on windward and leeward sides.
3. Ample decks and porch space for transitions between exterior and interior spaces.
4. Ceramic tile first floor provides cool surface.
5. Building configuration helps induce wind through central core of the building.
6. Kitchen ventilation direct to exterior.
7. Exterior shower.
8. Louvered bifold doors permit additional interior air movement.
9. Ceiling fans to augment air circulation.
1. Elevated structure minimizes wind resistance.
2. High, open interiors permit maximum air movement.
3. Clerestory opening for warm air exhaust.
4. Wide roof and floor cantilevers for sun shading.
5. Louvered doors provide cross ventilation and maintain visual privacy.
6. Sunscreens provide protection from direct sun, rain and serve as typhoon and security protection in louvered position.
7. Thermo-syphon hot water system.
8. Provision for future water catchment system.
9. Walls constructed of urethane waffle and plaster system providing excellent insulation.
10. Maximum quality of openings provided.
11. Ceiling fans to augment interior air movement.
McCully-Cadmus House

This naturally ventilated house located on the beach extends indoor living space through a variety of porches and terraces. Covered by a large sheltering roof, the outdoor spaces provide protection from sun and rain, and offer flexibility in living arrangements. The house is raised four feet on stilts for protection from heavy seas and to promote the cooling effects of air movement under as well as around the structure.

The house uses open planning of interior spaces to take advantage of free-flowing natural breezes to every room. A central clerestory at the peak of the roof, with louver windows facing downwind, dominates the high ceiling of the living room and bedroom areas. Warm air is expelled naturally by means of the chimney effect while the high windows provide a warm and interesting play of indirect light to the spaces below.

A combination of doors, louvers and sliding windows provide a variety of methods for introducing and controlling air flow through the house.

An outdoor screened porch adjacent to the living room provides an informal space for entertaining and relaxing by the ocean. The kitchen is located downwind of the other living spaces to exhaust cooking heat directly to the exterior. Lush tropical vegetation on the site was selectively thinned to enhance air movement and views.

The house is constructed of reinforced concrete and masonry construction. Interior flooring is glazed ceramic tile for coolness and maintainability. Outdoor terraces have exposed redwood flooring.

A future addition, consisting of guest house and studio, is planned as a separate building connected to the main house by a covered walkway. Detachment of building elements in this way will provide maximum free area for natural ventilation and air movement for both buildings.
Open living spaces with few separating walls promotes air circulation.

1. Clerestory at high point exhausts heat
2. High ceiling in living area lets heat rise
3. Ceiling fans aid circulation
4. Windows protected by wide overhangs
5. Air circulation under house promotes cooling
Winkler Residence

The Winkler house was designed to take maximum advantage of a spectacular cliffline site on the windward coast of Guam.

It sits on an intermediate ledge of a 200-foot-high cliff overlooking the Pacific Ocean and coastal plateau below.

The narrow ledge prompted use of a linear plan with living spaces along a central circulation spine. Bedroom, dining and service spaces are on the upper level of the two-story home. A living room, library and children’s den are on the lower floor. The living room is a two-story space that opens from the mezzanine-level dining area.

The house is divided into two main areas with separate wings for each. An open-air walkway connects the main areas and provides variety in the linear circulation spine.

Projecting windows on the ocean side and high louvers in the corridor maintain comfortable air-flow ventilation. The sloped roof and high interior spaces encourage air movement and take advantage of convection.

Sloping overhangs limit direct sunlight at the upper level and the cantilevered second floor provides shade and rain protection for the lower floor. Lush, tropical surrounding landscape on the northeast and west elevations provide additional shade.

The roof is insulated with 2 inches of styrofoam with the roof painted white for reflectance. A large percentage of the building perimeter is nestled into the side of the cliff limiting overall heat gain. The central spine is designed for central air conditioning ducts and the window systems’ locations and selection are compatible with air conditioning. However, the level of comfort from natural ventilation has precluded the need to install air conditioning.

Architect: Jack B. Jones, AIA
Consultant: Jerry Hazelwood
Contractor: Phil/Guam Construction Co. and Pacific Construction Co., Inc.
Construction Date: 1974

Building and Partial Site Section

1. Sloped, high ceiling for natural ventilation.
2. Clerestory openings at observation deck level for exhaust of warm air.
3. Building nestled into edge of cliff reducing overall heat gain.
4. Building spaces stacked to minimize building envelope area.
5. Ceiling designed for future central air conditioning system.