A METHOD FOR EVALUATING THE ANNUAL EFFECTIVENESS OF FIXED, EXTERIOR SHADING DEVICES

By

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1982

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF ARCHITECTURAL ENGINEERING
December, 1984

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PREFACE

This study is concerned with developing a method that evaluates the annual effectiveness of fixed, exterior shading devices. The method quantitatively measures the effectiveness of a device to shade during overheated months and to allow insolation during underheated months, and thus facilitates the selection and sizing of fixed, exterior shading devices. In developing the method, a procedural synopsis is presented of assessing shading needs and selecting and sizing shading devices. Existing latitude-based and climate-based methods for determining recommended projection lengths are analyzed to see how (and whether) the methods address the problems of balancing summer shading with winter insolation and late summer shading with spring insolation.

The author wishes to express his appreciation to his major advisor, Dr. Lester L. Boyer, Professor of Architecture and Architectural Engineering, for his guidance and assistance throughout this study. Appreciation is also expressed to Walter T. Grondzik, Associate Professor of Architecture, for his guidance in formulating and organizing the material. A note of thanks is given to W. George Chamberlain, Professor of Architecture, John H. Bryant, Professor and Head of Architecture, Dr. Jerald D. Parker, Professor of Mechanical Engineering, Dr. John A. Wiebelt, Professor of Mechanical Engineering, and Haven D. Mankin for their invaluable assistance as committee members.

Appreciation is also expressed to Stan Hunt and Marsha Speer for their assistance in typing the manuscript and suggesting format.

Finally, special gratitude is expressed to my parents, Dale and Evelyn Magnus for their prayers, understanding and encouragement.

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LIST OF SYMBOLS

D	declination
c	depth of louver
e	left or right overhang extension
e_L	left overhang extension
e_R	right overhang extension
$\tilde{e}$	ratio of left or right overhang extension to window height
h	spacing between louvers
g_H	separation height
$\tilde{g}$	ratio of separation height to window height
k	fraction of window in shade
L	latitude
n	weighting factor to balance the importance of summer shading and winter insolation
N	number of days before or after solstice
N_o	number of days before or after summer solstice that complete shade is desired
N_u	number of days before or after winter solstice that complete insolation is desired
p	overhang projection length
$\tilde{p}$	ratio of overhang projection length to window height
R	daily range
t_H	total height
T	temperature

T_b	balance point temperature
T_{max}	maximum temperature
T_{min}	minimum temperature
v_W	width of overhang
w_H	height of window
w_W	width of window
$\tilde{w}$	ratio of window width to window height
Ω	profile angle
Ω_o	overheated profile angle during overheated period
Ω_u	underheated profile angle during underheated period
β	solar altitude
γ	surface-solar azimuth
ε	annual ΔT-effectiveness
ε_o	overheated ΔT-effectiveness
ε_u	underheated ΔT-effectiveness
*	asterisk

GLOSSARY

For identification, glossary terms throughout this study are followed by an asterisk (*) the first time and at strategic times each is used.

Air gap - The distance between the plane of a wall and the nearest point of a shading device; prevents hot air from collecting under a solid shading device by allowing vertical air movement.

Auxiliary heating system - A conventional heating system used to supplement solar heat.

Average day - That day which has the extraterrestrial radiation closest to the average for the month.

Balance point temperature - The outside temperature below which heating is required and above which heating is not required; used as the demarcation temperature between overheated and underheated periods.

Beam radiation - Direct radiation (solar).

Checking period - The period of time less than or equal to the overheated period, determined by local outside temperatures and the amount of direct radiation striking a window.

Complete insolation - The state at which all incoming direct solar radiation is allowed to strike all of a receiver.

Complete shade - The state at which all incoming direct solar radiation is prevented from striking any part of a receiver.

Complete-shade day - A day in which a receiver is completely shaded from sunrise to sunset.

Complete-shade period - The period of time (normally centered on the summer solstice) that consists entirely of complete-shade days.

Conjugate dates - Dates having identical sun paths (e.g., April 21 and August 21).

Daylighting - Utilizing light originating from the sky hemisphere to supplement interior, electric lighting.

Declination - The angular position of the sun at solar noon with respect to the plane of the equator; varies between -23.45^o at the winter solstice and $+23.45^o$ at the summer solstice.

Depth of louver - The size of a louver measured parallel to its major plane.

Device-line(s) - The border(s) of a shading mask determined by the shading characteristics of a shading device.

Diffuse radiation - The component of solar radiation that has been scattered by atmospheric molecules and particles, or by ground or other reflecting surfaces.

Effectiveness - The ability to produce a desired effect; normally, with respect to shading devices, effectiveness is the ability of a shading device to shade direct radiation when shade is desired (during the overheated period); however, overall effectiveness is the ability of a shading device to not only shade when shading is desired, but to produce other desired effects such as visibility, weatherability, daylighting, etc.

Equinox - Either of the two times each year when the earth rotates about the sun normal to the equator, and day and night are everywhere of equal length; approximately March 21 and September 21.

Extension (of an overhang) - That part of an overhang which extends past the sides of a window.

Full-time overheated period - The overheated period indicated on a sun-path diagram for which shading is needed on both conjugate dates.

Half-to-full-time overheated period - The overheated period indicated on a sun-path diagram for which shading is needed on at least one of two conjugate dates.

Horizon-line(s) - The border(s) of a shading mask determined by the rising or the setting of the sun.

Incidence angle - The angle between incoming direct solar rays and a line normal to that surface being insolated.

Incremental shading mask - A shading mask that indicates shading of a window in a series of regular consecutive percentages of shaded area.

Infinite extension - The extension of an overhang that extends sufficiently past the sides of a window so as to allow only a negligible amount of direct radiation to strike the window.

Insolation - Solar radiation that has been received by a surface (usually a window surface).

Interface - The place at which a building's interior and exterior meet.

Isotropic - Uniformly distributed; independent of angle.

Latitude - Angular distance north or south from the earth's equator measured through 90^{o}.

Load Collector Ratio (LCR) - A ratio of a building's heat loss rate to south window area, indicating solar heating performance.

Locus - The set of all points whose location is determined by stated conditions.

Louver position angle - The angle, in a vertical plane normal to the surface to be shaded, between a louver and that surface.

Overhang ratio - The ratio between the projection length of an overhang and the window height; also called "relative projection length".

Overheated period - The time period of a year during which shading is needed and the outside temperature is above the building balance point temperature.

Overheated profile angle - The profile angle that determines the position and dimensions of a shading device for shading during the overheated period.

Partial angle - Shading less than 100 percent but more than zero percent of a window from direct solar radiation.

Profile angle - The angle between a line normal to the window plane and the direct rays of the sun in a plane normal to the window plane; determines the position and dimensions of a shading device.

Projection angle - The angle, in a plane normal to the surface to be shaded, between a shading device and that surface.

Projection length - The dimension of a shading device measured normal to the window plane, that determines the amount of shade a window receives.

Screen density - A measure of the weave opacity of a screen-type shading device.

Separation distance - The distance between the top or sides of a window and a shading device, that determines the amount of insolation a window receives.

Separation height - The vertical distance between the top of a window and the lowest point of an overhang.

Separation ratio - The ratio between the separation height of an overhang and the window height; also called "relative separation height".

Shading mask - The area on a sun-path diagram where shading of all or part of a window occurs.

Sky-line(s) - The border(s) of a shading mask determined by shading from surroundings (buildings, trees, objects, etc.).

Solar altitude angle - The angle between the sun and a horizontal plane.

Solstice - One of the two points on the ecliptic at which the sun's distance from the equator is greatest and which is reached by the sun each year about June 21 and December 21.

Spacing between louvers - The distance parallel to the plane of a shading device between louvers.

Surface-solar azimuth angle - The angle between the projection on a horizontal plane of a line normal to the surface and the projection on a horizontal plane of a line from the sun to the surface.

Total height - The vertical distance between the sill of a window and the lowest point of an overhang; the sum of the window height and the separation height.

Underheated period - The time period of the year during which shading is undesired and the outside temperature is below the building balance point temperature.

Underheated profile angle - The profile angle that determines the position and dimensions of a shading device for allowing insolation during the underheated period.

Wall-line(s) - The border(s) of a shading mask determined by times when the sun is behind the wall of the window to be shaded.

Window height - The vertical distance between the sill of a window and the top of a window.

CHAPTER I

INTRODUCTION

Problem Statement

One of the characteristics of modern architecture is the widespread use of glazing in building facades. Corbusier once stated, "... as we possess steel and reinforced concrete... nothing these days prevents us from opening toward the solar rays, not a mere fraction, but 100 percent of a facade" (1, p. 10). However, this freedom of "opening toward the solar rays" of the sun is restrained by a necessity of controlling solar heat gain, especially during hot summer months, to maintain comfort. Often, the architect, engineer, and building owner use energy in the form of air conditioning to "cancel out" the solar heat gained through building fenestration. The cost of such a strategy can be compared to the "window tax" of the 18th and 19th centuries:

> In England, between 1696 and 1851, home owners paid a "window tax" based on the number and size of their windows. Houses were designed and windows were often bricked up to avoid this detested assessment. Even the rumor that such a tax was going to be imposed in America caused an armed insurrection in Pennsylvania in 1796, and Federal troops had to be called to quell the disturbances that followed (2, p. 3).

Although today no window taxes are being assessed, many building owners are still paying a modern version of this levy in the form of unnecessarily high energy bills. A solution to the problem of high energy bills due to excessive solar heat gain is to prevent the entrance of solar energy by shading sun-exposed windows in the summer. During certain times of the year when a building is being mechanically heated, however, solar heat gain is not excessive, but rather, desired. In many cases solar gain enables properly designed fenestrations to allow more energy into a building rather than out of a building over the course of a year, making the fenestrations energy-contributing rather than energy-consuming (3).

Heat gain through windows can be controlled by exterior shading devices, interior blinds or drapes, and/or interface* techniques such as glass composition and films. Exterior, fixed (non-movable) shading devices were chosen as the topic of this study for the following reasons:

1. The most effective way to reduce the solar load on fenestration is to intercept direct radiation from the sun before it reaches the glass (3).
2. Fixed shading devices do not require automatic or manual control, and are thus advantageous over operable devices from a practical day-to-day point of view.

In some cases, exterior, interior and interface shading may not be feasible. Cool summer temperatures, prominent cloudy skies, minimal incident solar radiation due to orientation, shading from surroundings, and building type might lead a designer to leave a window unshaded. However, when windows can be externally shaded, such shading should be carefully designed. Too often fixed, exterior shading devices are considered only on the basis of shading during the summer. Obviously a "shading device" ought to shade. Ideally though, a device should shade a window during overheated periods* and allow solar insolation* during underheated periods*. However, shading with a stationary device during all months of the overheated period necessarily implies partial shading* during some months of the underheated period. The design problem then, of fixed, exterior shading devices, is to determine the configuration in which effects of winter insolation and summer shading, as well as spring insolation and late summer shading, are balanced in such a way as to optimize overall building performance.

In addition to balancing shading and insolation needs, is the important aspect of evaluating fixed, exterior shading devices with respect to other factors that comprise the overall effectiveness* of a shading device. For instance, a series of fixed shading devices may have the same shading characteristics, yet their effect on view, air movement, control of diffuse radiation*, daylighting*, and other factors may differ considerably.

Objectives

The objectives of this study are to develop a method that evaluates the effectiveness of exterior, fixed shading devices, and in the development of the method to evaluate existing work and influential factors related to the design of exterior shading devices. The specific goals of the study are:

1. Provide a general guide in assessing shading needs and determining factors which influence the effectiveness and facilitate the selection of exterior, fixed shading devices.
2. Compare and evaluate existing latitude-based and climate-based methods of shading device design.

3. Develop a climate-based method that quantitatively determines the annual effectiveness of exterior, fixed shading devices, and to provide a flowchart to aid in the future development of a computer program to facilitate solutions of the proposed method.

Scope and Limitations

Since this is a study of exterior fixed shading devices, operable devices (whether inside or outside), interior drapes and blinds, and types of glass and films are not considered. Instead, this study considers four general types of exterior, fixed shading devices: horizontal, vertical, screen-type, and combined horizontal and vertical. Examples of each type are shown in Figures 1 through 4.

The emphasis of this study is to determine the effectiveness of shading devices with respect to shading during overheated months and allowing insolation during underheated months. Consequently, daylighting, economics, aesthetics, and other factors that influence the overall effectiveness of shading devices are presented in a broad-based sense and are not fully developed.

While evaluating various devices, the intent is to aid the designer in getting close to the selection of an optimum shading device design for a particular location and building application. In seeking "optimum" design, J. Douglas Balcomb states an appropriate scope to this study:

> All [the designer] really wants to do is get near the top, knowing that attaining an exact optimum is rather meaningless because costs are not well known and there are various other uncertainties... Experience shows that in most instances energy economics are not the major factor in the design process. A simple procedure that gives answers in the right ball park will receive much wider use and thus have a much

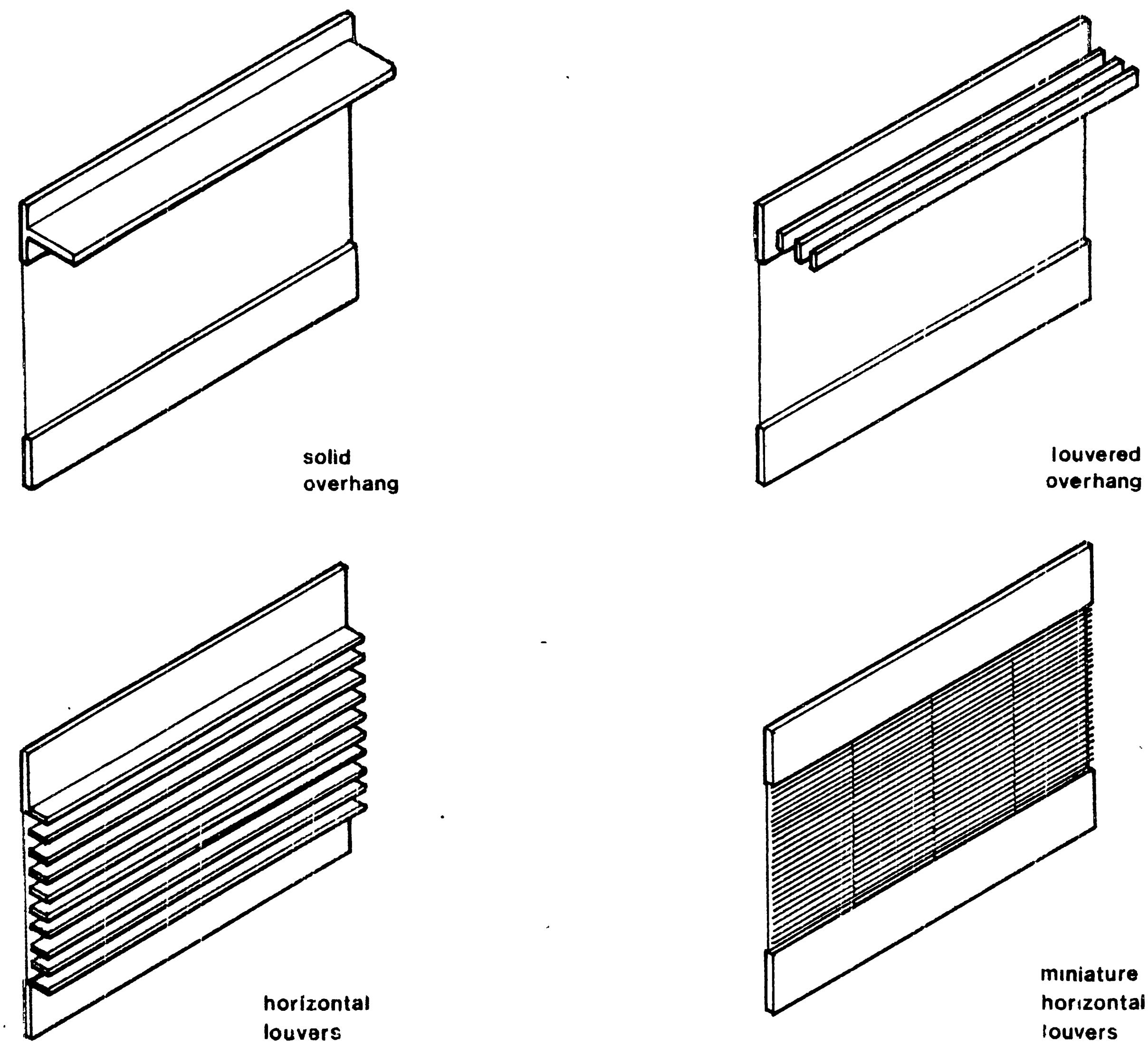


Figure 1. Illustrations of Horizontal Shading Devices

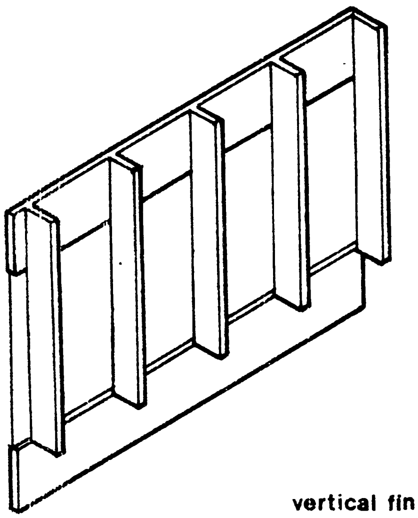


Figure 2. Illustration of Vertical Shading Device

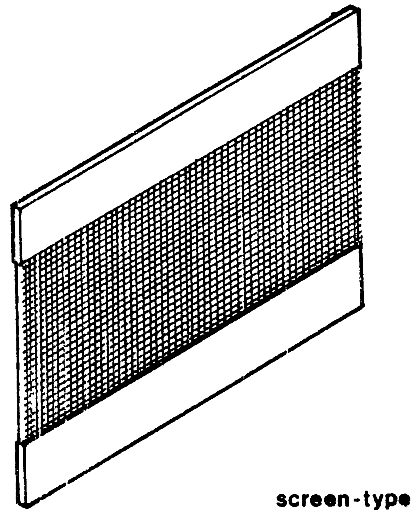


Figure 3. Illustration of Screen-Type Device

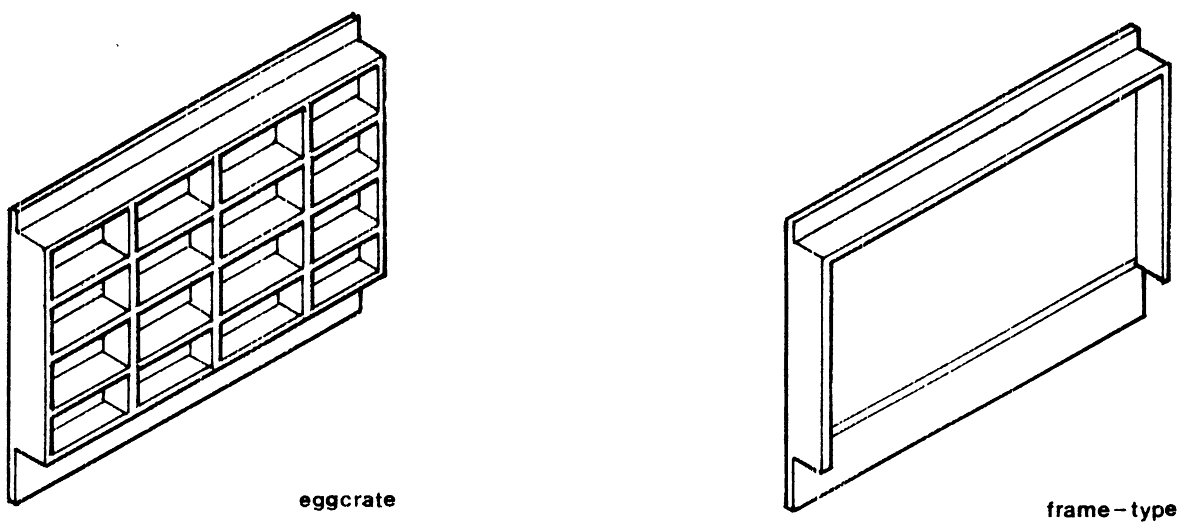


Figure 4. Illustrations of Combined Horizontal and Vertical Shading Devices

> greater impact on design than a complex procedure that leads to more precise answers but will rarely be used (4, p. 13).

Approach

The approach taken to achieve the objectives of this study is to first provide a synopsis of the process of assessing shading needs and selecting fixed, exterior shading devices. In doing so, those aspects that determine the overall effectiveness of shading devices are identified and investigated.

Then, existing methods, including those by Egan, Mazria, Utzinger, Olgyay and Lau, presently used to determine overhang lengths and shading device design, are compared and evaluated.

Finally, on the basis of these methods and aspects of shading device design, a method that quantitatively evaluates the yearly effectiveness of exterior, fixed shading devices is proposed and analyzed.

To aid in understanding terms and symbols, a glossary and list of symbols is included after the Table of Contents. Terms throughout the study that are followed by an asterisk (*) are included in the glossary.

CHAPTER II

SYNOPSIS OF SELECTION PROCESS

Exterior shading devices strongly influence the appearance of building facades and, therefore, unless considered early in the design of buildings, are often not incorporated. Instead, interior or interface* shading devices and techniques are often used which more subtly affect building facades and which reduce summer solar heat gains considerably less than exterior shading devices. While it is recognized that the most effective way of reducing solar load in the summer is to intercept direct radiation from the sun before it reaches a window, not all climates and orientations need exterior shading (3). However, as Richard Stein points out:

> In the U.S., modern buildings tend to look very much the same whether they are in northern or southern climates and regardless of their orientation on a particular site. This is because buildings have been designed largely to keep natural phenomena outside, to separate conditions inside from the outdoors as much as possible, relying on mechanical systems to do much of the work. Not only is this wasteful in terms of energy consumption, but it also seems quite boring in terms of regional aesthetics (5, p. 34).

The purpose of this chapter is to provide a guide for assessing shading needs and selecting exterior, fixed shading devices for a given location and building application. Figure 5 shows a general flowchart of the process outlined in this chapter.

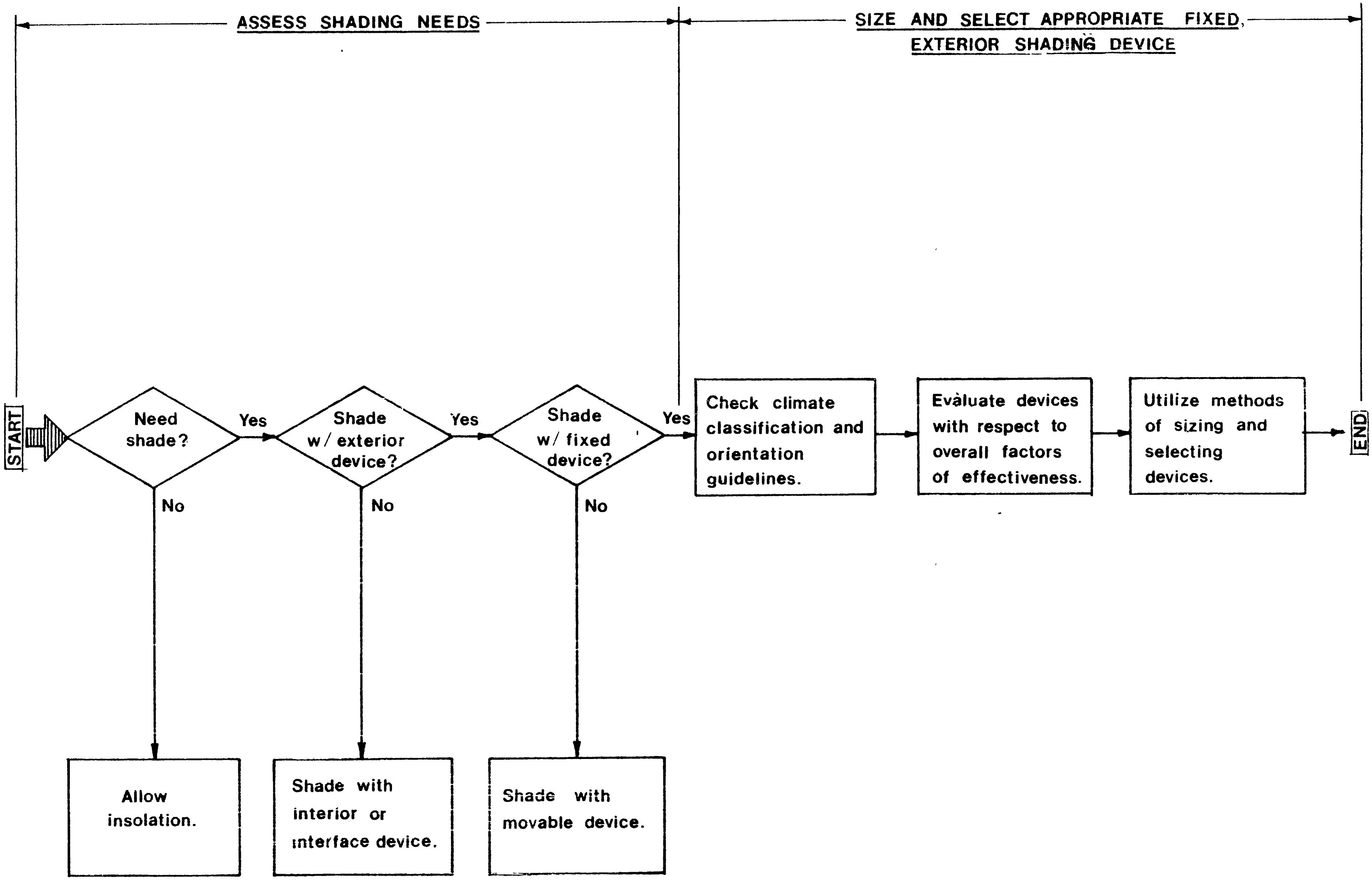


Figure 5. General Flowchart of Assessing Shading Needs and Selecting Exterior, Fixed Shading Devices

Assessment of Shading Needs

Before evaluating specific types of exterior, fixed shading devices, it must first be decided whether shading is needed. Once it is determined that shading is needed, then the decision whether to shade with interior, interface or exterior shading devices must be made. If exterior shading is chosen as a strategy, then one must assess the advantages and disadvantages of operable versus fixed shading devices. Finally, once it is decided to incorporate or consider fixed, exterior shading devices for a certain design application, then the appropriateness of various types of shading devices is evaluated. This section summarizes the factors that should be considered in assessing shading needs before evaluating various fixed, exterior shading devices.

Applicability of Shading

To determine whether shading is needed, building characteristics, thermal climate, sky conditions, orientation, and surrounding obstructions should be known.

In studying building characteristics with respect to shading needs, shading may be desired for walls (especially dark walls with high absorptivity) in addition to windows, since shading can help reduce exterior surface temperatures. If a building requires a mechanical system or some level of comfort, either for occupants, equipment, or items in storage, shading is needed when outdoor temperatures are above the building balance point temperature*. Equation (2.1) may be used to calculate building balance point temperature, T_b:

$$T_b = T_{set} - q_i/UA \quad (2.1)$$

where

T_{set} = thermostat setting; if a building has a night setback thermostat, then a time weighted average of the thermostat's settings is used (^oF),

q_i = average hourly internal gains from people, lights, etc. over a 24-hour period (Btuh), and

UA = total heat loss rate of a building including losses due to infiltration (Btuh/^oF).

Balance point temperature of a house is the lowest outdoor air temperature at which the interior remains within comfort limits without either a net gain or loss of heat under a specified solar contribution, and may be thought of as the outdoor temperature below which heating is required and above which no heating is required (6).

Shading may not be desired if outdoor temperatures for a certain location are seldom above T_b, or if sky conditions in a certain location have a low percentage of sunshine. Most geographical locations in the United States, however, have temperatures commonly above T_b in the summer months, and have an average amount of possible sunshine in summer months greater than 50 percent (Figure 6).

Shading by shading devices may not be desired if surrounding obstructions shade a building or if a particular orientation of a building rarely receives solar radiation, such as a north orientation. The procedure described by Mazria in defining a sky-line* is helpful in determining when and at what angles the sun would be blocked by surrounding obstructions (7).

	State and Station	Length of record (Years)	Jan.	Feb.	Mar.	Apr	May	June	July	Aug.	Sept.	Oct.	Nov	Dec.	Annual
AL	Montgomery	25	47	53	58	64	66	65	63	65	63	66	57	50	59
AK	Juneau	30	33	32	37	38	38	34	30	30	25	19	23	20	31
AZ	Phoenix	80	78	80	83	89	93	94	85	85	89	88	83	77	86
AR	Little Rock	32	46	54	57	61	68	73	71	73	68	69	56	48	63
CA	Los Angeles	32	69	72	73	70	66	65	82	83	79	73	74	71	73
	Sacramento	27	45	61	70	80	86	92	97	96	94	84	64	46	79
	San Francisco	38	56	62	69	73	72	73	66	65	72	70	62	53	67
CO	Denver	26	72	71	69	66	64	70	70	72	75	73	65	68	70
CN	Hartford	21	58	57	56	57	58	58	61	63	59	58	46	48	57
DE	Wilmington*	25	50	54	57	57	59	64	63	61	60	60	54	51	53
DC	Washington	27	48	51	55	56	58	64	62	62	62	60	53	47	57
FL	Jacksonville	25	57	61	66	71	69	61	59	58	53	56	61	56	61
	Key West	17	72	76	81	84	80	71	75	76	69	68	72	74	75
GA	Atlanta	41	47	52	57	65	69	67	61	65	63	67	60	50	61
HI	Honolulu	23	63	65	69	67	70	71	74	75	75	67	60	59	68
ID	Boise	35	41	52	63	68	71	75	89	85	82	67	45	39	67
IL	Chicago	33	44	47	51	53	61	67	70	68	63	62	41	38	57
	Peoria	32	45	50	52	55	59	66	68	67	64	63	44	39	57
IN	Indianapolis	32	41	51	51	55	61	68	70	71	66	64	42	39	58
IO	Des Moines	25	51	54	54	55	60	67	71	70	64	64	49	45	59
KS	Wichita	22	59	59	60	62	64	69	74	73	65	66	59	56	65
KY	Louisville	28	41	47	50	55	62	67	66	68	65	63	47	39	57
LA	Shreveport	23	49	54	56	55	64	71	74	72	68	71	62	53	64
ME	Portland	35	55	59	56	56	56	60	64	65	61	58	47	53	58
MD	Baltimore	25	51	55	55	55	57	62	65	62	60	59	51	48	57
MA	Boston	40	54	56	57	56	58	63	66	67	63	61	51	52	59
MI	Detroit	32	32	43	49	52	59	65	70	65	61	56	35	32	54
	Sault Ste Marie	34	34	46	55	55	56	57	63	58	46	41	23	28	48
MN	Duluth	25	49	54	56	54	55	58	67	61	52	48	34	39	54
	Minneapolis-St. Paul	37	51	57	54	55	58	63	70	67	61	57	39	40	58
MS	Jackson	11	48	55	61	60	63	67	61	62	58	65	54	45	59
MO	Kansas City	3	64	54	61	65	67	72	84	69	51	62	46	54	64
	St. Louis	16	52	51	54	56	62	69	71	66	63	62	49	41	58
MT	Great Falls	33	49	57	67	62	64	65	81	78	68	61	46	46	64
NE	Omaha	40	55	55	55	59	62	68	76	72	67	67	52	48	62
NV	Reno	33	66	68	74	80	81	85	92	93	92	83	70	63	80
NH	Concord	34	52	54	52	53	54	57	62	60	54	54	42	47	54
NJ	Atlantic City	15	49	48	51	53	54	58	60	62	59	57	50	42	54
NM	Albuquerque	36	73	73	74	77	80	83	76	76	80	79	78	72	77
NY	Albany	37	46	51	52	53	55	59	64	61	56	53	36	38	53
	Buffalo	32	34	40	46	52	58	66	69	66	60	53	29	27	53
	New York†	99	50	55	56	59	61	64	65	64	63	61	52	49	59
NC	Charlotte	25	55	59	63	70	69	71	68	70	68	69	63	58	66
	Raleigh	21	55	58	63	64	60	61	61	61	60	63	63	56	60
ND	Bismarck	36	54	56	60	58	63	64	76	73	65	59	44	47	62
OH	Cincinnati	60	41	45	51	55	61	67	68	67	66	59	44	38	57
	Cleveland	34	32	37	44	53	59	65	68	64	60	55	31	26	52
	Columbus	24	37	41	44	52	58	62	64	63	62	58	38	30	53
OK	Oklahoma City	23	59	61	63	63	65	73	75	77	69	68	60	59	67
OR	Portland	26	24	35	42	48	54	51	69	64	60	40	27	20	47
PA	Philadelphia	33	50	53	56	56	57	63	63	63	60	60	53	49	58
	Pittsburgh	23	36	38	45	48	53	60	62	60	60	56	40	30	50
RI	Providence	22	57	56	55	55	57	57	59	59	58	60	49	51	56
SC	Columbia	22	56	59	64	67	66	65	64	65	65	66	64	60	63
SD	Rapid City	33	54	59	61	59	57	60	71	73	67	65	56	54	62
TN	Memphis	25	48	54	57	63	69	73	72	75	69	71	58	49	64
	Nashville	33	40	47	52	59	62	67	64	66	63	64	50	40	57
TX	Amarillo	34	69	68	71	73	73	77	77	78	74	75	73	67	73
	El Paso	33	78	82	85	87	89	89	79	80	82	84	83	78	83
	Houston	6	41	54	48	51	57	63	68	61	57	61	58	69	56
UT	Salt Lake City	38	47	55	64	66	73	78	84	83	84	73	54	44	70
VT	Burlington	32	42	48	52	50	56	60	65	62	55	50	30	33	51
VA	Norfolk	19	57	58	63	66	67	68	65	65	64	60	60	57	63
	Richmond	25	51	54	59	62	64	67	65	64	63	59	56	51	60
WA	Seattle-Tacoma	10	21	42	49	51	58	54	67	65	61	42	27	17	49
	Spokane	27	26	41	53	60	63	65	81	78	71	51	28	20	57
WV	Parkersburg	78	32	36	43	49	56	59	62	60	59	54	37	29	48
WI	Milwaukee	35	44	47	51	54	59	63	70	67	60	57	41	38	56
WY	Cheyenne	40	61	65	64	61	59	65	68	68	69	68	60	59	64
PR	San Juan	20	65	69	74	69	61	57	64	65	59	59	57	56	63

Source U S National Oceanic and Atmospheric Administration, *Comparative Climatic Data*.
* Data not available, figures are for a nearby station
† City office data

Figure 6. Average Percentage of Possible Sunshine for Selected Cities (8, p. 46)

Applicability of Shading with Exterior Devices

The major advantage of exterior shading devices is that the direct solar rays from the sun are intercepted before striking a window and entering the building as a heat gain. Olgyay, from his study of shading, concludes that effectiveness in preventing solar heat gain "increases 35 percent by using outside shade protection" rather than inside shade protection (9, p. 70). ASHRAE states, "the most effective way to reduce the solar load on fenestration is to intercept direct radiation from the sun before it reaches the glass." (3, p. 27.46).

From an aesthetic viewpoint, because of their high visibility on the facades of buildings, exterior devices should be considered early in the design of a building, and integrated carefully with the design concept of building facades.

The major disadvantages of interior shading devices is that regardless how reflective, they trap heat on the interior of the glass, so heat remains indoors. Some window units circumvent a few of the thermal disadvantages of internal shades or blinds by placing narrow louvers within the airspace between glazing sheets (6, p. 189). Because interior shading devices such as curtains or venetian blinds are normally operable, they may be used to supplement exterior shading. The advantages of interior devices over exterior devices are that they are protected from the outside environment so they can be made of less expensive and less durable materials, they can be used to enhance the interior design of a space, and unlike exterior devices, they subtly impact the facades of buildings.

Interface shading techniques such as heat-absorbing clear and tinted glazings, reflective coatings, and solar control films, although helpful in reducing solar transmission, are disadvantageous in their non-selective nature: they block needed solar gain in the winter. Heat absorbing glass and tinted glazing reduce solar transmission by absorbing heat within the glazing material itself. Absorption by glass will result in high glass temperatures (30F or more above air temperature is not uncommon) which, although less significant than transmitted heat gain, adds heat to the interior by conduction and thermal radiation (6, p. 189).

Applicability of Shading with Exterior, Fixed Devices

Once it has been decided to not only shade, but to shade with an exterior shading device, the choice between operable and fixed shading devices is made. There is a disadvantage to any fixed shading device because average temperatures through the year peak from late July to mid-August while the declination* of the sun peaks on June 21 (summer solstice*). Because of this difference between maximum solar declination and maximum yearly temperatures, a compromise between shading in late summer and allowing insolation on a conjugate date* in spring must be made if fixed shading devices are to be used. Movable shading devices make it possible to uncompromisingly shade during overheated* times and permit insolation during underheated* times. However, since movable shading devices are movable, they are likely to require more maintenance then fixed devices. Movable devices, whether operated manually or automatically, are also likely to be more expensive and require more post-installation attention than fixed devices. An economic study that considers costs of automatically operated devices, and benefits of shading uncompromisingly should be made to help determine whether shading with fixed or operable devices is best.

Selection of Exterior, Fixed Shading Devices

In Chapter I, the scope of this study was limited to eight types of exterior, fixed shading devices:

1. solid overhangs,
2. louvered overhangs,
3. horizontal louvers,
4. miniature horizontal louvers,
5. solid vertical fins,
6. eggcrate devices,
7. frame-type devices, and
8. screen-type devices.

There are many variations to the positioning and physical configuration of each type of shading device listed above. Table I shows some of the variations possible for each type of shading device. From the table it can be seen that devices may vary with respect to air gap*, projection angle*, louver position angle*, spacing between louvers*, depth of louvers*, screen density*, projection length*, or separation distance*.

An air gap is the distance between the plane of a wall and the nearest point of a shading device. Air gaps are important for solid shading devices as they keep hot air from collecting next to a window under the shading device by allowing air movement.

TABLE I

APPLICABILITY OF POSSIBLE VARIATIONS IN PHYSICAL DESIGN AND CONFIGURATION OF EXTERIOR, FIXED SHADING DEVICES

Type of Device	Air Gap	Projection Angle	Projection Length	Separation Distance	Louver Position Angle	Spacing Between Louvers	Depth of Louvers	Screen Density
Solid overhang	X	X	X	X	--	--	--	--
Louvered overhang	X	X	X	X	X	X	X	--
Horizontal louvers	X	--	--	--	X	X	X	--
Miniature horizontal louvers	X	--	--	--	Note 1	Note 1	Note 1	--
Solid vertical fins	X	X	X	X	--	--	--	--
Eggcrate	X	X	X	--	--	--	--	--
Frame-type	X	X	X	X	--	--	--	--
Screen-type	X	--	--	--	--	--	--	X

Applicable: X
Not Applicable: --
Note 1: Miniature horizontal louvers originally developed by KoolShade are tilted down at 17^{o}, 0.05 inches deep, and spaced either 17 or 23 to an inch (10).

A projection angle is the angle between a shading device and the plane of a wall, and differs from a louver position angle in that a louver position angle refers only to louvers. For example, the louvered overhang shown in Figure 7 is a shading device that projects at a 90^{o} projection angle, but has louvers which are tilted at a 45^{o} angle.

The spacing between louvers, h, is the distance parallel to the window plane from one louver to the next, while the depth of louver, c, is the louver size as shown in Figure 8.

Screen density is an indication of the weave-opacity of a screen type device. The denser a screen is, the less radiation is allowed to penetrate through to a window.

Projection length is the horizontal distance between the plane of a window and the extreme point of a shading device, while separation distance is the distance (parallel to the plane of a wall) between the edge of a window and a shading device, as shown in Figure 9.

The projection length of an overhang determines the amount of shade a window receives in the summer, while the separation height from the top of a window to the underside of an overhang is responsible for the amount of insolation a window receives in the winter. The angle that determines the position and dimensions of a shading device for shading during the overheated period is the overheated profile angle*, Ω_o, and is the angle above which complete summer shading is possible. The angle that determines the position and dimensions of a shading device for allowing insolation during the underheated period is the underheated profile angle*, Ω_u, and is the angle below which complete winter insolation is possible. If a designer would like to

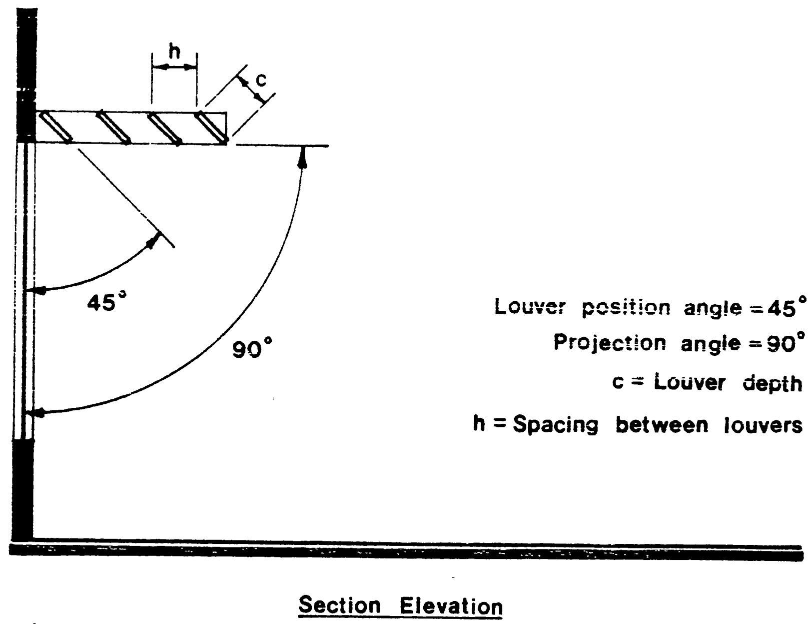


Figure 7. Illustration of Louver Position Angle and Projection Angle for a Louvered Overhang

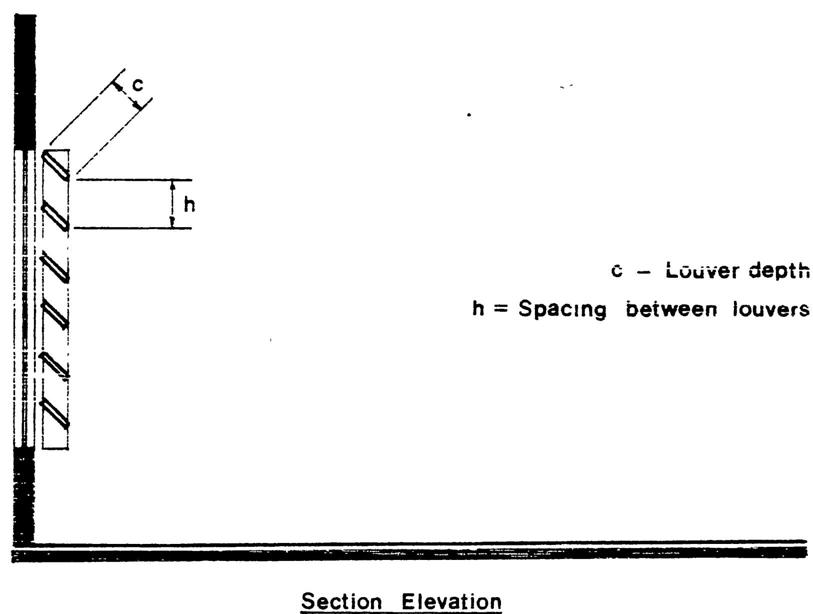


Figure 8. Illustration of Spacing Between Louvers and Depth of Louver for Horizontal Louvers

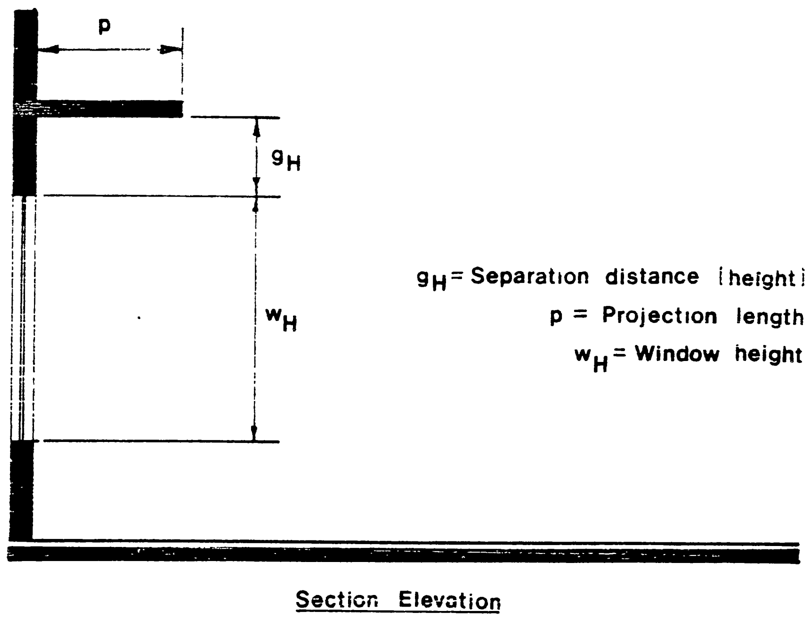


Figure 9. Illustration of Projection Length and Separation Distance of a Solid Overhang

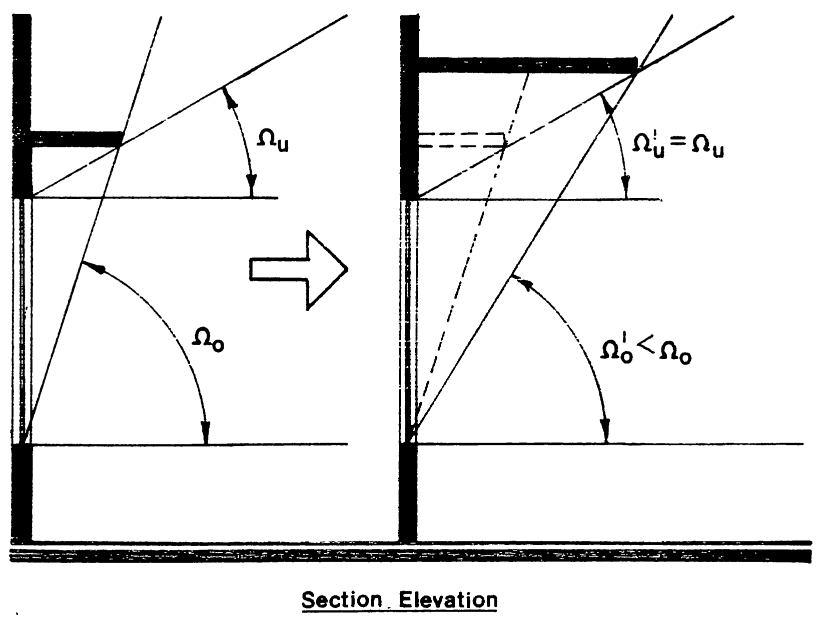


Figure 10. Illustration of the Procedure to Shade More in Summer While Allowing the Same Amount of Winter Insolation for an Overhang

shade a window more in the summer, but allow the same amount of insolation in the winter, the underheated profile angle can be held constant while the overheated profile angle is decreased, as shown in Figure 10. On the other hand, if a designer would like to allow more winter insolation, but shade the same amount of a window in summer, the overheated profile angle can be held constant, while the underheated profile angle is increased, as shown in Figure 11.

Louvers may be positioned to allow winter insolation, as shown in Figure 12. The louver position angle less 90^{o} is the underheated profile angle, Ω_u, at which complete winter insolation is allowed. The cut-off angle between louvers is the overheated profile angle, Ω_o, above which complete summer shading occurs.

The appropriateness of a particular exterior, fixed shading device for a given situation depends on several factors. As a guide to evaluating and specifying various types of fixed, exterior shading devices, the following steps are suggested:

1. Compare recommended devices with respect to climate classification and orientation.
2. Evaluate devices according to factors of overall effectiveness.
3. Utilize methods of sizing and selecting shading devices.

Climate Classification and Orientation Recommendations

Some guidelines for selecting exterior, fixed shading devices according to climate type and orientation are provided by various

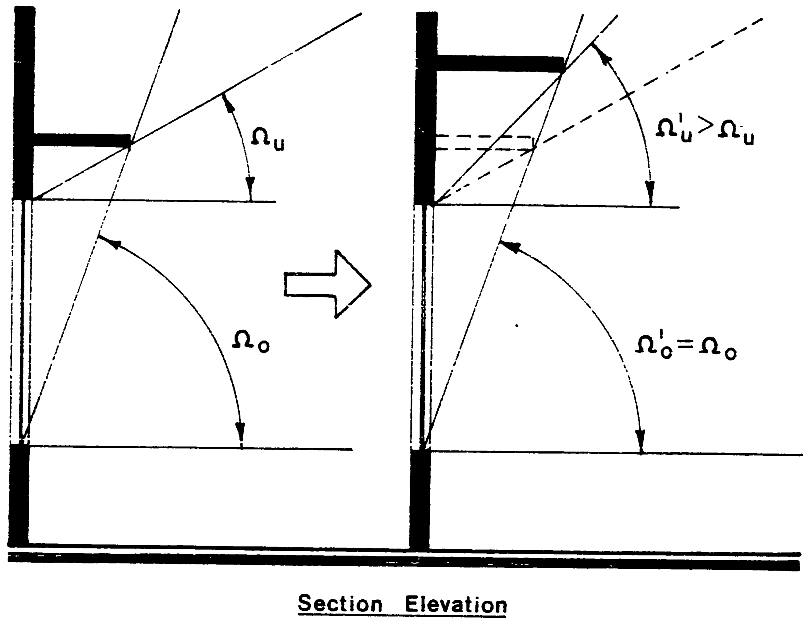


Figure 11. Illustration of the Procedure to Allow More Winter Insolation While Shading the Same in the Summer for an Overhang

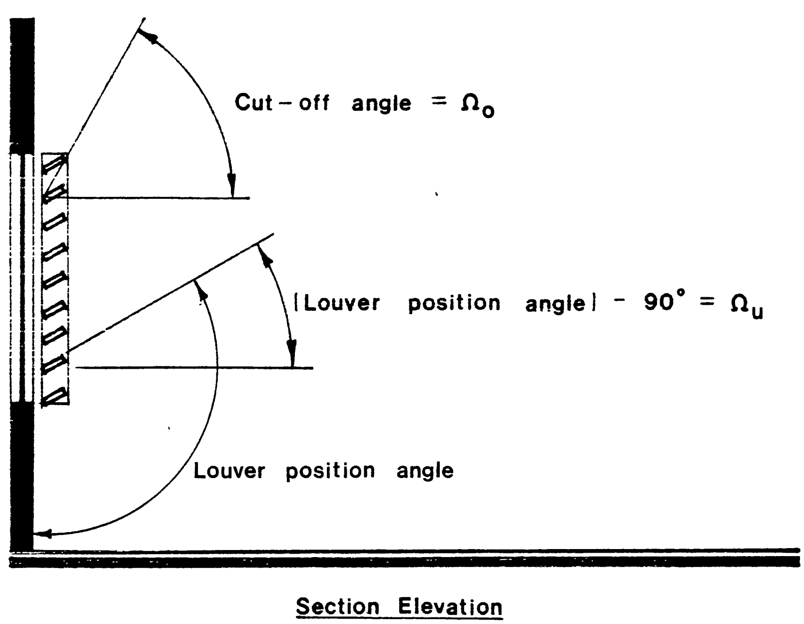


Figure 12. Illustration of Louvers Positioned to Allow Winter Insolation

authors in the field of climatic design. However, all-encompassing general statements concerning a particular orientation or climate classification usually differ, making it difficult to select a device on the basis of these recommendations.

Climate Classification Recommendations. There are many systems for categorizing climate types, but most authors generalize all climates into one of four groups:

1. hot-arid,
2. hot-humid,
3. temperate, and
4. cool (11).

Many locations do not fit neatly into just one of these categories. Figure 13 though, shows how Olgyay roughly locates the four climate-types in mainland United States (9).

Table II compares comments by Evans, Givoni, Olgyay and Szokolay concerning shading devices for the four general climate types. The significance of orientation, and the influence of air movement and reflected radiation can be seen in many of the remarks.

Orientation Recommendation. It would be helpful for a designer to know which type of exterior, fixed shading device is best suited for an orientation. From Table III it can be seen that for south orientations, horizontal shading devices are generally recommended. Givoni, however, recommends frame-type devices since they are most effective in blocking direct solar radiation (12). For southeast and southwest orientations, it is suggested that either

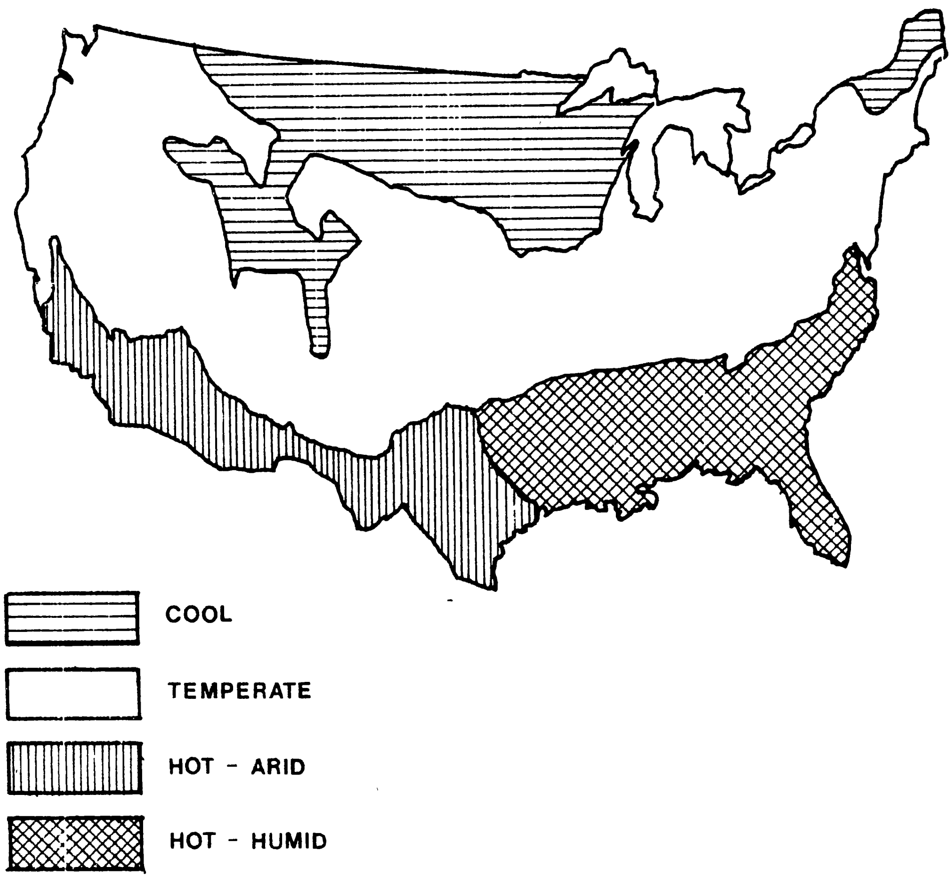


Figure 13. Olgyay's Regional Climate Zones of Mainland United States (9)

TABLE II

COMPARISON OF RECOMMENDED TYPES OF EXTERIOR, FIXED SHADING DEVICES FOR VARIOUS CLIMATE CLASSIFICATIONS

Climate Classification	Type of Device	Remarks	Source
Hot-humid (warm-wet)	louvered overhang	Louvered overhangs can provide full shade while at the same time reflect the sun's rays outwards and enable free air movement over the external surface of walls. Moreover, they allow better illumination than solid overhangs but provide less protection from driving rains. In multi-stored buildings solid overhangs tend to reflect an appreciable amount of solar radiation onto walls and windows of upper stories.	Givoni (12)
Hot-humid	horizontal device	Horizontal devices are preferable in warm humid climates as they provide protection from sky glare and rain, with minimal interference with air movement.	Evans (15)
Hot-humid (Miami)	all types	Shading devices are important because of powerful radiation mainly on east and west exposures; a north exposure for Miami receives more radiation than a south exposure due to low-latitude location.	Olgyay (1)
Hot-arid (hot-dry)	vertical fins	In hot-dry conditions vertical fins allow a view of high angle blue sky, while slightly reducing ground glare and the effect of hot dusty winds.	Evans (15)
Hot-arid (Phoenix)	separate from structure	Shading devices should be separate from structure, and exposed to wind convection.	Olgyay (1)
Hot-arid or hot-humid	eggcrate	An eggcrate's best use is in hot climate regions.	Olgyay (1)

TABLE II (Continued)

Climate Classification	Type of Device	Remarks	Source
Temperate (New York-New Jersey area)	overhang, eggcrate, and vertical fin	An overhang will protect south exposures (68^{o} profile angle for an overhang in New York-New Jersey area is recommended). Eggcrate type devices will protect east and west exposures, and vertical fins will protect north exposures in temperate climate regions.	Olgyay (1)
Temperate (moderate, cool-moderate, and warm-moderate)	horizontal device	For south exposures and moderate climates, windows should be protected by a device having a profile angle of 90^{o} - latitude. In a cool-moderate location, this profile angle could be a few degrees higher, and in warm-moderate climates a few degrees lower.	Szokolay (18)
Cool (Minneapolis)	horizontal device	Shading in summer is desirable but should not interfere with solar impact during overheated times. For southern orientations, horizontal shading devices may be used (66^{o} profile angle for an overhang in Minneapolis is recommended).	Olgyay (1)

TABLE III

COMPARISON OF RECOMMENDED TYPES OF FIXED, EXTERIOR SHADING DEVICES FOR VARIOUS ORIENTATIONS

Orientation	Recommended Type	Remarks	Source
East and West	eggcrate	Adequate shading for east and west orientations can be provided by an eggcrate shading device, especially if the vertical members are angled 45^{o} to the north.	Givoni (12)
East and West	horizontal shading	Horizontal shading is more effective than vertical shading for east and west walls. In fact vertical shading, even with infinite height, provides very poor shading in the summer, while cutting off almost all radiation in the winter.	Givoni (12)
East and West	eggcrate or vertical	A sunshade of only vertical elements is not sufficient to shade an east or west wall. It is necessary to add small horizontal elements or to extend a vertical shade beyond the lintel.	Shaviv (13)
East and West	vertical	Vertical devices serve well, having radial shading masks. If slanted, the devices should incline toward the north, to give more protection from the southern positions of the sun.	Olgyay (1)
East and West	eggcrate	Vertical fins with adequate overhangs (eggcrate) will shade an east or west orientation. An overhang with a large projection length is ineffective on east and west walls.	Ramsey/ Sleeper (14)
East and West	not horizontal	The solar altitude is generally so low on east and west orientations that horizontal projections, to be effective, would have to be excessively long.	ASHRAE (3)
West	vertical	For windows which are oriented close to west, closely spaced vertical louvers may be the best way of excluding sunlight.	Evans (15)

TABLE III (Continued)

Orientation	Recommended Type	Remarks	Source
East	horizontal	The common architectural practice of using vertical shades on the eastern side is wrong. The efficiency of a horizontal shade (to block direct radiation) is greater than that of a vertical shade. However, contrary to the case of a western window, it is impractical to have a single horizontal overhang.	Shaviv (13)
West	horizontal	It is a common misconception on the part of architects that the sun-shades of a western window must be vertical. Results show that a horizontal sun-shade is practical on a west wall.	Shaviv (13)
Southeast and Southwest	horizontal/ frame-type	For southeast and southwest orientations, horizontal shading is more effective in blocking direct radiation than a vertical shading device, while a frame shape is most effective.	Givoni (12)
Southeast, Southwest	eggcrate	The eggcrate device works well on southeast and southwest orientations.	Olgyay (1)
Southeast, Southwest, South	horizontal	Horizontal projections can considerably reduce solar heat gain by providing shade on south, southeast and southwest exposures during late spring, summer and early fall.	ASHRAE (3)
East through South to West	horizontal	In all orientations from east through south to west, horizontal shading is more effective than vertical shading.	Givoni (12)
South	horizontal/ frame-type	For south orientations, horizontal shading is more effective in blocking direct solar radiation than vertical shading, while the frame shape is most effective.	Givoni (12)
South	horizontal	A solar-shade for a southern window must be basically horizontal.	Shaviv (13)

TABLE III (Continued)

Orientation	Recommended Type	Remarks	Source
South	horizontal	Horizontal louvers or overhangs are effective on the south.	Ramsey/ Sleeper (14)
South	horizontal/ eggcrate	Horizontal devices, with arcual shading masks work well on southern orientations; at low latitudes eggcrate devices work well.	Olgyay (1)
North	vertical/ eggcrate	Fixed vertical devices are recommended on north walls for large surfaces and for hot regions; at low latitudes eggcrate devices work well.	Olgyay (1)
North	none/ small	Typical concrete walls are thick enough to shade north windows. In the case of larger windows, a small shade is sufficient.	Shaviv (13)

eggcrate or horizontal shading be applied. For east and west orientations, horizontal, vertical or eggcrate devices are recommended. This disparity of recommendations for east and west orientations makes it difficult to determine which general type of shading to use at these orientations.

Givoni and Hoffman have analyzed the efficiency of various types of fixed shading devices in different orientations by computing:

1. the daily portion of direct solar radiation falling on an unshaded window (according to the radiation conditions of Israel, 32^{o} N. latitude),
2. the percentage of shade areas, given by various types of fixed shading devices, as a function of the projection length, and
3. the intensity of direct solar radiation on the unshaded part of a window (12).

In this way, daily curves of the intensities of direct solar radiation falling on windows with various types of shading devices with different orientations for different months were obtained for a variety of fixed, exterior shading devices (Figures 14 through 17). These devices included:

1. horizontal shading, H, assuming infinite extensions*,
2. vertical shading, V, with a perpendicular projection angle, and
3. frame-type shading, H + V, of horizontal and vertical projections perpendicular to the wall.

Givoni's conclusions to the analysis presented in Figures 14 to 17 are included in Table III.

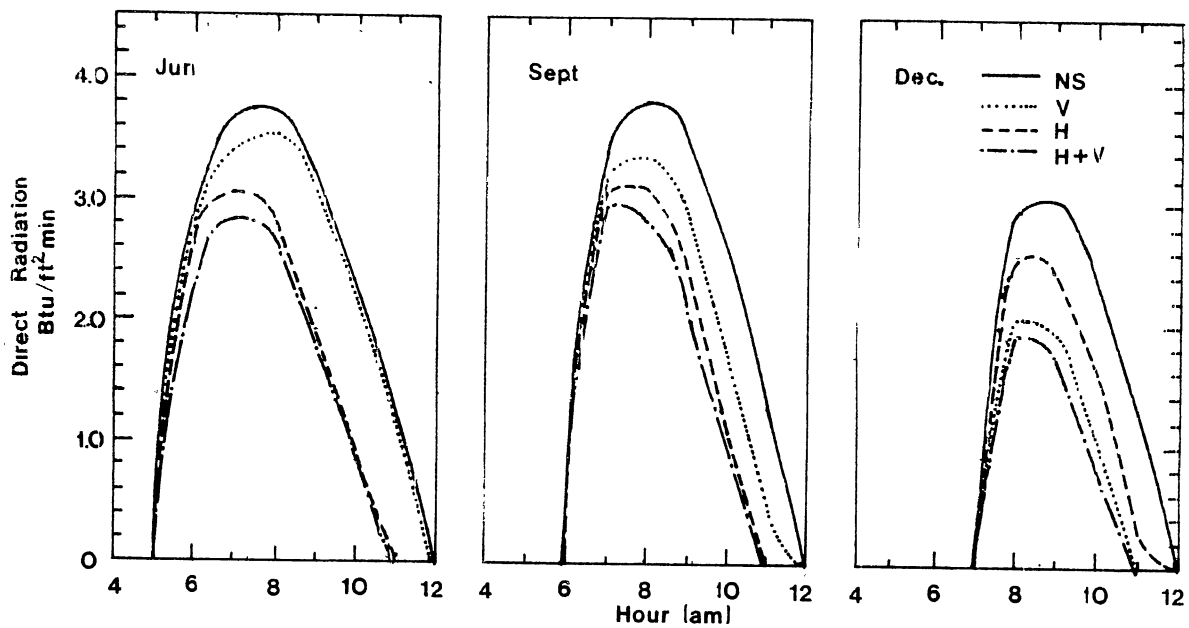


Figure 14. Diurnal Pattern of Impinging Direct Radiation on a Square Eastern Window (12)

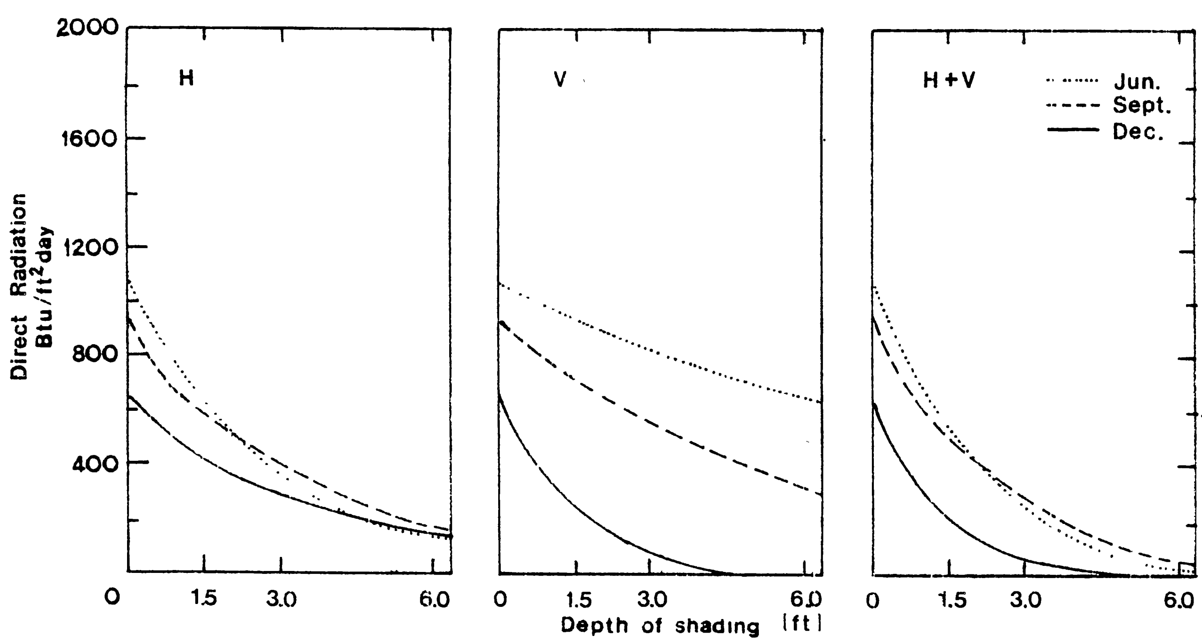


Figure 15. Effect of Projection Depth of Various Fixed Shading Devices on Direct Radiation Striking an East or West Window (12)

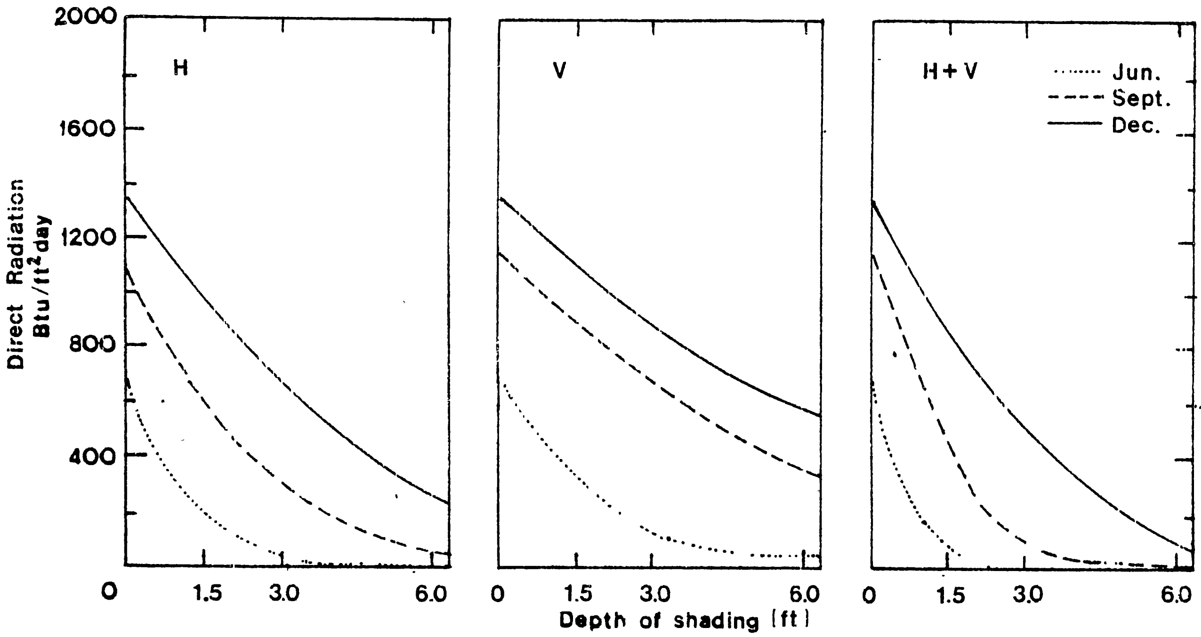


Figure 16. Effect of Projection Depth of Various Fixed Shading Devices on Direct Radiation Striking a Southeast or Southwest Window (12)

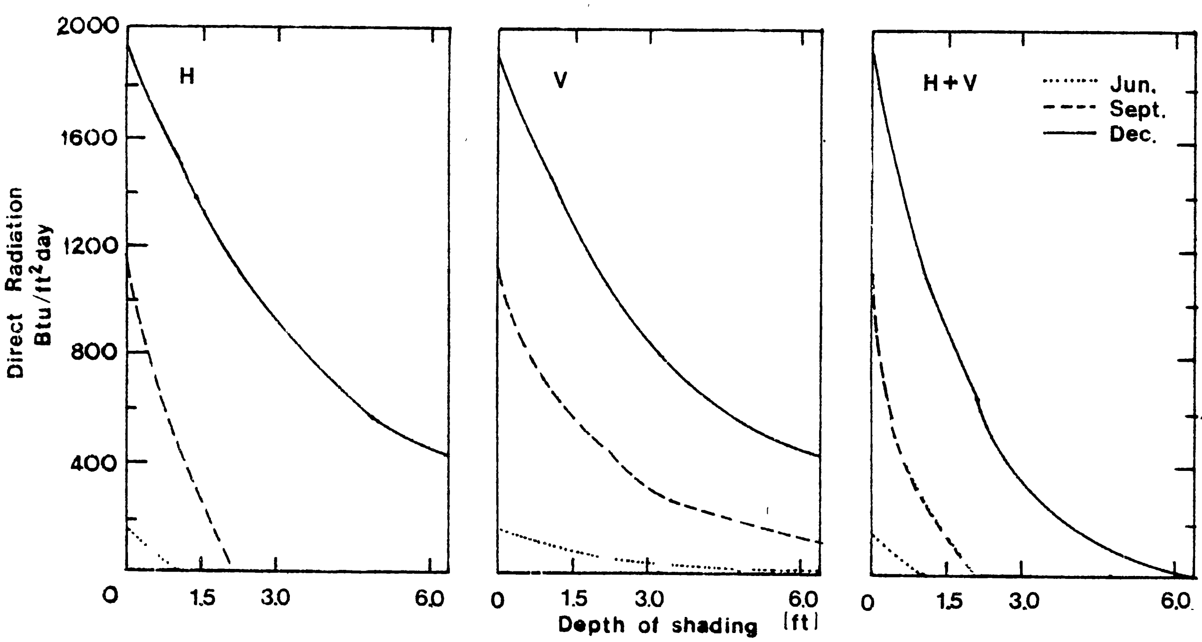


Figure 17. Effect of Projection Depth of Various Fixed Shading Devices on Direct Radiation Striking a South Window (12)

Figure 14 shows the daily pattern of direct solar radiation impinging on a 3.28 ft. X 3.28 ft. (1 m. X 1 m.) eastern window with a 1.1 ft. (0.3 m.) horizontal, vertical and frame-type projection length in June, September, and December. (NS denotes "no shading").

Figures 15 through 17 show the effect of projection length of various shading devices on direct radiation impacting a window facing different orientations.

Factors of Overall Effectiveness

Usually, in evaluating the effectiveness of a shading device, the major concern is its shading performance. However, there are a number of factors besides shading that influence the selection of a fixed, exterior shading device. Table IV lists the eight types of devices of this study, and qualitatively presents the effectiveness of each type of device in controlling sky and ground glare, allowing a view out, allowing free air movement, improving insulation value of glazing assembly, allowing winter insolation, and controlling diffuse radiation.

In addition to the factors in Table IV, other considerations in the selection of exterior, fixed shading devices include:

1. cost,
2. aesthetics,
3. weatherability,
4. resistance to vandalism,
5. resistance to bird nesting and perching,
6. rain protection of a wall or sidewalk,
7. fire-fighter access to interior,

TABLE IV

COMPARISON OF OVERALL FACTORS OF EFFECTIVENESS FOR FIXED, EXTERIOR SHADING DEVICES

Type of Device	Controls Sky Glare	Controls Ground Glare	Allows Horizontal View Out	Allows Free Air Movement	Improves Insulation of Window	Allows Winter Insolation	Controls Diffuse Radiation
Solid overhang	No	No	Yes	Note 2	No	Note 4	No
Louvered overhang	No	No	Yes	Yes	No	Note 5	No
Horizontal louvers	Yes	Yes	Note 1	Yes	No	Note 6	Yes
Miniature horizontal louvers	Yes	Yes	Some	Note 3	Yes	No	Yes
Vertical fins	Some	Some	Some	Yes	No	Note 4	Some
Eggcrate	Yes	Yes	Some	Note 2	No	No	Yes
Frame-type	No	No	Some	Note 2	No	Note 4	No
Screen-type	Yes	Yes	Some	Note 3	Yes	No	Yes

Note 1: Depends on angle of louver position.
Note 2: Air movement allowed if there is a structural gap between device and wall surface.
Note 3: Hinders air movement, but consequently increases insulation value.
Note 4: Winter insolation allowed if separation distance is applied.
Note 5: Winter insolation allowed if separation height is applied or if louvers are properly positioned.
Note 6: Winter insolation allowed if louvers are properly positioned.

8. reradiation of heat, and
9. impact on daylighting.

A shading device's performance with respect to many of the factors listed above and in Table IV is dependent on the type of material used, installation technique, and/or color of material. Often, trade-offs between factors must be made in the selection of a device. One of the most important conflicts is between daylighting* and shading.

Daylighting and Shading. When shading office buildings with exterior, fixed shading devices, care must be taken not to significantly decrease the potential energy savings from daylighting. Harvey Bryan has summarized the advantages of daylighting in commercial office buildings:

> Since electric lighting is often the single largest user of energy in commercial buildings, much attention has been focused on the energy-saving potential of daylighting. However, few have recognized the potential that daylighting offers for the control of peak demand; i.e., most utilities peak on hot summer afternoons, which is coincident with peak daylighting availability. The researchers who have studied daylighting's relationship to peak demand have found that the savings derived from a demand-driven analysis are significantly greater (in some cases several fold) than those derived from an energy-driven analysis. Thus, many of the claims being made for daylighting may be on the conservative side (16, p. 105).

A "demand-driven" analysis takes into account a utility company's stipulations of the "ratchet clause," which requires that a percentage (often at levels as high as 80 percent) of the year's maximum demand be incorporated as a fixed demand charge through the remaining 11 billing periods. Thus, a building owner may pay an enormous penalty for just one 15-minute surge in demand (Figure 18).

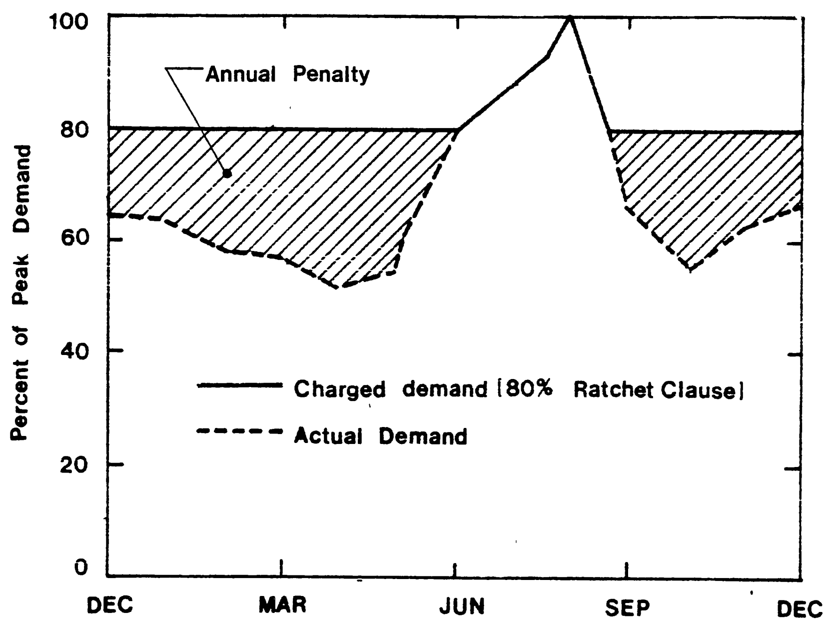


Figure 18. Comparison of Actual Demand With the Demand Charged Assuming an 80 Percent Ratchet Clause for an All-Electric Office Building (16)

It is difficult in designing exterior, fixed shading devices to integrate shading, which saves energy by decreasing summer solar heat gain, and daylighting which saves energy by decreasing electric lighting load. Some of the conflicts are listed below:

1. Shading devices designed to allow direct radiation in the winter decrease the quality of daylight by increasing glare from low-angle winter sun (17).
2. On cloudy days, if incoming light is to be maintained, then exterior, fixed devices become excessively restrictive to diffuse daylight (17).
3. At times of the day when the sun is behind a wall (particularly an east or west wall) and not radiating direct beams on a window, fixed shading devices become excessively restrictive to diffuse daylight.
4. The efficiency of an exterior shading device in reducing the heating effect of solar radiation increases with darker colors, while the efficiency of reflecting light off the device for daylighting decreases with darker colors (12).

Olgyay has developed equations to determine the "daylighting efficiency" of various fixed, exterior shading devices in terms of the percentage of sky that is seen by a shaded window. However, the calculations are made with the following assumptions:

1. The sky has equal luminance of radiation at all points.
2. No reflections from surroundings or louvers are received.
3. Louvers extend far enough that light entering from sides can be neglected (1).

For horizontal overhangs or louvers, the daylighting efficiency can be expressed by the following equation:

$$\text{Efficiency} = [\sqrt{1 + (c/h)^2} - c/h]\ 100\% \qquad (2.2)$$

where c and h are shown in Figure 19.

For tilted horizontal overhangs or louvers, the daylighting efficiency can be expressed as:

$$\text{Efficiency} = [\sqrt{1 - 2(c/h)\sin A + (c/h)^2} - (c/h)\cos A]\ 100\% \qquad (2.3)$$

where c, h and A are shown in Figure 20.

For vertical fins, perpendicular to a wall or tilted, the daylighting efficiency is:

$$\text{Efficiency} = (1/2)[\sqrt{1 - 2(c/w)\sin A + (c/w)^2}$$

$$- \sqrt{1 + 2(c/w)\sin A + (c/w)^2} - (c/w)]\ 100\% \qquad (2.4)$$

where c, w and A are shown in Figure 21.

Szokolay recognized the integration problem of daylighting and shading, and developed a simple geometrical optimization method for a window with an overhang facing south (or near-south) (18). The method is summarized in Figure 22 and the following steps:

1. A daylight factor is assumed at point P on a working plane.
2. Working the protractor daylight factor method in reverse, an initial sky component is found.
3. From the initial sky component, the required angle can be found to establish line "a" (drawn from point P), which is the locus* of all possible points where the lowest edge of any overhang can be.

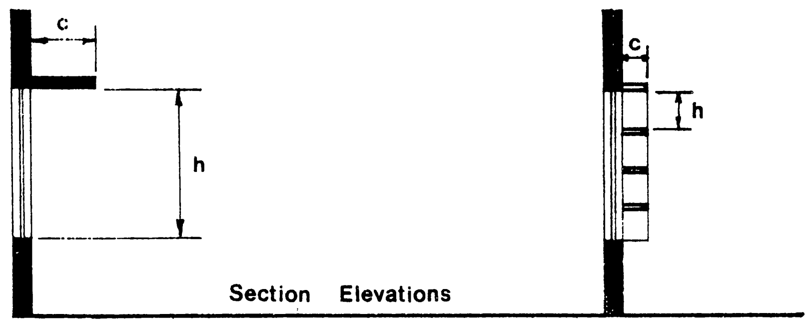


Figure 19. Illustration of Horizontal Overhang and Louver Dimensions for Use in Equation (2.2) (1)

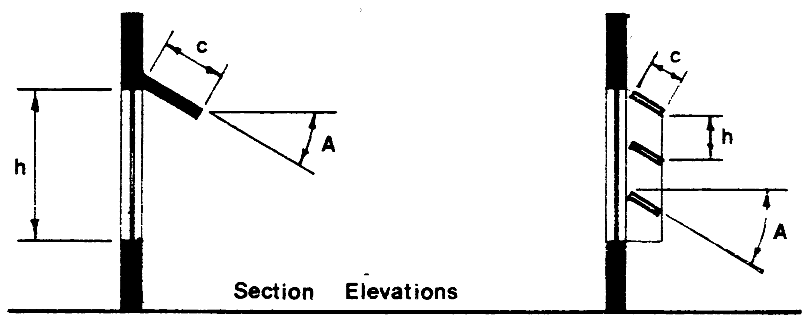


Figure 20. Illustration of Angled Overhang and Louver Dimensions for Use in Equation (2.3) (1)

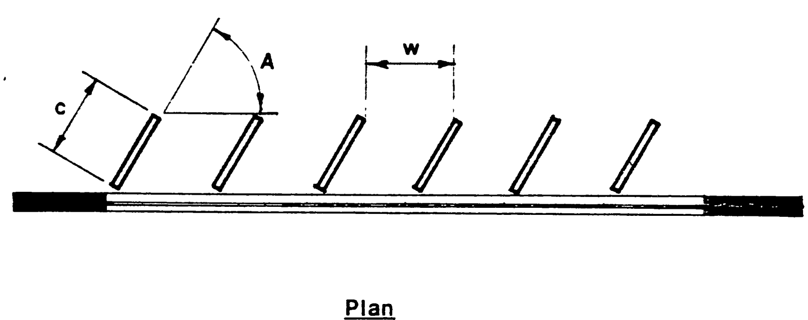


Figure 21. Illustration of Vertical Fin Dimensions for Use in Equation (2.4) (1)

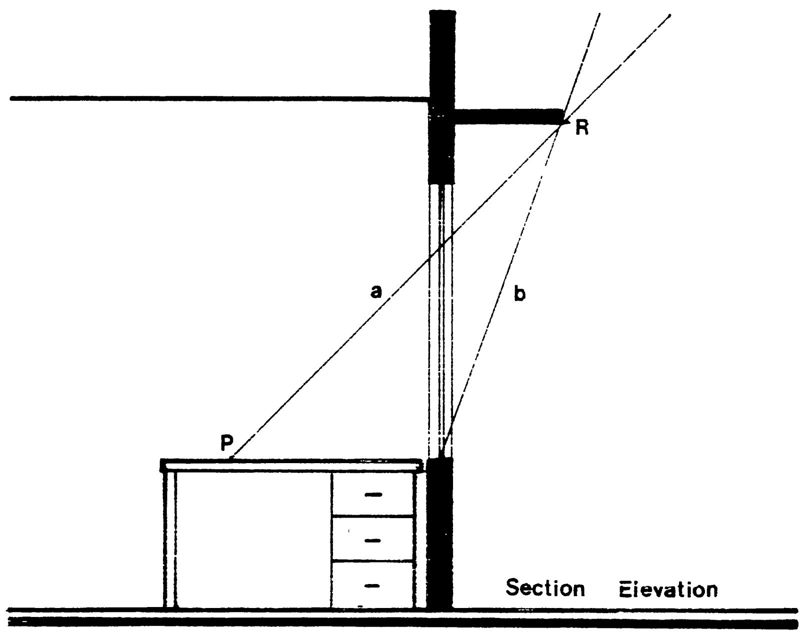


Figure 22. Illustration of Szokolay's Geometrical Optimization Method for Shading and Daylighting (18)

4. From a method of sizing overhangs, an angle can be found to establish line "b" (drawn from the window sill), which is the locus of all possible points to which the overhang must reach.
5. The only possible point that would satisfy both requirements is the intersection of the two loci, the resultant point R.

Since daylighting is primarily concerned with reflected and diffuse radiation as a source of low glare light, and since shading is primarily concerned with direct radiation* as a source of heat, a discussion now follows about the components and quantities of total radiation striking a shaded window.

Radiation on a Shaded Window. The total solar radiation on an unshaded window is the sum of three components:

1. beam (also called direct) radiation* from the sun,
2. diffuse radiation* from the sky, and
3. diffuse radiation reflected from the ground and other surfaces (19).

A fully shaded window, on the other hand, blocks the beam component of solar radiation, and receives only sky and ground reflected radiation. The quantity of sky and ground reflected diffuse radiation striking a window is influenced by the color and reflectance of ground surfaces (and shading device surfaces), the percent of sky blocked by a shading device, the cloudiness of the sky, the solar altitude angle of the sun, and the orientation of the window (even though in calculations, diffuse radiation is assumed to be isotropic*). Figure 23 shows how measured quantities of diffuse radiation striking different orientations vary

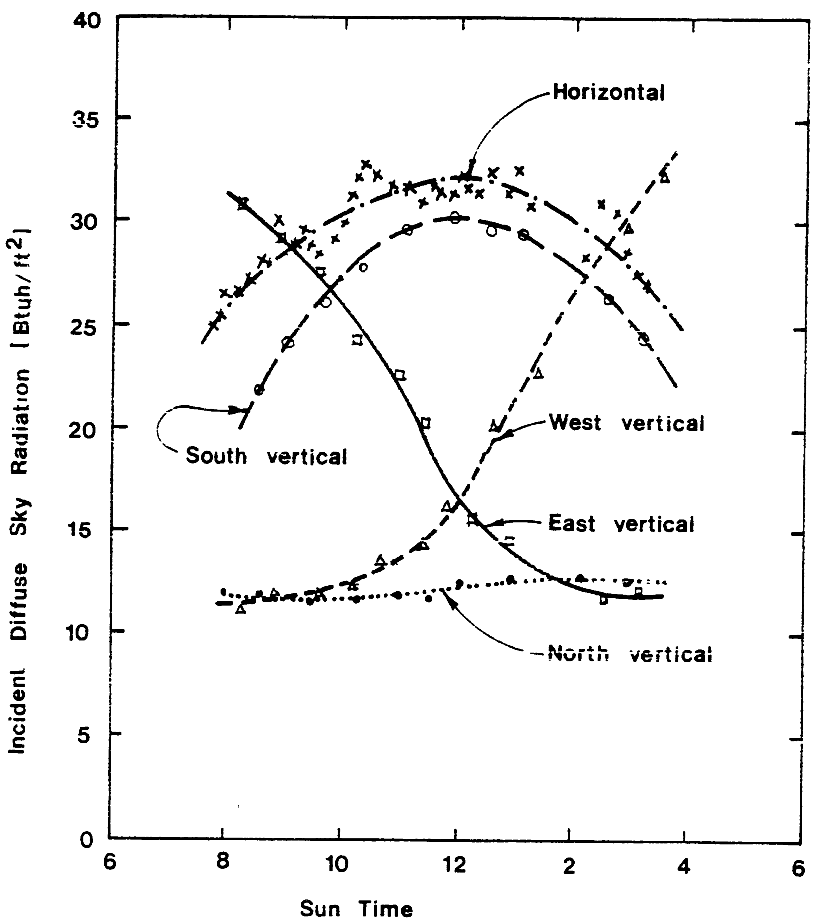


Figure 23. Variation of Diffuse Solar Radiation from a Clear Sky on September 14 in Minneapolis (20, p. 183)

for a clear sky in Minneapolis on September 14 (20). Since this diffuse radiation comes from all parts of the sky, its intensity is difficult to predict and subject to change throughout any given day (3, p. 27.3).

In the common case of a solid overhang fully shading a window, beam radiation is blocked, diffuse sky radiation is partially blocked (since part of the window's view to the sky is blocked), but diffuse ground reflected radiation may increase on lower stories since some additional reflection takes place on an overhang's underside. However, it has been determined that for winter conditions (with snow cover reflectance = 70 percent) the effect of radiation reflected from the underside of an overhang with 70 percent reflectance is +1 percent and may be judged to be negligible (21).

According to Utzinger and Klein, who examined overhang shading in Minneapolis and Albuquerque, and developed a relationship to determine the mean monthly solar radiation incident on a south-facing, shaded receiver, the average solar radiation received by receivers fully shaded from direct solar radiation in June ranges from 50 to 80 percent of the total solar radiation received by an unshaded receiver (21). Their findings are summarized as follows:

> Figures [24 and 25] compare monthly average daily radiation on shaded and unshaded receivers in Minneapolis, Minnesota and Albuquerque, New Mexico. The radiation on the shaded receiver is also separated into its beam, diffuse, and ground reflected components. During November, December, and January, radiation on shaded and unshaded receivers are nearly identical in both locations. During May, June, and July, even though the beam radiation has been reduced to near zero, the total radiation on the shaded receiver is more than half the value of the radiation on the unshaded receiver surface (roughly 70 percent for the receiver located in Albuquerque). Even though the summer value of K_T (atmospheric clearness index) averaged 0.72 in

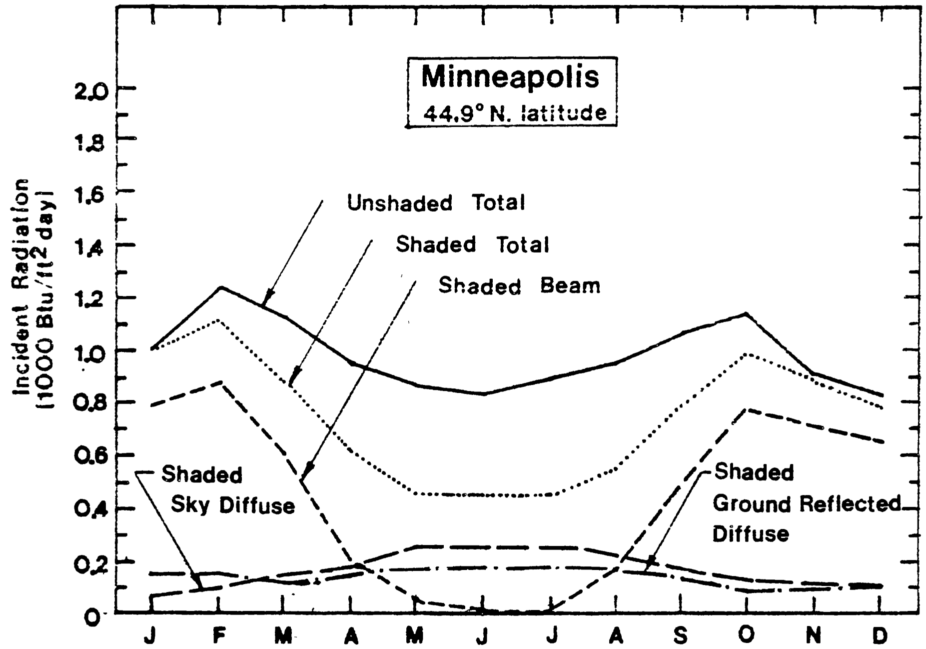


Figure 24. Components of Solar Radiation Striking a Shaded and Unshaded, South-Facing Receiver in Minneapolis (21, p. 378)

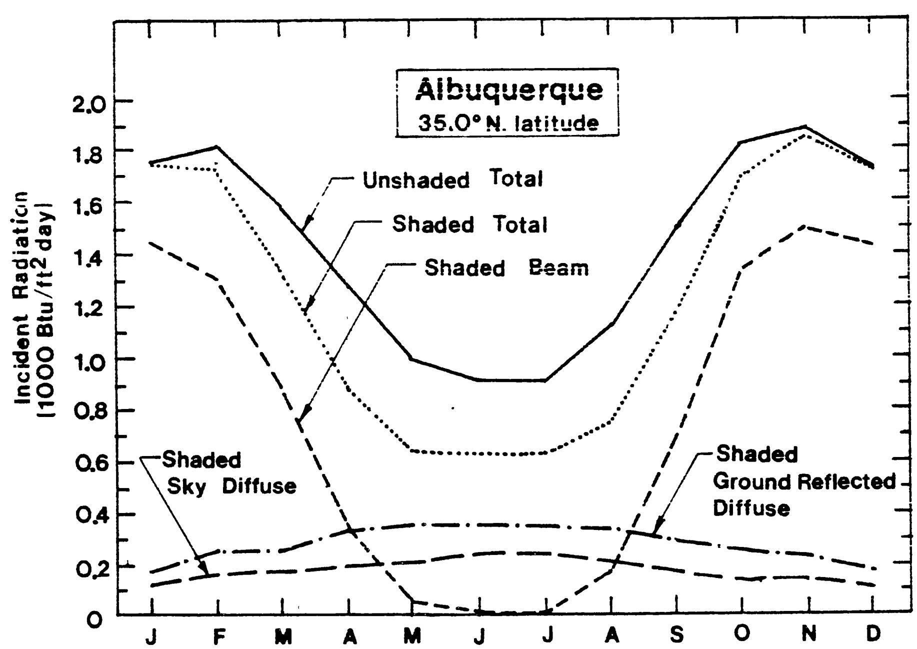


Figure 25. Components of Solar Radiation Striking a Shaded and Unshaded, South-Facing Receiver in Albuquerque (21, p. 378)

> Albuquerque compared to 0.53 in Minnesota, the overhang has a larger effect in reducing radiation in Minneapolis than in Albuquerque. This is partly due to differences in the average value of $\overline{R}_b$ during these three months (0.28 in Minneapolis and 0.14 in Albuquerque) and partly to using a value of the ground reflectance of 0.2 in Minneapolis and 0.3 in Albuquerque. In both locations the amount of radiation incident on the shaded receiver during the summer is significant. It is evenly divided between diffuse and ground reflectance radiation. The overhang does shade a significant amount of radiation from the receiver during summer, although a larger amount of radiation remains unshaded (21, p. 377).

At first glance, it would appear that the findings of Utzinger and Klein's study are contrary to statements by ASHRAE, Givoni, Mazria and Olgyay. ASHRAE states "Windows fully shaded from the outside will have a solar heat gain reduction of as much as 80 percent" (3, p. 27.46).

Givoni claims "With dark, external shading, as little as 10 percent of impinging radiation may enter the building" (12, p. 278).

Mazria says ". . . on clear days diffuse radiation comprises only a small fraction of the total [striking the earth's surface]" (7, p. 15).

Olgyay states "Diffuse radiation is the sum of scattered sky radiation and reflected direct radiation and is less important as a source of heat than the direct radiation" (1, p. 56).

After close examination of the findings of Utzinger and Klein, it can be seen that the high percentages of diffuse radiation in the study are due to the low quantity of direct radiation striking a vertical, south-facing window during May, June, and July when the sun is high. On an east or west window, or during cooler months when the altitude angle of the sun is lower, more direct radiation strikes a window, thus causing the percentage of diffuse radiation to be considerably lower.

Also, if a shading device like a screen or miniature horizontal louver is used instead of an overhang, more diffuse radiation would be blocked since the window's view to the sky and ground is decreased.

Another point to consider is that since impinging direct radiation strikes a window at such high incidence angles*, the transmittance of direct radiation through window glazing decreases considerably as shown in Figure 26. In calculations, isotropic* diffuse radiation is assumed to have the same transmittance as beam radiation at an incidence angle of 60° (22).

Based on the research of Utzinger and Klein, Lau has done a study that shows how monthly solar radiation transmitted through a double-glazed, south-facing window varies when shaded by overhangs of different lengths as shown in Figure 27 (23).

By studying the results shown in Figure 28 for Phoenix, the following observations can be made:

1. The amount of radiation that is transmitted through an unshaded, south-facing window decreases during summer months.
2. The difference between the total monthly radiation transmitted through an unshaded south window and a south window shaded by a short overhang stays fairly constant throughout the year, despite a short overhang's ability to block a much larger percentage of direct radiation striking a window during the summer months than during the winter months.
3. The largest difference between the total monthly radiation transmitted through an unshaded south window and a south window shaded by a 7-foot overhang occurs during the spring and fall months.

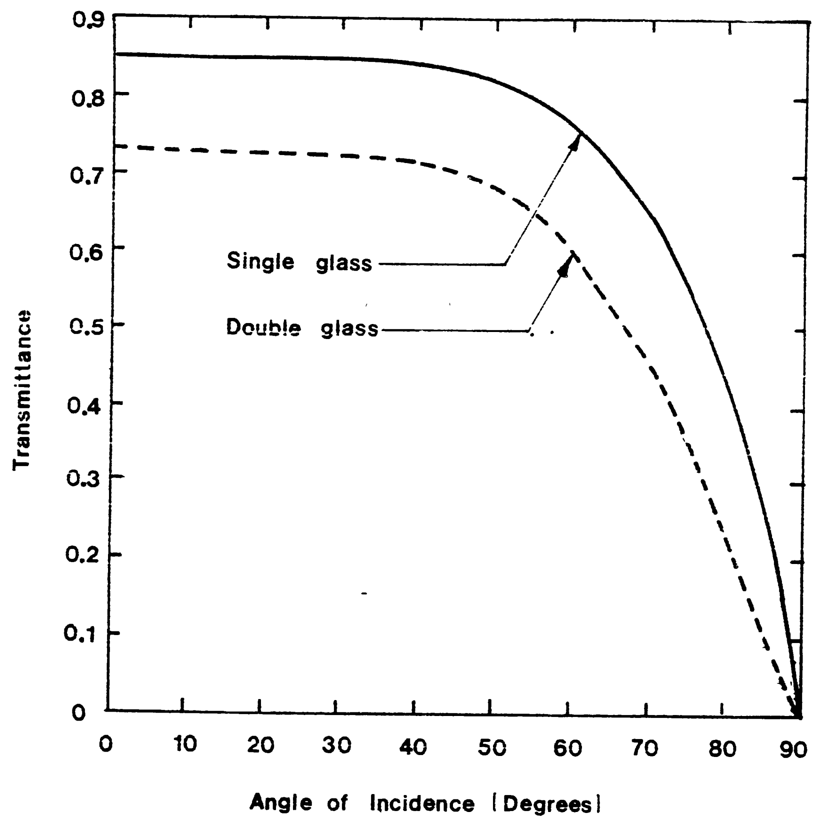


Figure 26. Transmittance of Radiation Through a Double and Single Glazed Window at Various Incidence Angles (7, p. 20)

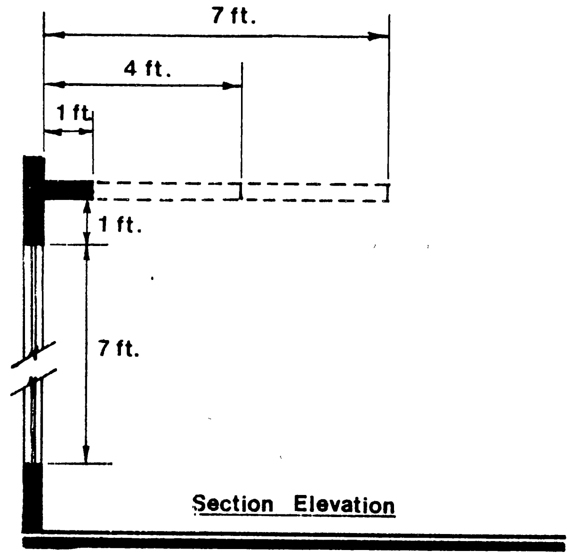


Figure 27. Illustration of Overhang Geometry (19)

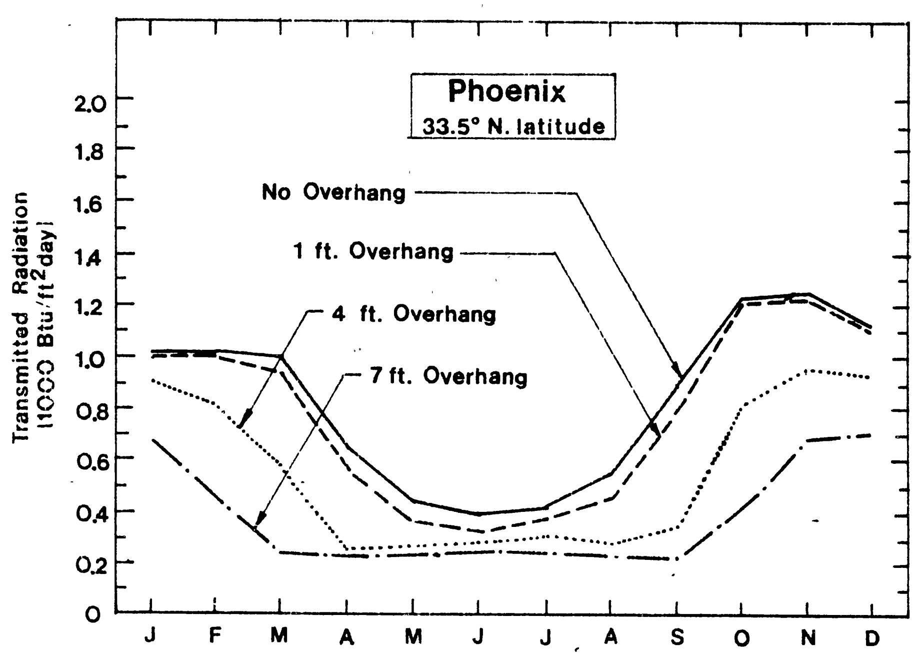


Figure 28. Effect of Various Overhang Lengths on Solar Radiation Transmitted Through a South-Facing Window in Phoenix (19)

4. During the summer months, a fairly large percentage of solar radiation transmits through a south-facing, shaded window despite being shaded from direct radiation by overhangs with 4- and 7-foot projection lengths.

Methods of Sizing and Selecting Shading Devices

Many methods have been developed to help designers in sizing and selecting exterior, fixed shading devices. Latitude-based methods, presented in Chapter III, are the simplest type of methods since climatological data is not used directly. Of the latitude-based methods presented in this study, all are for overhangs (the most common type of fixed, exterior shading device) and most are for south-facing orientations only. When using a latitude-based method, it is important to know how many complete-shade days* the method assumes, which is determined in Chapter III. The latitude-based methods presented that consider only summer shading are:

1. FMHA (Farmers Home Administration) Method,
2. Mazria Rule-of-Thumb,
3. Mazria F-Factor,
4. Egan K-Value,
5. Shade Line Factor, and
6. Szokolay Rule-of-Thumb.

The latitude-based methods presented that consider both summer shading and winter insolation are:

1. DOE-LANL Rule-of-Thumb,
2. Small Homes Council, and

3. Utzinger Nomograph.

Climate-based methods are more complex and time-consuming than latitude-based methods since a specific location's climate is taken into account. Of the climate-based methods presented in Chapter IV, most apply to any type of fixed, exterior shading device, and most are for any orientation. The climate-based methods in Chapter IV that consider only summer shading are:

1. Olgyay Shading Mask Method,
2. Novell Method,
3. Saleh Method, and
4. Shaviv Method.

The climate-based methods presented that take into account both summer shading and winter insolation are:

1. Olgyay Shading Effect Ratio Method,
2. Lau Method, and
3. Jones Method.

The proposed annual ΔT-Effectiveness method presented in Chapter V is a quantitative, climate-based method that may be applied to any type of shading device for any location, and considers both summer shading and winter insolation.

When using a method to determine the projection length of an overhang, infinite extensions* are assumed to ensure the overhang does not allow radiation from the sun to strike a window from the sides. However, from a practical viewpoint, overhangs have limits to how far past the sides of a window they may extend. Based on a study by Utzinger and Klein, if an overhang of finite extension meets or exceeds the following combinations of relative window width ($\tilde{w}$) and relative extension ($\tilde{e}$), an infinite extension can be assumed: (24)

$\tilde{w} \geq 25$ and $\tilde{e} \geq 0$

$\tilde{w} \geq 8$ and $\tilde{e} \geq 1.4$

$\tilde{w} \geq 4$ and $\tilde{e} \geq 2.0$

$\tilde{w} \geq 1$ and $\tilde{e} \geq 3.0$

The relative window width ($\tilde{w}$), is the ratio of the window width (w_W) to the window height (w_H), and is expressed as follows:

$$\tilde{w} = w_W/w_H \qquad (2.5)$$

The relative extension ($\tilde{e}$) is the ratio of the right or left extension (e) to the window height (w_H) and is expressed as follows:

$$\tilde{e} = e/w_H \qquad (2.6)$$

Physical representations of w_W, w_H, and e are shown in Figure 30 in Chapter III.

Plotting $\tilde{w}$ versus $\tilde{e}$ results in a curve as shown in Figure 29. If, for a given window-overhang configuration, the relative width is plotted with the relative extension, and the point falls on or above the curve in the unshaded area, then an infinite extension can be assumed.

To illustrate the use of Figure 29, consider a window with a height of 3.5 ft. and a width of 30 ft., having an overhang that

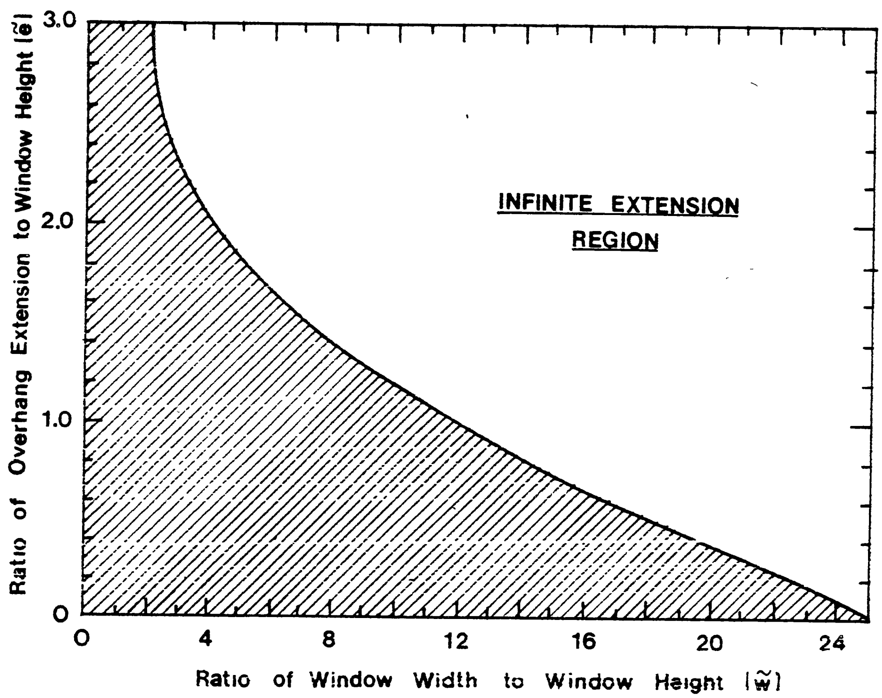


Figure 29. Infinite Extension Assumption Curve for an Overhang

extends 6 ft. past the sides of the window. From Equations (2.5) and (2.6):

$$\tilde{w} = 30/3.5 = 8.6$$

and

$$\tilde{e} = 6/3.5 = 1.7$$

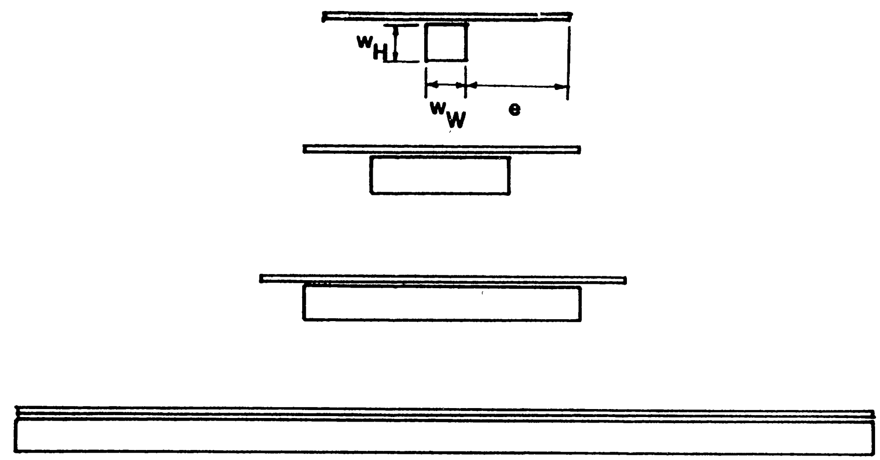
Plotting these ratios on Figure 29 shows that the overhang extension is long enough to be considered an infinite extension.

For the purpose of visualizing the implications of the ratios of Figure 29, w_W and e are shown in relation to each other for a window height of 3.5 ft. in Table V.

TABLE V

IMPLICATIONS OF WINDOW WIDTHS RELATED TO OVERHANG EXTENSIONS

$\tilde{e}$	$\tilde{w}$	w_W(ft.)	e(ft.)	Window-Overhang Relationship Scale: 1" = 20' - 0"
3.0	1.0	3.5	10.5	
2.0	4.0	14.0	7.0	
1.4	8.0	28.0	4.9	
0.0	25.0	87.50	0.0	



CHAPTER III

LATITUDE-BASED METHODS

Overview

This chapter evaluates and compares methods that are based on latitude* and an assumed number of complete-shade days*. Although there are differences in format (i.e., methods are in the form of a table, nomograph, or rule-of-thumb), and in the range of applicable latitudes, the major variation between methods is the number of complete-shade days. Because the methods presented in this chapter are not based on climatological data, either a method assumes a number of complete-shade days resulting in the same projection length for all locations along a particular latitude, or a method leaves to the designer the decision of establishing the number of complete-shade days.

The most important aspects of this chapter on latitude-based methods are as follows:

1. The periods of complete-shade* and complete-insolation* vary considerably for each method, resulting in widely different overhang lengths; this result underscores the need for climate-responsive design of overhangs.

2. Each method can be reduced to equation form with the only variables being overhang projection length*, total height*, window height*, separation height*, latitude, and number of days complete shade and/or complete insolation is desired.

Method Limitations

It should be noted that the latitude-based methods presented here are applicable to overhangs only. Overhangs are the most common type of fixed, exterior shading device and used extensively in residential applications. As pointed out in Chapter II, horizontal shading devices (such as overhangs) are generally used on south-facing facades and extend well past the sides of windows. Therefore, the methods presented in this chapter may be applied to overhangs having infinite extensions* and positioned over south-facing windows.

Window-Overhang Geometry

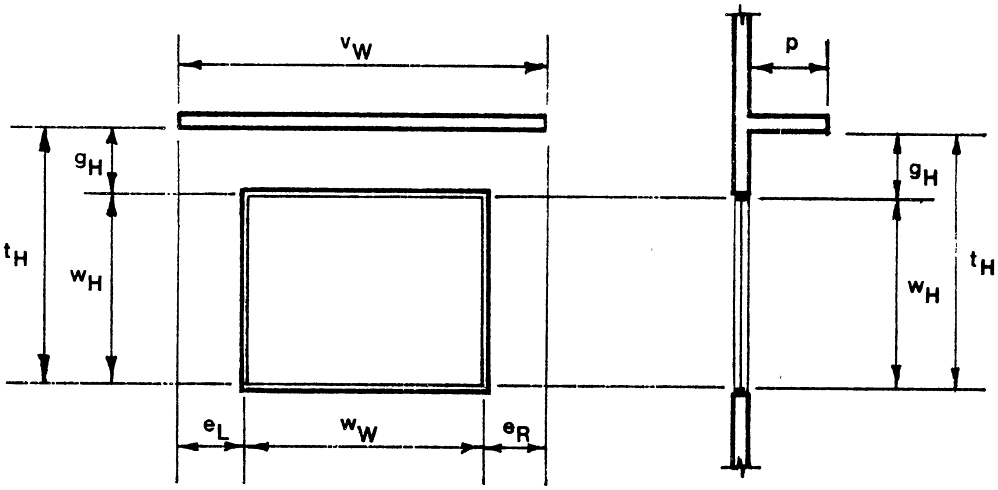
For clarification, before evaluating the various latitude-based methods of this chapter, certain angles and dimensions are defined below in Figures 30 and 31. In Figure 30, note that:

$$g_H + w_H = t_H \tag{3.1}$$

In Figure 31, note the difference between profile angle (Ω) and solar altitude angle (β).

Complete-Shade Period

For comparison purposes, the complete-shade period* was determined for the methods. From Equation (3.2), the profile angle at noon on the



e_L	left overhang extension	p	overhang projection length
e_R	right overhang extension	v_W	width of overhang
g_H	gap or separation height	w_H	height of window
t_H	total height	w_W	width of window

Figure 30. Illustration of Window-Overhang Relationship

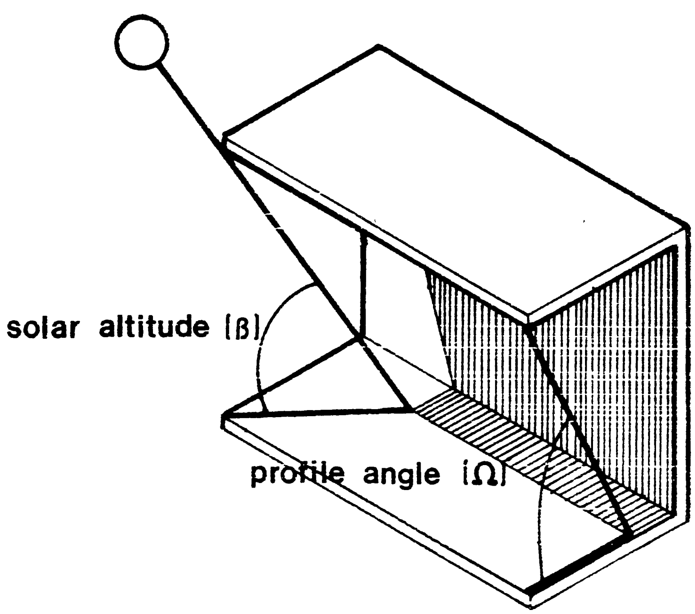


Figure 31. Illustration of Profile Angle and Solar Altitude Angle

first complete-shade day* in the spring (Ω_o) can be determined. From Equation (3.3), the declination* (D) is found, which is used in Equation (3.4) to find the number of days (N_o) before or after summer solstice* (June 21) that complete shade* is possible for the overhang projection length in Equation (3.2). Once N_o is known, the period of complete shade is easily determined by adding and subtracting N_o from June 21.

$$\Omega_o = \tan^{-1}(t_H/p) \tag{3.2}$$

where

t_H = total height,

p = overhang projection length, and

Ω_o = lowest noon profile angle of complete-shade period.

$$D = L - \cos^{-1}(\sin\Omega_o) \tag{3.3}$$

where

D = declination (positive in summer),

L = latitude.

$$N_o = (365/360)\cos^{-1}(D/23.45) \tag{3.4}$$

where

N_o = number of complete-shade days before or after summer solstice.

To clarify the complete-shade period, it must be understood that the sun's path is symmetrical about the summer and winter solstice. Because of this symmetry, the sun's path is the same on the Nth day before the summer solstice as on the Nth day after the summer solstice. For example, the sun's path on May 11 is the same as the sun's path on

August 1, since both dates are forty days from June 21 (the summer solstice). Therefore, a fixed shading device designed to completely shade a south-facing window on August 1 will also completely shade the same window on May 11. Dates on which the sun's path are the same (such as May 11 and August 1) are called conjugate dates.

The declination of the sun increases as the sun nears its summer solstice. Consequently, a solid overhang that shades a south-facing window completely on August 1, not only identically shades on May 11, but also shades a window completely for the entire period between May 11 and August 1. Because of this fact, a complete-shade period can be determined by knowing only one date: the first complete-shade day of the spring or the last complete-shade day of the summer.

It is significant to understand how complete-shade periods are determined because sometimes a complete-shade period for a fixed device is given to be from June 21 to August 1, yet such a device will also shade from May 11 to June 21. In another case, a fixed, solid overhang may be designed to shade completely on August 1 (as in the case of Egan's tabular method), yet will actually completely shade for 81 days, from May 11 to August 1.

Derivation of Methods

Every latitude-based method that considers only summer shading is derived from Equation (3.5), which is derived from Equations (3.2) to (3.4).

$$p = t_H/\tan[90 - (L - 23.45\cos(360(N_o)/365))] \qquad (3.5)$$

where

p = overhang projection length*,

t_H = total height*,

L = latitude, and

N_o = number of complete-shade days before or after summer solstice.

Methods based on Equation (3.5) which consider only summer shading include:

1. FMHA (Farmers Home Administration) Method,
2. Mazria Rule-of-Thumb,
3. Mazria F-Factor,
4. Egan K-Value,
5. Shade Line Factor, and
6. Szokolay Rule-of-Thumb.

A designer could use Equation (3.5) to determine the projection length of an overhang over a south-facing window, if he is not concerned about winter insolation. For example, if complete shade at 36°N. latitude for a total height of 6.2 feet is desired from April 1 to September 1 (conjugate dates) (separation height = 0.0 feet), then N_o = 81 days, since there are 81 days from April 1 to June 21. Solving for p, Equation (3.5) yields:

$$p = 6.2/\tan[90 - (36 - 23.45\cos(360(81)/365))]$$

$$p = \underline{3.9 \text{ ft.}}$$

Every latitude-based method that considers both summer shading and winter insolation is derived from Equations (3.6) and (3.7), which are derived in Appendix B. The equations summarize the factors needed to determine the projection length* (p) and separation height* (g_H) for an overhang on south-facing exposures when both winter and summer shading and winter insolation are considered:

$$p = w_H/\{\tan[90 - (L - 23.45\cos(360(N_o)/365))] - \tan[90 - (L + 23.45\cos(360(N_u)/365))]\} \quad (3.6)$$

and

$$g_H = w_H\tan[90 - (L + 23.45\cos(360(N_o)/365))] / \{\tan[90 - (L - 23.45\cos(360(N_o)/365))] - \tan[90 - (L + 23.45\cos(360(N_u)/365))]\} \quad (3.7)$$

where

p = overhang projection length,

g_H = gap or separation height,

w_H = window height,

L = latitude,

N_o = number of days before or after summer solstice that complete shade* is desired, and

N_u = number of days before or after winter solstice that complete insolation* is desired.

A designer could use Equations (3.6) and (3.7) to determine the projection length of an overhang and corresponding separation height between the top of a window and the bottom of an overhang, if he is concerned about both summer shading and winter insolation. For example, at 36^{o}N. latitude, for a window height of 3.50 ft., if complete shade is desired from May 11 to August 1 (conjugate dates), then N_o = 40. If complete sun is desired from November 16 to January 26, then N_u = 34. Solving for p, Equation (3.6) yields:

$$p = 3.50/\{\tan[90 - (36 - 23.45\cos(360(40)/365))]$$

$$-\tan[90 - (36 + 23.45\cos(360(34)/365))]\}$$

$$p = 3.50/(3.09737 - .68608) = \underline{1.45\ \text{ft.}}$$

Solving for g_H, Equation (3.7) yields:

$$g_H = 3.50(.68608)/(3.09737 - .68608) = \underline{1.00\ \text{ft.}}$$

Methods based on Equations (3.6) and (3.7), which consider both summer shading and winter insolation, are:

1. LANL-DOE Rule-of-Thumb,
2. Small Homes Council Rule-of-Thumb, and
3. Utzinger Nomograph.

Explanation of Methods

FMHA (Farmers Home Administration) Method

The FMHA tabular method shown in Table VI claims to find the "exact" projection length of an overhang (25). Using Equations (3.2) to (3.4) and data from Table VI, it can be seen that an overhang with a projection length determined by this method will shade a window completely from about April 1 to September 11.

Mazria Rule-of-Thumb

As a general rule-of-thumb, Mazria recommends shading south glazing with a horizontal overhang located just above the glazing and equal in projection length to roughly one-fourth the total height in southern latitudes (36°N.) and one-half the total height in northern latitudes (48°N.) (7). In equation form, the rule-of-thumb is simply:

$$p = t_H/4 \tag{3.8}$$

for 36^{o}N. latitude, and

$$p = t_H/2 \tag{3.9}$$

for 48^{o}N. latitude.

This rule-of-thumb approach provides complete shade on south glazing for approximately forty-one days, from June 1 to July 11.

Mazria F-Factor

This flexible tabular method (Table VII), presents a range of "F-Factors" for a given latitude. The higher F-Factor for a specific latitude corresponds to an overhang projection that will completely shade a window for one day, June 21, (the summer solstice), and is simply the tangent of the profile angle at noon on June 21. Similarly, the lower F-Factor for a specific latitude corresponds to an overhang projection that will completely shade a window from May 11 to August 1, and is the tangent of the profile angle at noon on May 11 (or August 1) (7).

Once an F-Factor is determined, the following equation is used to determine the projection of a fixed overhang for south-facing glass.

$$p = t_H/\text{F-Factor} \tag{3.10}$$

by comparing Equation (3.10) with Equation (3.2), it can be seen, as stated above, that:

$$\text{F-Factor} = \tan \Omega_o \tag{3.11}$$

TABLE VI

FMHA (FARMERS HOME ADMINISTRATION) TABLE

NORTH LATITUDE	TOTAL HEIGHT (FEET)					
	3	4	5	6	7	8
	OVERHANG PROJECTION (FEET)					
25°	1.1	1.5	1.9	2.2	2.6	3.0
30°	1.4	1.9	2.4	2.9	3.4	3.8
35°	1.8	2.4	3.0	3.5	4.1	4.7
40°	2.1	2.8	3.6	4.3	5.0	5.7
45°	2.6	3.4	4.3	5.1	6.0	6.8
50°	3.0	4.1	5.1	6.1	7.1	8.2

TABLE VII

MAZRIA F-FACTORS

NORTH LATITUDE	F-FACTOR
28°	5.6 - 11.1
32°	4.0 - 6.3
36°	3.0 - 4.5
40°	2.5 - 3.4
44°	2.0 - 2.7
48°	1.7 - 2.2
52°	1.5 - 1.8
56°	1.3 - 1.5

TABLE VIII

EGAN K-VALUES (OR SHADE LINE FACTORS)

NORTH LATITUDE	K - VALUE			
	E & W	SE & SW	NW, N & NE	S
25°	0.83	1.89	4.63	10.10
30°	0.83	1.63	2.89	5.40
35°	0.82	1.41	1.79	3.55
40°	0.81	1.25	1.67	2.60
45°	0.80	1.13	1.44	2.05
50°	0.79	1.01	1.24	1.70

Egan K-Value (or Shade Line Factor)

Egan's K-Value method, also known as the Shade Line Factor (SLF) Method, is based on a five-hour average of maximum solar radiation on August 1 (26, 6). The time at which the five-hour average occurs determines overhang lengths for non-south orientations. For example, if the five-hour average of maximum solar radiation on a southeast wall, on August 1, occurs at 9:00 a.m., the overheated profile angle of the sun is found by knowing the date and time of day. From Equation 3.2, knowing Ω_o and t_H, a projection length may be determined. However, using a K-Value from Table VIII (which is the same as an SLF) and Equation (3.12), an overhang projection length may be determined without having to find Ω_o.

$$p = t_H/\text{K-Value} \tag{3.12}$$

From Equations (3.2) to (3.4) and data from Table VIII, a south-facing overhang with a projection length based on this method will completely shade a window from May 11 to August 1.

By comparing Equation (3.12) with Equations (3.2) and (3.11) it can be seen that:

$$\text{K-Value} = \tan \Omega_o \tag{3.13}$$

and

$$\text{K-Value} = \text{Lower F-Factor} \tag{3.14}$$

for a given latitude.

Szokolay Rule-of-Thumb

For moderate (or temperate) climates (i.e., hot summers, cold winters), as a rule-of-thumb, Szokolay states that south-facing windows should be protected by a device having an overheated profile angle of 90^{o}- latitude (i.e., the noon altitude angle of the sun at equinox) (18). So for the six "summer" months (March 21 to September 21) the device will completely shade a south-facing window. The following equations explain the relationship between an overheated profile angle (Ω_o), an overhang projection length (p), and Szokolay's rule-of-thumb:

$$p = t_H/\tan\,(90^{o} - \text{latitude}) \qquad (3.15)$$

where

$$\Omega_o = (90^{o} - \text{latitude}) \qquad (3.16)$$

In a cool-moderate location, the profile angle determined from Equation 3.15 could be a few degrees higher, resulting in a shorter overhang, and in a warm moderate climate, a few degrees lower resulting in a longer overhang.

LANL-DOE Rule-of-Thumb

According to the Passive Solar Design Handbook, prepared by the Los Alamos Scientific Laboratory:

> It is fairly good design practice to allow about 5^{o} of leeway at the window top in locating the overhang relative to the window as shown [in Figure 32]...It is also good design practice to allow for about 5^{o} of leeway at the window bottom for the summer design condition (27, pp. 109-110).

When considering the 5^{o} allowance shown in Figure 32, the resulting declination of the sun is then $23.45^{o} - 5^{o} = 18.45^{o}$. From Equation (3.4), a declination of 18.45^{o} corresponds to N = 39 days. Therefore, the 5^{o} allowance will completely shade a window for 79 days in the summer (May 11 to July 31), and will allow complete insolation of a window for 79 days in the winter (November 11 to January 30).

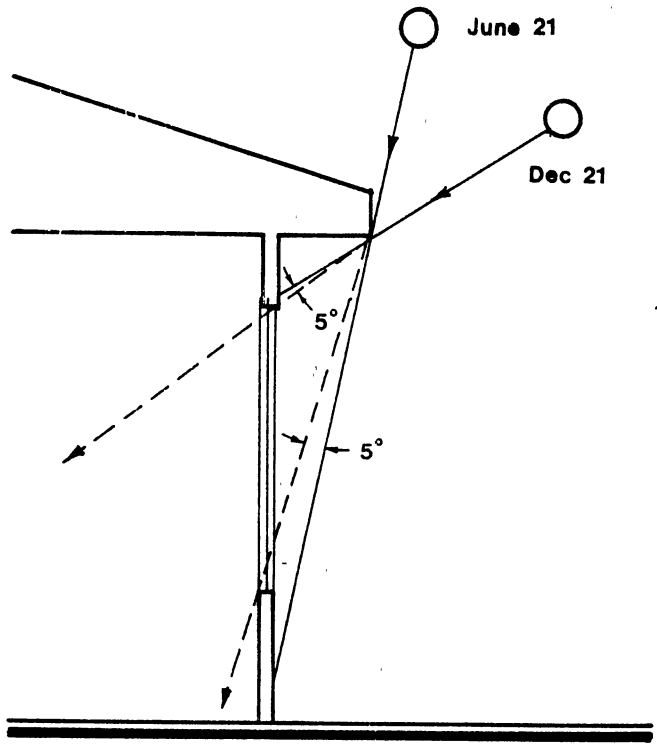


Figure 32. Illustration of LANL-DOE Rule-of-Thumb (27)

Small Homes Council Rule-of-Thumb

Based on a study of weather conditions and sun angles at various latitudes, the Small Homes Council of the University of Illinois reports that a standard 30/16 overhang (i.e., an overhang with a 30 in. (2.5 ft.) projection length located 16 in. (1.33 ft.) above the top of the window) will provide "good" sun control on south windows for "conventional sill and ceiling heights" (6, p. 159). It should be noted that this rule-of-thumb is quite general and stays constant with varying latitudes.

Utzinger Nomograph

Utzinger's method uses a nomograph to determine the projection of an overhang for vertical windows which have azimuths within 10 degrees of due south. The method depends on window height, separation height (between the top of the window and the bottom of the overhang), and latitude, as well as the number of days a window is to be totally shaded in the summer, and the number of days a window is to be unshaded in the winter (24).

The nomograph in Figure 33 is used to find p and g_H, by the following procedure:

1. Locate the latitude line for the site, interpolating if necessary.
2. Draw a line from B through the intersection of the latitude curve and the number of days the window is to be shaded before or after the summer solstice (June 21). The result is the summer shading line.

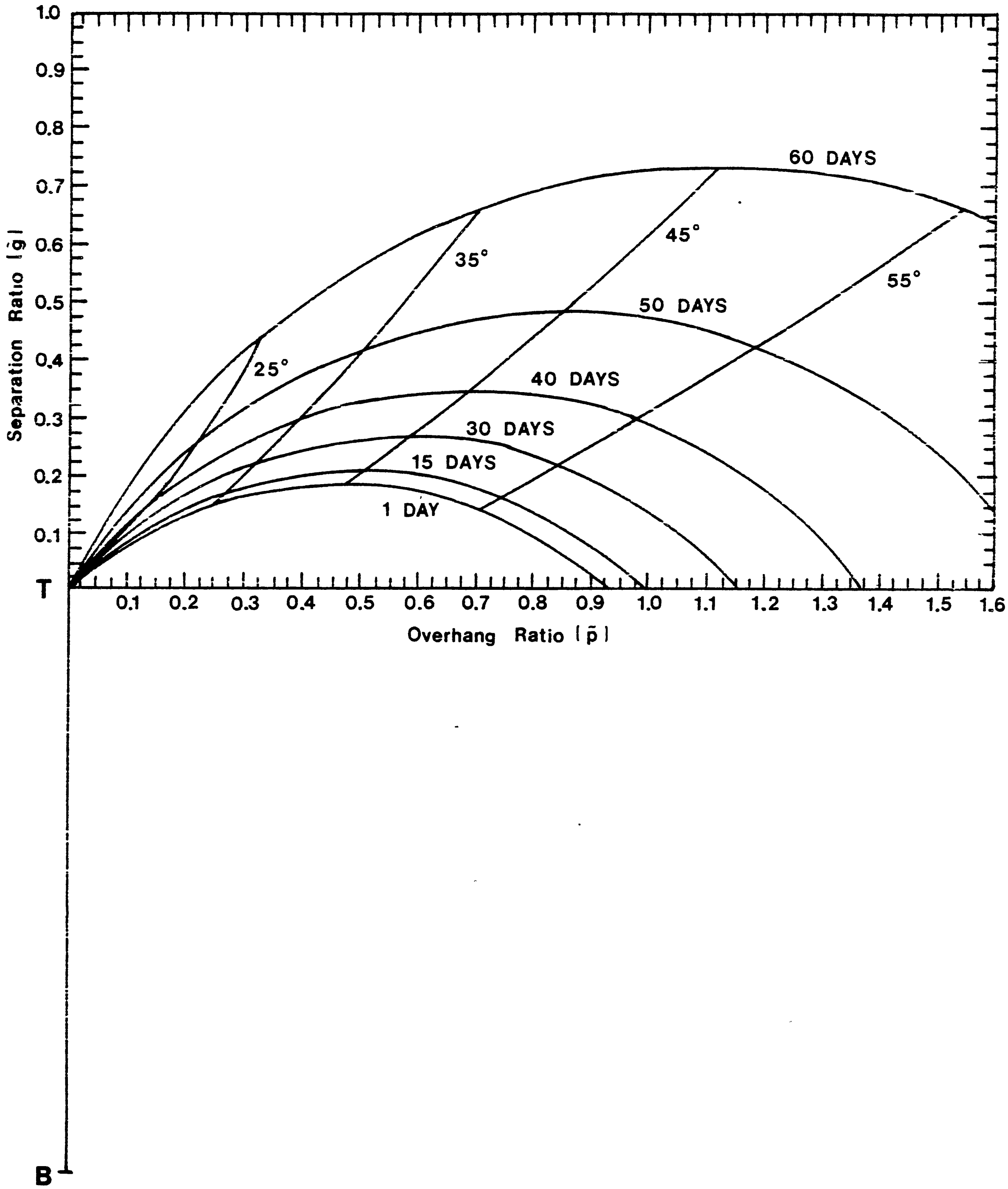


Figure 33. Utzinger Nomograph to Determine Projection Length and Separation Height of an Overhang (24)

3. Draw a line from T through the intersection of the latitude curve and the number of days the window is to be unshaded before or after the winter solstice (December 21). The result is the winter shading line.

4. The intersection point of the summer and winter shading lines gives $\tilde{p}$ (ratio of the overhang projection length, p, to the window height, w_H) and $\tilde{g}$ (ratio of the overhang separation height, g_H, to the window height, w_H):

$$\tilde{p} = p/w_H \qquad (3.17)$$

$$\tilde{g} = g_H/w_H \qquad (3.18)$$

5. Multiply the value of $\tilde{p}$ (overhang ratio*) by the window height to find the length of the overhang projection.

6. Multiply the value of $\tilde{g}$ (separation ratio*) by the window height to find the separation distance between the top of the window and the bottom of the overhang.

Comparison of Methods

Tables IX and X, and Figure 34 compare the methods presented in this chapter. Of the five methods shown for comparison in Table IX, three are tabular methods and two are rules-of-thumb. All five consider only summer shading. Overhang projections are produced that completely shade a window from one day (June 21) to 183 days (March 21 to September 21). The latitudes that each method considers are roughly the same, although the Mazria-Rule-of-Thumb requires much interpolation for north latitudes other than 36^{o} or 48^{o}.

The three methods shown for comparison in Table X consider both summer shading and winter insolation. Overhang projections and

TABLE IX

COMPARISON OF LATITUDE-BASED METHODS THAT CONSIDER ONLY SUMMER SHADING

Column One Method	Column Two Period of Complete Shade	Column Three Number of Complete-Shade Days	Column Four Latitudes	Column Five Form of Equation (3.2)	Column Six Example Overhang Length
FMHA Table	Apr 1 to Sep 11	163	25° to 50°N.	$p = t_H/\tan \Omega_o$	3.12 ft.
Mazria Rule-of-Thumb	Jun 1 to Jul 11	41	36° to 48°N.	$p = t_H$ (for 36°N) $p = t_H$ (for 48°N)	1.25 ft.
Mazria F-Factor	June 21 May 11 to Aug 1	1 81	28° to 56°N.	$p = t_H$/F-Factor	1.11 ft. 1.67 ft.
Egan K-Value	May 11 to Aug 1	81	25° to 50°N.	$p = t_H$/K-Value	1.52 ft.
(Shade Line Factor)	May 11 to Aug 1	81	25° to 50°N.	$p = t_H$/SLF	1.86 ft.
Szokolay Rule-of-Thumb	March 21 to Sep 21	183	Any Latitude	$p = t_H/\tan(90-\text{lat})$	3.63 ft.

TABLE X

COMPARISON OF LATITUDE-BASED METHODS THAT CONSIDER BOTH SUMMER SHADING AND WINTER INSOLATION

Column One	Column Two	Column Three	Column Four	Column Five	Column Six	Column Seven
Method	Period of Complete Shade	Number of Complete-Shade Days	Period of Complete Sun	Number of Complete-Sum Days	Example Overhang Length	Example Separation Height
DOE-LANL Rule-of-Thumb	May 11 to July 31	79	Nov 11 to Jan 30	79	2.06 ft.	1.48 ft.
Small Homes Council Rule-of-Thumb	Dependent on Window Height	Dependent on Window Height	Dependent on Window Height	Dependent on Window Height	2.50 ft.	1.33 ft.
Utzinger Nomograph	June 21	1	Dec 21	1	1.28 ft.(min.)	0.76 ft.(min.)
	Apr 21 to Aug 21	121	Oct 21 to Feb 21	121	3.71 ft.(max.)	3.34 ft.(max.)

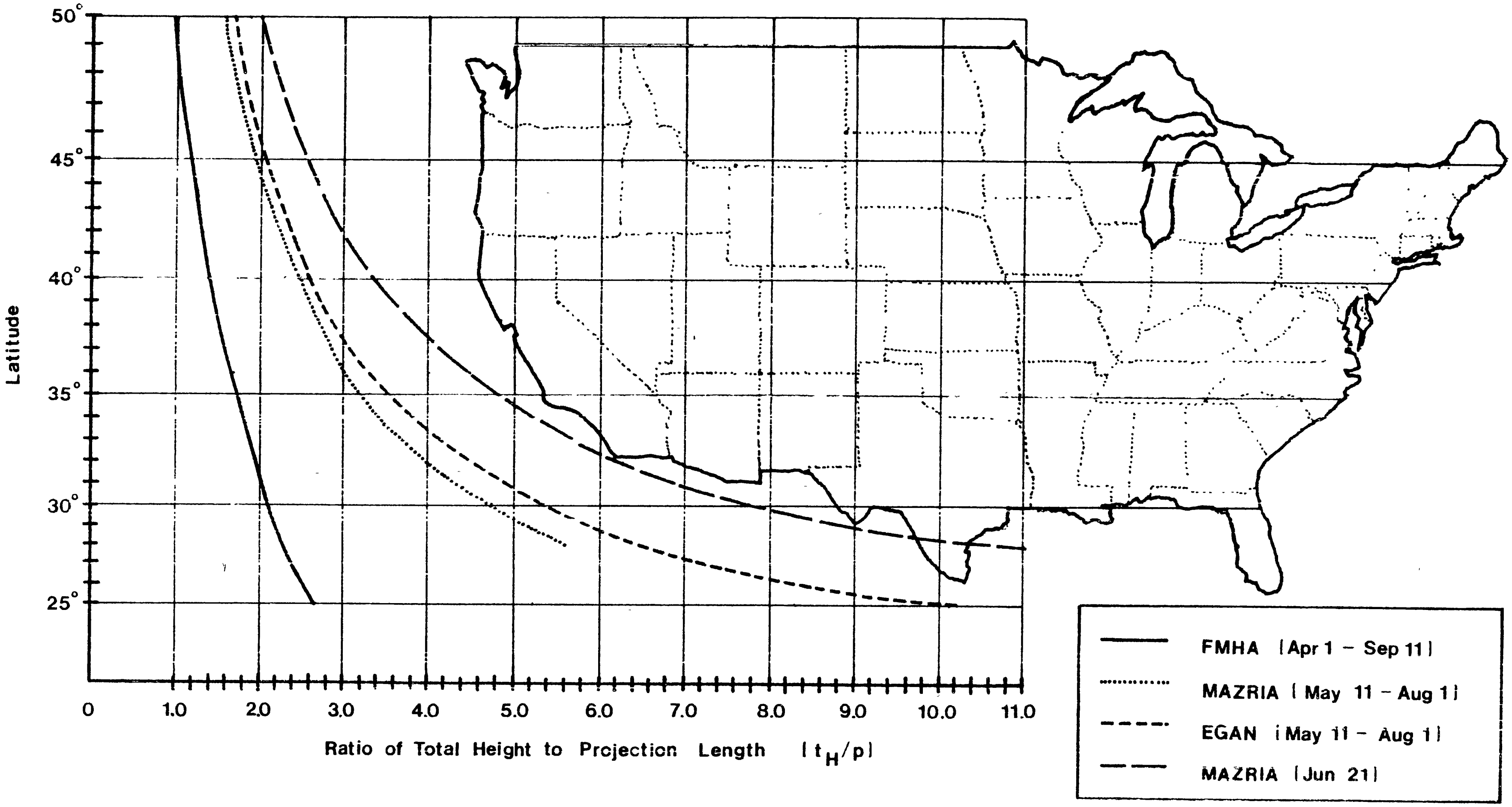


Figure 34. Graphical Comparison of Tabular Values of FMHA, Mazria F-Factor, and Egan K-Value Methods

separation heights are produced that completely shade a window from one day (June 21) to 121 days (April 21 to August 21), and that allow complete insolation from one day (December 21) to 121 days (October 21 to February 21).

Figure 34 compares and graphically presents the tabular values of the FMHA, Mazria F-Factor, and Egan K-Value methods for south-facing windows. Projection lengths can be found by multiplying the reciprocal of a value on the horizontal axis by the total height. For example, at 35°N. latitude, the value on the horizontal axis corresponding to Egan's K-Value curve is 3.5. For a 5 ft. window height and a 1 ft. separation height, the total height is 6 feet. The reciprocal of 3.5 multiplied by the total height is (1)/(3.5)(6) = 1.7 feet.

Example Problem

To further explain and compare existing latitude-based methods, consider the following example problem: A window with a height of 5.0 ft. faces due south at 36°N. latitude. Determine the recommended overhang projection length for each method in Table IX, and the recommended overhang projection length and separation height for each method in Table X.

According to the FMHA method, interpolating for a total height of 5.0 ft. at 36°N., the overhang projection would be 3.12 ft. It should be noted that in the stated example problem no separation height was given, so it is assumed that the total height equals the window height.

Mazria's rule-of-thumb, Equation (3.8), for 36°N., says the overhang projection should be:

$$p = 5.0/4 = 1.25 \text{ ft.}$$

According to the Mazria F-Factor method, Table VII, and Equation (3.10),

$$p = 5.0/4.5 = 1.11 \text{ ft.}$$

for an F-Factor of 4.5, and for complete shade on June 21 only. To shade from May 11 to August 1, an F-Factor of 3.0 is used and,

$$p = 5.0/3.0 = 1.67 \text{ ft.}$$

According to the Egan K-Value method, (and the Shade Line Factor method) to shade from May 11 to August 1, for 36^{o}N., a K-Value (and SLF) of 3.3 is used (by interpolation from Figure 34), and from Equation (3.12),

$$p = 5.0/3.3 = 1.52 \text{ ft.}$$

Szokolay's rule-of-thumb, Equation (3.15), says the overhang projection should be:

$$p = 5.0/\tan(90 - 36) = 3.63 \text{ ft.}$$

DOE-LANL's rule-of-thumb basically says to allow 79 days of complete insolation in the winter and 79 days of complete shade in the summer. Using Equations (3.6) and (3.7):

$$p = 2.06 \text{ ft.}$$

$$g_H = 1.48 \text{ ft.}$$

The Small Homes Council's rule-of-thumb is constant for all North American latitudes, so:

$$p = 2.50 \text{ ft. (30 inches)}$$

$$g_H = 1.33 \text{ ft. (16 inches)}$$

In order to work the above example, the Utzinger Nomograph method requires a decision by the designer about the number of days summer shade and winter sun is desired. The minimum and maximum projection lengths and separation heights for an overhang above a five ft. window, using the Utzinger Nomograph are:

$1.28 \leq p \leq 3.71$ (ft.)

$0.76 \leq g_H \leq 3.34$ (ft.)

where $p = 1.28$ ft. and $g_H = 0.76$ ft., when the periods of complete shade and insolation are June 21 and December 21 respectively; and $p = 3.71$ ft. and $g_H = 3.34$ ft., when the periods of complete shade and insolation are April 21 to August 21 and October 21 to February 21, respectively.

Summary

Latitude-based methods to determine proper overhang projection lengths are quick and easy, but have several limitations:

1. Local climate is not considered.
2. Building characteristics are not considered.
3. All the methods are based on latitude, which is easily determined, but not very useful by itself in sizing overhangs (28).
4. Only horizontal overhangs are considered.
5. With the exception of the Egan K-Value Method (or SLF Method), all are for south orientation only.
6. Determination of N_o and N_u is left up to the designer, with no guidance as to what magnitude each should be.

CHAPTER IV

CLIMATE-BASED METHODS

Brief Survey

Climate-based methods of shading device design are another category of methods, in addition to latitude-based methods, that have been developed to determine proper projection lengths of overhangs and other types of shading devices. Two problems inherent in the design of fixed shading devices that must be addressed when considering climatological data are:

1. balancing winter insolation and summer shading, and
2. striking a compromise between late summer shading and spring insolation.

First, three methods that attempt to balance winter insolation and summer shading are presented, then four methods are presented that suggest ways to strike a compromise between late summer shading and spring insolation.

Methods that Balance Summer Shading and Winter Insolation

One difficulty in the design of fixed shading devices is the aspect of balancing winter insolation and summer shading. From Table XI it can be seen that the three methods presented in this section differ in

TABLE XI

COMPARISON OF CLIMATE-BASED METHODS THAT BALANCE WINTER INSOLATION AND SUMMER SHADING

Means of Comparison	Olgyay Shading Effect Ratio	Lau	Jones
Place and date of development	Princeton 1957	Atlanta 1982	Los Alamos 1981
Resulting information	projection length	projection length and gap height	projection length and gap height
Applicable orientation	any orientation	south only	south only
Type of shading device	all types	overhangs	overhangs
Building characteristics considered?	No	Yes (LCR, T_b)	Yes (LCR, COP)
Temperature and/or radiation dependent?	temperature and radiation	temperature and radiation	temperature and radiation
Demarcation temperature	70F	Depends on T_b	T_{set} between 65F and 75F
Method format	graphical/ equation	graphical/ equation	charts/ computer

Notes: LCR = Load Collector Ratio
T_b = Building balance point temperature

method format, applicable orientations, resulting information, and types of shading devices considered. They also differ in whether or not building characteristics are taken into account.

Olgyay Shading Effect Ratio Method

In 1957, the Olgyay brothers developed a method to judge the yearly effectiveness of shading devices. As an introduction to their method, the following is pointed out:

> . . .the effectiveness of a shading device depends on the proportionate success with which it covers a given surface during the overheated period without interception of the sun's energy (by a shading device) during underheated times. Therefore, the efficiency of a device should be judged on its yearly performance, and on the relative balance between its "shading performance" and "heating efficiency" (1, p. 64).

The three most important factors of Olgyay's method are:

1. overheated shading performance, S_p
2. yearly heat efficiency, H_e
3. shading effect ratio, S_e

The overheated shading performance (S_p) is the percent of direct radiation intercepted by a shading device during the overheated period, and is given by the following equation:

$$S_p = (S_o/R_o) \times 100\% \qquad (4.1)$$

where

S_o = the amount of direct radiation prevented from striking a particular window during the overheated period, (Btu), and

R_o = the amount of direct radiation striking the unshaded window during the overheated period, (Btu).

The yearly heat efficiency (H_e) is given as:

$$H_e = [(S_o - S_u)/R_o] \times 100\% \qquad (4.2)$$

where

S_u = the amount of direct radiation prevented from striking a window during the underheated period (Btu).

The shading effect ratio (S_e) is one-half the sum of overheated shading performance and yearly heat efficiency, as follows:

$$S_e = (S_p + H_e)/2 \qquad (4.3)$$

Substituting Equations (4.1) and (4.2) into Equation (4.3) yields another form of the equation for shading effect ratio:

$$S_e = (S_o/R_o - \tfrac{1}{2} S_u/R_o) \times 100\% \qquad (4.4)$$

Built into Equation (4.4) is Olgyay's general assumption that "shading at overheated times is twice as important as heat gain during the underheated period" (1, p. 64). This assumption is based on the following intuitive statement:

> The importance of heat gain as opposed to "cooling" shade can be interpreted by different ratios. In fully air-conditioned buildings, according to the current heating-versus-cooling costs the ratio could be taken as one to five [cooling being five times as important as heating]. In certain cases, the ratio based on the economy of mechanical cooling is justified. But its seems that a more permanent yardstick would be established by relating their importance to human reactions, where a reasonable ratio would be one to two. (1, p. 64).

By using Equations (4.1) through (4.4) with appropriate solar radiation data, S_p, H_e, and S_e can be found to evaluate shading devices of various lengths and configurations for any location or orientation, until a device with the highest shading effect ratio is determined. Figure 35 illustrates the results of calculations for an overhang with profile angles of 65°, 68°, 70° and 73.5° for the New York-New Jersey area.

In determining direct solar radiation data to use in the calculations, Olgyay's method also entails a series of steps using a sun-path diagram showing the overheated period for a given location, a shading mask protractor, and a direct radiation protractor (1).

Lau Method

Another approach to balancing winter insolation and summer shading, developed by Andrew Lau in 1982, roughly takes into account local climate and building balance point temperature* in determining recommended projection lengths of overhangs for south-facing windows on residential buildings (19, 23).

According to Lau, the following equation determines a recommended overhang projection length (p):

$$p = g_H \tan(L - D_u) \tag{4.5}$$

where

g_H = separation height,

L = latitude, and

D_u = declination at mid-month of the latest underheated month (late winter or early srping) for which complete insolation is desired.

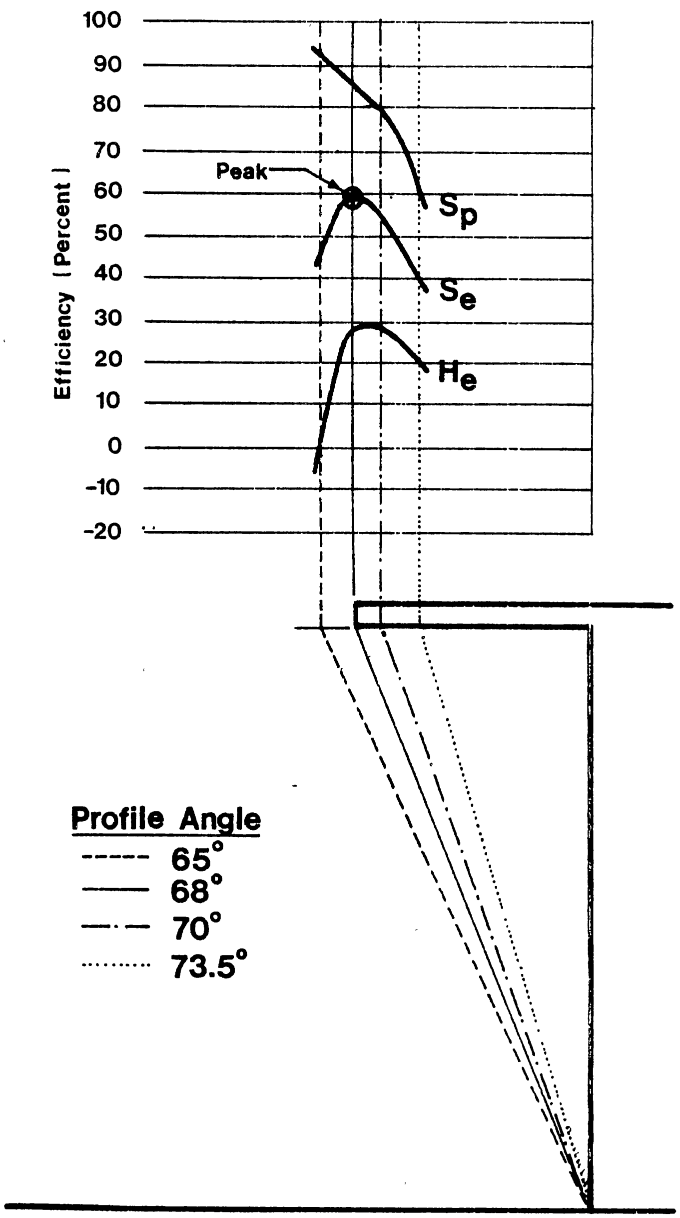


Figure 35. Evaluation of a South-Facing Overhang at 40° N. Latitude (New York-New Jersey Area) (1)

It should be noted that Lau emphasizes the importance of allowing winter insolation; as a result, Equation (4.5) uses an underheated declination (D_u) rather than an overheated declination, and separation height (g_H) rather than total height (t_H). Equation (4.5), therefore, contrasts directly with Equation (3.5) which considers summer shading only. It should also be noted that if the separation height can be chosen, the designer is wise to make it as large as feasible to allow more summer shading.

In determining the latest underheated month that complete insolation is desired, two factors must first be calculated or estimated:

1. balance temperature*, T_b, and
2. load collector ratio*, LCR.

The balance point temperature is the outdoor temperature below which heating is required and above which no heating is required. A building balance point temperature can be calculated using Equation (2.1) of Chapter II.

According to Lau, a building balance point temperature (or balance temperature) can be estimated according to the following:

> In practice, the balance temperature is only a couple of degrees below the thermostat setting for houses that are poorly insulated. Houses with good insulation and airtightness, however, may have balance temperatures 5-10F below the thermostat setting. Super insulated houses can have balance temperatures over 20F below the thermostat setting (19, p. 36).

Load collector ratio (LCR) is the ratio of the building load coefficient to the net south-facing window area, and may be calculated using the following equation:

$$LCR = BLC/A_c \tag{4.7}$$

where

BLC = building load coefficient (Btu/^{o}F day), and

A_c = net south-facing window area (ft^2).

An estimate for LCR is all that is needed in Lau's method, since only two LCR's are considered. An LCR of 38 Btu/^{o}F day ft^2 corresponds to a residence with:

1. large south window area (about 15-25 percent of floor area),
2. well-insulated roof and walls (R-19 to R-30 roof, R-11 to R-19 walls), or "super-insulated" roofs and walls, and
3. 0.5 to 0.75 air changes per hour.

An LCR of 96 Btu/^{o}F day ft^2 corresponds to a residence with:

1. moderate south window area (about five to ten percent of floor area),
2. well insulated roof and walls (R-19 to R-30 roof, R-11 to R-19 walls), and
3. 0.5 to 0.75 air changes per hour.

Once a building's LCR and T_b are known, the latest winter month that complete insolation is desired can be determined from Figure 36 or 37.

The geographical limits to the regions of Figures 36 and 37 correspond to calculations performed for 25 cities, with the following assumptions:

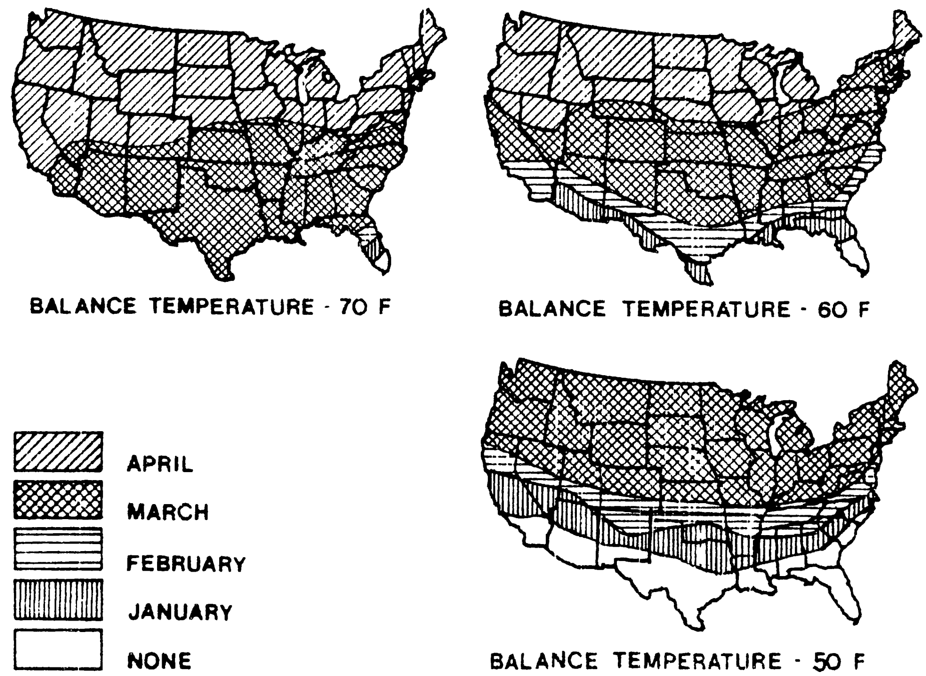


Figure 36. Estimated Last Month for Which Complete Insolation is Desired for LCR = 96 Btu/^{o}F day ft^{2} and T_b = 50, 60 or 70F (19)

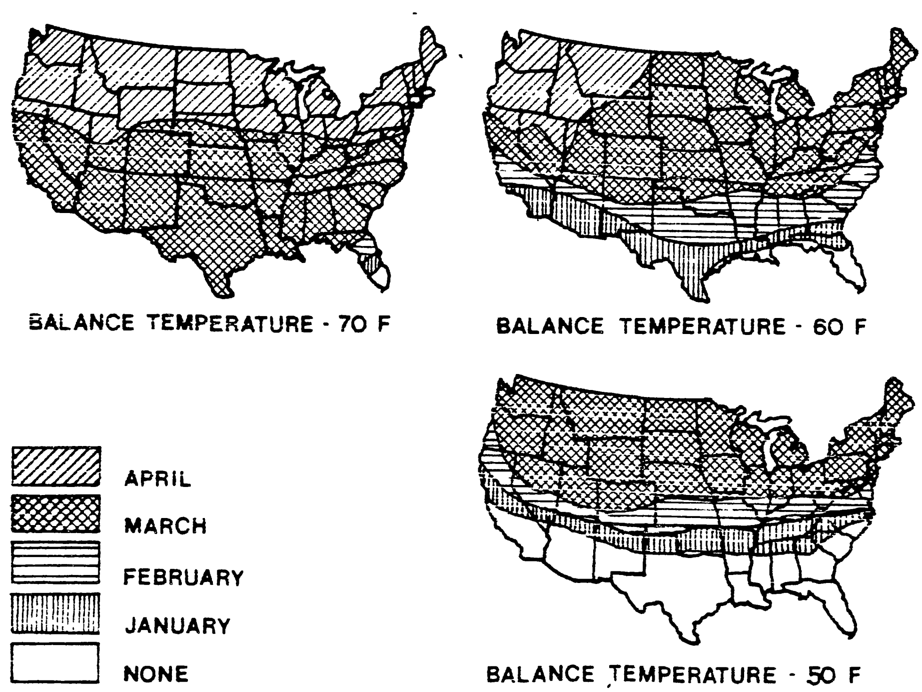


Figure 37. Estimated Last Month for Which Complete Insolation is Desired for LCR = 38 Btu/^{o}F day ft.^{2} and T_b = 50, 60 or 70F (19)

1. If the monthly auxiliary (conventional) heating* requirement of a house was less than 1,000,000 Btu, complete insolation of a window was considered unnecessary.
2. The outer limits of the underheated period's length, centered on December 21 (winter solstice), was based on a window collecting 80 percent of its annual useful solar heat (or insolation). This useful solar heat gain was estimated for various conditions and locations with the monthly solar load ratio (SLR) method for a direct-gain system (19).

Having determined the last month for which complete insolation is desired, the declination value for use in Equation (4.5) is found from the following table of declinations of a recommended average day* for each month (22).

Jones Method

In 1981, R. W. Jones of Los Alamos National Laboratory developed another approach for balancing winter insolation and summer shading. His method specifically determines the projection length and separation height for overhangs on south-facing glazing. At the time of its publication, it was limited to passive solar homes having water wall construction (28).

Figure 38 shows an example of the results of Jones' method. The contours are lines of equal energy savings. The values of the contours are relative annual energy savings ($\Delta Q'$) calculated from Equation (4.8) in units of 1000 Btu per ft^2 of glazing.

$$\Delta Q' = \Delta Q_h + \Delta Q_c/COP \qquad (4.8)$$

TABLE XII

DECLINATION VALUES OF RECOMMENDED AVERAGE DAYS*

Month	Average Day	Declination
January	17th	-20.9^{o}
February	16th	-13.0^{o}
March	16th	-2.4^{o}
April	15th	$+9.4^{o}$

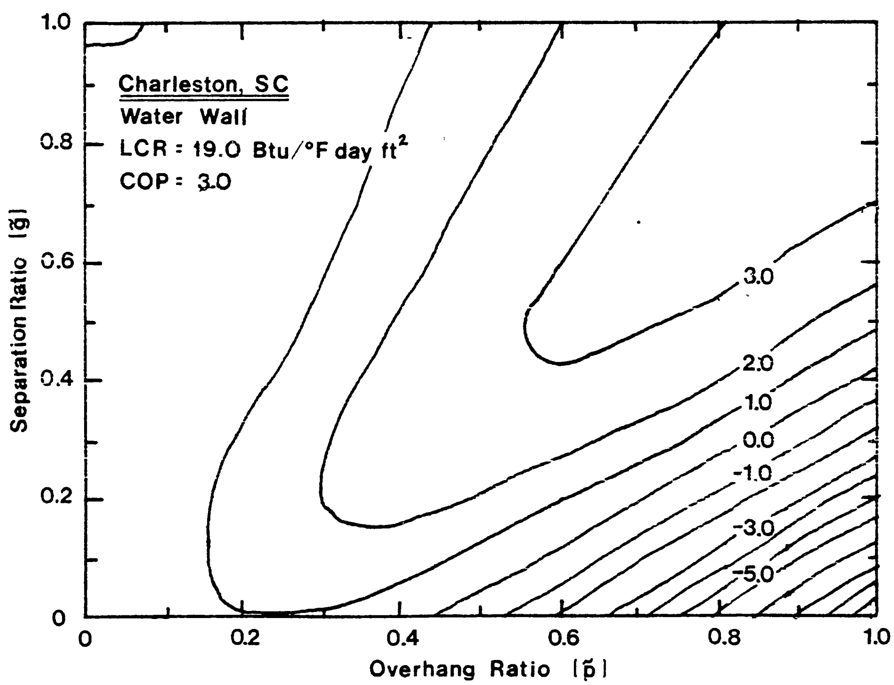


Figure 38. Curves of Equal Relative Annual Energy Savings (1000 Btu/ft.^{2}) Achieved by South-Facing Overhang of Various Overhang and Separation Height Ratios (28)

where

ΔQ_h = heating load without an overhang less the heating load with an overhang (1000 Btu/ft^2)

ΔQ_c = cooling load without an overhang less the cooling load with an overhang (1000 Btu/ft^2)

COP = coefficient of performance of the cooling system relative to the auxiliary heating system*.

ΔQ_h is negative since an overhang interferes with passive solar heating, and ΔQ_c is positive since an overhang reduces solar gain, so that Equation (4.8) becomes an algebraic expression of the trade-off between winter insolation and summer shading.

In general terms, the relative COP, is the "cost" of heating relative to cooling and is a parametric expression of the relative importance of heating and cooling in the design solution. For example, the relative COP could be regarded as the cost of heating relative to cooling in terms of one or more of the following:

1. primary, volumetric fuel consumption,
2. dollar cost of fuel(s) consumed, and/or
3. subjective measures of the desired design balance such as the inconvenience or discomfort of underheating relative to undercooling.

Figure 38 is for a particular city, type of passive system, LCR, and COP; and is a summary of 26 annual energy savings calculations of $\Delta Q'$ as a function of overhang and separation ratios* from zero to one. (Recall Equations (3.17) and (3.18) for overhang and separation ratio definitions). To develop Figure 38, and to calculate the relative energy savings ($\Delta Q'$) as a function of overhang ratios ($\tilde{p}$), separation ratios ($\tilde{g}$), LCR, and COP, an hour-by-hour computer simulation was performed using Typical Meteorological Year (TMY) data for Charleston. The characteristics and assumptions of the simulation model include the following:

1. Heating and cooling thermostat set-points are 65F and 75F respectively.
2. Heating and cooling loads are calculated as the auxiliary energy flows required to maintain the space temperature between the thermostat set-points.
3. Solar gains through a south-facing (or equatorial-facing) double-glazed windows are taken into account.
4. Incident solar radiation is calculated from TMY's total horizontal and direct normal solar radiation data assuming isotropic diffuse sky radiation and a ground reflectance of 0.3.
5. Heat losses through the glazing system are calculated in detail.
6. Conduction and infiltration gains and losses through nonsolar parts of the building envelope are calculated in terms of a single building load coefficient (BLC).
7. There are no internal sources.

From Figure 38, two features of overhang performance are evident for a building in Charleston, South Carolina, having water wall passive solar construction, an LCR of 19 Btu/^{o}F day ft^{2}, and a relative COP of 3.0:

1. It is possible for overhangs to yield an energy penalty (negative $\Delta Q'$). For example, it can be seen from Figure 38 that an overhang ratio of 0.8 and separation ratio of 0.0 (i.e., no separation height between the top of a window and the bottom of the overhang) yields a relative annual energy "savings" of -7.0×10^3 Btu/ft^2.
2. There is a broad region of relative values of overhang and separation ratio pairs where maximum energy savings occur within the limits of the chart. From Figure 38, the recommended overhang ratios are between 0.6 and 1.0 with corresponding separation ratios of 0.5 to 1.0 to yield a relative annual energy savings of 3.0×10^3 Btu/ft^2.

Methods That Consider Only Summer Shading

Not all climate-based methods attempt to balance winter insolation and summer shading. Instead, some climate-based methods consider only the overheated period during summer months. Overheated periods* are asymmetrical about the summer solstice while the sun's path is symmetrical about the summer solstice*. The shift of symmetry of the overheated period creates a problem for fixed shading devices: shading in late summer when shading is desired necessarily implies shading in the spring when shading is not desired. Therefore, a compromise must be made between spring insolation and late summer shading. This section examines how four climate-based methods deal with the problem of striking a compromise between late summer shading and spring insolation. Table XIII compares each of the four methods and serves as a means of introduction to methods by Olgyay, Novell, Saleh, and Shaviv.

TABLE XIII

COMPARISON OF CLIMATE-BASED METHODS THAT CONSIDER SUMMER SHADING ONLY

Means of Comparison	Olgyay Shading Mask	Novell	Saleh	Shaviv
Place and date of development	Princeton 1957	Alabama 1981	Australia 1979	Israel 1975
Resulting information	projection length	projection length	theoretical outline	theoretical outline
Applicable orientation	any orientation	any orientation	any orientation	any orientation
Type of shading device	all types	all types	overhang and frame-type	all types
Building characteristics considered?	No	No	No	No
Temperature and/or radiation dependent?	temperature	temperature	temperature	temperature and radiation
Demarcation temperature	70F	70F	70F	dependent on insolation
Method format	equidistant sun-path diagram	orthographic sun-path diagram	shadow chart	computer/graphical

Olgyay Shading Mask Method

In the last section, Olgyay's Shading Effect Ratio Method was presented that dealt with balancing winter insolation and summer shading by using efficiency equations. If a designer does not wish to enter into Olgyay's yearly efficiency equations, a rule-of-thumb concerned with the coverage of shading masks* on a sun-path diagram showing an overheated period is given by Olgyay:

> . . .if the 50 percent border of a shading mask covers the outer perimeter of the indicated overheated period, the shading device will be effective (1, pp. 79-80).

To clarify this statement, a shading mask is the area on a sun-path diagram where shading occurs due to a particular type of shading device. As shown in Figure 39, horizontal devices create arcual masks, vertical devices create radial masks, and eggcrate devices create combination masks. The 100 percent border of a shading mask bounds the area on a sun-path diagram where the full height of a window is completely shaded. The 50 percent border of a shading mask bounds the area on a sun-path diagram where at least 50 percent (typically the top half) of a window is completely shaded. Figure 40 shows the 50 and 100 percent borders of a typical shading mask with corresponding profile angles.

Since a single arcual line on a sun-path diagram represents the path of the sun on a pair of conjugate dates*, the overheated period is divided into a "full-time overheated period*", where shading is needed on both conjugate dates, and a "half-to-full-time overheated period*", where at least one of the two conjugate dates requires shading. It is in this "half-to-full-time overheated period" that a compromise must be

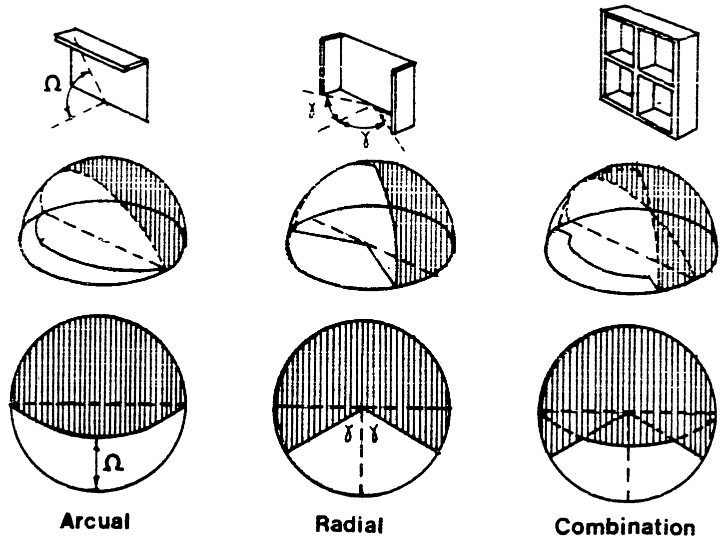


Figure 39. Derivation of Shading Masks (29)

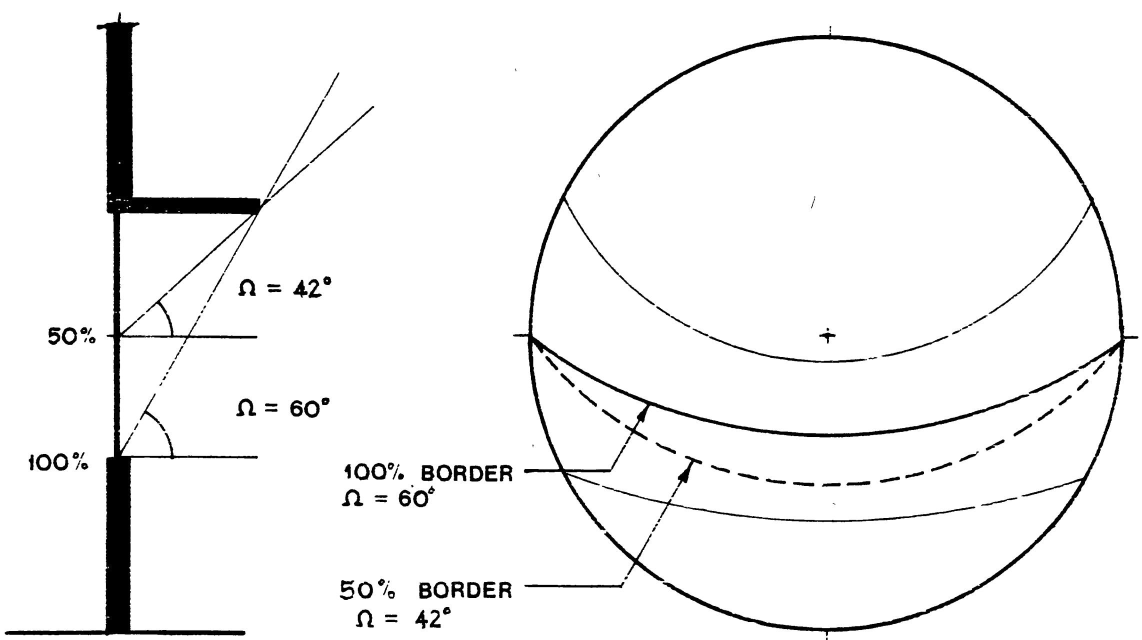


Figure 40. Relationship Between an Overhang and 50 and 100 Percent Shading Masks

made between shading in late summer or allowing insolation in spring. An overheated period, determined from climatological data and defined as the times of the year when shading is needed (or when outside temperatures are above the building balance point temperature), can be transferred to a sun-path diagram. Olgyay assumes shading is needed when outside temperatures are greater than 70F, which is considerably greater than most building balance point temperatures.

Assuming Olgyay meant both the half-to-full-time period and the full-time overheated period, when referring to an overheated period in his statement above, Olgyay's statement could be reworded to say that as a rule-of-thumb, a shading device is effective if it shades at least half (typically the top half) of a window during both the half-to-full-time and full-time overheated periods. An example of such a device for an arbitrary situation is shown in Figure 41.

Novell Method

Bruce Novell's approach to designing shading devices is very similar to Olgyay's approach in the Shading Mask Method (30). Novell's method also involves shading masks covering a sun-path diagram showing an overheated period. The differences between the two methods are that Novell transfers overheated periods to an orthographic sun-path diagram called a "cylindrical sun chart" (such as the chart shown in Figure 42), rather than to the equidistant sun-path diagram used by Olgyay (Figure 43), and that Novell recommends shading an entire window during all of the full-time overheated period, rather than shading at least half of a window during both the half-to-full-time and full-time overheated periods. Novell assumes shading is needed when outside temperatures are

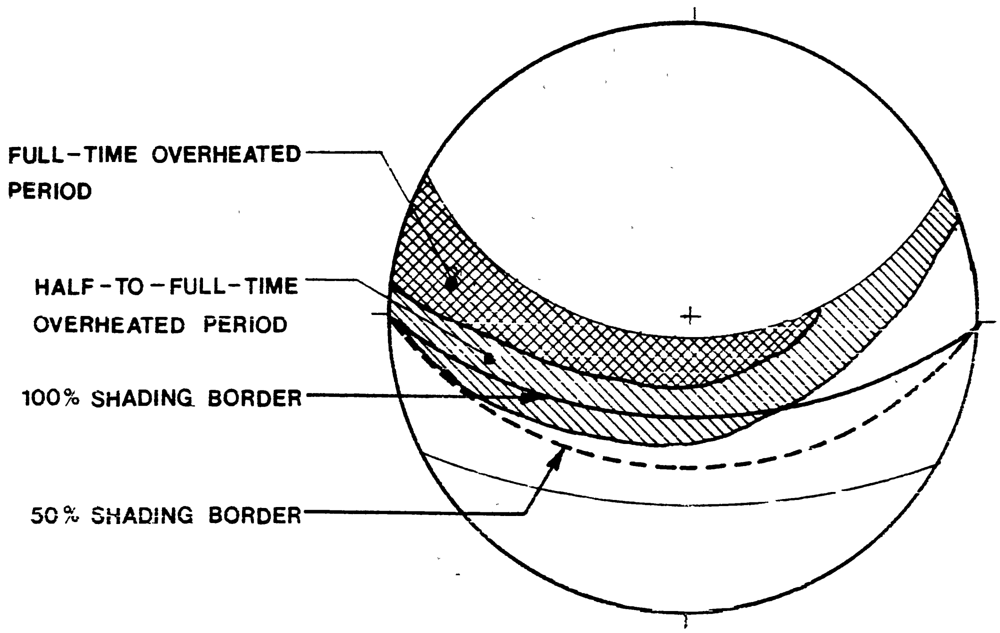


Figure 41. An Example of Olgyay's Rule-of-Thumb for Shading Masks Covering an Overheated Period on a Sun-Path Diagram

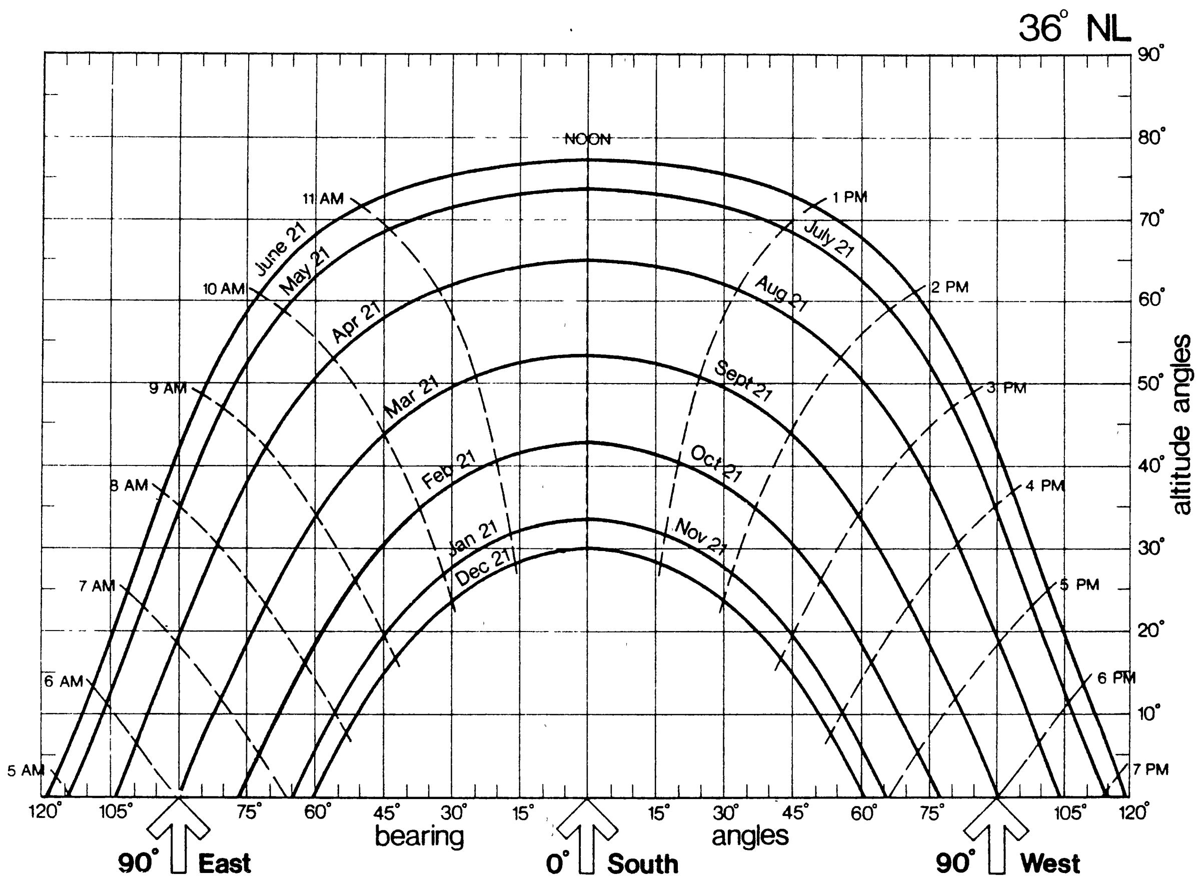


Figure 42. Orthographic Sun-Path Diagram (7, p. 317)

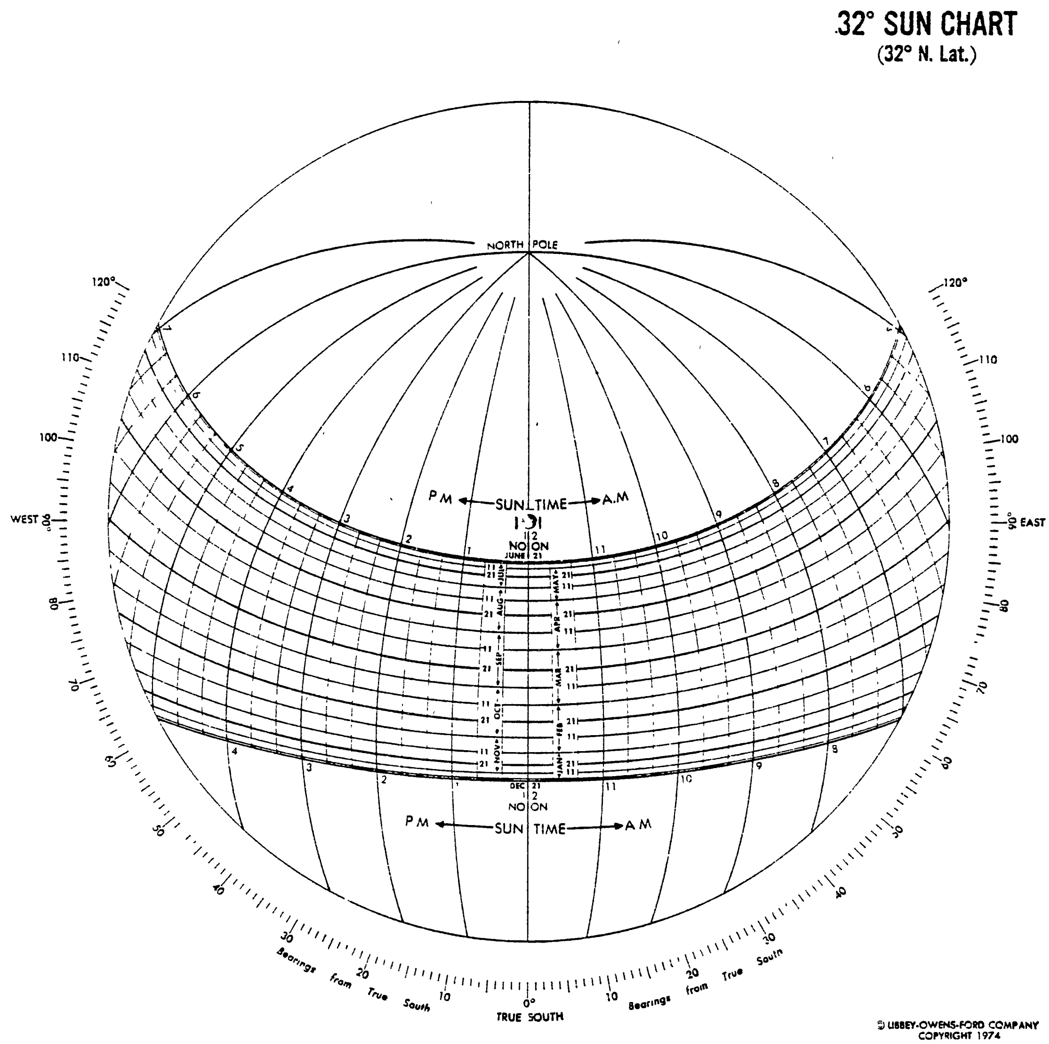


Figure 43. Equidistant Sun-Path Diagram (31)

greater than 70F. Figure 44 illustrates an example of Novell's rule-of-thumb for compromising spring insolation and late summer shading. The figure shows an equidistant sun-path diagram for comparison with Olgyay's rule-of-thumb.

Saleh Method

Rather than plotting an overheated period on a sun-path diagram, Saleh plots an overheated period on a "shadow chart" (also known as a Kuwait Sunshade Calculator), like the chart shown in Figure 45 for Marseille, France (32). A plotted overheated period is called a "shadow template" and is used directly in finding the exact theoretical outline of an overhang or frame-type shading device. Figure 46 shows an example of a shadow template for Sydney, Australia where the overheated period occurs during "winter" months and the sun primarily strikes north exposures. Figure 47 illustrates the direct application of the shadow template in forming a theoretical outline of an overhang.

Saleh's shading devices are designed to shade an entire window for both the half-to-full-time overheated period and the full-time overheated period, using approximately 70F as the demarcation temperature between the overheated and underheated periods.

Shaviv Model

The last climate-based method that considers primarily summer shading takes a quite different approach from the others presented in this section. Shaviv's computer-based method generates a series of shading solutions to satisfy a prescribed set of shading needs (13).

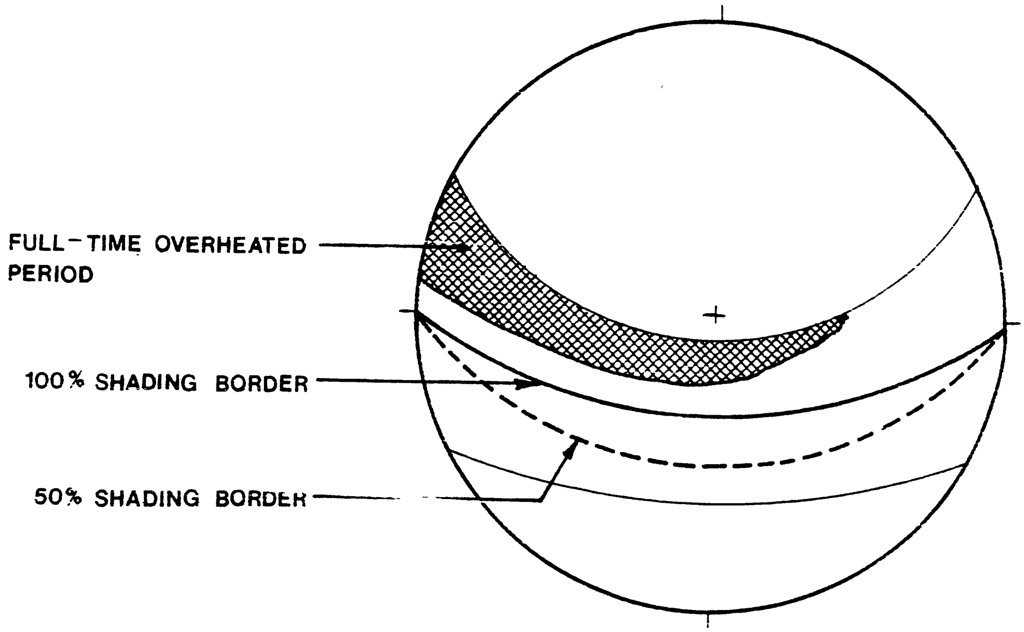


Figure 44. Example of Novell's Rule-of-Thumb for Shading Masks Covering the Full-Time Overheated Period on a Sun-Path Diagram

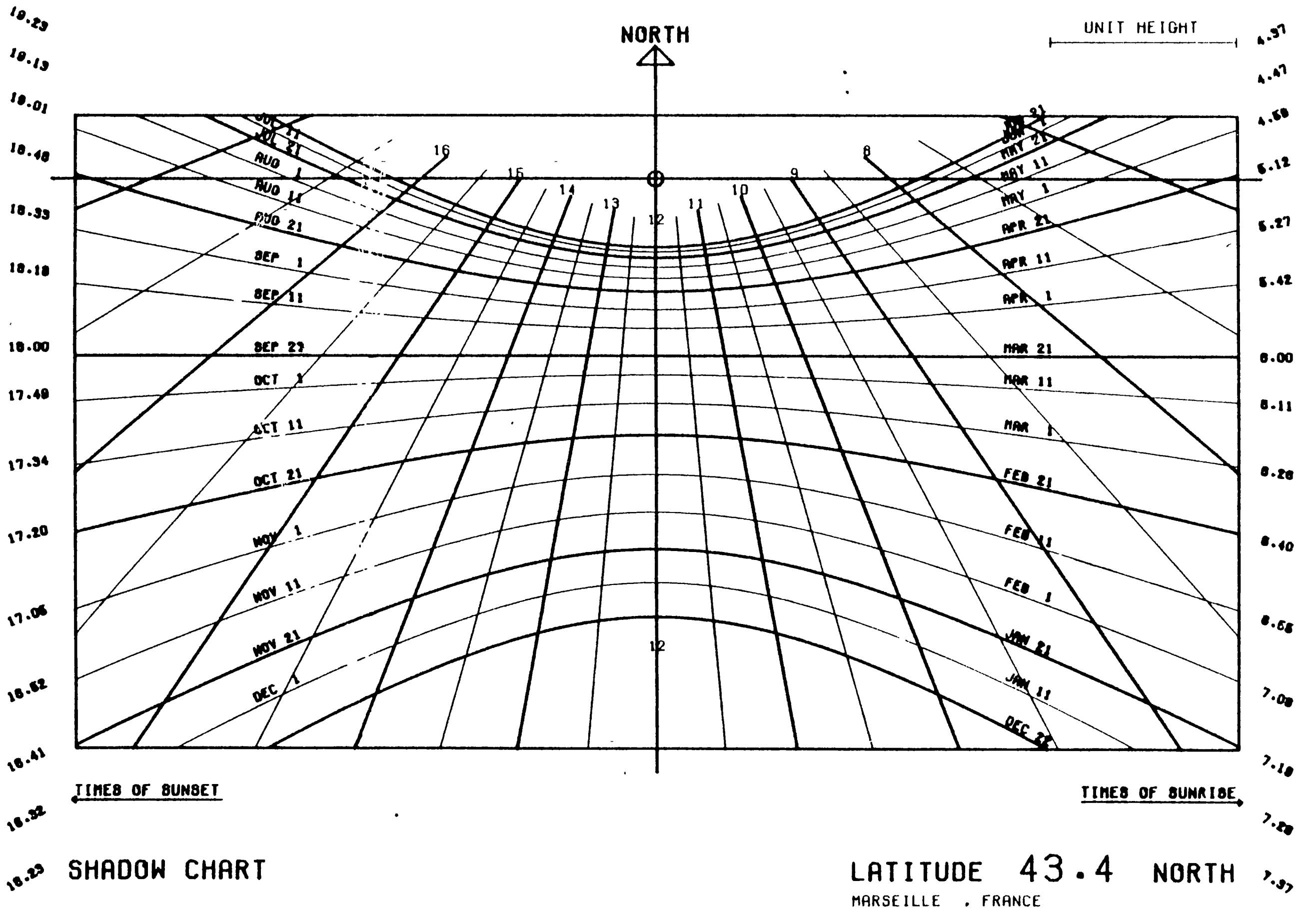


Figure 45. Saleh's Shadow Chart (or Kuwait Sunshade Calculator) (32, p. 244)

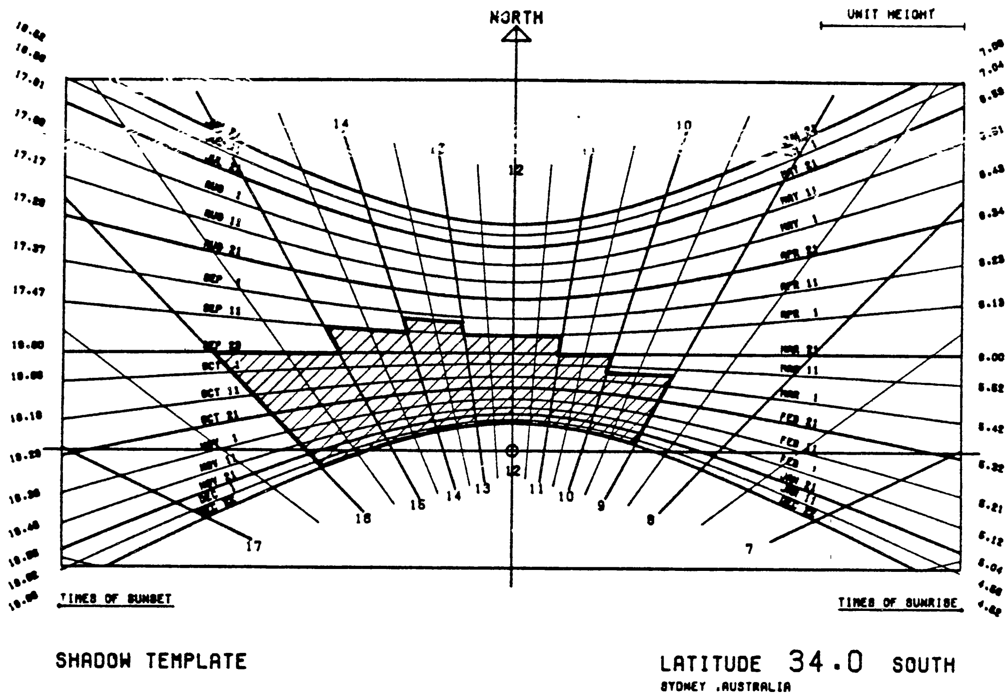


Fig. 5(a).

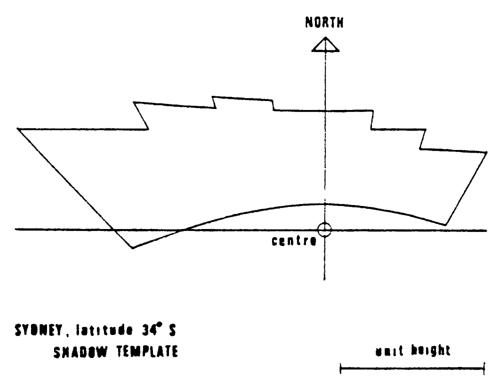


Figure 46. Shadow Template for Sydney, Australia (32, p. 247)

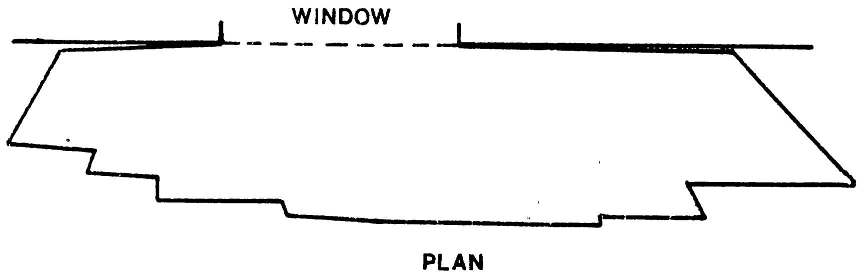


Figure 47. Theoretical Outline of an Overhang from a Shadow Template (32)

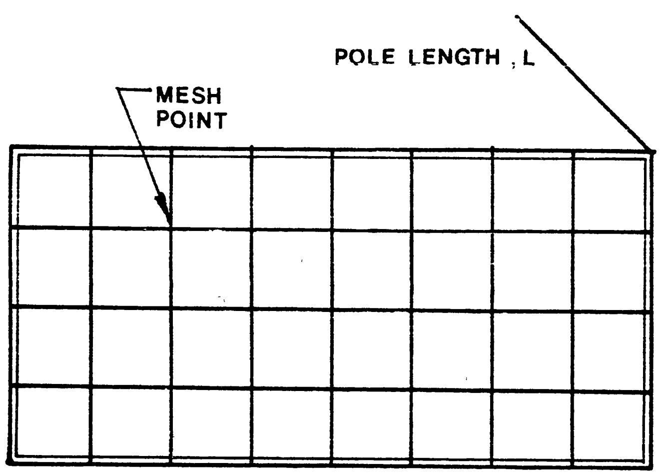


Figure 48. Division of a Window into a Set of Mesh Points (13)

The first step of Shaviv's method divides a window in a fine mesh (Figure 48). A "pole" of length L is imagined to be located perpendicular to the wall at each mesh point. The length of L is calculated in such a way as to cast a shadow sufficiently long to reach the frame of a window for all hours of the checking period*. The checking period primarily depends on local temperatures, but is also dependent on the amount of direct radiation that would strike a window, and on the time of day that the building is being used. Therefore, the length of a checking period is less than or equal to the length of an overheated period.

The distribution of L in the field of a window forms a nomogram from which a series of axonometric schemes (theoretical outlines) are presented (Figure 49). An architect then uses the theoretical outlines as a basis for his shading design.

Further Comparisons

Working through an example problem to compare results is unfeasible due to the various scopes of the methods discussed in this chapter. For example, Jones' method may be applied only to buildings having water wall construction and finds a broad range of recommended projection lengths and separation heights for an overhang; Saleh's method requires a "shadow chart" and finds the theoretical outline of an overhang that has several projection lengths (Figure 47); and Shaviv's method requires a computer program and finds a range of different types of shading devices.

The basis for balancing summer shading and winter insolation varies considerably between the methods by Olgyay, Jones, and Lau:

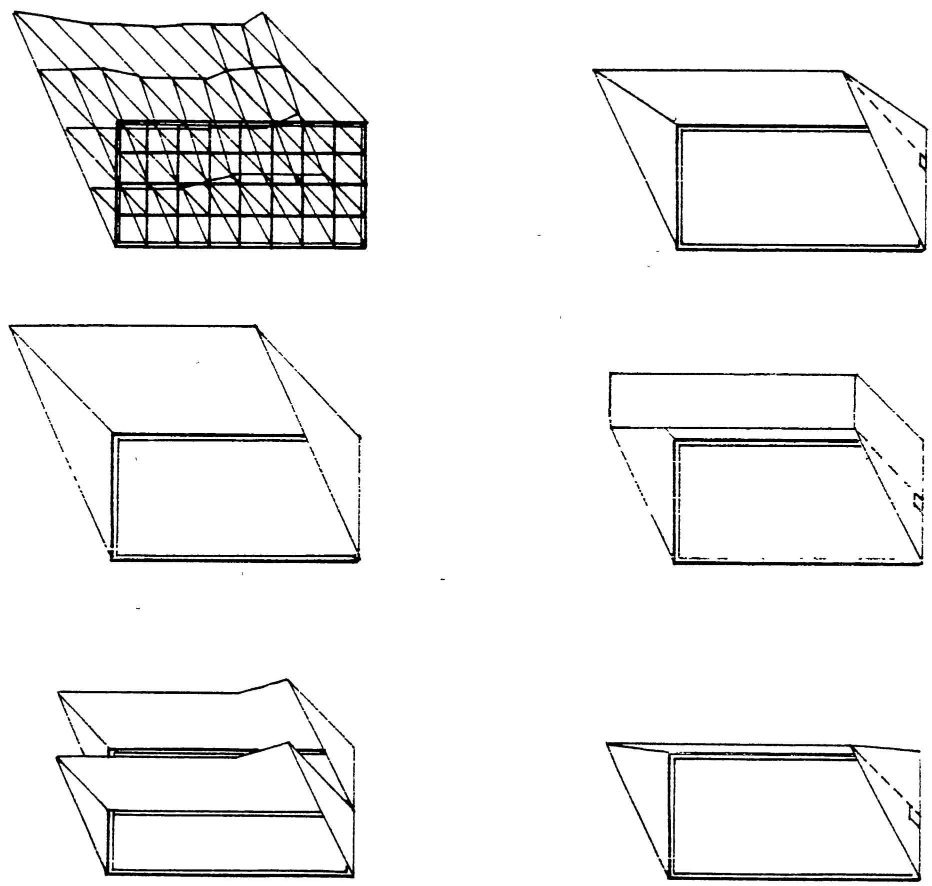


Figure 49. Shaviv's Nomogram With a Series of Schemes for a Southern Window (13)

1. Olgyay's Shading Effect Ratio method sums yearly radiation quantities and intuitively sets summer shading twice as important as winter insolation.
2. Jones' method develops a series of equal relative energy savings contours as a function of overhang and separation ratios. The contours are based on a particular type of passive solar building construction, and form a "plateau" suggesting a broad region of maximum energy savings for several combinations of overhang projection lengths and separation heights.
3. Lau's method determines the latest underheated month for a particular location, and recommends an overhang projection length on the basis of the separation height that allows insolation for underheated months.

The basis for balancing late summer shading and spring insolation also varies considerably. Table XIV summarizes the recommendations of the four methods that consider only summer shading. For clarification, shading during both the "half-to-full-time" and "full-time" overheated periods generally means shading during both the spring and late summer, while shading only during the "full-time" overheated period generally means allowing insolation in both spring and late summer.

TABLE XIV

SHADING RECOMMENDATIONS OF CLIMATE-BASED METHODS THAT CONSIDER SUMMER SHADING ONLY

Method	Percentage of Window in Shade		Duration of Shading Period	
	Shade at least 50 percent of window	Shade 100 percent of window	Shade during both half-to-full-time and full-time overheated periods	Shade only during full-time overheated period
Olgyay Shading Mask Method	X		X	
Novell Method		X		X
Saleh Method		X	X	
Shaviv Method		X	Note 1	

Note 1: Shaviv's method recommends shading for the duration of the "checking period" for a particular location, which is less than or equal to the duration of the overheated period.

CHAPTER V

PROPOSED ANNUAL ΔT-EFFECTIVENESS METHOD

Having presented in Chapter II the factors involved with the proper selection of various fixed, exterior shading devices, a method of evaluating the annual effectiveness* of shading devices is now presented to further aid in the proper selection and sizing of shading devices. Many of the factors involved in the selection of shading devices are subjective and difficult to quantify, such as disruption of visibility, daylighting impact, and weatherability. The method presented in this chapter uses ΔT (the difference between outside temperature and building balance point temperature) to quantitatively evaluate the effectiveness of a shading device, and incorporates certain components of the methods presented in Chapters III and IV.

General Description and Rationale

The proposed annual ΔT-Effectiveness method takes into account:

1. latitude,
2. window height, w_H,
3. separation height, g_H,
4. estimated hourly temperatures on the 1st, 11th and 21st day of each month,

5. building balance point temperature, T_b,
6. sunrise and sunset times,
7. surrounding obstructions,
8. orientation,
9. summer and winter balance factor, n, and
10. partial shading*.

Latitude is taken into account because the solar altitude angles of the sun vary with latitude; as latitude increases, the solar altitude angles of the sun decrease. Both window height and separation height are considered because a device's effectiveness in shading is related to window height, while effectiveness in allowing insolation is related to separation height. By using estimated outside temperatures for both summer and winter, times of shading and insolation needs are determined. A building balance point temperature is used rather than 70F (70F is a common demarcation temperature among the methods presented in Chapter IV) to take into account internal heat gains and a building's insulative quality. Sunrise and sunset times, surrounding obstructions, and orientation are taken into account because the method evaluates the effectiveness of a device when the sun is above the horizon, not blocked by surrounding buildings, and behind the wall of the window to be shaded. A summer and winter balance factor, n, which varies with location is used as a quantitative expression of the relative importance of shading in the summer versus allowing insolation in the winter. Partial shading in the form of incremental shading masks is considered because a device that shades part of a window should be evaluated as more effective than a device that shades none of a window.

It should be noted that there are several ways to define the effectiveness of a shading device. The key is in choosing some means of quantitatively measuring effectiveness so that comparisons between shading devices can be made. By using ΔT's (the difference between outside temperature and building balance point temperature) rather than time, the effectiveness of a device is weighted in proportion to the magnitude of ΔT's. In other words, if a device shades for two of three hours that shading is needed, its hourly effectiveness is 2/3 = 0.67, or 67 percent. However, if the sum of the ΔT's for the three hours that shading is desired is 20 + 20 + 5 = 45 and a shading device shades for the two hours having ΔT's of 20F, then its ΔT-effectiveness is (20 + 20 + 0)/49 = 0.89, or 89 percent.

Two possible ways of defining effectiveness that relate to the total heat transmission through glass are ΔT and direct radiation. Total heat transmission through glass is the sum of conduction heat gain and solar heat gain. Direct radiation relates to solar heat gain and ΔT relates to conduction heat gain. The major reason for choosing ΔT as a measure of effectiveness rather than direct radiation is that by plotting ΔT's on a timetable for both overheated and underheated periods, as shown later in Figures 54 and 55, one can see the relative importance of shading versus allowing insolation for a pair of conjugate dates* by comparing ΔT's. For example, on September 21 at noon in Oklahoma City, the estimated outside temperature is 20F above the balance point temperature of 60F (i.e., ΔT = 20F). On March 21 (the conjugate date of September 21) at noon, the estimated outside temperature is 5F below the balance point temperature of 60F. In such a case, if a fixed, exterior shading device is to be used, and if summer shading is considered more important than winter insolation, one would probably choose to shade on this particular pair of conjugate dates since the conduction heat gain on September 21 is greater than the conduction heat loss on March 21. If, on the other hand, direct radiation were used as a measure of effectiveness and plotted on a timetable, the solar heat gain through a window due to direct radiation would be the same (since the sun's incidence angle are the same) for both March 21 and September 21. Because direct radiation striking a vertical, south-facing window at noon on March 21 and September 21 is equivalent, one would not know whether to shade or allow insolation on this particular pair of conjugate dates.

A method that considers both ΔT and direct radiation as measures of effectiveness would relate more closely to total heat transmission through a window than ΔT or direct radiation alone, but would not help more than a method that considers only ΔT in deciding whether to shade or allow insolation on a pair of conjugate dates.

Another reason for choosing ΔT as a measure of effectiveness rather than direct radiation, is that the summer and winter balance factor, n, is related to the sum of overheated and underheated ΔT's. If, for a certain location, the sum of the underheated ΔT's is much lower than the sum of the overheated ΔT's, then shading in the summer would be considered more important than allowing insolation in the winter; thus n would be adjusted to indicate the imbalance between summer shading and winter insolation. Further explanation of n is found in Step Seven of the next section.

The steps involved in determining the ΔT-Effectiveness of a shading device, detailed in the next section, are:

1. construct an incremental shading mask* on a sun-path diagram,
2. transfer the incremental shading mask to a timetable,
3. estimate hourly temperatures,
4. determine overheated and underheated periods based on T_b,
5. plot overheated and underheated ΔT's on a timetable,
6. calculate overheated and underheated ΔT-effectiveness, and
7. calculate annual ΔT-effectiveness.

The rationale for each of the above steps is presented in the next section as the step-by-step procedure is presented in detail.

Detailed Step-by-Step Procedure

The following is a step-by-step procedure detailing the steps taken to determine the annual ΔT-effectiveness of a shading device. These steps are applied to the example in the next section for clarification.

Step One: Construct an Incremental Shading Mask on a Sun-Path Diagram

A shading mask represents the area on a sun-path diagram where shading of all or part of a window occurs, due to a particular shading device. When applied to the ΔT-Effectiveness method, a shading mask* with incremental device-lines* is bounded by:

1. wall-line borders* (due to shading caused by the wall containing the window),
2. solstice-line borders* (due to summer and winter solstice),
3. horizon-line borders* (due to the rising or the setting of the sun), and

4. sky-line borders* (due to shading by surrounding objects).

Referring back to Figure 39, it can be seen that device-lines on equidistant sun-path diagrams are arcual for horizontal shading devices, radial for vertical devices, and both arcual and radial for eggcrate devices. Device-lines for horizontal shading devices are determined by profile angles*, while device-lines for vertical shading devices are determined by surface-solar azimuth angles*. A 100 percent device-line of a shading mask bounds the area on a sun-path diagram where the full height (100 percent) of a window is completely shaded. A 50 percent device-line of a shading mask bounds the area on a sun-path diagram where at least 50 percent (typically the top half) of a window is completely shaded. Therefore, an incremental shading mask having device-lines of ten percent increments indicates areas on a sun-path diagram where zero percent, ten percent, 20 percent... and so on to 100 percent of a window is completely shaded.

Figure 50 shows an incremental shading mask with incremental device-lines bounded by two wall-line borders, two solstice-line borders, and two horizon-line borders. It is assumed in the example shown that there are no surrounding obstructions, so the shading mask is not bounded by a sky-line border. The actual location and curvature of device-lines are determined by profile angles.

<u>Step Two: Transfer Incremental Shading Mask to Timetable</u>

A timetable linearly represents the paths of the sun for each daytime hour on the 1st, 11th and 21st of each month of the year. A timetable with an incremental shading mask is shown in Figure 51. A

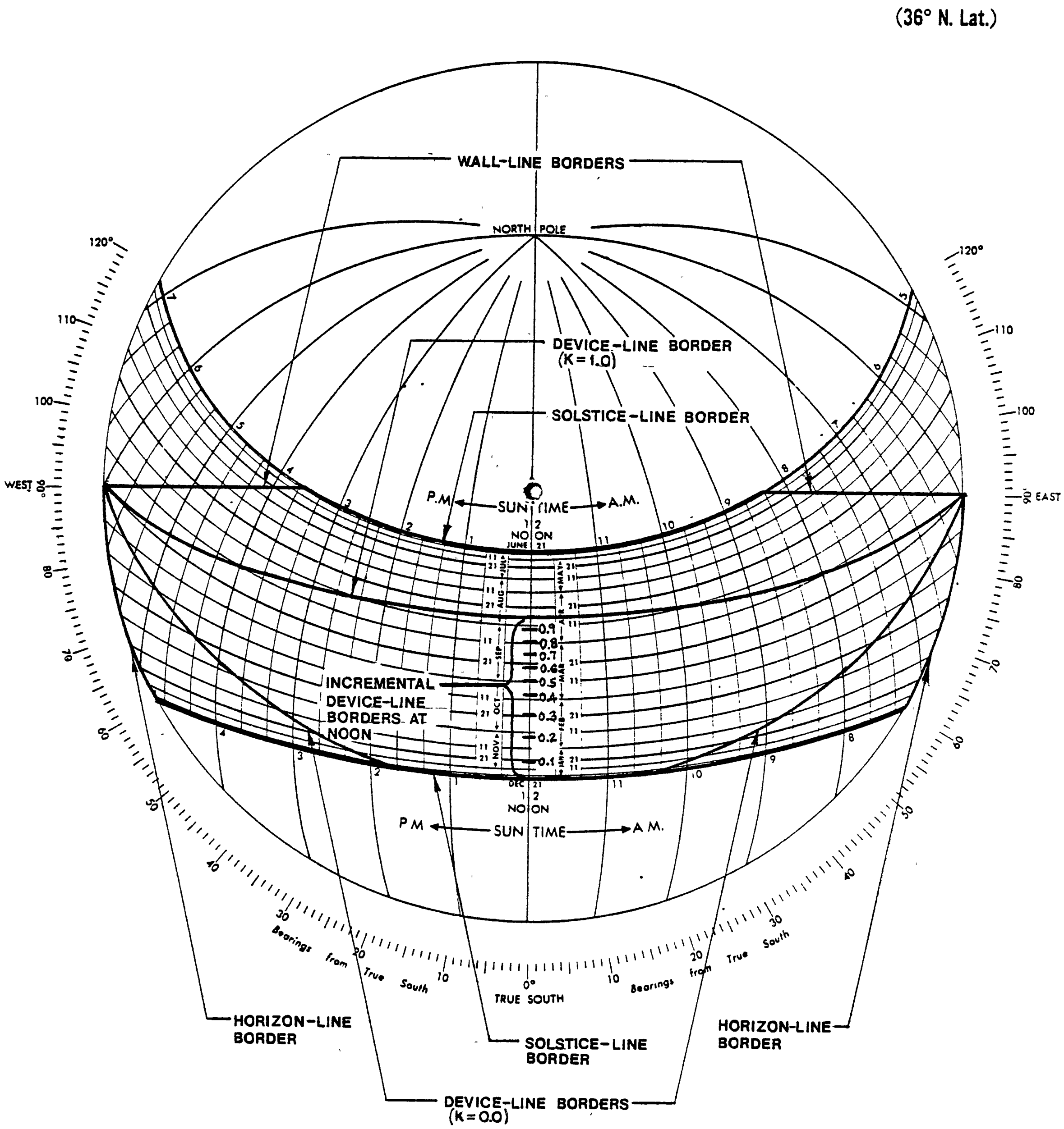


Figure 50. Incremental Shading Mask on Equidistant Sun-Path Diagram

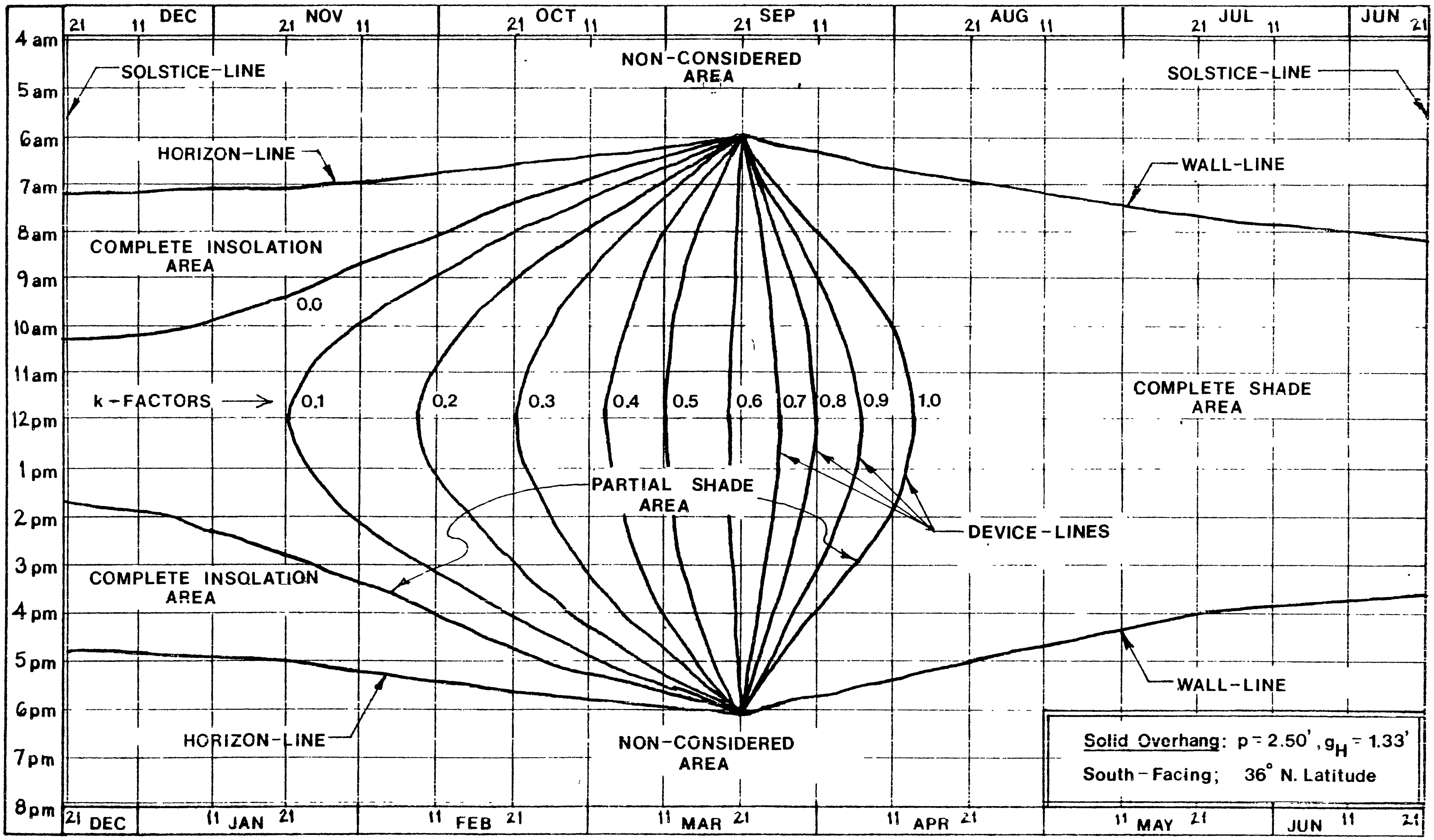


Figure 51. Timetable With Incremental Shading Mask

blank timetable is shown in Appendix C, Figure 60. The purpose of transferring the shading mask from a sun-path diagram to a timetable is to allow space for plotting ΔT's in Step Five.

From Figure 51, four distinct areas are formed by the borders of the shading mask:

1. complete shade* area,
2. complete insolation* area,
3. partial shade* area, and
4. non-considered area.

Step Three: Estimate Hourly Temperatures

Having determined the incremental shading mask for a selected shading device, approximate hourly temperatures are determined for the areas within the shading mask borders. Using the form in Appendix C, Figure 61, approximate hourly temperatures are found by first finding average maximum and minimum temperatures for the 1st, 11th and 21st of each month. By subtracting the minimum temperature from the maximum temperature, the average daily temperature range is found. By multiplying the daily range by an S-Factor (the fraction of daily range for a specific hour), and adding the product to the date's minimum temperature, the approximate hourly temperatures are found:

$$T = T_{min} + S(R) \tag{5.1}$$

where

T = approximate hourly temperature,

T_{min} = minimum temperature,

S = S-Factor; fraction of daily range, and

R = daily range.

S-Factors are determined from Figure 52, assuming the highest temperature of the day to be at 2:00 p.m. and the lowest temperature of the day to be at 6:00 a.m. (30). Figure 53 shows a completed form for Oklahoma City.

It should be noted that the values of Figure 53 relate to a residence in Oklahoma City with continual occupancy, so apparent solar time can be used directly. However, if the calculations were done for a building with set operation starting and closing times, apparent solar time (AST) would need to be converted to local standard time (LST) using Equation (5.2) (3).

$$LST = AST - ET - 4(LSM - LON) \tag{5.2}$$

where

ET = equation of time, minutes of time,

LSM = local standard time meridian, degrees of arc,

LON = local longitude, degrees of arc, and

4 = minutes of time required for 1.0 degree rotation of earth.

If daylight savings time is applied, then one hour should be added to LST during summer months.

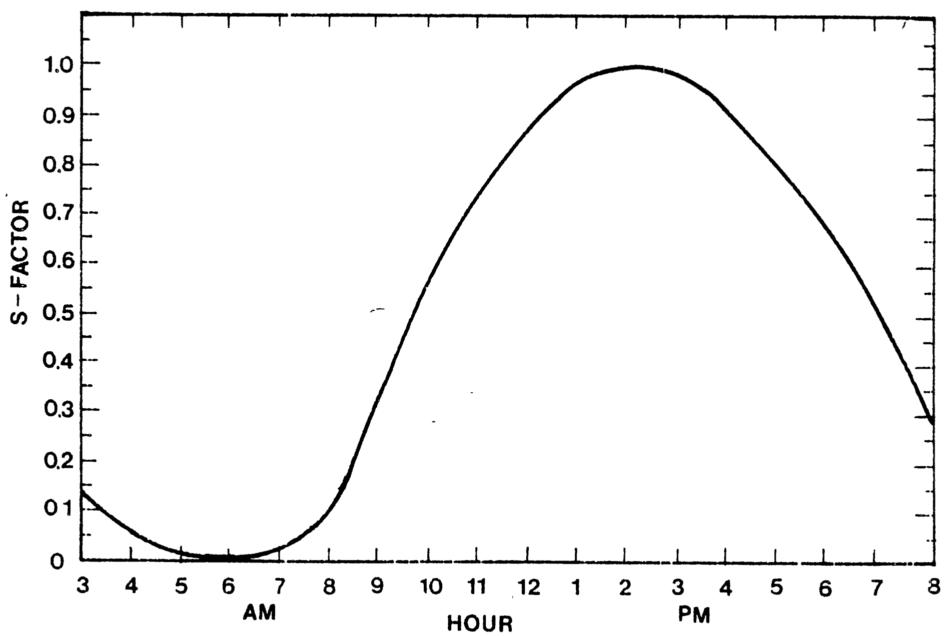


Figure 52. Relationship of S-Factor to Daytime Hours (30)

MONTH / TIME	S	J 1	J 11	J 21	F 1	F 11	F 21	M 1	M 11	M 21	A 1	A 11	A 21	M 1	M 11	M 21	J 1	J 11	J 21
T_{max}		47	46	45	46	47	47	51	54	58	64	69	75	77	80	82	84	87	89
T_{min}		27	26	25	27	28	30	32	35	37	43	48	54	56	58	60	63	66	69
RANGE		20	20	20	19	19	17	19	19	21	21	21	21	21	22	22	21	21	20
TIME	S	APPROXIMATE HOURLY TEMPERATURES																	
4 am	0.056																		
5 am	0.019																		
6 am	0.0																		
7 am	0.029					29	30	33	36	38	44	49	55						
8 am	0.111	29	28	27	29	30	32	34	37	39	45	50	56	58	60	62	65	68	71
9 am	0.315	33	32	31	33	34	35	38	41	44	50	55	61	63	65	67	70	73	75
10 am	0.583	39	38	37	38	39	41	43	46	49	55	60	66	68	71	73	75	78	81
11 am	0.726	42	41	40	41	42	42	46	49	52	58	63	69	71	74	76	78	81	84
12 am	0.861	44	43	42	43	44	45	48	51	55	61	66	72	74	77	79	81	84	86
1 pm	0.968	46	45	44	45	46	46	50	53	57	63	68	74	76	79	81	83	86	88
2 pm	1.0	47	46	45	46	47	47	51	54	58	64	69	75	77	80	82	84	87	89
3 pm	0.979	47	46	45	46	47	47	51	54	58	64	69	75	77	80	82	84	87	89
4 pm	0.917	45	44	43	44	45	46	49	52	56	62	67	73	75	78	80			
5 pm	0.814				42	43	44	47	50	54	60	65							
6 pm	0.694																		
7 pm	0.522																		
8 pm	0.444																		

MONTH / TIME	J 1	J 11	J 21	A 1	A 11	A 21	S 1	S 11	S 21	O 1	O 11	O 21	N 1	N 11	N 21	D 1	D 11	D 21
T_{max}	90	91	92	92	91	90	88	85	83	79	76	72	67	61	56	53	51	48
T_{min}	70	71	72	70	69	67	66	64	63	59	55	51	46	41	36	33	31	28
RANGE	20	20	20	22	22	23	22	21	20	20	21	21	21	20	20	20	20	20
TIME	APPROXIMATE HOURLY TEMPERATURES																	
4 am																		
5 am																		
6 am																		
7 am							67	65	64	60	56	52	47	42	37			
8 am	72	73	74	72	71	69	68	66	65	61	57	53	48	43	38	35	33	30
9 am	76	77	78	77	76	74	73	71	69	65	62	58	53	47	41	39	37	34
10 am	82	83	84	83	82	80	79	76	75	71	67	63	58	53	48	45	43	40
11 am	85	86	87	86	85	83	82	79	78	74	71	66	61	51	51	48	46	43
12 am	87	88	89	89	88	87	85	82	80	76	73	69	64	58	53	50	48	45
1 pm	89	90	91	91	90	89	87	84	82	78	75	71	66	60	55	52	50	47
2 pm	90	91	92	92	91	90	88	85	83	79	76	72	67	61	56	53	51	48
3 pm	90	91	92	92	91	90	88	85	83	79	76	72	67	61	56	53	51	48
4 pm				90	89	88	36	83	81	77	74	70	65	59	54	51	49	46
5 pm				88	87	86	84	81	79	75	72	68	63	57	52	49	47	44
6 pm																		
7 pm																		
8 pm																		

DEMARCATION LINE BETWEEN OVERHEATED AND UNDER-HEATED PERIODS

USED IN EXAMPLE

Figure 53. Approximate Hourly Temperatures for Oklahoma City

<u>Step Four: Determine Overheated and Underheated Periods Based on T_b</u>

By using Equation (2.1), building balance point temperature* is determined, which is used as the demarcation temperature between the overheated period, when shading is desired, and the underheated period, when insolation is desired.

<u>Step Five: Plot Overheated and Underheated ΔT's on Timetable</u>

Figures 54 and 55 show overheated and underheated temperature differences on two separate timetables. An overheated temperature difference (ΔT_o) is determined by subtracting the building balance point temperature (T_b) from hourly temperatures (T) greater than T_b. An underheated temperature difference (ΔT_u) is determined by subtracting hourly temperatures (T) less than T_b from the building balance point temperature (T_b). ΔT_o and ΔT_u are found using Equations (5.3) and (5.4).

$$\Delta T_o = T - T_b \tag{5.3}$$

$$\Delta T_u = T_b - T_u \tag{5.4}$$

Because the date line is the same for a pair of conjugate dates, two ΔT's may be plotted at one point, indicating that shading or insolation is desired for both conjugate dates at that point.

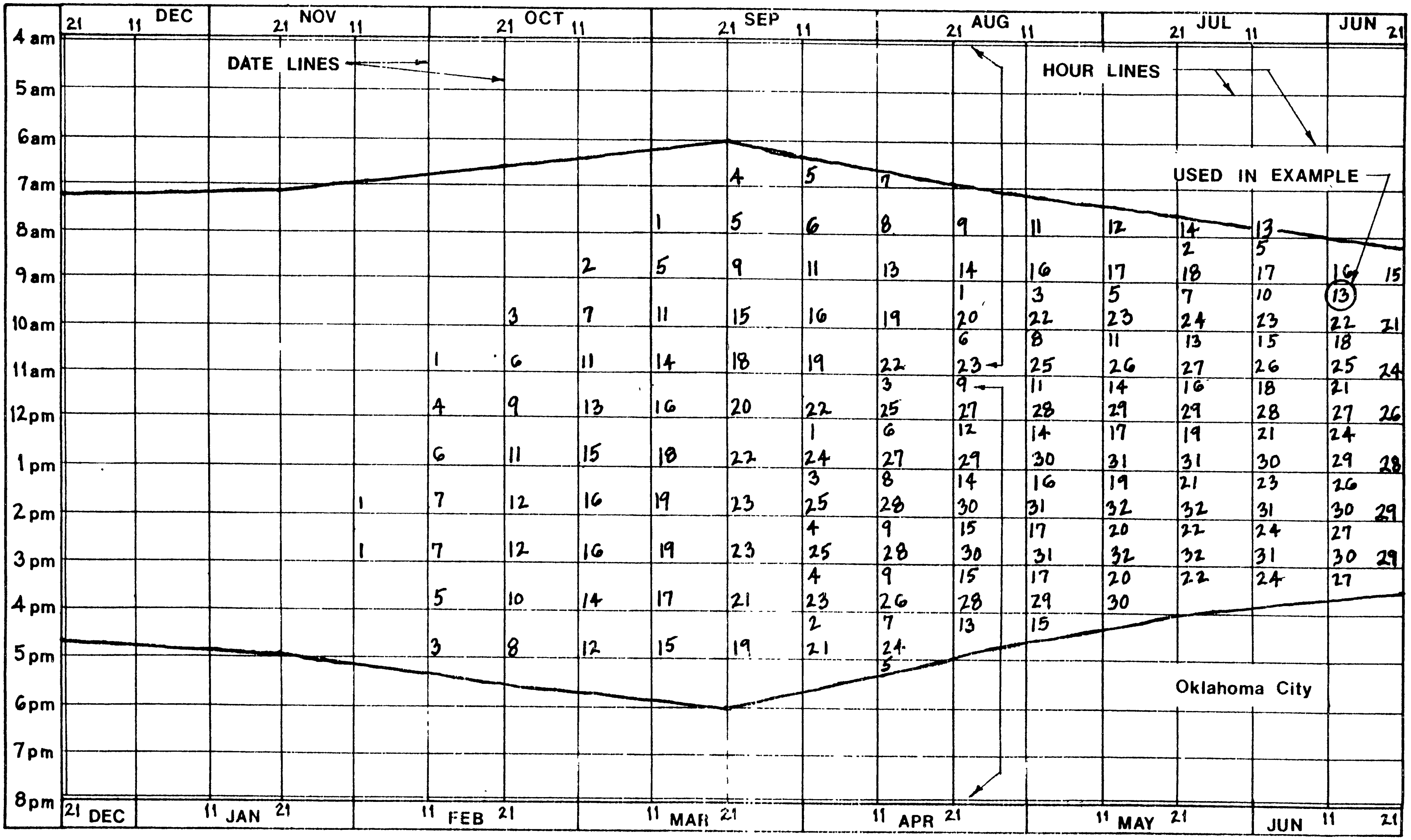


Figure 54. Overheated ΔT's Plotted on a Timetable for Oklahoma City

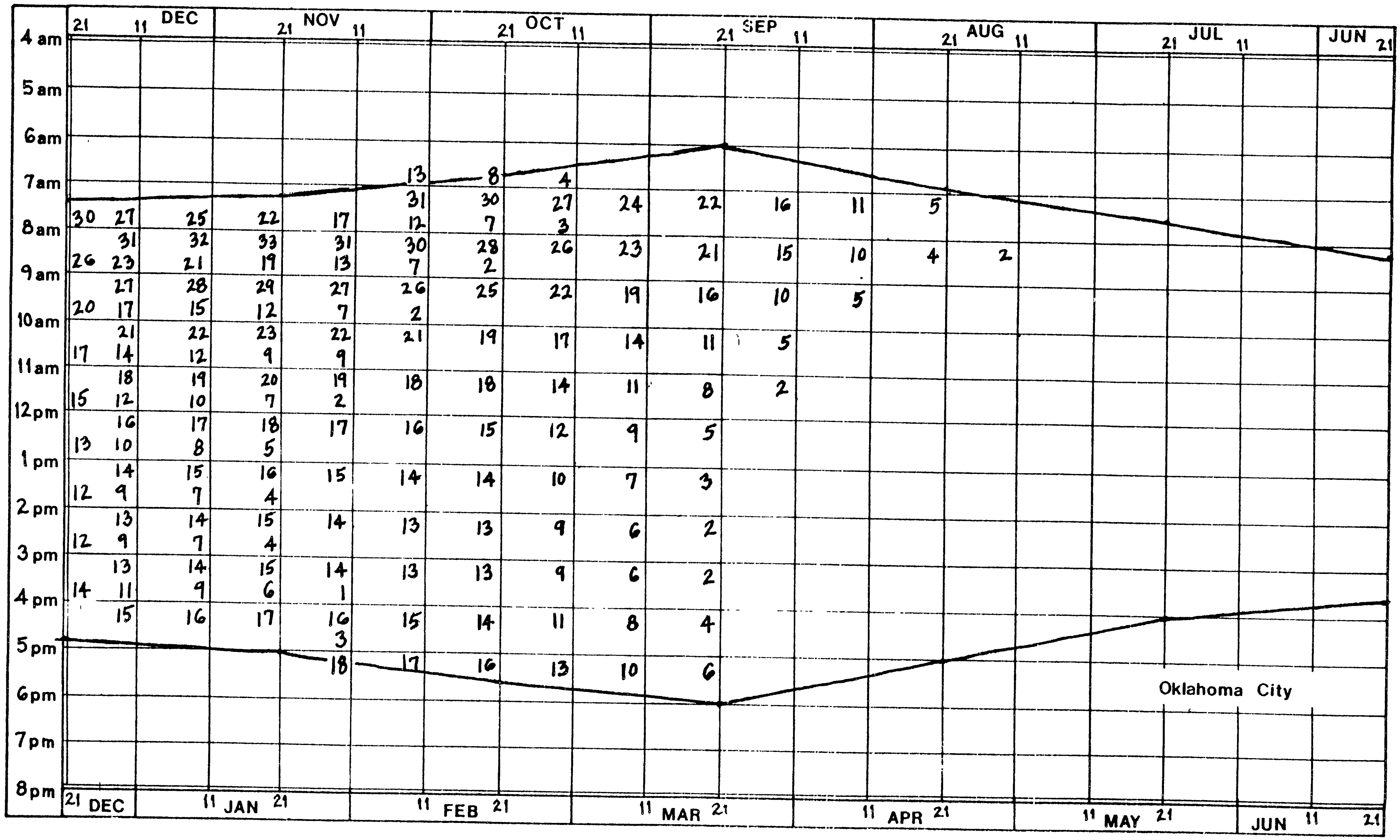


Figure 55. Underheated ΔT's Plotted on a Timetable for Oklahoma City

Step Six: Calculate Overheated and Underheated ΔT-Effectiveness

To calculate the overheated ΔT-effectiveness (ε_o) of a shading device, Equation (5.5) is used:

$$\varepsilon_o = \Sigma(\Delta T_o k) / \Sigma(\Delta T_o) \qquad (5.5)$$

where

$\Sigma T_o k$ = sum of the differences between all overheated temperatures and the balance point temperature, multiplied by the fraction of a window in shade, (k), related to each overheated temperature.

ΣT_o = sum of the differences between all overheated temperatures and the balance point temperature.

To calculate the underheated ΔT-effectiveness (ε_u) of a shading device, Equation (5.6) is used:

$$\varepsilon_u = \Sigma(\Delta T_u(1 - k)) / \Sigma(\Delta T_u) \qquad (5.6)$$

where

$\Sigma(\Delta T_u(1 - k))$ = sum of the differences between all underheated temperatures and the balance point temperature, multiplied by the fraction of a window in sun, (1 - k), related to each underheated temperature.

$\Sigma(\Delta T_u)$ = sum of the differences between all underheated temperatures and the balance point temperature.

Step Seven: Calculate Annual ΔT-Effectiveness

To calculate the annual ΔT-Effectiveness (ε) of a shading device, Equation (5.7) is used:

$$\varepsilon = [\varepsilon_o + n(\varepsilon_u)]/(1 + n) \quad (5.7)$$

where

n = weighting factor to balance the importance of summer shading and winter insolation.

The value of n varies according to the location of the building, since the importance of summer shading related to winter insolation depends on one or more of the following (suggested by Jones):

1. fuel consumption in summer versus winter,
2. dollar cost of fuel(s) consumed, and
3. subjective measures of the desired balance, such as the inconvenience or discomfort of underheating relative to undercooling (28).

If Olgyay's general assumption that "shading at overheated times is twice as important as heat gain during the underheated period" is applied to Equation (5.7), then = 0.5 (1, p. 64). However, n changes according to the above factors and, as a general guide, if $n = 1.0$, the importance of summer shading is the same as winter insolation. If $n>1$, winter insolation is more important than summer shading. If $n<1$, winter insolation is less important than summer shading. Determination of exact values of n are beyond the scope of this study, and worthy of future research.

Because exact values of n are not well established, the annual ΔT-effectiveness of shading devices in different geographical locations cannot be compared. However, comparisons can be made of ΔT-effectiveness for shading devices in the same location, since n remains constant.

Example Problem

To illustrate the use of the ΔT-effectiveness method, an example problem of an overhang over a south-facing window for a house in Oklahoma City, Oklahoma ($35^{o}20'$ N. latitude) is presented. The overhang has a projection length of 2.50 ft. (p = 2.50) and is 1.33 ft. above a 3.50 ft. window. The overhang dimensions are chosen using the rule-of-thumb by the Small Homes Council of the University of Illinois (6). It is assumed that the overhang extends well past the sides of the window, and that no surrounding buildings or objects obstruct the sun's direct rays from striking the window. The house balance point temperature is assumed to be 60F. Determine the overheated, underheated and annual ΔT-effectiveness of the shading device.

Step One: Construct an Incremental Shading Mask on a Sun-Path Diagram

To plot the device-lines of an incremental shading mask for horizontal shading devices, the profile angle between the sun and the window is determined for the window 100 percent shaded (k = 1.0), 90 percent shaded (k = 0.9), ... and so on to zero percent shaded (k = 0.0), by using Equation (3.2) and dimensions from Figure 56. For

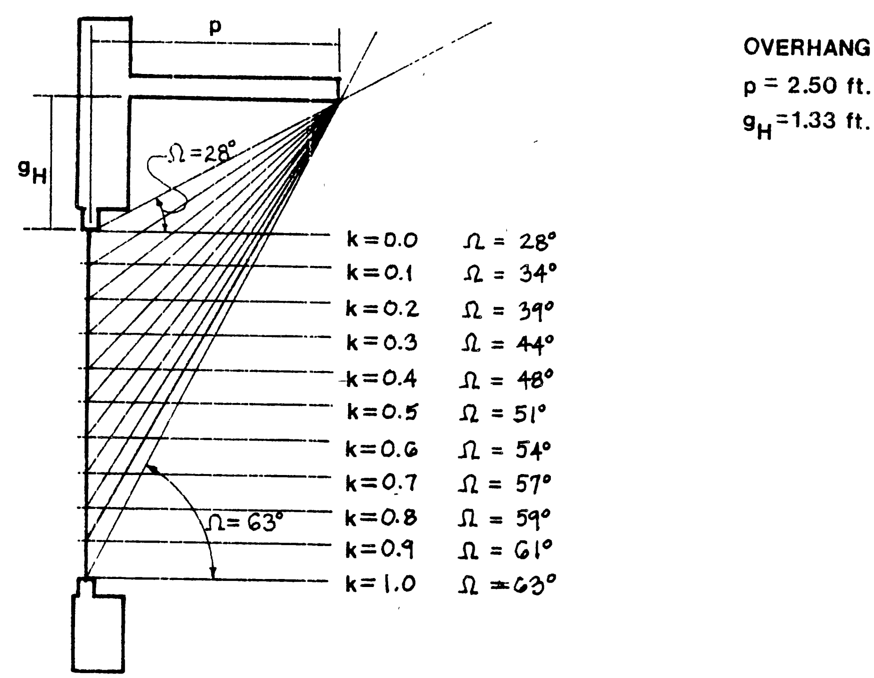


Figure 56. Dimensions and Profile Angles for Example Problem

clarity, only the 100 percent and zero percent device-lines are fully plotted on Figure 50. The device-lines from k = 0.1 to 0.9 are shown only as dashes on the noon hour-line.

By referring to Figure 50, it can be seen that the solstice-line borders extend from 10:20 a.m. to 1:20 p.m. on December 21, and from 8:20 a.m. to 3:40 p.m. on June 21. Wall-line borders extend linearly from 6:00 a.m. on March 21 to 8:20 a.m. on June 21, and from 3:40 p.m. on June 21 to 6:00 p.m. on March 21. Horizon-line borders extend from 6:00 a.m. on March 21 to 8:15 a.m. on December 21, and from 4:45 p.m. on December 21 to 6:00 p.m. on March 21. Since it is assumed that no buildings or objects obstruct the sun's rays from the window, the horizon-line borders are equivalent to the sky-line borders. Had there been surrounding buildings or other objects obstructing the sun's rays, the procedure outlined by Mazría in determining the sky-line of a location would have been applied (7).

Step Two: Transfer Incremental Shading Mask to Timetable

Figure 51 shows the incremental shading mask for the shading device on a timetable. Figure 51 is used to determine the k-factors that affect the ΔT's of Step Five.

Step Three: Estimate Hourly Temperatures

From climatological data in reference (6) for Oklahoma City, the minimum and maximum temperatures for the 21st of each month are recorded in the top two rows of Figure 53. T_{max} and T_{min} for the 1st and 11th of each month are interpolated. Many sources provide climatological data; if TMY data is used, hourly temperatures would not need to be estimated by the procedure outlined in this step; however, most sources of climatological data that are readily available to designers provide temperatures on a monthly basis and approximate hourly temperatures must be estimated. The hours that are not included in the estimates are the hours during the year that the sun is either below the horizon or behind the wall of the window to be shaded.

As an example, T_{max} = 87F and T_{min} = 66F on June 11, therefore, R = 87 - 66 = 21F. From Equation (5.1), T = 66 + (.315)(21) which is 73F (circled in Figure 53).

Step Four: Determine Overheated and Underheated Periods Based on T_b

For this problem, the building balance point temperature is assumed to be 60F, and serves as the demarcation temperature for which the overheated and underheated ΔT's are divided in Figure 53 (bold line).

Step Five: Plot Overheated and Underheated ΔT's on Timetable

By using Equation (5.3), the difference between approximate hourly overheated temperature and the balance point temperature of 60F is calculated for the overheated period and plotted by the correct date and hour of Figure 54. For example, the overheated temperature of 73F at 9:00 a.m. on June 11 (circled on Figure 53) is 13F above the balance temperature of 60F. Therefore, 13F is plotted just below and to the right of the intersection of the date and hour lines for June 11 at 9:00 a.m. (circled on Figure 54). It should be noted that since June 1 and June 11 are conjugate dates, the date-line for each is the same, so the ΔT of 16F located just above the ΔT of 13F (circled) represents the temperature difference plotted for June 1 at 9:00 a.m. In a similar manner, using Equation (5.4), the underheated ΔT's are plotted on a separate timetable (Figure 55).

Step Six: Calculate Overheated and Underheated ΔT-Effectiveness

Summing ΔT_o's plotted on Figure 54 yields:

$$\Sigma(\Delta T_o) = 3501F$$

To determine $\Sigma(\Delta T_o k)$, each ΔT of Figure 54 is multiplied by the corresponding k-factor from the shading mask of Figure 51. All of the ΔT_o's in the "complete shade area" are unchanged since k = 1.0. (If all ΔT_o's were in the "complete shade area", the overheated ΔT-effectiveness (ε_o) would be 100 percent). The ΔT_o's in the "partial shade area" are multiplied by the k-factors of Figure 51. For example, on September 21 at 12 noon, ΔT_o = 20, which is multiplied by a k-factor of 0.6 to yield 7.2F. The ΔT's in the "complete insolation area" are reduced to zero since each is multiplied by k = 0.0.

Summing $\Delta T_o k$'s yields:

$$\Sigma(\Delta T_o k) = 2722F$$

Using Equation (5.5), the overheated ΔT-effectiveness (ε_o) is found to be:

$$\Sigma(\Delta T_o k)/\Sigma(\Delta T_o) = 2722/3501 = 0.78, \text{ or } 78 \text{ percent.}$$

In a similar manner, the underheated ΔT-effectiveness (ε_u) is determined using ΔT_u's from Figure 55 and (1 - k) instead of k from Figure 51. From Equation (5.6):

$$\Sigma(\Delta T_u(1 - k))/\Sigma(\Delta T_u) = 1953/2237 = 0.87, \text{ or } 87 \text{ percent.}$$

<u>Step Seven</u>: <u>Calculate Annual ΔT-Effectiveness</u>

From Equation (5.7), and ε_o and ε_u determined in Step Six, the annual ΔT-effectiveness for the overhang shown in Figure 56 is found. Arbitrarily using Olgyay's value of 0.5 for n:

$$\varepsilon = [0.78 + (0.5)(0.87)]/(1 + 0.5) = 0.81, \text{ or } 81 \text{ percent.}$$

If, however, a value of 1.0 for n is used, then the results would be:

$$\varepsilon = [0.78 + (1.0)(0.87)]/(1 + 1.0) = 0.83, \text{ or } 83 \text{ percent.}$$

Comparison of ΔT-Effectiveness Method for Various Devices

Knowing ε_o, ε_u and ε for a shading device is most valuable when compared with similar values for other shading devices for the same window. Table XV compares the results of the example problem (for n = 0.5) to the results for an overhang with p = 2.5 ft. and $g_H = 0$, and for no shading device (wall depth to window plane is assumed equal to 0.38 ft.). Shading masks for these two additional shading schemes are shown in Figures 57 and 58.

TABLE XV

COMPARISON OF ΔT-EFFECTIVENESS RESULTS FOR VARIOUS SHADING DEVICES OF EXAMPLE PROBLEM

Type of Device	ε_o	ε_u	ε
Overhang with p = 2.50 ft. and g_H = 1.33 ft.	.78	.87	.81
Overhang with p = 2.50 ft. and g_H = 0.	.95	.63	.84
No shading device; assume wall depth to window plane = 0.38 ft. (4.5 in.)	.29	.98	.52

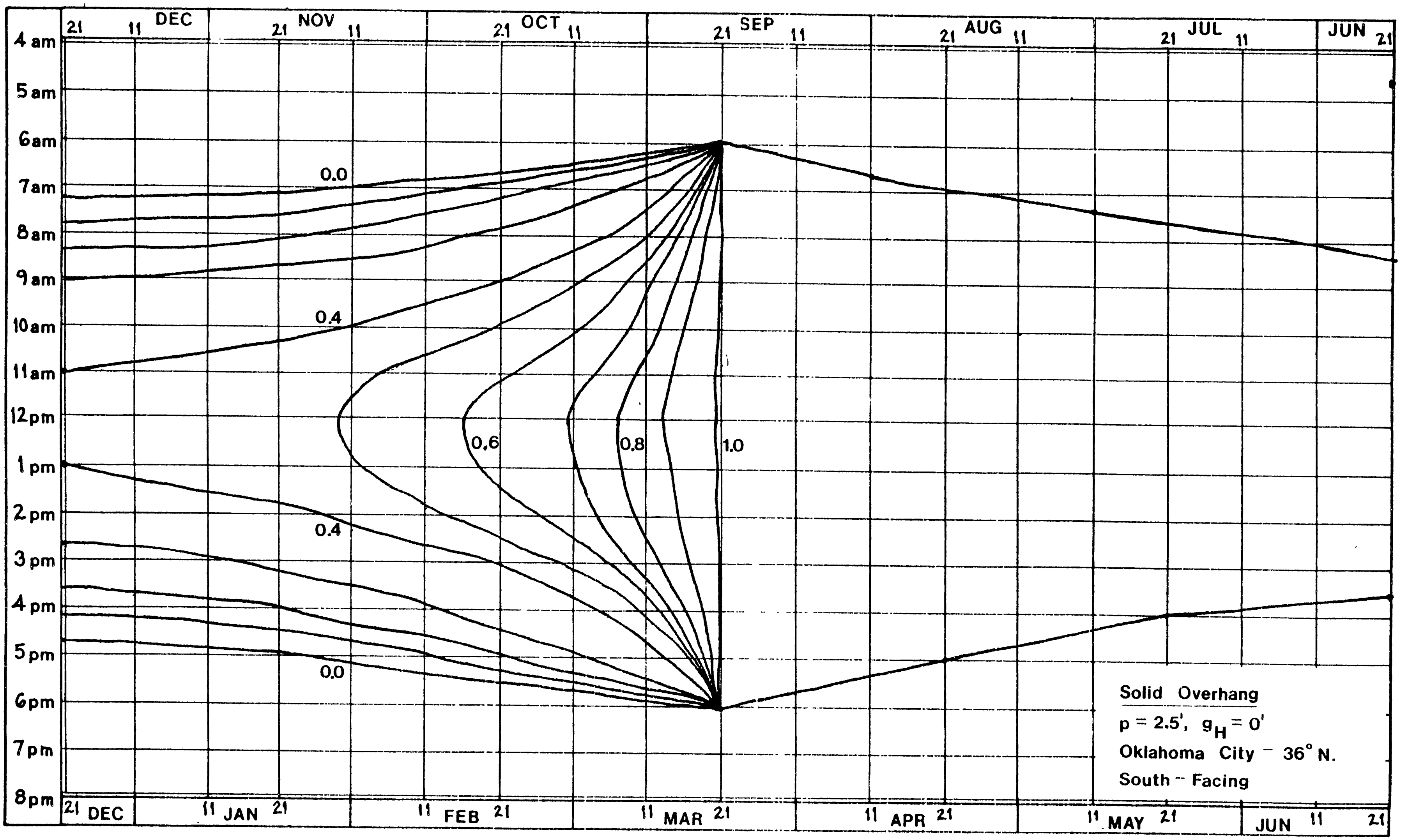


Figure 57. Timetable With Incremental Shading Mask for a Solid Overhang (p = 2.5 ft. and g_H = 0 ft.)

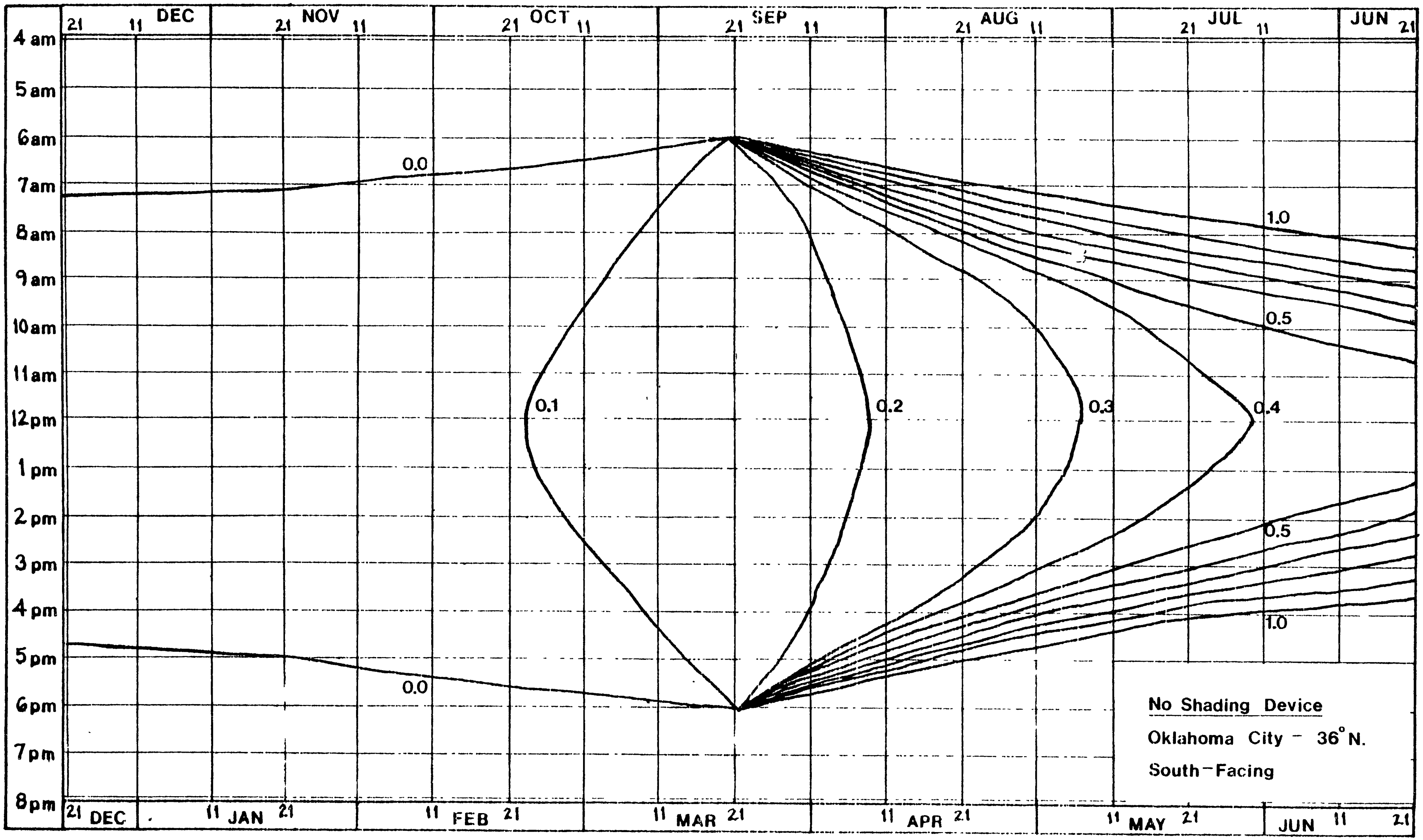


Figure 58. Timetable With Incremental Shading Mask for No Shading Device on a South-Facing Window

It can be seen from Table XV that even though the overhang with no separation height has a much lower ε_u than the overhang with a separation height of 1.33 ft., ε is about 3 percent higher for the overhang with no separation height. If, however, the value of 1.0 for n were used in Equation (5.7) (recalling that when $n = 1.0$, summer shading and winter insolation are considered equally important), ε would be about 3 percent higher for the overhang with a separation height of 1.33 ft.

Remarks

In its present form, the ΔT-effectiveness method presented in this chapter is most useful for evaluating and comparing rather than for designing shading devices. As the user becomes more familiar with how shading masks are affected by adjustments in shading device dimensions and configurations, he is more able to work backward through the method to intelligently estimate proper shading device dimensions. For instance, by scanning the overheated and underheated ΔT's of Figures 54 and 55, one can get an idea of how many days shading is desired in the summer and how many days insolation is desired in the winter. If the desired shading device is an overhang over a south-facing window, N_o and N_u can then be estimated and used in Equations (3.6) and (3.7) of Chapter III to find a projection length and separation height.

If adapted for computer use ε, ε_o, and ε_u could be quickly calculated based on more accurate estimates of hourly temperatures using TMY data. An unlimited array of fixed, exterior shading devices for any orientation, geographical location, and building type could be easily compared. However, as noted earlier, if shading devices for different geographical locations are to be compared, more research to determine n must be done.

A flowchart suggesting application of the ΔT-effectiveness method to a computer program is provided in Appendix D.

CHAPTER VI

CONCLUSIONS

Summary of Findings

This study developed a method for evaluating the annual effectiveness of fixed, exterior shading devices using approximate hourly temperatures, building balance point temperature, and a factor directly related to the percent-shade of a window. The method takes into account both summer shading and winter insolation, and results in an overheated ΔT-effectiveness (ε_o), an underheated ΔT-effectiveness (ε_u), and an annual ΔT-effectiveness (ε). As background in developing the method, a general procedure for assessing shading needs, and guidelines for evaluating the overall effectiveness of eight types of fixed, exterior shading devices was presented. Existing latitude-based and climate-based methods for determining recommended projection lengths were analyzed to determine how each method addresses the problems of balancing summer shading and winter insolation, and balancing spring insolation with late summer shading.

It was determined that the ΔT-effectiveness method is most useful in evaluating and comparing, rather than designing fixed, exterior shading devices applied to a building in a particular geographical location for any orientation. However, by working through the method backward, a designer could determine a rough approximation of a recommended projection length and separation height for a shading device.

Analysis of existing latitude-based methods showed major differences in assumptions concerning the recommended number of days that shading is desired in the summer. Equations (3.6) and (3.7), summarizing the latitude-based methods, were developed to aid designers in calculating the projection length and separation height of an overhang over a south-facing window, based on the number of days from the summer solstice that complete shade is desired, and the number of days from the winter solstice that complete insolation is desired.

Analysis of existing climate-based methods showed much contrast between the methods with respect to resulting information, applicable orientations, demarcation temperature, consideration of building characteristics, dependency on temperature versus radiation, and method format.

Recommendations for Future Study

In the development of the ΔT-effectiveness method, the necessity of quantitatively expressing the relative importance of shading in summer versus the importance of allowing insolation in winter for various locations became readily apparent in calculations of annual ΔT-effectiveness (ε). At this point, only intuitive estimates can be used.

The ΔT-effectiveness method could be enhanced greatly by the development of a computer program based on the flow-chart in Appendix D. Not only could ε, ε_o, and ε_u be calculated more quickly and sensitively, resulting in more comparisons between shading devices, but with enough calculations and computer runs, results could be determined and published for an unlimited number of locations and shading devices. Such a publication would be a helpful and ready reference for designers.

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APPENDICES

APPENDIX A

UNIT CONVERSION FACTORS

The conversion factors used in this study to convert from SI (Systeme International) to English Units are listed below. The primary source for these conversion factors is Chapter 37 of ASHRAE Handbook-1981 Fundamentals (3). Another source is Chapter 1 of Passive Solar Design Analysis (27).

Area

$1\ ft^2 = 9.290304 \times 10^{-2}\ m^2$

Energy

$1\ Btu = 1.055056 \times 10^3 J$

Energy Flux

$1\ Btu/ft^2 = 1.135653 \times 10^4\ J/m^2$

$1\ Btuh/ft^2 = 3.154591\ W/m^2$

$1\ Btu/(ft^2\ day) = 2.718499\ kcal/(m^2\ day)$

$1000\ Btu/(ft^2\ day) = 1.135653 \times 10^1\ MJ/(m^2\ day)$

LCR (Load Collector Ratio)

$1\ Btu/(^oF\ day\ ft^2) = 20.4\ kJ/(^oC\ day\ m^2)$

Temperature

$^oF = {^oC}(1.8) + 32$

APPENDIX B

DERIVATION OF EQUATIONS (3.6) AND (3.7)

The relative projection length of an overhang, $\tilde{p}$, and the relative separation height, $\tilde{g}$, are expressed as:

$$\tilde{p} = p/w_H \qquad (B.1)$$

$$\tilde{g} = g_H/w_H \qquad (B.2)$$

where

p = projection length,

g_H = separation height, and

w_H = window height (24).

Figure 59 shows p, g_H and w_H, and their relation to the overheated profile angle, Ω_o, and the underheated profile angle, Ω_u.

Utzinger expresses the relative projection length and relative separation height as (24):

$$\tilde{p} = 1/(\tan \Omega_o - \tan \Omega_u) \qquad (B.3)$$

$$\tilde{g} = \tan \Omega_u/(\tan \Omega_o - \tan \Omega_u) \qquad (B.4)$$

Combining Equations (B.1) and (B.3) yields:

$$p/w_H = 1/(\tan \Omega_o - \tan \Omega_u) \qquad (B.5)$$

or

$$p = w_H/(\tan \Omega_o - \tan \Omega_u) \qquad (B.6)$$

Combining Equations (B.2) and (B.4) yields:

$$g_H/w_H = \tan \Omega_u/(\tan \Omega_o - \tan \Omega_u) \qquad (B.7)$$

or

$$g_H = w_H \tan \Omega_u/(\tan \Omega_o - \tan \Omega_u) \qquad (B.8)$$

Since the profile angle of the sun on a south-facing window is the solar altitude angle at noon, the profile angle, Ω, may be expressed as:

$$\Omega = \sin^{-1}\left[\sin L \sin D + \cos L \cos D\right] \qquad (B.9)$$

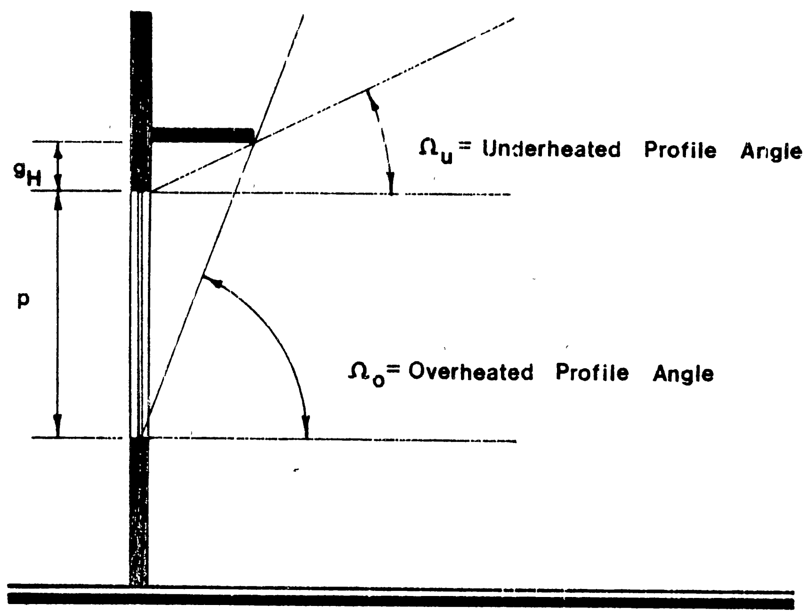


Figure 59. Illustration of the Relationship Between Overheated and Underheated Profile Angles, and Total and Separation Heights

where

L = latitude, and

D = declination (24).

The following trigonometric identity may be used to simplify Equation (B.9) (33).

$$\cos (L - D) = \sin L \sin D + \cos L \cos D \qquad (B.10)$$

So Equation (B.9) may be rewritten as:

$$\Omega = \sin^{-1}(\cos(L - D)) \qquad (B.11)$$

From trigonometry,

$$\sin^{-1}\cos(L - D) = 90 - (L - D) \qquad (B.12)$$

which allows Equation (B.11) to be simplified to:

$$\Omega = 90 - (L - D) \qquad (B.13)$$

Since declination, D, is negative from September 22 to March 20 (winter months) and positive from March 22 to September 20 (summer months), Equation (B.13) may be applied to an overheated profile angle (during summer months) and an underheated profile angle (during winter months) as follows:

$$\Omega_o = 90 - (L - D) \qquad (B.14)$$

$$\Omega_u = 90 - (L + D) \qquad (B.15)$$

Utzinger expresses the declination, D, as a function of the number of days, N, before or after the summer or winter solstice in Equation (B.16) (24):

$$D = 23.45 \cos (360(N)/365) \qquad (B.16)$$

Substituting Equation (B.16) into Equations (B.14) and (B.15) yields:

$$\Omega_o = 90 - [L - (23.45 \cos (360(N_o)/365))] \qquad (B.17)$$

$$\Omega_u = 90 - [L + (23.45 \cos (360(N_u)/365))] \qquad (B.18)$$

where

N_o = number of days from summer solstice, and

N_u = number of days from winter solstice.

Finally, substituting Equation (B.17) and (B.18) into Equations (B.6) and (B.8) yields:

$$p = w_H / \{\tan [90 - (L - 23.45 \cos (360(N_o)/365))] - \tan [90 - (L + 23.45 \cos (360(N_u)/365))]\} \quad (B.19)$$

and

$$g_H = w_H \tan [90 - (L + 23.45 \cos (360(N_u)/365))] / \{\tan [90 - (L - 23.45 \cos (360(N_o)/365))] - \tan [90 - (L + 23.45 \cos (360(N_o)/365))]\} \quad (B.20)$$

which are Equations (3.6) and (3.7).

APPENDIX C

TABLES FOR USE WITH THE ANNUAL ΔT-EFFECTIVENESS METHOD

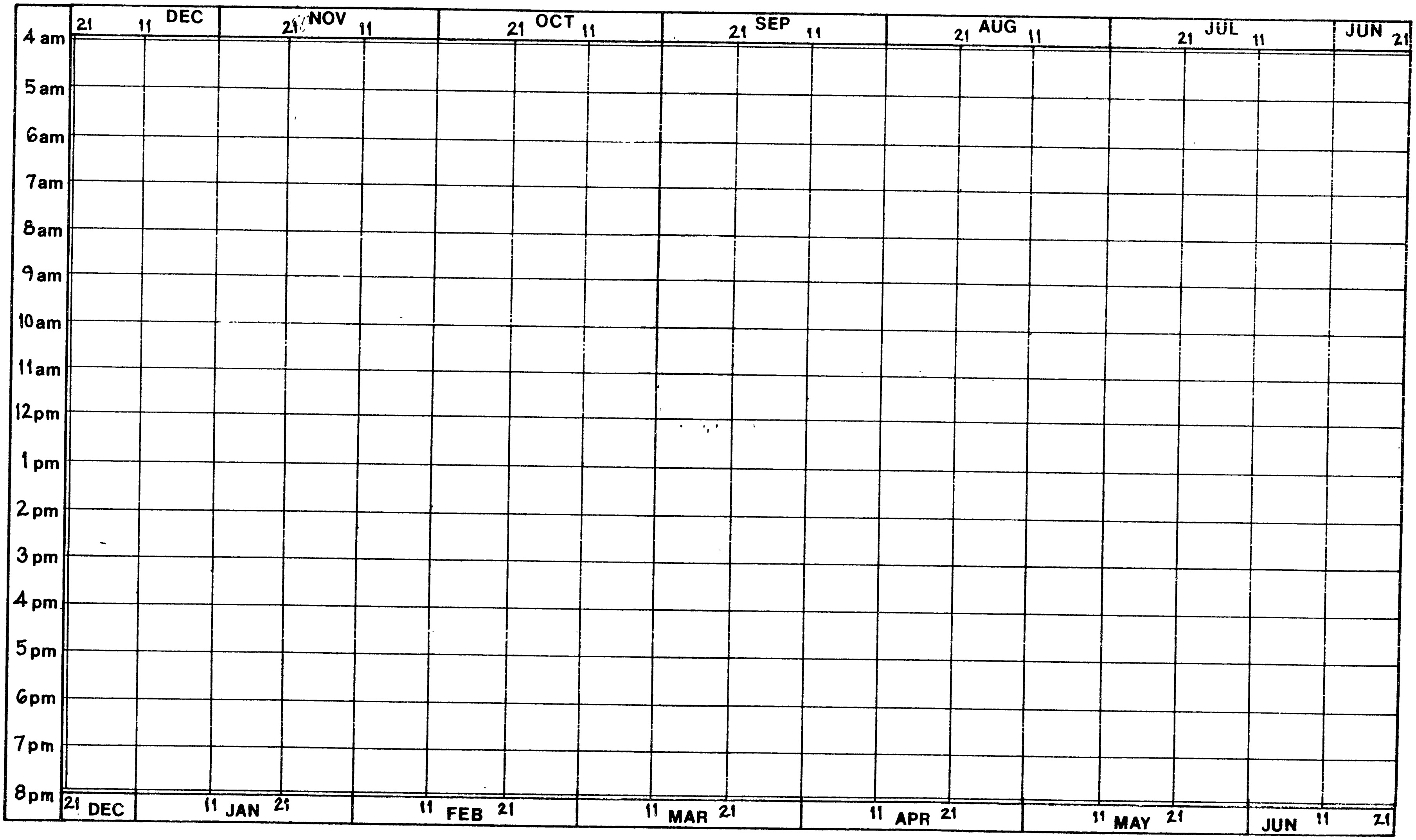


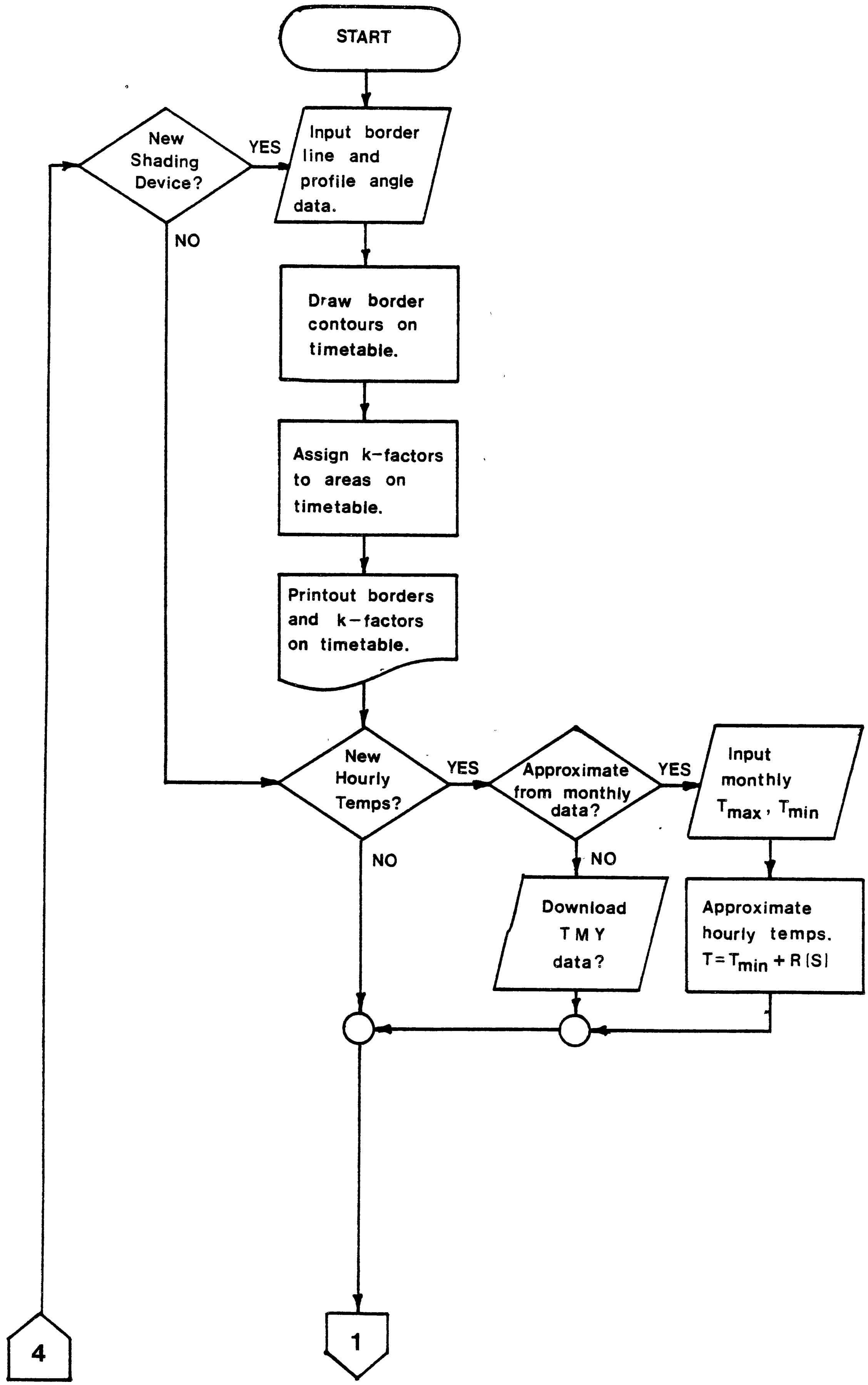
Figure 60. Timetable for Use With ΔT-Effectiveness Method

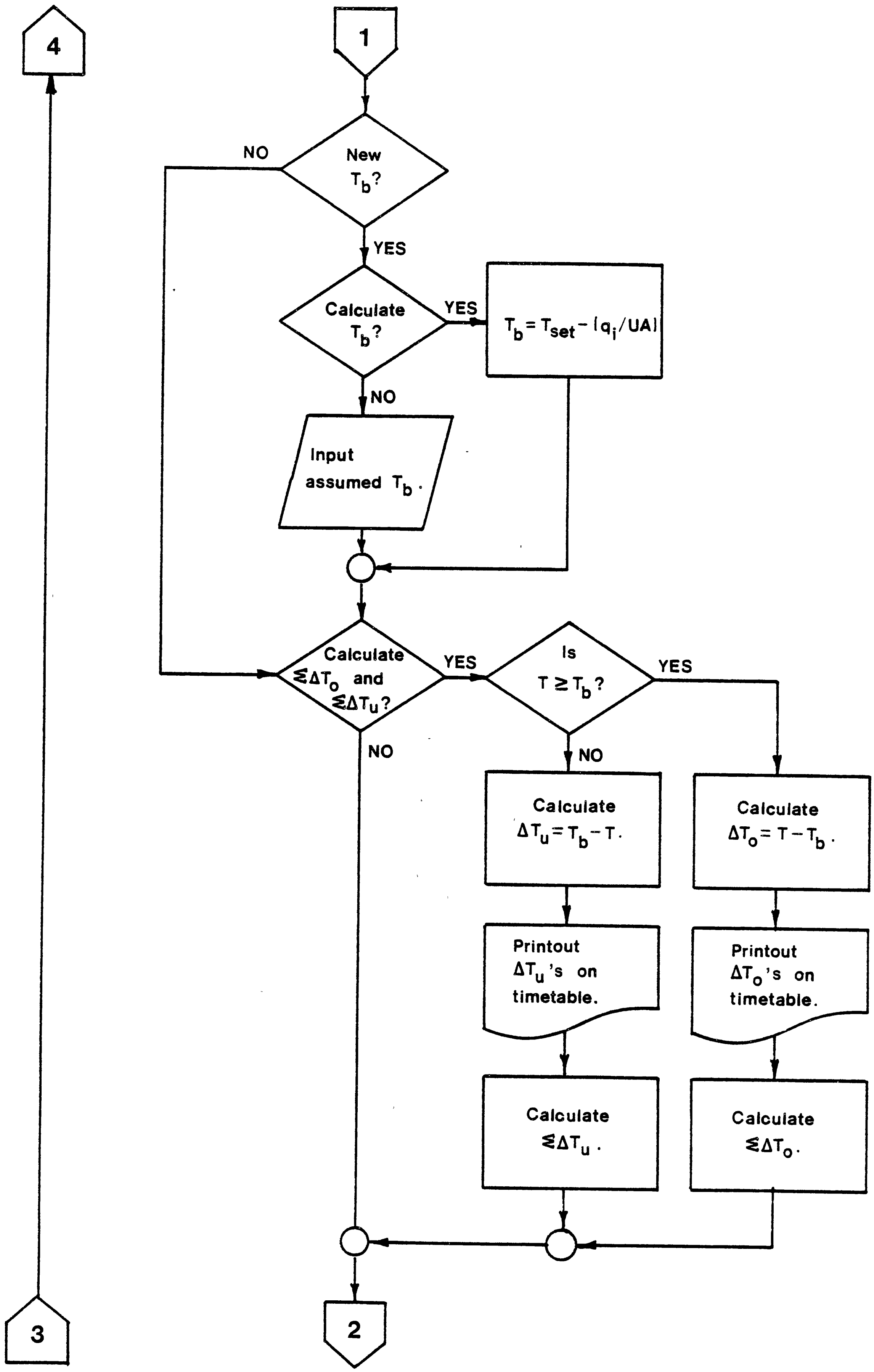
MONTH		J			F			M			A			M			J			J			A			S			O			N			D		
		1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21	1	11	21
T_{max}																																					
T_{min}																																					
RANGE																																					
TIME	S	APPROXIMATE HOURLY TEMPERATURES																																			
4 am	0.056																																				
5 am	0.019																																				
6 am	0.0																																				
7 am	0.029																																				
8 am	0.111																																				
9 am	0.315																																				
10 am	0.583																																				
11 am	0.726																																				
12 am	0.861																																				
1 pm	0.968																																				
2 pm	1.0																																				
3 pm	0.979																																				
4 pm	0.917																																				
5 pm	0.814																																				
6 pm	0.694																																				
7 pm	0.522																																				
8 pm	0.444																																				

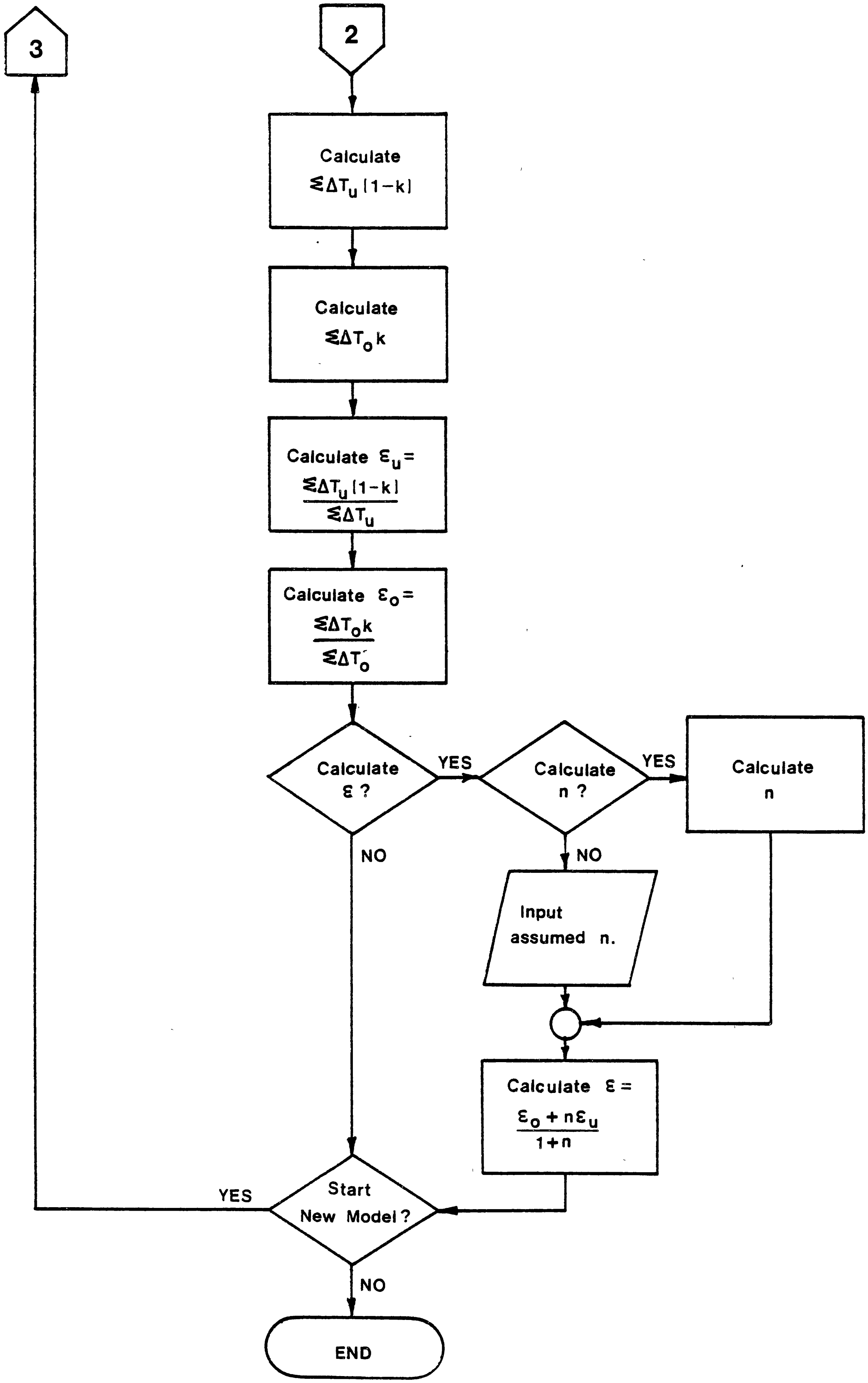
Figure 61. Table to Plot Approximate Hourly Temperatures for Use With ΔT-Effectivenss Method

APPENDIX D

ANNUAL ΔT-EFFECTIVENESS METHOD FLOWCHART


START
Input border line and profile angle data.
New Shading Device?
YES
NO
Draw border contours on timetable.
Assign k-factors to areas on timetable.
Printout borders and k-factors on timetable.
New Hourly Temps?
YES
NO
Approximate from monthly data?
YES
NO
Input monthly T_{max}, T_{min}
Download TMY data?
Approximate hourly temps. $T = T_{min} + R(S)$
4
1


4
1
NO
New T_b?
YES
Calculate T_b?
YES
$T_b = T_{set} - (q_i/UA)$
NO
Input assumed T_b.
Calculate $\Sigma\Delta T_o$ and $\Sigma\Delta T_u$?
YES
Is $T \geq T_b$?
YES
NO
NO
Calculate $\Delta T_u = T_b - T$.
Calculate $\Delta T_o = T - T_b$.
Printout ΔT_u's on timetable.
Printout ΔT_o's on timetable.
Calculate $\Sigma\Delta T_u$.
Calculate $\Sigma\Delta T_o$.
3
2


3
2
Calculate
$\Sigma \Delta T_u (1-k)$
Calculate
$\Sigma \Delta T_o k$
Calculate $\varepsilon_u = \frac{\Sigma \Delta T_u (1-k)}{\Sigma \Delta T_u}$
Calculate $\varepsilon_o = \frac{\Sigma \Delta T_o k}{\Sigma \Delta T_o}$
Calculate
ε ?
YES
Calculate
n ?
YES
Calculate
n
NO
NO
Input
assumed n.
Calculate $\varepsilon = \frac{\varepsilon_o + n\varepsilon_u}{1+n}$
YES
Start
New Model ?
NO
END

VITA

Doyle Wayne Magnus

Candidate for the Degree of

Master of Architectural Engineering

Thesis: A METHOD FOR EVALUATING THE ANNUAL EFFECTIVENESS OF FIXED, EXTERIOR SHADING DEVICES

Major Field: Architectural Engineering

Biographical:

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Education: Graduated from Del City High School, Del City, Oklahoma, in May, 1978; received Bachelor of Science degree in Architectural Studies from Oklahoma State University in May, 1982; completed requirements for the Master of Architectural Engineering degree at Oklahoma State University in December, 1984.

Professional Experience: Graduate research assistant, School of Architecture, Oklahoma State University, 1982-83; employed at BCMC Architects and Planners, summer, 1983; graduate teaching assistant, School of Architecture, Oklahoma State University, 1983-84.

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