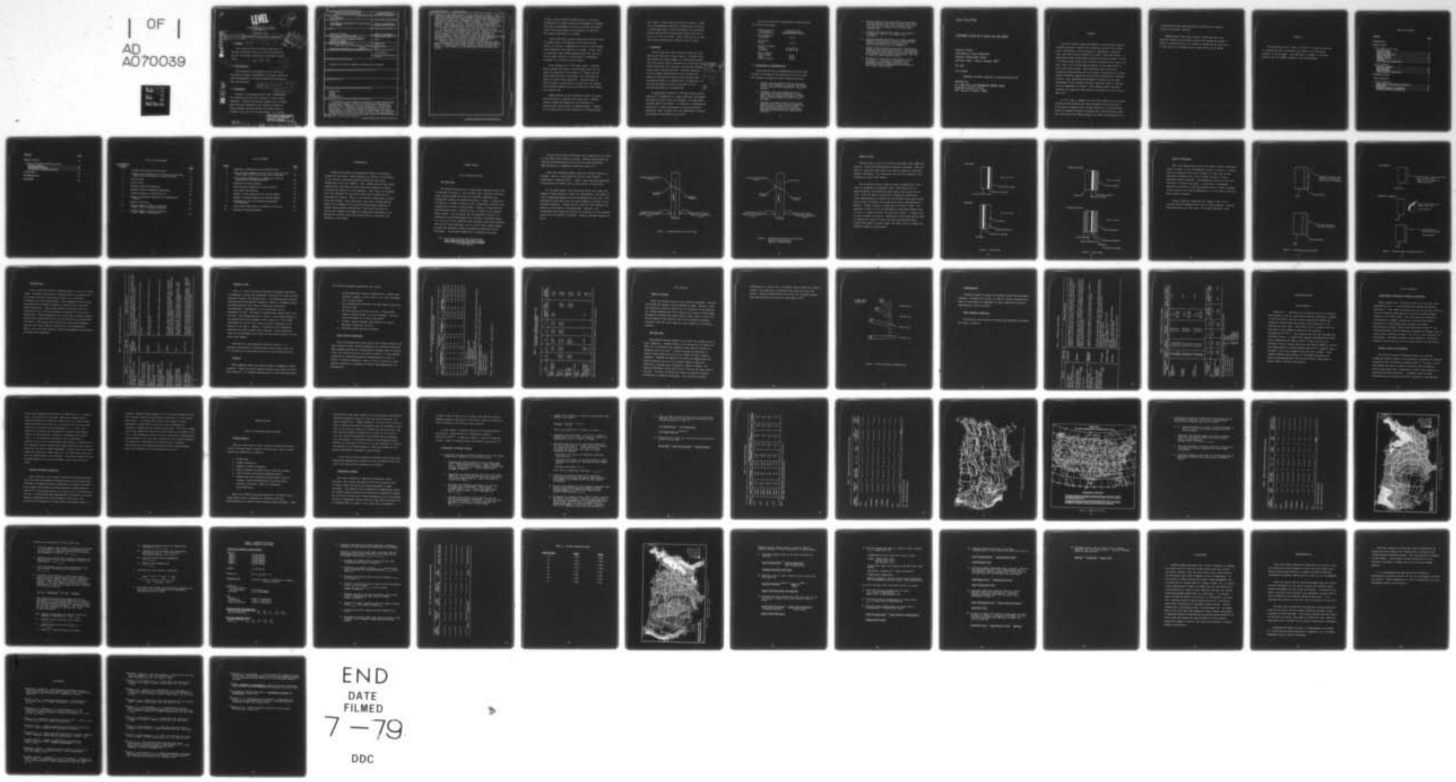
AD-A070 039 JOHNS-MANVILLE SALES CORP DENVER COLO RESEARCH AND D--ETC F/G 13/1
PERFORMANCE EVALUATION OF SOLAR FILMS AND SCREENS.(U)
APR 79 R R BISHOP DAAK70-78-D-0002

UNCLASSIFIED USAFESA-TSD-2060 NL

1 OF 1
AD
A070039



END
DATE
FILMED
7-79
DDC

CONTRACT DAAK 70-78-D-0002
TASK ORDER NO. 3

TECHNICAL NOTE

Performance EVALUATION OF SOLAR FILMS and SCREENS

Ronald R. Bishop

1.0 PURPOSE

This Technical Note provides guidelines for economic evaluation of solar films and screens for use with the Energy Conservation Investment Program (ECIP).

Final rept. 6 Jun - Sep 78,
Apr 79
71p.

2.0 APPLICABILITY

This Technical Note applies to all Facilities Engineering elements responsible for Design, Operation, and/or Maintenance of Energy Conservation Programs at Army installations.

USAFESA-TSD
2060

3.0 DISCUSSION

Windows in buildings provide light, ventilation, and communication with the outdoors for the building occupants. Concern over energy conservation in recent years has been responsible for labeling windows as energy wasters and some efforts have been taken to minimize their use in new construction. As a result

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: FESA-TS-2060	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): PERFORMANCE EVALUATION OF SOLAR FILMS AND SCREENS	5. TYPE OF REPORT & PERIOD COVERED: Final, 6/6/78-9/78
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Ronald R. Bishop	8. CONTRACT OR GRANT NUMBER(s): DAAK 70-78-D-0002
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Johns-Manville Sales Corporation, Research and Development Center, Ken-Caryl Ranch, Denver, CO 80217	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 0003
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Facilities Engineering Support Agency, Technology Support Div, Ft Belvoir VA	12. REPORT DATE: April 1979
	13. NUMBER OF PAGES: 58
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Solar film
window
Energy
Conservation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

→ The use of solar films and screens to reduce energy usage is surveyed by means of Market and Literature Surveys that provide basic information on the availability, manufacture, function, cost, and solar optical properties of solar films and screens. A simplified method of determining potential energy savings is given in a step by step format that includes consideration of solar heat gain, heat loss, and daylighting

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. aspects of the application of solar films and screens. This simplified hand calculation procedure should provide an interim means of providing the energy saving information required by the Energy Conservation Investment Program. More sophisticated methods of calculation are under development by the Lawrence Berkeley Laboratory under a contract with the Department of Energy. This computer model technique combined with empirical data should be available by mid to end of year 1979. ←

At this time, it appears that for most regions of the country flexible window shading that can be adjusted during the day or from season to season offer the most potential to saving energy. Fixed or permanent shading techniques may reduce desirable solar heat gain during the heat season and reduce daylighting into a room negating energy saving potential available by reducing interior artificial lighting.

Reducing solar heat gain through a window may have very positive benefits during summer months, but unless the shading device is flexible and can be raised or removed during the winter, it may result in increased energy usage during winter months.

of more closely directed research work, it has been determined that proper design and management of windows can lead to improvement of building energy efficiency. Solar films and screens are one method of improving the energy efficiency of a window.

Solar films are a plastic sheet which may be tinted or coated with a thin metallic film giving it the ability to reflect a substantial portion of the incident solar radiation when applied to a window. Solar films are available from several manufacturers and come in a roller shade variety or a film which is permanently attached to an interior glass surface.

Solar screens are of two basic types. Louvered metal screens have been in use for many years and are generally applied on the outside of a window and are often used much like a bug screen, but providing the ability to block solar radiation. Various types of fabric screens are available in forms that are applied like louvered screens or are available as roller shades for interior use.

Shades applied to the outside are about 15 percent more effective in reducing solar heat gain. However, interior shades are generally more effective in reducing heat loss during the heating season. Screens act to block vision to the outdoors to a greater extent than films. Screens are more durable, however. Films that are permanently applied to glass must be done by an authorized agent of the manufacturer or warranties against peeling and cracking which range from one to five years will be voided. Solar films act as a night time mirror preventing an exterior view at night.

4.0 ECONOMICS

For an individual case, energy savings will be a complicated function of many factors. Although films and screens can reduce summer air conditioning loads, they also reduce natural lighting due to daylight and reduce solar heat gain and heat loss through windows during winter heating periods. Services offered by film and screen manufacturers do not consider all aspects of the problem and are only reliable where the heating season is insignificant in comparison to the cooling season and due to the depth of the building daylighting is ineffective.

An approximate approach to evaluate energy saving potential is presented in a report entitled "Performance Evaluation of Solar Films and Screens", provided under Contract DAAK 70-78-D-0002. In addition, a computerized evaluation is under development at Lawrence Berkeley Laboratory under contract with the Department of Energy. This should be available by mid 1979.

The table below gives approximate installed costs for films and screens.

Shading Material or Device	Installed Cost (Dollar/Square Foot)
Film Permanent to Window	$1.65
Film Roller Shade	$2.80
Louvered Screens	
Kaiser	$2.50-$4.50
Koolshade	$6.00-$7.50
Fabric Screens	
Fiber Glass	$1.90
Vinyl	$2.00
Roller Screens	$3.00

5.0 GUIDELINES TO IMPLEMENTATION

The following basic recommendations provide scme guidance to determine the feasibility of solar films and screens as economic energy conservation tools.

1. Natural shading devices such as deciduous trees, roof overhang, or awnings can negate most of the positive benefits of films and screens.

2. Permanent films and screens should be considered as having potential in areas where the air conditioning season is long and the heating season is short or non-existent.

3. Flexible or movable shading that can be removed during winter to allow beneficial solar heating or controlled to admit daylight are preferable to fixed shades when daylighting and winter heating are involved.

4. Natural light can provide adequate illumination for approximately the first 15 feet into a room with artificial light being required only on overcast days, at night, or for local task illumination.

5. Daylight may also provide some of the ambient illumination from 15 to 40 feet into a building.

6. Natural daylighting should be utilized whenever possible with electric lighting used only when needed and turned down or off when task function and safety are not impared.

7. Energy cost effectiveness may vary significantly depending upon window orientation. A particular case may show solar controls to be cost effective on southeast and southwest orientations, but not on south or north facing windows.

8. Evaluation of the cost effectiveness of film or screen in a particular instance can be estimated by the process outlined in the referenced report, "Performance Evaluation of Solar Films and Screens".

REPORT FESA-TS-2060

PERFORMANCE EVALUATION OF SOLAR FILMS AND SCREENS

RONALD R. BISHOP
JOHNS-MANVILLE SALES CORPORATION
RESEARCH & DEVELOPMENT CENTER
KEN-CARYL RANCH, DENVER, COLORADO 80217

MAY 1979

FINAL REPORT

PREPARED FOR
U.S. ARMY FACILITIES ENGINEERING SUPPORT AGENCY
TECHNOLOGY SUPPORT DIVISION
FORT BELVOIR, VIRGINIA 22060

SUMMARY

The use of solar films and screens to reduce energy usage is surveyed by means of Market and Literature Surveys that provide basic information on the availability, manufacture, function, cost, and solar optical properties of solar films and screens. A simplified method of determining potential energy savings is given in a step by step format that includes consideration of solar heat gain, heat loss, and daylighting aspects of the application of solar films and screens. This simplified hand calculation procedure should provide an interim means of providing the energy saving information required by the Energy Conservation Investment Program. More sophisticated methods of calculation are under development by the Lawrence Berkeley Laboratory under a contract with the Department of Energy. This computer model technique combined with empirical data should be available by mid to end of year 1979.

At this time, it appears that for most regions of the country flexible window shading that can be adjusted during the day or from season to season offer the most potential to saving energy. Fixed or permanent shading techniques may reduce desirable solar heat gain during the heating season and reduce daylighting into a

room negating energy saving potential available by reducing interior artificial lighting.

Reducing solar heat gain through a window may have very positive benefits during summer months, but unless the shading device is flexible and can be raised or removed during the winter, it may result in increased energy usage during winter months.

PREFACE

The assistance of Mr. James W. Griffith in preparing material on daylighting and in assisting with some of the calculation methods is acknowledged. The permission of ASHRAE to reproduce figures from the ASHRAE Journal is also acknowledged.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

Windows have enjoyed a multipurpose function in building design over the years. These purposes are related to daylighting of the interior, providing natural ventilation and visual communitation with the outdoors. With renewed concern over energy conservation, heat loss and solar heat gain aspects of windows have been the subjects of much emphasis. This report is concerned with the evaluation of only one of many ways of improving the efficiency of windows. That is, the retrofit application of solar films and screens. Solar heat gain, heat loss, and daylighting aspects are considered in a simplified approximate approach to compare energy saving alternatives. The ventilation and air infiltration aspects of windows are considered unaffected by the application of solar films and screens and are, therefore, not included in this study.

MARKET SURVEY

Solar Reflective Films

How They Work

The general operation of a commercially available solar film is depicted in Figure 2. The incident solar radiation striking a glass surface backed with film is reflected, absorbed, and transmitted through the glass-film medium. Figure 1 illustrates the amount of incident radiation that is absorbed, reflected, and transmitted for plain 1/4-inch glass. Figure 2 illustrates the same phenomenon when a reflective film is placed on the second glass surface. Of the energy that is absorbed, a portion is radiated and conducted outward and a portion is directed inward. As a result of tests conducted under standard conditions generally taken as 40^{o} North Latitude, July 21, with a West facing window, an important parameter called the Shading Coefficient can be determined. The Shading Coefficient is defined as follows:

$$SC = \frac{\text{Solar Heat Gain Through Fenestration with Shading Devices Applied to Window}}{\text{Solar Heat Gain Through Single Glazed 1/4-inch Glass}}$$

Values of the Shading Coefficient vary depending on the type of glass upon which films are placed. Shading Coefficients are reported by manufacturers of film and have been determined experimentally by independent laboratory tests.[1,2,3]

Films also influence another important thermal property of windows. That is, they reduce the overall heat transfer coefficient U (Btu/hr-ft^2-$^\circ$F). Again, tests have been conducted to determine this effect and are given later in this report.

As one would expect, heat reflective films also reduce the amount of light entering a window for daylighting. The amount of light transmitted depends upon the wavelength of the light. One manufacturer may state that his film transmits 17 percent of the available daylight. Another may say that his film transmits 18 percent of the light at 5500 Angstroms. Actually, the transmission may range from as high as 20 percent at one frequency and as low as 5 percent at another. Usually, average figures are given.

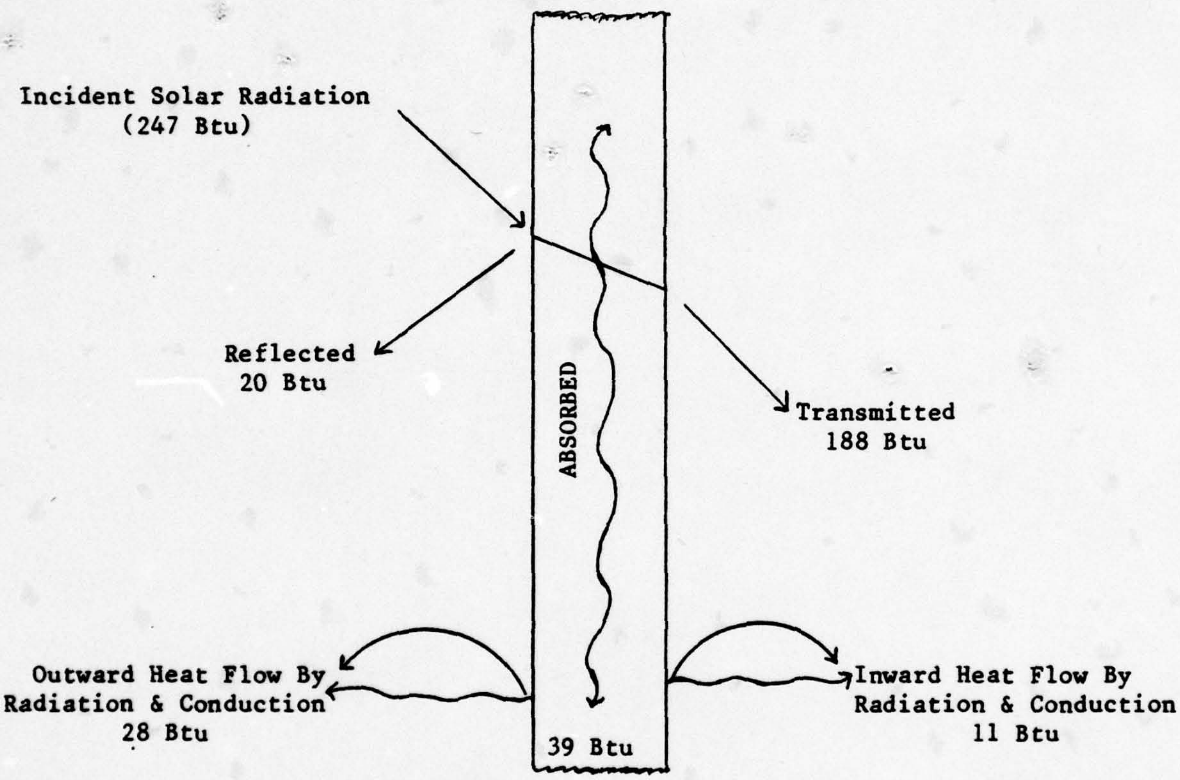


Figure 1. Incident Radiation on Plain Glass

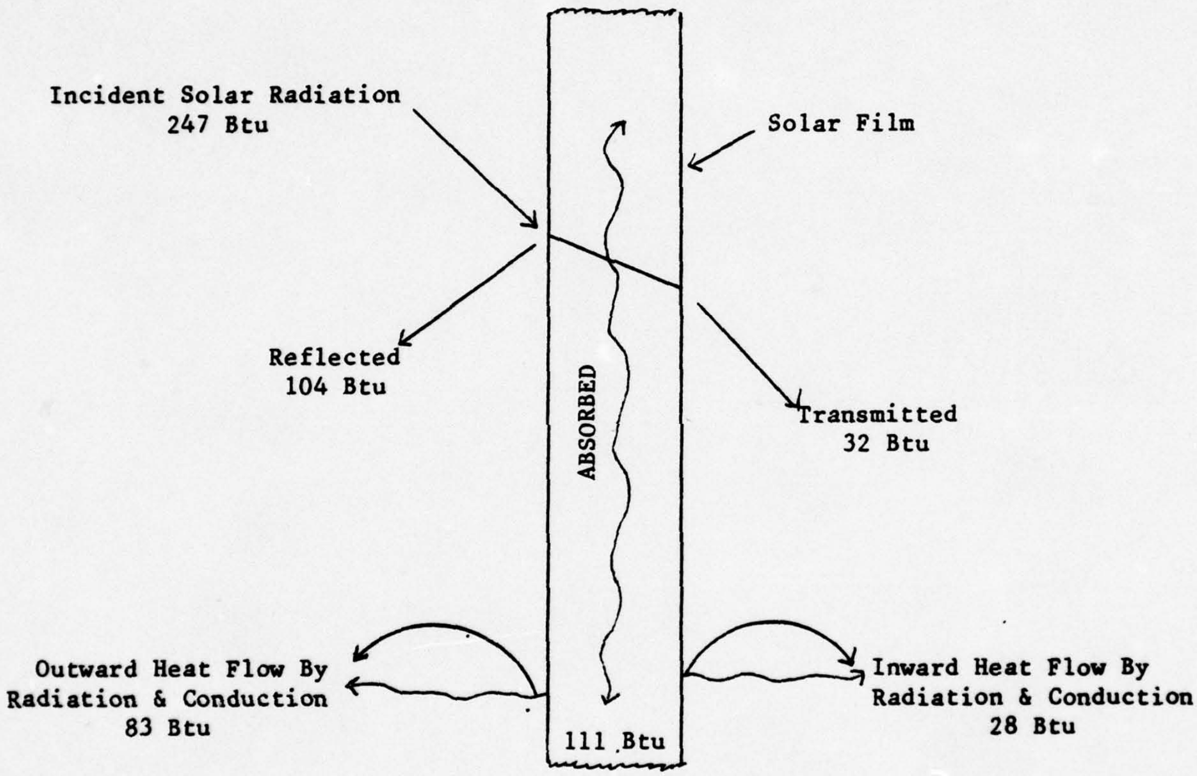


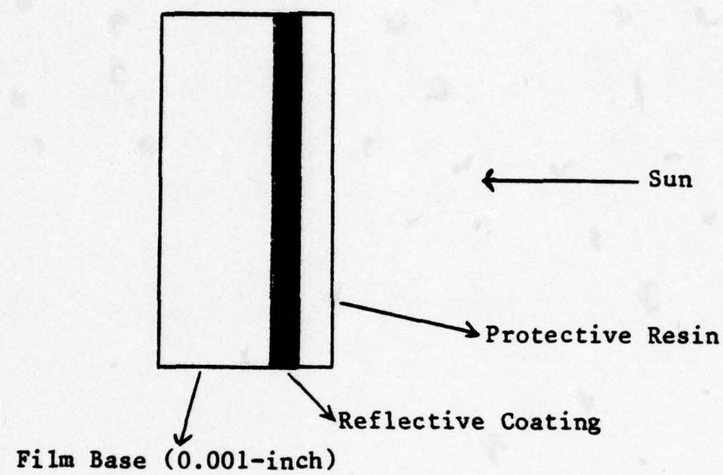
Figure 2. Incident Solar Radiation on Plain Glass
With Solar Reflective Film
Applied to Inside Surface

Types of Film

Several types of film are currently available from commercial sources. Films are manufactured for specific purposes. Some are made for glare and fade control and some are made for improving shatter resistance. The discussion here will be limited to film designed for solar heat control.

The so-called "silver" films are made by depositing a thin layer of aluminum on a polyester film. The density of the aluminum deposit determines the heat control properties of the film. Films are made in three basic categories: those which reject approximately 80 percent of the incident solar heat, those which reject 60 percent, and those which reject approximately 40 percent. Figure 3 shows a cross-section of silver films. The laminated variety of film is produced by laminating another layer of clear or tinted film over the aluminum coating. A second type of film is shown in Figure 4. These are tinted films and are made by laminating a sheet of dyed film over the metalized sheet. Tinted films come in bronze, smoke, and gold colors to blend with different types of architecture.

SOLID BASE



LAMINATED

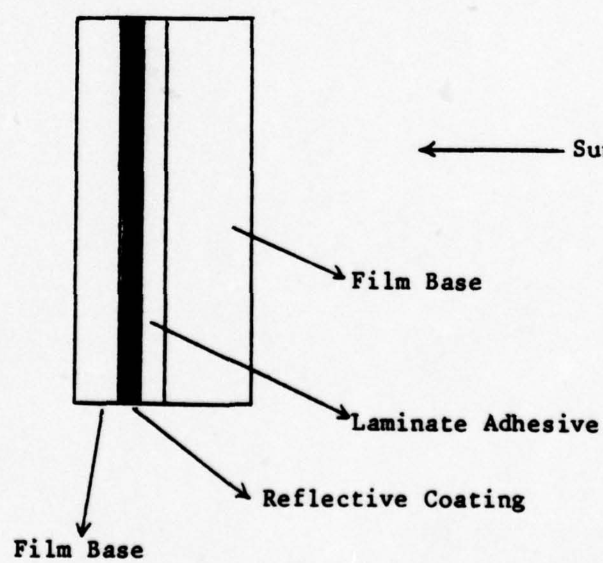
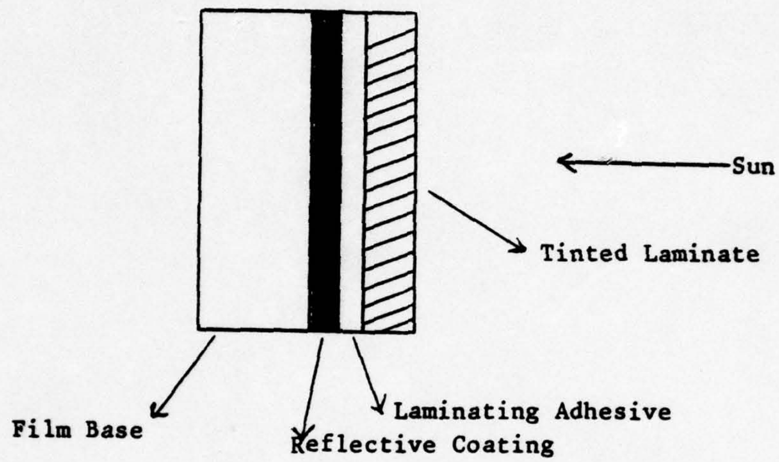


Figure 3. Silver Films

COLOR ON ONE SIDE



COLOR ON TWO SIDES

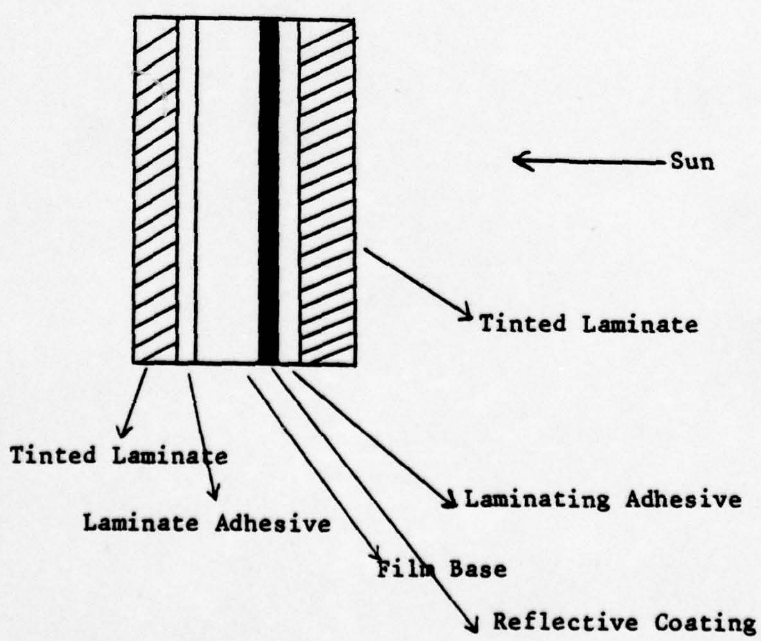
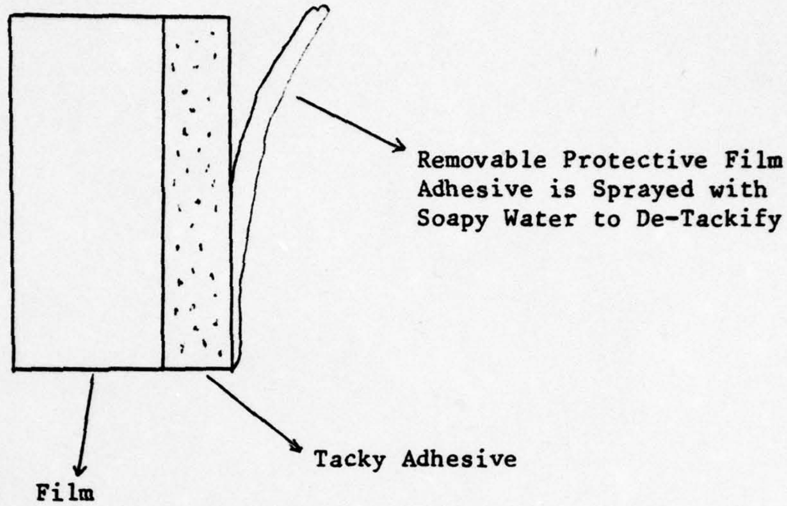


Figure 4. Tinted Films

Types of Adhesives

Most film adhesives are one of two types: pressure sensitive, shown in Figure 5, and self-adhesive, shown in Figure 6. Pressure sensitive adhesives have been available for some time and are available protected with a water soluble coating or with a removable plastic sheeting. Self-adhesives, applied to the film and dried, are water activated. In addition, a rewettable adhesive is available in the marketplace which is either sprayed on the glass at the time of application or is dry when on the film and is water activated.

Pressure sensitive adhesives are normally used in dry climates and self-adhesives are used in humid climates. However, some applicators use both types in the same geographic area.



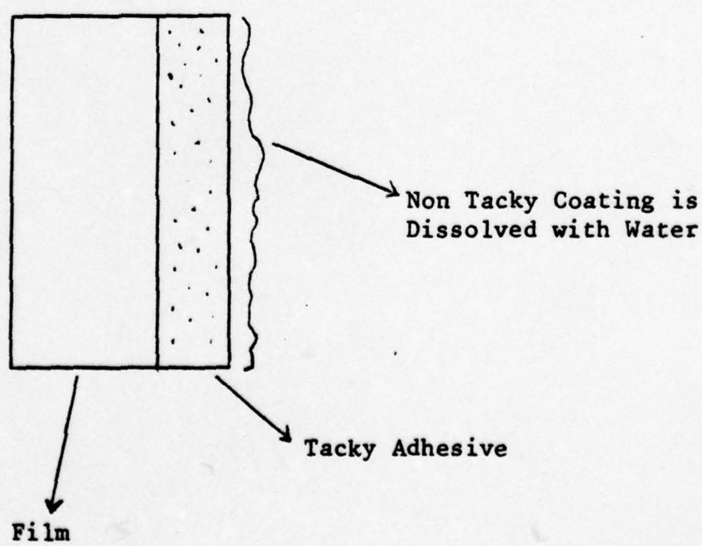


Figure 5. Pressure Sensitive Adhesives

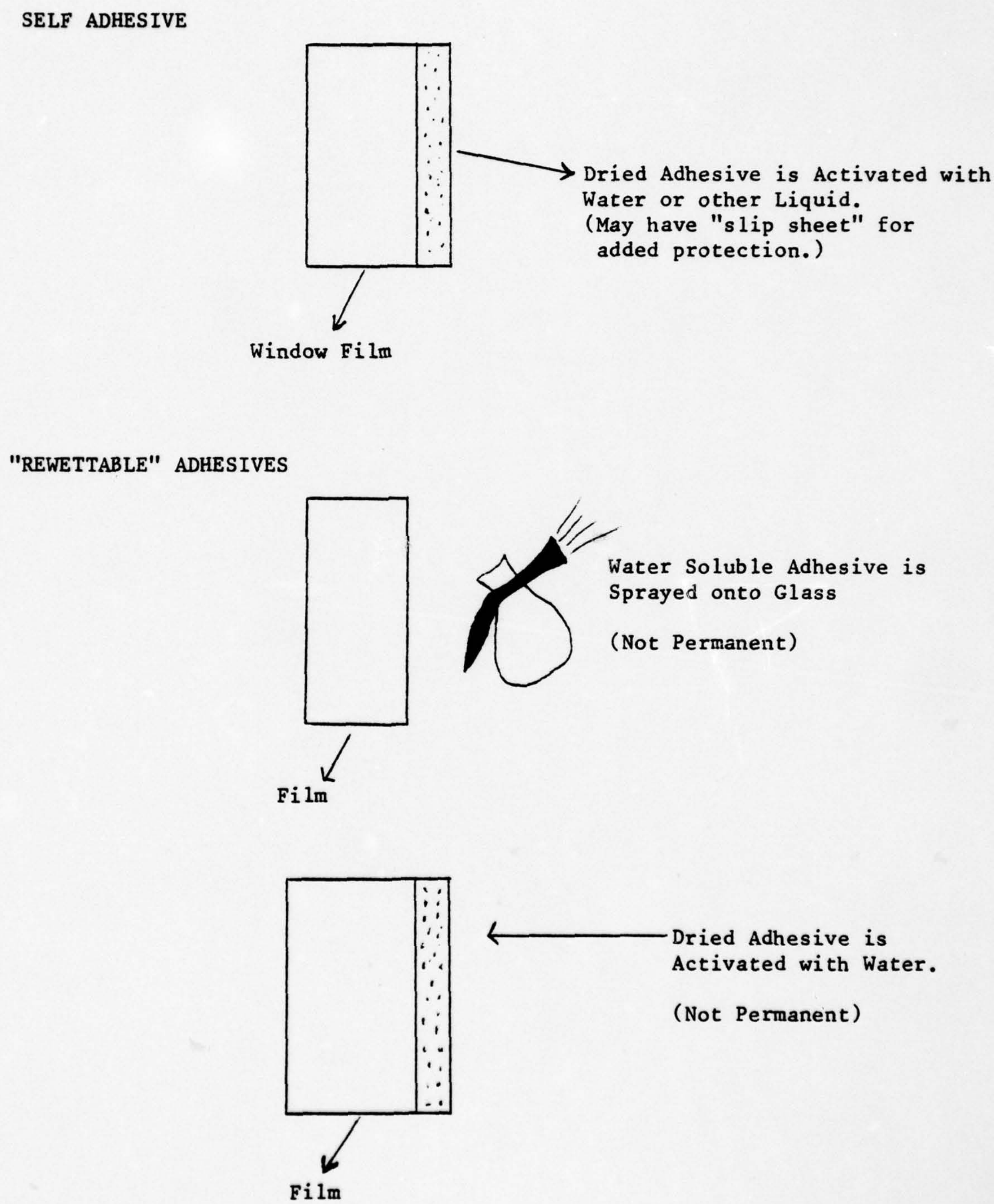


Figure 6. Adhesive Added & Rewettable Adhesives

Manufacturers

Solar reflective films are supplied under a variety of trade names. Polyester film itself is manufactured by a relative few. 3M, Dupont, Celanese, ICI United States, Inc., and Martin Processing are film manufacturers. The transparent film is then metalized and processed by companies which sell to authorized dealer-installers. These local dealers will either sell the finished film to a do-it-yourselfer or contract to do the film application. Every manufacturer will void their warranty against peeling and cracking unless the film is applied by an authorized contractor. Warranties range from two to five years depending upon the film type, method of application, and manufacturer. Table 1 lists the name, address, and film and adhesive description of several film suppliers.

TABLE 1. SUPPLIERS OF REFLECTIVE SOLAR CONTROL FILM

SUPPLIER	TRADE NAME	PRODUCT DESCRIPTION
Plastic View Transparent Shades, Inc. 15468 Cabrito Road Van Nuys, California 91408 213-786-2801	SEE THRU Window Shades SUNFIGHTER Film	Heat reflective transparent shades available in metal spring rollers or in cord and reel gravity operated rollers. Also distribute film to glass polyester film (LLUMAR dyed and aluminized by Martin Processing).
Material Distributors Corporation (MADICO) 64 New Industrial Parkway Woburn, Massachusetts 01801	REFLECTIVE SHIELD	Full line of heat reflective films in several color and heat rejection.
National Metalizing Division Saxon Industries Company RD No. 2 Cranbury, New Jersey 08512 609-655-4000	NUN-SUN	Full line of heat reflective film, also available for use as a roller shade material.
New England Plastic Shade 739 Boylston Street Boston, Massachusetts 02116 617-261-8200	Sun Tamer	Heat reflective transparent shades available on spring rollers.
Solar-X Corporation 25 Needham Street Newton, Massachusetts 02161 617-244-8686	SOLAR-X	Full range of heat reflective films with 80%, 65%, and 50% heat rejection in silver, bronze, gray, and gold colors. Pressure sensitive and liquid adhesives available. Pressure sensitive type has peel-off protective sheet.
Sun-X International 4125 Richmond Avenue Houston, Texas 77027 713-623-2425	Sun-X	Full range of heat reflective films in several colors. Both pressure sensitive and liquid adhesive systems are available. Pressure sensitive adhesive is water activated.
3M Corporation 3M Center 207-1W St. Paul, Minnesota 55101 612-733-9465	Scotch Tint	Full range of heat reflective films in several colors. Both water activated and detackified pressure sensitive adhesives. Also are marketing an insolating film claiming an overall heat transfer coefficient of U = 0.68 on 1/4-inch clear glass.

History of Use

The U. S. Army Construction Engineering Research Laboratory of Champaign, Illinois has conducted a survey of 337 users of film produced by major film manufacturers. The manufacturers surveyed were Material Distributors Corporation (Madico); Minnesota Mining and Manufacturing (3M); Solar-X Corporation; and Sun-X International. Respondents of the survey were from 15 geographical areas. The ages of installations ranged from 0.7 to 10 years. The average age was 3.3 years. Forty-seven percent of the installations were between 2 and 4 years old. The overall performance of the film was rated as good to excellent by 90 percent of the users. However, 34 percent of the respondents described the film as being easily damaged. Since reflective films can be scratched, care should be used where children or pets might cause damage.

Additionally, CERL conducted laboratory tests to (1) determine the effects of cleaning materials on solar films, and (2) evaluate the films effectiveness as a solar energy barrier.

Cleaning

CERL conducted tests with several kinds of commercial window cleaners.[1] Spray or aerosol applied cleaners were found to be the most effective. No chemical deterioration of the films was noted.

The following general precautions were noted:

1. Liquid detergents should be applied with a hand spray, synthetic sponge, or soft cloth if it is not furnished as an aerosol spray.
2. Only non-abrasive detergents and weak ammonia solutions should be used.
3. The film should be dried with soft, lintless paper towels, turkish towels, or a soft squeegee. The film should be wiped wet to avoid scratching.
4. Brushes, natural sponges, and abrasive or caustic detergents should not be used.
5. Excessive wiping should be avoided.

Solar Optical Properties

Most film manufacturers have tested their films carefully and their claims of solar optical properties are accurately reported. CERL commissioned Matrix, Incorporated to conduct tests of several films, the results of which are given in Table 2.[4] Solar optical properties as reported by several manufacturers are given in Table 3. Generally speaking, there is little variation in solar optical properties of comparable products from manufacturer to manufacturer.

TABLE 2. SOLAR OPTICAL PROPERTIES OF PLAIN 1/4-INCH (6.35 mm) CLEAR GLASS AND FILM ON GLASS WITH NO SHADING

SAMPLE*	TRANSMITTANCE (%)				REFLECTANCE (%)		ABSORPTANCE (%)	e_g**	"U"-FACTOR**		N_i**	SC**
	Vis	Solar	UV	IR	Vis	Solar	Solar		Summer	Winter		
No. 1	19	13	17	0	43	42	45	0.63	1.01	1.05	0.25	0.28
No. 2	16	11	23	0	44	43	46	0.53	0.95	0.99	0.24	0.25
No. 3	20	13	0	0	43	42	45	0.61	1.00	1.04	0.25	0.28
No. 4	18	12	0	0	46	43	45	0.62	1.01	1.04	0.25	0.27
No. 5	88	76	56	0	7	8	16	0.81	1.06	1.15	0.27	0.92

* Samples: No. 1 - 3M P-18
No. 2 - Madico RSLW 100-20HCX
No. 3 - Solar-X PS-80
No. 4 - Sun-X F-88
No. 5 - LOF Clear Float Glass
All solar film samples have reflective aluminum or silver finish and pressure-sensitive adhesive.

**"U"-Factor Units are Btu/hr-sq ft-^{o}F (the overall heat transfer coefficient);
e_g -Hemispherical Emittance Ratio;
N_i -Inward Flow Factor;
SC -Shading Coefficient.

Tested: 10 March 1976 by Matrix, Inc., Report No. 6010-143.

TABLE 3. SOLAR OPTICAL PROPERTIES OF COMMERCIAL FILMS AS REPORTED BY FILM MANUFACTURERS

FILM	T_v	T_s	T_{uv}	R_s	A_s	U (Btu/ft^2-hr) Summer	U (Btu/ft^2-hr) Winter	SHADING COEFFICIENT
Sun-X*								
8815.1 (Silver)		0.11	0.007	0.56	0.33	0.83		0.20
6610.1 (Silver)		0.33	59.8	0.28	0.39	1.01		0.49
3M*								
A18-P18	0.16	0.13	0.21	0.46	0.41		0.87	0.25
P19	0.17	0.14	0.2	0.41	0.45		0.68	0.29
A33-P33	0.30	0.25	0.32	0.33	0.42		0.87	0.40
Solar-X*								
PS80, S80	0.17		0-0.5				0.83	0.24
PS65, S65	0.35		0-0.5				0.91	0.41
PS50, S50	0.50		0-0.5				0.96	0.55
Venetian Blinds								
Light								0.55
Medium								0.64
Glass								
Double Strength		0.86	0.88	8	6	1.06		1.00
1/8-Inch Gray		0.59						0.80
Heat Absorbing 3/16-Inch		0.52						0.75

*Solar Optical Properties are listed for films applied to 1/4-inch clear glass.

Solar Screens

Types of Screens

There are several kinds of solar screens available. They may be divided into metallic and non-metallic types. Metallic types are generally louvered screens that are installed on the exterior of a window opening much like a normal bug screen or storm window. Non-metallic screens are fabric mats of fiber glass or vinyl and can be placed on the exterior side of the window as louvered screens or they are often used as roller shades on the building interior.

How They Work

Non-louvered screens simply act to block the incoming rays of solar radiation. Screens placed on the outside of the window are about 15 to 20 percent more effective than interior screens in reducing solar heat gain. Louvered screens are depicted in Figure 7 which shows how they act as shades to block incoming radiation. Because the amount of sun shut out depends upon the profile angle of the sun, the louvered shade is much more difficult to analyze than non-metallic shades or films. The Shading Coefficient varies every hour of the day and every day of the year. In order to account for this, an effective Shading Coefficient is generally developed. This effective Shading

Coefficient is a value that if constant, would effectively shade a window in the same way a louvered screen does over some time period. Shading Coefficients and U Values for louvered screens have been determined by several investigators.[5,6,7]

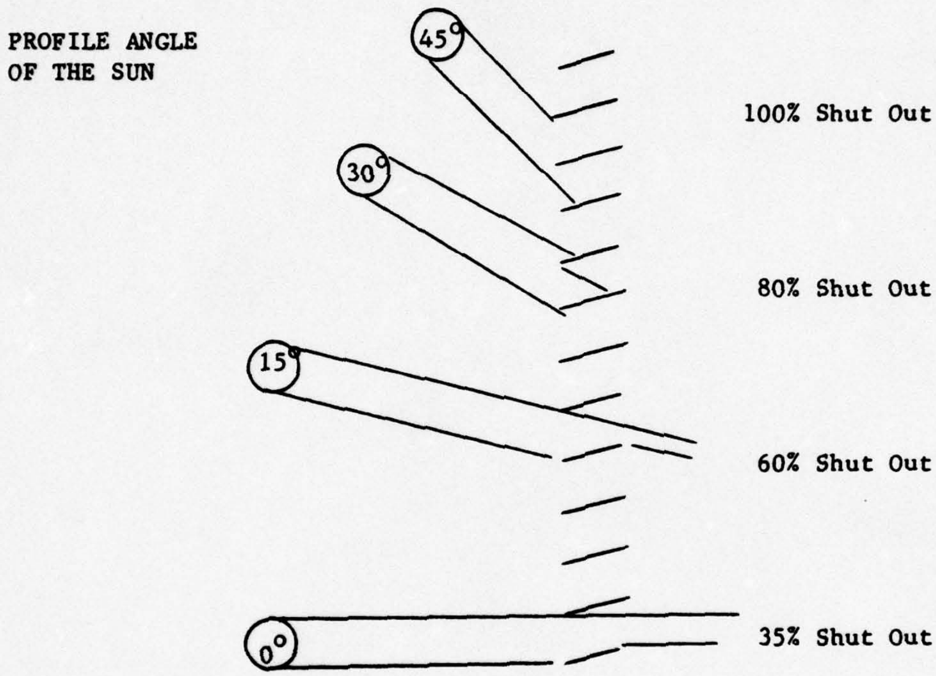


Figure 7. Louvered Screens as Shading Device

Manufacturers

Louvered screens are made by Koolshade Corporation and Kaiser Aluminum. Non-metallic screens are made by several manufacturers. Table 4 lists names and addresses of major suppliers along with descriptions of their products.

Solar Optical Properties

Properties of both metallic louvered and non-metallic screens are given in Table 5.

TABLE 4. SUPPLIERS OF SOLAR SCREENS

SUPPLIER	TRADE NAME	PRODUCT DESCRIPTION
Kaiser Aluminum Kaiser Center 300 Lakeside Drive Oakland, California 94643	SHADESCREEN	Louvered aluminum screen is sold as roll goods through local distributors and fabricators. Fabricators are located in most States. Available as exterior movable screen, can be placed in double vertical sliding screen windows.
Koolshade Corporation 722 Genevieve Street Solana Beach, California 92075 714-755-5126	KOOLSHADE	Louvered brass screen comes in Standard with 17 louvers per inch and Low Sun Angle with 23 louvers per inch. Authorized contractors are located in most States. A wide variety of external frames are available allowing them to be moved during winter if desired.
Joel Berman Associates, Inc. 102 Prince Street New York, New York 10012 212-226-2050	THERMOSHADE THERMOVEIL	Polyvinyl chloride and polyester vinyl woven fabric design to be applied either as an exterior screen or as an interior roll-up shade.
Pittsburg Plate Glass Fiber Glass Division One Gateway Center Pittsburgh, Pennsylvania 15222		Fiber glass woven screen design for permanent or movable exterior application as well as an interior roll-up blind. Sold through screen manufacturers who buy fiber glass yarn from PPG. Screen Manufacturers are:
	SUN SCREEN	Phifer Wire Products Company P. O. Box 1700 Tuscaloosa, Alabama 35401 (205-345-2120)
	COMFORT SCREEN	J. P. Stevens Company, Inc. Box 1138 Walterboro, South Carolina 29488 (803-538-8041)
	SUN CHEK	Chicopee Manufacturing Company Box 47520 Atlanta, Georgia 30362 (404-455-3754)

TABLE 5. SOLAR OPTICAL PROPERTIES OF SOLAR SCREENS

(LOUVERED SCREENS) SCREEN	PROFILE ANGLE*	SHADING COEFFICIENT	EFFECTIVE SHADING COEFFICIENT	GLASS*** ORIENTATION	OVERALL HEAT TRANSFER COEFFICIENT U (Btu/ft^2-hr)
Kaiser	0^o	0.53	0.29	N	0.85
SHADESCREEN	10^o	0.411	0.26	E & W	
(Green)	20^o	0.333	0.21	S	
	30^o	0.232	0.27	NE & NW	
	$40-90^o$	0.195	0.22	SE & SW	
	$>90^o$	0.333			
Koolshade	10^o	0.51	0.28	N	0.85
Standard	20^o	0.42	0.26	E & W	
	30^o	0.31	0.20	S	
	40^o	0.18	0.26	NE & NW	
	50^o	0.18	0.21	SE & SW	
	$>50^o$	0.18			
Koolshade	10^o	0.35	0.26	N	0.85
Low Sun Angle	20^o	0.17	0.23	E & W	
	30^o	0.15	0.20	S	
	40^o	0.15	0.28	NE & NW	
	50^o	0.15	0.23	SE & SW	
	$>50^o$				

(WOVEN FABRIC) SCREEN	T_v**	T_s	A_s	R_s	SHADING COEFFICIENT	U (Btu/ft^2-hr) Winter	U (Btu/ft^2-hr) Summer
PPG	0.26	0.235	0.123	0.642	0.32		
Joel Berman Interior							
THERMOVEIL	0.32	0.29		0.37	0.47	0.85	0.80
THERMOSHADE	0.08	0.11		0.34	0.49		

* Profile Angle is the angle the sun rays make with a horizontal surface.

**T_v -Visual Transmittance
T_s -Solar Transmittance
A_s -Solar Absorbance
R_s -Solar Reflectance

***N - North
E - East
W - West
S - South
NE - NorthEast
NW - NorthWest
SE - SouthEast
SW - SouthWest

LITERATURE SURVEY

Early Research

Research work conducted at the American Society of Heating, Refrigeration, and Air Conditioning Engineers Laboratory (ASHRAE) in the late 1950's and early 1960's conclusively showed that shading of fenetrations can provide large reductions in air conditioning peak loads. The results of this research work are published in four Research Reports of the Society's Transactions.[8,9,10,11] This research work has been extended and refined by others. A theoretical analysis was applied by Farber, Smith, Pennington and Reed in 1963.[12] Solar heat gain for different kinds of window glass were reported by ASHRAE in 1962.[13] The effectiveness of window shading materials[14], drapes[15], metal awnings[16], and roller shades[17] have also been studied. These research efforts have resulted in the ASHRAE techniques for cooling load determination and are not directly applicable to energy usage or savings calculations.

Current Research

Construction Engineering Research Laboratory

Major research work relating to solar films has just been completed by the U. S. Army Constructin Engineering Research Laboratory.[1] This report concludes that the use of solar films is not cost effective when applied to an Army barracks building located at Fort Hood, Texas. This conclusion was reached by incorporating a computer simulation of the barracks using a forerunner of the Building Loads Analysis and System Thermodynamics Program (BLAST) also developed by CERL.[18] The program contains a fairly exhaustive treatment of windows, but not enough detail has been obtained to be able to fully evaluate its performance. The BLAST program is being placed on the Boeing Computer Service and will shortly be available from that source.

National Bureau of Standards

The National Bureau of Standards Center for Building Technology issued a report on the analysis of thermal and lighting characteristics of windows in February 1978.[19] The goal of this NBS program has been to isolate the thermal and illumination effects associated with a window and to model these effects in a simplified building situation. A computer model has been developed and case studies have been conducted to simulate both office and residential conditions for Washington, D. C. weather data. As a result of this study, NBS has concluded "that a properly designed and operated window system can reduce overall operating costs below those for a solid wall for the two rooms simulated in the Metropolitan Washington, D. C. area. The reduction is greatest for managed south-facing, double-glazed windows in which daylight replaces or supplements artificial light." It is carefully pointed out that this study is theoretical with little experimental varification. Nevertheless, the findings clearly indicate that annual operating costs can be reduced by the use of window management (thermal barrier on winter nights and shading on summer days will cut undesirable heat loss and gain significantly) and daylight. "The single option that has the most impact is the use of daylight rather than artificial light."

Lawrence Berkeley Laboratory

Under funding by the Consumer Products and Technology Branch of the Building and Community Systems Division of the Department of Energy, the Lawrence Berkeley Laboratory initiated a program to plan, manage, and conduct an Energy Efficient Windows Research Program.[20] This program began in the latter part of 1976 and has the goal of accelerating and complimenting the efforts of private industry, maximizing the effectiveness of energy use, and fostering the acceptance of energy saving technology related to windows. Among the many aspects of this research program are two that directly relate to the effective evaluation of solar films and screens. A transportable window test chamber is being developed to gather data on various window treatments for different orientations and climatic conditions. This test chamber is now near completion and initial data should be available by mid 1979. Also, analytical efforts are being directed at developing a detailed model of the net heat transfer through a window assembly. This model will incorporate an annual analysis including daylighting and the thermal performance of the total building. Again, this program will be available during 1979.

ENERGY SAVINGS

Factors Influencing Energy Savings

Thermal Aspects

There are many factors which influence window performance in terms of thermal energy transport through them. Some of these factors are enumerated as follows:

1. Window Size
2. Window Orientation
3. Number of Layers of Glazing
4. Type of Glazing including Use of Films and Screens
5. Other Internal and External Shading Devices
6. Window Shape and Building Location Factors such as Climate, Cloud Cover/Sunshine, Prevailing Winds, Latitude, Elevation, Extent of Vegetation, and Ground Cover.

There is no method currently available to correlate all of these factors into a technique for evaluating the cost effectiveness of a retrofit energy saving window treatment. Most manufacturers that offer computer and hand analysis techniques to determine payback periods for films and screens consider the cooling season only. ASHRAE methods of calculation are primarily used to determine cooling and heating loads for equipment sizing and are not directly usable for determining energy savings. The CERL and NBS computer programs are, at least at this point in time, not readily accessible to the average Facility Engineer. For this purpose, a simplified method of approximating energy savings is given here to provide an initial guideline in finding the potential cost effectiveness of films and screens for the Energy Conservation Investment Program (ECIP).

In the step by step calculation procedure that follows many simplifying assumptions are made to bring the method within the reach of as many Facility Engineers as possible.

Daylighting Aspects

The indoor lighting of commercial buildings, office buildings, and schools provided by artificial electric light consumes a major portion of the energy consumed in these buildings. The effective use of daylight can effectively reduce the cooling loads resulting from electrical illumination systems. For the first 15 feet into a room, daylighting can be the primary source of illumination with artificial light being required only on overcast days, at night, or for local task illumination.

Between 15 and 40 feet into a building, daylight may provide adequate ambient lighting with artificial lighting required for task illumination and interior space lighting.

A great number of factors influence the effectiveness of daylighting. These factors are discussed in several publications.[22,23] In addition, Mounir M. Botros of FESA has written a paper on lighting design and energy conservation.[24]

Calculation of Energy Savings

A. Calculate the Energy Savings Expected During the Cooling Season due to Reduction in Air Conditioning.

1. Estimate the square footage of glass facing each major compass orientation (i.e., East, NorthEast, etc.). Corrections to magnetic compass reading can be made using Figure 9. Insert glass square footage in Table 7.

2. Determine the cooling season Solar Heat Gain Factor (SHGF) for your latitude and for each orientation from Table 6 and Figure 9. Insert the SHGF in Column 3 of Table 7.

3. Determine the Shading Coefficient for the type of glass being retrofitted. Clear double strength glass = 1.0. Values for other types can be found in Table 3 or in Reference 21. SC_G = ______.

4. Determine the Shading Coefficient for the sun control shading being considered. Values for this are given in Tables 2, 3, and 5 when they are applied to clear double strength glass. SC_S = ______.

5. Compute the difference in Shading Coefficients from Items 3 and 4 above.

$\underset{(3)\ SC_G}{\_\_\_\_\_\_} - \underset{(4)\ SC_S}{\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_$

Insert the difference in Column 4 of Table 7.

6. Determine the Load Factor. Use 0.9 for exterior shading and 0.75 for interior shading. Insert the appropriate value in Column 5 of Table 7.

7. Determine the hours of air conditioner operation for the cooling season. Insert the actual values in Column 6 of Table 7. If actual hours of operation are not known, they may be roughly estimated as follows:

   - determine total hours of compressor operation from Figure 8.

   - multiply this figure by the daily sunshine hours obtained from Figure 11, then divide this number by 24.

   - multiply the answer by 1.2.

   hours of air conditioner operation - ________.

8. Calculate the cooling season load savings by multiplying the figures of Table 7 and inserting the product in the last column for each window orientation.

9. Add the load savings for each window orientation and place the sum in the blank provided for total cooling season air conditioning load savings. Cooling Load Savings = ______.

10. Determine the Kilowatt Hours (KWH) of power required to remove 1 Btu of heat. This will vary with the type of unit, manufacturer, and outside temperature. If an actual value for the air conditioner in question is known, it should be used. Otherwise, 9.77×10^{-5} KWH/Btu can be used for estimating.

11. Find the power savings input to the air conditioner. Multiply the cooling load savings of Item 9 by the conversion factor of Item 10.

______________ X ______________ =
(9) Load Savings   (10) Conversion

______________ KWH/Year.
(11) Power Savings

12. Calculate the annual cost savings by multiplying the energy cost per KWH.

__________ X ______________ = ______________
Dollar/KWH   Power Savings/Year   Annual Savings

TABLE 6. SOLAR HEAT GAIN FACTORS

LATITUDE	SEASON	COMPASS ORIENTATION OF GLASS							
		NORTH	NORTHEAST	EAST	SOUTHEAST	SOUTH	SOUTHWEST	WEST	NORTHWEST
32^oN	Winter	172	298	1278	2065	1614	489	173	172
	Summer	35	108	151	113	39	29	28	28
40^oN	Winter	187	302	1264	1865	1782	531	207	164
	Summer	33	87	159	154	66	38	32	32
48^oN	Winter	106	132	827	1671	1508	516	106	106
	Summer	34	88	164	153	74	39	31	31
56^oN	Winter	69	81	573	1294	1227	457	71	69
	Summer	36	89	173	172	92	40	31	31

NOTE: Solar Heat Gain Factors for Winter are expressed as Btu/ft^2-day; while Summer values are given in Btu/ft^2-hr.

TABLE 7. CHANGE IN SOLAR HEAT GAIN FOR COOLING SEASON

WINDOW ORIENTATION	SQUARE FEET GLASS		SOLAR HEAT GAIN FACTOR		$SC_G - SC_S$		LOAD FACTOR		HOURS AIR CONDITIONER OPERATION		COOLING LOAD REDUCTION
South	________	X	________	X	________	X	________	X	________	=	________
North	________	X	________	X	________	X	________	X	________	=	________
NorthWest	________	X	________	X	________	X	________	X	________	=	________
NorthEast	________	X	________	X	________	X	________	X	________	=	________
SouthEast	________	X	________	X	________	X	________	X	________	=	________
SouthWest	________	X	________	X	________	X	________	X	________	=	________
East	________	X	________	X	________	X	________	X	________	=	________
West	________	X	________	X	________	X	________	X	________	=	________
									TOTAL	=	

SC_G - Shading Coefficient/Glass

SC_S - Shading Coefficient/Sun

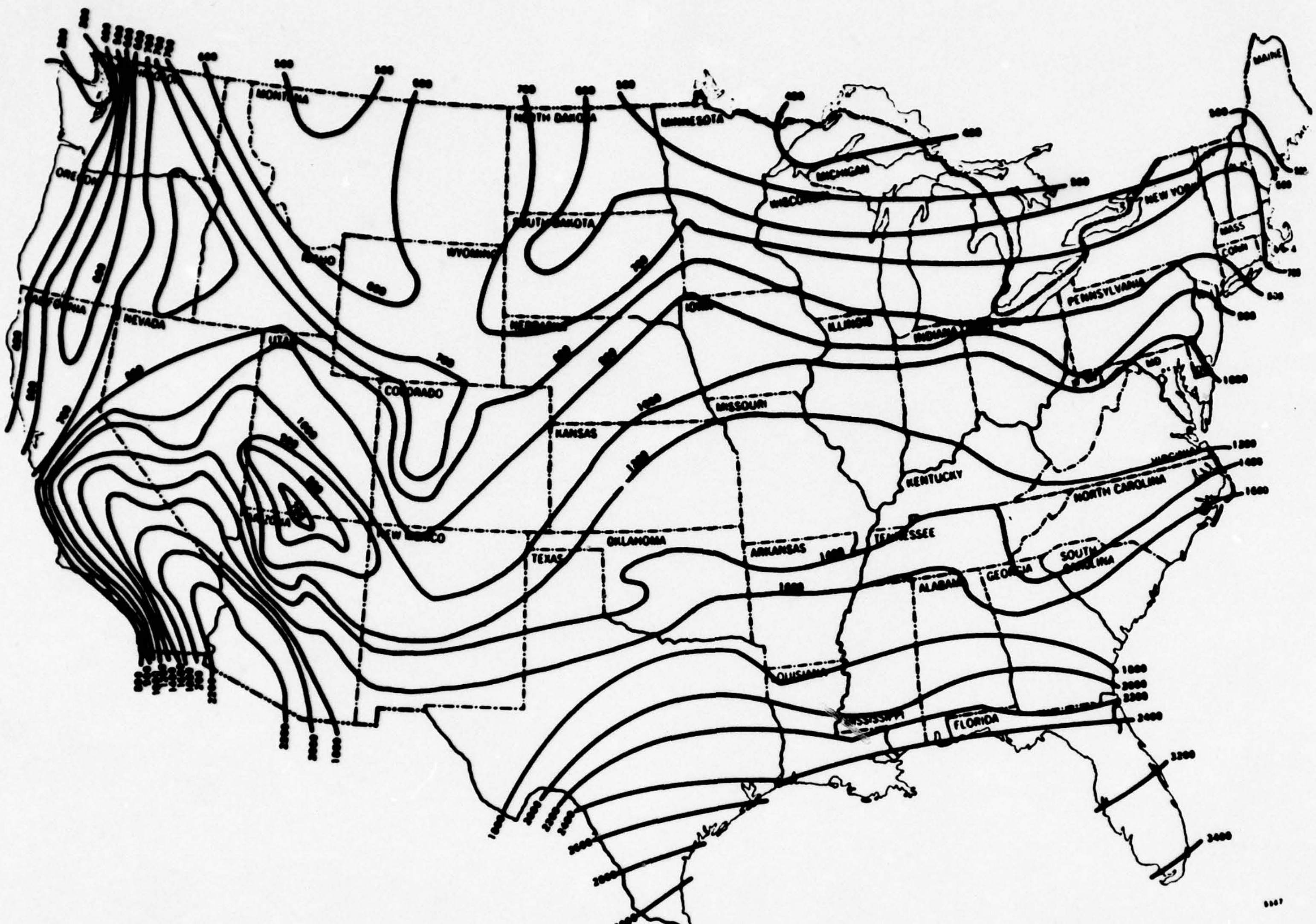
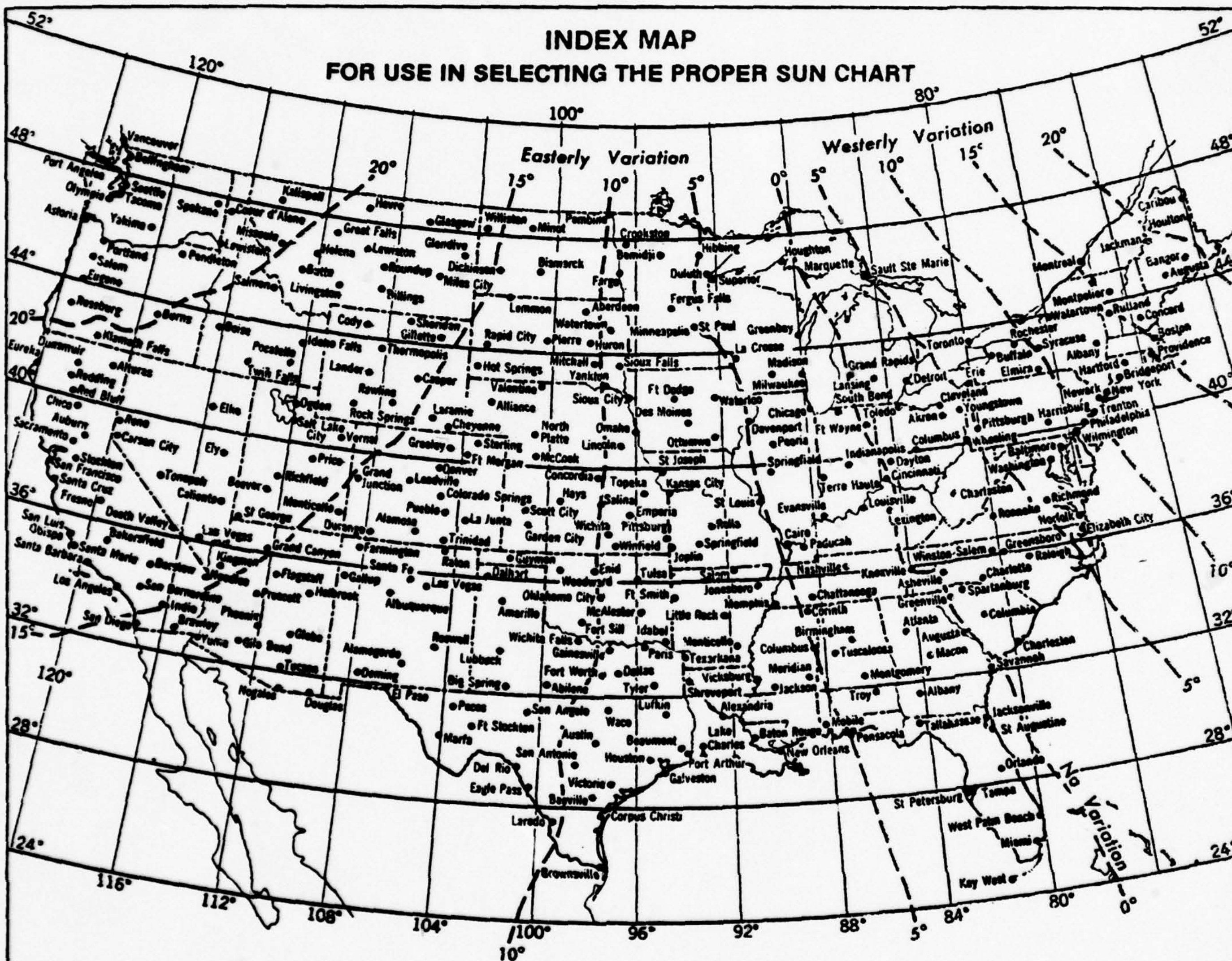


Figure 8. Hours of Compressor Operation for Residential Systems (Reprinted by Permission from ASHRAE Journal, 16, Part 1, No. 2, 1974)



MAGNETIC VARIATION

The magnetic compass points to magnetic north rather than true north. In most localities magnetic north does not coincide with true north but is toward the east ("easterly variation") or toward the west ("westerly variation") from it

The heavy broken lines on this map connect points of equal magnetic variation, and present a generalized picture of magnetic variation in the United States. Due to "local attraction" it may be quite different in your locality. For more exact information consult your local surveyor.

Figure 9. Magnetic Variation

B. Calculate the Change in Energy Usage Anticipated During the Heating Season due to Retrofit of Windows with Solar Films or screens that are not moved.

1 - 6. Following Steps 1 to 6 for the Cooling Season in Part A, fill in the blanks of Table 8 for the Heating Season.

7. Determine the average number of hours of sunshine daily for the heating season from local weather data or from Figure 10.
Average Hours of Sunshine = ______.

8. Find the reduction in natural heating by multiplying the factors of Table 8 together for each window orientation.

9. The total change in solar heat to the building may be calculated by adding the last column of figures in Table 8.

TABLE 8. CHANGE IN NATURAL HEATING FOR HEATING SEASON

WINDOW ORIENTATION	GLASS AREA		SOLAR HEAT GAIN FACTOR		$SC_G - SC_S$		LOAD FACTOR		SUN SHINE		REDUCTION IN NATURAL HEATING
South	____	X	____	X	____	X	____	X	____	=	____
North	____	X	____	X	____	X	____	X	____	=	____
NorthWest	____	X	____	X	____	X	____	X	____	=	____
NorthEast	____	X	____	X	____	X	____	X	____	=	____
SouthEast	____	X	____	X	____	X	____	X	____	=	____
SouthWest	____	X	____	X	____	X	____	X	____	=	____
East	____	X	____	X	____	X	____	X	____	=	____
West	____	X	____	X	____	X	____	X	____	=	____
									TOTAL	=	

SC_G - Shading Coefficient/Glass

SC_S - Shading Coefficient/Sun

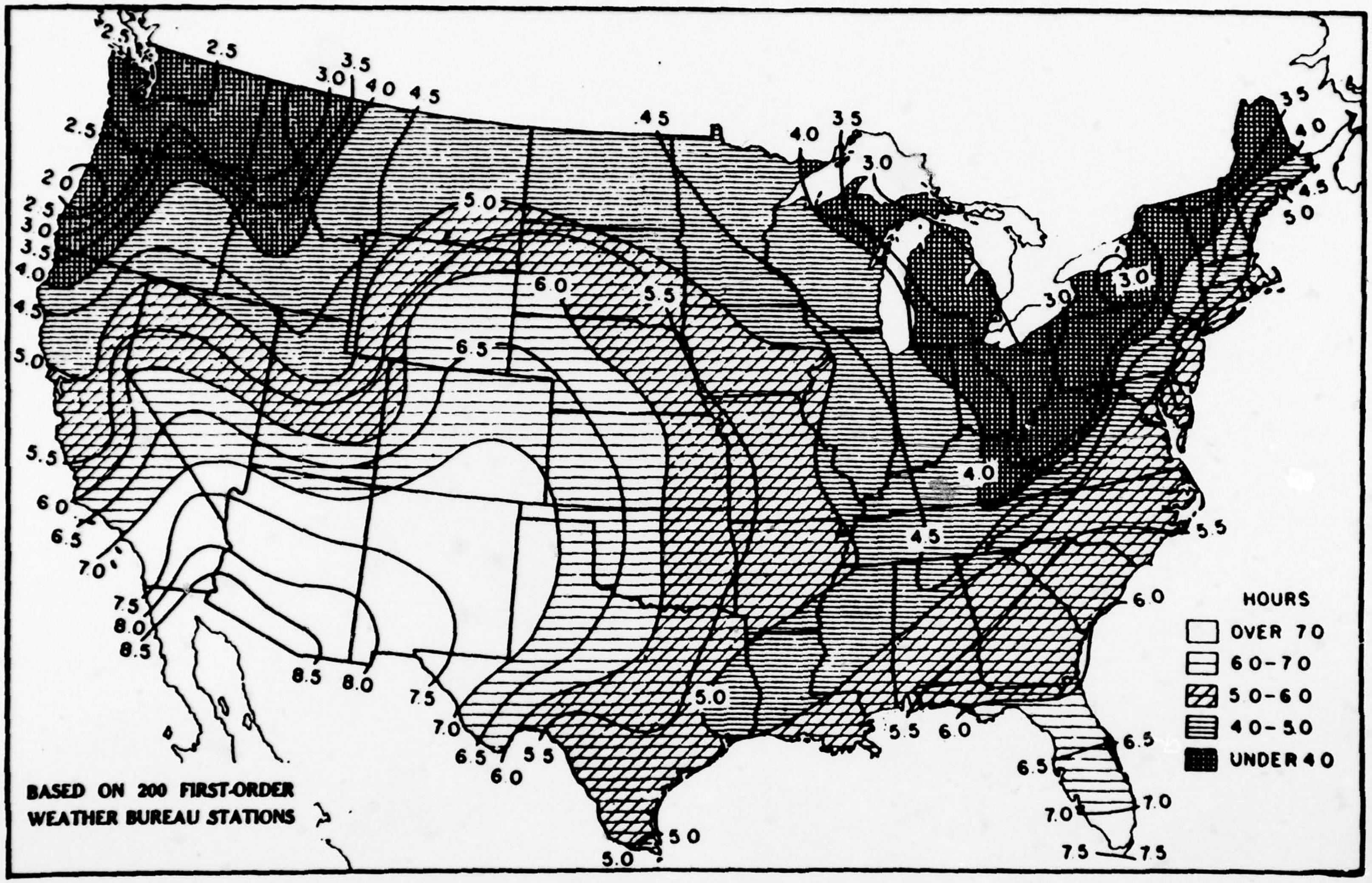


Figure 10. Average Number of Hours of Sunshine Daily, Winter (December - February)

C. Calculate the Reduction in Winter Heat Loss.

1. Find the overall heat transfer coefficient from data for the screen or film being used applied to the type of glass in question. This may be determined from Tables 2, 3, and 5. U_S = ______.

2. Determine the overall heat transfer coefficient for glass without film or screen applied in Table 2 or Reference 21. U_G = ______.

3. Find the average winter outdoor temperature from local weather information or Reference 21. T_o = ______.

4. Calculate the reduction in winter heat loss by subtracting the average winter outdoor temperature from the design indoor temperature or thermostat setting. Then, multiply this difference by the product of the total glass area and the difference between the U Value of the glass and the U Value of the glass with shading.

$$\underset{U_G - U_S}{\underline{\qquad\qquad}} \times \underset{\text{Glass Area}}{\underline{\qquad\qquad}} \times \underset{T_i - T_o}{\underline{\qquad\qquad}} = \underset{\text{Btu/Hour}}{\underline{\qquad\qquad}}$$

5. The reduction in winter fuel needs can now be calculated from the modified degree day procedure. Determine the heating degree days for your locality, the interim correction factors for degree days and for the fuel system from Table 9, the heating value of the fuel from Table 9, and the full load furnace efficiency.

DD - Heating Degree Days for Locality from Local Weather or Reference 21. DD = ______.

q - Change in Heat Loss from Item 4 above. q = ______.

H - Heating Value of Fuel from Table 9. H = ______.

U - Rated Full Load Efficiency of Furnace.

C_D - Interim Correction Factor for Degree Days. See Table 9. C_D = ______.

C_F - Interim Correction Factor for Fuel System. See Table 9. C_F = 1.0 for Electrical Resistance Heating. C_F = ______.

T_o - Average Outside Winter Temperature. T_o = ______.

T_i - Design Indoor Temperature. T_i = ______.

6. Calculate the fuel savings as follows:

$$F = \frac{\underset{DD}{\underline{\qquad}} \times \underset{q}{\underline{\qquad}} \times \underset{C_D}{\underline{\qquad}} \times \underset{C_F}{\underline{\qquad}}}{\underset{U}{\underline{\qquad}} \times \underset{T_i - T_o}{\underline{\qquad}} \times \underset{H}{\underline{\qquad}}}$$

7. The annual cost savings are obtained by applying the fuel unit cost to the reduction in consumption determined in Item 6 above.

TABLE 9. CONSTANTS FOR USE WITH MODIFIED DEGREE-DAY CALCULATIONS

TYPICAL HEAT CONTENT OF VARIOUS SOURCES:

FUEL OIL	
Number 1	137,400 BTU/gal.
Number 2	139,600 BTU/gal.
Number 3	141,800 BTU/gal.
Number 4	145,100 BTU/gal.
Number 5	148,800 BTU/gal.
Number 6	152,400 BTU/gal.
PROPANE	91,500 BTU/gal.
NATURAL GAS	950 to 1150 BTU/cu. ft.
PURCHASED STEAM	1012 BTU/1b (based on 10 PSIG supply, condensate returned at 180^{o}F)
ELECTRICITY	
Resistance Heating or Heat from Lights	3,413 BTU/watt-hour
Heat Pumps	up to 13,000 BTU/KWH
COAL	
Bituminous	11,500 to 14,000 BTU/1b
Sub-Bituminous	9,500 to 11,500 BTU/1b
Lignite, Brown Coal	6,300 to 8,300 BUT/1b

CORRECTION FACTOR FOR DEGREE DAYS:

Outdoor Design Temperature (^{o}F)	-20	-10	0	10	20
Correction Factor C_D	0.57	0.64	0.71	0.79	0.89

PART LOAD CORRECTION FACTOR:

Percent Oversizing	0	20	40	60	80
Factor C_F	1.36	1.56	1.79	2.04	2.32

D. Calculate the Electrical Energy Required to Replace Daylight if Fixed Controls are Employed on the Windows.

Calculate the hours per year times the square feet of window area that sun is incident on the glass during the summer cooling cycle ______ to ______ .

1. Estimate the square feet of glass area for each orientation and insert in Table 10.

2. Determine your North latitude ______ from Figure 9 and the appropriate multiplying factor ______ from Table 11.

3. Estimate the average hours of daily sunshine ______ from Figure 11.

4. Multiply the value in Item 3 above by the multiplying factor in Item 2 above.
   ______ X ______ = ______ % Sun Hours/Day.
   Insert in Table 10.

5. Estimate the hours per day of possible sun on each window orientation if there were no clouds. Insert in Table 10.

6. Estimate the days occupied during the summer cooling cycle ______ and insert in Table 10.

7. Calculate the total glass area with possible sun on it.

8. Calculate the total square feet hours per year of sun incident on the window orientations and add the totals.

TABLE 10. TOTAL SQUARE FEET HOURS OF WINDOW SUN PER YEAR

WINDOW ORIENTATION	SQUARE FEET GLASS		% SUN HOURS/DAY		HOURS/DAY POSSIBLE SUN		DAYS OCCUPIED		SQUARE FEET HOURS/YEAR
______	______	X	______	X	______	X	______	=	______
______	______	X	______	X	______	X	______	=	______
______	______	X	______	X	______	X	______	=	______
______	______	X	______	X	______	X	______	=	______
______	______	X	______	X	______	X	______	=	______
TOTAL		SQUARE FEET					TOTAL	=	

TABLE 11. DAYLIGHT MULTIPLYING FACTOR

NORTH LATITUDE	SUMMER	WINTER
24	0.077	0.091
28	0.075	0.093
32	0.074	0.095
36	0.072	0.098
40	0.071	0.101
44	0.069	0.104
48	0.068	0.108
52	0.066	0.111

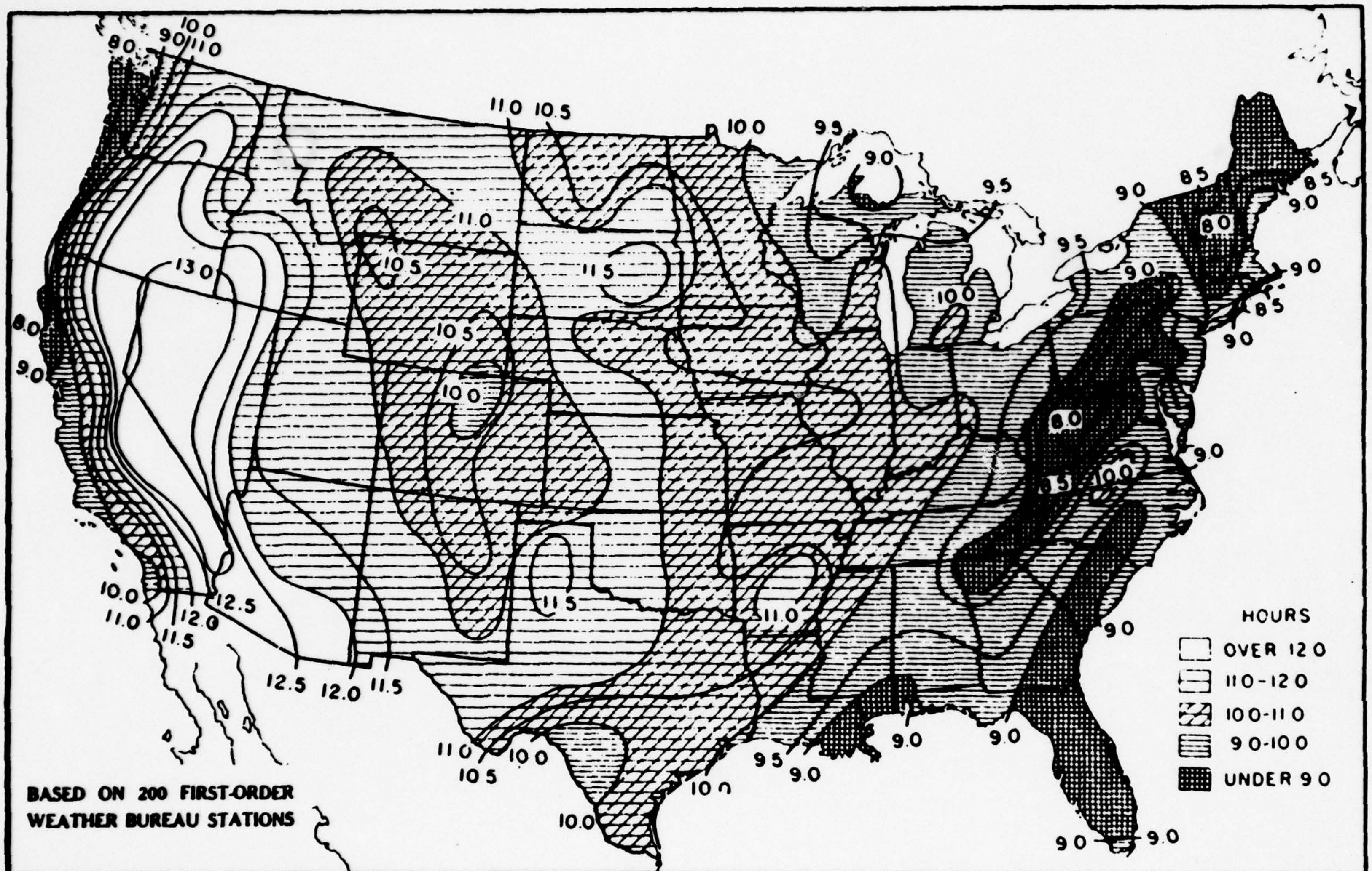


Figure 11. Average Number of Hours of Sunshine Daily, Summer (June - August)

Calculate extra annual electric lighting needed to replace daylight if fixed controls are on the windows.

9. Calculate annual hours of daylight occupancy of facility.

_______________ X _______________ =
Days Occupied/Year   Average Daylight Hours Occupied/Year

____
Occupied Daylight Hours/Year

10. Multiply value in Item 9 above by total glass area from Table 10.

_______________ Hrs/Yr X _______ SqFt =
Occupied Daylight   Table 10 Glass

____
Square Feet Hours/Year of Daylight

11. Subtract the total square feet hours per year of sun on windows in Table 10 from the value in Item 10 above.

_______________ - _______________ =
Square Feet Hours/Year Occupied Daylight   Square Feet Hours/Year Table 10/Sun

____
Square Feet Hours/Year

12. Estimate lumens per watt for electric light fixtures
______ lumens/lamp watt.

- Incandescent with a Light Loss Factor of 80%

  Lamps: 60-100 watt (12)*
  150-200 watt (15)*
  300-500 watt (16)*

- Fluorescent lamps with auxiliary and 80% Light Loss Factor

  Deluxe-40* Standard-50* Energy Saving-55*

  *Approximate lumens/watt.

- Mercury & Sodium - Obtain initial lumen rating/watt and recommended Light Loss Factor from Manufacturer.

Calculate daylight loss from fixed control on window.

13. Determine visible transmittance of glass.
______ Glass Transmittance.
Clear glass is approximately 88%.

14. Determine visible transmittance of fixed control.
______ Fixed Control Transmittance.

15. Multiply Glass Transmittance by Fixed Control Transmittance = Transmittance Total.

________________ X ________________ =
Glass Transmittance Fixed Control Transmittance

____
Transmittance Total

16. Subtract Transmittance Total from Glass Transmittance to get Transmittance Loss from control.

__________________ - __________________ =
Glass Transmittance   Transmittance Total

____
Transmittance Loss

17. Calculate lumens loss/square foot of glass. Multiply the available daylight (500 lumens/square foot is considered a normal equivalent sky if local data is not available) by the Transmittance Loss above.

__________________ X __________________ =
Lumen/Square Foot   Transmittance Loss

____
Lumen Loss/Square Foot

18. Calculate additional KWH/year needed to offset daylight loss from fixed control. Multiply lumens loss/square foot above by square foot hours/year in Item 11.

__________________ X __________________ =
Lumen Loss/Square Foot   Square Feet Hours/Year

____
Lumen Hour Loss

19. Divide the lumens loss above by lamp lumens per watt estimate in Item 12. Multiply the product by 0.001 to obtain the additional KWH/year to offset the loss of daylight.

__________________ - __________________ = __________
Lumen Hour Loss   Lumens/Watt X 0.001   KWH/Year

20. Calculate annual cost of electricity to offset daylight loss from fixed control. Multiply KWH/year above by the cost/KWH.

______ X ______ = ______

KWH/Year   Dollar/KWH   Annual Cost

CONCLUSIONS

Energy savings associated with retrofit treatment of windows with solar control films and screens depend upon many factors. It is certain, however, that for most cases greater energy savings are realizable from window treatments that are manageable. In fact, there is some evidence that proper window management that includes use of a thermal barrier (drapes, shades, etc.) on winter nights combined with shading on summer days and the substitution of daylighting for electric light whenever practical can improve window performance beyond that of a solid wall. In locations where the heating season is very short or non-existent, one must still consider possible energy reductions by use of artificial light before considering an unmovable shading device. Natural shading such as deciduous trees, roof overhangs, etc. can negate most of the solar heat gain aspects of other shading techniques. A simplified method of determining the energy saving potential of solar films and screens has been provided to guide facility engineering people in making life cycle cost analysis of various shading alternatives.

RECOMMENDATIONS

Since the common commerically available solar control films and screens have been adequately tested concerning their solar optical properties according to commonly accepted techniques established by ASHRAE, additional such tests are not recommended.

There is a great need for field performance data that would provide information on the annual (heating and cooling) energy saving performance of solar films and screens. A program of this type is currently being funded by the Department of Energy and is being conducted by the Lawrence Berkeley Laboratory. It is expected that results of this work will be available by mid 1979.

The data being collected by the Lawrence Berkeley Laboratory could be utilized to verify computer modeling programs already available from NBS and CERL. Once these programs have been tuned in with the real world, they could be written for easy access by those desiring to evaluate various energy conservation techniques.

Consideration should be given to establishment of programs for instructing building supervisors, homeowners, etc. on window management and sun control techniques.

Some very limited work with dual shading systems such as drapes and roller shades with combinations of reflective and diffuse shading indicates promise. This area should be explored in more detail. John Yellott has been doing work in this direction and hopes to present his work at the next ASHRAE meeting.

It is recommended that some efforts be directed at determining the State of the Art of the use of automatic controls for shading. Several methods are in use in Europe and are in the development stage in this country.

REFERENCES

[1]Kanarowski, Stanley M., "Investigation of Reflective Solar Control Films for Windows", Special Report M-240, Construction Engineering Research Laboratory, Champaign, Illinois, June 1978.

[2]Yellott, John I., "Selective Reflectance - A New Approach to Solar Heat Control", ASHRAE Transactions, Vol. 69, 1963, p. 418.

[3]Morrison, C. A., Wheeler, J. M., and Farber, E. A., "An Experimental Determination of Shading Coefficients for Selected Insulating Reflective Glasses and Drapes", No. 2382, RP 132, pg. 38-58.

[4]Matrix, Inc., Report No. 6010-143, 10 March 1976. (Matrix, Inc. formerly Yellott Solar Energy Laboratories)

[5]Yellott, John I., "Energy Conservation and Economy Through Sun Control", Report Prepared for Koolshade Corporation.

[6]Pennington, C. W., "How Louvered Sun Screens Cut Cooling, Heating Loads", Heating, Piping and Air Conditioning, December 1968.

[7]Yellott, John I., "Effect of Louvered Sun Screens Upon Fenestration Heat Loss", ASHRAE Transactions, Vol. 78, Part I, 1972.

[8]Parmelee, George V., "Shading of Sunlit Glass; An Analysis of Uniformly Spaced Flat Opaque Stats", ASHVE Transactions, Vol. 58, 1952, p. 377.

[9]Parmelee, George V., Aubele, W. W., Vild, Donald J., "Shading of Sunlit Glass - An Experimental Study of Slat Type Sun Shades for Use in Load Estimating", ASHVE Transactions, Vol. 59, 1953, p. 221.

[10]Parmelee, George V., and Vild, Donald J., "Design Data for Slat Type Sun Shades for Use in Load Estimating", ASHVE Transactions, Vol. 59, 1953, p. 403.

[11]Ozisik, N. and Schutrum, L. F., "Solar Heat Gain Factors for Windows with Drapes", ASHRAE Transactions, Vol. 66, 1960, p. 228.

[12]Farber, E. A., Smith, W. A., Pennington, C. W. and Reed, J. C., "Theoretical Analysis of Solar Heat Gain Through Insulating Glass with Inside Shading", ASHRAE Transactions, Vol. 69, 1963, p. 392.

[13]Schutrum, L. F., "Solar Heat Gains Through Types of Flat Window Glass", ASHRAE Transactions, Vol. 68, 1962, p. 167.

[14]Jordan, R. C. and Threlkeld, J. L., "Determination of the Effectiveness of Window Shading Materials on the Reduction of Solar Radiation Heat Gain", ASHRAE Transactions, Vol. 65, 1959, p. 683.

[15]Ozisik, N. and Schutrum, L. F., "Solar Heat Gain Factors for Windows with Drapes", ASHRAE Transactions, Vol. 66, 1960, p. 228.

[16]Ozisik, N. and Schutrum, L. F., "Heat Gain Through Windows Shaded by Metal Awnings", ASHRAE Transactions, Vol. 65, 1959, p. 311.

[17]Ozisik, N. and Schutrum, L. F., "Heat Flow Through Glass with Roller-Shades", ASHRAE Transactions, Vol. 65, 1959, p. 697.

[18]Hittle, D. C., "The Building Loads Analysis and System Thermodynamics Program Volume I: User's Manual", U. S. Army Construction Engineering Research Laboratory, Champaign, Illinois, December 1977.

[19]Kusuda, T. and Collins, B. L., "Simplified Analysis of Thermal and Lighting Characteristics of Windows: Two Case Studies", NBS Building Science Series 109, February 1978.

[20]Selkowitz, S. and Berman, S., "Energy Efficient Windows Program Activities", Unpublished Report by Windows and Lighting Program of the Lawrence Berkeley Laboratory on a DoE Funded Research Program.

[21]ASHRAE, Handbook of Fundamentals, American Society of Heating, Refrigeration, and Air Conditioning Engineers, New York, 1972.

[22]Illuminating Engineering Society, Recommended Practice of Daylighting, August 1962.

[23]Holton, J. K., "Daylighting of Buildings: A Compendium and Study of Its Introduction and Control", National Bureau of Standards, PB-259 523, October 1976.

[24]Botros, M. M., "Lighting Design and Energy Conservation", FESA-RT-2043, August 1977.