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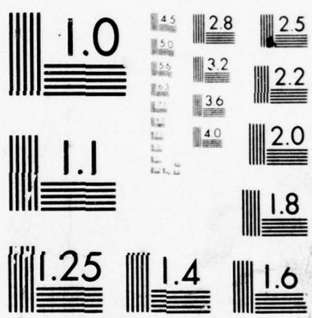

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SPECIAL REPORT M-240
June 1978
Evaluation and Introduction of New Construction
Materials and Techniques

LEVEL IV

INVESTIGATION OF REFLECTIVE SOLAR CONTROL FILMS FOR WINDOWS

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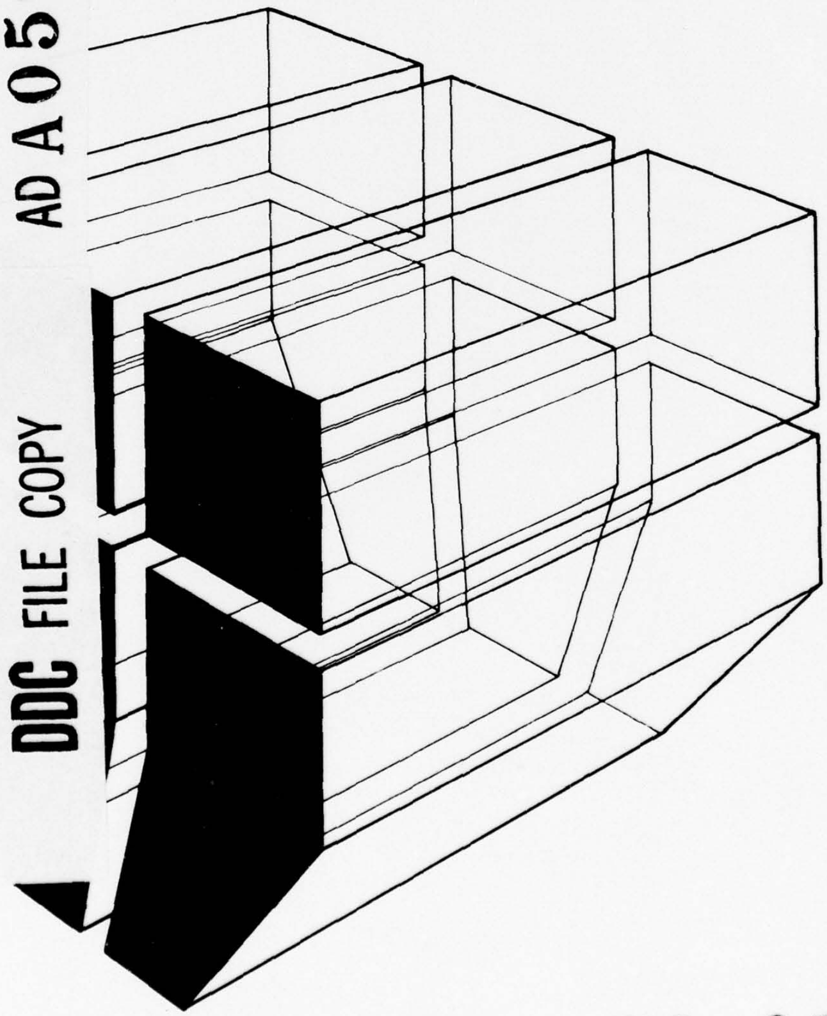

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This report presents the results of a study of flexible solar control film applied on windows to eliminate or reduce glare and solar heat, and to conserve energy. Four manufacturers' films were investigated by (1) surveying users in 15 areas of the United States, (2) visiting selected installations, and (3) conducting a laboratory evaluation of film/glass samples. In addition, solar radiation heat

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balance profiles were developed to indicate the solar heat gain through clear glass with and without solar film. A computer heating and cooling load and systems simulation program was run on a typical 72-man barracks module. Annual heating and cooling loads and costs and the related life-cycle cost (LCC) for the barracks module were computed for several types of window glass, solar film on clear glass, and interior shading.

Building management personnel and occupants who responded to the survey generally favored using solar film on windows because of glare and solar heat reduction. They further felt that there was reduction in cooling costs, some possible reduction in heating costs, and improved comfort. Performance was considered good to excellent by 90 percent of the respondents. The solar radiation heat balance profiles indicate that the film reduces solar radiation heat transmitted through windows into a building.

The annual gas heating costs were low for the nine window systems programmed on the barracks module using Fort Worth, TX weather data. Costs varied from $25 for 1/8-in. (3.18-mm) clear glass with solar film (no interior shading) to $33 for 1/8-in. (3.18-mm) clear glass with medium venetian blinds. Total annual electric costs including cooling varied insignificantly from $3096 for 1/8-in. (3.18-mm) clear glass with solar film and medium venetian blinds to $3184 for 1/8-in. (3.18-mm) clear glass alone. The solar film systems with or without venetian blinds had the lowest total annual gas and electric costs, but the savings were only $92 or less.

Considering energy requirements for the nine window systems, the LCC varied from $224,751 for 1/8-in. (3.18-mm) clear glass alone to $290,784 for 1/8-in. (3.18-mm) reflecting glass with medium venetian blinds. The solar film/window system with or without interior shading was the second highest in LCC.

FOREWORD

This laboratory investigation was conducted as part of the Facilities Investigation and Studies Program sponsored by the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under OM&A Project 4K078012A0K1, "Engineering Criteria for Design and Construction"; Task 02, "Applications Engineering"; Work Unit 106, "Evaluation and Introduction of New Construction Materials and Techniques." The work was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL. Dr. G. R. Williamson is Chief of EM. The OCE Technical Monitor was Mr. W. R. Darnell, DAEN-MCE-S.

Acknowledgment is made to the Libbey-Owens-Ford Company for furnishing and cutting the small glass samples used in original laboratory tests and the University of Illinois for conducting transmission measurements in the near infrared spectral region. Contractors were Matrix, Inc. (measurement of the solar radiation heat gain or loss through the film/glass systems), and the Naval Avionics Facility (specular reflectance measurements). Contributions to this study were made by Mr. R. E. Aufmuth, Mr. R. Neathammer, Mr. D. Herron, Mr. D. C. Hittle, and Ms. F. Abt, of CERL.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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INVESTIGATION OF REFLECTIVE SOLAR CONTROL FILMS FOR WINDOWS

1 INTRODUCTION

Background

It is the Army's policy to introduce new and improved materials which perform more efficiently and at lower costs into the military construction program as quickly as possible. This investigation deals with the use of flexible reflective films that can be applied to windows of new and existing construction in an attempt to reduce solar heat and glare, and to conserve energy by reducing cooling costs.

Objective

The objectives of this report are (1) to investigate the use of flexible reflective films designed to reduce solar heat and glare, and (2) to delineate the characteristics of the films that could contribute to reduced operation and maintenance costs at Army installations.

Approach

A comprehensive search was conducted to determine whether specifications for solar film are available. Manufacturers of solar film were contacted to obtain product information, names of users, and solar film samples for laboratory studies. A field survey of users with solar film installations over 2 years old was conducted in 15 geographical locations in the United States. Specific information on the installations was obtained together with a performance appraisal. Nineteen installations were visited to investigate film performance under various conditions.

Solar radiation heat balance profiles were developed to indicate the magnitude of solar heat gain through 1/4-in. (6.35-mm) clear glass with solar film at 40° north latitude and peak load. A computer heating and cooling load and system simulation program was run, and a life-cycle cost comparison was made using several types of window glass, solar film on clear glass, and interior shading. A 72-man barracks module at Fort Hood was used as the sample building for data input. Data regarding occupants' psychological reactions to the use of film in buildings were obtained.

Scope

This investigation covers the pressure-sensitive and adhesive-added types of solar film sold by each of the four major manufacturers (Appendix A). It does not include other systems such as flow-on coatings, solar control window shades, and solar window screens.

Mode of Technology Transfer

This report will impact on U.S. Army Corps of Engineers Guide Specification CEGS-08810, *Glass and Glazing* (November 1977).

2 PRODUCT DESCRIPTION

Flexible solar reflective film is manufactured primarily for interior applications, although it is sometimes used on exterior window surfaces. It is approximately 1 mil (0.0254 mm) thick and is available in a variety of colors including silver, gray, bronze, and gold.

The most common type of solar film consists of clear polyester film (polyethylene terephthalate) vapor-coated on one side with a metal (generally aluminum) and finish-coated with a protective coating. The density of the metal coating can be varied depending on the degree of reflection and transmission desired. Prior to metal coating, an ultraviolet light inhibitor is usually incorporated in the film.

A second type of solar film is made by vapor-coating a 0.5 mil (0.0127 mm) thickness of polyester film and laminating another 0.5 mil (0.0127 mm) thickness of clear or tinted polyester film over the aluminum coating. This type of film offers the advantages of being available in combinations of two colors (e.g., gray on one side and reflective aluminum on the other) and provides additional protection to the aluminum coating. Films are available for various types of glass, including tinted glass and heat-absorbing glass.

Most solar reflective films are furnished with one of two types of adhesive systems--pressure-sensitive and adhesive-added. Generally, the pressure-sensitive type has adhesive on the film; the adhesive is covered with a strippable plastic sheet which is removed just prior to installation. With the adhesive-added system, a separate adhesive is applied to the film at the time of installation.

One manufacturer, however, uses two water-activatable systems. In one system, a pressure-sensitive type, a water-soluble protective coating is washed away prior to installation. In the second system, the adhesive is applied at the factory and reactivated with water on the job site rather than applied at the site as in the regular adhesive-added system.

Pressure-sensitive adhesive types of solar film are usually used in humid climates while the adhesive-added system is used in dry climates (see Chapter 3). Some applicators use both types in the same geographical area.

Solar reflective films are supplied under a variety of trade names. Manufacturers use code numbers which relate to the fraction of solar transmission of the particular film.

Warranties range from 2 to 5 years depending on the film type, method of application, and manufacturer.

Solar film can be installed by professional applicators or by users since each manufacturer furnishes detailed installation instructions. Installation is simple and requires a minimum of equipment; a tool kit can be purchased for between $4 and $30 (professional kit).

Manufacturers furnish materials for the protection of the film's surface and for filling any scratches. If the film is damaged, it can be patched or the bad section cut out and replaced; however, since some overlap is needed to seal out moisture, the edges of the patch will be visible and the color can vary. Most manufacturers are opposed to patching because of the appearance and the resulting reduction of optical clarity. They recommend replacing the entire sheet.

Forty-seven organizations (Table 1) were contacted between March and June 1974 to determine whether specifications for solar films and coatings for windows were available. Data obtained were very limited, and no specifications other than manufacturers' product properties and an American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard[1] were found to be available. Appendix B lists related specifications.

Table 1
Organizations Contacted

American Insurance Association
American National Standards Institute
American Society of Heating, Refrigerating, and Air-Conditioning Engineers
American Society of Mechanical Engineers
American Society for Testing and Materials
Construction Specifications Institute
National Fire Protection Association
Society of the Plastics Industry
Underwriters' Laboratories

Building Officials Conference of America
International Association of Plumbing & Mechanical Officials
International Conference of Building Officials
Southern Building Code Congress

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[1] *Method of Measuring Solar-Optical Properties of Materials*, ASHRAE Standard 74-73 (1973).

CE Glass Division of Combustion Engineering, Inc.
Corning Glass Works
Libbey-Owens-Ford Company
PPG Industries, Inc.

3M Company, Industrial Tape Division
Madico Material Distributors Corporation
Solar Control Products Corporation
Sun-X International, Inc.
Standard Packaging Corporation
General Solar Corporation
A-Beta Industries
Koolshade Corporation
Sun Check, Inc.
Transparent Glass Coatings Co., Inc.

Optical Coating Laboratory, Inc.
Solar Energy Applications, Inc.
Yellott Solar Energy Laboratory (Arizona State University)
DuPont Co., Film Department
Rohm & Hass Company

ICI United States, Inc.*
Celanese Plastics Co.*
Martin Processing, Inc.*

Atomic Energy Commission
Bureau of Reclamation
Federal Housing Administration
Fort Belvoir
Government Services Administration
Naval Facilities Engineering Command
National Aeronautics and Space Administration
National Bureau of Standards
Picatinny Arsenal, Plastics Technical Evaluation Center
Wright Patterson Air Force Base

Boeing Airplane Company
Sandia Laboratories

* Contacted in 1976.

3 FIELD INVESTIGATION

The field investigation portion of this study consisted of (1) a field survey of users of solar film, (2) site visits to installations, and (3) interviews with occupants of buildings having solar film on the windows.

Field Survey of Users of Solar Film

The four major solar film manufacturers--Material Distributors Corp. (Madico), Minnesota Mining & Manufacturing (3M), Solar Control Products Corp.* (Solar-X), and Sun-X International, Inc.--provided addresses of 337 users in the 15 geographical locations in the United States selected for survey (Table 2). These users were sent a questionnaire (Appendix C) designed so responses could be easily input into a computer for analysis; 219 (65 percent) responded.

The ages of installations surveyed ranged from 0.7 to 10 years. The average age was 3.3 years; 47 percent of the installations were between 2 and 4 years old.

One hundred thirty-eight users reported installations which varied in size from 36 to 55,500 sq ft (3.3 to 5156.1 m^2). Average installation size was 3136 sq ft (291.3 m^2).

Table 2
Survey Locations

1. Seattle, WA	9. St. Louis, MO
2. San Francisco, CA	10. Indianapolis, IN
3. Los Angeles, CA	11. Cincinnati, OH
4. Phoenix, AZ	12. New York, NY
5. Denver, CO	13. Philadelphia, PA
6. Dallas, TX	14. Baltimore, MD
7. Houston, TX	15. Orlando and Miami, FL
8. Chicago, IL	

Data from 209 of the 219 respondents (10 responses were considered unusable) were analyzed. The analysis results are summarized below.

---
* Name changed to Solar-X Corporation in 1976.

Installation Data

Of the 209 responses analyzed, 29 (13.9 percent) were from users of Madico film, 80 (38.3 percent) from users of 3M film, 53 (25.3 percent) from users of Solar Control Products film, and 47 (22.5 percent) from users of Sun-X film. Table D1 (Appendix D) breaks down questionnaire responses by manufacturer's film used. General survey results were as follows:

Chief reasons for using solar film--

To eliminate or reduce glare and reduce solar heat	26.7 percent
To reduce solar heat	26.2 percent
To eliminate or reduce glare	19.5 percent
Miscellaneous	27.6 percent
	100.0 percent (N=195)

Solar film installed on windows facing--

South	23.9 percent
West	16.2 percent
South and west	13.2 percent
East, south, and west	11.7 percent
Miscellaneous other combinations	35.0 percent
	100.0 percent (N=197)

Types of windows to which solar film was applied--

Clear glass	75.0 percent
Tinted	16.0 percent
Thermopane	2.5 percent
Miscellaneous	6.5 percent
	100.0 percent (N=200)

Glass thickness of windows--

1/4 in. (6.35 mm)	63.7 percent
3/16 in. (4.76 mm)	11.8 percent
1/8 in. (3.18 mm)	6.9 percent
3/8 in. (9.53 mm), 5/16 in. (7.94 mm), and other	17.6 percent
	100.0 percent (N=102)

Ninety-nine percent of 106 users responding to the question regarding warranty period stated they had a warranty period of between 1 and 5 years.

Installation costs reported by 97 film users varied from \$0.50 to \$4/sq ft (\$5.38 to \$43.01/m^2) with an average cost of \$1.71/sq ft (\$18.39/m^2).

Performance Data

Overall performance was evaluated as--

Excellent	34.2 percent
Very good	27.0 percent
Good	28.6 percent
Fair	4.6 percent
Other	5.6 percent
	100.0 percent (N=196)

Eighty-six percent of 130 respondents stated that air-conditioning costs were reduced, while 14 percent reported no reduction. Only 51 of the users indicated the amount of cost reduction experienced; reductions ranged from 1 to 50 percent, with an average of 16.7 percent.

Forty-six percent of 108 respondents reported reduced heating costs, while 54 percent reported no reduction. Only 19 of the users indicated the amount of cost reduction experienced; percent reduction ranged from 5.3 to 21.1, with an average of 13.2.

Users indicated that the film is effective in reducing or eliminating glare (97.5 percent of 200 respondents) and in reflecting solar heat (96.7 percent of 182 respondents), but does not shut out an undue amount of light (82.2 percent of 197 respondents) or obstruct the view to the outside (89.1 percent of 193 respondents). Of 196 users responding, 27.6 percent said that film does not affect indoor plants while 4 percent said it does; 68.4 percent said they did not know.

Durability and Cleaning Data

Eighty-nine percent of 194 users responding stated that the film can withstand cleaning. The types of cleaning materials used were:

Water	33.5 percent
Water and ammonia	20.1 percent
Soap and water	28.5 percent
Commercial cleaner	17.9 percent
	100.0 percent (N=179)

Of 192 users responding, 55.7 percent said the film is not easily damaged while 33.9 percent stated that it is. The remaining 10.4 percent gave other, qualified answers.

Of 194 respondents to the question on aging,* 73.2 percent reported no effect, 20.6 percent reported a small effect, and 6.2 percent reported a large effect or gave a qualified response.

Of the 38 installations more than 5 years old** (average 6.4 years), 55 percent were not affected by aging, 24 percent had a small effect, 16 percent had some effect, and 5 percent were more affected.

The types of aging effects mentioned were pinholes, slight scratches from cleaning, loose edges, slight blotching, splitting, peeling in spots, and slight irregularities.

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* Three manufacturers and a processor of the basic unmetallized polyester film were contacted for their comments on aging; Appendix E summarizes their responses.

**From a separate analysis of the user field survey.

To show possible effects of aging on responses to other questions, Table D2 (Appendix D) summarizes user responses for installations 3 years old or less, and those more than 3 years old.

Reported Advantages and Disadvantages of Using Solar Film

The major advantages of solar film reported were--

Eliminates sun damage	13.1 percent
Controls heat and glare	13.1 percent
Limits vision into building	11.1 percent
Helps eliminate glare	10.1 percent
Solves heat problem at reasonable cost	9.1 percent
Others (16)	43.5 percent
	100.0 percent (N=99)

The major disadvantages reported were--

Reduces available light	17.9 percent
Some visibility to outside lost	14.3 percent
Cost	10.7 percent
Cleaning care	7.1 percent
Reflections	7.1 percent
Replacement when windows broken and scratches	10.8 percent
Others (15)	32.1 percent
	100.0 percent (N=56)

Table D3 (Appendix D) summarizes users' comments on advantages and limitations or disadvantages of solar film.

Installation Visits

Selected installations which use solar film in Illinois and Arizona were visited to evaluate field performance and user satisfaction. Tables D4 and 5 (Appendix D) summarize data collected during these site visits.

Fort Huachuca, AZ

Personnel contacted at Fort Huachuca were satisfied with both the Madico RSL-100-20 and Solar-X S-80 adhesive-added films being used. They reported that both types reduce or eliminate glare, reflect solar heat, reduce air-conditioning load and heating cost, and improve overall comfort and cooling balance. Scratches and nicks in film installed on doors were the only problems experienced.

Pressure-sensitive film was not used at Fort Huachuca, since the adhesive dried too fast during installation. (If this occurred during application of adhesive-added type film, more adhesive could be applied.)

Additional solar film has been requested at Fort Huachuca--approximately 80,000 sq ft (7432.2 m^2) in administrative offices, and approximately 275,000 sq ft (25548.3 m^2) in military family quarters.

Phoenix, AZ, Area

Ten buildings where 3M, Sun-X International, and Solar Control Products films were used were investigated. Users interviewed at three installations ranging from 1 to 4-2/3 years old were well satisfied with the performance of solar film. Users reported (1) a savings in air-conditioning and, to some extent, heating costs, (2) reflection of solar heat, and (3) a reduction in glare. (For a detailed listing of user responses, see Table D4, Appendix D.)

Data on the remaining seven buildings are listed in Table D5 in Appendix D.

University of Illinois, Urbana-Champaign, IL

Three buildings with solar film installations ranging in age from one-half to 3-1/2 years were investigated on the University of Illinois campus. The engineer associated with the project characterized the film's performance as "very good" to "excellent." Users also reported reductions in air-conditioning and heating costs, solar glare, an increase in reflection of solar heat, and in comfort. However, aging has had a small effect on the film, and it is subject to damage.

U.S. Post Office, Champaign, IL

This installation is 2-1/3 years old and the film is performing excellently, according to the postmaster. Air-conditioning cost has been reduced, solar heat is reflected, and glare reduced.

Occupant Interviews

Thirty-three occupants of six local (Champaign-Urbana, IL) buildings which use solar film were interviewed to assess their reactions to the film. (See Tables D4 and D6, Appendix D.)

Some generalizations are:

1. 82 percent had occupied the building before solar film was installed.

2. 94 percent had no previous experience with solar film.

3. Noticeable differences in glare, temperature, and privacy were reported by 79, 46, and 43 percent of the occupants, respectively.

4. 49 percent of the occupants thought there was no view obstruction and 33 percent thought there was no difference in control of light and privacy; 39 percent thought employee attitude had improved.

5. 73 percent liked solar film on windows, 6 percent had no response.

6. 91 percent were accustomed to the film.

7. 64 percent reported no maintenance problems.

8. 46 percent of experienced users had favorable comments about solar film, 12 percent had unfavorable comments.

9. More users were satisfied with venetian blinds compared to drapes and curtains as devices for interior shading. Drapes were generally considered unsatisfactory.

10. 76 percent preferred a window combination of film and control devices, e.g., venetian blinds.

Table D6 in Appendix D is a detailed tabulation of the occupants' comments.

4 LABORATORY INVESTIGATIONS

The laboratory investigation consisted of: (1) determination of the effects of cleaning materials on solar film, and (2) evaluation of solar film's effectiveness as a solar energy barrier.

Effect of Cleaning Materials on Solar Film

The following nine cleaning materials were randomly selected for use in the two cleaning tests:

1. Windex Glass Cleaner with Ammonia D--Aerosol Spray
2. Windex Glass Cleaner with Ammonia D--Hand Pump Spray Bottle
3. Bo-Peep (cloudy) Ammonia, 2 fl oz/qt (62.5 cm^3/L) water--Spray Bottle
4. Glass Cleaner, Isopropanol, Di Water, GSA--Spray Bottle
5. Easy-Off Window Cleaner with Ammonia--Aerosol Spray
6. Joy, Lemon Fresh, 2 fl oz/qt (62.5 cm^3/L) water--Spray Bottle
7. Gulf Window Cleaner with Ammonia--Aerosol Spray
8. Sparkle Glass Cleaner--Hand Pump Spray Bottle
9. Calgon Water Softener, 1/2 tsp/qt (2.60 cm^3/L) water--Spray Bottle

In the first test, separate sections of a window having aluminum or silver finish solar film were sprayed with each of the above cleaners. The cleaners were wiped off with a lintless paper towel, and the film's surface felt by hand for grittiness and examined visually for cleanliness and damage. All the cleaners successfully removed dirt from the film and did not scratch or otherwise damage it. However, some spread better, had better wetting action, and tended to hold better and not run down in streaks. The three aerosol sprays (1, 5, and 7) were the best in this respect. Cleaners 2, 3, 6, and 8 were also acceptable. Cleaners 4 and 9 had limited wetting action, similar to water on a waxed or greasy surface.

The second test evaluated whether any of the nine cleaners caused any chemical deterioration, etching, loss of mirror gloss or polish, scratching, or other visible effects on the surface of a similar sheet of film. A sheet of film was laid on a table top and nine separate areas were marked. Each of the cleaners was applied by finger on one area and allowed to remain on the film for 16 hr at room temperature. After 16 hr, the sheet was examined; each of the dried cleaners left a residue on the film. The residues were removed with warm water and a paper towel (lintless), and the areas were examined. No visible effect was noted from any of the cleaners.

General Precautions for Cleaning Solar Film on Windows

Liquid detergent should be applied with a hand spray, synthetic sponge, or soft cloth if it is not furnished as an aerosol spray. Only nonabrasive detergents and weak ammonia solutions should be used.

The film should be dried with soft, lintless paper towels, a soft turkish towel, or a soft squeegee (on large areas). Film should be wiped while wet to avoid scratching.

Brushes, natural sponges, and abrasive or caustic detergents should not be used, and excessive wiping of dry film should be avoided.

Effectiveness of Solar Film as a Solar Energy Barrier

This evaluation consisted of: (1) measuring the solar optical properties (solar radiation transmitted, reflected, and absorbed)* of various combinations of glass and solar film in direct sunlight over a wavelength range of 200 to 4500 nanometers (nm), and (2) making spectrophotometric laboratory measurements of the energy transmitted and reflected within the wavelength range of 300 to 3000 nm, minimum.

Solar Optical Properties

Two test series were conducted in the evaluation of solar optical properties. The initial test series evaluated only the solar transmittance characteristics of various glass and solar film combinations. The second test series evaluated the total solar optical properties (transmittance, reflectance, and absorptance) of typical glass and solar film combinations.

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* When radiant heat energy strikes an object it forms three separate components: transmitted energy (heat that goes through the object), absorbed energy (heat diffused within the object, part of which is reradiated in and part reradiated out), and reflected energy (the component that is neither diffused nor transmitted but is bounced back).

For the initial test series, samples of pressure-sensitive, water-activated, and adhesive-added film systems were furnished by the four major manufacturers. The films used in the CERL tests were applied to nine different glass specimens (see Table 3) by the film manufacturer's representatives. Sample size was 2 in. x 3 in. (50.8 mm x 76.2 mm). There were 18 samples for each of the four manufacturers plus nine plain glass samples without film for a total of 81 samples.

Matrix, Inc.,* conducted solar transmittance tests on all 81 samples at a 90 degree angle between the solar rays and sample surface. Instrumentation used included a thermopile pyrheliometer, potentiometer, variable resistor, and recorder. The transmittance values were calculated as heat gains in Btu. Table 3 gives the results of these tests.

The film greatly reduced the percentage of solar Btu heat gain through all nine types of glass, with values among the four manufacturers generally comparable. The 3/16-in. (4.76-mm) and 1/4-in. (6.35-mm) tinted and heat-absorbing glass/film systems had lower solar heat gains than the corresponding clear glass/film systems. The tinted and heat-absorbing glasses without film permitted less heat gain than plain clear glass of the same thickness. A trend of reduction in solar heat gain with increasing glass thickness is also apparent. The solar optical properties of reflectance and absorptance were not included in this test since larger samples, 12 in. x 12 in. (0.3048 m x 0.3048 m) are required.

The second series of tests investigated total solar optical properties and Btu heat gains of typical glass and solar film combinations. Libbey-Owens-Ford 1/4-in. (6.35-mm) clear float glass was used. Pressure-sensitive solar film from the four major manufacturers was applied on 24-in. x 24-in. (61-cm x 61-cm) squares of the glass in accordance with manufacturers' instructions. Pieces of the film were also applied on 2-in. x 2-in. (5.08-cm x 5.08-cm) squares of the same type of glass for emittance tests. Eight film/glass samples and each size of plain glass were sent to Matrix, Inc., where tests were performed using a thermopile pyrheliometer, potentiometer, variable resistor, and recorder.

Figures 1a through 1e show the solar radiation Btu heat balance profiles for the four manufacturers' film and the plain glass (also see Tables 4 and 5). The profiles show much lower total solar heat gains through the film/glass samples--67 to 74 Btu/hr-ft^2 (211 to 233 W/m^2) under the specified conditions compared to 214 Btu/hr-ft^2 (675 W/m^2) for the plain clear glass. Solar heat rejected by the film/glass samples was much higher--187 to 193 Btu/hr-ft^2 (590 to 609 W/m^2) compared to 48 Btu/hr-ft^2 (151 W/m^2) rejected by the plain clear glass.

* Formerly Yellot Solar Energy Laboratories.

Table 3

Heat Gain (Btu) From Solar Transmittance Through Nine Types of Plain Glass and Film on Glass

Glass Thickness	1/8 in. (3.18 mm)		3/16 in. (4.76 mm)								1/4 in. (6.35 mm)							
Glass Type*	Clear		Clear		Bronze		Gray		Heat-Absorbing		Clear		Bronze		Gray		Heat-Absorbing	
	Btu	% Transm	Btu	% Transm	Btu	% Transm	Btu	% Transm	Btu	% Transm	Btu	% Transm	Btu	% Transm	Btu	% Transm	Btu	% Transm
Uncoated or plain glass	204	82.4	192	77.9	133	53.9	129	52.1	135	54.5	184	74.5	120	48.6	114	46.3	118	47.9
1. SC**(PS-80)†	25	10.0	27	10.4	18	7.1	16	6.5	19	7.6	24	9.9	16	6.3	15	6.0	16	6.6
2. M (RSLW-100-20 HCX)††	38	15.3	36	14.6	25	10.1	24	9.9	27	11.0	35	14.1	23	9.4	23	9.2	24	9.8
3. S (F-88 Special)	35	14.0	34	13.9	24	9.8	21	8.5	20	7.9	37	14.9	16	6.4	15	6.2	19	7.5
4. 3M (P-18)	35	14.2	33	13.3	23	9.2	22	9.1	25	10.1	32	13.1	18	7.1	17	6.9	20	8.0
5. SC (S-80)	32	13.0	31	12.4	20	8.2	20	8.1	23	9.5	30	12.3	19	7.6	20	7.9	21	8.3
6. M (RSLW-100-20)††	31	12.4	30	12.0	20	8.1	19	7.6	21	8.3	27	11.0	18	7.4	17	6.8	18	7.3
7. S (F-88)	33	13.3	32	12.8	22	8.9	21	8.6	24	9.8	31	12.7	20	8.2	19	7.5	22	8.8
8. 3M (A-18)	31	12.6	29	11.7	18	7.4	19	7.7	22	8.9	28	11.5	17	7.0	18	7.2	20	8.1
Average for film on glass	33		32		21		20		23		31		18		18		20	

*All glass is float glass.

**Adhesive type (film on glass):
Films 1 through 4, pressure-sensitive.
Films 5 through 8, water-activated or adhesive-added.

†SC is Solar Control Products Corporation
M is Material Distributors Corporation (Madico)
S is Sun-X International, Inc.
3M is Minnesota Mining and Manufacturing Company.

††Tests on manufacturer's sample series 2 and 6 were conducted in January 1975 rather than early October 1974, when other samples were tested. The slight change in spectrum (lower angle of the sun) in January probably caused the transmittance values to be 1.5 percent lower. Therefore, an increment of 3.7 Btu (1.5 percent transmission) was included in the values listed above.

NOTE: The Btu heat gains above are based on North Latitude 40°, 21 July, 4 p.m., west windows with a 7-1/2 mph breeze outside, none inside, and incident solar radiation of 247 Btu/hr-ft^2 on the exterior surface of the glass. Btu metric conversion (International Table): 1 Btu/hr-ft^2 = 3.154591 W/m^2.

Metric conversions
for Figure 1a - 1e:

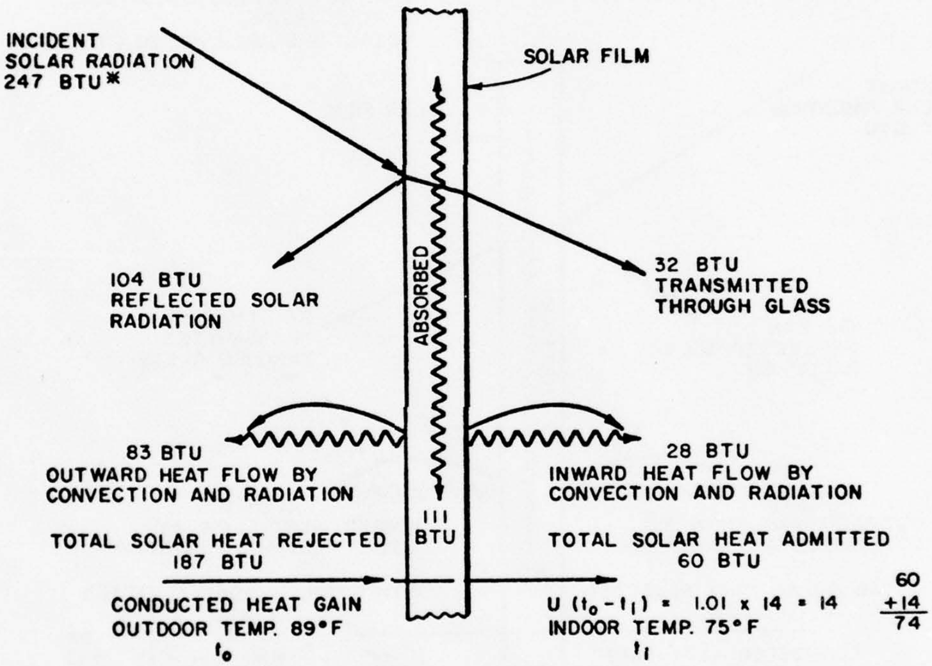
1 Btu/hr-ft^2 = 3.154591 W/m^2.

1 Btu/hr-ft^2 - °F = 5.678263 W/m^2 · K

5°F = -15.0°C	75°F = 23.9°C
68°F = 20.0°C	89°F = 31.7°C

CONDITION A

NORTH LATITUDE 40°
JULY 21, 4 PM, WEST WINDOW
7-1/2 MPH BREEZE OUTSIDE,
NONE INSIDE
TOTAL SHG, BTU/HR.-SQ. FT. = 74



"U" VALUE = 1.01 SUMMER; 1.05 WINTER; BTU/HR. - SQ.FT. - °F

SC = 0.28

WINTER - CONDUCTED OUT (68°F INSIDE TEMP., 5°F OUTSIDE TEMP., NO SUNSHINE)
1.05 (68° - 5°F) = 66 BTU/HR. - SQ.FT.

* INCIDENT SOLAR HEAT AT EXTERIOR SURFACE OF GLASS, BTU/HR-SQ.FT.

Figure 1a. Solar radiation Btu heat balance profiles for solar film on glass (3M P-18 film on 1/4-in. [6.35-mm] clear float glass).

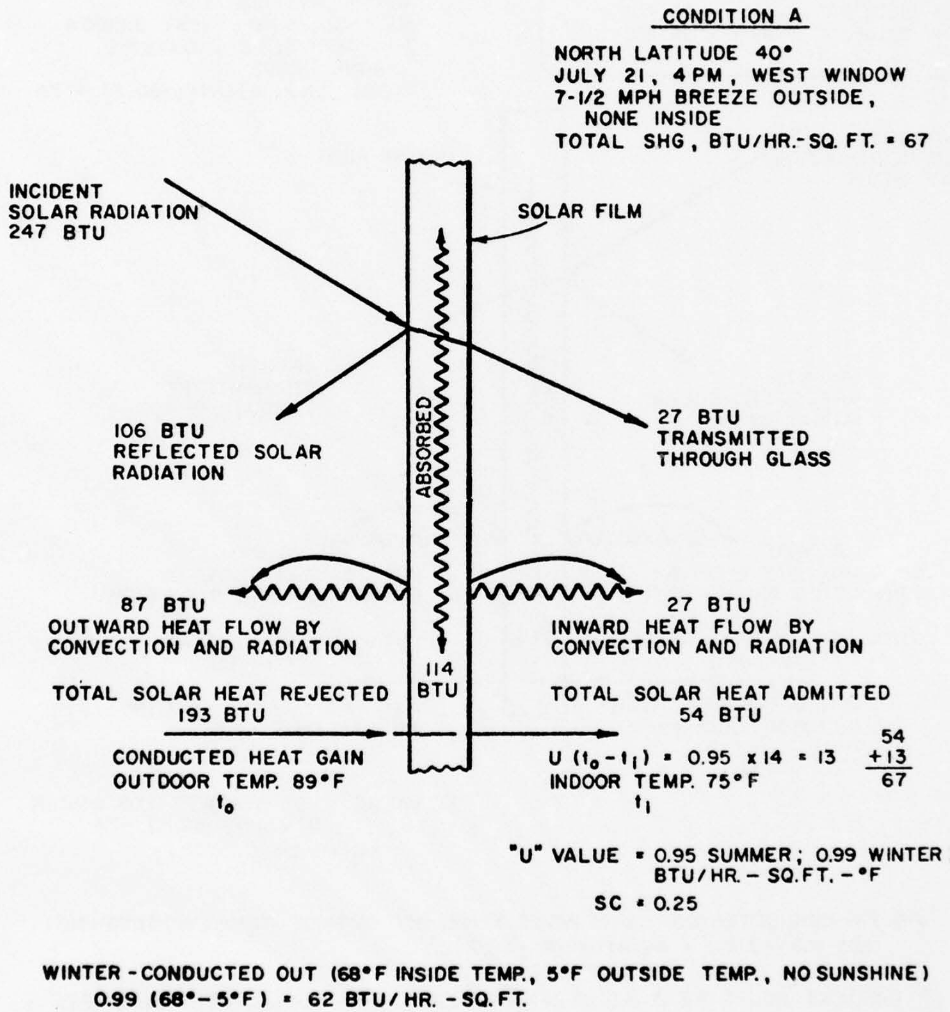


Figure 1b. Solar radiation Btu heat balance profile for solar film on glass (Madico RSLW 100-20 HCX film on 1/4-in. [6.35-mm] clear float glass.)

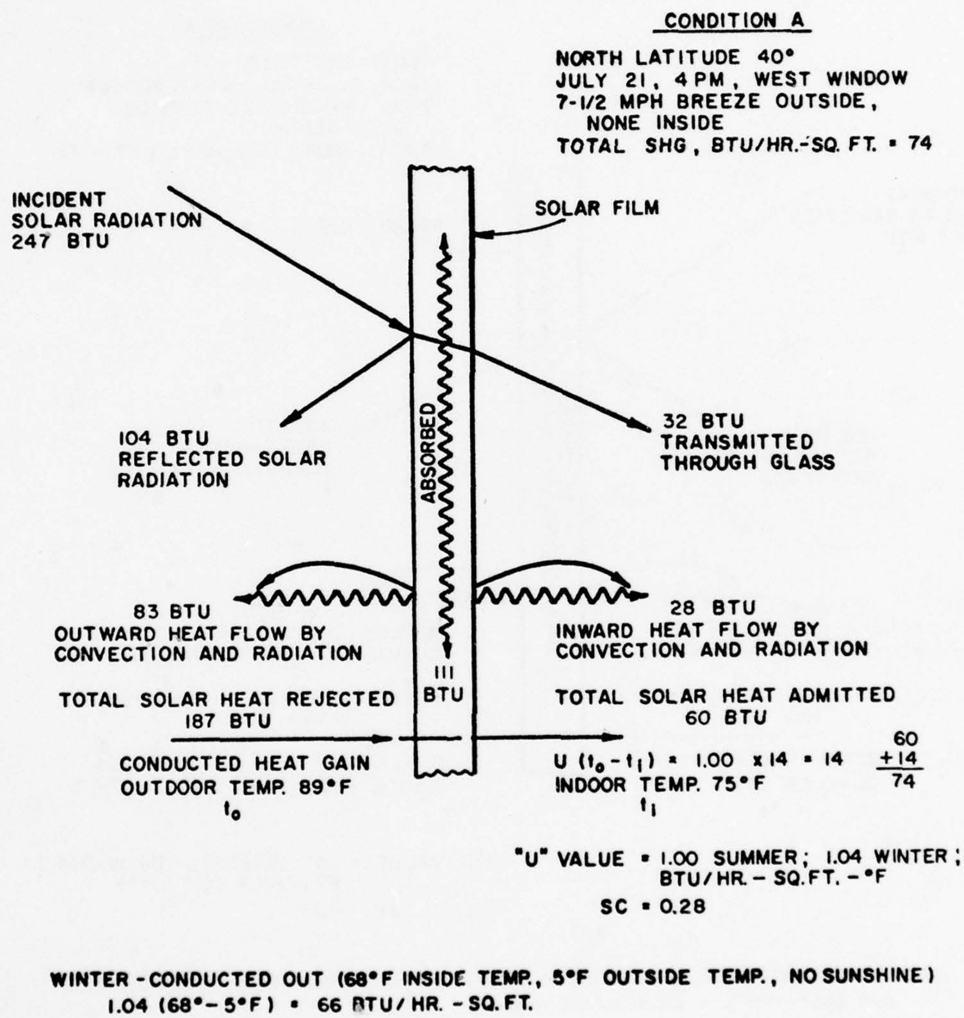


Figure 1c. Solar radiation Btu heat balance profile for solar film on glass (Solar-X PS-80 film on 1/4-in. [6.35-mm] clear float glass.)

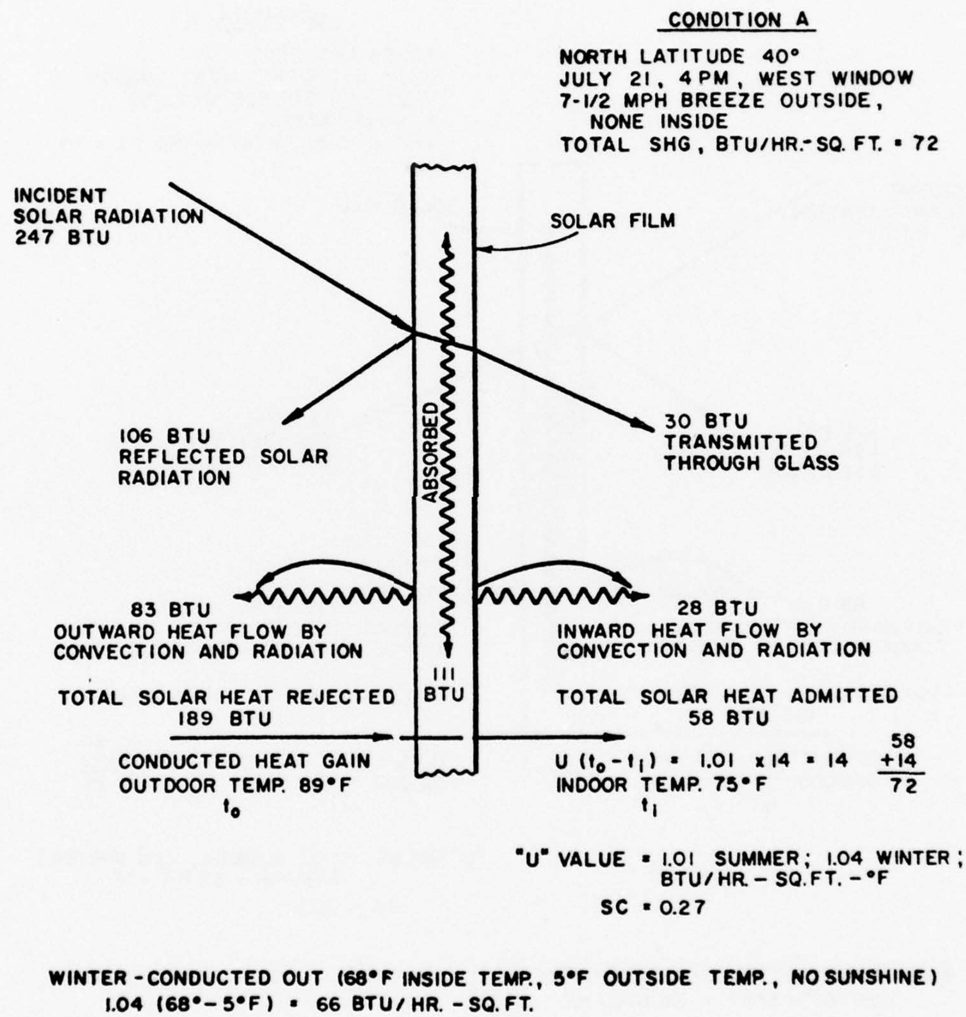


Figure 1d. Solar radiation Btu heat balance profile for solar film on glass (Sun-X International F-88 film on 1/4-in. [6.35-mm] clear float glass.)

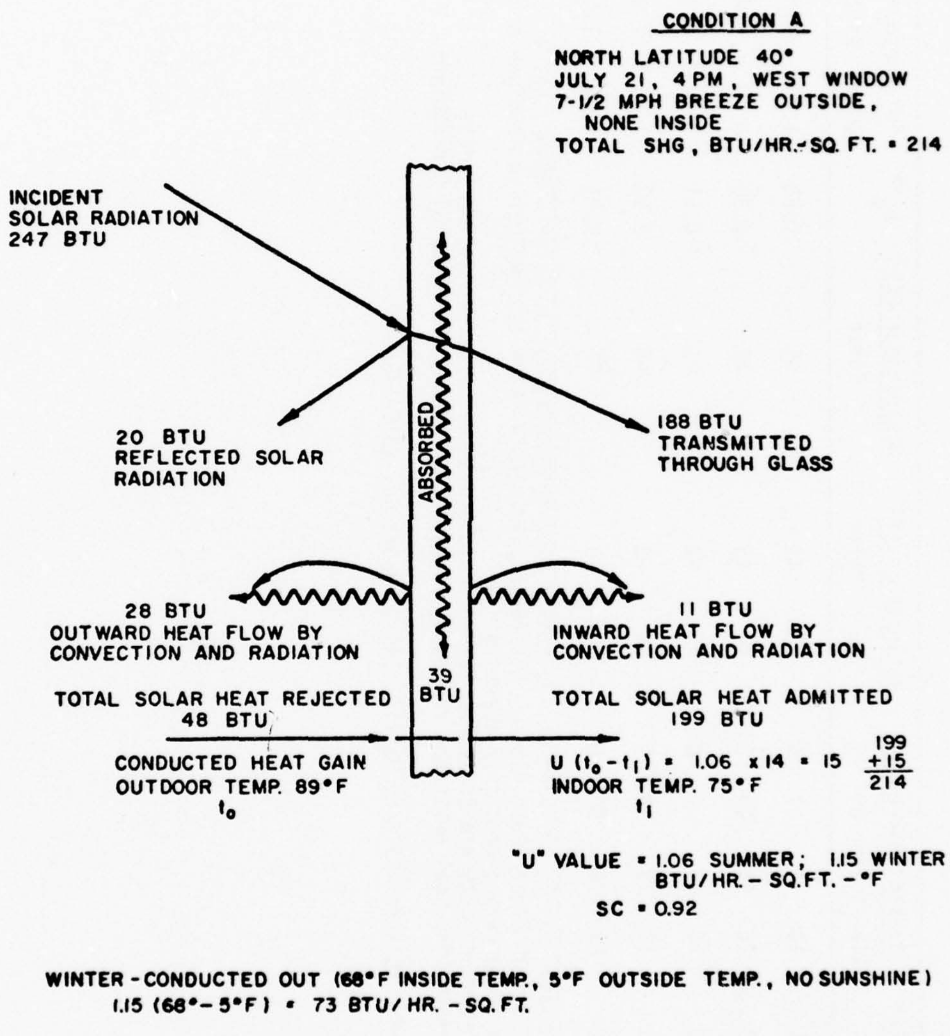


Figure 1e. Solar radiation Btu heat balance profile for plain glass (LOF 1/4-in. [6.35-mm] clear float glass.)

Table 4

Solar Optical Properties of Plain 1/4-in. (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 the reflective aluminum or silver finish and the pressure-sensitive adhesive.

**"U"-factor units are Btu/hr-sq ft-°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 5

Solar Heat Gain and Loss Data for Btu Profile of Plain 1/4-in. (6.35-mm) Clear Glass and Film on Glass With No Shading*

Sample**	Transmitted	Reflected	Absorbed	Re-Radiated In	Re-Radiated Out	Conducted In	Total In	Winter Conducted Out†
No. 1	32	104	111	28	83	14	74	66
No. 2	27	106	114	27	87	13	67	62
No. 3	32	104	111	28	83	14	74	66
No. 4	30	106	111	28	83	14	72	66
No. 5	188	20	39	11	28	15	214	73

*All values have units of Btu/hr-sq ft. Btu metric conversion (International Table): 1 Btu/hr-ft^2 = 3.154591 W/m^2.

**Samples are same as in Table 4.

†No sunshine.

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

Table 4 shows an ultraviolet transmittance range of 0 to 23 percent for the film/window systems and 56 percent for plain glass. Some of these values do not agree with manufacturers' data.

Spectrophotometric Laboratory Evaluation

An intensity vs wavelength scan was made through the 300 to 3000 nm wavelength range to determine (1) the energy transmitted and (2) the energy reflected by solar film glass systems vs plain glass at each wavelength in the range. This range represents the ultraviolet (below 400 nm), visible (400 to 700 nm), and part of the infrared spectrum (greater than 700 nm).

Transmission measurements were performed at CERL and the University of Illinois at Urbana-Champaign using a Beckman Spectrophotometer DBG for the ultraviolet and visible regions, a Beckman IR-20 for infrared, and a Cary 14 for near infrared. Figures 2, 3, and 4 present data for 1/8-in. (3.18-mm) clear and 1/4-in. (6.35-mm) clear and gray glass with and without film. The graphs clearly indicate the strong influence of solar film in reducing the percent transmission in the ultraviolet and visible regions. Table 6 presents data on transmission tests for the same samples in the wavelength range 700 to 5000 nm. As before, both thicker and tinted plain glasses showed lower transmittance values than the thinner, clear glass. However, the glass/film samples show much less transmittance than plain glass. At 1650 nm, the transmittance of the film/glass samples is 5 percent or less.

Specular reflectance measurements were performed at the Naval Avionics Facility, Indianapolis, IN, using a Beckman ACTA M-VII Spectrophotometer. Figures 5, 6, and 7 present data for 1/8-in. (3.18-mm) clear and 1/4-in. (6.35-mm) clear and gray glass with and without film. As in the transmission tests, the data clearly indicate the strong influence of solar film in increasing specular reflectance. The upper spectrograms (200 to 800 nm) represent the ultraviolet-visible region while the lower (800 to 3000 nm) represent the infrared. Reflectance of film/glass samples using 1/4-in. (6.35-mm) gray glass (Figure 7) is less than half that of the 1/8-in. (3.18-mm) and 1/4-in. (6.35-mm) clear glasses in the ultraviolet-visible region.

Window Reflectance of Room Heat

Some of the solar reflective film manufacturers claim that during winter, room radiation will be reflected back into the room from the solar film/window system thus making it more comfortable to sit near a window. This appears to be true. Attempts are presently being made by some of these manufacturers to define and determine the extent of the radiation. In this study, contacts with various authorities and glass

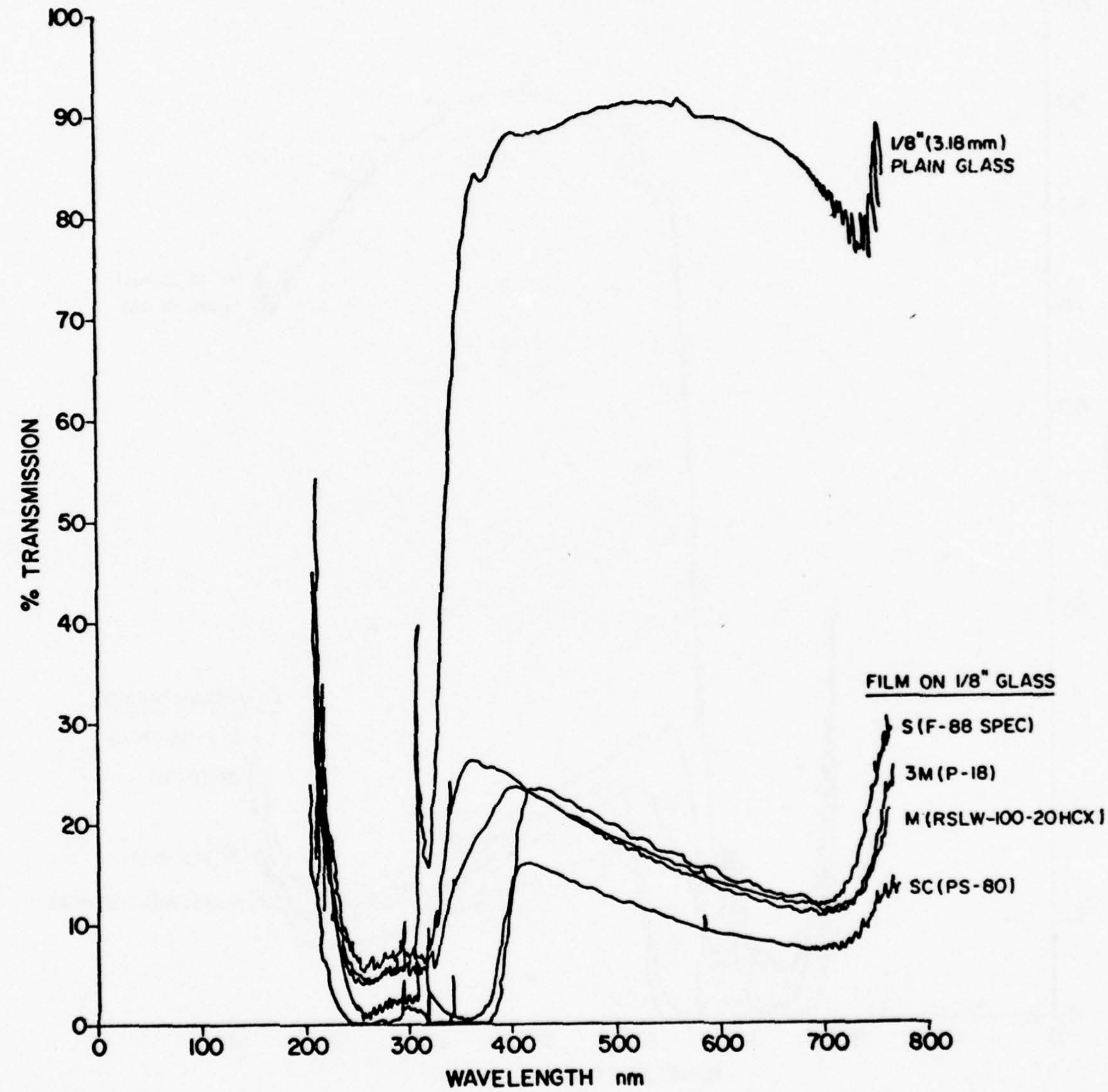


Figure 2. Percent transmission for 1/8-in. (3.18-mm) plain glass vs solar-control-film-coated glass.

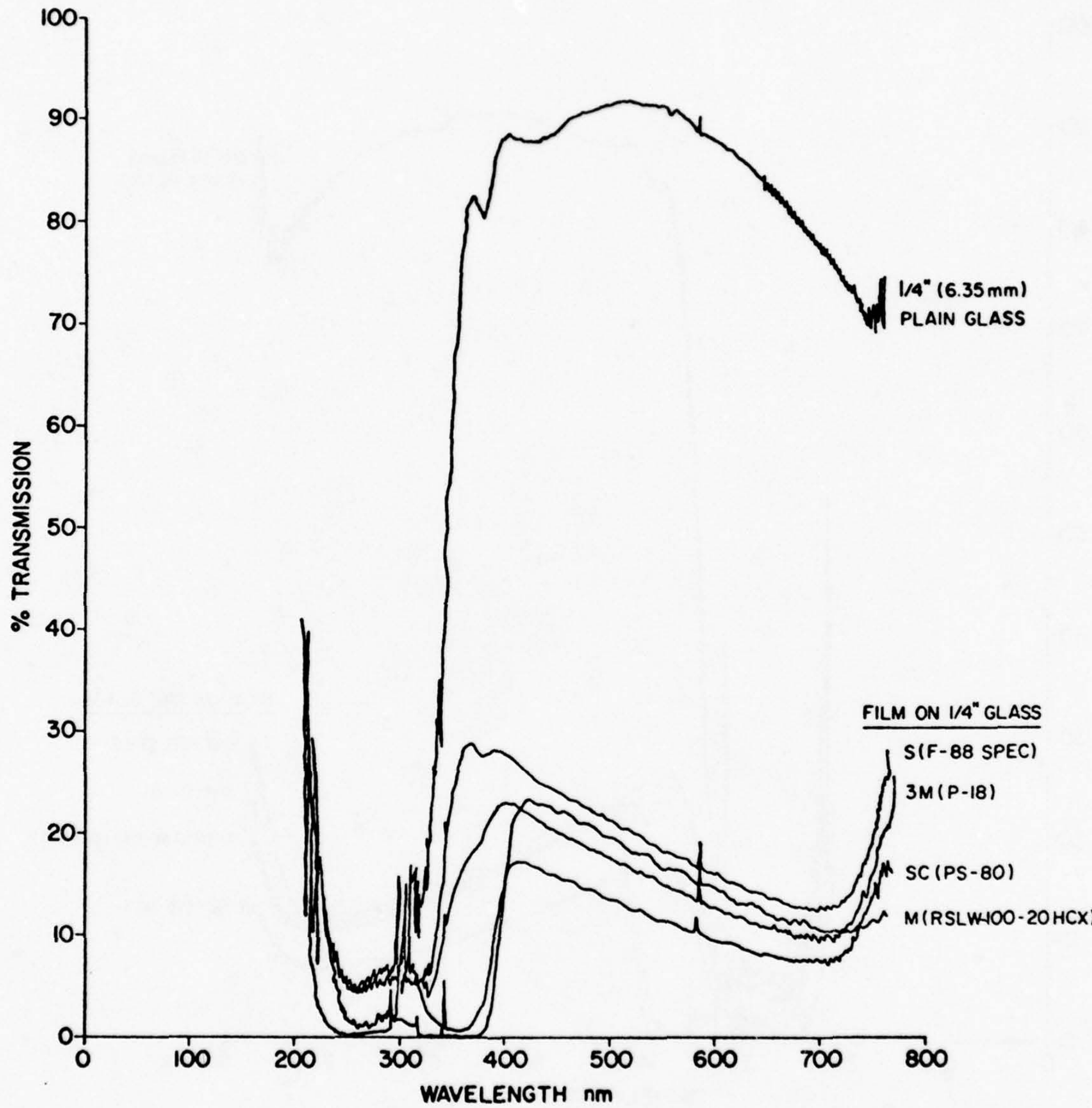


Figure 3. Percent transmission for 1/4-in. (6.35-mm) plain glass vs solar-control-film-coated glass.

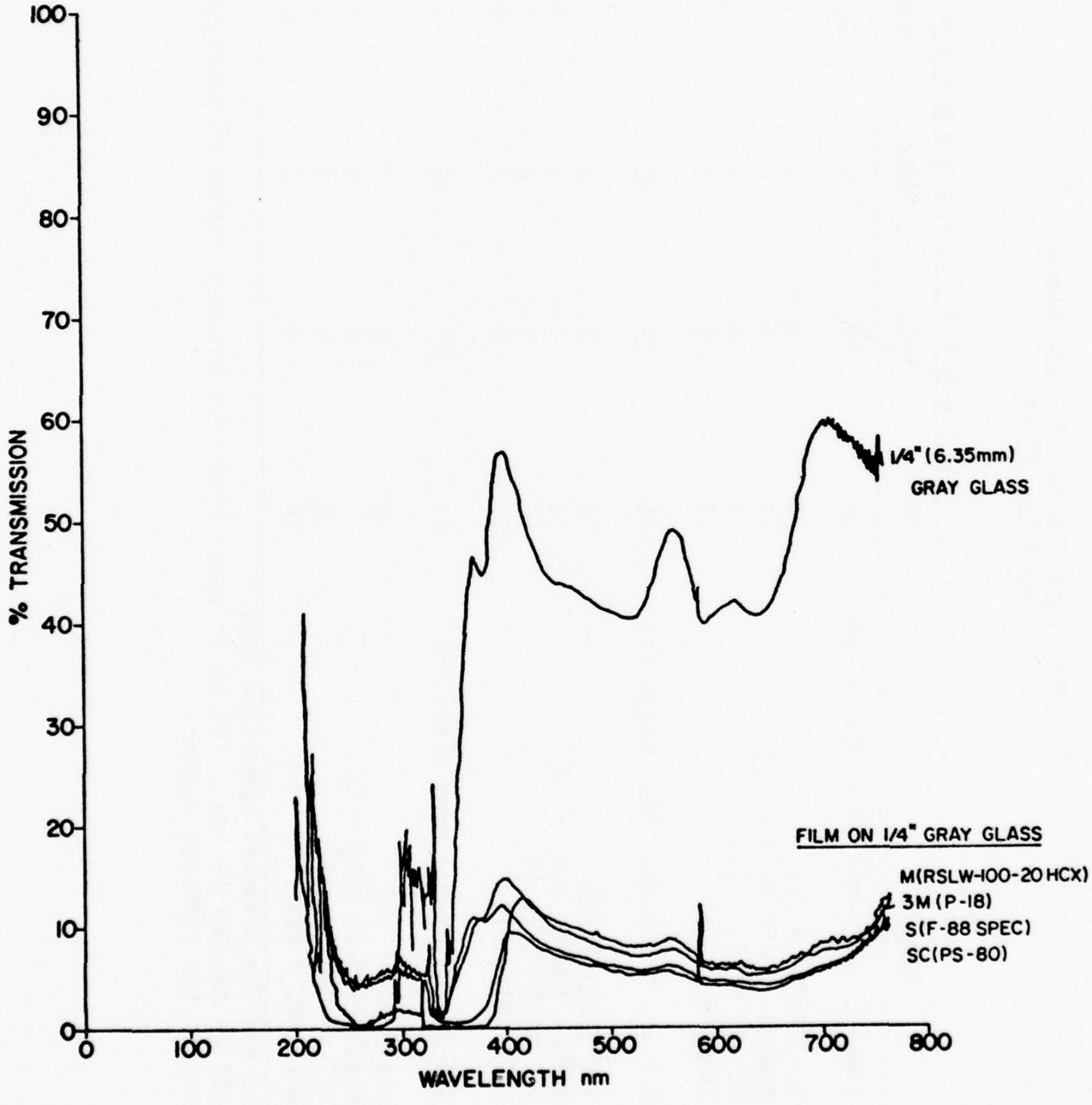


Figure 4. Percent transmission for 1/4-in. (6.35-mm) plain gray glass vs solar-control-film-coated glass.

Table 6

Percent Transmission of Plain Glass
and Solar Film*

Sample		Percent Transmission				
		700**	1650	2600	3000	5000
No. 82	1/8-in. (3.18-mm) Clear Glass (a)	88	83	72	22	0
No. 1	SC (PS-80) + (a)	9	3	1	1	0
No. 19a	M(RSLW-100-20 HCX) + (a)	11	4	2	0	0
No. 37	S(F-88 SPEC) + (a)	17	4	2	0	0
No. 55	3M(P-18) + (a)	17	5	3	1	0
No. 87	1/4-in. (6.35-mm) Clear Glass (f)	70	68	53	5	0
No. 6	SC(PS-80) + (f)	12	3	2	0	0
No. 24a	M(RSLW-100-20 HCX) + (f)	10	3	1	0	0
No. 42	S(F-88 SPEC) + (f)	18	5	2	0	0
No. 60	3M(P-18) + (f)	15	4	2	0	0
No. 89	1/4-in. (6.35-mm) Gray Glass (h)	53	50	45	4	0
No. 8	SC(PS-80) + (h)	8	2	1	0	0
No. 26a	M(RSLW-100-20 HCX) + (h)	7	2	1	0	0
No. 44	S(F-88 SPEC) + (h)	8	1	1	0	0
No. 62	3M(P-18) + (h)	11	3	2	0	0

*All films are the pressure-sensitive type.

**Wavelength in nanometers (nm). 700 nm is upper limit for visible region of spectrum. Higher values are in the infrared region.

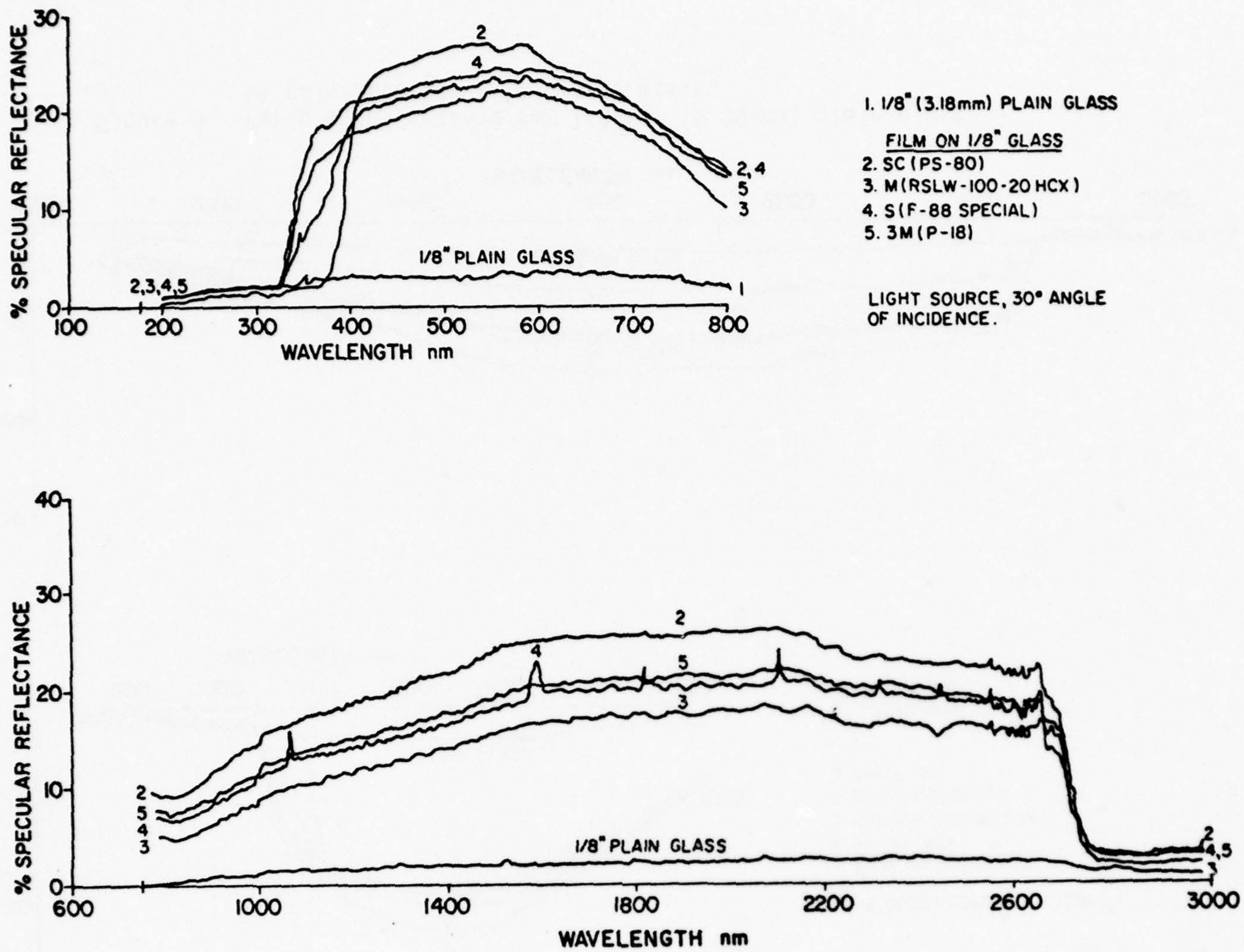


Figure 5. Percent reflectance for 1/8-in. (3.18-mm) plain glass vs solar-control-film-coated glass.

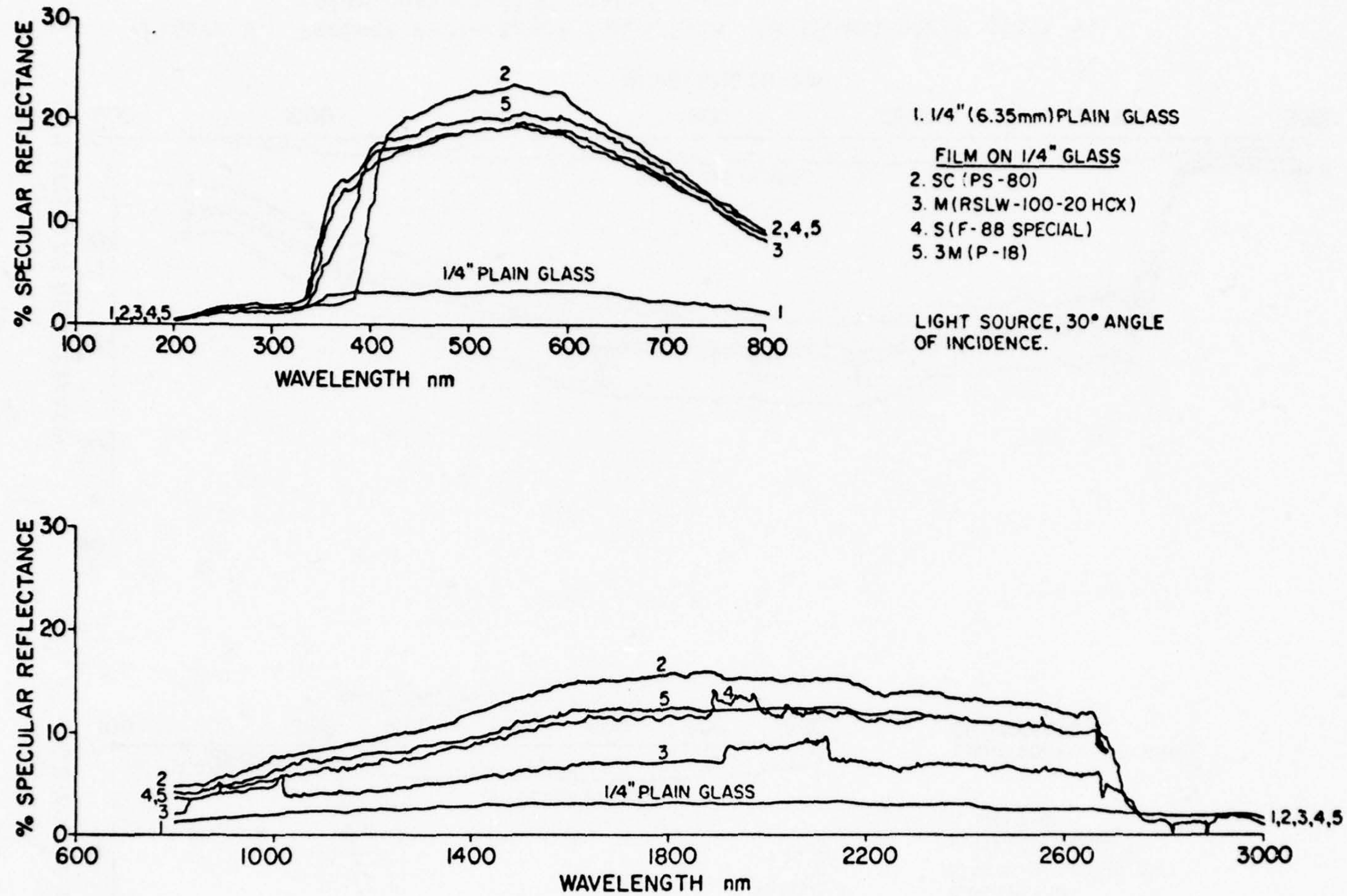


Figure 6. Percent reflectance for 1/4-in. (6.35-mm) plain glass vs solar-control-film-coated glass.

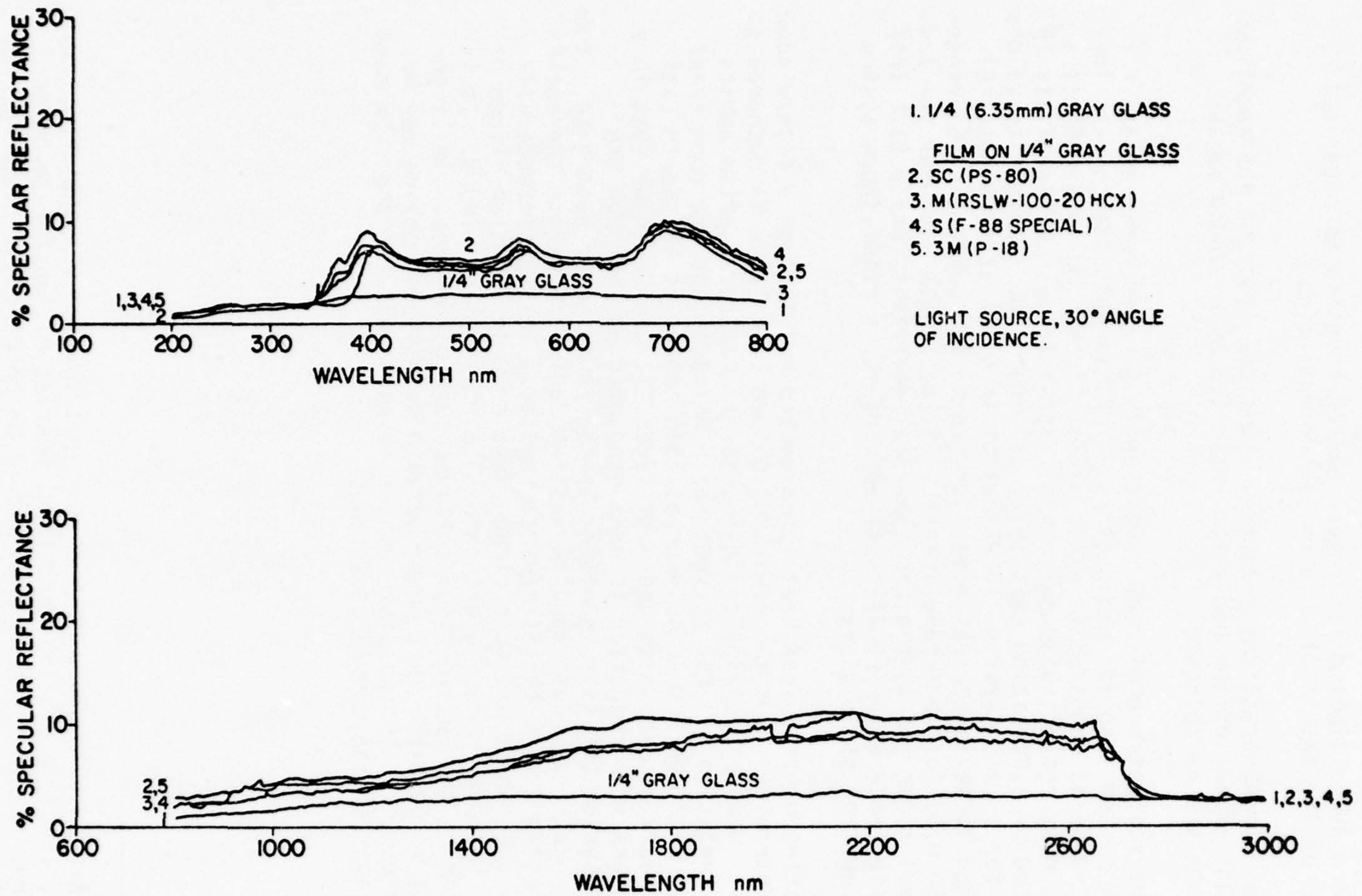


Figure 7. Percent reflectance for 1/4-in. (6.35-mm) plain gray glass vs solar-control-film-coated glass.

manufacturers and a limited literature search revealed no clear-cut information on the extent of this reflected radiation.

Some of the observations resulting from this study on the magnitude and resultant effect of the radiation reflected by a window system within a room are as follows:

1. The reflectance of room radiation is greater for a solar film/window system than for plain glass. This is indicated by the lower emissivity value as compared to plain glass. According to Kirchhoff's law,[2] the sum of reflectivity and emissivity is unity. Reflectivity (R) is calculated by subtracting emissivity (E) from 1.0. Emissivity values determined for film on 1/4-in. (6.35-mm) clear glass at 70^{o}F (21.1^{o}C) and converted to hemispherical emissivity ratio (93 percent of E) ranged from 0.53 to 0.63 for four manufacturers' films (Table 4). For the 1/4-in. (6.35-mm) clear glass, the hemispherical emissivity was 0.81. This shows a reflectance value of 37 to 47 percent for a film/window system and 19 percent for plain glass.

2. During winter, less heat is conducted out through a film/window system as determined from the lower "U" values (see Table 4) compared to plain glass. However, during sunshine, the film/window system admits less solar radiation and the reflectance benefit inside the room seems negligible. Based on ASHRAE solar heat gain tables at 40^{o} North Latitude, 21 January on the south and west sides, it can be shown that in a 24-hr day there is a reduction in heat conducted out through the film/window system but this is offset by the lower solar heat gain. The greater net heat loss would require heating equipment within the building to operate more for the film/window system. This difference will become less when there are more cloudy days or when venetian blinds or drapes are closed to reduce glare through a plain glass window. It is also affected by the outside/inside temperature difference. In larger buildings it is possible that under certain conditions cooling may be required in winter. The possible winter disadvantage for the film must be weighed against the summer advantage.

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[2] Dahl, A. I., ed., "Applied Methods and Instruments" (Reinhold Publishing Corp., 1962), p 515 (in Herzfield, Charles M., editor-in-chief, *Temperature, Its Measurement and Control in Science and Industry*, Vol 3, part 2).

5 ECONOMICS VS TYPES OF WINDOW GLASS AND INTERIOR SHADING

Simulation of Annual Heating and Cooling Loads for Barracks Module

The heating and cooling loads of an LBC&W* or EM (enlisted man's) barracks module at Fort Hood, TX, were simulated for nine types of window systems (Table 7) using the CERL Thermal Loads Analysis and Systems Simulation program.[3] The program, which predicts energy consumption in buildings, consists of two major subprograms: the Thermal Loads Analysis Program, which computes hourly space load in a building or zone based on user input and hourly weather data, and the Systems Simulation Program, which uses output from the first program and user inputs describing the heating and cooling system to calculate building energy consumption.

The Thermal Loads Analysis portion of the program incorporates a modified version of the National Bureau of Standards Load Determining Program (NBSLD).[4] The Systems Simulation program element is composed principally of a portion of National Aeronautics and Space Administration's Energy Cost Analysis Program (NECAP).

Inputs for the program were obtained from a number of sources. "U" values and shading coefficients were obtained from manufacturers' literature, contacts with manufacturers, and ASHRAE. Fort Hood, TX, provided the utility cost data. Hourly weather and solar data for a 1-year period in the Fort Worth, TX, area were acquired from the National Climatic Center, Asheville, NC.

Table 7, which provides the results of the simulation, shows the annual electricity and gas costs for the nine types of window systems used in the program. Annual gas heating costs were low, varying from $25 for 1/8-in. (3.18-mm) clear glass with solar film (no interior shading) to $33 for 1/8-in. (3.18-mm) clear glass with medium venetian blinds. Total annual electric costs including cooling varied insignificantly from $3096 for 1/8-in. (3.18-mm) clear glass with solar film and medium venetian blinds to $3184 for 1/8-in. (3.18-mm) clear

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[3] Hittle D. C., and B. Sliwinski, *CERL Thermal Load Analysis and Systems Simulation Program*, Vol 1: User's Manual, Interim Report E-81 (U.S. Army Construction Engineering Research Laboratory [CERL], 1975).

[4] Kusuda, T., *NBSLD, Computer Program for Heating and Cooling Loads in Buildings*, NBSIR 74-574 (Center for Building Technology, Institute for Applied Technology, National Bureau of Standards, November 1974).

* Named after the designer, Lyles-Bissett-Carlisle and Wolff, Architects/Engineers/Planners of Columbia, SC.

Table 7

Annual Heating and Cooling Loads in LBC&W Barracks
Module Simulation vs Window Glass
Type and Interior Shading

			Electricity					Gas	Water	Costs		
Window Systems	Window System Properties "U" Value	Shading Coefficient	Lights & Eqpt[a†] Annual Cons* (kWh)	Cool Cons[b] Annual (kWh)	Heat Cons[c] Annual (kWh)	Fans Cons Annual (kWh)	Total Elec Annual Cons (kWh)	Gas Heat Annual Cons (Therms)	City Water[d] Annual Cons (K gal)	Annual Cost Electricity Total ($)	Annual Cost Gas Total ($)	TOTAL Annual Cost ($)
1/8-in. clear glass	1.13	1.00	140322.6	35185.0	2432.8	7379.2	185319.6	216.6	82.7	3183.79	30.32	3214.11
1/8-in. clear glass & solar film	.84	.24	140322.6	31757.6	2245.7	6269.6	180595.5	181.2	74.4	3102.63	25.37	3128.00
1/8-in. blue-green heat abs	1.13	.82	140322.6	34365.7	2443.2	7061.6	184193.1	200.5	80.7	3164.44	28.07	3192.51
1/8-in. reflecting	.85	.35	140322.6	32279.2	2256.1	6451.9	181309.8	188.9	75.7	3114.90	26.45	3141.35
1/8-in. clear glass & med ven blinds	.84	.64	140322.6	33612.1	2245.7	7020.9	183201.3	237.7	79.1	3147.40	33.28	3180.68
1/8-in. clear glass & solar film & med ven blinds	.76	.18	140322.6	31474.1	2193.7	6215.2	180205.6	186.1	73.7	3095.93	26.05	3121.98
1/8-in. blue-green heat abs & med ven blinds	.84	.60	140322.6	33438.6	2245.7	6938.0	182944.9	234.7	78.6	3142.99	32.86	3175.85
1/8-in. reflecting & med ven blinds	.85	.29	140322.6	32020.8	2256.1	6352.5	180952.0	184.3	75.0	3108.76	25.80	3134.56
1/8-in. clear glass & med drapes	.84	.61	140322.6	33481.7	2245.7	6954.6	183004.6	235.2	78.7	3144.02	32.93	3176.95

*Cons = Consumption

†a--for lights and building equipment, internal; external = 0; b--includes chillers, water pumps, and cooling tower fan; c--includes hot water pumps and auxiliaries; d--for HVAC system only

**Fort Hood Utility Costs Used
Natural Gas--$1.40/1000 cu ft (28.317 m^3) or $0.14/therm
Electricity-- 0.0718/kWh (3.6007 x 10^{+6} J)
Water -- 0.15113/1000 gal (3.7854 m^3)

Metric Conversion:

1/8 in. = 3.18 mm
"U" value - 1Btu/hr-ft^2 °F = 5.678263 W/m^2-K
1 kWh = 3.600655 x 10^{+6} J
1 gal (U.S.) 3.785411784 x 10^{-3} m^3
1 cu ft = 2.831684659 x 10^{-2} m^3

glass alone. The solar film systems with or without venetian blinds had the lowest total annual gas and electric costs (heating and cooling), but the saving was $92 or less. Reflective glass was the second lowest in utility costs. Total utility costs were slightly lower for each system when venetian blinds were used as compared to the same system without interior shading.

Life-Cycle Cost Analysis

The Office of the Chief of Engineers (OCE) method[5] was used for the life-cycle cost (LCC) analysis. Table 8 shows the cumulative 25-year window system, replacement, utility, and investment costs for each of the nine window systems. Table 9 gives the unit cost data used in LCC, and Tables 10 through 18 present the LCC analysis base for each system.

The LCC (Table 8) considering energy requirements for the nine window systems being investigated varied from $224,751 for 1/8-in. (3.18-mm) clear glass alone to $290,784 for 1/8-in. (3.18-mm) reflecting glass with medium venetian blinds. The solar film/window system with or without interior shading was second highest in LCC. The higher LCC for solar film is due to projected window breakage and subsequent replacement of the film as well as the 10-year projected life of the film. In addition, the window area is only about 12 percent of the wall space in the barracks module, and weather data in another location could have a different effect on the heating and cooling loads and costs. Compass orientation of windows can also be a factor. No dollar value was assigned to the solar film benefits of glare reduction and added window safety. (See Table D3, Appendix D for a more complete discussion of benefits and advantages.)

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5 *Engineering Economic Studies--Life-Cycle Costing Instructions* (Department of the Army, May 1971) with Appendix B (March 1972) and Appendix C (July 1972).

Table 8

LBC&W Barracks Module Window Systems vs Energy and Life-Cycle (25-year) Cost*

Window System†	Replacement Cost ($)		Maintenance Cost ($)	Heating & Cooling Cost ($)		Investment Cost ($)	Cumulative Cost ($)
	Window	Solar Film	Venetian Blinds	Gas	Total Electricity		
1	24,984			1,749	197,076	942	224,751
2	24,984	32,316		1,464	192,053	5,023	255,839
3	31,984			1,620	195,879	1,910	231,392
4	70,392			1,526	192,812	7,221	271,951
5	24,984		16,638	1,920	194,824	3,554	241,920
6	24,984	32,316	16,638	1,500	191,638	7,636	274,711
7	31,984		16,638	1,896	194,551	4,522	249,591
8	70,392		16,638	1,489	192,432	9,833	290,784
9	24,984		3,036**	1,900	194,615	7,554	232,088

*Life-Cycle Costing: OCE Method

**Medium drapes used instead of medium venetian blinds

†Systems

1. 1/8-in. clear glass
2. 1/8-in. clear glass & solar film
3. 1/8-in. blue-green heat absorbing
4. 1/8-in. reflecting
5. 1/8-in. clear glass and medium venetian blinds
6. 1/8-in. clear glass & solar film & medium venetian blinds
7. 1/8-in. blue-green heat absorbing & medium venetian blinds
8. 1/8-in. reflecting & medium venetian blinds
9. 1/8-in. clear glass & medium drapes

Metric conversion: 1/8 in. = 3.18 mm

Table 9

Unit Cost Data Used in Life-Cycle Costing

Window System*	System Cost, ($/sq ft) Glass	Solar Film	Med Ven Blinds	Med Drapes	System Cost Total	General Notes
1	0.36				475.92	Glass: cost from Libbey-Owens-Ford Co. Does not include frame or sash and installation.
2	0.36	1.56			475.92 2062.32	Solar Film: cost is average of 3M and Solar-X (both on GSA) and includes installation. Used 10-year life.
3	0.73				965.06	Venetian Blinds: cost from Centex Mfg. Co. and includes installation.
4	2.76				3648.72	Annual maintenance cost obtained from Chanute Air Force Base, $4.00 per window (x 78). Used 5-year life with 50% replacement.
5	0.36		1.00		475.92 1320.00	Drapes: Cost from Military Service Co. and includes traverse rods and installation.
6	0.36	1.56	1.00		475.92 2062.32 1320.00	No maintenance cost used. Used 6-year life with 20% replacement.
7	0.73		1.00		965.06 1320.00	System Cost Total: For window area of 1,322 sq ft in LBC&W barracks module simulation. Total wall area is 11,315 sq ft. Glass area is 11.7% of wall area
8	2.76		1.00		3648.72 1320.00	
9	0.36			2.527	475.92 3341.00	

*See Table 8, systems description.

Metric conversion: 1 sq ft ($0.0929\ m^2$).

Table 10

Life-Cycle Cost Analysis, Base 1

PROJECT (Sample): LBC&W (or EM) Barracks Module, Fort Hood, TX
ALTERNATE: 1/8-in. (3.18-mm) Clear Window Glass, 1322 sq ft (122.8 m^2)

Original Cost of Alternate* = $475.92

Interest Rate on Principal = 6.125%

Duration of Investment = 25 years

Annual Investment Cost = $ 37.67

Annual Base Costs			Annual Cost Growth
Maint.-Replace Broken Window Glass	=	$ 624.59	5.00% of Base Cost
Gas-Heating**	=	30.32	20% to 1980; 7% from 1981 +
Electricity, Including Cooling**	=	3183.79	20% to 1980; 9% from 1981+
Water	=	0.00	0.00
Sewage	=	0.00	0.00

GENERAL:

LCC Method as prescribed by OCE

* Cost of glass alone. Frames or sash considered as equivalent in cost for all systems. Venetian blinds or drapes used only in systems 5, 6, 7, 8, 9 (Tables 14 through 18).

**All based on annual computer heating and cooling loads and systems simulation program in above project sample module using Fort Worth, TX weather data. Electricity includes total electrical annual consumption including cooling (See Table 7 under Electricity). For unit costs, see Table 9.

Table 11

Life-Cycle Cost Analysis, Base 2

PROJECT (Sample): LBC&W (or EM) Barracks Module, Fort Hood, TX
ALTERNATE: 1/8-in. (3.18-mm) Clear Window Glass & Solar Film, 1322 sq ft (122.8 m^2)

Original Cost of Alternate	= $2,538.24
Interest Rate on Principal	= 6.125%
Duration of Investment	= 25 years
Annual Investment Cost	= $ 200.93

Annual Base Costs		Annual Cost Growth
Maint.-Replace Broken Window Glass & Solar Film	= $1362.47	5.00% of Base Cost
Gas-Heating	= 25.37	20% to 1980, 7% from 1981+
Electricity, Including Cooling	= 3102.63	20% to 1980, 9% from 1981+
Water	= 0.00	0.00
Sewage	= 0.00	0.00
<u>Cyclical Maintenance Costs</u>		<u>Annual Cost Growth</u>
$1152.50* Every 10 years starting at year 10		5.00% (Factors = 1.45, 0.98)

* To replace solar film on 64.2% of total window area (849 sq ft or 78.9 m^2) not previously replaced x 75% (estimated affected). This replacement due to 10-year projected life of film.

Table 12

Life-Cycle Cost Analysis, Base 3

PROJECT (Sample): LBC&W (or EM) Barracks Module, Fort Hood, TX

ALTERNATE: 1/8-in. (3.18-mm) Blue-Green Heat Absorbing Window Glass, 1322 sq ft (122.8 m^2)

Original Cost of Alternate	=	$965.06
Interest Rate on Principal	=	6.125%
Duration of Investment	=	25 years
Annual Investment Cost	=	$ 76.39

Annual Base Costs			Annual Cost Growth
Maint.-Replace Broken Window Glass	=	$ 799.60	5.00% of Base Cost
Gas-Heating	=	28.07	20% to 1980; 7% from 1981+
Electricity, Including Cooling	=	3164.44	20% to 1980; 9% from 1981+
Water	=	0.00	0.00
Sewage	=	0.00	0.00

Table 13

Life-Cycle Cost Analysis Base, 4

PROJECT (Sample): LBC&W (or EM) Barracks Module, Fort Hood, TX
ALTERNATE: 1/8-in. (3.18-mm) Reflecting Window Glass, 1322 sq ft (122.8 m^2)

Original Cost of Alternate	=	$3648.72
Interest Rate on Principal	=	6.125%
Duration of Investment	=	25 years
Annual Investment Cost	=	$288.83

Annual Base Costs			Annual Cost Growth
Maint.-Replace Broken Window Glass	=	$1759.79	5.00% of Base Cost
Gas-Heating	=	26.45	20% to 1980; 7% from 1981+
Electricity, Including Cooling	=	3114.90	20% to 1980; 9% from 1981+
Water	=	0.00	0.00
Sewage	=	0.00	0.00

Table 14

Life-Cycle Cost Analysis, Base 5

PROJECT (Sample): LBC&W (or EM) Barracks Module, Fort Hood, TX
ALTERNATE: 1/8-in. (3.18-mm) Clear Window Glass & Venetian Blinds*, 1322 sq ft (122.8 m^2)

Original Cost of Alternate	= $1795.92
Interest Rate on Principal	= 6.125%
Duration of Investment	= 25 years
Annual Investment Cost	= $142.17

Annual Base Cost		Annual Cost Growth
Maint.-Replace Broken Window Glass	= $ 624.59	5.00% of Base Cost
Maint.-Repair Venetian Blinds	= 312.00	5.00% of Base Cost
Gas-Heating	= 33.28	20% to 1980; 7% from 1981+
Electricity, Including Cooling	= 3147.40	20% to 1980; 9% from 1981+
Water	= 0.00	0.00
Sewage	= 0.00	0.00

Cyclical Maintenance Costs	Annual Cost Growth
$660.00** Every 5 years starting at year 5	5.00%

* Medium venetian blinds used in Tables 14 to 17.

** For replacing 50% of venetian blinds (estimated affected) at 5-year projected life.

Table 15

Life-Cycle Cost Analysis, Base 6

PROJECT (Sample): LBC&W (or EM) Barracks Module, Fort Hood, TX
ALTERNATE: 1/8 in. (3.18 mm) Clear Window Glass with Solar Film & Venetian Blinds, 1322 sq ft (122.8 m^2)

Original Cost of Alternate	=	$3858.24
Interest Rate on Principal	=	6.125%
Duration of Investment	=	25 year
Annual Investment Cost	=	$305.42

Annual Base Costs			Annual Cost Growth
Maint.-Replace Broken Window Glass & Solar Film	=	$1362.47	5.00% of Base Cost
Maint.-Repair Venetian Blinds	=	312.00	5.00% of Base Cost
Gas-Heating	=	26.05	20% to 1980; 7% from 1981+
Electricity, Including Cooling	=	3095.93	20% to 1980; 9% from 1981+
Water	=	0.00	0.00
Sewage	=	0.00	0.00

Cyclical Maintenance Costs	Annual Cost Growth
$660.00* Every 5 years starting at year 5	5.00%
$1152.50** Every 10 years starting at year 10	5.00% (Factors 1.45, 0.98)

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* For replacing venetian blinds

** Solar film, 10-year life (see system 2, Table 11)

Table 16

Life-Cycle Cost Analysis, Base 7

PROJECT (Sample): LBC&W (or EM) Barracks Module, Fort Hood, TX
ALTERNATE: 1/8-in. (3.18-mm) Blue-Green Heat Absorbing Window Glass & Venetian Blinds, 1322 sq ft (122.8 m^2)

Original Cost of Alternate	=	$2,285.06
Interest Rate on Principal	=	6.125%
Duration of Investment	=	25 years
Annual Investment Cost	=	$ 180.89

Annual Base Costs			Annual Cost Growth
Maint.-Replace Broken Window Glass	=	$ 799.60	5.00% of Base Cost
Maint.-Repair Venetian Blinds	=	312.00	5.00% of Base Cost
Gas-Heating	=	32.86	20% to 1980; 7% from 1981+
Electricity, Including Cooling	=	3142.99	20% to 1980; 9% from 1981+
Water	=	0.00	0.00
Sewage	=	0.00	0.00

Cyclical Maintenance Costs	Annual Cost Growth
$660.00 Every 5 years starting at year 5	5.00%

Table 17

Life-Cycle Cost Analysis, Base 8

PROJECT (Sample): LBC&W (or EM) Barracks Module, Fort Hood, TX
ALTERNATE: 1/8-in. (3.18-mm) Reflecting Window Glass & Venetian Blinds, 1322 sq ft (122.8 m^2)

Original Cost of Alternate	=	$4,968.72
Interest Rate on Principal	=	6.125%
Duration of Investment	=	25 years
Annual Investment Cost	=	$ 393.32

Annual Base Costs			Annual Cost Growth
Maint.-Replace Broken Window Glass	=	$1,759.79	5.00% of Base Cost
Maint.-Repair Venetian Blinds	=	312.00	5.00% of Base Cost
Gas-Heating	=	25.80	20% to 1980; 7% from 1981+
Electricity, Including Cooling	=	3,108.76	20% to 1980; 9% from 1981+
Water	=	0.00	0.00
Sewage	=	0.00	0.00

Cyclical Maintenance Costs	Annual Cost Growth
$660.00 Every 5 years starting at year 5	5.00%

Table 18

Life-Cycle Cost Analysis, Base 9

PROJECT (Sample): LBC&W (or EM) Barracks Module, Fort Hood, TX
ALTERNATE: 1/8-in. (3.18-mm) Clear Window Glass & Drapes*, 1322 sq ft (122.8 m^2)

Original Cost of Alternate	= $3,816.92
Interest Rate on Principal	= 6.125%
Duration of Investment	= 25 years
Annual Investment Cost	= $ 302.15

Annual Base Costs		Annual Cost Growth
Maint.-Replace Broken Window Glass	= $ 624.59	5.00% of Base Cost
Maint.-Drapes	= 0.00	0.00
Gas-Heating	= 32.93	20% to 1980; 7% from 1981+
Electricity, Including Cooling	= 3,144.02	20% to 1980; 9% from 1981+
Water	= 0.00	0.00
Sewage	= 0.00	0.00

Cyclical Maintenance Costs	Annual Cost Growth
$606.00** Every 6 years starting at year 6	5.00%

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* Medium drapes.
** For replacing 20% of drapes at 6 year projected life.

6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Results from the survey of users in 15 geographical areas indicate that (in the opinions of those surveyed) solar film reduces air conditioning costs, solar glare, reflects solar heat, and improves overall comfort and cooling balance. Reduced heating is also indicated. Users indicated that solar film does not shut out an undue amount of light or obstruct the view to outdoors, and does resist aging.

2. Survey data for 10 cities--San Francisco, Los Angeles, Phoenix, Denver, Dallas, Chicago, St. Louis, Philadelphia, Baltimore, and Orlando--having at least 10 users each were compared; no statistically significant differences were found in responses to 14 questions (from separate analysis of user data).

3. Users surveyed also indicated that the chief advantages in using film are heat and glare control, elimination of sun damage, and, to a slightly lesser extent, blocking sight into the building in the daytime. The chief limitations are the reduction in light available, some loss in visibility to the outside, cost, extra precautions required in cleaning, and reflections.

4. Since film can be purchased from three of the manufacturers through GSA, the cost of solar films should be reasonable.

5. No significant difference in performance among the four manufacturers' films is apparent.

6. Application of solar films is easy and can be accomplished by inexperienced personnel after some instruction. Tools and equipment required are minimal and inexpensive.

7. Users at 12 installations visited were well satisfied with the performance and cost savings resulting from use of solar films.

8. Of 38 solar film installations 5 to 10 years old, 55 percent were not affected by aging, while 24 percent had a small effect. When provided with an ultraviolet inhibitor, and film is properly maintained and not scratched, the film's life should be over 10 years, possibly as much as 15 years. The film is affected by ultraviolet light and moisture, which can enter through deep scratches in the film.

9. Damaged film can be patched if there is no objection to appearance. Manufacturers recommend replacement of the whole sheet.

10. Interviews with occupants in six local (Champaign-Urbana,IL) buildings having a solar film installation indicated that a majority felt that film performance was satisfactory; however, they preferred to use the film in combination with a control device, such as venetian blinds.

11. Laboratory tests indicated that most window cleaners investigated were satisfactory for cleaning solar film on windows. Abrasive detergents and abrasive materials which can scratch or deteriorate the film, such as caustic detergents and high ammonia concentrations, brushes, natural sponges, and coarse wiping cloths should be avoided.

12. Laboratory tests indicated that solar heat gain at peak load summer weather conditions was reduced by 66 percent, from 214 Btu/hr-ft^2 (675 W/m^2) for plain glass to 72 Btu/hr-ft^2 (227 W/m^2) for the same glass with solar film on it. Solar heat rejected by the film/glass was 189 Btu/hr-ft^2 (596 W/m^2) as compared to 48 Btu/hr-ft^2 (151 W/m^2) for the plain glass. Other laboratory tests also indicated the strong influence of solar films in reducing transmission of solar radiation through window glass and increasing reflectance of the glass, thus reducing glare and solar heat in a building.

13. The CERL Computer Heating and Cooling Load and Systems Simulation program for the 72-man barracks module indicated that the solar film systems with or without venetian blinds had the lowest total annual gas and electric costs, but the saving was $92 or less (a 2.9 percent reduction in costs). In another location or compass orientation of windows, or different type of building, or greater window area, this could vary.

14. The 25-year LCC analysis indicated that the solar film/window systems with or without interior shading were the second highest in cost, with reflective glass being the highest. This cost is specific to an LBC&W barracks module in Fort Worth weather conditions but using Fort Hood utility costs. Several factors contribute to the high LCC of solar films, including replacement due to broken windows and the 10-year projected life. However, no dollar value has been placed on other advantages claimed by users.

Recommendations

1. Prior to deciding what type of window system and interior shading is to be used to conserve energy, a computer heating and cooling load and systems simulation study should be made for the particular building in the particular location, utilizing area weather data and local utility costs. LCC should be determined with consideration being given to the many advantages of solar film to which no dollar value was applied in this study.

2. The effects of using glass thicker than 1/8 in. (3.18 mm) on the amount of window breakage should be investigated to determine whether the LCC would be significantly less than determined in this study.

3. Computer simulation and LCC analysis on the same type of barracks module used at Fort Hood should be performed using weather data and local utility costs at other selected locations in the United States.

4. Due to recent changes in cost, reflective glass may be competitive to the solar control film/window system for use in new construction.

5. If solar film is used, the manufacturer's representative should inspect the building and determine the proper type of film to use based on the type of window glass on which the film will be applied. Film application and cleaning instructions should also be furnished to the user.

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Pennington, Clark W., and G. L. Moore, "Measurement of Solar-Optical Properties of Glazing Materials," *ASHRAE Journal* (July 1971).

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Yellott, John I., "Calculation of Solar Heat Gain Through Single Glass," *Solar Energy*, Vol 7, No. 4 (1963).

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Yellott, John I., *Effect of Louvered Sun Screens Upon Fenestration Heat Loss*, paper presented at ASHRAE meeting, January 1972.

Yellott, John I., *Energy, Economy and Sun Control, A Report on the Conservation of Energy* (Koolshade Corporation, undated).

Yellott, John I., *Selective Reflectance--A New Approach to Solar Heat Control*, presented at ASHRAE meeting, June 1963.

Yellott, John I., *Shading Coefficients and Sun-Control Capability of Single Glazing* (ASHRAE, 1966).

APPENDIX A:

SOLAR FILM MANUFACTURERS

1.	Material Distributors Corporation 64 New Industrial Parkway Woburn, MA 01801	Madico Reflecto-Shield Phone: 617-935-7850
2.	Minnesota Mining & Manufacturing Co. Sun Control Products Industrial Tape Division St. Paul, MN 55101	Scotchtint Sun Control Film Phone: 612-733-1110
3.	Solar Control Products Corporation* 25 Needham Street Newton, MA 02161	Solar-X Sun Control Film Phone: 617-244-8686
4.	Sun-X International, Inc. P.O. Box 7764 702 Ashland St. Houston, TX 77007	Sun-X Reflective Glass Tinting Film Phone: 713-869-8331 800-231-6623 (WATS)
5.	National Metallizing Division Saxon Industries Co. RD #2, Cranbury, NJ 08512	Nunsun Phone: 609-655-4000

* Name changed to Solar-X Corporation in 1976.

APPENDIX B:

SOLAR CONTROL FILM RELATED SPECIFICATIONS

Aluminum Windows, Federal Construction Guide Specification, Section 08-1, MCGS 08520, November 1973.

Coating Systems, Elastomeric, Thermally Reflective and Rain Erosion Resistant, Military Specification MIL-C-27315A (U.S. Air Force) (Department of Defense, February 1972).

Density of Plastics by the Density-Gradient Technique, ASTM: D1505-68 Reapproved 1975 (American Society for Testing and Materials [ASTM], 1975).

Flammability of Flexible Plastics, ASTM: D 568-74 (ASTM, 1974).

Flammability of Plastics Using the Oxygen Index Method, ASTM: D 2863-74 (ASTM, 1974).

Glass and Glazing, Federal Construction Guide Specification, Section 08810, MCGS 08810, CE-08810 (October 1973).

Glass, Plate (Float), Sheet, Figured, and Spandrel (Heat Strengthened and Fully Tempered), Federal Specification DD-G-1403B (General Services Administration [GSA], August 1972).

Glass, Plate, Sheet, Figured (Float, Flat, For Glazing, Corrugated, Mirrors and Other Uses), Federal Specification DD-G-451C and Amendment 4 (GSA, January 1968).

Haze and Luminous Transmittance of Transparent Plastics, ASTM: D 1003-61 Reapproved 1970 (ASTM, 1970).

Light Dosage in Carbon-Arc Light Aging Apparatus, ASTM: D 1920-69 (ASTM, 1969).

Mechanical Design, Heating, Ventilating, and Air Conditioning, Technical Manual TM 5-810-1 (Department of the Army, January 1956).

Method of Measuring Solar-Optical Properties of Materials, ASHRAE Standard 74-73 (ASHRAE, 1973).

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Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Exposure of Plastics, ASTM: D1499-64 Reapproved 1971 (ASTM, 1971).

Operating Xenon Arc-Type (Water-Cooled) Light- and Water-Exposure Apparatus for Exposure of Plastics, ASTM: D 2565-75 (ASTM, 1975).

Outdoor Weathering of Plastics, ASTM: D 1435-75 (ASTM, 1975).

Pennington, Clark W., and G. L. Moore, "Measurement of Solar-Optical Properties of Glazing Materials," *ASHRAE Journal* (ASHRAE, July 1971).

Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings, ANSI Z97.1-1972 (American National Standards Institute, Inc., 1972).

Plastic Sheet and Strip, Polyester, Federal Specification L-P-377b (GSA, Feb 1966).

Screening, Insect, Nonmetallic, Federal Specification L-S-125B (GSA, February 1972).

Solar Energy Transmittance and Reflectance (Terrestrial) of Sheet Materials, ASTM: E 424-71 (ASTM, 1971).

Specular Gloss of Plastic Films, ASTM: D 2457-70 (ASTM, 1970).

Tensile Properties of Thin Plastic Sheeting, ASTM: D882-75b (ASTM, 1975).

Transparent Plastic Window Shades, Federal Aviation Administration Specification FAA-E-2470 (Department of Transportation, May 1971).

Vinyl-Coated Glass Fiber Insect Screening and Louver Cloth, Commercial Standard CS248-64 (Department of Commerce, National Bureau of Standards, February 1964).

Water Absorption of Plastics, ASTM: D 570-63 Reapproved 1972 (ASTM, 1972).

APPENDIX C:

QUESTIONNAIRE*

SOLAR CONTROL WINDOW FILM DATE:________
USER INFORMATION

Please circle appropriate numbers and give additional comments on other side.

Name of Building ________________________________

Address ________________________________

1. Type of Film ________________________________ 1-11

2. Age of Installation, Yrs ________________________ 12-14

3. Reason for Choosing Film: 1. Lowest Cost 2. Eliminate/Reduce Glare
   3. Reduce Solar Heat 4. Conserve Energy 5. Other ____________ 15-19

4. Area of Installation: 1. East 2. South 3. West 4. North 20-21
   Total Sq Ft ________________________________ 22-26

5. Type of Windows: 1. Clear 2. Tinted 3. Thermopane 4. [illegible]t
   Reflecting 5. Heat Absorbing 6. Other ____________ 27-29
   Window Thickness ________________________________ 30

6. Cost/Sq Ft: Film Material ________ Labor ________ Total ________ 31-33

7. Warranty Period ________________________________ 34-35

8. Has Film Reduced Air-Conditioning Cost: 1. Yes 2. No By What %____ 36,37-38

9. Has Film Reduced Heating Cost: 1. Yes 2. No By What % __________ 39,40-41

10. Performance to Date: 1. Excellent 2. Very Good 3. Good 4. Fair
    5. Poor 6. Comment ________________________________ 42-43

11. Effect of Aging on Film, Is it Blotchy or Non-Uniform: 1. No Effect
    2. Small Effect 3. Large Effect 4. Comment ______________ 44-45

12. Can Film Withstand Cleaning: 1. Yes 2. No 3. Don't Know
    4. Comment ________________________________ 46-47

13. Cleaning Materials Used: 1. Water 2. Water & Ammonia 3. Soap &
    Water 4. Commercial Cleaner 5. Name Cleaner and Comment
    ________________________________ 48-49

14. Is Film Easily Damaged, Scratched or Torn: 1. Yes 2. No
    3. Comment ________________________________ 50-51

* Questionnaire was approved by the Office of Management and Budget (OMB) under OMB No. 49-S74007 on 22 November 1974.

15. Is Film Effective in Reducing or Eliminating Glare: 1. Yes 2. No 52

16. Is Film Effective in Reflecting Solar Heat: 1. Yes 2. No 53

17. Does Film Shut Out an Undue Amount of Light: 1. Yes 2. No

    3. Comment ______________________________ 54-55

18. Other Advantages ______________________________ 56-57

19. Disadvantages or Limitations ______________________________ 58-59

20. Does Film Obstruct View (To Outdoors): 1. Yes 2. No 60

21. Does Film Affect Indoor Plants: 1. Yes 2. No 3. Unknown 61

APPENDIX D:

DATA FROM FIELD INVESTIGATIONS

Table D1

Solar Film User Data Comparison vs Manufacturer

	Madico	3M	Solar Control	Sun-X
Responses Received From Users, Total	29	80	53	47
Age of Installations, Yr				
Range	1 to 8.3	1 to 10	0.7 to 8	0.8 to 6
Average	3.7	3.9	2.5	3.2
Users Responding	29	79	53	47
Area of Installation, Sq Ft				
Range	50 to 50,000 (4.6 to 4645.2 m^2)	40 to 55,500 (3.7 to 5156.1 m^2)	80 to 28,000 (7.4 to 2601.3 m^2)	36 to 19,000 (3.3 to 1765.2 m^2)
Average	3,043 (282.7 m^2)	3,862 (358.8 m^2)	2,528 (234.9 m^2)	2,862 (265.9 m^2)
Users Responding	23	47	40	28
Window Thickness				
1/4 in. (6.35 mm)	80.0%	59.0%	60.7%	65.0%
Users Responding	15	39	28	20
Warranty Period, Yr				
Range	1 to 5	1 to 5	1 to 5	0.2 to 5
Average	2.2	1.8	4.3	2.2
Users Responding	12	43	26	25
Has Film Reduced Air-conditioning Cost?				
Yes	77.8%	83.0%	85.7%	96.8%
Users Responding	18	53	28	31
Air Conditioning Cost (Percent Reduction)				
Range	5 to 30	1 to 50	2 to 35	6 to 20
Average	14.4	18.2	17.5	13.9
Users Responding	9	18	17	7
Has Film Reduced Heating Cost?				
Yes	33.3%	48.9%	60.0%	38.5%
No	66.7%	51.1%	40.0%	61.5%
Users Responding	15	47	20	26

Table D1 (Cont'd)

	Madico	3M	Solar Control	Sun-X
Heating Cost (Percent Reduction)				
Range	5 to 30	1 to 30	5 to 25	20
Average	15.0	11.2	12.7	20
Users Responding	5	6	7	1
Performance to Date				
Good to Excellent	93.1%	84.7%	91.7%	95.1%
Fair	6.9%	3.8%	4.2%	4.9%
Other	None	11.5%	4.1%	None
Users Responding	29	78	48	41
Effect of Aging of Film				
No Effect	57.1%	68.8%	82.2%	81.8%
Small Effect	35.7%	22.1%	15.6%	13.6%
Large Effect & Other	7.2%	9.1%	2.2%	4.6%
Users Responding	28	77	45	44
Can Film Withstand Cleaning?				
Yes	89.3%	87.7%	81.2%	97.8%
Don't Know	10.7%	1.4%	12.5%	None
No and Other	None	10.9%	6.3%	2.2%
Users Responding	28	73	48	45
Is Film Easily Damaged?				
No	48.1%	55.3%	66.7%	51.2%
Yes	51.9%	31.6%	20.0%	41.9%
Other	None	13.1%	13.3%	6.9%
Users Responding	27	76	45	43
Is Film Effective in Reducing or Eliminating Glare?				
Yes	96.6%	94.7%	100.0%	100.0%
No	3.4%	5.3%	None	None
Users Responding	29	76	49	46
Is Film Effective in Reflecting Solar Heat?				
Yes	87.5%	97.2%	100.0%	97.8%
No	12.5%	2.8%	None	2.2%
Users Responding	24	71	41	46

Table D1 (Cont'd)

	Madico	3M	Solar Control	Sun-X
Does Film Shut Out an Undue Amount of Light?				
Yes	20.7%	16.2%	6.4%	25.5%
No	75.9%	82.4%	93.6%	74.5%
Partially	3.4%	1.4%	-	-
Users Responding	29	74	47	47
Advantages of Using Solar Film	Generally applicable to all manufacturers (21 advantages). Some major advantages are: solves heat and glare problem, eliminates sun damage, privacy, good appearance, shatterproof.			
Users Responding	11	40	16	32
Disadvantages or Limitations	Generally applicable to all manufacturers (21 disadvantages). Some major disadvantages are: reduces light availability and some visibility, and cost.			
Users Responding	7	24	10	15
Does Film Obstruct View to Outdoors?				
No	82.1%	91.7%	89.4%	89.1%
Yes	17.9%	8.3%	8.5%	10.9%
At Night	-	-	2.1%	-
Users Responding	28	72	47	46
Does Film Affect Indoor Plants?				
Yes	-	5.4%	-	8.5%
No	21.4%	31.1%	19.1%	34.0%
Unknown	78.6%	63.5%	80.9%	57.5%
Users Responding	28	74	47	47

Table D2

Solar Film User Data Analysis vs Age of Installation

	Installation Age (Years)	
Solar Film by Manufacturer (%)		
	0.7 to 3	3.2 to 10.0
Madico	10.8	18.0
3M	31.7	47.1
Solar Control Products	35.0	12.4
Sun-X	22.5	22.5
	100.0	100.0
Users Responding	120	89
Age of Installation (Yr)		
Range	0.7 to 3.0	3.2 to 10.0
Average	2.2	4.9
Users Responding	119 out of 120	89
Reason for Choosing Film (%)		
Eliminate/Reduce Glare, Reduce Solar Heat, and Conserve Energy	97.3	89.2
Users Responding	111 out of 120	84 out of 89
Area of Installation (sq ft)		
Range	40 to 55,500 (3.7 to 5156.1 m^2)	36 to 23,936 (3.3 to 2223.7 m^2)
Average	3740 (347.5 m^2)	2252 (209.2 m^2)
Users Responding	82 out of 120	56 out of 89

Table D2 (Cont'd)

	Installation Age (Years)	
Type of Windows (%)	0.7 to 3	3.2 to 10.0
Clear	68.0	84.0
Tinted	20.0	9.0
Miscellaneous	12.0	7.0
	100.0	100.0
Users Responding	115 out of 120	85 out of 89
Window Thickness (%)		
1/4 in. (6.35 mm)	62.7	65.1
3/16 in. (4.76 mm)	11.9	11.6
1/8 in. (3.18 mm)	6.8	7.0
Other	18.6	16.3
	100.0	100.0
Users Responding	59 out of 120	43 out of 89
Has Film Reduced Air Conditioning Cost? (%)		
Yes	82.9	90.0
No	17.1	10.0
	100.0	100.0
Users Responding	70 out of 120	60 out of 89
Air Conditioning Cost (% Reduction)		
Range	2 to 50	1 to 25
Average	18.3	14.3
Users Responding	31 out of 120	20 out of 89

Table D2 (Cont'd)

	Installation Age (Years)	
Has Film Reduced Heating Cost? (%)		
	0.7 to 3	3.2 to 10.0
No	52.5	55.1
Yes	47.5	44.9
	100.0	100.0
Users Responding	59 out of 120	49 out of 89
Heating Cost (% Reduction)		
Range	2 to 30	1 to 20
Average	15.1	9.2
Users Responding	13 out of 120	8 out of 89
Performance to Date (%)		
Good to Excellent	91.0	88.3
Fair	5.5	3.5
Other	3.5	8.2
	100.0	100.0
Users Responding	110 out of 120	86 out of 89
Effect of Aging on Film (%)		
No Effect	80.8	63.5
Small Effect	17.4	24.7
Large Effect	.9	4.7
Other	.9	7.1
	100.0	100.0
Users Responding	109 out of 120	85 out of 89

Table D2 (Cont'd)

	Installation Age (Years)	
Can Film Withstand Cleaning? (%)		
	0.7 to 3	3.2 to 10.0
Yes	91.9	84.4
With Care	.9	4.8
No	1.8	4.8
Other	5.4	6.0
	100.0	100.0
Users Responding	111 out of 120	83 out of 89
Is Film Easily Damaged? (%)		
No	57.4	53.6
Yes	30.6	38.1
Other	12.0	8.3
	100.0	100.0
Users Responding	108 out of 120	84 out of 89
Is Film Effective in Reducing or Eliminating Glare? (%)		
Yes	99.1	95.3
No	.9	4.7
	100.0	100.0
Users Responding	114 out of 120	86 out of 89
Is Film Effective in Reflecting Solar Heat? (%)		
Yes	97.1	96.2
No	2.9	3.8
	100.0	100.0
Users Responding	103 out of 120	79 out of 89

Table D2 (Cont'd)

	Installation Age (Years)	
Does Film Shut Out an Undue Amount of Light? (%)		
	0.7 to 3	3.2 to 10.0
No	82.1	82.3
Yes	17.0	16.5
Partially	.9	1.2
	100.0	100.0
Users Responding	112 out of 120	85 out of 89
Advantages of Using Solar Film		
	Advantages listed are generally the same for each age range	
Users Responding	50 out of 120	49 out of 89
Disadvantages or Limitations (%)		
Major Disadvantages		
Reduces Light Availability	19.4	16.0
Cost	12.9	8.0
Some Visibility	9.7	20.0
Had Some Cracked Windows	9.7	Not Listed
Cleaning Care	Not Listed	16.0
Other	48.3	40.0
	100.0	100.0
Number of Disadvantages Listed	16	12
Users Responding	31 out of 120	25 out of 89

Table D2 (Cont'd)

	Installation Age (Years)	
Does Film Obstruct View to Outdoors? (%)		
	0.7 to 3	3.2 to 10.0
No	86.4	92.8
Yes	12.7	7.2
At Night	.9	--
	100.0	100.0
Users Responding	110 out of 120	83 out of 89
Does Film Affect Indoor Plants? (%)		
Unknown	70.3	65.9
No	25.2	30.6
Yes	4.5	3.5
	100.0	100.0
Users Responding	111 out of 120	85 out of 89

Table D3

User Comments on Advantages and Limitations Of Solar Film

Advantages

1. Blocks out glare and gives better working conditions, comfort, cooling balance, and people efficiency.

2. Film cuts down on the intense heat of direct sunlight.

3. Conservation of energy.

4. After installation of film, area can be cooled.

5. Labor for application and maintenance is minimal.

6. Scratches or nicks can be repaired.

7. If no air conditioning exists, the film protects from light rays and reduces cooling cost.

8. Desk areas near windows are cooler and can be utilized.

9. Use of film stabilizes glass and makes both sides of building a more even temperature. Hot spots are eliminated.

10. Possible slight reduction in heating cost especially where percent of glass in a multistory building exceeds 30 percent.

11. Reduces eye fatigue when handling white paper.

12. Films are provided for tinted or heat-absorbing glass.

13. Reduces vision from outside to inside in daytime providing privacy.

14. One-way daytime visibility offers security.

15. Does not restrict visibility.

16. Film is less expensive than curtains, drapes, or tinted glass.

17. Reduces deterioration and fading of drapes, carpets, and other furnishings.

18. Reduces amount spent for cleaning.

19. Drapes can now be open.

20. Eliminates need for dirt-catching venetian blinds.

21. Prevents glass from shattering or splintering.

22. Gives building an attractive appearance.

23. External film covers discolored glass to give a uniform appearance.

24. Less load and maintenance on existing air-conditioning equipment.

25. In new construction, can design for lower tonnage air-conditioning equipment.

Table D3 (cont'd)

Limitations

1. Glare from interior lighting.

2. Late afternoon sun still comes through.

3. Some do not like to lose heat of sun in winter (Phoenix), overhang can protect.

4. At least two adhesive systems are available; the proper one must be used depending on surrounding moisture and humidity conditions.

5. Vaporizers or humidifiers will loosen film.

6. Certain rough types of window glass do not permit good adhesion of film.

7. Signs cannot be painted on glass that has solar film. Displays cannot be seen through windows.

8. Cannot tape signs or posters over the film on windows. Tape pulls film off.

9. Film on windows may inhibit indoor plant growth.

10. Some installations develop cracked windows. Heat absorption can crack glass depending on the type of window glass, flexibility of sealing material present, and type of film used.

11. At night, with lights on, one cannot see to the outside, and film reflects like a mirror inside. It is possible, however, to see inside from outdoors.

12. Reflection of film. Mirror effect on exterior.

13. Some view-obstruction to oudoors.

14. Film made interior darker.

15. Less light from windows on dark days.

16. Shadows are sharper.

17. Reflection can blind drivers.

18. Attracts dust.

19. Film can come off if not washed carefully.

20. Interior cleaning.

21. Damaged easily and requires care in cleaning to prevent scratches or tears.

22. Cannot use abrasives for cleaning.

23. Cannot use on traffic doors because of scratching.

24. If film is scratched, water can get behind it and form a bubble.

25. Small holes in window (BB gun) must be repaired immediately because of ray-like effect from sun into the building.

Table D4

Solar Film Installations Visited and Users Contacted

User	Installation Approx Date	Type of Solar Film	Installed (sq ft)	Warranty Period (yr)	Total Cost (per sq ft)	User's Comments
Murr Service Club Building Fort Huachuca, AZ	Spring 1973	Madico Reflecto-Shield, RSL-100-20 (adhesive-added)	1,200 (111.5 m^2)	5	\$1.22 (\$13.12/m^2)	Performance is excellent. Air-conditioning and heating costs are reduced as well as glare. Solar heat is reflected and film is not easily damaged or torn. No aging effect on film. Overall comfort improved. Had some scratches and nicks in film on door from fingers. Vinegar and water recommended for cleaning.
JAG Building Fort Huachuca, AZ	July 1973	Same as above	1,250 (116.1 m^2)	5	\$1.14 (\$12.26/m^2)	Same comments as above. Applicator does not recommend the pressure-sensitive adhesion film in this dry climate since the adhesive dries too fast during installation.
Raymond W. Bliss Army Hospital Fort Huachuca, AZ	July 1974	Solar Control, Solar-X (S-80) (adhesive-added)	1,160 (107.8 m^2)	5	\$1.65 (\$17.74/m^2)	Very good performance. Film cuts down on solar heat and glare. Film is not easily damaged, scratched, or torn.
Education Building Univ. of Illinois Urbana-Champaign, IL	July 1971	3M A-33 (water-activitated adhesive)	6,500 (603.9 m^2)	2	\$1.15 (\$12.37/m^2)	Performance is excellent. Air conditioning and heating costs are reduced as well as glare. Solar heat is reflected and comfort is good. Aging has a small effect on the film and it can be damaged.
Fine & Applied Arts Building Univ. of Illinois Urbana-Champaign, IL	June 1971	3M P-18	4,783 (444.4 m^2)	2	\$1.36 (\$14.62/m^2)	Performance is very good. Air-conditioning and heating costs are reduced as well as glare. Solar heat is reflected and can more easily air-condition the building now. Aging has a small effect on the film and it can be damaged. Recently, numerous repairs were required due to glass breakage and vandalism.
Mercy Hospital Urbana, IL	1968-1969 Summer 1973	3M P-18	(2 large windows) (6 large windows)	--	--	Glare and temperature reduced. No view obstruction to outside and users liked film on windows. Drapes were unsatisfactory.

Table D4 (Cont'd)

User	Installation Approx. Date	Type of Solar Film	Installed (sq ft)	Warranty Period (yr)	Total Cost (per sq ft)	User's Comments
Student Services Building Univ. of Illinois Urbana-Champaign, IL	July 1972 to June 1974	3M P-18	1,040 (June 1974) (96.62 m^2)	2	\$1.44 (\$15.48/m^2)	Performance is excellent. Air conditioning and heating costs are reduced as well as glare. Solar heat is reflected and steam consumption reduced. Aging has a small effect on the film and it can be damaged.
U.S. Army Construction Engineering Research Laboratory, Champaign, IL	June 1974 & Feb 1976	Solar-X PS-80	(2 Windows)	5	--	Performance is satisfactory. Glare is reduced and can still see outside. People can't see in. Most occupants liked having film on windows. Venetian blinds no longer needed.
U.S. Post Office Champaign, IL	April 1974	3M P-18 Silver	300 (27.9 m^2)	2	\$2.00 (\$21.51/m^2)	Performance is excellent. Air-conditioning cost is reduced. Solar heat is reflected and glare reduced. Well satisfied with installation.
Phoenix General Hospital Phoenix, AZ	1972-1973	3M A-18 Silver (water-activated adhesive	1,000 Approx. (92.90 m^2)	2	\$1.60-2.25 (\$17.20-\$24.19/m^2)	Well satisfied. Having savings on air-conditioning and heating costs. Recommended the product. Film was scratched on a window in a hallway where people congregated.
Liquid Air, Inc. Phoenix, AZ	June 1971	Sun-X F-88 Silver (adhesive-added)	(10 Large windows)	None	Unknown	Performance to date is excellent. Solar heat is reflected and glare reduced. Film is not easily damaged, scratched, or torn and there is no aging effect on film. Drapes now left open.
The Arizona Bank 3131 N. 19th Ave. Phoenix, AZ	April 1970	Sun-X F-88 Silver (adhesive-added)	(Above front doors)	-	Unknown	Satisfied with performance. Air-conditioning cost reduced and heating slightly reduced. Film has reduced glare and solar heat transmission. The product has not torn, has no scratches and no deterioration due to aging.

Table D5

Solar Film Installations Visited and Applicators Contacted

User	Installation Approx. Date	Type of Solar Film	Installed (sq ft)	Warranty Period (yr)	Total Cost (per sq ft)	User's Comments
Del Webb Town House Hotel Phoenix, AZ	1970-1974	3M A-18 Silver Water-Activated Adhesive	2,750 Approx. (255.5 m^2)	2	\$1.60-\$2.25 (\$17.20-\$24.19/m^2)	User contacted but did not furnish required information.
Doctor's Hospital Phoenix, AZ	August 1971	Same as Above	500 Approx. (46.5m^2)	2	\$1.60-\$2.25 (\$17.20-\$24.19/m^2)	Film is effective in reducing or eliminating glare and reflecting solar heat. Performance to date (2-4-75) is excellent.
Woolco Dept. Store Mesa, AZ	April 1973	Solar Control Prod. Solar-X S-65 Adhesive Added	913 (84.8 m^2)	5	\$1.50 (\$16.13/m^2)	Film is effective in reducing or eliminating glare and reflecting solar heat. Performance to date (3-28-75) is good.
Fellowship Towers Phoenix, AZ	Dec 1972	Solar Control Prod. Solar-X PS-65	12,547 (1165.7 m^2)	5	\$1.13 (\$12.15/m^2)	Film is effective in reducing or eliminating glare and reflecting solar heat. Performance to date (3-10-75) is good.
Greyhound Bus Term. Phoenix, AZ	Sept 1973	Solar Control Prod. Solar-X S-65 Adhesive Added	226 (21.0 m^2)	5	-	Film is effective in reducing or eliminating glare and reflecting solar heat. Performance to date (3-7-75) is very good. Film had circular wash cloth marks.
Stewart Title Co. Phoenix, AZ	August 1973	Solar Control Prod. Solar-X S-80 Adhesive-Added	872 (81.0 m^2)	5	\$1.65 (\$17.74/m^2)	Film is effective in reducing or eliminating glare and reflecting solar heat. Performance to date (3-21-75) is very good.
United Bank of Ariz. 64 E. Broadway Tempe, AZ	August 1972	Solar Control Prod. Solar-X PS-65	553 (49.5 m^2)	5	-	User contacted but did not furnish required information.

Table D6

Occupants' Comments*

1a. Did you occupy this building before solar film was installed on the windows?

Yes	82%
No	18%
	100%

1b. How long?

Range	1 to 22 years
Average	8.1 years
Not stated or N/A	10 Occupants

2a. What type of sun control/privacy control devices were used? (shades, blinds, etc.)

Venetian Blinds	46%
Drapes	42%
Curtains	3%
Not Stated	9%
	100%

2b. Were these devices satisfactory?

Venetian Blinds	
Yes	27%
No	9%
Not completely	9%
Drapes	
Yes	3%
No	31%
Not completely	6%
Curtains	
No	3%
Not Stated	12%
	100%

3. Once the film was installed, was there a noticeable difference in any of the following?

a. Glare

Yes	79%
Some	6%
Not enough	3%
Not stated or N/A	12%
	100%

b. Temperature

Yes	46%
Some	15%
No	12%
No difference	6%
No way of telling	3%
Not stated	18%
	100%

*33 Occupants responded to the questions.

Table D6 (Cont'd)

c. Privacy

Yes	43%
Some	3%
No	15%
No difference	15%
Not stated	24%
	100%

d. View Obstruction

No	49%
Improved	3%
Yes	18%
Tendency	9%
Not stated	21%
	100%

e. Personal Control of Light/Privacy

No	33%
Yes	27%
Drapes also used	9%
Need more light	3%
Not stated	28%
	100%

f. Employee Attitude

Yes	18%
Improved	21%
Disliked	12%
No	9%
No difference	9%
Taken for granted	3%
Not stated	28%
	100%

4. Do you like having film on windows?

Yes	73%
Yes, but not at night	3%
No	18%
Not stated	6%
	100%

5. Are you accustomed to the film?

Yes	91%
No	6%
Not stated	3%
	100%

Table D6 (Cont'd)

6. Have you noticed any maintenance problems due to the film?

Yes**	27%
No	64%
Not if applied properly	3%
Not stated	6%
	100%

7a. Did you formerly occupy a building with film on windows?

No	94%
Not stated	6%
	100%

How long

Don't know	3%
N/A	9%
Not stated	88%
	100%

7b. If you've had any experience with the film, please give a brief comment on your reaction† to it:

-Temperature does not rise so rapidly - summer is more comfortable (1)
-Too hot before installation of film (1)
-Reduces heat and light in summer; reduces glare (1)

-Less glare (1)
-Reduces glare; wants film to remain (1)
-Adequate for glare and controlling heat loss; relatively maintenance free (1)
-Allows curtains to be open a greater percentage of time (1)

-Generally pleased (1)
-System works well with large surface glass (2)
-Like it very much (2)
-Fine, however removal of previously applied scotch tape tears film (1)
-Used to have headaches before installation; doesn't help ventilation (1)
-Answers need for privacy and glare (1)

**Small amount of peeling, film has bubbles, tears not repairable.

†Favorable to film 46%

Table D6 (Cont'd)

-Plants don't grow; building next door cuts sunlight; draw drapes used (1)
-Expensive and depressing (2)
-Blistering showed up in 4-1/4 years after installation at bottom of windows (1)
-Bubbles in film; film unglued in spots; seems to reduce heat (1)

			%
Comments favorable to film	(15)		46
Comments unfavorable (5)	(4)	users	12
N/A	(2)		6
No answer	(9)		27
No experience	(3)		9
			100

7c. Even though you have had no experience with the film, please give a brief comment on your reaction to it:

Reduces glare Like the privacy Allows natural light Aids air conditioning in summer More comfortable in hot weather Approve it	30%
Makes sky look gloomy Color change annoying; impossible to see through at night Prefer tinted glass Did not make room cooler in summer Depressing and expensive Not sufficiently effective Difficult to grow plants	21%
Not stated	49%
	100%

8. Which of the following would you prefer:

a. Window alone	3%
b. Window with sun and privacy control devices	15%
c. Window with film	3%
d. Window with combination of film and control devices	76%
e. Not stated	3%
	100%

APPENDIX E:

MANUFACTURERS' COMMENTS ON AGING

Comments of three manufacturers and a processor* of the basic unmetallized polyester film on aging are summarized below:

1. Solar film is affected by weathering (ultraviolet light) and moisture. Incorporation of a barrier coating or inhibitor provides resistance to ultraviolet light. Assured adhesion of the edges of the film and caution to prevent scratching during cleaning will keep out moisture and ultraviolet light and prolong the life of the film.

2. Without an ultraviolet inhibitor, the film discolors, becomes brittle, and flakes away. Other effects are loss of strength, cracking, crazing, and deterioration of the adhesive.

3. If the film is scratched or cut, moisture seepage will oxidize the aluminum surface, loosen it, and make it "pick" away from the film.

One manufacturer of metallized polyester film (3M) stated that projected laboratory tests on solar film indicate a 15-year or longer life if properly maintained and unscratched.

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* ICI United States, Inc., Celanese Plastics Co., DuPont Co., and Martin Processing, Inc.

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