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Working Document

Optical Properties Database For High Performance Glazings

A report of Task 12: Building Energy Analysis and Design Tools for Solar Applications

Subtask A.1: High Performance Glazings

June 1992

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

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Optical Properties Database for High Performance Glazings

Task 12: Building Energy Analysis and Design Tools for Solar Applications
Subtask A.1: High-Performance Glazing

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PREFACE

INTRODUCTION TO THE INTERNATIONAL ENERGY AGENCY

BACKGROUND

The International Energy Agency was founded in November 1974 as a cooperation among industrialized nations to address energy policy issues. It is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OEDC). Twenty-one countries are presently members, with the Commission of the European Communities also participating in the work of the IEA under a special agreement.

One element of the IEA's program involoves cooperation in the research and development of alternative energy resources in order to reduce excessive dependence on oil. A number of new and improved energy technologies which have the potential of making significant contribution to global energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), comprising representatives from each member country, supported by a small Secretariat staff, is the focus of IEA RD&D activities. Four Working Paries (in Conservation, Fossil Fuels, Renewable Energy, and Fusion) are charged with identifying new areas for cooperation and advising the CRD on policy matters in their respective technology areas.

SOLAR HEATING AND COOLING PROGRAM

Solar Heating and Cooling was one of the technologies selected for joint activities. During 1976–1977, specific projects were identified in key area of this field and a formal Implementing Agreement drawn up. The Agreement covers the obligations and rights of the Participants and outlines the scope of each project or "task" in annexes to the document.There are now eighteen signatories to the Agreement:

Australia
Austria
Belgium
Canada
Denmark
Commission of the European Communities
Germany
Greece
Italy
Japan
Netherlands
New Zealand
Norway
Spain
Sweden
Switzerland
United Kingdom
United States

The overall program is managed by an Executive Committee, while the management of the individual tasks is the responsibility of Operating Agents. The tasks of the IEA Solar Heating and Cooling Program, their respective Operating Agents, and current status (ongoing or completed) are as follows:

Task 1 Investigation of the Performance of Solar Heating and Cooling Systems—Technical University of Denmark (Completed).

Task 2 Coordination of Research and Development of Solar Heating and Cooling—Solar Research Laboratory—GIRN, Japan (Completed).

Task 3 Performance Testing of Solar Collectors—Forschungszentrum Jülich, Germany, University College, Cardiff, U.K. (Completed).

Task 4 Development of an Isolation Handbook and Instrument Package—U.S. Department of Energy (Completed).

Task 5 Use of Existing Meterological Information for Solar Energy Application—Swedish Meterological and Hydrological Institute (Completed).

Task 6 Performance of Solar Heating, Cooling, and Hot Water Systems using Evacuated Collectors—U.S. Department of Energy (Completed).

Task 7 Central Solar Heating Plants with Seasonal Storage—Swedish Council for Building Research (Completed).

Task 8 Passive and Hybrid Solar Low Energy Buildings—U.S. Department of Energy (Completed).

Task 9 Solar Radiation and Pyranometry Studies—Forschungszentrum Jülich, Germany (Completed).

Task 10 Solar Materials R&D—AIST, Ministry of International Trade and Industry, Japan (Completed).

Task 11 Passive and Hybrid Solar Commercial Buildings—Swiss Federal Office of Energy (Completed).

Task 12 Building Energy Analysis and Design Tools for Solar Applications—U.S. Department of Energy (Ongoing).

Task 13 Advanced Solar Low Energy Buildings—Norwegian Institute of Technology (Ongoing).

Task 14 Advanced Active Solar Energy Systems—Canadian Department of Energy Mines and Resources (Ongoing).

Task 15 Advanced Central Solar Heating Plants with Seasonal Storage (In Planning Stage).

Task 16 Photovoltaics in Buildings—Forschungszentrum Jülich, Germany (Ongoing).

Task 17 Measuring and Modelling Spectral Radiation Affecting Solar Systems and Buildings—Forschungszentrum Jülich, Germany (Ongoing).

Task 18 Advanced Glazing Materials—U.K. Department of Energy (Ongoing).

Task 19 Solar Air Systems for Buildings—Swiss Federal Office of Energy (Ongoing).

Task 20 Solar Energy in Building Renovation—Swedish Council for Building Research (Ongoing).

TASK 12: BUILDING ENERGY ANALYSIS AND DESIGN TOOLS FOR SOLAR APPLICATIONS

The scope of Task 12 includes: (1) selection and development of appropriate algorithms for modeling of the interaction of solar energy related materials, components and systems with the building in which these solar elements are integrated; (2) selection of analysis and design tools and evaluation of the algorithms as to their ability to model the dynamic performance of the solar elements in respect to accuracy and ease of use; and (3) improvement of the usability of the analysis and design tools, through preparation of common formats and procedures and by standardization of specifications for input/output, default values and other user-related factors.

The subtasks of this project are:

A : Model Development
B : Model Evaluation
C : Model Use

The participants in this Task are: Denmark, Germany, Norway, Sweden, Switzerland, and the United States. The United States serves as Operating Agent for this Task.

This report documents work carried out under Subtask A.1 of this Task entitled High Performance Glazings.

EXECUTIVE SUMMARY

This document presents the framework and foundation for an optical properties database undertaken as part of Subtask A.1, High-Performance Glazings, of Task 12 of the IEA Solar Heating and Cooling Program.

At the start of the Task, the participants agreed that a database of glazing optical properties would prove invaluable in the performance modeling of windows. The compilation of an optical properties database for glazing materials is intended to provide researchers with a common set of data for modeling fenestration systems and their components. The database also serves as a cross-reference for materials and products produced in different countries, and can be used for hourly annual building energy simulations programs such as DOE-2.1E.

The WINDOW program for calculating the thermal performance of fenestration systems was used to establish the optical properties database. WINDOW 4.0 calculates the total window system thermal and optical properties. The format of the database is consistent with WINDOW 4.0 libraries that are directly accessible by WINDOW. The database contains the optical properties of commonly-found glazing systems and glazings, and is included in the appendices.

Future work on this database could include glazing and glazing system optical property data from each country, the collection of spectral data, the development of guidelines for reporting and methods for evaluating optically complex materials, and the establishment of a mechanism for maintaining the database.

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I. INTRODUCTION

1.1 Background

Subtask A is concerned with improving the capability of building energy analysis and design tools to evaluate new and emerging solar heating, cooling and daylighting materials, components and systems. Material properties are an essential input to any analysis or design tool, and the need for libraries of consistent and accurate data is recognized throughout the research and design communities. This led the participants to choose this area of collaborative research.

1.2 Purpose of this Report

The optical properties of glazing materials are essential to any evaluation technique for calculating the performance of glazing materials and window systems. Furthermore, the basic inputs for calculating system performance and comparing evaluation techniques must be the same. An optical properties database would provide consistent data to researchers and eliminate an unknown in attempts to reconcile inequalities between evaluation techniques. Such a database would also promote the transfer of information between countries.

1.3 Structure of the Report

Section II describes the framework used for the database; section III addresses maintaining and updating the database; and section IV covers extensions of the database.

The appendices include the glass library (Appendix A) and the glazing system library (Appendix B) which form the foundation of the optical property database, and a spectral data reporting format (Appendix C). The WINDOW program can be obtained from the Building Technologies Program at Lawrence Berkeley Laboratory.

1.4 Intended Audience

The primary audience for the Optical Property Database are researchers, engineers, manufacturers, and architects. Generally speaking, this database provides useful information to anyone working or designing with glazing materials.

1.5 Acknowledgments

This report was instigated through cooperation between the IEA participating researchers and the government agencies which sponsored the work in the respective countries. The participants who provided comments and criticism on earlier drafts are thanked for their effort, without which this report could not have been completed.

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II. COMPILATION OF DATABASE

The WINDOW program for calculating the thermal and optical performance of fenestration systems was used to compile libraries of glazing and window properties. The program was developed by the Windows and Daylighting Group at Lawrence Berkeley Laboratory and is available at no cost to the public. The program runs on any IBM PC (XT or higher) or clone, and requires 640 kBytes of memory.

The WINDOW program includes libraries of glazing materials, window systems, and their associated thermal and optical properties. The optical properties are the total direct-hemispherical solar, visible, and thermal infrared properties. The total optical properties for a window system are calculated from those of the individual glazing layers. Thermal performance indices are also calculated, although they will not be discussed here. For more details on the program see "A Versatile Procedure for Calculating Heat Transfer Through Windows," by D. Arasteh, S. Reilly, and M. Rubin in the ASHRAE Transactions 1989, volume 95, part 2.

The glass library (Appendix A) and summary of the window system library (Appendix B) represent commonly available products. The window system library was created for incorporation into the building energy simulation program, DOE2.1E. Its use is not limited to this program, and the format is easily adaptable to other building simulation energy programs. An example of the output for a window is included in Appendix B.

III. DATABASE MAINTENANCE

A mechanism for maintaining and updating the database needs to be established. This could take the form of a central facility for collecting and updating the database, or a periodic meeting of interested parties for exchanging information. Task 18 will assume some responsibility for this as part of the new IEA glazing materials project.

IV. EXTENSIONS OF THE DATABASE

4.1 Country-Specific Libraries

The libraries included here constitute a foundation for the optical properties database. Additional libraries are needed which are country-specific. This would allow products to be cross-referenced internationally and enhance the transfer of technology and new ideas.

New libraries can be created with WINDOW simply by entering the glazing properties or window design directly into the program. Data files containing glass properties of the products offered by most of the major glass and window manufacturers are available for the United States.

4.2 Spectral Data

Spectral data are required to calculate the thermal and optical properties of advanced multi-pane window systems with spectrally selective glazings. The optical behavior of these glazings can change significantly over the solar, visible, and infrared ranges. When such glazings are combined with glazings that also exhibit some spectral dependence (e.g., green glass and low-emissivity glass), use of the total properties for the individual layers in calculating the system properties is inaccurate. Spectral data are not commonly published for many commercially available glazings.

Spectral data files can be associated with glazings library entries in WINDOW 4.0. The program will then calculate the system optical properties wavelength by wavelength when spectral data exist for each of the layers in a window system. A spectral-data file format has been set-up for use with WINDOW 4.0 (see Appendix C). The release of WINDOW 4.0 this year will include spectral data from manufacturers in the United States.

4.3 Optically Complex Materials

The characterization of optically complex materials needs to be addressed. Examples of such materials are venetian blinds, fresnel lenses, aerogel, and honeycomb structures. Existing building energy simulation programs cannot adequately model these systems, especially in terms of daylighting effects. Complex materials include a broad range of products and require better definition and measurement and evaluation techniques.

APPENDIX A - WINDOW 4.0 Glass Library
(WINDOW 4.0 Program Description, LBL-32091)

WINDOW-4 Glass Layer Library

Description

Following is a listing of the WINDOW-4 glass layer library. It is shown here to indicate the properties of the individual glass layers that were used by WINDOW-4 to build the DOE-2/WINDOW-4 Window Library, whose index is shown in Table 2.12. Each layer entry gives the ID number, name, thickness (mm), solar transmittivity, front and back side solar reflectance, visible transmittance, front and back side visible reflectance, thermal infrared transmittivity, front and back side thermal infrared hemispherical emissivity, and thermal conductivity (W/m-K). This library is not accessible from DOE-2; it is shown here for reference only.

Index to WINDOW-4 Glass Layer Library

ID	GLASS	d(mm)	Tsol	Rfsol	Rbsol	Tvis	Rfvis	Rbvis	Tir	Emis1	Emis2	k
1	CLEAR	2.500	.850	.075	.075	.901	.081	.081	.033	.840	.840	.900
2	CLEAR	3.000	.837	.075	.075	.898	.081	.081	.000	.840	.840	.900
3	CLEAR	6.000	.775	.071	.071	.881	.080	.080	.000	.840	.840	.900
4	CLEAR	12.000	.653	.064	.064	.841	.077	.077	.000	.840	.840	.900
5	BRONZE	3.000	.645	.062	.062	.685	.065	.065	.000	.840	.840	.900
6	BRONZE	6.000	.482	.054	.054	.534	.057	.057	.000	.840	.840	.900
7	BRONZE	10.000	.326	.048	.048	.379	.050	.050	.000	.840	.840	.900
8	GREY	3.000	.626	.061	.061	.611	.061	.061	.000	.840	.840	.900
9	GREY	6.000	.455	.053	.053	.431	.052	.052	.000	.840	.840	.900
10	GREY	12.000	.217	.044	.044	.187	.045	.045	.000	.840	.840	.900
11	GREEN	3.000	.635	.063	.063	.822	.075	.075	.000	.840	.840	.900
12	GREEN	6.000	.487	.056	.056	.749	.070	.070	.000	.840	.840	.900
13	LOW IRON	2.500	.904	.080	.080	.914	.083	.083	.000	.840	.840	.900
14	LOW IRON	3.000	.899	.079	.079	.913	.082	.082	.000	.840	.840	.900
15	LOW IRON	4.000	.894	.079	.079	.911	.082	.082	.000	.840	.840	.900
16	LOW IRON	5.000	.889	.079	.079	.910	.082	.082	.000	.840	.840	.900
17	BLUE	6.000	.480	.050	.050	.570	.060	.060	.000	.840	.840	.900
200	REF A CLEAR LO	6.000	.066	.341	.493	.080	.410	.370	.000	.840	.400	.900
201	REF A CLEAR MID	6.000	.110	.270	.430	.140	.310	.350	.000	.840	.470	.900
202	REF A CLEAR HI	6.000	.159	.220	.370	.200	.250	.320	.000	.840	.570	.900
210	REF A TINT LO	6.000	.040	.150	.470	.050	.170	.370	.000	.840	.410	.900
211	REF A TINT MID	6.000	.060	.130	.420	.090	.140	.350	.000	.840	.470	.900
212	REF A TINT HI	6.000	.100	.110	.380	.100	.110	.320	.000	.840	.530	.900
220	REF B CLEAR LO	6.000	.150	.220	.380	.200	.230	.330	.000	.840	.580	.900
221	REF B CLEAR HI	6.000	.240	.160	.320	.300	.160	.290	.000	.840	.600	.900
230	REF B TINT LO	6.000	.040	.130	.420	.050	.090	.280	.000	.840	.410	.900
231	REF B TINT MID	6.000	.100	.110	.410	.130	.100	.320	.000	.840	.450	.900
232	REF B TINT HI	6.000	.150	.090	.330	.180	.080	.280	.000	.840	.600	.900
240	REF C CLEAR LO	6.000	.110	.250	.490	.130	.280	.420	.000	.840	.430	.900
241	REF C CLEAR MID	6.000	.170	.200	.420	.190	.210	.380	.000	.840	.510	.900
242	REF C CLEAR HI	6.000	.200	.160	.390	.220	.170	.350	.000	.840	.550	.900

Index to WINDOW-4 Glass Layer Library

ID	GLASS	d(mm)	Tsol	Rfsol	Rbsol	Tvis	Rfvis	Rbvis	Tir	Emis1	Emis2	k
250	REF C TINT LO	6.000	.070	.130	.490	.080	.130	.420	.000	.840	.430	.900
251	REF C TINT MID	6.000	.100	.100	.420	.110	.100	.380	.000	.840	.510	.900
252	REF C TINT HI	6.000	.120	.090	.390	.130	.090	.350	.000	.840	.550	.900
260	REF D CLEAR	6.000	.429	.308	.379	.334	.453	.505	.000	.840	.820	.900
270	REF D TINT	6.000	.300	.140	.360	.250	.180	.450	.000	.840	.820	.900
300	PYR LoE A CLEAR	3.000	.750	.100	.100	.850	.120	.120	.000	.840	.400	.900
350	PYR LoE B CLEAR	3.000	.740	.090	.100	.820	.110	.120	.000	.840	.200	.900
351	PYR LoE B CLEAR	6.000	.680	.090	.100	.810	.110	.120	.000	.840	.200	.900
400	SPUT LoE CLEAR	3.000	.630	.190	.220	.850	.079	.056	.000	.840	.100	.900
401	SPUT LoE CLEAR	6.000	.600	.170	.220	.840	.055	.078	.000	.840	.100	.900
451	SPUT LoE TINT	6.000	.360	.093	.200	.500	.035	.054	.000	.840	.100	.900
500	SS LoE CLEAR	3.000	.450	.340	.370	.780	.070	.050	.000	.840	.040	.900
501	SS LoE CLEAR	6.000	.430	.300	.420	.770	.070	.060	.000	.840	.040	.900
550	SS LoE TINT	6.000	.260	.140	.410	.460	.060	.040	.000	.840	.040	.900
600	S-POLY LoE 88	.051	.656	.249	.227	.868	.064	.060	.000	.136	.720	.140
601	S-POLY LoE 77	.051	.504	.402	.398	.766	.147	.167	.000	.075	.720	.140
602	S-POLY LoE 66	.051	.403	.514	.515	.658	.256	.279	.000	.057	.720	.140
603	S-POLY LoE 55	.051	.320	.582	.593	.551	.336	.375	.000	.046	.720	.140
604	S-POLY LoE 44	.051	.245	.626	.641	.439	.397	.453	.000	.037	.720	.140
605	S-POLY LoE 33	.051	.178	.739	.738	.330	.566	.591	.000	.035	.720	.140

Legend

REF A	stainless steel reflective coating
REF B	titanium reflective coating
REF C	pewter reflective coating
REF D	tin oxide reflective coating
LO	low-transmittance coating
MID	medium-transmittance coating
HI	high-transmittance coating
LoE	low-emittance coating
PYR	pyrolytic
SPUT	sputtered
SS	spectrally selective
S-POLY	suspended polyester film
d(mm)	glazing layer thickness
Tsol	solar transmittance of the glazing layer
Rfsol	the front (exterior) surface solar reflectance of a glazing system
Rbsol	the back (interior) surface solar reflectance of a glazing system
Tvis	visible transmittance of the glazing layer
Rfvis	the front (exterior) surface visible reflectance of a glazing system
Rbvis	the back (interior) surface visible reflectance of a glazing system
Tir	thermal infrared transmittance of a glazing layer
Emis1	infrared emittance of the exterior glazing layer surface
Emis2	infrared emittance of the interior glazing layer surface
k	thermal conductivity of the glazing material

APPENDIX B - DOE-2.1E Glazing System Library

NEW WINDOW LIBRARY

DOE-2.1E contains a new window library with 176 entries covering commonly-available glazings.* The choices are shown in the library index, Table 2.12. Included are single-, double-, triple- and quadruple-pane glazings with different tints, coatings, gas fills, glass thicknesses, and gap widths. This library is called the "DOE-2/WINDOW-4 Window Library" (or simply "Window Library"), since it was created for DOE-2 using WINDOW-4, a computer program that does a very detailed calculation of conduction and solar heat gain through windows (see D.K. Arasteh, M.S. Reilly, and M.D. Rubin, "A Versatile Procedure for Calculating Heat Transfer Through Windows "). When glazings from this library are selected, the window heat transfer calculation in DOE-2 will be very close to that in WINDOW-4.

An entry from this library is selected by specifying GLASS–TYPE–CODE = 1000 or higher (the ID value in Table 2.12). Because conductance data, number of panes, and solar-optical properties will be obtained from the library entry, the GLASS–TYPE keywords GLASS–CONDUCTANCE, PANES, and VIS–TRANS do not have to be specified (and, if specified, will be ignored).

Example:
For low-E clear double-pane window with 6mm glass and 12mm gap filled with argon (ID number 2635 in Table 2.12), enter:

u-name = GLASS–TYPE   GLASS–TYPE–CODE = 2635 ..

For upward compatibility with previous versions of DOE-2, the user may still specify glazing characteristics using SHADING–COEF, or GLASS–TYPE–CODE = 1 to 11 (see *Reference Manual (2.1A)*, pp.III.87-93). However, using the DOE-2/WINDOW-4 Window Library (GLASS–TYPE–CODE = 1000 or above) will give the most accurate window heat transfer calculation since (1) the angular dependence of transmission and absorption of solar radiation is precisely modeled, and (2) the temperature dependence of the window U-value is taken into account.

Index to the Window Library
Table 2.12 is an index to the Window Library. Single-pane entries are given first, followed by double-, triple-, and quadruple-pane. For a given number of panes, clear and low-iron glazings are are given first, followed by tinted, reflective, and low-E options.

The column headings are as follows:

ID — Identification number or GLASS–TYPE–CODE. The first digit is the number of panes. The second digit is 0 for clear or low-iron; 2 for tinted but no coating; 4 for reflective coating with clear or tinted glass; and 6 for low-E coating on clear or tinted glass.

U-SI — Center-of-glass U-value in SI units (W/m^2-K) for ASHRAE winter conditions [-17.8°C (0°F) outside temperature, 21.1°C (70°F) inside temperature,

* The DOE-2/WINDOW-4 Window Library and the implementation of the WINDOW-4 heat transfer calculations in DOE-2 are the result of a collaboration among the Simulation Research Group, D.K. Arasteh and M.S. Reilly of the LBL Windows and Daylighting Group, and W.L. Carroll of the LBL Building Systems Analysis Group.

15 mph windspeed and zero incident solar radiation].

U-IP — Center-of-glass U-value in inch-pound units (Btu/ft^2-h-F) for ASHRAE winter conditions.

SC — Shading coefficient for ASHRAE summer conditions [35C (95F) outside temperature, 24C (75F) inside temperature, 3.3 m/s (7.5 mph) windspeed, and near-normal incident solar radiation of 783 W/m^2 (248 Btu/h-ft^2)]

SHGC — Solar heat gain coefficient for ASHRAE summer conditions.

Tsol — Overall solar transmittance at normal incidence.

Rfsol — Overall solar reflectance at normal incidence for radiation incident from the front.

Tvis — Overall visible transmittance at normal incidence.

Rfvis — Overall visible reflectance at normal incidence for radiation incident from the front.

LAYn ID — Identification number of the *n*th solid layer (pane) in the glazing assembly. The panes are numbered from the outdoor side of the window to the room side. (For windows in an interior wall between a sunspace and adjacent room, the "outdoor" side is the sunspace side.) The properties of this layer are given in Appendix D, "WINDOW-4 Glass Layer Library." (This library, which is not accessible by DOE-2 and is shown here for reference only, was used with WINDOW-4 to create the Window Library.)

LAYn WID — Thickness of the *n*th pane (mm).

GAPn GAS — Type of gas (air, argon, etc.) in the *n*th gap. Gaps are numbered from the outdoor side of the window to the room side.

GAPn WID — Thickness of the *n*th gap (mm).

Terminology is as follows:

CLEAR or CLR — no impurities added to the glass mix.

LOW IRON — clear glass with a low iron content, resulting in higher transmittance.

TINT — outer pane is tinted, i.e., inorganic materials are added to the glass mix to increase absorption in certain areas of the visible spectrum in order to produce a certain color.

REF	reflective; i.e., a metallic coating is applied to one surface of a pane in order to increase solar reflection. REF A refers to stainless steel coatings, REF B to titanium, REF C to pewter, and REF D to tin-oxide. L, M, and H refer to low, medium, and high transmittance coating, respectively.
LOW-E	low emissivity: a metallic coating is applied in order to increase thermal infrared reflectance. The coated surface is indicated by en=v, where n=1 is the outside of the outer pane, n=2 is the inside of the outer pane, etc., and v is the emissivity (see, for example, ID = 2635, where e2=.1 indicates a coating with an emissivity of 0.1 on surface #2).
IG	insulating glass: multipane glass with the gap(s) between panes filled with air or some other gas to produce an insulating effect.
FILM	a plastic film (with low-E coating) stretched between glass panes. The approximate visible transmittance of the film (in percent) is shown as (nn); see, for example, ID = 3641.

Table 2.12

Index to the Window Library

ID	WINDOW	U-SI	U-IP	SC	SHGC	Tsol	Rfsol	Tvis	Rfvis	LAY1 ID	LAY1 WID
SINGLE CLEAR											
1000	CLEAR	6.31	1.11	1.00	.86	.84	.08	.90	.08	2	3
1001	CLEAR	6.17	1.09	.95	.81	.77	.07	.88	.08	3	6
1002	LOW IRON	6.31	1.11	1.05	.90	.90	.08	.91	.08	14	3
1003	LOW IRON	6.22	1.10	1.04	.90	.89	.08	.91	.08	16	5
SINGLE TINT											
1200	BRONZE	6.31	1.11	.84	.73	.64	.06	.69	.06	5	3
1201	BRONZE	6.17	1.09	.71	.61	.48	.05	.53	.06	6	6
1202	GREEN	6.31	1.11	.83	.72	.63	.06	.82	.08	11	3
1203	GREEN	6.17	1.09	.71	.61	.49	.06	.75	.07	12	6
1204	GREY	6.31	1.11	.83	.71	.63	.06	.61	.06	8	3
1205	GREY	6.17	1.09	.69	.59	.46	.05	.43	.05	9	6
1206	BLUE	6.17	1.09	.71	.61	.48	.05	.57	.06	17	6
SINGLE REF A											
1400	CLEAR-L	4.90	.86	.23	.19	.07	.34	.08	.41	200	6
1401	CLEAR-M	5.11	.90	.29	.25	.11	.27	.14	.31	201	6
1402	CLEAR-H	5.41	.95	.36	.31	.16	.22	.20	.25	202	6
1403	TINT-L	4.93	.87	.26	.22	.04	.15	.05	.17	210	6
1404	TINT-M	5.11	.90	.29	.25	.06	.13	.09	.14	211	6
1405	TINT-H	5.29	.93	.34	.29	.10	.11	.10	.11	212	6
SINGLE REF B											
1406	CLEAR-L	5.44	.96	.35	.31	.15	.22	.20	.23	220	6
1407	CLEAR-H	5.50	.97	.45	.39	.24	.16	.30	.16	221	6
1408	TINT-L	4.93	.87	.26	.23	.04	.13	.05	.09	230	6
1409	TINT-M	5.05	.89	.33	.28	.10	.11	.13	.10	231	6
1410	TINT-H	5.50	.97	.40	.34	.15	.09	.18	.08	232	6
SINGLE REF C											
1411	CLEAR-L	4.99	.88	.29	.25	.11	.25	.13	.28	240	6
1412	CLEAR-M	5.23	.92	.37	.32	.17	.20	.19	.21	241	6
1413	CLEAR-H	5.35	.94	.41	.35	.20	.16	.22	.17	242	6
1414	TINT-L	4.99	.88	.29	.25	.07	.13	.08	.13	250	6
1415	TINT-M	5.23	.92	.34	.29	.10	.10	.11	.10	251	6
1416	TINT-H	5.35	.94	.37	.31	.12	.09	.13	.09	252	6
SINGLE REF D											
1417	CLEAR	6.12	1.08	.58	.50	.43	.31	.33	.45	260	6
1418	TINT	6.12	1.08	.53	.46	.30	.14	.25	.18	270	6
SINGLE LOW-E CLEAR											
1600	(e2=.4)	4.99	.88	.91	.78	.75	.10	.85	.12	300	3
1601	(e2=.2)	4.34	.76	.89	.77	.74	.09	.82	.11	350	3
1602	(e2=.2)	4.27	.75	.84	.72	.68	.09	.81	.11	351	6

Table 2.12 (continued)

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ID	U-SI	U-IP	SC	SHGC	Tsol	Rfsol	Tvis	Rfvis	LAY1 ID	LAY1 WID	GAP1 GAS	GAP1 WID	LAY2 ID	LAY2 WID
DOUBLE CLEAR IG														
2000	3.23	.57	.88	.76	.70	.13	.81	.15	2	3	Air	6	2	3
2001	2.79	.49	.89	.76	.70	.13	.81	.15	2	3	Air	12	2	3
2002	2.61	.46	.89	.76	.70	.13	.81	.15	2	3	Arg	12	2	3
2003	3.16	.56	.81	.69	.60	.11	.78	.14	3	6	Air	6	3	6
2004	2.74	.48	.81	.70	.60	.11	.78	.14	3	6	Air	12	3	6
2005	2.56	.45	.81	.70	.60	.11	.78	.14	3	6	Arg	12	3	6
DOUBLE LOW IRON IG														
2006	3.23	.57	.96	.83	.81	.14	.84	.15	14	3	Air	6	14	3
2007	2.79	.49	.96	.83	.81	.14	.84	.15	14	3	Air	12	14	3
2008	2.61	.46	.96	.83	.81	.14	.84	.15	14	3	Arg	12	14	3
2009	3.18	.56	.95	.82	.80	.14	.83	.15	16	5	Air	6	16	5
2010	2.76	.49	.95	.82	.80	.14	.83	.15	16	5	Air	12	16	5
2011	2.58	.45	.95	.82	.80	.14	.83	.15	16	5	Arg	12	16	5
DOUBLE TINT BRONZE IG														
2200	3.23	.57	.72	.62	.54	.09	.62	.10	5	3	Air	6	2	3
2201	2.79	.49	.72	.62	.54	.09	.62	.10	5	3	Air	12	2	3
2202	2.61	.46	.72	.62	.54	.09	.62	.10	5	3	Arg	12	2	3
2203	3.16	.56	.57	.49	.38	.07	.47	.08	6	6	Air	6	3	6
2204	2.74	.48	.57	.49	.38	.07	.47	.08	6	6	Air	12	3	6
2205	2.56	.45	.56	.49	.38	.07	.47	.08	6	6	Arg	12	3	6
DOUBLE TINT GREEN IG														
2206	3.23	.57	.72	.62	.53	.09	.74	.13	11	3	Air	6	2	3
2207	2.79	.49	.71	.61	.53	.09	.74	.13	11	3	Air	12	2	3
2208	2.61	.46	.71	.61	.53	.09	.74	.13	11	3	Arg	12	2	3
2209	3.16	.56	.58	.50	.38	.07	.66	.12	12	6	Air	6	3	6
2210	2.74	.48	.57	.49	.38	.07	.66	.12	12	6	Air	12	3	6
2211	2.56	.45	.57	.49	.38	.07	.66	.12	12	6	Arg	12	3	6
DOUBLE TINT GREY IG														
2212	3.23	.57	.71	.61	.53	.09	.55	.09	8	3	Air	6	2	3
2213	2.79	.49	.71	.61	.53	.09	.55	.09	8	3	Air	12	2	3
2214	2.61	.46	.70	.61	.53	.09	.55	.09	8	3	Arg	12	2	3
2215	3.16	.56	.55	.47	.35	.07	.38	.07	9	6	Air	6	3	6
2216	2.74	.48	.54	.47	.35	.07	.38	.07	9	6	Air	12	3	6
2217	2.56	.45	.54	.47	.35	.07	.38	.07	9	6	Arg	12	3	6
DOUBLE TINT BLUE IG														
2218	3.16	.56	.57	.49	.37	.07	.50	.09	17	6	Air	6	3	6
2219	2.74	.48	.57	.49	.37	.07	.50	.09	17	6	Air	12	3	6
2220	2.56	.45	.56	.49	.37	.07	.50	.09	17	6	Arg	12	3	6
DOUBLE REF A CLEAR-L IG														
2400	2.79	.49	.17	.14	.05	.34	.07	.41	200	6	Air	6	3	6
2401	2.26	.40	.15	.13	.05	.34	.07	.41	200	6	Air	12	3	6
2402	2.02	.36	.14	.12	.05	.34	.07	.41	200	6	Arg	12	3	6
DOUBLE REF A CLEAR-M IG														
2403	2.86	.50	.22	.19	.09	.27	.13	.31	201	6	Air	6	3	6
2404	2.35	.41	.20	.17	.09	.27	.13	.31	201	6	Air	12	3	6
2405	2.13	.38	.20	.17	.09	.27	.13	.31	201	6	Arg	12	3	6

Table 2.12 (continued)

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									LAY1		GAP1		LAY2	
ID	U-SI	U-IP	SC	SHGC	Tsol	Rfsol	Tvis	Rfvis	ID	WID	GAS	WID	ID	WID
DOUBLE REF A CLEAR-H IG														
2406	2.95	.52	.27	.23	.13	.22	.18	.25	202	6	Air	6	3	6
2407	2.47	.44	.26	.22	.13	.22	.18	.25	202	6	Air	12	3	6
2408	2.26	.40	.25	.22	.13	.22	.18	.25	202	6	Arg	12	3	6
DOUBLE REF A TINT-L IG														
2410	2.80	.49	.18	.15	.03	.15	.05	.17	210	6	Air	6	3	6
2411	2.27	.40	.15	.13	.03	.15	.05	.17	210	6	Air	12	3	6
2412	2.04	.36	.15	.13	.03	.15	.05	.17	210	6	Arg	12	3	6
DOUBLE REF A TINT-M IG														
2413	2.86	.50	.20	.17	.05	.13	.08	.14	211	6	Air	6	3	6
2414	2.35	.41	.18	.15	.05	.13	.08	.14	211	6	Air	12	3	6
2415	2.13	.38	.17	.15	.05	.13	.08	.14	211	6	Arg	12	3	6
DOUBLE REF A TINT-H IG														
2416	2.92	.51	.24	.21	.08	.11	.09	.11	212	6	Air	6	3	6
2417	2.42	.43	.22	.19	.08	.11	.09	.11	212	6	Air	12	3	6
2418	2.21	.39	.21	.19	.08	.11	.09	.11	212	6	Arg	12	3	6
DOUBLE REF B CLR-L IG														
2420	2.96	.52	.27	.23	.12	.22	.18	.23	220	6	Air	6	3	6
2421	2.48	.44	.25	.22	.12	.22	.18	.23	220	6	Air	12	3	6
2422	2.27	.40	.25	.21	.12	.22	.18	.23	220	6	Arg	12	3	6
DOUBLE REF B CLR-H IG														
2426	2.98	.53	.35	.30	.19	.16	.27	.17	221	6	Air	6	3	6
2427	2.50	.44	.34	.29	.19	.16	.27	.17	221	6	Air	12	3	6
2428	2.30	.41	.34	.29	.19	.16	.27	.17	221	6	Arg	12	3	6
DOUBLE REF B TINT-L IG														
2430	2.80	.49	.18	.15	.03	.13	.05	.09	230	6	Air	6	3	6
2431	2.27	.40	.16	.14	.03	.13	.05	.09	230	6	Air	12	3	6
2432	2.04	.36	.15	.13	.03	.13	.05	.09	230	6	Arg	12	3	6
DOUBLE REF B TINT-M IG														
2433	2.84	.50	.24	.20	.08	.11	.12	.10	231	6	Air	6	3	6
2434	2.33	.41	.22	.19	.08	.11	.12	.10	231	6	Air	12	3	6
2435	2.10	.37	.21	.18	.08	.11	.12	.10	231	6	Arg	12	3	6
DOUBLE REF B TINT-H IG														
2436	2.98	.53	.29	.25	.12	.09	.16	.08	232	6	Air	6	3	6
DOUBLE REF C CLEAR-L IG														
2440	2.82	.50	.22	.19	.09	.25	.12	.28	240	6	Air	6	3	6
2441	2.30	.41	.20	.18	.09	.25	.12	.28	240	6	Air	12	3	6
2442	2.07	.36	.20	.17	.09	.25	.12	.28	240	6	Arg	12	3	6
DOUBLE REF C CLEAR-M IG														
2443	2.90	.51	.28	.24	.14	.20	.17	.21	241	6	Air	6	3	6
2444	2.40	.42	.27	.23	.14	.20	.17	.21	241	6	Air	12	3	6
2445	2.18	.38	.26	.23	.14	.20	.17	.21	241	6	Arg	12	3	6

Table 2.12 (continued)

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									LAY1		GAP1		LAY2	
ID	U-SI	U-IP	SC	SHGC	Tsol	Rfsol	Tvis	Rfvis	ID	WID	GAS	WID	ID	WID
DOUBLE REF C CLEAR-H IG														
2446	2.94	.52	.32	.27	.16	.16	.20	.17	242	6	Air	6	3	6
2447	2.45	.43	.30	.26	.16	.16	.20	.17	242	6	Air	12	3	6
2448	2.23	.39	.30	.26	.16	.16	.20	.17	242	6	Arg	12	3	6
DOUBLE REF C TINT-L IG														
2450	2.82	.50	.21	.18	.06	.13	.07	.13	250	6	Air	6	3	6
2451	2.30	.41	.19	.16	.06	.13	.07	.13	250	6	Air	12	3	6
2452	2.07	.36	.18	.15	.06	.13	.07	.13	250	6	Arg	12	3	6
DOUBLE REF C TINT-M IG														
2453	2.90	.51	.24	.21	.08	.10	.10	.10	251	6	Air	6	3	6
2454	2.40	.42	.22	.19	.08	.10	.10	.10	251	6	Air	12	3	6
2455	2.18	.38	.21	.19	.08	.10	.10	.10	251	6	Arg	12	3	6
DOUBLE REF C TINT-H IG														
2456	2.94	.52	.26	.23	.10	.09	.12	.09	252	6	Air	6	3	6
2457	2.45	.43	.24	.21	.10	.09	.12	.09	252	6	Air	12	3	6
2458	2.23	.39	.24	.20	.10	.09	.12	.09	252	6	Arg	12	3	6
DOUBLE REF D CLEAR IG														
2460	3.15	.56	.49	.42	.34	.32	.31	.46	260	6	Air	6	3	6
2461	2.72	.48	.49	.42	.34	.32	.31	.46	260	6	Air	12	3	6
2462	2.54	.45	.49	.42	.34	.32	.31	.46	260	6	Arg	12	3	6
DOUBLE REF D TINT IG														
2470	3.15	.56	.41	.35	.24	.15	.23	.19	270	6	Air	6	3	6
2471	2.72	.48	.40	.35	.24	.15	.23	.19	270	6	Air	12	3	6
2472	2.54	.45	.40	.34	.24	.15	.23	.19	270	6	Arg	12	3	6
DOUBLE LOW-E (e3=.4) IG														
2600	2.85	.50	.84	.72	.63	.15	.77	.18	2	3	Air	6	300	3
2601	2.30	.41	.85	.73	.63	.15	.77	.18	2	3	Air	12	300	3
2602	2.05	.36	.85	.73	.63	.15	.77	.18	2	3	Arg	12	300	3
DOUBLE LOW-E (e3=.2) IG														
2610	2.61	.46	.84	.72	.62	.15	.74	.18	2	3	Air	6	350	3
2611	1.99	.35	.85	.73	.62	.15	.74	.18	2	3	Air	12	350	3
2612	1.70	.30	.86	.74	.62	.15	.74	.18	2	3	Arg	12	350	3
2613	2.57	.45	.77	.66	.53	.13	.72	.17	3	6	Air	6	351	6
2614	1.96	.35	.78	.67	.53	.13	.72	.17	3	6	Air	12	351	6
2615	1.67	.29	.79	.68	.53	.13	.72	.17	3	6	Arg	12	351	6
DOUBLE LOW-E (e2=.1) CLEAR IG														
2630	2.47	.44	.69	.60	.54	.22	.77	.14	400	3	Air	6	2	3
2631	1.81	.32	.69	.60	.54	.22	.77	.14	400	3	Air	12	2	3
2632	1.48	.26	.69	.59	.54	.22	.77	.14	400	3	Arg	12	2	3
2633	2.43	.43	.65	.56	.47	.20	.75	.11	401	6	Air	6	3	6
2634	1.78	.31	.65	.56	.47	.20	.75	.11	401	6	Air	12	3	6
2635	1.46	.26	.66	.56	.47	.20	.75	.11	401	6	Arg	12	3	6

Table 2.12 (continued)

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									LAY1		GAP1		LAY2	
ID	U-SI	U-IP	SC	SHGC	Tsol	Rfsol	Tvis	Rfvis	ID	WID	GAS	WID	ID	WID
DOUBLE LOW-E (e2=.1) TINT IG														
2636	2.43	.43	.45	.39	.28	.10	.44	.05	451	6	Air	6	3	6
2637	1.78	.31	.43	.37	.28	.10	.44	.05	451	6	Air	12	3	6
2638	1.46	.26	.43	.37	.28	.10	.44	.05	451	6	Arg	12	3	6
DOUBLE LOW-E (e3=.1) CLEAR IG														
2640	2.47	.44	.74	.63	.54	.23	.77	.13	2	3	Air	6	400	3
2641	1.81	.32	.75	.64	.54	.23	.77	.13	2	3	Air	12	400	3
2642	1.48	.26	.75	.65	.54	.23	.77	.13	2	3	Arg	12	400	3
DOUBLE LOW-E (e2=.04) CLEAR IG														
2660	2.38	.42	.51	.44	.39	.36	.70	.12	500	3	Air	6	2	3
2661	1.68	.30	.51	.44	.39	.36	.70	.12	500	3	Air	12	2	3
2662	1.34	.24	.50	.43	.39	.36	.70	.12	500	3	Arg	12	2	3
DOUBLE LOW-E (e2=.03) CLEAR IG														
2663	2.32	.41	.49	.42	.34	.31	.68	.12	501	6	Air	6	3	6
2664	1.64	.29	.48	.42	.34	.31	.68	.12	501	6	Air	12	3	6
2665	1.30	.23	.48	.42	.34	.31	.68	.12	501	6	Arg	12	3	6
DOUBLE LOW-E (e2=.03) TINT IG														
2666	2.32	.41	.35	.30	.21	.14	.41	.08	550	6	Air	6	3	6
2667	1.64	.29	.33	.28	.21	.14	.41	.08	550	6	Air	12	3	6
2668	1.30	.23	.32	.28	.21	.14	.41	.08	550	6	Arg	12	3	6

Table 2.12 (continued)

Index to the Window Library

									LAY1		GAP1		LAY2		GAP2		LAY3	
ID	U-SI	U-IP	SC	SHGC	Tsol	Rfsol	Tvis	Rfvis	ID	WID	GAS	WID	ID	WID	AS	WID	ID	WID
TRIPLE CLEAR IG																		
3001	2.19	.39	.79	.68	.60	.17	.74	.20	2	3	Air	6	2	3	Air	6	2	0
3002	1.79	.32	.79	.68	.60	.17	.74	.20	2	3	Air	12	2	3	Air	12	2	0
3002	1.64	.29	.79	.68	.60	.17	.74	.20	2	3	Arg	12	2	3	Arg	12	2	0
TRIPLE LOW-E (e5=.1) CLEAR IG																		
3601	1.81	.32	.67	.57	.46	.24	.70	.18	2	3	Air	6	2	3	Air	6	400	0
3602	1.28	.23	.67	.58	.46	.24	.70	.18	2	3	Air	12	2	3	Air	12	400	0
3603	1.06	.19	.67	.58	.46	.24	.70	.18	2	3	Arg	12	2	3	Arg	12	400	0
TRIPLE LOW-E (e2=e5=.1) CLEAR IG																		
3621	1.55	.27	.54	.47	.36	.29	.66	.17	400	3	Air	6	2	3	Air	6	400	0
3622	.99	.17	.55	.47	.36	.29	.66	.17	400	3	Air	12	2	3	Air	12	400	0
3623	.77	.14	.55	.47	.36	.29	.66	.17	400	3	Arg	12	2	3	Arg	12	400	0
TRIPLE LOW-E FILM (88) CLEAR IG																		
3641	1.83	.32	.66	.57	.48	.28	.71	.18	2	3	Air	6	600	0	Air	6	2	0
3642	1.32	.23	.67	.57	.48	.28	.71	.18	2	3	Air	12	600	0	Air	12	2	0
TRIPLE LOW-E FILM (77) CLEAR IG																		
3651	1.79	.32	.53	.46	.38	.38	.64	.24	2	3	Air	6	601	0	Air	6	2	0
3652	1.26	.22	.54	.47	.38	.38	.64	.24	2	3	Air	12	601	0	Air	12	2	0
TRIPLE LOW-E FILM (66) CLEAR IG																		
3661	1.75	.31	.41	.35	.26	.40	.54	.31	3	6	Air	6	602	0	Air	6	3	0
3662	1.23	.22	.42	.36	.26	.40	.54	.31	3	6	Air	12	602	0	Air	12	3	0
TRIPLE LOW-E FILM (66) TINT IG																		
3663	1.75	.31	.30	.26	.16	.18	.32	.14	6	6	Air	6	602	0	Air	6	3	0
3664	1.23	.22	.29	.25	.16	.18	.32	.14	6	6	Air	12	602	0	Air	12	3	0
TRIPLE LOW-E FILM (55) CLEAR IG																		
3671	1.74	.31	.35	.30	.21	.44	.45	.37	3	6	Air	6	603	0	Air	6	3	0
3672	1.22	.22	.36	.31	.21	.44	.45	.37	3	6	Air	12	603	0	Air	12	3	0
TRIPLE LOW-E FILM (55) TINT IG																		
3673	1.74	.31	.26	.23	.13	.19	.27	.16	6	6	Air	6	603	0	Air	6	3	0
3674	1.22	.22	.25	.22	.13	.19	.27	.16	6	6	Air	12	603	0	Air	12	3	0
TRIPLE LOW-E FILM (44) TINT IG																		
3681	1.74	.31	.23	.20	.10	.21	.22	.18	6	6	Air	6	604	0	Air	6	3	0
3682	1.21	.21	.22	.19	.10	.21	.22	.18	6	6	Air	12	604	0	Air	12	3	0
TRIPLE LOW-E FILM (33) TINT IG																		
3691	1.74	.31	.19	.16	.07	.23	.17	.23	6	6	Air	6	605	0	Air	6	3	0
3692	1.20	.21	.17	.15	.07	.23	.17	.23	6	6	Air	12	605	0	Air	12	3	0

									LAY1		GAP1		LAY2		GAP2	
ID	U-SI	U-IP	SC	SHGC	Tsol	Rfsol	Tvis	Rfvis	ID	WID	GAS	WID	ID	WID	GAS	WID
QUAD LOW-E GLAZING / LOW-E FILMS CLEAR IG																
4651	.66	.12	.52	.45	.34	.34	.62	.21	2	3	Kry	7	600	0	Kry	3

LAY3		GAP3		LAY4	
ID	WID	GAS	WID	ID	WID
600	0	Kry	7	2	0

Edge-of-Glass Effects

Because of two-dimensional heat conduction effects in multipane windows, the U-value of the edge-of-glass region (a 2.5-in wide border strip at the boundary of the glazing) differs from the U-value in the center-of-the-glass region (the central part of the glazing). The edge-of-glass U-value depends on the center-of-glass U-value and the type of spacer used to separate the panes. For windows from the Window Library, the spacer type is specified using the following GLASS-TYPE keyword:

GLASS-TYPE

SPACER-TYPE-CODE — is an integer indicating the type of spacer used to separate the glass layers in multipane windows. It is applicable only to *multipane* windows (GLASS-TYPE-CODE = 2000 or above) from the Window Library. Allowed values are shown in Table 2.13. The default is 1 (aluminum spacer). If SPACER-TYPE-CODE = 0, spacer information is obtained from the Window Library entry corresponding to the specified GLASS-TYPE-CODE.

Table 2.13

Between-Glass Spacers

SPACER-TYPE-CODE	Spacer type
0	Spacer is taken from DOE-2/WINDOW-4 Window Library
1(default)	Aluminum
2	Glass
3	Butyl/Metal
4	Wood or Fibreglas

Printing Out the Selected Window Library Entry

A printout of the contents of the selected entry can be obtained as part of the DOE-2 input echo by entering

DIAGNOSTIC COMMENTS ..

in the line just before the GLASS-TYPE instruction. This printout can be used to verify that the selected entry is what the user really wants. Appendix E shows a sample Window Library entry and describes its contents.

Creating Custom Windows

Users may add their own custom windows to the Window Library. To do this, layer-by-layer glass characteristics are entered in the WINDOW-4 computer program.* Running WINDOW-4 then produces an ASCII output file that can be appended to the Window Library file, which is called W4LIB.DAT.

The ID value for a custom window should not be the same as that of an existing entry in Table 2.12. We therefore suggest using the following ID ranges for custom windows:

1900-1999 for single glazing,
2900-2999 for double glazing,
3900-3999 for triple glazing,
4900-4999 for quadruple glazing, and
5900-5999 for quintuple glazing (the maximum number of solid layers allowed is five).

Using Shading Devices with Windows from the Window Library

The effect of shading devices like blinds and drapes can be modeled for glazing from the Window Library by using the WINDOW keywords SHADING-SCHEDULE, CONDUCT-SCHEDULE, VIS-TRANS-SCH, etc. (see *Reference Manual (2.1A)*, p.III.107, and Table 2.4, "Window Shading Device Control Options," on p.2.43 of this Supplement).

Example:

A window with argon-filled, low-E insulating glass (GLASS-TYPE-CODE = 2635) has light-colored drapes deployed in the summer that reduce the shading coefficient of the glass by 40% and have negligible effect on the conductance of the glass:

```
   $ -- DRAPES  ON  GLAZING  FROM  WINDOW  LIBRARY -- $
SH-SCH-1   =SCHEDULE      THRU MAY 31 (ALL)(1,24)(1.0)
                          THRU OCT 31 (ALL)(1,24)(0.6)
                          THRU DEC 31 (ALL)(1,24)(1.0) ..

GT-1       =GLASS-TYPE    GLASS-TYPE-CODE=2635 ..

WIN-1      =WINDOW        HEIGHT = 5  WIDTH = 10
                          GLASS-TYPE = GT-1
                          SHADING-SCHEDULE = SH-SCH-1 ..
```

In this example, the multiplier, 0.6, is the ratio of the shading coefficient of the glass with drapes present (a number that can usually be obtained from the glass manufacturer's data sheets) to the shading coefficient of the bare glass (which can be obtained from the glass manufacturer's data sheets or from Table 2.12).

* Write Bostik Construction Products, P.O. Box 8, Huntingdon Valley, PA 19006 for information on obtaining WINDOW-4 and its documentation. For technical questions about WINDOW-4 code, contact the Windows and Daylighting Group, 90-3111, Lawrence Berkeley Laboratory, Berkeley, CA 94720 (tel. 415-486-5064)

SWITCHABLE GLAZING (SMART WINDOWS)

In DOE-2.1E a model has been added for switchable glazing (sometimes also called "smart windows"). This is glazing with solar-optical properties that can change according to environmental conditions. An example of switchable glazing is electrochromic glass that can be switched from a clear to a colored state by changing the applied voltage in response to a control variable such as outside temperature or solar radiation. Switchable glazing has the potential for a higher level of solar gain control than is possible with conventional glazing having fixed solar-optical properties.

To model switchable glazing the user enters the glass type for the unswitched state, the glass type for the fully switched state, the control variable, the switching set points, and a schedule that tells when switching is allowed. Figure 2.21 shows the control action that DOE-2 uses for all control options except SWITCH-CONTROL = DAYLIGHT-LEVEL.

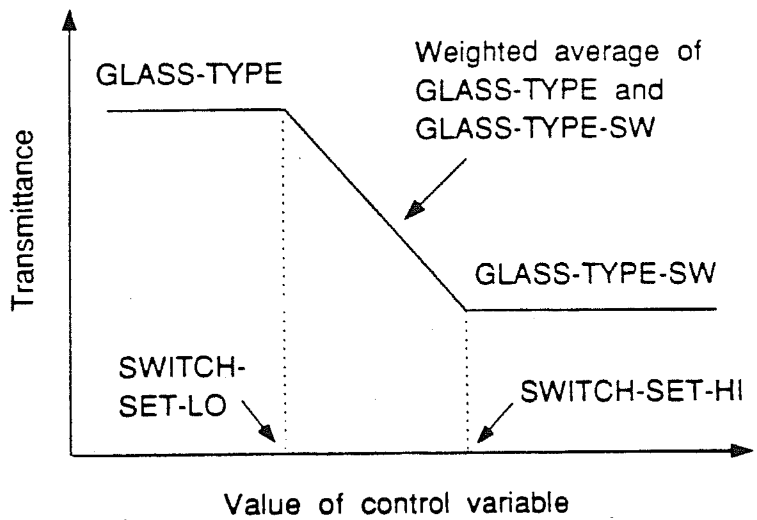

Figure 2.21: Control action for switchable glazing. Glass properties, such as solar transmittance, depend on the value of a user-specified control variable.

If the value of the control variable is less than SWITCH-SET-LO, the glass is in the *unswitched* state, with solar-optical properties given by GLASS-TYPE. If the control variable is greater than SWITCH-SET-HI, the glass is in the *fully switched* state, with solar-optical properties given by GLASS-TYPE-SW. If the control variable is between SWITCH-SET-LO and SWITCH-SET-HI, the glass is in a *partially switched* state, with solar-optical properties given by a weighted average of GLASS-TYPE and GLASS-TYPE-SW. For example, if T_1 and T_2 are the direct solar transmittances for GLASS-TYPE and GLASS-TYPE-SW, respectively, and V is the value of the control variable in a particular hour, then the resultant transmittance is $T = T_1 * S + T_2 * (1 - S)$, where S, the "switching factor", is calculated by the program according to:

$$S = 1.0, \text{ if } V \leq \text{SWITCH–SET–LO}$$

$$S = \frac{(\text{SWITCH–SET–HI}) - V}{(\text{SWITCH–SET–HI}) - (\text{SWITCH–SET–LO})}, \quad \text{if } (\text{SWITCH–SET–LO}) < V < (\text{SWITCH–SET–HI})$$

$$S = 0.0, \text{ if } V \geq \text{SWITCH–SET–HI}$$

Hourly values of S for each window are printed by hourly report VARIABLE-TYPE = u-name of WINDOW, Variable-List Number 18.

For daylit spaces, a different control scheme can be used by specifying SWITCH-CONTROL = DAYLIGHT-LEVEL. In this case, the visible transmittance of the window is modulated between unswitched and fully switched values in order to provide daylight illuminance that is as close as possible to the illuminance setpoint at the first reference point. This type of control is a way of avoiding unwanted solar gain during the cooling season.

As of this writing (June 1991), the Window Library does not yet contain specific electrochromic products since they are still in the experimental stage. For now, runs with switchable glazing are made by choosing conventional glazings from the Window Library to represent the unswitched and switched states. Actual electrochromic examples will be added to the Window Library in the future.

WINDOW

GLASS-TYPE — accepts the u-name of the glass type for the *unswitched* state. For switchable glazing, glass types *must* be chosen from the DOE-2/WINDOW-4 Window Library. These glass types have GLASS-TYPE-CODE $\geq$ 1000 (see "New Window Library" p.2.89).

GLASS-TYPE-SW — accepts the u-name of the glass type for the *fully switched* state. For switchable glazing, glass types *must* be chosen from the DOE-2/WINDOW-4 Window Library. These glass types have GLASS-TYPE-CODE $\geq$ 1000 (see "New Window Library"). An error will result if the number of glass layers is different for GLASS-TYPE and GLASS-TYPE-SW.

SWITCH-CONTROL — accepts a code-word that specifies the control variable for switching. The choices are:

- *NO-SWITCH* — No switching (the default).
- *DIR-SOL-INC* — Direct solar incident on the glazing (Btu/ft^2-h), after shading by overhangs, setback, neighboring buildings, etc.
- *TOT-SOL-INC* — Total (direct plus diffuse) solar radiation incident on the glazing (Btu/ft^2-h), after shading by overhangs, setback, neighboring buildings, etc.
- *DIR-SOL-TR* — Direct solar radiation transmitted by the glazing in the unswitched state (Btu/ft^2-h).
- *TOT-SOL-TR* — Total (direct plus diffuse) solar radiation transmitted by the glazing in the unswitched state (Btu/ft^2-h).

In the left column above, bold-faced words are commands, non-bold words are keywords, and italicized words are code-words.

TOT-SOL-HOR Total (direct plus diffuse) solar radiation incident on an unobstructed horizontal plane (Btu/ft^2-h).

OUTSIDE-TEMP Outside drybulb temperature (°F).

SPACE-LOAD Previous-hour thermal load per square foot of floor area for the space that contains the window (Btu/h-ft^2 [floor area]). Note that cooling loads in DOE-2 are positive and heating loads are negative. Switching control based on space load should be modeled only if the actual space temperature for hours that the control is in effect is within a few degrees of the LOADS calculation temperature (as given by the TEMPERATURE keyword in SPACE-CONDITIONS).

DAYLIGHT-LEVEL The visible transmittance of the glazing is adjusted continuously between the values corresponding to GLASS-TYPE and GLASS-TYPE-SW in order to provide a daylight illuminance that is as close as possible to the illuminance setpoint at the first daylighting reference point. The solar properties of the glazing are adjusted accordingly. For this control option, an error will result if the visible transmittance (at normal incidence) for GLASS-TYPE is greater than that for GLASS-TYPE-SW.

SWITCH-SET-LO is the lower setpoint value for the control variable (see Fig. 2.21).
Unused if SWITCH-CONTROL = DAYLIGHT-LEVEL.

SWITCH-SET-HI is the upper setpoint value for the control variable (see Fig. 2.21). Unused if
SWITCH-CONTROL = DAYLIGHT-LEVEL.
SWITCH-SET-HI should be $\geq$ SWITCH-SET-LO.

SWITCH-SCH accepts the u-name of a schedule the specifies when switching is allowed (schedule value = 1) and not allowed (schedule value = 0). This schedule allows switching to be disabled at times of the day or year when it might be disadvantageous. If SWITCH-SCH is not entered, the program will assume that switching is allowed all the time.

Notes:

(1) If there is more than one window in a space, some may have switching control and others not. For example, skylights might be controlled and view windows not. Also, multiple windows in a space can have different control types.

(2) Switching control is applicable only to exterior windows (windows in EXTERIOR-WALLs). It does not work for interior windows.

(3) Switching control is in effect only during sun-up hours. It does not work at night. It should not be used to switch between window U-values; use the WINDOW keyword

CONDUCT-TMIN-SCH instead.

(4) Shading devices such as blinds and drapes (as specified with WINDOW keywords SHADING-SCHEDULE, VIS-TRANS-SCH, etc.) can be used in conjunction with switching control of the glazing. In this case, the program decides what state the glazing should be switched to, ignoring the possible presence of shading devices, and then adjusts the solar intensity through the switched glazing for the presence of the shading device. For example, if MAX-SOLAR-SCH is used to deploy a shading device when the transmitted direct solar gain exceeds a trigger value, the program will first apply the switching control to the glazing and then calculate the transmitted solar intensity based on the solar properties of the switched glass.

Example (1):
During the summer, the outer pane of insulating glass switches from clear to fully tinted over a range of 20 to 100 Btu/ft^2-h of incident solar radiation.

```
$ --- SWITCHING CONTROLLED BY INCIDENT SOLAR DURING THE SUMMER --- $

CLEAR-IG-1    = GLASS-TYPE  GLASS-TYPE-CODE = 2003 ..

TINTED-IG-1   = GLASS-TYPE  GLASS-TYPE-CODE = 2203 ..

SUMMER-1     = SCHEDULE   THRU MAY 31 (ALL)(1,24)(0)
                          THRU SEP 30 (ALL)(1,24)(1)
                          THRU DEC 31 (ALL)(1,24)(0) ..

WIN-1 = WINDOW   GLASS-TYPE        = CLEAR-IG-1
                 GLASS-TYPE-SW     = TINTED-IG-1
                 SWITCH-CONTROL    = TOT-SOL-INC
                 SWITCH-SET-LO     = 20
                 SWITCH-SET-HI     = 100
                 SWITCH-SCH        = SUMMER-1
                 .
                 .
                 .
                 ..
```

Example (2):
For a window in a daylit space, the visible transmittance is adjusted to a value between 0.78 and 0.38 during the summer so that the resulting daylight illuminance is as close as possible to the illuminance setpoint. At other times of the year, the switching does not occur.

```
        $ --- SWITCHING  CONTROLLED  BY  DAYLIGHT  ILLUMINANCE --- $

SUMMERONLY-1      = SCHEDULE         THRU MAY 31 (ALL)(1,24)(0) $ no switching $
                                     THRU SEP 30 (ALL)(1,24)(1) $ switching ok $
                                     THRU DEC 31 (ALL)(1,24)(0) $ no switching $ ..

CLEAR-IG-1        = GLASS-TYPE       GLASS-TYPE-CODE = 2003 .. $ tvis=.78 $

GREY-IG-1         = GLASS-TYPE       GLASS-TYPE-CODE = 2215 .. $ tvis=.38 $

WIN-2 = WINDOW    GLASS-TYPE         = CLEAR-IG-1
                  GLASS-TYPE-SW      = GREY-IG-1
                  SWITCH-CONTROL     = DAYLIGHT-LEVEL
                  SWITCH-SCH         = SUMMERONLY-1
                  .
                  .
                  .
                  ..
```

Example (3):
The glazing switches from clear (shading coefficient = 0.81) to reflective (shading coefficient = 0.17) when the space has a cooling load the previous hour (i.e., when the previous-hour space load is greater than zero).

```
    $ --- SWITCHING  CONTROLLED  BY  SPACE  LOAD  ALL  YEAR --- $

CLEAR-IG-1 = GLASS-TYPE    GLASS-TYPE-CODE = 2003 .. $ sc=.81 $

REFL-IG-1 = GLASS-TYPE     GLASS-TYPE-CODE = 2400 .. $ sc=.17 $

ALLYEAR-1 = SCHEDULE       THRU DEC 31 (ALL)(1,24)(1) ..

WIN-3 = WINDOW    GLASS-TYPE         = CLEAR-IG-1
                  GLASS-TYPE-SW      = REFL-IG-1
                  SWITCH-CONTROL     = SPACE-LOAD
                  SWITCH-SET-LO      = 0
                  SWITCH-SET-HI      = 0
                  SWITCH-SCH         = ALLYEAR-1
                  .
                  .
                  .
                  ..
```

WINDOW FRAMES

In versions of DOE-2 previous to 2.1E, heat conduction through the frame of a window could not easily be modeled. It was necessary to include frame effects, if important, by adjusting the U-value and shading coefficient of the window or by entering the frame as a separate exterior wall. In DOE-2.1E, frames can be explicitly defined. However, we recommend that frames be entered only if the frame area is more than 10% or so of the glazed area, which is generally the case only in residential applications.

To define a window frame the user enters — in the WINDOW instruction — the overall height and width of the window (including the frame), and the height and width of the glazed portion of the window (excluding the frame). In addition, the solar absorptance of the frame, the frame type (from which the program calculates the U-value of the frame), and the spacer type (from which the program calculates the edge-of-glass U-value) are entered in the GLASS-TYPE instruction.

WINDOW

HEIGHT — is the height of the glazed portion of the window.

WIDTH — is the width of the glazed portion of the window.

HEIGHT-PLUS-FRAME — is the overall height of the window, including the frame (see Fig. 2.22). The default is HEIGHT.

WIDTH-PLUS-FRAME — is the overall width of the window, including the frame (see Fig. 2.22). The default is WIDTH.

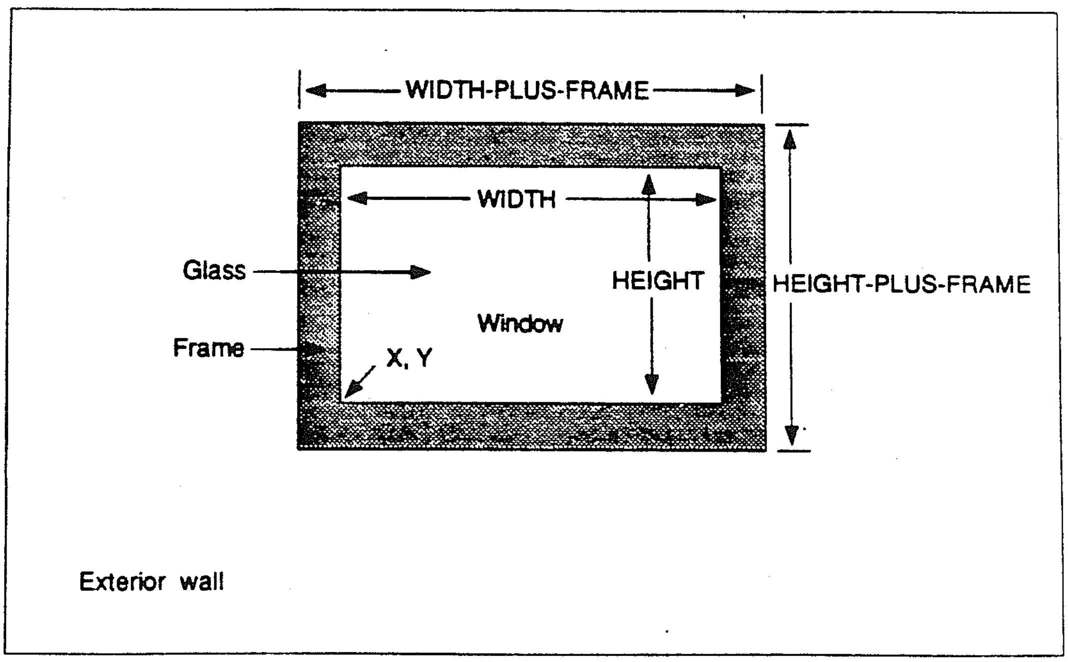

Figure 2.22: The dimensioning of a window with a frame. The WINDOW keywords X and Y, which indicate the position of the window on the wall, refer to the lower left corner of the glazed portion, *not* the lower left corner of the frame.

GLASS–TYPE

FRAME–ABS is the solar absorptance of the outside surface of the frame. The default is 0.7 and the range is 0.0 to 1.0.

FRAME–TYPE–CODE is an integer indicating the frame type, which in turn determines the U-value of the frame. Allowed values are shown in Table 2.15. The default for FRAME–TYPE–CODE is 4 (wood with or without cladding).

Notes:

(1) In DOE-2, frames can be defined only for exterior windows.

(2) The overall window area (HEIGHT–PLUS–FRAME times WIDTH–PLUS–FRAME) is automatically removed from the associated exterior wall area.

(3) Frame heat conduction is added to the glass heat conduction in the LOADS calculation. Therefore, "glass conduction" and "window conduction" quantities in the summary and hourly reports include the contribution of frame heat conduction. Likewise, the "Glass U-value" in verification report LV-D includes the frame. However, WINDOW hourly report variable #1 is the U-value of the glazed portion only — the frame is excluded.

(4) A window MULTIPLIER also multiplies the frame.

(5) Window fins and overhangs shade the frame as well as the glazing.

Table 2.15

Types of Window Frames

FRAME–TYPE–CODE	Frame Type	U-value Btu/ft^2-h	U-value W/m^2-K
0	If GTC $\geq$ 1000, frame is taken from the Window Library	--	--
	If GTC $\leq$ 11 or SHADING–COEF is specified, frame has U-val=0	0.0	0.0
1	Thermally broken aluminum	1.00	5.68
2	Thermally unbroken aluminum	1.90	10.79
3	External flush glazed aluminum	0.70	3.97
4(default)	Wood with or without cladding	0.40	2.27
5	Vinyl	0.30	1.70

Example:
The glazed part of a window is 3.0ft wide and 4.0ft high. The glazing is double-pane low-E with 6-mm glass thickness and argon gas fill (GLASS-TYPE-CODE = 2635). The wood frame is 3in (0.25ft) wide on all sides and has an absorptivity of 0.8. The spacer separating the glass panes is aluminum.

```
            $ -- WINDOW WITH FRAME -- $

GT-1   = GLASS-TYPE    GLASS-TYPE-CODE       = 2635
                       SPACER-TYPE-CODE      = 1
                       FRAME-ABS             = 0.8
                       FRAME-TYPE-CODE       = 4 ..

WIN-1  = WINDOW        GLASS-TYPE            = GT-1
                       HEIGHT                = 4.0
                       WIDTH                 = 3.0
                       HEIGHT-PLUS-FRAME     = 4.5
                       WIDTH-PLUS-FRAME      = 3.5 ..
```

WEATHER TAPE vs. DESIGN–DAY SIZING OF PLANT EQUIPMENT

In DOE-2.1D and earlier versions, automatic sizing of PLANT equipment was based on design-day peaks from SYSTEMS *when DESIGN-DAYs were input in LOADS*. In DOE-2.1E automatic sizing in PLANT still defaults to design-day SYSTEMS peaks; however, users now have the option to revert to weather tape sizing by using a new keyword, PLANT–SIZING–BY:

PLANT–PARAMETERS

PLANT–SIZING–BY — takes code-words that determine whether PLANT sizing is done from DESIGN–DAYs (the default) or from the weather tape. Allowed code-words are:

DD–IF–PRESENT — (the default) indicates that SYSTEMS peaks based on DESIGN–DAYs will be used to size PLANT equipment. If DESIGN–DAYs have not been input, PLANT sizing will be based on SYSTEMS peaks from the weather tape.

WEATHER — indicates that SYSTEMS peaks from the weather tape will be used to size PLANT equipment whether or not DESIGN–DAYs are input.

In the left column above, bold-faced words are commands, non-bold words are keywords, and italicized words are code-words.

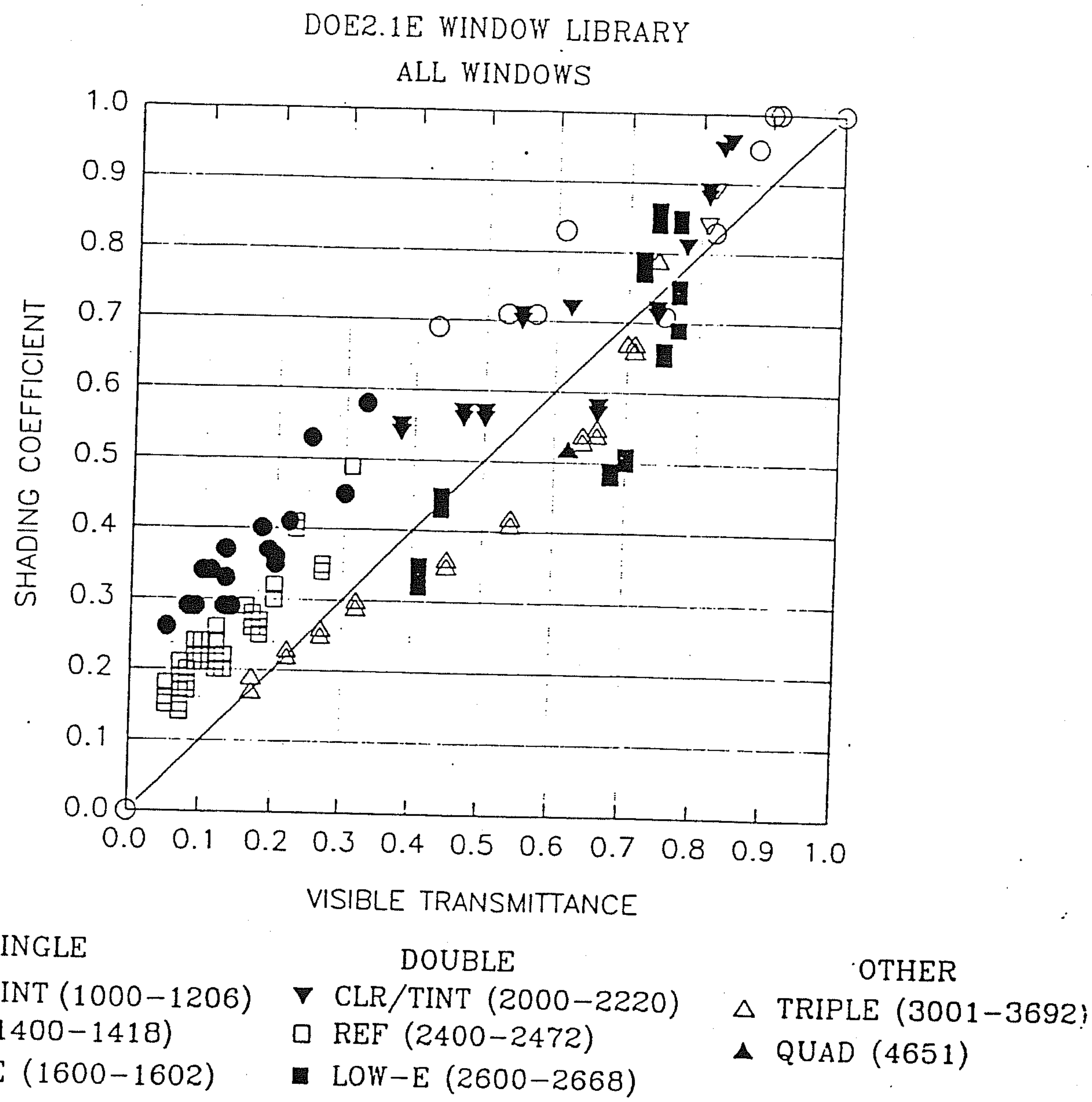

Figure 2.22: Shading coefficient (ASHRAE summer conditions) vs. visible transmittance for all glazings in the Window Library. The values shown correspond to SC and Tvis, respectively, in the Index to the Window Library, Table 2.12. CLR/TINT is clear or tinted glass. REF is glass with a reflective coating. LOW-E is glass with a low-emissivity coating. SINGLE, DOUBLE, TRIPLE and QUAD refer to the number of panes. Numbers in parantheses give the ID range from Table 2.12.

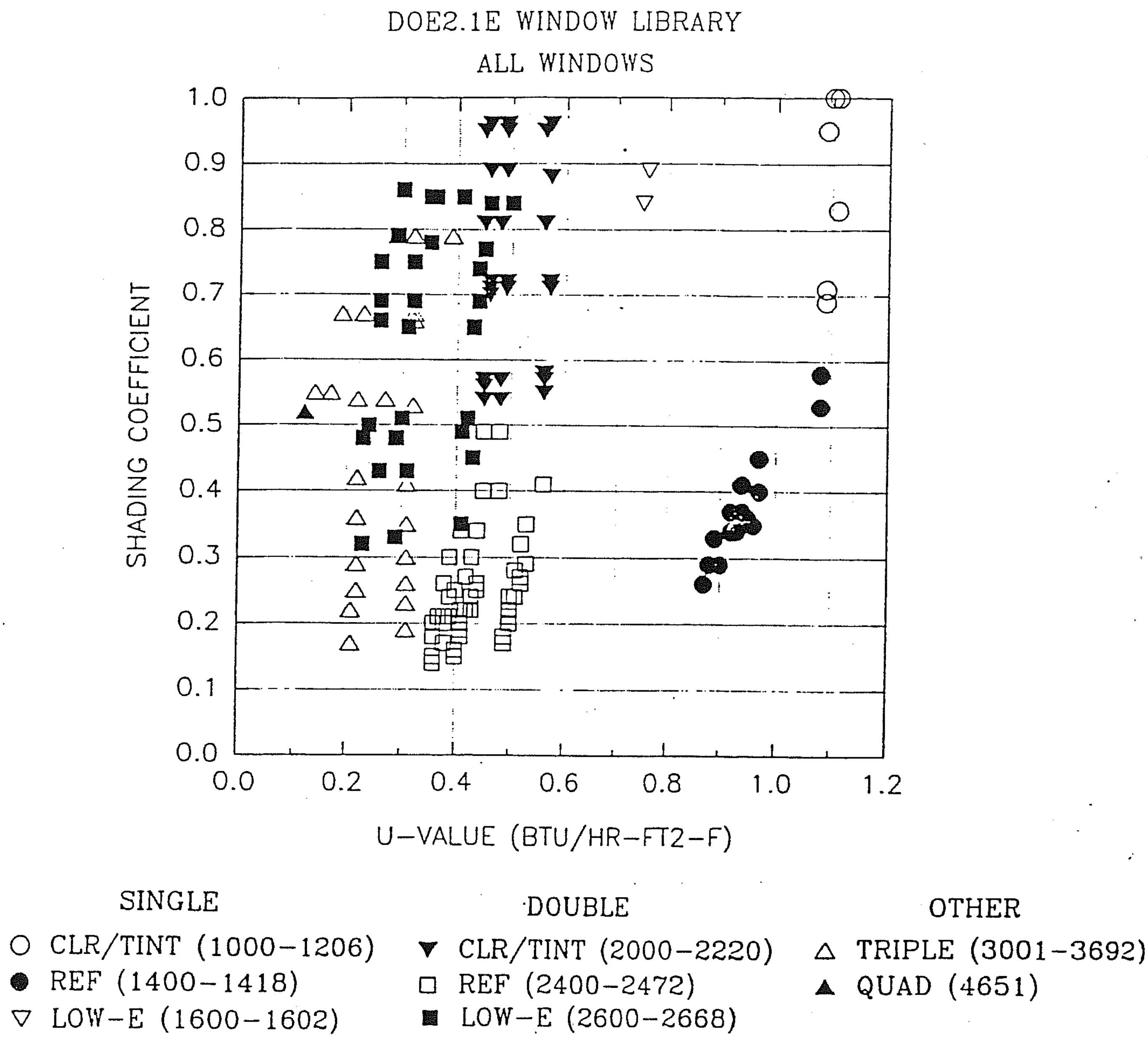

Figure 2.23: Shading coefficient (ASHRAE summer conditions) vs. U-value (ASHRAE winter conditions) for all glazings in the Window Library. The values shown correspond to SC and U-IP, respectively, in the Index to the Window Library, Table 2.12. CLR/TINT is clear or tinted glass; REF is glass with a reflective coating. LOW-E is glass with a low-emissivity coating. SINGLE, DOUBLE, TRIPLE and QUAD refer to the number of panes. Numbers in parantheses give the ID range from Table 2.12.

Example Entry from the DOE-2/WINDOW-4 Window Library

Description

This appendix shows an example of an entry from the DOE-2/WINDOW-4 Window Library. In the following line-by-line description of the entry, *pane* refers to a solid layer (glass, plastic, etc.) and *gap* refers to a gas-filled space between panes. Panes are numbered starting with the outside pane, so that for double glazing, for example, pane 1 is the outside pane and pane 2 is the inside pane. Gaps are numbered starting with the outside pane, so that for triple glazing, for example, gap 1 is between panes 1 and 2 and gap 2 is between panes 2 and 3.

Line Description

3. Units type. All units in this library are SI.

5. Short description of glazing; same descriptor appears in the Index to the Window Library, Table 2.12. "Single Band Calculation" means that the optical properties of the glazing system were calculated by WINDOW-4 using the total (wavelength-integrated) optical properties of the glass layers. "Multiple Band Calculation" means that the properties of the glazing system were calculated wavelength by wavelength using the spectral properties of the layers, and then averaged to give the total properties over the solar, visible, and thermal infrared spectral ranges (see WINDOW-4 documentation).

6. GLASS-TYPE-CODE

7. Tilt angle in degrees for which the U-values, lines 52-55, were calculated; tilt = 90 corresponds to vertical glazing. DOE-2 recalculates U-value for actual tilt of glazing.

8. Number of panes.

9. FRAME-TYPE-CODE, frame descriptor, and U-value of frame (which was used to calculate the frame contribution to the overall U-values in lines 52-55). In DOE-2, other frame types besides the one indicated can be specified for this glazing.

10. SPACER-TYPE-CODE, spacer descriptor, and spacer coefficients. Used to calculate the edge-of-glass contribution to the overall U-values in lines 52-55.

11-14. Overall height and width of window including frame; height and width of glazed portion of window, excluding frame. Used to calculate overall U-values in lines 52-55. Actual frame and glazing dimensions must be separately specified in the DOE-2 input for the window.

17-21. Thermophysical properties of the gap gas fill. For double glazing, only gap 1 (line 17) is relevant. For triple glazing, only gaps 1 and 2 are relevant. In this example there is one gap and the gas fill is argon. Given are gap width (mm), conductivity (W/m-K), temperature derivative of conductivity (W/m-K^2 x 10^{-5}), viscosity (kg/m-s x 10^{-5}), temperature derivative of viscosity (kg/m-s-K x 10^{-7}), density (kg/m^3), temperature derivative of density (kg/m^3-K), Prandtl number, and temperature derivative of Prandtl number (1/K).

23-35. Solar-optical properties of the glazing for angles of incidence between 0° (normal incidence) and 90°, and for hemispherical diffuse radiation.

Tsol = overall solar transmittance of glazing assembly.

Abs$N$ = solar absorptance of pane N, i.e., the fraction of incident solar absorbed in pane N.

Rfsol = overall solar reflectance of the glazing assembly for radiation incident from the front, i.e., from the outside.

Rbsol = overall solar reflectance for radiation incident from the back, i.e., from the inside.

Tvis = overall visible transmittance of the glazing assembly.

Rfvis and Rbvis = the overall visible reflectance for radiation incident from the front and back, respectively.

SHGC = the solar heat gain coefficient, which is the fraction of the solar radiation incident on the glazing that enters the room as heat. Calculated by WINDOW-4 for ASHRAE summer conditions (95F outside temperature, 75F room temperature, 7.5 mph windspeed, and near-normal incident solar radiation of 248 Btu/h-ft^2).

36. Shading coefficient, which is the solar heat gain through the glazing divided by the solar heat gain through 1/8-in, double-strength clear glass. Calculated by WINDOW-4 for ASHRAE summer conditions.

37-39. Color indices (see WINDOW-4 documentation).

40-46. Thermophysical data for each pane. Layer ID# = identification number from the WINDOW-4 Glass Layer Library, Appendix D.

Tir = thermal infrared transmittance,

Emis F and Emis B = thermal emissivity of front and back surface, respectively,

Cond = conductance (W/m^2-K),

Spectral File: name of file containing transmittance and reflectance values at different wavelengths for each glass layer for multiband calculation of overall solar-optical properties of the glazing assembly (see WINDOW-4 documentation).

52-55. Summary of U-values for overall window (including edge of glass and frame) and for center of glass, as a function of incident solar radiation, windspeed, and outdoor temperature. All values shown are as calculated by WINDOW-4. (These values are recalculated each hour by DOE-2.) hcout and hrout are convective and radiative outside air film conductances, respectively (hrout assumes the outside surface radiates to a black body). hin is the combined convective plus radiative inside air film conductance (assuming the inside surface radiates to a black body). Column pairs beneath each outside temperature give overall and center-of-glass U-values. For example, 1.46W/m^2-K is the center-of-glass U-value for outdoor temperature = -17.8°C (0°F), incident solar radiation = 0, and windspeed = 6.71 m/s (15 mph).

Sample Entry from DOE-2/WINDOW-4 Window Library

```
 1. WINDOW 4  Data File : Single Band Calculation
 2.
 3. Unit System: SI
 4. Name         : DOE2 WINDOW LIB
 5. Desc         : LOW-E (e2=.1).CLEAR IG
 6. Window ID    : 2635
 7. Tilt         : 90.0
 8. Glazings     : 2
 9. Frame        : 3   Alum, flush          3.970
10. Spacer       : 1   Aluminum           1.310   0.736   0.000
11. Total Height: 1828.8 mm
12. Total Width : 1219.2 mm
13. Glass Height: 1714.5 mm
14. Glass Width : 1104.9 mm
15. Mullion      : None
16. Gap          Thick   Cond   dCond    Vis    dVis    Dens    dDens     Pr      dPr
17. 1 Argon       12.7 0.01620  5.000  2.110   6.300   1.700  -0.0060   0.680 0.00066
18. 2 Air           0.      0.     0.     0.      0.      0.       0.      0.       0.
19. 3 Air           0.      0.     0.     0.      0.      0.       0.      0.       0.
20. 4 Air           0.      0.     0.     0.      0.      0.       0.      0.       0.
21. 5 Air           0.      0.     0.     0.      0.      0.       0.      0.       0.
22. Angle     0.    10.    20.    30.    40.    50.    60.    70.    80.    90.  Hemis
23. Tsol   0.472  0.475  0.467  0.456  0.442  0.416  0.361  0.261  0.117  0.000  0.388
24. Abs1   0.238  0.241  0.250  0.257  0.259  0.266  0.286  0.310  0.270  0.001  0.266
25. Abs2   0.094  0.095  0.095  0.097  0.099  0.099  0.096  0.083  0.059  0.000  0.092
26. Abs3      0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
27. Abs4      0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
28. Abs5      0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
29. Abs6      0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
30. Rfsol  0.196  0.189  0.187  0.190  0.200  0.219  0.257  0.345  0.555  0.999  0.244
31. Rbsol  0.205  0.201  0.199  0.200  0.207  0.224  0.265  0.363  0.569  1.000  0.254
32. Tvis   0.745  0.744  0.739  0.733  0.722  0.693  0.620  0.468  0.232  0.000  0.641
33. Rfvis  0.112  0.111  0.112  0.115  0.125  0.151  0.217  0.362  0.620  1.000  0.194
34. Rbvis  0.141  0.140  0.141  0.145  0.155  0.181  0.250  0.400  0.655  1.000  0.226
35. SHGC   0.564  0.567  0.560  0.551  0.538  0.513  0.458  0.349  0.181  0.000  0.480
36. SC: 0.66
37. Chrom: x  :     0.34   y  :    0.35   (CIE 1931)
38.        u':     0.21   v':     0.49   (CIE 1976)
39. nDomWL:  0.58 microns    % Purity: 19.0
40. Layer ID#            401        3        0        0        0        0
41. Tir                0.000    0.000       0.       0.       0.       0.
42. Emis F             0.840    0.840       0.       0.       0.       0.
43. Emis B             0.100    0.840       0.       0.       0.       0.
44. Thickness(mm)        6.0      6.0       0.       0.       0.       0.
45. Cond(W/m2-C)       150.0    150.0       0.       0.       0.       0.
46. Spectral File       None     None     None     None     None     None
47.
```

Sample Entry from DOE-2/WINDOW-4 Window Library

48. Overall and Center of Glass Window U-values (W/m2-C)

49.	Outdoor Temperature					-17.8 C		15.6 C		26.7 C		37.8 C	
50.	Solar	WdSpd	hcout	hrout	hin								
51.	(W/m2)	(m/s)	(W/m2-C)										
52.	0	0.00	12.25	3.24	7.58	1.93	1.40	1.88	1.33	1.90	1.37	1.96	1.44
53.	0	6.71	25.47	3.21	7.60	1.98	1.46	1.92	1.38	1.94	1.42	2.00	1.49
54.	783	0.00	12.25	3.47	7.24	1.94	1.42	1.96	1.44	2.00	1.49	2.04	1.53
55.	783	6.71	25.47	3.34	6.82	2.00	1.49	1.99	1.47	2.03	1.53	2.07	1.57

APPENDIX C - WINDOW 4.0 Spectral Data Format
(WINDOW 4.0 Program Description, LBL-32091)

Appendix C: Use of Spectral Data Files in WINDOW 4

C.1 WINDOW 4.0's Multi-Band Spectral Model

Previous versions of the WINDOW program used the total optical properties of individual glazing layers to calculate the total optical properties for a system of glazing layers. For example, the WINDOW 3.1 glass library stored the total visible and solar transmittances and reflectances of individual layers. When two or more layers were combined in a glazing system, the total system properties were calculated based on the layer properties. This approach is known as the "single-band" approach because it considers the entire spectrum (either visible or solar) to be comprised of only one band. While this approach is adequate for glazing systems comprised of layers whose properties do not change dramatically over the solar spectrum, it introduces a noticeable error into the results for systems with more than one spectrally selective layers (i.e. layers whose properties vary over the solar spectrum).

To more accurately model glazing systems with spectrally selective glazings, a multi-band model has been incorporated into WINDOW 4.0. In this model, WINDOW 4.0 calculates the transmittance and reflectances for the glazing layer or the glazing system wavelength by wavelength, and then weights the properties by the appropriate weighting functions to obtain the total solar, visible, thermal infrared properties, damage-weighted transmittance, and transmittance between 0.30 and 0.38 microns.

The following table presents the total visible (Tv), solar (Ts), and solar heat gain (SHG) properties for a double glazed unit made up of 1/4" green (outer layer) and a typical 1/4" low-E on clear (inner layer). Properties were calculated using both the single band model and the multi-band model.

	Ts	Tv	Shading Coefficient	SHG Coefficient
Single Band	.24	.61	.39	.33
Multi-Band	.19	.61	.34	.29

A technical explanation of this model is included in [Arasteh et. al., 1989].

To use the multi-band model, WINDOW needs a spectral data file for each glazing layer. These files must be placed in the \SPECDAT subdirectory (see Figure 1). Once the files are placed in this subdirectory, they can be brought into the program by adding the files' names to the Glass Library and then using the Update feature. An * will appear following the names of glazings in the Glass Library which have spectral data files associated with them. A true multi-band analysis will be performed if all the glazing layers specified have an associated spectral data file. If some of the glazing layers have associated spectral data files and some do not, WINDOW assumes a flat spectral behavior of the glazings without spectral data files based on their stated visible and solar properties. If none of the glazings have associated spectral data files, WINDOW defaults to the one-band model used in WINDOW 3.1.

C.2 Spectral Data File Format

Spectral data files used in WINDOW must have a specified format. These spectral data files have two parts, the header and the spectral data.

The header contains information concerning the units, the material thickness and conductivity, and default thermal infrared properties. The header must follow the format below; no extra or blank lines separating the input lines are permitted. The last two lines of the header are optional entries. These options are provided for manufacturers who do not have the capabilities to make spectral measurements beyond 2.0 microns. (For uncoated glass the thermal infrared hemispherical emittance is 0.84, and the thermal infrared hemispherical transmittance is 0.0.) Otherwise, we suggest that normal reflectance data be supplied out to at least 25 microns.

The spectral data consists of four columns of data: wavelength, transmittance, front reflectance, and back reflectance. The spectral data portion must consist of only numbers; these numbers can be separated by spaces or commas. No other characters are permitted on these data lines.

The information in a spectral file is presented in the following order:

```
Units   wavelength
Glazing Thickness
Glazing Conductivity
tir=.xx
emis=ef eb
wl      Trans  Rf     Rb
.       .      .      .
.       .      .      .
.       .      .      .
```

where:

Units can be either SI or IP.

A wavelength unit other than the default of "microns" can be specified. Alternatives are "nanometers" or "wavenumber".

Glazing Thickness is the thickness in either inches (for IP units) or mm (for SI units).
The Glazing Conductivity is the thermal conductivity in Btu/hr-ft-°F for (for IP units) or W/m-°C (for SI units).

tir=.xx is a fixed thermal infrared hemispherical transmittance (<1.0). This only needs to be specified if the user specifies a fixed emittance (see next line) and if the value is not 0.0. (All glass products have a thermal infrared transmittance of 0.0). Spectral data need only extend out to 2.0 (2.5 is preferred) microns when the infrared properties are fixed. Fixed infrared properties will override spectral data.

emis= ef eb are the thermal infrared hemispherical emittance (<1.0) for the front surface, ef, and the back surface, eb. If only one value is entered both surfaces are assumed to have the same emittances. A value must be specified even if no coatings are used. Spectral data need only extend out to 2.0 (2.5 is preferred) microns when the infrared properties are fixed. Fixed infrared properties will override spectral data.

wl is the wavelength at which the properties are reported.

Trans is the normal transmittance at the specified wavelength.

Rf is the normal reflectance of the front surface at the specified wavelength.

Rb is the normal reflectance of the back surface at the specified wavelength.

You can enter * for Trans, Rf, and Rb indicating that the values are the same as those for the preceding line. Rb can be omitted if it equals Rf, and Rf can be omitted if it is the same as for the preceding wavelength.

Comments can be enclosed in brackets, {....}, and can span more than one line. See Section A.2.2 for sample spectral data files.

C.2.1 Recommended Wavelengths for Reporting Spectral Data

To accurately represent spectral data, we recommend measuring samples at the following wavelengths and increments. The data between 0.3 and 1.0 microns should be reported at 0.01 micron (10 nm) intervals, from 1.0-2.0 (out to 2.5 microns if you have the facilities) at 0.1 micron (100 nm) intervals, and from 2.5-25.0 (out to 40.0 microns if you have the facilities) microns at 0.5 micron intervals. A finer set of measurements should certainly be used if it is available.

Note that different files containing spectral data do not have to use the same wavelengths, even if these files are used in one glazing system. However, solar spectral data must extend from at least 0.35 to 2.0 microns, and preferably from 0.30 to 2.5 microns. If data are not available at 0.32 microns, WINDOW will extrapolate data from 0.35 microns or the lowest value to a value of 0 at 0.32 microns. The damage weighted transmittance and UV transmittance will not be calculated unless data are provided at 0.30 microns. If data is not presented out to 2.5 microns, WINDOW use the last input value (as long as it is at least at 2.0 microns) as a value at 2.5 microns also.

Once these data are measured, if disk space and/or calculation speed are issues, it can be filtered for use by WINDOW. For example, if there are several spectral data points all on a line, WINDOW does not need the intermediate data points since it performs a linear interpolation between any two data points. Note that it is impossible to know what points are on a line until they have been measured. The program SPECPACK.EXE performs this packing process and is located on the main directory. To use SPECPACK, type

SPECPACK [options] filename

where the following options are available:

[-o] overwrites the original file with the new packed file. This is not recommended unless you have a copy of the original file and wish to keep the same name.

[-e xxx] creates a packed file with a new file extension called xxx.

[-t yyy] specifies a tolerance of yyy for determining linearity. The default is 0.003 which means that a point can be considered to be a linear interpolation of the two points on either side if the exact linear interpolation is within 0.3% of the real point.

Note that options -o and -e cannot be used together. The default extension is .PAK if neither of these options are specified.

In order to save disk space and calculation time, we processed all the files we received by manufacturers with SPECPACK using a tolerance of 0.3% (.003). This processing will lead to changes in the reported data for a single glazing layer of not more than a difference of 0.001 in the final value.

C.2.2 Sample Spectral Data Files

A sample spectral data file for measurements made out to 40 microns (40000 nanometers in this case) is shown below.

```
{ units } SI  nanometers
{ thickness } 6.0
{ conductivity } .22
        300    .7     .2     .2
        310    .75    .15
        320    .8     .1
        330    .82    *
         .      .      .      .  {Not part of actual data file}
         .      .      .      .
         .      .      .      .
         .      .      .      .
        40000  0      .2     .2
```

A sample spectral data file for a piece of glass with a default emittance of 0.10 on the front surface is shown below:

```
SI
2.5
.9
{ IR transmittance   } tir=  0.0
{ hemispherical emittance } e=0.10
        .3     .7     .2     .22
        .31    *      *      *
        .32    .8     .1     .13
        .33    .82    .09
         .      .      .      .      {Not part of actual data file.}
         .      .      .      .
         .      .      .      .
        2.5    0      .16    .70
```

Additional sample data files are included on the Program Disk under the \SPECDAT sub-subdirectory.

C.3 Manufacturer Supplied Spectral Data

Most of the glazing product manufacturers who supplied us with data listed in the glass library also provided us with associated spectral data files. Manufacturers did not necessarily provide spectral data for all of their products. These files are contained on the two spectral data disks. The data for a particular manufacturer is stored in a subdirectory on one of these disks. If you would like to use that manufacturer's spectral data, simply use the DOS copy command to copy all the desired spectral data files into the WINDOW 4 sub-subdirectory SPECDAT. Extensions (and subdirectories) unique to each manufacturer are listed below:

AFG Industries, Inc.	(no spectral data files)
DuPont	.dup
Ford Glass Division	.fmc
Guardian Industries, Inc.	.grd
Interpane	.inp
Libbey Owens Ford	.lof
Monsanto Company	.mon
PPG Industries, Inc.	.ppg
Southwall Technologies	.swt
Viracon, Inc.	.vir

A listing of all manufacturers' spectral data files and a cross-reference to their products follows.

All data supplied with WINDOW 4 is laboratory-measured data, and small deviations from sample to sample will occur, particularly for coated glazings. Questions regarding the optical data for these entries should be directed to the appropriate manufacturers. Although we provided guidelines to the manufacturers on how to prepare these data, they have not been checked by LBL. Much of the data has been condensed (see Section A.2.1); however, this will not lead to any noticeable changes in calculated results.