Standard 90.1's ENVSTD: Both a Compliance Program and an Envelope Design Tool

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ABSTRACT

Since 1982, ASHRAE and the U.S. Department of Energy have worked together to update ANSI/ASHRAE/IES Standard 90A-1980, "Energy Conservation in Building Design." The new standard, ASHRAE/IES Standard 90.1-1989, "Energy-Efficient Design of New Buildings Except Low-Rise Residential Buildings," is substantially changed in form and concept from Standard 90A-1980, especially in how it deals with exterior envelopes.

In the new standard, designers can use either of two methods -- prescriptive or system performance -- to comply with building envelope requirements. Under the prescriptive method, requirements are listed in tabular form and designers must demonstrate compliance with each individual requirement. In the system performance method, designers generate the requirements for their specific building using a set of equations. The equations establish limits on permissible heating and cooling coil loads based on the local climate and the internal loads in the exterior zones of the building.

A personal computer program, ENVSTD (ENVelope STanDard), has been written to simplify compliance with the system performance path of the standard. The program can also be used to evaluate the impact of varying envelope characteristics on building heating and cooling coil loads in specific locations.

This paper provides examples of the impacts that the standard's envelope requirements have on envelope design. Use of the ENVSTD program as a design tool to determine the heating and cooling load impacts of various envelope strategies is also demonstrated.

BACKGROUND

In 1982, the U.S. Department of Energy (USDOE) initiated a research project to develop recommended changes to the existing ANSI/ASHRAE/IES Standard 90A-1980 (ASHRAE 1980). A major part of the research focused on developing a comprehensive approach to deal with the complex interactions of building envelopes with other building systems. Standard 90A-1980 treats building envelopes simply, as a means of preventing heat flow. It does not deal with many phenomena important in commercial building design such as solar gains through fenestration, daylighting, and other factors. Because of these limitations in the existing standard, and a desire to allow designers greater flexibility in complying with envelope criteria, a new approach to building envelope requirements was developed -- treating exterior walls and zones as an interactive thermal system.

A set of regression equations was developed from heating and cooling coil loads from more than 3000 DOE-2.1B energy simulations in 36 locations around the United States (PNL 1983). These regression equations predict annual heating and cooling coil loads based on envelope and other internal load characteristics of the exterior zones of the building. The equations are

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complex (more than nine single-spaced pages) and extremely difficult to use manually. The exterior envelope criteria are maximum annual thermal loads based on the climate, the envelope physical characteristics, and the level of combined lighting and equipment internal loads. Together, the regression equations and criteria define the building envelope system performance requirements of the standard (Wilcox et al. 1985; Crawley and Briggs 1985).

In 1984, ASHRAE formed Standing Standards Project Committee 90R (SSPC 90R) to begin the process of revising Standard 90. In early drafts, the committee implemented the regression equations in a spreadsheet to check the equations and the evolving criteria and found that the spreadsheet eased the complexity of determining compliance with the standard. Then, a BASIC microcomputer program that implemented the equations was developed for the committee's use. In 1986, Pacific Northwest Laboratory developed a spreadsheet-like PASCAL microcomputer language version of the envelope equations and requirements.

During the three public reviews of Standard 90.1-1989, many designers found that the program not only gave them a quick and easy means to calculate compliance with the complex envelope requirements, but also provided a way to determine the relative impact of various envelope components in their specific location. Thus, the program has also become a strong design aid and teaching tool for building envelopes.

The next section deals with the two ways in which the program can be used -- first as a compliance tool for the exterior envelope requirements of Standard 90.1-1989 and second as a design aid and teaching tool for commercial building exterior envelope design.

ENVSTD AS A COMPLIANCE TOOL

In the new standard, designers can use either of two methods for demonstrating compliance with envelope requirements -- prescriptive or system performance. For the prescriptive method, all envelope component requirements, e.g., maximum conductance or minimum resistance, for a location are listed in tabular form, and building designs must comply with each specific requirement separately. To develop the prescriptive criteria, the SSPC 90R calculated the system performance criteria for specific climate ranges and combinations of exterior wall thermal characteristics. For the system performance method, designers use a set of equations to generate the requirements for their specific building. The equations establish limits on permissible heating and cooling coil loads for the building location and internal loads in the exterior zones of the building.

These equations and criteria were implemented in a C microcomputer language program known as ENVSTD (for ENVelope STanDard). The main exterior wall screen of this program is shown in Figure 1. All requirements of Standard 90.1-1989 relating to compliance with the exterior wall criteria of the system performance method are incorporated on this screen. For skylight areas and roof, walls and floors next to unconditioned spaces, and slab-on-grade, shown in Figure 2, the second or "Other Envelope Requirements" screen, the criteria are maximum U_0 and minimum R-values.

To determine compliance with the exterior wall requirements of the standard, the program requires two entries about the building in general:

- location (city code)
- whether the building will be only heated or cooled, or both heated and cooled.

The designer enters the following data about the building design exterior walls and zones, by orientation:

- total exterior wall area (opaque and glazed)
- fenestration area, shading coefficient, visible light transmittance, and U-value

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2 The U.S. Department of Energy has developed a standard for federal non-residential buildings (USDOE 1989) that parallels the requirements and criteria of Standard 90.1-1989. When the USDOE Standard was completed and published in 1989, the program was rewritten in the C microcomputer language. The examples shown in this paper are taken from the USDOE version of the program (Crawley et al. 1989).

- projection factor (ratio of depth of overhang to height above window sill) for horizontal shading overhangs
- U-value, heat capacity, and position of insulation relative to wall mass for opaque walls
- lighting power density
- miscellaneous equipment power density
- fraction of exterior zone lighting controlled for daylight utilization.

After the designer enters this information into the program, the criteria and predicted annual heating and cooling coil loads for the design can be calculated. These criteria are a function of two design-specific variables: climate data for the city and internal loads (sum of equipment and lighting power density). To comply with the external wall requirements of the standard, the total loads for the design must be lower than the calculated maximum allowable levels. The exterior wall design must meet one other requirement -- a maximum U-value for lightweight opaque walls [walls with heat capacity less than 7 Btu/(ft^2•°F)]. If the exterior walls pass the system performance criteria of the standard, the program displays a "PASSES" message at the bottom of the screen when the **F9** function key (calculate) is pressed.

For each entry in the program, online help is available by pressing the **F7** key. An example of the help message for wall U_o (overall wall U-value) is shown in Figure 3. Similar help information is available for all other data entries required by the program.

The user enters information on the "Other Envelope Requirements" screen shown in Figure 2 to determine whether other elements of the building envelope comply:

- percentage of roof area in skylights and skylight attributes
- U-value of roof assemblies
- U-values of walls and floors next to unconditioned spaces
- R-value of walls below grade
- slab-on-grade R-value.

Each envelope component must meet the requirements shown under the "Limit" column (Figure 2) for the specific location, either a maximum U-value or minimum R-value. If they do comply, the program will display a "Meets Other Envelope Requirements" message at the bottom of the screen when the **F9** function key (calculate) is pressed.

One of the more important decisions that a designer must make when using the program is which city to use. For 234 locations throughout the United States, specific climate data have been incorporated into the program. Thus, for most major U.S. cities, a designer will find city codes for his or her location. When a designer presses the **F6** function key and enters the postal abbreviation for a state, a window appears with a list of cities and their corresponding codes. As an example, the list of cities and city codes for New Mexico is shown in Figure 4. If the exact project location is not listed, the designer should select the city that is closest climatologically, not necessarily the one closest in terms of distance. For example, if the building location were in the mountains of northern New Mexico, several nearby locations in New Mexico and Colorado might be suitable: Albuquerque, Eagle, Pueblo, and Grand Junction. Albuquerque may be closest in terms of distance, but Eagle, Pueblo, or Grand Junction may be more accurate if the altitude of the project site is significantly different from Albuquerque. Another example is the San Francisco Bay area of California. The climate varies considerably depending on how close a city is to the Pacific Ocean: locations on the bay tend to be moderate with lower daily temperature variation, while interior cities tend to be more extreme (hotter and colder) with much larger daily temperature variations. Thus, a designer should carefully select the city that best represents the climate conditions of the building site.

Another important consideration is how lighting and equipment power density is used. As described earlier, the equations predict annual heating and cooling coil loads, not energy consumption or peak load. The equations deal only with the thermal impacts (heating and cooling) of the lighting and miscellaneous equipment; direct energy use of these systems is addressed elsewhere in the standard. As shown in Figure 1, the program also allows the designer to consider the thermal benefits of daylighting by indicating the fraction of each exterior zone where the lighting system is automatically controlled for daylighting. Again, the equations consider only the thermal load impacts; energy and peak load considerations for lighting and automatic daylighting controls are dealt with separately in the lighting criteria. If a designer wants to consider the benefits of combined interactions of fenestration, lighting systems, and daylighting controls together, the Building Energy Cost compliance path must be used. Otherwise, the thermal impacts are dealt with in the envelope requirements and the direct energy impacts are dealt with in the lighting requirements.

An example of the program's output for a building in compliance with all envelope requirements is shown in Figure 5. This example is for a three-story office building with a gross floor area of 48,664 ft^2. The window-to-wall ratio is 0.28 (28% of the total wall area is fenestration), and the location is El Paso, TX (city code 70). As shown in Figure 5, the load appearing under the "Total" column of the main screen, 59.872, is lower than the criterion shown to its right, 66.420. Thus, this combination of building envelope component characteristics complies with the exterior wall requirements of the standard. Note that the heating total load of 8.357 is higher than the criterion value of 6.986 -- the standard requires only that the total loads be less than the total criteria, allowing designers to trade off heating and cooling loads.

A building envelope design not in compliance with the standard requires modifications to meet the standard. Fortunately, the envelope program also functions well as a design tool. If the example office building shown in Figure 5 is "moved" to Minneapolis, MN and none of the envelope characteristics changed, it would fail compliance. This is described in the next section. Also discussed are several examples of how the program can be used to determine what building envelope components are most important.

ENVSTD AS A DESIGN TOOL

To redesign the envelope and bring the example into compliance in Minneapolis, the characteristics of several envelope components must be changed. After the city code is changed from 70 (El Paso) to 140 (Minneapolis) and the **F9** key is pressed, the program flashes a message that the wall U-value (U_o) is above the limit allowed for Minneapolis. To comply with the requirements for lightweight walls, the opaque wall U_o value must be lowered to 0.116 Btu/(h•ft^2•°F). Another way to meet this requirement would be to increase the opaque wall thermal mass by using higher-density wall materials such as concrete block. By increasing the heat capacity (HC) of the opaque wall, bringing it above 7 Btu/(ft^2•°F), the minimum wall U-value requirement no longer applies.

Even after changing the wall U-value, the total loads for the Minneapolis example still are higher than the criterion allows. Thus, we have to improve other envelope components. For this example, we decided to change the glazing from the single-pane U-value of 1.042 Btu/(h•ft^2•°F) used for the El Paso example to a double pane U-value of 0.50 Btu/(h•ft^2•°F). This brings the example into compliance with the exterior wall requirements for Minneapolis, as shown in Figure 6. Changing the glazing U-value is only one way to bring the example into compliance. Each designer can decide what tradeoffs are most appropriate given aesthetic or thermal considerations. The designer could adjust window and wall areas, or the individual characteristics of each envelope component.

When the relative loads shown in Figures 5 and 6 are compared, the totals are close in magnitude but the heating and cooling loads are very different. This leads to two questions: which variables are most important in El Paso and are the same variables important in Minneapolis? To demonstrate this, we used the medium office building example again to determine the impact of several variables on the heating, cooling, and total loads predicted by the program. Several examples of the impacts of varying envelope components on the heating and cooling loads follow to demonstrate how the program (regression equations) can be used to help designers understand which characteristics are important for their location. We will use the example office building described earlier with El Paso and Minneapolis as the climate locations again. Three envelope components are varied and the impact on heating, cooling and total loads shown: Figures 7 and 8 show wall U_o value, Figures 9 and 10 show glass U_o values, and Figures 11 and 12 show glass shading coefficient.[3]

3 The ENVSTD program does not automatically produce comparisons such as those shown in Figures 7 through 12. Data for these figures were generated by incrementally changing each characteristic and recording the results.

In Figures 7 and 8, the impact of changing the wall U_o value from 0.0 to 0.24 Btu/(h•ft^2•°F) is shown for El Paso and Minneapolis, respectively. Note that values are shown only for U-values up to 0.116 for Minneapolis -- the maximum allowed for lightweight walls, as discussed earlier. Even with the relatively significant change in wall U-value, the change in overall thermal loads is less than 10% in both cases, but is larger in Minneapolis. A similar comparison is shown for glazing U-value varying from 0.0 to 1.4 Btu/(h•ft^2•°F) in Figures 9 and 10. The loads change more for glazing U-value as compared to wall U-value in both cities, but again the impact is much larger in Minneapolis. The last comparison of envelope components, shown in Figures 11 and 12, demonstrates the impacts of varying the fenestration shading coefficient (SCx) from 0.0 to 1.0. The impact of shading coefficient is much larger for El Paso (almost 100% over the range of SCx) than for Minneapolis (<10% over the entire SCx range).

By examining Figures 7 through 12, it becomes obvious which of these three envelope components is most important in El Paso and Minneapolis. The fenestration shading coefficient, shown in Figure 11, has the greatest impact on overall building loads in El Paso and generally will be the most important design consideration there. The fenestration U-value, shown in Figure 10, is the most important of the three components for Minneapolis. By using the program to look at the relative importance of individual components, designers can learn which components impact envelope loads most significantly in their area.

CONCLUSIONS

The envelope program provides designers with an easy-to-use means to demonstrate that their building designs comply with the building envelope system performance criteria of Standard 90.1-1989. Although it is primarily intended and designed for demonstrating compliance, the program can also be used by building envelope designers to help them understand the relative importance of various envelope components in their climate locations. Although Standard 90.1-1989 provides criteria for the entire country, most designers work in a limited number of climate locations. The envelope program will help them learn what is critical for their building envelope designs.

ACKNOWLEDGMENTS

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CITY:
CODE <B,C,H>:

BUILDING:
DATE:

	WALL ORIENTATION								WEIGHTED	
	N	NE	E	SE	S	SW	W	NW	AVERAGE	CRITERIA
WL AREA										
GL AREA										
SCx										
PF										
VLT										
Uof										
WALL Uo										
HC										
INS POS										
EQUIP										
LIGHTS										
DLCF										
	LOADS								TOTAL	
HEATING										
COOLING										
TOTAL										

F1 Load F2 Save	F3 Clear Input F4 Directory	F5 Other Screen F6 List Cities	F7 Help F9 Calculate	F10 Copy Across Esc Exit to DOS

Figure 1. Exterior wall screen

CITY:
DATE:

MAXIMUM PERCENTAGE OF ROOF AREA IN SKYLIGHTS:	DESIGN	LIMIT
Visible Transmittance of Skylight	0.500	0.500
Design Lighting Footcandles of Space	50	50
Percentage of Roof Area in Skylights:		
MAXIMUM ALLOWABLE Uo:		
Roof		
Wall Adjacent of Unconditioned Space		
Floor Over Unconditioned Space		
MINIMUM ALLOWABLE R-VALUE:		
Wall Below Grade		
Slab on Grade (Heated or Unheated)	Unheated	Unheated
Insulation Position	Horizontal	Horizontal
Depth or Width (Inches)	24 in.	24 in.
R-Value of Concrete Slab Insulation		

F5 Return to Wall Screen F7 Help	F9 Calculate Del Delete Entry	Arrows Move

Figure 2. Other envelope requirements screen

```
CIT
COD  WALL Uo

          Enter the U-value of the exterior opaque wall (WALL Uo),      RIA
          in Btu/(h•ft2•F), including the effects of parallel-path
WL        conduction.  Section 5.3 of the Standards describes
GL        procedures for determining the effects of parallel paths.
          The program accepts values from 0.0 to 1.4.



WAL
INS POS
EQUIP
LIGHTS
DLCF
-------------------------- L O A D S ---------------------TOTAL------
HEATING
COOLING
TOTAL

F1 Load  | F3 Clear Input | F5 Other Screen | F7 Help      | F10 Copy Across
F2 Save  | F4 Directory   | F6 List Cities  | F9 Calculate | Esc Exit to DOS
```

Figure 3. Sample help message for wall Uo

```
CITY:                                   BU
CODE <B,C,H>:                                   City List for NM
        ---------- WALL ORIENTATIO           Enter State Abbreviation
          N     NE     E     SE     S
                                              5 Albuquerque
WL AREA                                      49 Clayton
GL AREA                                     184 Roswell
   SCx                                      217 Truth or Consequences
   PF                                       219 Tucumcari
   VLT
   Uof
WALL Uo
   HC
INS POS
EQUIP
LIGHTS
DLCF
------------------------ L O A D S
HEATING
COOLING
TOTAL

F1 Load  | F3 Clear Input | F5 Other Sc
F2 Save  | F4 Directory   | F6 List
```

Figure 4. Sample list of cities for New Mexico

ENVELOPE SYSTEM PERFORMANCE COMPLIANCE CALCULATION PROGRAM
VERSION 2.1
U.S. DEPARTMENT OF ENERGY
VOLUNTARY PERFORMANCE STANDARDS FOR NEW COMMERCIAL AND MULTI-FAMILY
HIGH RISE RESIDENTIAL BUILDINGS; MANDATORY FOR FEDERAL BUILDINGS

CITY: 70 El Paso TX BUILDING: Medium Office Building
CODE <B,C,H>: Both Heated and Cooled DATE: July 24, 1989

	WALL ORIENTATION N	NE	E	SE	S	SW	W	NW	WEIGHTED AVERAGE	CRITERIA
WL AREA	4113		7137		4299		6023		0.28	0.281
GL AREA	1096		1950		1170		1914		WWR	WWR
SCx	0.482		0.482		0.482		0.482		0.48	0.500
PF	0.20		0.18		0.18		0.20		0.19	0.0
VLT	0.36		0.36		0.36		0.36		0.36	N/A
Uof	1.042		1.042		1.042		1.042		1.04	1.150
WALL Uo	0.22		0.22		0.22		0.22		0.22	0.158
HC	5.33		5.33		5.33		5.33		5.33	1
INS POS	3		3		3		3		3	N/A
EQUIP	0.50		0.50		0.50		0.50		0.50	0.500
LIGHTS	1.73		1.73		1.73		1.73		1.73	1.730
DLCF	0		0		0		0		0.00	0.0
					L O A D S				-TOTAL-	
HEATING	2.008		2.594		1.355		2.400		8.357>	6.986
COOLING	7.697		17.731		10.028		16.059		51.515<	59.433
TOTAL	9.706		20.325		11.383		18.458		59.872<	66.420

********** PASSES **********

OTHER ENVELOPE REQUIREMENTS

MAXIMUM PERCENTAGE OF ROOF AREA IN SKYLIGHTS:	DESIGN		LIMIT
Visible Transmittance of Skylight	0.500		0.500
Design lighting Footcandles of Space	50		50
Percentage of Roof Area in Skylights:	0.0	<	5.4

MAXIMUM ALLOWABLE Uo:			
Roof	0.050	<	0.061
Wall Adjacent to Unconditioned Space	0.200	<	0.249
Floor Over Unconditioned Space	0.100	<	0.115

MINIMUM ALLOWABLE R-VALUE:			
Wall Below Grade	0.000	=	0.000
Slab on Grade (Heated or Unheated)	Unheated		Unheated
Insulation Position	Horizontal		Horizontal
Depth or Width (Inches)	24 in.		24 in.
R-Value of Concrete Slab Insulation	0	=	0

********* MEETS OTHER ENVELOPE REQUIREMENTS *********

Figure 5. *El Paso office building sample output*

ENVELOPE SYSTEM PERFORMANCE COMPLIANCE CALCULATION PROGRAM
VERSION 2.1
U.S. DEPARTMENT OF ENERGY
VOLUNTARY PERFORMANCE STANDARDS FOR NEW COMMERCIAL AND MULTI-FAMILY
HIGH RISE RESIDENTIAL BUILDINGS; MANDATORY FOR FEDERAL BUILDINGS

CITY: 140 Minneapolis MN BUILDING: Medium Office Building
CODE <B,C,H>: Both Heated and Cooled DATE: July 24, 1989

	WALL ORIENTATION								WEIGHTED	
	N	NE	E	SE	S	SW	W	NW	AVERAGE	CRITERIA
WL AREA	4113		7137		4299		6023		0.28	0.300
GL AREA	1096		1950		1170		1914		WWR	WWR
SCx	0.5		0.5		0.5		0.5		0.50	0.606
PF	0.20		0.18		0.18		0.20		0.19	0.0
VLT	0.36		0.36		0.36		0.36		0.36	N/A
Uof	0.50		0.50		0.50		0.50		0.50	0.450
WALL Uo	0.116		0.116		0.116		0.116		0.12	0.071
HC	5.33		5.33		5.33		5.33		5.33	1
INS POS	3		3		3		3		3	N/A
EQUIP	0.50		0.50		0.50		0.50		0.50	0.500
LIGHTS	1.73		1.73		1.73		1.73		1.73	1.730
DLCF	0		0		0		0		0.00	0.0
					LOADS				-TOTAL-	
HEATING	6.932		10.580		5.310		9.315		32.137>	23.502
COOLING	4.130		8.220		5.008		7.411		24.770<	33.653
TOTAL	11.062		18.800		10.318		16.727		56.907<	57.155

********** PASSES **********

OTHER ENVELOPE REQUIREMENTS

MAXIMUM PERCENTAGE OF ROOF AREA IN SKYLIGHTS:	DESIGN		LIMIT
Visible Transmittance of Skylight	0.500		0.500
Design lighting Footcandles of Space	50		50
Percentage of Roof Area in Skylights:	0.0	<	8.1

MAXIMUM ALLOWABLE Uo:			
Roof	0.040	<	0.047
Wall Adjacent to Unconditioned Space	0.110	<	0.116
Floor Over Unconditioned Space	0.040	=	0.040

MINIMUM ALLOWABLE R-VALUE:			
Wall Below Grade	12.00	>	10.545
Slab on Grade (Heated or Unheated)	Unheated		Unheated
Insulation Position	Horizontal		Horizontal
Depth or Width (Inches)	24 in.		24 in.
R-Value of Concrete Slab Insulation	20	>	18

********* MEETS OTHER ENVELOPE REQUIREMENTS *********

Figure 6. *Minneapolis office building sample output*

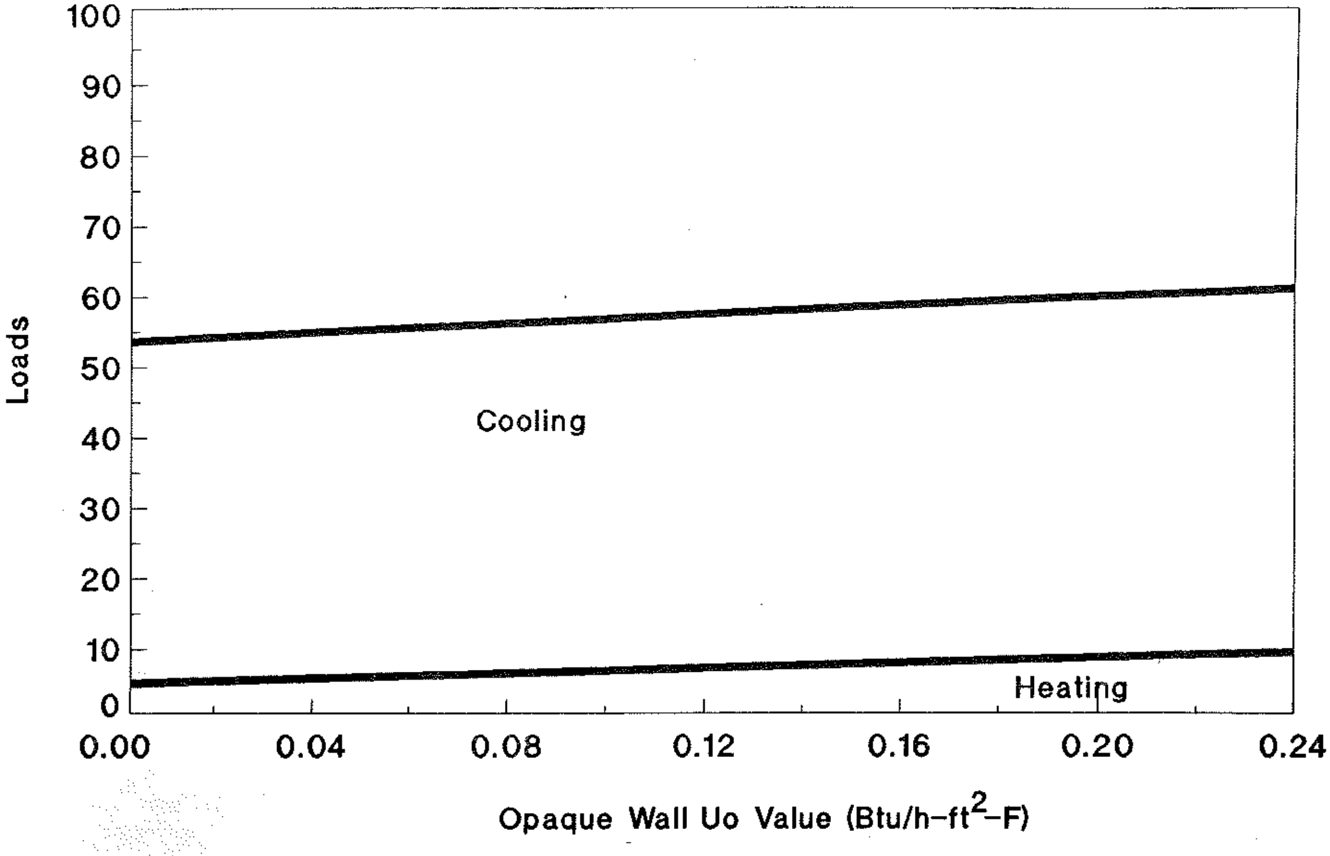

Figure 7. Heating and cooling loads versus wall Uo value for El Paso example

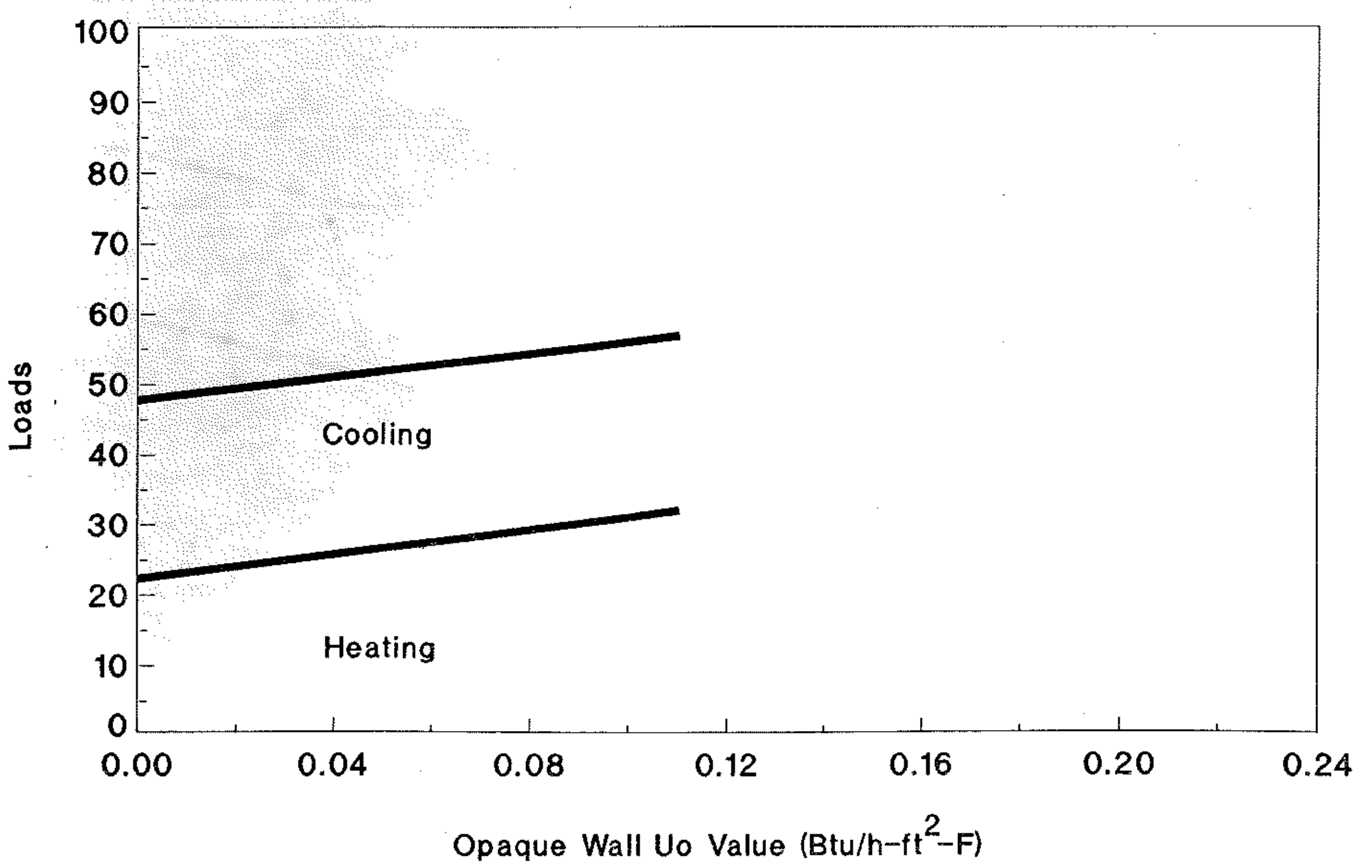

Figure 8. Heating and cooling loads versus wall Uo value for Minneapolis example

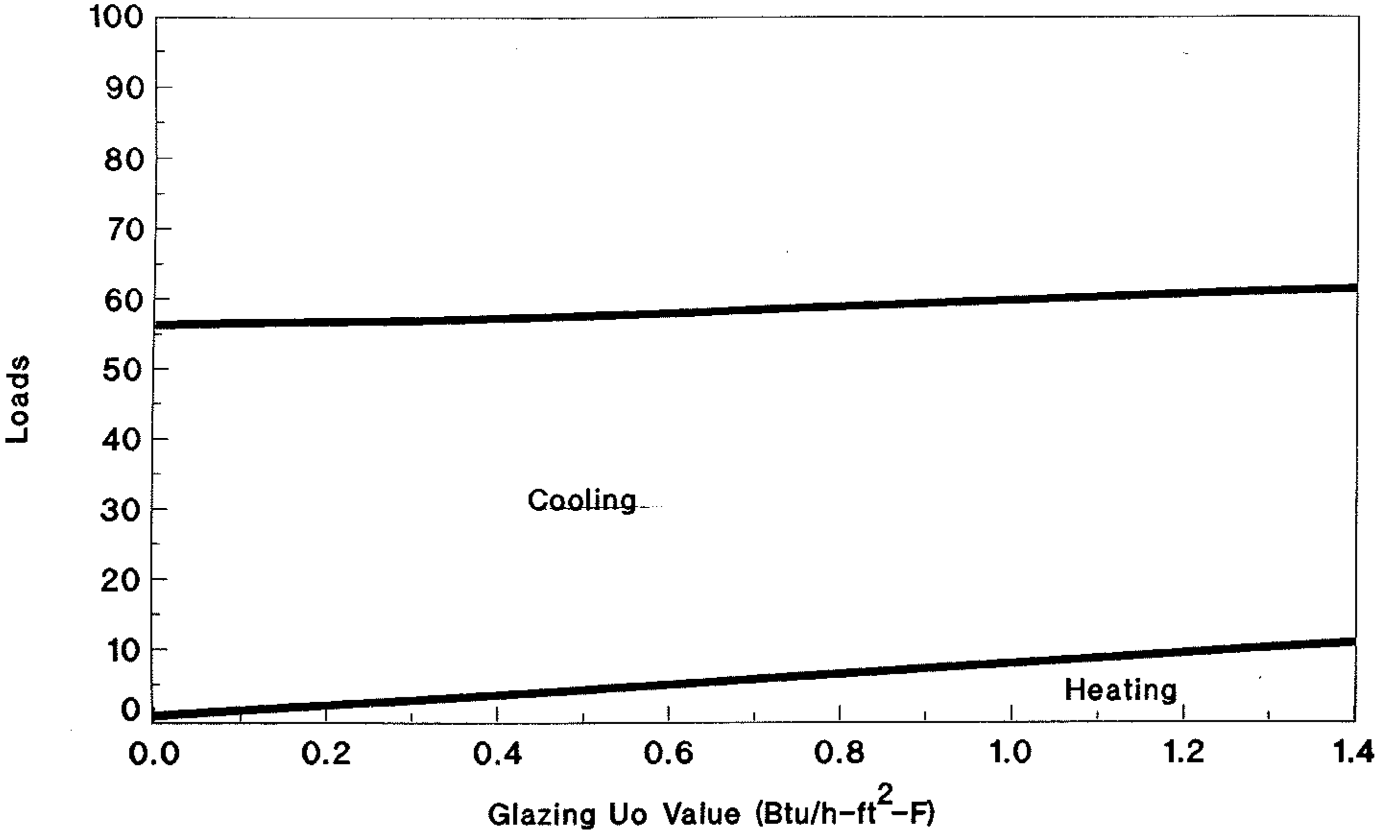

Figure 9. Heating and cooling loads versus glass Uo value for El Paso example

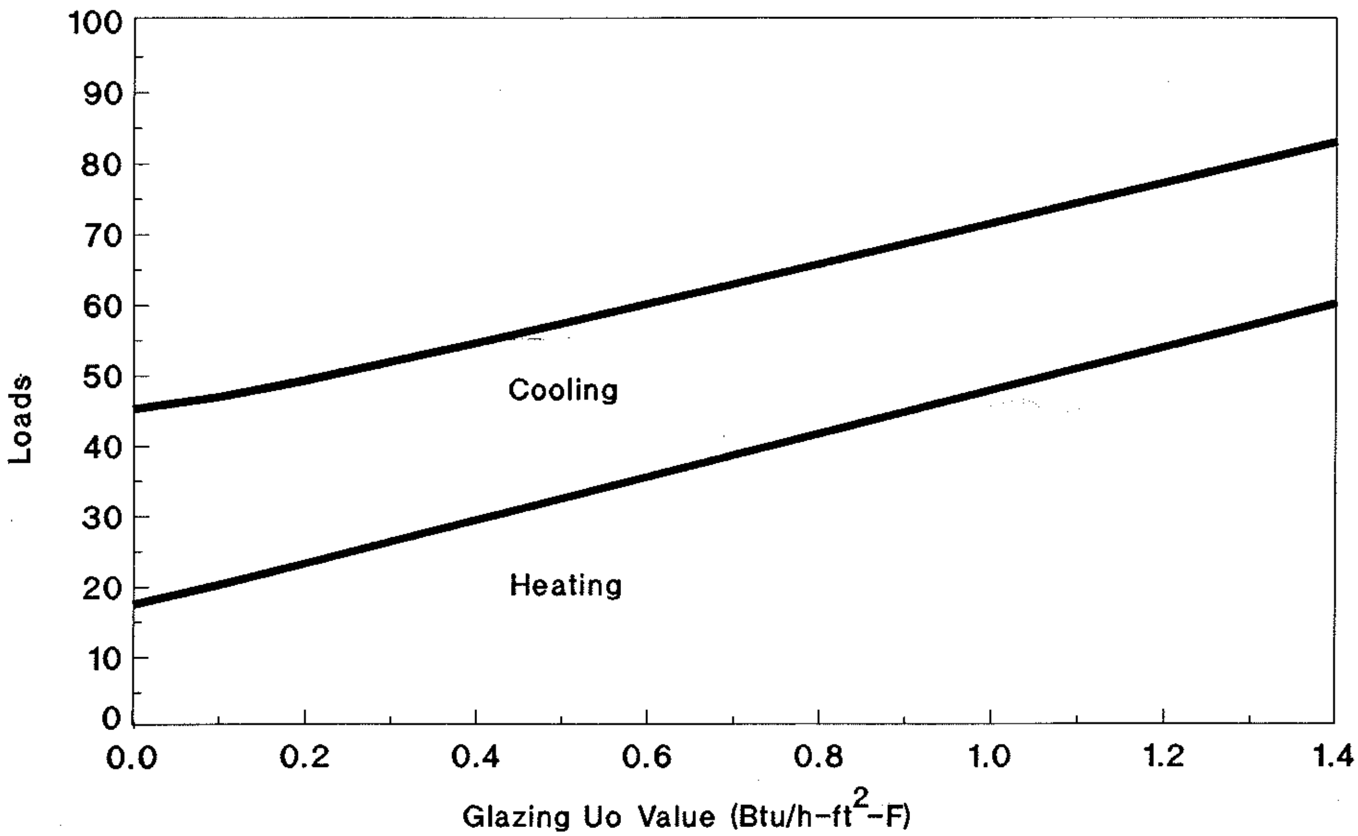

Figure 10. Heating and cooling loads versus glass Uo value for Minneapolis example

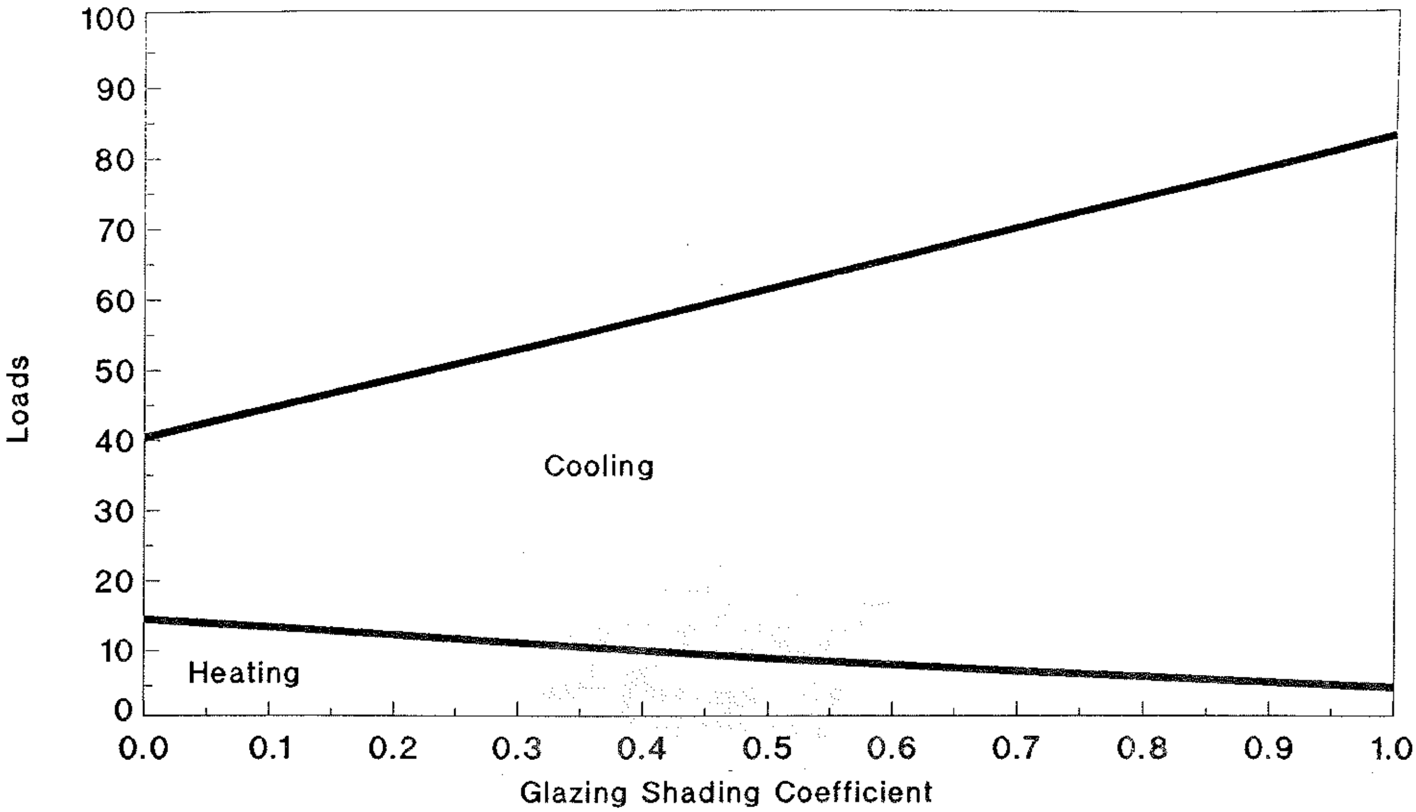

Figure 11. *Heating and cooling loads versus glass SC for El Paso example*

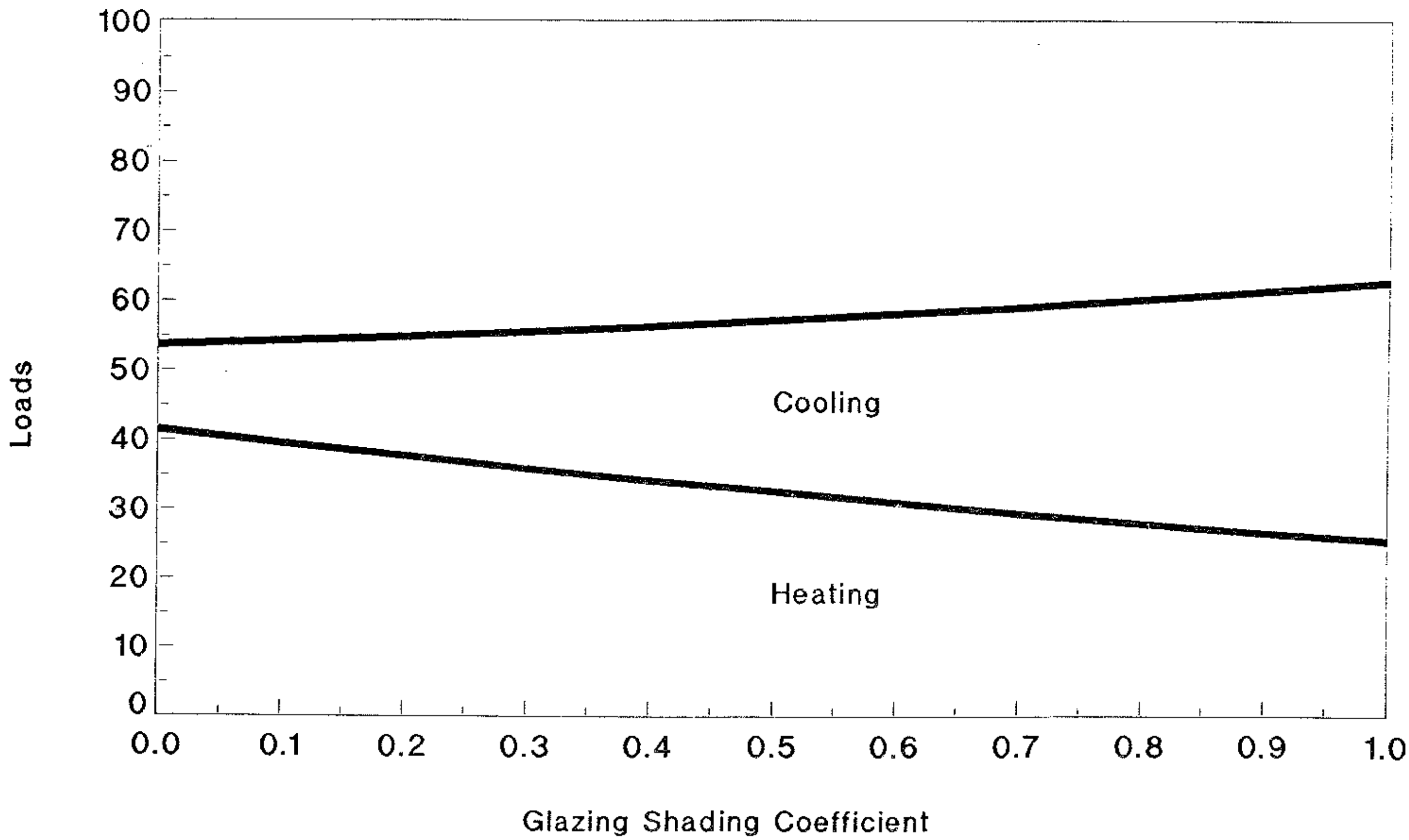

Figure 12. *Heating and cooling loads versus glass SC for Minneapolis example*