COMPARISON OF SIMULATION METHODS FOR EVALUATING IMPROVED FENESTRATION USING THE DOE-2.1E BUILDING ENERGY SIMULATION PROGRAM

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ABSTRACT

In most of the United States, the shading coefficient method along with pre-calculated ASHRAE weighting factors have been used for determining the prescriptive tables for the International Energy Conservation Code (IECC). Although these methods were considered accurate for simulating single-pane and double-pane windows, simulations using the WINDOW-5 program have been shown to provide more accurate results when simulating low-E windows. Therefore, this study investigates the inaccuracies of calculating energy savings using the shading-coefficient/pre-calculated ASHRAE weighting factor method versus simulations performed with the more accurate WINDOW-5/custom weighting factor method in the DOE-2.1e program. The results show that the difference in the total annual energy savings can be significant (7% for low-E glazing), and more importantly, differences in peak energy savings can be as high as 30 %. Hence it is recommended to incorporate the use of the new, more accurate fenestration model (i.e., WINDOW-5), combined with custom weighting factors in the determination of prescriptive tables for the IECC.

INTRODUCTION

In September 2001, Texas adopted the 2000 International Energy Conservation Code (IECC 2000), including the 2001 Supplement (IECC 2001) as its official energy code for buildings. As part of this legislation, the Energy Systems Laboratory was directed to evaluate the state-wide energy savings and air pollution reductions from the implementation of the energy code, which included the simulation of energy savings from the use of the new IECC Energy code. On examining the previous simulations, which were used to develop the prescriptive tables in the IECC, it was found that older versions of the DOE-2 program had been used that contained the shading coefficient method, and pre-calculated ASHRAE weighting factors. Although these methods were considered accurate for simulating single-pane and double-pane windows, simulations using the WINDOW-5 program together with Custom weighting Factors have been shown to provide more accurate results when simulating low-E and other high-performance windows.

In the 1970s and 1980s emerging high-performance glazing technology pushed researchers at LBNL to develop new and more sophisticated algorithms for fenestration simulation software (Arasteh et al. 1998). Research by Rubin (1982a, 1982b) and later Arasteh et al. (1989) played a key role in establishing calculation procedures used in the WINDOW-5 program. Experimental verification of the simulation models has also been performed. This new program was then tested in a series of experiments conducted by Klems who examined the thermal performance of fenestration systems under realistic conditions and compared the results with those obtained from the Lawrence Berkeley National Laboratories (LBNL) simulation models (Klems 1989; Klems et al. 1995).

DOE-2.1e gives several options for calculating heat gain through windows (LBNL, 1981). In the shading coefficient (SC) method, the program first calculates the angle-dependent solar heat gain using transmission coefficients for clear, 1/8” glass using the angle-dependent polynomial developed by ASHRAE Task Group on Energy Requirements-TGER (1975). The solar heat gain is then calculated by multiplying this result with the shading coefficient value input by the user. In the method referencing the WINDOW-5 program, the user uses a four digit code to reference a window in the input file from a pre-assembled, user-defined library file (i.e., WIN.DAT) which contains a list of WINDOW-5 generated output files arranged by four digit code numbers. The DOE-2.1e program references these files for incident angle dependent solar heat gain coefficient (SHGC) values which are used by the DOE-2.1e program. A number of studies have shown that the SHGC more accurately accounts for the angle-dependent transmittance properties than the SC method of assessing solar heat gain through windows, and WINDOW-5 includes more accurate convection coefficients (McCluney 1991; Reilly et al. 1995).

DOE-2.1e uses weighting factors to calculate the thermal loads and space temperatures (LBNL, 1981). Two options are available to specify the weighting factors. In the pre-calculated weighting factor method a pre-calculated floor weight is assigned to represent thermal capacity of each space (or in some cases the entire building). In the custom weighting factor method, the entire construction assembly is elaborately specified.

On examining the SC and WINDOW-5 methods used in DOE-2.1e, Reilly et al. (1995) conclude that the use of the WINDOW-5 library gives the most accurate window heat transfer calculations because the angular dependence of transmission and adsorption of solar radiation is more precisely modeled and the temperature dependence of the window U-value is more accurately calculated. However the study did not include the impact of activating DOE-2's custom weighting factors versus results from using the pre-calculated weighting factors in specifying the building envelope components of the simulation model.

An informal survey of simulation models used to develop the prescriptive tables for the IECC and ASHRAE 90.1 revealed that in the simulations used in the current code (i.e., the IECC 2003 and ASHRAE Standard 90.1-2004), the modelers may not have used the more accurate WINDOW-5 program, and that pre-calculated ASHRAE weighting factors may have been used. In addition, an informal review of the simulation procedures used for the residential EnergyStar program revealed similar issues.

Therefore, this study investigates the inaccuracies of calculating energy savings using the shading coefficient (SC)/pre-calculated ASHRAE weighting factor method (i.e., Quick mode) versus simulations performed with the more accurate WINDOW-5/custom weighting factor method (i.e., Thermal mode) in the DOE-2.1e program.

TEST MATRIX

The DOE-2.1e (Version 119) program was selected as the simulation program to be used for obtaining the results. A customized input file was created to facilitate the numerous simulations that needed to be run for this study. The building model used for the DOE-2.1e input file was based on the 2000/2001 IECC specifications for a single family building. This model has been developed by the Energy Systems Laboratory, to calculate the energy savings from code adoption (Haberl et al., 2003a). The model is a single-story light weight structure (13 lb/sqft) with a garage attached on the west side of the building. This version of the input file uses electricity for space cooling with heating energy and heating for domestic hot water provided by natural gas. Houston was used as the climate location for this study since it represents a sizable percentage of the population living in the ozone non-attainment areas identified by the Environmental Protection Agency. The TMY2 weather file (NREL, 1995) for Houston was used to carry out simulations. Three glazing options, Single Pane Clear (SPC), Double Pane Clear (DPC) and Double Pane Low-E (DPlow-E), were selected for the purpose of the analysis. Properties of the glazing types selected are presented in Table 1. Results from both the LOADS and SYSTEMS section of DOE-2's simulation output were analyzed and are presented in terms of hourly / daily reports, annual reports and peak load reports.

The first section presents the performance of glazing types when tested under the four options available (i.e., SC, WINDOW-5, Pre-calculated Weighting Factors and Custom Weighting Factors). The second section of this paper presents and analyses the variation in energy savings obtained when a building with lower performing glazing is compared to a building with higher performing glazing when using the four options mentioned above.

SIMULATION RESULTS AND DISCUSSION

Comparing The Use Of Custom Weighting Factors (Thermal Mode) With The Use Of ASHRAE Pre-Calculated Weighting Factors (Quick Mode) Along With The Use Of SC And WINDOW-5 Methods

To obtain a detailed analysis of the impact of activating DOE-2's custom weighting factors (Thermal mode) and using the WINDOW-5 program for fenestration specifications, one week in August and one week in January were considered for a detailed analysis. The appropriate hourly data were extracted from DOE-2's hourly reports and plotted for analysis. The combined hourly solar and conduction loads were examined from the DOE-2 LOADS sub-program, while hourly zone temperature, cooling electricity and heating fuel use were analyzed from the DOE-2's SYSTEMS sub-program. Results from DPC and DPlow-E are presented in Figures 1 to 4.

Results from DOE-2s LOADS sub-program.

An inspection of the results for the LOADS sub-program analysis (i.e., the upper plot in Figure 1 – Figure 4) shows that analysis using the SC method to specify fenestration show larger variations in solar radiation (i.e., a range of approximately –2,000 Btu/hr to 19,000 Btu/hr for DPC for days in the summer) than the options using WINDOW-5 method (i.e., a range of –1,900Btu/hr to 15,000 Btu/hr for DPC for days in the summer). It is also observed that during the daytime hours, using the WINDOW-5 method yielded lower results when compared to the SC method for both Quick and Thermal mode by approximately 15-25%. The trends are reversed during the night time hours. During the night time the WINDOW-5 analysis produces a higher energy loss than the SC analysis by approximately 25%. This trend is more prominent for the week in the winter than it is in the summer. These results reinforce the conclusions from the previous research, which states that the use of the WINDOW-5 program predicts larger conduction losses because it is more sensitive to the environmental conditions (Reilly et al., 1995). While this energy loss recorded by the WINDOW-5 option can be beneficial for energy consumption in the summer season, it accounts for greater heating energy losses during the winter.

On switching from Quick to Thermal mode, there is on an average a 30% to 40% drop from the combined solar and conduction loads for the glazing options considered. Results obtained when using the Quick mode show greater diurnal variation (i.e., a range of approximately 0 Btu/hr to 17,500 Btu/hr for DPC for days in summer) than when using the Thermal mode (i.e., a range of approximately 1,000 Btu/hr to 11,000 Btu/hr for DPC for days in summer). The results imply that activating the custom weighting factors results in higher retention of heat gain in the building envelope components which in turn results in lower cooling and heating loads to the simulated space which has repercussions on the HVAC system used to control the space temperature.

Results From DOE-2's SYSTEMS Sub-program.

To analyze the impact on the HVAC loads, the required thermostat cooling set-point temperature defined in the SYSTEMS section of the DOE-2 input file was set at 78°F from 7:00 p.m. to 12:00 a.m. midnight, and set back to 83°F between 1:00 a.m. and 6:00 a.m in the summer. While the heating set-point temperature was defined at 68°F from 7:00 a.m. to 12:00 a.m. and set back at 63°F between 1:00 a.m. and 6 a.m. These settings are defined in Section 402.1.3.5 in 2001 IECC specifications. In the analysis it was observed that during hours when the cooling temperature was set back to 83°F or the when heating set-point temperature was set back at 68°F, the resultant zone temperature in the simulated space is allowed to float in the DOE-2 simulation between the cooling and heating set points. This thermostat setback has a significant impact on the influence of the window on the HVAC heating and cooling loads.

For the week in the summer (i.e., the lower plot in Figure 1–Figure 2), the zone temperature was allowed to float as the cooling thermostat was set up to 83°F. When using pre-calculated custom weighting factors, a steep drop was observed in the floating zone temperatures. This indicates very little sensitivity to thermal mass, which yields an erroneous result. Conversely, an inspection of the analysis using custom weighting factors reveals that the heat that has been retained by materials in the space is released into the zone air after the thermostat is set up to 83°F, thus causing higher floating zone temperatures. Since the system is effectively turned-off during this period, when the thermostat temperature is set back, a small spike in the cooling electric loads is observed when the cooling electric is turned back on, which is more prominent in the options using custom weighting factors. In addition, just before turning off, cooling electric loads for options using custom weighting factors exhibited slightly higher cooling values than results obtained from the options using pre-calculated weighting factors, which reflect an accelerated cooling-off trend, most likely due to reduced retention of heat in the Quick mode. When comparing the options using pre-calculated weighting factors to options using custom weighting factors, the DPC glazing reports percentage differences which are in the range of 17% to 25% for both SC and WINDOW-5 methods, while DPlow-E glazing records slightly lower percentage difference with 12% when using SC method and 8% when using WINDOW-5 method of input to report cooling electric consumption.

A similar pattern of floating zone temperatures was observed during the daytime hours in winter (i.e., the lower plot in Figure 3–Figure 4). In these figures the zone temperatures were allowed to float above the heating set-point temperature; at times approaching the cooling systems set point. This is primarily due to the solar heat gain through windows and can be seen on clear days (i.e., January 15 – 17th). During this time no heating is provided to the space. The use of custom weighting factors yields lower zone temperatures than when using the pre-calculated weighting factors. In addition, the use of WINDOW-5 method to input fenestration yields decreased zone temperatures. As a result the Quick mode option using the SC glazing yields the highest floating zone temperatures followed by the Quick mode option for WINDOW-5 glazing. Next is the Thermal mass option using SC glazing while the Thermal mass option for WINDOW-5 glazing yielded the lowest floating zone temperatures. Although the heating system is switched off during this period, these lower space temperatures imply greater storage of heat in the Thermal mass and therefore less heating to warm up the space when the system is switched back on.

The spikes in heating fuel consumption reflect the amount of energy needed by the system to heat the zone (beginning at 7:00 a.m.). These spikes can be important when DOE-2 is auto-sizing as they can often determine the furnace size. When the furnace is oversized, it leads to greater periods of part-load performance and lower efficiency. In general, a difference in the early morning heat requirements can be seen from different options implemented. The options using custom weighting factors yield results which are approximately 40-50% lower than results which are obtained from the use of pre-calculated weighting factors. Heating fuel consumption, when calculated using pre-calculated weighting factors and WINDOW-5 options, yields highest results, followed by results obtained from using pre-calculated weighting factors and SC options. Results obtained from using custom weighting factors and WINDOW-5 options, as well as results obtained from using custom weighting factors and SC options yield the lowest heating fuel consumption.

During the night-time hours when the zone temperatures drop and need to be maintained at specified levels, another spike is observed in the heating fuel consumption. For a given option, the fall in the floating temperature below the set- point temperature triggers the spike in the corresponding heating fuel consumption. Heating fuel consumption when using the pre-calculated weighting factors and WINDOW-5 method to define glazing yields the highest results followed by the option which uses custom weighting factors and WINDOW-5 method to define glazing and the option which uses pre-calculated weighting factors and SC method to define glazing, while the option which uses custom weighting factors and SC method to define glazing yields the lowest results.

Annual and Peak Load Results Comparing SC And WINDOW-5 Method, Including Pre-Calculated Weighting Factors And Custom Weighting Factors In The DOE-2.1e Program

This section of the analysis considered the percent savings that can be obtained on going from lower performance windows to higher performance windows using the four methods (i.e., SC, WINDOW-5, Quick and Thermal). This is of particular interest to the energy codes which do not make any distinctions of specifying more accurate methods for fenestration specifications when using the performance method path for compliance. The study used this opportunity to demonstrate the advantages of using the more accurate methods for modeling Thermal mass (i.e., the WINDOW-5 and CWF modeling method) over conventionally used methods (i.e., SC and Quick mode of input). Subsequently, results are presented as a difference in percentage savings for SC and WINDOW-5 for both Quick and Thermal mass methods of input. The results for both annual and peak loads are tabulated in Tables 2 and Table 3. An analysis of the percentage savings when going from DPC to DPlowE is presented.

When going from the lower performance glazing to a higher performance glazing, a comparison of SC and WINDOW-5 methods shows that the SC method yields a savings of 8.8 MBtu (13.27%) while the WINDOW-5 yields a savings of 6.8 MBtu (10.43%), which over-predicts the savings by 2.0 MBtu (21.42%). On activating the custom weighting factors, the SC method yields a savings of 5.9 MBtu (9.95%) while the WINDOW-5 yields a savings of 5.0 MBtu (8.53%), which over-predicts the savings by 0.9 MBtu (14.24%).

When considering peak cooling, when going from the lower performance glazing to a higher performance glazing, a comparison of SC and WINDOW-5 methods shows that the SC method yields a savings of 7.53 kBtu/hr (29.39%) while the WINDOW-5 yields a savings of 6.09 kBtu(26.59%), which over predicts the savings by 1.45 kBtu/hr (9.52%). On activating the custom weighting factors, the SC method yields a savings of 5.01kBtu/hr (27.02%) while the WINDOW-5 yields a savings of 4.34 kBtu/hr (25.19%), which over-predicts the savings by 0.67 kBtu/hr (6.76%). When considering peak heating, when going from the lower performance glazing to a higher performance glazing, a comparison of SC and WINDOW-5 methods shows that the SC method yields a savings of -3.36 kBtu/hr

(21.88%) while the WINDOW-5 yields a savings of -2.17 kBtu(14.11%), which over-predicts the savings by -1.19 kBtu/hr (35.51%). On activating the custom weighting factors, the SC method yields a savings of -2.48 kBtu/hr (19.71%) while the WINDOW-5 yields a savings of -2.43 kBtu/hr (16.18%), which over predicts the savings by -0.05 kBtu/hr (17.89%).

CONCLUSIONS AND RECOMMENDATIONS

From the first section of analysis it is concluded that the cooling and heating loads are affected by zone temperatures which are significantly different for each of the four options tested. Activating DOE-2's custom weighting factors reduces the solar conduction loads, cooling electric loads and heating fuel loads by approximately 30 - 50%. However, using the WINDOW-5 method for fenestration specification in the input file has a small annual impact, with reductions in solar conduction loads, cooling electric loads and heating fuel loads of approximately 10 - 20%.

From the second section of analysis it is concluded that using SC method tends to over-predict the energy savings when going from lower performance window to higher performance window for both annual as well as peak heating and cooling loads. Activating the custom weighting factors reduce the percentage savings from both methods by approximately 30 - 50% but do not affect trends.

The percentage reduction in total annual energy consumption due to the use of WINDOW-5 in defining glazing type is not significant for the glazing types considered by this study. However, the potential of this DOE-2 model can only be fully realized by incorporating high-performance glazing (i.e., WINDOW-5), whose properties are vastly different from single pane glazing. The impact of the Thermal mass model is considerable for all options of glazing used. Hence, the use of new, more accurate models for carrying out simulations for code compliance is highly recommended.

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Table 1: Transmittance, absorptance and reflectance properties of the selected glazing (Source: WINDOW-5 output files, Lokmanhekim 1975)

Type of Glazing	**Properties**		
	% Transmittance	**% Absorptance**	**% Reflectance**
Single Pane Clear (Lokmanhekim 1975)	86	8	6
Single Pane Clear (1000)	83.7	8.8	7.5
Double Pane Clear (2000)	70.5	16.8	12.8
Double Pane Low-E (2661)	35.8	28.7	35.5

Table 2: Difference in energy consumption: a) Quick to Thermal mass mode b) SC to WINDOW-5 option

TABLE: DIFFERENCE OBTAINED FROM USING DIFFERENT OPTIONS IN BEPS AND PEAK HEATING & COOLING REPORT

				SC	WINDOW5	DIFFERENCE
		% SAVING FORMULA		SAVING	SAVING	SC-W5
			Annual BEPS (Mbtu/yr)	4.30	5.00	-0.70
			Annual Heating (Mbtu/yr)	2.70	2.80	-0.10
			Annual Cooling (Mbtu/yr)	1.40	1.90	-0.50
			Peak Hourly Heating (Kbtu/hr)	-4.13	-3.23	-0.90
	SP-DP	((SP-DP)/SP)*100	Peak Hourly Cooling (Kbtu/hr)	2.55	3.11	-0.55
			Annual BEPS (Mbtu/yr)	13.10	11.80	1.30
			Annual Heating (Mbtu/yr)	4.00	3.50	0.50
			Annual Cooling (Mbtu/yr)	7.90	7.20	0.70
			Peak Hourly Heating (Kbtu/hr)	-7.49	-5.40	-2.09
	SP-LOWE	((SP-LE)/SP)*100	Peak Hourly Cooling (Kbtu/hr)	10.09	9.19	0.90
			Annual BEPS (Mbtu/yr)	8.80	6.80	2.00
			Annual Heating (Mbtu/yr)	1.30	0.70	0.60
			Annual Cooling (Mbtu/yr)	6.50	5.30	1.20
			Peak Hourly Heating (Kbtu/hr)	-3.36	-2.17	-1.19
QUICK	**DP-LOWE**	((DP-LE)/SP)*100	Peak Hourly Cooling (Kbtu/hr)	7.53	6.09	1.45
			Annual BEPS (Mbtu/yr)	2.40	3.30	-0.90
			Annual Heating (Mbtu/yr)	1.70	1.90	-0.20
			Annual Cooling (Mbtu/yr)	0.70	1.20	-0.50
			Peak Hourly Heating (Kbtu/hr)	-3.23	-3.72	0.49
	SP-DP	((SP-DP)/SP)*100	Peak Hourly Cooling (Kbtu/hr)	1.49	1.80	-0.31
			Annual BEPS (Mbtu/yr)	8.30	8.30	0.00
			Annual Heating (Mbtu/yr)	2.10	1.80	0.30
			Annual Cooling (Mbtu/yr)	5.40	5.70	-0.30
			Peak Hourly Heating (Kbtu/hr)	-5.70	-6.15	0.45
	SP-LOWE	((SP-LE)/SP)*100	Peak Hourly Cooling (Kbtu/hr)	6.50	6.14	0.36
			Annual BEPS (Mbtu/yr)	5.90	5.00	0.90
			Annual Heating (Mbtu/yr)	0.40	-0.10	0.50
			Annual Cooling (Mbtu/yr)	4.70	4.50	0.20
			Peak Hourly Heating (Kbtu/hr)	-2.48	-2.43	-0.05
CWF	**DP-LOWE**	((DP-LE)/SP)*100	Peak Hourly Cooling (Kbtu/hr)	5.01	4.34	0.67

Table 3: Percentage difference in energy consumption: a) Quick to Thermal mass mode b) SC to WINDOW-5 option

TABLE: PERCENTAGE DIFFERENCE OBTAINED FROM USING DIFFERENT OPTIONS IN BEPS AND PEAK HEATING & COOLING REPORT

		% SAVING FORMULA		SC % SAVING	WINDOW5 % SAVING	DIFFERENCE SC-W5	% DIFFERENCE ((SC-W5)/SC)*100
QUICK	SP-DP	((SP-DP)/SP)*100	Annual BEPS (Mbtu/yr)	6.09	7.12	-1.03	-16.94
			Annual Heating (Mbtu/yr)	40.30	30.77	9.53	23.65
			Annual Cooling (Mbtu/yr)	6.25	9.55	-3.30	-52.76
			Peak Hourly Heating (Kbtu/hr)	21.20	17.35	3.85	18.14
			Peak Hourly Cooling (Kbtu/hr)	9.06	11.95	-2.89	-31.88
	SP-LOWE	((SP-LE)/SP)*100	Annual BEPS (Mbtu/yr)	18.56	16.81	1.75	9.41
			Annual Heating (Mbtu/yr)	59.70	38.46	21.24	35.58
			Annual Cooling (Mbtu/yr)	35.27	36.18	-0.91	-2.59
			Peak Hourly Heating (Kbtu/hr)	38.44	29.01	9.43	24.52
			Peak Hourly Cooling (Kbtu/hr)	35.79	35.37	0.42	1.18
	DP-LOWE	((DP-LE)/SP)*100	Annual BEPS (Mbtu/yr)	13.27	10.43	2.84	21.42
			Annual Heating (Mbtu/yr)	32.50	11.11	21.39	65.81
			Annual Cooling (Mbtu/yr)	30.95	29.44	1.51	4.87
			Peak Hourly Heating (Kbtu/hr)	21.88	14.11	7.77	35.51
			Peak Hourly Cooling (Kbtu/hr)	29.39	26.59	2.80	9.52
CWF	SP-DP	((SP-DP)/SP)*100	Annual BEPS (Mbtu/yr)	3.89	5.33	-1.44	-37.06
			Annual Heating (Mbtu/yr)	48.57	35.19	13.39	27.56
			Annual Cooling (Mbtu/yr)	3.98	7.45	-3.48	-87.40
			Peak Hourly Heating (Kbtu/hr)	20.43	19.86	0.57	2.80
			Peak Hourly Cooling (Kbtu/hr)	7.43	9.44	-2.02	-27.15
	SP-LOWE	((SP-LE)/SP)*100	Annual BEPS (Mbtu/yr)	13.45	13.41	0.04	0.32
			Annual Heating (Mbtu/yr)	60.00	33.33	26.67	44.44
			Annual Cooling (Mbtu/yr)	30.68	35.40	-4.72	-15.39
			Peak Hourly Heating (Kbtu/hr)	36.12	32.83	3.28	9.09
			Peak Hourly Cooling (Kbtu/hr)	32.44	32.25	0.18	0.56
	DP-LOWE	((DP-LE)/SP)*100	Annual BEPS (Mbtu/yr)	9.95	8.53	1.42	14.24
			Annual Heating (Mbtu/yr)	22.22	-2.86	25.08	112.86
			Annual Cooling (Mbtu/yr)	27.81	30.20	-2.39	-8.60
			Peak Hourly Heating (Kbtu/hr)	19.71	16.18	3.53	17.89
			Peak Hourly Cooling (Kbtu/hr)	27.02	25.19	1.83	6.76

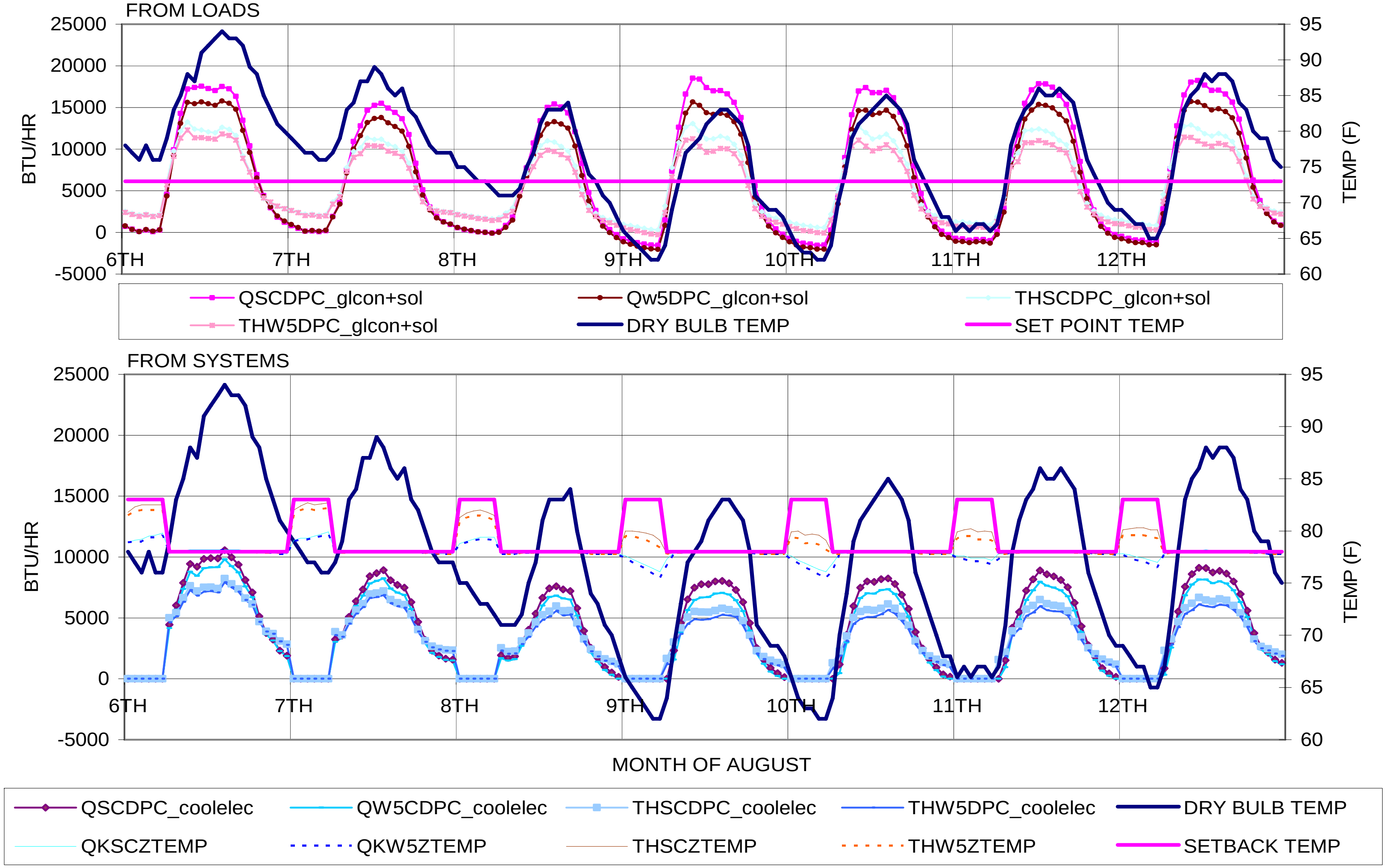

Figure 1: Cooling loads from loads and system data for DPC

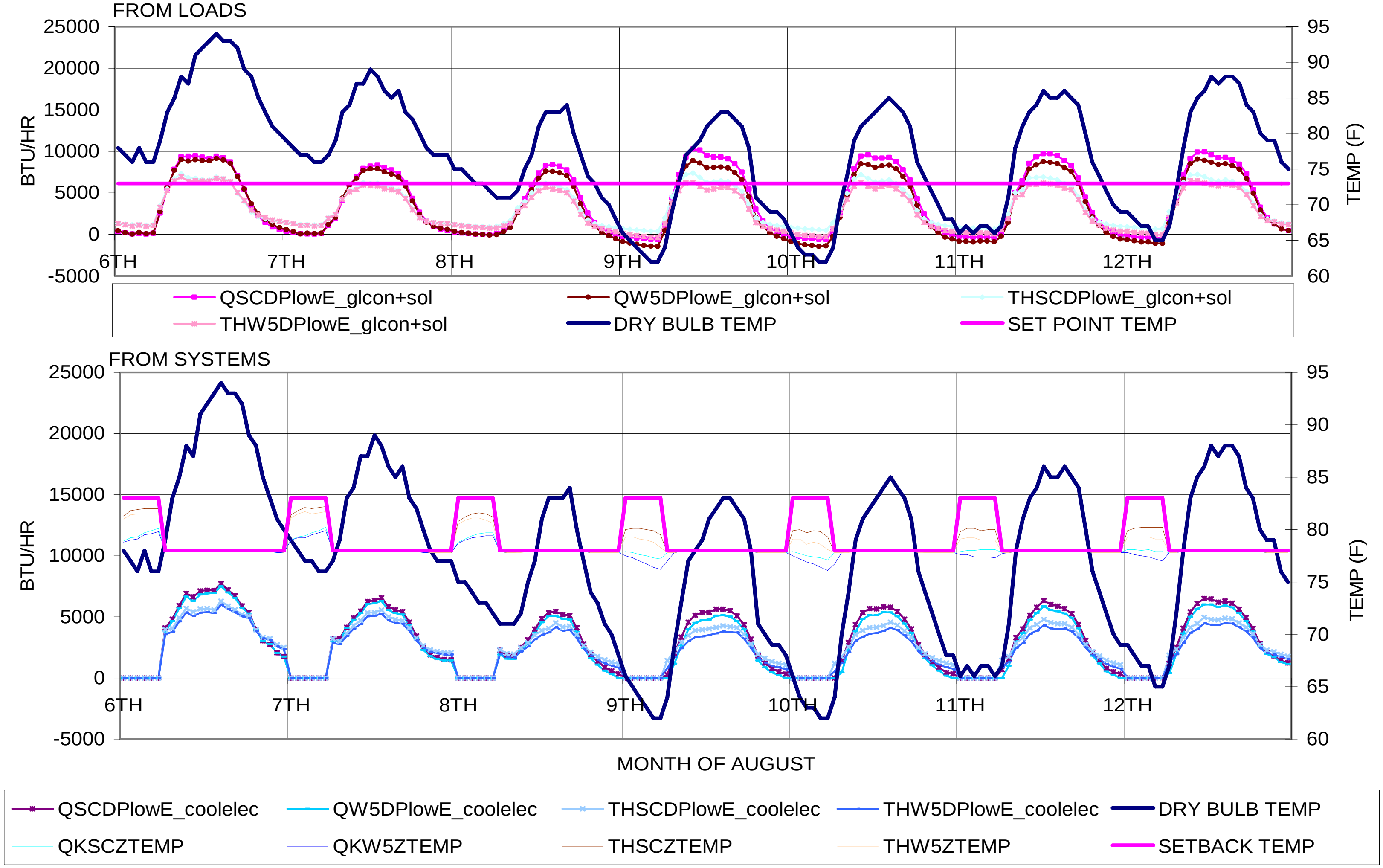

Figure 2: Cooling loads from loads and system data for DPlow-E glazing

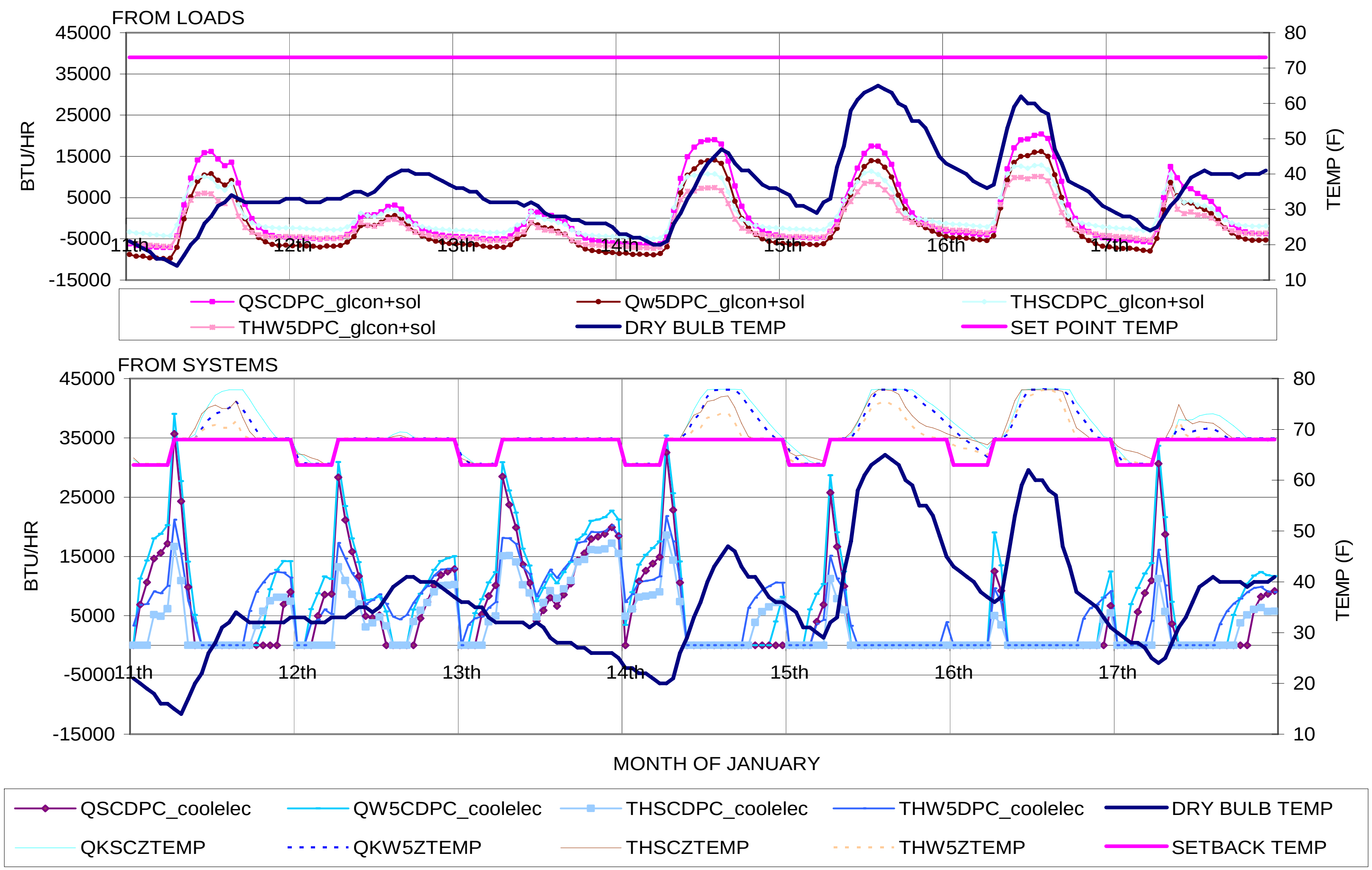

Figure 3: Heating loads from loads and system data for DPC glazing

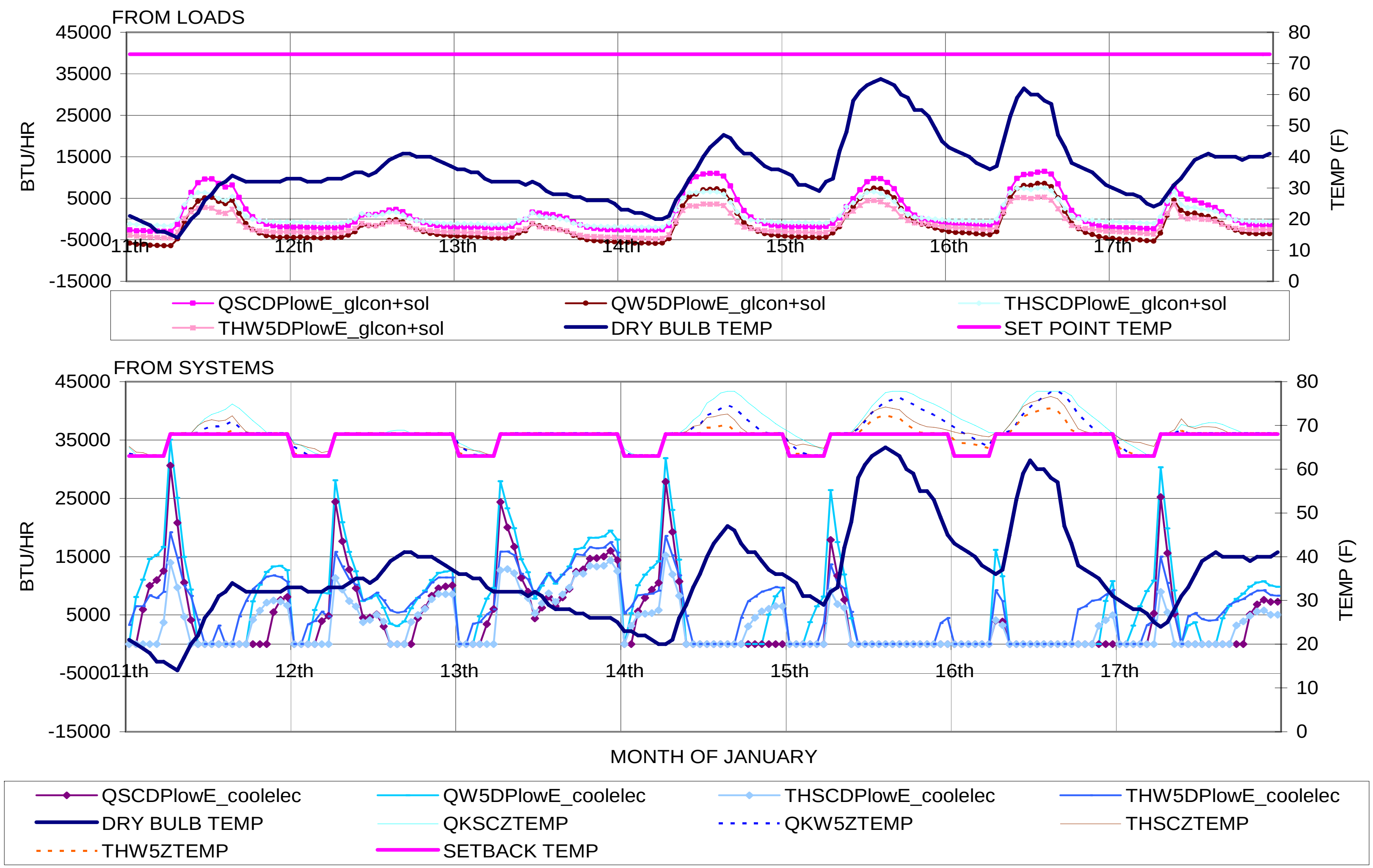

Figure 4: Heating loads from loads and system data for DP low-E glazing