PERFORMANCE OF HIGH-PERFORMANCE GLAZING IN IECC COMPLIANT BUILDING SIMULATION MODEL

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ABSTRACT

Current specifications for glazing in the 2000 IECC code adopted by Texas imply the use of low-E glazing. However, the trends in the development of high-performance glazing technology indicate that windows have the potential to provide net positive energy benefits making it inevitable for future versions of the IECC to incorporate high-performance glazing. This study examines the performance of a number of such glazing options when incorporated in the IECC compliant residential building. The results show that in some cases the resultant energy consumption obtained from installing high-performance windows was lower than the energy consumption of a base-case windowless house (Approximately 6% total energy savings, and 40% heating).

INTRODUCTION

The use of low-E glazing is implied in the current specifications for glazing in the 2000 International Energy Conservation Code (IECC 2000) as modified by the 2001 supplement (2001). However, the trends in the development of high-performance glazing technology indicate that windows could be a potential source of significant energy savings (Apte et al., 2003; Carmody et al. 2004). These high-performance glazing types have higher performance characteristics than that of the currently specified low-E glazing. Hence the incorporation of high-performance glazing in codes becomes inevitable for future versions of the IECC.

Several technologies have been developed to improve heat transfer through windows. These include multi-layered windows with evacuated or low-conductance, gas-filled gaps (Carmody et al. 2004), and aerogel windows to reduce the heat loss (U-factor) of windows (Hartman et al. 1987). Technologies to reduce solar heat gain include improvements to existing low-E coatings, light redirecting layers, and self-shading windows (Apte et al. 2003). More recent developments include investigating advanced façade systems which are designed to manage energy flows, view and comfort (Carmody et al., 2004). These technologies are slowly being incorporated into commercial buildings, but have yet to be implemented on a large scale in the residential building industry. Furthermore, no attempts have been made to incorporate these technologies into residential building code specifications.

A relatively recent concept – Zero Net Energy Homes (ZNEH) – is becoming popular for residential construction. The aim of a ZNEH is to combine solar energy technology with energy-efficient construction techniques to help create a new generation of cost-effective buildings that have zero net annual non-renewable energy use. A study conducted at LBNL by Apte et al. (2003) found that even today's highest performing commercially available window products did not meet the requirements of a ZNEH. The study suggested that one way to improve climate-specific glazing was to develop the concept of dynamic fenestration systems that can alter their solar heat gain properties according to seasonal/temperature variations. Eight U.S cities that represent a range of climates were considered in their study. The study concluded that the products with dynamic heat gain properties were found to offer significant potential in reducing energy use and peak demand technologies in northern climates while windows with low solar gain properties offered the most potential in southern climates.

Their study based its conclusions on a single house size and window area. The levels of insulation were based on the Model Energy Code standards. Dynamic glazing types were simulated using the shading-coefficient and conductance schedules available in the DOE-2.1e simulation program. The results were presented in terms of whole-house cooling and heating energy, primary house HVAC energy consumption, window heating and cooling energy consumptions and peak cooling demand.

This current study takes off from Apte et al.'s work by focusing on the performance of the glazing options under the climatic conditions of Houston, Texas. The simulation model is based on the 2000 IECC code standards (IECC 2000) as modified by the 2001 supplement. Simulations are performed for three houses with the window-to-wall area ratios (WWAR) defined by the IECC code specifications. Results are presented in terms of whole building energy consumption.

METHODOLOGY

Simulation model

The DOE-2.1e Version 119(LBNL, 1993) 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 by this study. The building model used for the DOE-2.1e input file is based on the IECC specifications for a single family building. This model has been developed by the Energy Systems Laboratory, Texas A&M University to calculate energy savings from code-compliant construction (Haberl et al., 2003). The model is a single storied light weight structure (13lb/sqft) with a garage attached on the west side of the building. This study used electricity for space cooling while heating energy and heating for domestic hot water is provided by natural gas. Houston (TX) was considered to represent the hot and humid climatic conditions. The TMY2 weather file (NREL, 1995) for Houston is used to carry out simulations.

Selection of high-performance glazing

Six glazing options were selected for this set of simulations to represent a range of current and potential window types. An attempt was made to simulate window options which could be practically assembled. The first option is a base-case model, which is currently implemented by the IECC (CODE). The next three options; i.e. low-E low-solar (LELS), super low-E low-solar (SULS) and ultra low-E low-solar (ULLS) represent a range of currently available high-performance windows used in residential construction. The last two options (dynamic options) represent a range of the next generation products. These windows were assumed to have the heating season performance of a high gain super window and the cooling season performance of the low gain super window. The WINDOW-5 program was used to model these windows (Finlayson et al., 1995). The option of modeling switchable windows provided by DOE-2.1e (LBNL, 1993b) was used to model dynamic glazing. However, in some cases the schedules were modified to obtain the ideal glazing properties that were being examined. A detailed description of the properties of the glazing selected is given in Table 1.

Test matrix

The study was carried out in two sections. Hourly reports from both the LOADS and SYSTEMS sub-programs of the DOE-2.1e program were examined in the first section. A house with an area of 2500 ft^2 and 25% WWAR was used as a simulation model. From the LOADS sub-program, the dry-bulb temperature from the TMY2 file for Houston was plotted alongside the hourly solar conduction + radiation loads. From the SYSTEMS sub-program, the dry-bulb temperature and the zone-temperature were considered in addition to the heat extraction, cooling electric and heating fuel consumption rates extracted from the DOE-2 hourly reports. Hourly reports for the static option SULLS and the dynamic option DySULLS are also considered for this study. In the second section, overall energy consumption of the simulated building model as a result of implementing each glazing type is compared for three house sizes and WWARs as specified in the IECC. The analysis is divided into two sections. In the first section, the performance of high-performance glazing options are compared against the code specified low-E glazing (CODE). In the second section the performance of high-performance glazing options are compared against a windowless base-case.

RESULTS

- **Hourly performance of selected high-performance fenestration**

The performance in terms of cooling was nearly identical for both the static and dynamic glazing options. For the dynamic option there is a considerable reduction in heating. A drop in the ambient temperature below the switch point temperature deactivates the switch set in the simulation program resorting back to the high solar properties of glazing. During the transition seasons of the year where the outside temperature is only marginally lower than the switch point temperature, the un-switched state of the window allows more than necessary solar heat gain. Hence several surges are seen in the hourly solar load results given in the LOADS section (Figure 2, heat extraction plot for the months of April and November). The excessive solar heat gain causes the internal temperatures to rise above the thermostat set point which produced several surges. These spikes get reflected in the results from SYSTEMS in the observed extraction rates and cooling electric trends. However, compared to the significant difference seen in results from solar loads in the LOADS sub-program (first graph in Figure 1 & 2) the difference in results obtained from the SYSTEMS sub-program is virtually insignificant.

Table 1: Description of glazing alternates used in the simulation

Glazing type	**Code name**	**Description**	**Specifications**	**Product / input code description**	**W-5 code**	**U-factor multiplier**
BASE-CASE Low-E glazing	CODE	Double glazing with low-E coating on clear glass	U = 0.35 SHGC = 0.4 SC = VT =	Exterior lite: Comfort TiAC on clear / AGF industries Gap 1 : Air (1/2 “) Interior lite: Clear glass (1/4 “)	2661	
Low-E Low Solar	LELS	Double glazing with low-solar gain low-E coating on spectrally selective tinted glass	U = 0.35 SHGC = 0.4 SC = VT =	Exterior lite: Silver Hi%T low-E on green Gap 1 : Air (1/2 “) Interior lite: Clear glass (1/4 “)	8004	
Super Low-E Low Solar	SULS	Triple glazing with low-E coating on exterior glazing and low-E coating on plastic film between the two panes of glass	U = 0.35 SHGC = 0.4 SC = 0.32 VT = 0.521	Exterior lite: Comfort TiAC on clear / AGF industries Gap 1 : Krypton (1/4 “) Film 1: Heat mirror, single coat suspended film / Southwall technologies Gap 2 : Krypton (1/4 “) Interior lite: Clear glass (1/4 “)	8002	
Dynamic Super Low-E Low Solar	DySULS	Triple glazing with low-E coating on the inner lite of the exterior glazing and low-E coating on plastic film Minimum set temperature used to regulate switching temperature. Defined in the input file as P-SWITCHTEMP[] Conductance property of high solar option of glazing adjusted to yield lower results	U = 0.191 SHGC = 0.615 SC = 0.709 VT = 0.718	Exterior lite: Starphir / PPG Industries Gap 1 : Krypton (1/4 “) Film 1:Heat mirror, twin coat 88 suspended film / Southwall Technologies Gap 2 : Krypton (1/4 “) Interior lite: Clear glass (1/4 “)	8002-8003	0.64
Ultra Low Solar	ULLS	Quadruple glazing with exterior low-E glazing and low-E coating applied to 2 suspended plastic films	U = 0.085 SHGC = 0.230 SC = 0.265 VT = 0.407	Exterior lite: Silver Hi%T low-E on green Gap 1 : Krypton (1/4 “) Film 1: Heat mirror, single coat suspended film / Southwall technologies Gap 2 : Krypton (1/4 “) Film 2: Heat mirror, single coat suspended film / Southwall technologies Gap 3 : Krypton (1/4 “) Interior lite: Clear glass (1/4 “)	8001	
Dynamic Ultra Low Solar	DyULLS	Quadruple glazing with exterior low-E glazing and low-E coating applied to 2 suspended plastic films Minimum set temperature used to regulate switching temperature. Defined in the input file as P-SWITCHTEMP[] Conductance property of high-solar option of glazing adjusted to yield lower results	U = 0.122 SHGC = 0.531 SC = 0.612 VT = 0.661	Exterior lite: Starphir / PPG Industries Gap 1 : Krypton (1/4 “) Film 1:Heat mirror, twin coat 88 suspended film / Southwall Technologies Gap 2 : Krypton (1/4 “) Film 2:Heat mirror, twin coat 88 suspended film / Southwall Technologies Gap 3 : Krypton (1/4 “) Interior lite: Clear glass (1/4 “)	8000-8001	0.69

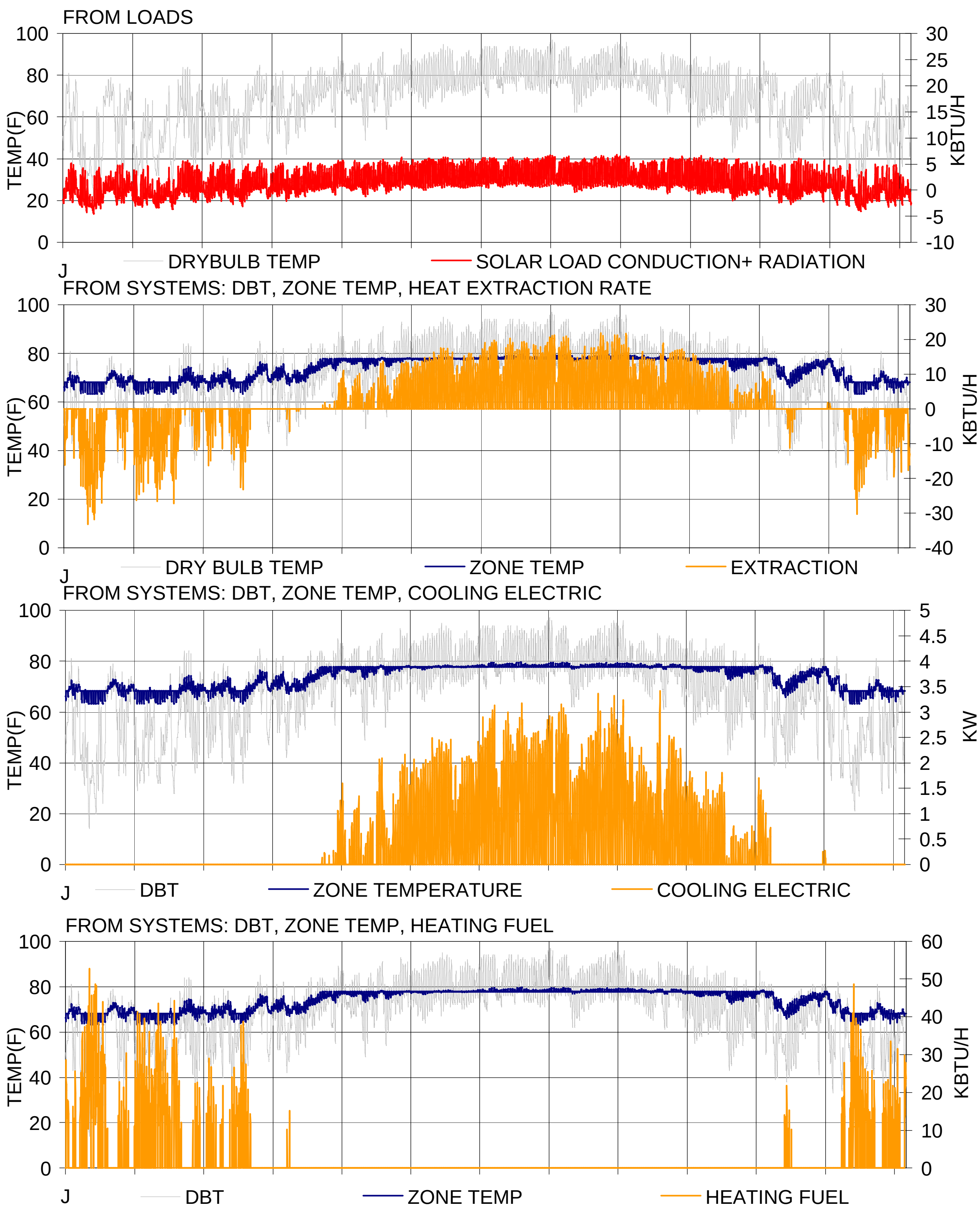


Figure 1: Annual performance for static option of super low-E low-solar (SULS) window

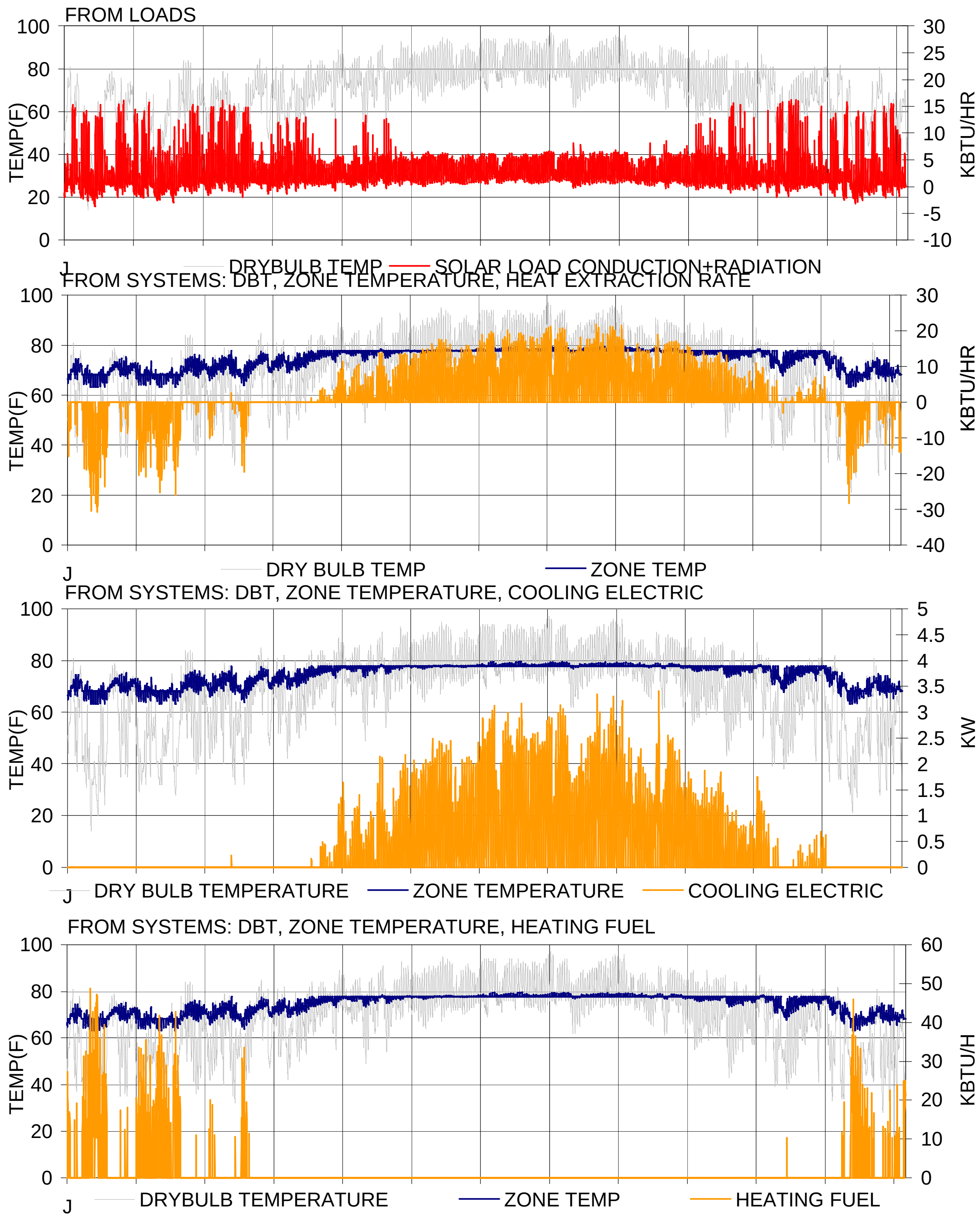
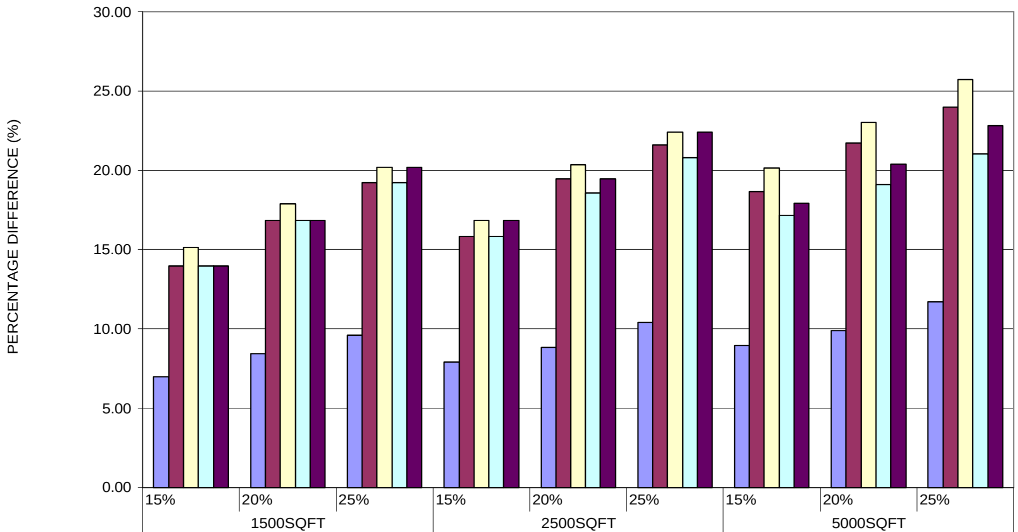
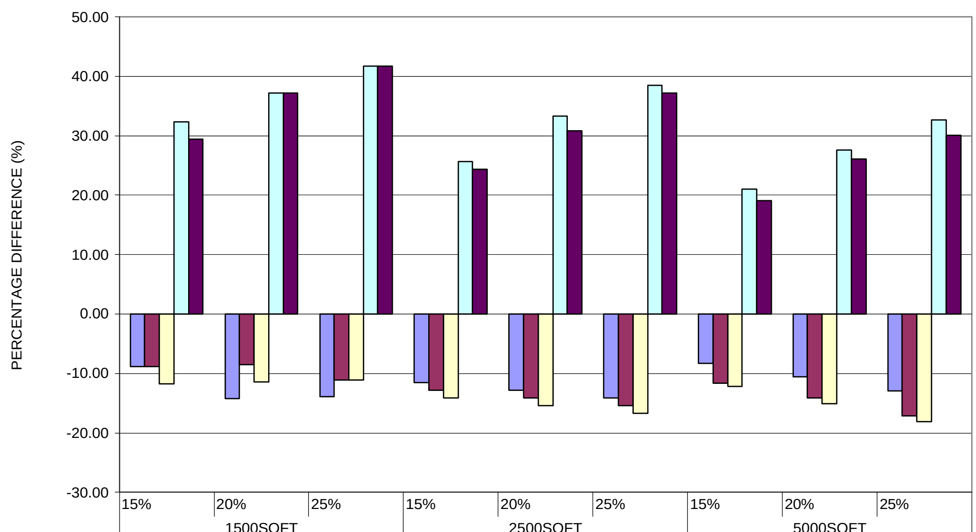


Figure 2: Annual performance for dynamic option of super low-E low-solar (DySULS) window



	1500SQFT 15%	1500SQFT 20%	1500SQFT 25%	2500SQFT 15%	2500SQFT 20%	2500SQFT 25%	5000SQFT 15%	5000SQFT 20%	5000SQFT 25%
LOW-E - LELS	6.98	8.42	9.62	7.92	8.85	10.40	8.96	9.87	11.70
LOW-E - SULS	13.95	16.84	19.23	15.84	19.47	21.60	18.66	21.71	23.98
LOW-E - ULLS	15.12	17.89	20.19	16.83	20.35	22.40	20.15	23.03	25.73
LOW-E - DYSULS	13.95	16.84	19.23	15.84	18.58	20.80	17.16	19.08	21.05
LOW-E - DYULLS	13.95	16.84	20.19	16.83	19.47	22.40	17.91	20.39	22.81

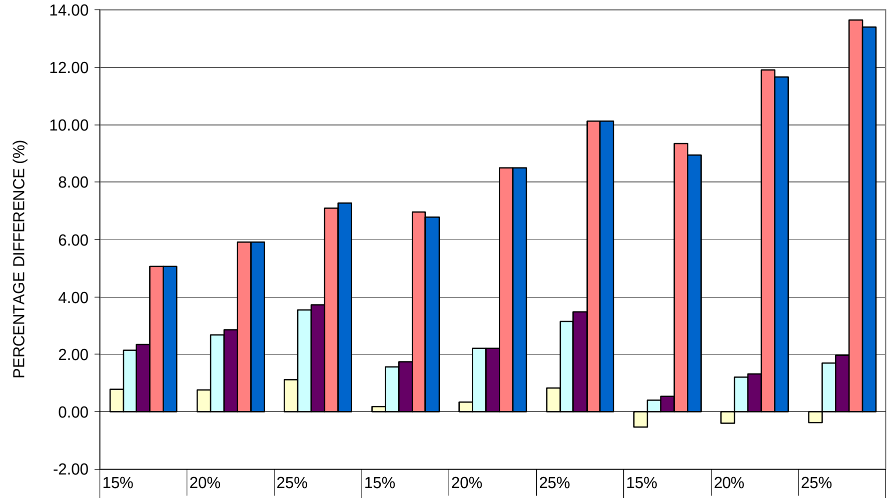
Heating energy consumption



	1500SQFT 15%	1500SQFT 20%	1500SQFT 25%	2500SQFT 15%	2500SQFT 20%	2500SQFT 25%	5000SQFT 15%	5000SQFT 20%	5000SQFT 25%
LOW-E - LELS	-8.82	-14.29	-13.89	-11.54	-12.82	-14.10	-8.29	-10.55	-12.95
LOW-E - SULS	-8.82	-8.57	-11.11	-12.82	-14.10	-15.38	-11.71	-14.07	-17.10
LOW-E - ULLS	-11.76	-11.43	-11.11	-14.10	-15.38	-16.67	-12.20	-15.08	-18.13
LOW-E - DYSULS	32.35	37.14	41.67	25.64	33.33	38.46	20.98	27.64	32.64
LOW-E - DYULLS	29.41	37.14	41.67	24.36	30.77	37.18	19.02	26.13	30.05

Cooling energy consumption

Figure 3: Percentage difference between low-E glazing base-case and high-performance options for heating and cooling energy consumption



	1500SQFT			2500SQFT			5000SQFT		
	15%	20%	25%	15%	20%	25%	15%	20%	25%
LOW-E - LELS	0.78	0.76	1.12	0.17	0.34	0.83	-0.54	-0.40	-0.39
LOW-E - SULS	2.14	2.67	3.54	1.57	2.21	3.15	0.41	1.21	1.69
LOW-E - ULLS	2.33	2.86	3.73	1.74	2.21	3.48	0.54	1.32	1.95
LOW-E - DYSULS	5.06	5.92	7.09	6.96	8.50	10.12	9.34	11.92	13.65
LOW-E - DYULLS	5.06	5.92	7.28	6.78	8.50	10.12	8.93	11.66	13.39

Figure 4: Percentage difference between low-E glazing base-case and high-performance options for overall energy consumption

These surges can be optimized by selecting a cut-off temperature for cooling, below which the cooling equipment will be turned off. The heat gain absorbed by the envelope components can be later released to fulfill the heating requirements, harnessing the passive solar heating potential of the window. However, analyzing such passive solar and temperature control strategies is outside the scope of this paper.

Overall heating, cooling and annual energy comparisons from BEPS report

BEPS report comparison using low-E as base-case

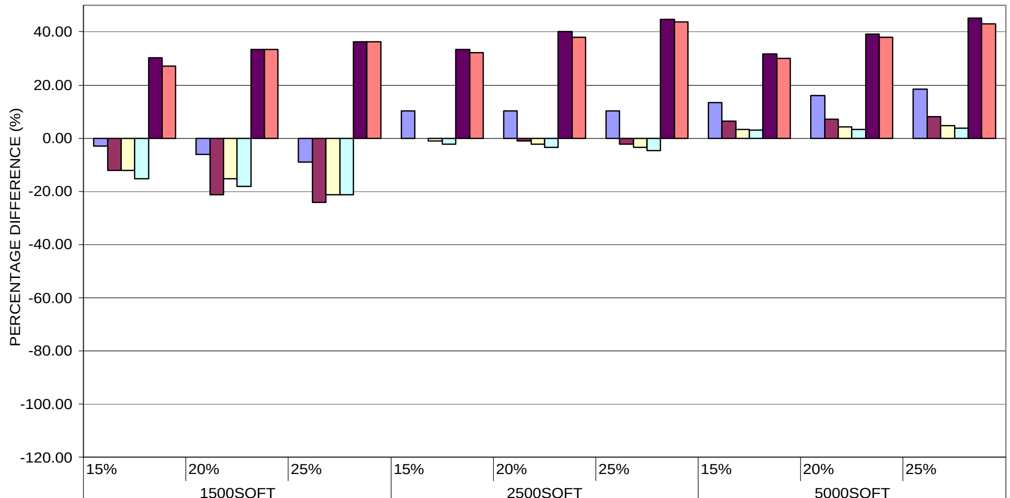
Figures 3 and 4 present the percentage difference in energy consumption on comparing the performance of code compliant glazing (low-E) with high-performance glazing. The percentage difference is calculated using the formula:

$$\text{\% difference in heating, cooling and overall energy consumption} = \frac{\left(\text{Energy consumption using Low-E glazing} - \text{Energy consumption using High performance glazing}\right) \times 100}{\text{Energy consumption using Low-E glazing}}$$

Actual results of cooling, heating and overall energy consumption can be found in the thesis on analysis of improved fenestration for code-compliant residential buildings in hot and humid climates by Mukhopadhyay (2005).

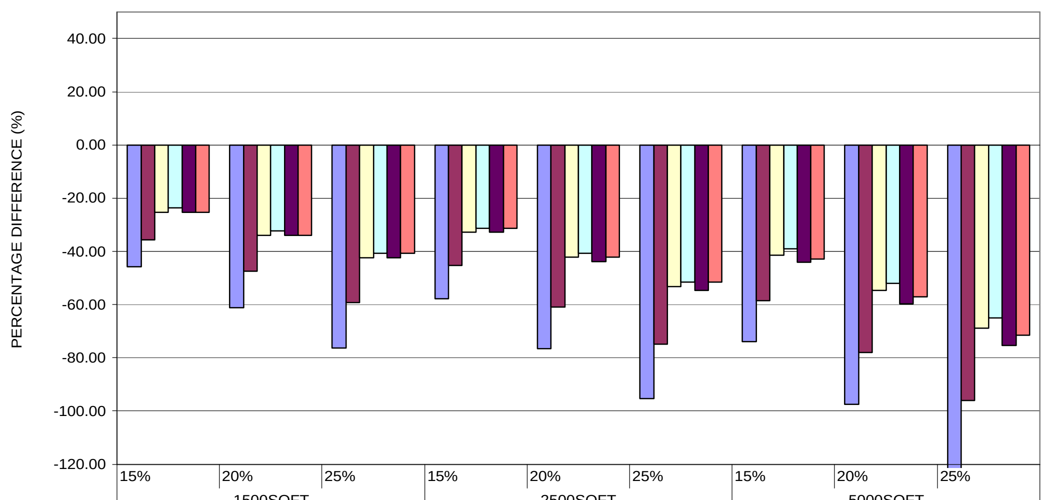
For the case of heating energy consumption, it was observed that static options yielded net heating energy losses while dynamic options yielded net heating energy gains. The static glazing option of ULLS yielded energy consumptions that were higher than the base-case by 11 to 18%. Its dynamic counter part glazing option DyULLS performed considerably better yielding heating energy consumptions that were lower than the code compliant base case by 20-40%. It is also noted that the percentage savings from smaller house sizes (30 – 40%) are greater than the percentage savings obtained from larger house sizes (20 – 30%).

For cooling energy consumption, trends are predictable in almost all the cases with percentage difference in cooling loads increasing when going from smaller to larger house size and smaller to larger WWARs. The ULLS glazing option yields the highest savings with a range of 15-25% savings in cooling energy consumption. Dynamic options do not perform as well as their static counter parts for cooling energy consumption option due to the switch temperature settings in the DOE-2.1e input code for the building model.



	1500SQFT 15%	1500SQFT 20%	1500SQFT 25%	2500SQFT 15%	2500SQFT 20%	2500SQFT 25%	5000SQFT 15%	5000SQFT 20%	5000SQFT 25%
BC - LOWE	-3.03	-6.06	-9.09	10.34	10.34	10.34	13.50	16.03	18.57
BC - LELS	-12.12	-21.21	-24.24	0.00	-1.15	-2.30	6.33	7.17	8.02
BC - SULS	-12.12	-15.15	-21.21	-1.15	-2.30	-3.45	3.38	4.22	4.64
BC-ULLS	-15.15	-18.18	-21.21	-2.30	-3.45	-4.60	2.95	3.38	3.80
BC-DYSULS	30.30	33.33	36.36	33.33	40.23	44.83	31.65	39.24	45.15
BC-DYULLS	27.27	33.33	36.36	32.18	37.93	43.68	29.96	37.97	43.04

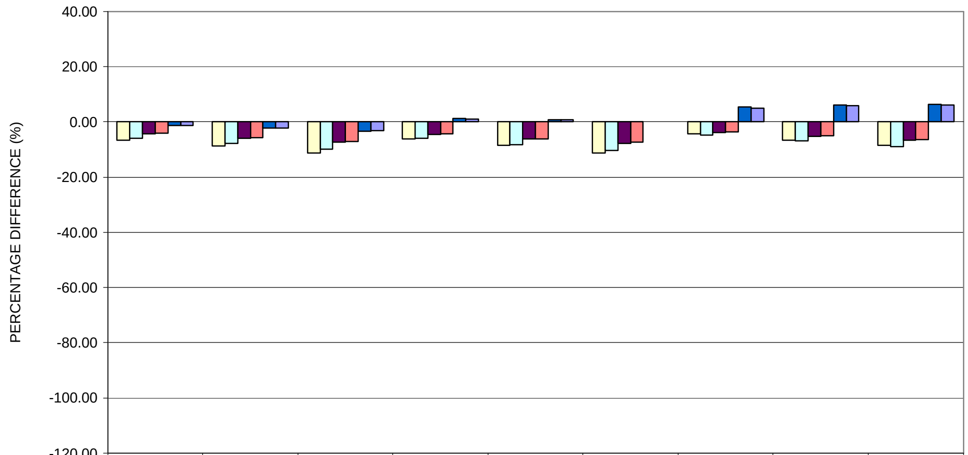
Heating energy consumption



	1500SQFT 15%	1500SQFT 20%	1500SQFT 25%	2500SQFT 15%	2500SQFT 20%	2500SQFT 25%	5000SQFT 15%	5000SQFT 20%	5000SQFT 25%
BC - LOWE	-45.76	-61.02	-76.27	-57.81	-76.56	-95.31	-74.03	-97.40	-122.08
BC - LELS	-35.59	-47.46	-59.32	-45.31	-60.94	-75.00	-58.44	-77.92	-96.10
BC - SULS	-25.42	-33.90	-42.37	-32.81	-42.19	-53.13	-41.56	-54.55	-68.83
BC-ULLS	-23.73	-32.20	-40.68	-31.25	-40.63	-51.56	-38.96	-51.95	-64.94
BC-DYSULS	-25.42	-33.90	-42.37	-32.81	-43.75	-54.69	-44.16	-59.74	-75.32
BC-DYULLS	-25.42	-33.90	-40.68	-31.25	-42.19	-51.56	-42.86	-57.14	-71.43

Cooling energy consumption

Figure 5: Percentage difference between windowless base-case and high-performance options for heating and cooling energy consumption



	1500SQFT			2500SQFT			5000SQFT		
	15%	20%	25%	15%	20%	25%	15%	20%	25%
BC - LOWE	-6.64	-8.71	-11.20	-6.09	-8.49	-11.25	-4.23	-6.49	-8.46
BC - LELS	-5.81	-7.88	-9.96	-5.90	-8.12	-10.33	-4.80	-6.91	-8.89
BC - SULS	-4.36	-5.81	-7.26	-4.43	-6.09	-7.75	-3.81	-5.22	-6.63
BC-ULLS	-4.15	-5.60	-7.05	-4.24	-6.09	-7.38	-3.67	-5.08	-6.35
BC-DYSULS	-1.24	-2.28	-3.32	1.29	0.74	0.00	5.50	6.21	6.35
BC-DYULLS	-1.24	-2.28	-3.11	1.11	0.74	0.00	5.08	5.92	6.06

Figure 6: Percentage difference between windowless base-case and high-performance options for overall energy consumption

When considering the annual energy consumption of the glazing options considered, the difference of going from the CODE glazing option to a high-performance glazing option is within 14% of the reported annual energy consumption for all the WWARs and glazing options. It is seen that for smaller house size of 1500 ft^2, the dynamic options yielded a greater percentage savings with percentage savings between 5 to 7% versus results obtained from other high-performance options which yielded percentage savings between 2 to 4%. In the case of 5000 ft^2 house size switching to dynamic glazing yielded a percentage saving between 9 to 13% which was considerably greater than switching to high-performance windows, which yielded a percentage savings up to 3.5%.

BEPS report comparison using windowless model as base-case

For the case of space heating, the window-less base case outperforms the static glazing options for the case of 1500 ft^2 house while the trends are reversed for larger house sizes. Looking at the performance of the SULS version, for the 1500 ft^2 house the heating energy consumption is greater than the window-less base-case by 12 to 21%. However, for the 5000 ft^2 house the trends are reversed with the SULS version performing better than the window-less base-case by 3 to 4% approximately. Dynamic options of the glazing types selected on the other hand always yield heating energy consumption results which are lower than the results obtained from the window-less base-case. Considering the performance of DySULS, it is seen that for all the house sizes this glazing option performs better than the window-less base case by 30-43%.

For the case of space cooling performance, a predictable percentage increase in cooling energy consumption was observed for all the house sizes and WWAR. High-performance static glazing options perform consistently better than the dynamic glazing options. Dynamic options yield slightly higher cooling energy consumption results when compared to their static counter parts. The answer to this observation is found in the previous section of this study wherein surges in cooling loads are observed during intermediate seasons in the performance of dynamic options.

Figures 5 and 6 present the percentage savings for overall energy consumption on going from the windowless base-case high-performance glazing to high-performance options. When compared to the windowless base case, the percentage difference for the annual energy consumption is marginally greater in smaller houses than in larger house sizes (windows prove to be more beneficial in larger houses). On looking at the performance of ULLS glazing type it was seen that for the 1500 ft^2 house, energy consumption was higher by 4.15 to 7%, while for the 5000 ft^2 house the energy consumption was greater by 3 – 6%. Simulation models incorporating dynamic windows used as little or at times less energy than the windowless base case. Looking at the performance of DYSULS, the percentage increase in energy consumption for the 1500 ft^2 house was negligible within the range of -1.24 and 3.32%, while for 5000 ft^2 house the glazing option performed better than the base-case with a percentage difference in total energy consumption within the range of 5 to 6%.

The trends indicate that optimally regulated SHGC (as in the case of dynamic options) plays a larger role in regulating heat gain through windows than the U-value specifications for climatic conditions specific to Houston. It is also observed that in larger house sizes, static high-performance glazing options make less of an impact, while the dynamic options had a greater impact. Moreover, dynamic options always outperform their static counter parts. This is because beneficial cuts in cooling energy consumption get evened out by increased heating energy losses for static glazing options in the case of larger house sizes which are dominated by envelope loads (See description of the 2000 IECC house for details).

CONCLUSIONS AND RECOMMENDATIONS

In comparing the high-performance glazing options to the code compliant base-case, dynamic glazing options yield higher energy savings than the static high-performance glazing options. The percentage saving for annual energy consumption is in the range of 5 to 13%. In comparing the high-performance glazing options to the windowless base-case, the dynamic glazing options yielded the lowest energy consumption results which were in some cases lower than the energy consumption results obtained from the windowless base-case; i.e. up to 6.35% overall energy consumption savings were obtained for the case of DySULS option. The findings confirm the conclusions from Apte et al., (2003).

For the cooling climate of Houston, which also has a substantial number of Heating Degree Days, the primary conclusion was that DYSULS and DYULLS offered a greater potential to significantly increase energy consumption savings that cannot be achieved with the current code specified glazing or even available high-performance glazing LELS. Dynamic options yield lower heating energy costs than static options with the same U-factors, with very slight changes in space cooling loads. This decrease is because there is a significant difference in the summer and winter SHGC's and U-values, which are regulated by an optimum schedule.

Dynamic options do not yield any major peak reductions when compared to their Static counter parts. This is because in the summer, both Static and Dynamic options have the same SHGC, while in the winter the peak loads are U-value dependent. House size and WWAR impacts the performance of glazing options to a certain degree. In the case of smaller house sizes U-value properties gain precedence in controlling heat loss, while the SHGC properties gain precedence in larger house sizes. This trend is seen when comparing the performance of DYSULS and DYULLS for space heating loads. While both the glazing options perform similarly for smaller house size, DYSULLS which has a higher SHGC value performs better in the case of larger house sizes. From the results it is seen that incorporating switchable options in the energy code proves to be highly beneficial in reducing total energy use and can contribute towards the goal of a ZNEH house.

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