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ENERGY STAR WINDOWS' PERFORMANCE AND ORIENTATION

Maral Jalili[1], Caroline M. Clevenger[2,3], Mehmet E. Ozbek[1] and Moatassem A. Abdallah[2]
[1] Colorado State University, USA
[2] University of Colorado Denver, USA
[3] caroline.clevengerl@ucdenver.edu

Abstract: In 2012 and 2013, ten building product categories were eligible for United States ENERGY STAR Federal Tax Credits. High performance windows that meet certain energy efficiency criteria are one of the qualifying products. The ENERGY STAR Tax Credit program sets U-factor and Solar Heat Gain Coefficient (SHGC) standards for these windows according to four climate zones. Research demonstrates that buildings with well-designed and constructed fenestration systems can lower requirements for heating, cooling and lighting during operation. However, previous research and energy modeling also demonstrates that, in addition to energy efficiency characteristics, orientation impacts the energy performance of windows. The ENERGY STAR tax program makes no distinction regarding window orientation or placement when evaluating tax credit eligibility. This research studies the potential impact of orientation on performance for qualifying ENERGY STAR window products. Using TRNSYS energy modeling comparisons, findings suggest that the performance of qualifying windows may vary up to 14 percent for different orientations depending on climate zone.

1 INTRODUCTION

In the United States in 2010, residential and commercial building sectors accounted for approximately 41 percent of nation's primary energy consumption. In residential buildings, space conditioning (heating and cooling) accounted for 43 percent of energy consumption, followed by water heating and lighting (EERE, 2014a). Building Technologies Office (BTO) is a part of the US Department of Energy (DOE), with the mission "to improve the efficiency of existing and new building in both the residential and commercial sector through the development of high-impact energy efficiency technologies and practices" (EERE, 2014a, p. vii). A 2014 BTO report prepared by Energetics Incorporated identified windows and building envelope technologies as two areas with significant potential to reduce energy consumption in buildings (EERE, 2014a). The 2011 Building Energy Data Book states that 25 to 35 percent of the energy used for the heating, cooling and lighting of buildings is wasted through inefficient windows (BEDB, 2012). The BTO report on Window and Building Envelope Research and Development projects that the use of cost-effective and energy-efficient technologies could result in savings of 23.4 quads in the United States in 2030, 23 percent of which would be the result of improvements in windows and building envelope technologies.

Several tax incentive programs by the United States Federal government currently exist for energy efficient building features (DOE, 2014b). Specifically, 179D Federal tax deduction refers to Section 179D of the Federal Tax Code, which provides tax deductions for energy efficiency improvements (e.g., Building envelope, HVAC and lighting) to qualifying commercial buildings (EERE, 2014b). In 2012 and 2013, United States ENERGY STAR Federal Tax Credits were available for residential buildings for ten product categories including: Biomass Stoves; Heating, Ventilation, Air Conditioning (HVAC); Insulation; Roofs; Water Heaters; Windows and Doors; Geothermal Heat Pumps; Small Wind Turbines; Solar Energy Systems; and Fuel Cells (EnergyStar, 2014a). A major difference between many of these eligible products and high performance windows, is the potential for orientation of installation to impact performance. Whereas many products, themselves, (e.g., biomass stoves, insulation, roofing, etc.) provide relatively consistent performance irrespective of the building orientation, research has shown that windows' impact on building performance can vary significantly depending on the orientation (self-shading) of the building, as well as the façade on which they are placed. Specifically, a window's performance is directly related to solar angles striking its surface and solar angles differ significantly relative to orientation. The goal of this research is to use energy modeling to begin to assess the performance range of ENERGY STAR windows based on orientation across climate zones.

1.1 ENERGY STAR Tax Credit Program

ENERGY STAR products can cost more than traditional alternatives. The goal of the ENERGY STAR program is to provide financial incentives to support technologies that pay back through lower energy bills within a reasonable amount of time. In order for windows to qualify as ENERGY STAR certified, they must meet three main criteria: (1) The product is manufactured by an Energy Star partner, (2) The products are tested and certified independently by National Fenestration Rating Council (NFRC), and (3) The products' NFRC ratings meet the guidelines set by US DOE (EnergyStar, 2014c). In addition, ENERGY STAR sets minimum qualification requirements for the windows' performance characteristics according to climate zone (see Table 1). ENERGY STAR defines U-factor as the heat transfer per time per area and per degree of temperature difference, and Solar Heat Gain Coefficient (SHGC) as the fraction of incident solar radiation entering the space through the window. The windows must also be installed on your "principal residence" to be eligible for the Tax Credit. ENERGY STAR defines four climate zones (i.e., Northern, North-Central, South-Central and Southern) as relevant to these performance criteria (see Figure 1).

Table 1: ENERGY STAR qualification criteria for residential windows (EnergyStar, 2014c)

Climate Zone	U-value ($\frac{Btu}{hr.ft^2.F}$)	SHGC
	≤ 0.30	Any
Northern	$= 0.31$	≥ 0.35
	$= 0.32$	≥ 0.40
North-Central	≤ 0.32	≤ 0.40
South-Central	≤ 0.35	≤ 0.30
Southern	≤ 0.60	≤ 0.27

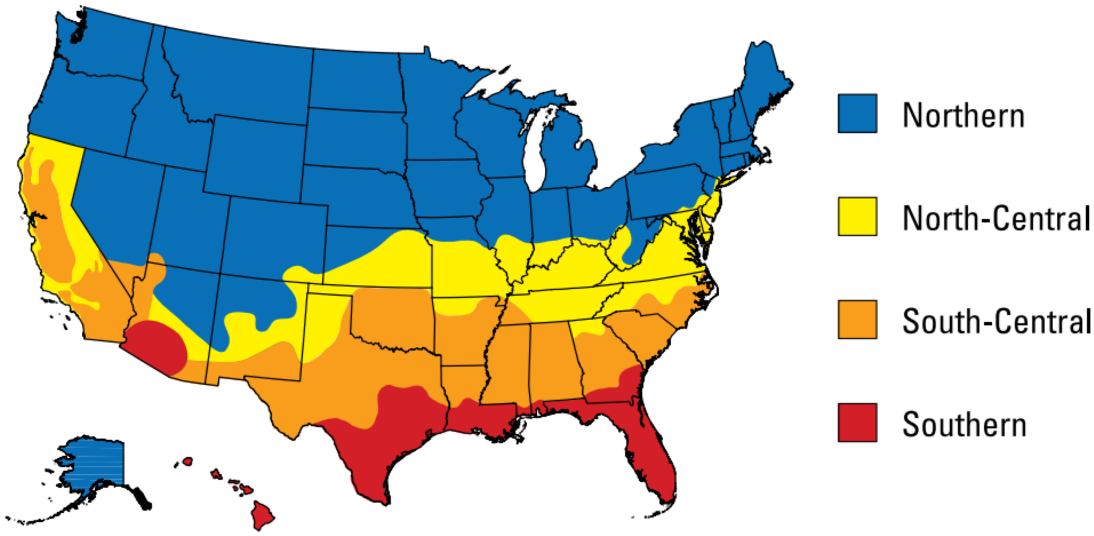

Figure 1: ENERGY STAR climate zones (EnergyStar, 2014d)

In 2012 and 2013, homeowners could receive a Federal tax credit equal to 10 percent of the product cost up to $200, with a $500 maximum per homeowner for all energy efficiency tax credits (EnergyStar, 2013). The following sections present a simple study to assess the impact of orientation on minimally compliant Energy Star windows in all of the four specified climate zones.

1.2 Background

Research demonstrates that buildings with well-designed glazing and efficient fenestration systems can lower the requirements for heating, cooling and lighting. Several studies suggest that energy usage and total peak demand of buildings can be reduced by up to 15 percent through effective design of fenestration and daylighting systems (Johnson et al., 1984; Tahmasebi at al., 2011). Windows also provide many known psychological benefits resulting from access to daylight and views of the outside (Tahmasebi et al., 2011).

Several studies have used a variety of energy modeling or building performance simulation programs to investigate the influence of glazing characteristics in combination with various parameters such as window size, orientation, frame type, insulation, ventilation, internal loads, external shading devices and climate. Eskin and Türkmen (2008) used EnergyPlus to simulate the interactions between different building conditions and control strategies in office buildings across climate types in Turkey. The findings of the study suggest that low emissivity, double glazed windows can decrease the maximum energy requirement of the building as much as 15.9 percent (Eskin & Türkmen, 2008). Poirazis et al. (2008) used IDA ICE 3.0 to study the impacts of glazing type, window size, building orientation, shading devices and control set points on highly glazed office buildings in Sweden. The findings suggest that low SHGC values for windows greatly influence the cooling demand, however, increased window to wall ratio and window orientation appeared less impactful (Poirazis et al., 2008). Gasparella et al. (2011) utilized TRNSYS to investigate the impacts of double and triple glazed systems, window sizes, and orientation of the main windowed façade on energy usage and peak demand for well-insulated residential building across four climate types in south and central Europe in both winter and summer. The study suggests that placing the windows on south orientation improves the energy performance of the building, especially during winter, and recommended the use of shading systems to improve the summer performance without sacrificing winter performance (Gasparella et al., 2011).

Morrissey et al. (2011) investigate the implications of building orientation on residential houses in Australia in an attempt to maximize passive solar benefits (Morrissey et al., 2011). Another study by Persson et al. (2006) used DEROB-LTH to examine the performance of windows for low energy houses in Gothenburg, Sweden. Results suggested the size of the glazed surface does not have significant impacts on the winter heating demand, but can contribute to reducing the summer cooling demands (Persson et al., 2006). Similarly, Wall (2006) used the same dynamic simulation tool to study the impacts of several building variables on passive houses in Sweden. Results suggest that energy efficient windows are essential in reducing thermal losses in buildings while providing thermal comfort for the occupants (Wall, 2006). Hassouneh et al. (2010) investigated the effects of different glazing types, window orientation and windows size using self-developed simulation software on residential buildings for the climate of Amman City. Results suggest that certain glazing types are more efficient in certain orientations. For example, clear glass is effective for south, west and east orientations, but increases energy losses when installed on the north facade (Hassouneh et al., 2010).

Although considerable research exists that suggests a range of factors can influence overall window performance, few, if any studies exist which assess the impact of orientation on ENERGY STAR qualified windows for the four ENERGY STAR climate zones specified by the program.

2 METHOD

For this research, the authors created a simple, square, one story 25 m2 (269 SF) building model with facades oriented North, South, East and West. In all cases, a total of 15 m2 (161 SF) of glazing was placed on the model façade(s). For the baseline model, the glazing was equally distributed on all facades. Four alternative models were also developed with all glazing placed exclusively on North, South, East or West facades respectively. Each of these five models was simulated using weather files from four cities, representative of the four ENERGY STAR climate zones: Denver, CO (Northern Zone); Albuquerque, NM (North-Central Zone); Atlanta, GA (South-Central Zone) and Miami, FL (Southern Zone) resulting a total of twenty simulations. Window specifications (U-factor and Solar Heat Gain Coefficient (SHGC) standards) were set to meet ENERGY STAR criteria in each climate (see Table 1).

2.1 Energy Model

The authors developed a simple energy model of a small, square building using TRNSYS software (TRNSYS, 2013). Modeling assumptions were based on similar, existing energy modeling research including (Clevenger et al., 2014; Saeli et al., 2010) as well as building codes and standards (ASHRAE, 2010). Simulation set time was one year, with data simulated every hour. Simulations were performed using climate data from four representative cities. In each of these climate zones, a market-available window which met the program's criteria was selected and assigned a window type: A, B, C, D. The performance criteria of these products are shown in Table 2.

Table 2: Selected (ENERGY STAR eligible) window performance criteria per climate zone

Climate Zone	Representative City	Window Type	U-value	SHGC
Northern	Denver, CO	A	0.32	0.614
North-Central	Albuquerque, NM	B	0.28	0.392
South-Central	Atlanta, GA	C	0.17	0.230
Southern	Miami, FL	D	0.44	0.196

To model these windows, the authors used TRNSYS Type 56 window library. The window library is created using software developed by Lawrence Berkeley National Labs and references ASHRAE 90.1.99 Table A17, ASHRAE Standard 140 and the Building Energy Simulation TEST (BESTEST) Standard. These windows were placed in a baseline model with glazing equally distributed on all facades, plus four alternative models with glazing placed exclusively on North, South, East or West facades respectively. Subsequently, each of these five models was simulated using weather files from the four representative cities for a total of 20 simulations.

3 RESULTS

Table 3 shows the total estimated energy usage and the percentage difference between the baseline and each alternative by climate zone. A positive number indicates that the performance of the alternative has improved (uses less energy) compared to the baseline. A negative number indicates that the performance of the alternative has declined (uses more energy) compared to the baseline.

Table 3: Estimated energy consumption ($\frac{kWh}{m^2}$) and percentage differences by orientations

		Baseline		South		West		North		East		
Climate	City	Energy	% Diff	Energy	% Diff	Energy	% Diff	Energy	% Diff	Energy	% Diff	Delta
Northern	Denver, CO	479	0	468	2%	510	-7%	505	-5%	498	-4%	9%
North-Central	Abq, NM	388	0	362	7%	413	-7%	406	-5%	413	-7%	14%
South-Central	Atlanta, GA	304	0	289	5%	316	-4%	305	0%	306	-1%	9%
Southern	Miami, FL	198	0	197	1%	198	0%	173	13%	197	1%	1%

The far right (Delta) column of Table 3 shows the energy modeling results that assess the potential range of impact that orientation can have on energy consumption for the tested ENERGY STAR qualified windows. This number represents the greatest difference in potential building performance. Table 4 provides estimates of the potential average cost impacts (electricity only) of these differences in performance.

Table 4: Potential cost Impacts of energy performance differences by climate zone

Climate Zone	City, State	Average Annual Electricity Bill by State*	Potential Cost Impact per year (Electricity only)
Northern	Denver, CO	$971	$87 (9%)
North-Central	Albuquerque, NM	$895	$125 (14%)
South-Central	Atlanta, GA	$1473	$132 (9%)
Southern	Miami, FL	$1481	$15 (1%)

*2012 Average Annual Residential Electricity Bill by State (Data from forms EIA-861- schedules 4A-D, EIA-861S and EIA-861U). Costs account for electricity average price differences per State. However, no other fuel type (i.e.; natural gas or propane) is included.

4 DISCUSSION

This study presents preliminary energy modeling results to estimate the potential range of energy performance (use and cost) impacts of installing ENERGY STAR windows on various orientations. While the examples (all glazing on one orientation) are extreme, they, nevertheless, provide valuable insight about how design decisions on window product installation can have significant impact on energy and cost savings. Currently, the ENERGY STAR program for windows, doors and skylights does not include any provision for orientation.

One of the reasons that the ENERGY STAR tax credit program may not consider window orientation is that building science principles are complex and interactive. For example, a window's impact on buildings' energy performance is not a direct function of available solar resource. Table 5 demonstrates the average annual incident solar irradiance on a vertical surface in all four orientations by representative city (Greenstream, 2014; NREL, 2014). Solar irradiance is the amount of solar energy that arrives at a specific area at a specific time, which varies throughout the year. However, the benefits of available solar resource is greatly influenced by other climate factors (i.e.; temperature) and building characteristics (i.e.; thermal mass, insulation etc.).

Table 5: Average annual solar irradiance ($\frac{kWh}{m^2}$) on vertical surfaces

Location	Average Vertical Surface Irradiance	South	% Diff	West	% Diff	North	% Diff	East	% Diff
Denver, CO	971.35	1331	37%	1064	10%	426	56%	1064	10%
Abq, NM	994.93	1354	36%	1083	9%	460	54%	1083	9%
Atlanta, GA	805.34	1062	32%	850	6%	459	43%	850	6%
Miami, FL	813.64	1061	30%	849	4%	495	39%	849	4%

Comparing results from Tables 4 and Tables 5, it is clear that calculating performance using available solar resource alone, could over-estimates the impact of window orientation on energy performance. Therefore, more detailed and custom energy modeling is necessary for accurate assessment. Such modeling can quickly prove cost and time prohibitive and is likely a main deterrent to the ENERGY STAR program considering window orientation in the tax credit calculation. Nevertheless, results suggest (Table 4) that design decision related to the orientation of the installed window can have significant impact on pay back periods and the value of the tax credit investment.

The following additional observations and recommendations are based on the study's findings:

- Results suggest that placing the entire glazed surface on the south façade tends to improve building energy performance relative to baseline (evenly distributed glazing) in all climate zones. Improved performance over baseline ranges from approximately one percent in the Southern climate zone to seven percent in the North-Central climate zone.

- Results suggest that placing the entire glazed surface on any one façade on any orientation other than the south, tends to worsen building energy performance relative to baseline in the majority of climate zones, except in the Southern climate (i.e., Miami, FL). The magnitude of the negative impact ranges from one to seven percent. Interestingly, in Miami, FL concentrating windows on any one façade appears beneficial presumably because it limits the number of hours of solar exposure.

- Cumulatively, the annual energy consumption of the buildings could vary up to 14 percent between different climate zones based on the orientation of the glazed façade. This large variance could be seen in the North-Central area, where placing the window on the south façade improves the energy performance by 7 percent, while having the windows on the west side, reduces the building performance by 7 percent.

- Cumulatively, the annual cost impact for an individual residence of ENERGY STAR windows may vary on the order of magnitude of $15 (Southern) to $132 (South-Central) annually. Such a range can significantly change the economics and, specifically the payback of such an energy efficiency feature.

- In general, whether a climate is heating or cooling load dominated significantly impacts the role of ENERGY STAR windows (and their orientation) on overall building performance.

- Available solar resource (i.e.; average annual solar irradiance on vertical surfaces, Table 5) is not an accurate basis for estimating the impact of ENERGY STAR windows (and their orientation) on building energy performance. Therefore, more detailed and complex energy modeling is recommended.

5 CONCLUSION AND POLICY IMPLICATIONS

This study provides preliminary results based on twenty energy simulations for a simple, representative building model used to illustrate the range of the potential impact of ENERGY STAR qualified windows by orientation across climate types. Results suggest that the cost effectiveness of the incentive programs such as the ENERGY STAR Tax Credit program will vary not only based on the performance characteristics of products, but also based on design decisions related to orientation of installation. Currently, the ENERGY STAR Tax Credit Program only specifies U-values and SHGC minimums according to climate zone. As a result, findings suggest that the Tax Credit's effectiveness could vary by as much as 14 percent depending on installation.

Buildings are complicated systems, and multiple internal and external factors influence performance. For example, heating, cooling and lighting requirements in a building are affected by space conditioning requirements as well as external factors like ambient temperature, solar gain and shading devices. Airtightness and the level of insulation used in buildings in addition to occupants' preferences and behaviors could also have impacts on building energy performance. Such complexities present challenges for energy efficiency incentive programs. This research highlights the potential impact of orientation on qualifying ENERGY STAR window product performance and concludes that while performance can vary as much as 14 percent, accurate assessment is challenging since it requires detailed, custom energy modeling to account for such variation. Potential policy implications may be to tie incentives to installed performance. Additional energy modeling and economic studies related to the ENERGY STAR Tax Credit or other energy efficiency incentive programs are recommended to further analyze and illuminate the impact and effectiveness of such programs.

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