Looking Through Superwindows to a New Market Transformation Field

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The Bonneville Power Administration sponsored a demonstration project called Superwindows. The goal of this fenestration replacement project was to demonstrate the technical and economic feasibility of superinsulating windows as a market transformation technology. Custom made, vinyl framed, triple pane, low-e, krypton-filled windows ($u = 0.21$ Btu/hr/ft^{2}F) were installed in 98 homes located in two Pacific Northwest climate zones (4600 to 5900 HDD, 270 to 450 CDD base 65F). Building characteristics data and utility billing records were collected for each site. In addition, Short Term Energy Monitoring (STEM) tests were completed at 20 of the homes before and after the installation of the windows.

This paper describes the methodology and findings of an impact evaluation of savings achieved by the test homes. The evaluation included the estimation of gross and net savings for each home using two approaches: (1) single node simulations using SUNDAY and (2) billing history analysis using PRISM. The PRISM analysis was also performed on a control group of non-participants as the basis for a calculation of net energy savings. An economic analysis examined actual installed costs and program cost-effectiveness.

The paper also discusses average installed costs and the best estimate of savings by weather zone and baseline window type. It includes a discussion of the likelihood of this technology being a successful market transformation effort in the Pacific Northwest and concludes with a discussion of customer satisfaction with the windows.

INTRODUCTION

The Bonneville Power Administration (Bonneville), in cooperation with four Pacific Northwest utilities, sponsored the Superwindows Demonstration Project. The primary purpose of the project was to demonstrate the technical and economic feasibility of superinsulating windows by installing them in a sample of homes throughout the Bonneville service area and evaluating their in-situ performance. If successful, this demonstration would become the pilot phase of a major market transformation effort by Bonneville throughout the Pacific Northwest.

A major part of the overall demonstration project was the Superwindows Thermal Performance Study (STPS), which is the subject of this paper. The study quantified the energy savings from custom made, vinyl framed, triple pane, low-e, krypton-filled windows (referred to as Superwindows) that were retrofitted in 98 existing single family homes located in two Pacific Northwest climate zones. The test homes had single or double pane windows prior to the retrofit. The colder (5900 HDD, 450 CDD base 65F) climate zone East of the Cascades included homes from the service territories of three Eastern Washington utilities. The milder (4600 HDD,270 CDD base 65F) climate zone West of the Cascades included homes from one Western Washington utility.

Gross and net energy savings from Superwindows were evaluated using two separate approaches. These approaches included single node simulations of all homes using the SUNDAY model and billing history analysis of all homes using the Princeton Scorekeeping Method (PRISM). The PRISM analysis used a control group of qualified non-participants in addition to the test homes as the basis for the calculation of net energy savings. In addition to energy savings, the evaluation of the windows included an economic analysis of installed window costs and program administrative costs. Both the energy savings and costs were input to an assessment of program cost-effectiveness.

Six specific objectives were established as the basis for the Superwindows evaluation. They included: (1). Estimation of the electric energy savings achieved by the Superwindows installed in a sample of single family residences located throughout the Bonneville service area. (2). Evaluation of the implementation costs incurred by the demonstration project, including the installed window costs (material and labor) and the project administrative costs. (3). Estimation of mature market costs for the windows under large scale production. (4). Assessment of Superwindows cost-effectiveness under both demonstration project and mature market conditions. (5). Determination of customer satisfaction with the windows installed in the participant sample. (6). Comparison of alternative analysis techniques for estimating gross and net energy savings.

Background

The Superwindows were installed in the participant homes by qualified window contractors between August 1993 and January 1994. While at the site, each contractor in Eastern Washington also collected important building characteristics data that would be of use to future analyses. In Western Washington, characteristics data were collected by utility staff.

In addition, a series of detailed Short Term Energy Monitoring tests were performed by Macrodyne Energy International, Inc. (MEI) at 20 participant homes prior to and after the installation of the Superwindows. The STEM test results, along with other building characteristics and weather data, were used by MEI to estimate Superwindows annual energy savings with the PSTAR model for each tested site (Subbarao 1994). The STEM test results and the estimated savings for these 20 homes were used as a reference in the Superwindows Thermal Performance Study.

METHODOLOGY

The Superwindows evaluation was completed as a series of eight tasks that are summarized below.

(1) Selection of Sample Buildings—Initially, 100 single family homes that met certain selection criteria, were selected as pilot program participants. The homes were distributed between three Eastern Washington and one Western Washington utilities. Five of these homes were excluded from the sample early on in the evaluation because the windows were never installed or the installation was delayed to the point that insufficient billing data were available to this study.

A target sample size of 190 was established for the non-participant or reference group. Two non-participants were selected for each participant. The comparison group was recruited from the weatherization backlog list (including contact information) supplied by three of the four participating utilities. The 2 to 1 ratio was maintained across the East and West regions, to the extent that it could be supported by the candidate list. Recruitment of the full 190 non-participants was also limited by the availability of qualified candidates that would participate in the study. A total of 177 qualified non-participants were recruited.

(2) Data Collection—To support the calculation of gross and net energy savings, a variety of building characteristics and window performance data were compiled at each site to characterize the energy consumption characteristics of both the pre-retrofit and post-retrofit periods and to satisfy the input requirements of the SUNDAY and PRISM models. Data were also collected to support the economic analysis and the evaluation of customer satisfaction.

Weather data were also compiled for the two climate zones. Weather data for Portland, Oregon (4600 HDD,270 CDD base 65F) were selected to be most representative of the Western Washington utility. Weather data from Handford, Washington (5900 HDD,450 CDD base 65F) were selected to be most representative of the Eastern Washington utilities.

(3) SUNDAY Analysis—An analysis of gross and net energy savings for each participant home was performed using the SUNDAY simulation. SUNDAY was selected by Bonneville as the best available simplified simulation for this application. Separate simulations were performed at each site for the pre-retrofit and post-retrofit periods. Each model was run under actual weather conditions and calibrated to utility billing records for both the pre-and post periods. In all cases the model was calibrated when predicted annual consumption was within 2 percent of actual annual consumption. Thermostat setpoint, setpoint schedule and internal gains were the parameters most frequently modified in the model tuning process.

Each calibrated model was rerun under long term weather conditions and gross savings were computed. Net savings were computed in two ways with the SUNDAY simulation. Additional runs were made for each home to remove the Superwindows from the post-retrofit model (creating a new pre-retrofit model) and to add the measure to the pre-retrofit model (creating a new post-retrofit model). Two net savings values were computed for each home by subtracting energy consumption predicted by the respective pre-retrofit and post-retrofit models. This net analysis removed the effects of changes in occupancy characteristics between the pre- and post-periods (e.g., occupant turnover or changes in occupancy patterns) that were unrelated to the Superwindows.

Gross and net savings estimates were aggregated into four groups of homes that were categorized by their baseline conditions as follows: (a) Eastern Washington—single glass baseline with air-conditioning. (b) Eastern Washington—double glass baseline with air-conditioning. (c) Western Washington—single glass baseline with air-conditioning. (d) Western Washington—single glass baseline without air-conditioning.

(4) PRISM Analysis—An analysis of gross and net energy savings for each participant home was performed using the PRISM model. Separate analyses were performed for the pre- and post-periods at each site. The PRISM heating-only model was run on homes without air-conditioning. The heating-and-cooling (HC) model was used for those with air-conditioning. Gross savings were estimated for each participant using the pre- and post-period normalized annual consumption estimates produced by PRISM.

Net savings were computed by adjusting the gross savings with the results of the comparison group PRISM analysis. The model was run in a similar fashion on a sample of non-participants. Net savings were computed as the difference between the participant and non-participant estimates of savings. Both gross and net savings were aggregated into the four baseline groups discussed above.

(5) Comparison of Alternative Analysis Techniques—The savings estimates produced by the PRISM and SUNDAY models were compared. Reasons for discrepancies between the estimates were determined. Based on this comparison, best estimates of energy savings from Superwindows were prepared for the four baseline groups.

(6) Economic Analysis—The best estimates of savings were combined with invoiced window costs and other economic assumptions to compute the levelized cost of Superwindows for the four groups of sites. A BPA system cost adjustment was included in the levelized cost calculation. To be cost-effective, the levelized cost for Superwindows had to be less than 25 mills/kWh saved. If the windows were not cost-effective, the analysis determined the future cost reduction that must be achieved for Superwindows to be cost-effective. An incremental cost analysis was also performed to determine if cost-effectiveness could be improved. The incremental analysis assumed that Superwindows customers intended to upgrade to double glazing outside of a utility program. The cost-effectiveness calculation considered only the incremental cost and energy savings between standard double glazing and Superwindows.

(7) Market Transformation Assessment—A survey of ten triple glass manufacturers and two glass manufacturer trade organizations that serve the Pacific Northwest was performed to help determine the feasibility of Superwindows as a market transformation technology. The primary issue addressed by the survey was the decrease (if any) in retail window costs that could be achieved with an increase in sales volume. The survey also addressed the pricing structure of the triple glass market and solicited the opinion of industry on how utilities can assist in the future reduction of glass costs and marketing of efficient windows.

(8) Customer Satisfaction Survey—A survey of 87 participants was performed to determine customer satisfaction with the Superwindows. The questions addressed the following four aspects of customer satisfaction: (a) satisfaction with various attributes of the windows; (b) satisfaction with the Superwindows program (including installation contractors); (c) reasons for participation; and (d) recommendations for improvements to the windows or to the program.

RESULTS

The methodology described above was successfully applied to the participant and non-participant building samples. Major findings from the research are summarized below.

Summary of Building Characteristics

Salient physical characteristics of the participant sample are summarized in Table 1. This table shows that an average participant home had 1421 square feet of conditioned floor area and contained three occupants. The average floor area of the East of the Cascades homes was observed to be 27 percent greater than the West of the Cascades and 9 percent greater than the sample mean. The number of occupants was quite consistent across the East and West of the Cascades regions. The most popular heating system in the East of the Cascades region was the central forced air furnace, accounting for 82 percent of the total observations in that region. The most popular heating system in the West of the Cascades region was radiant panels, accounting for two-thirds of the total observations in the West region. Baseboard heating also accounted for a significant portion (25 percent) of the total in the West region. All of the participants in the East region had air conditioning, with central electric being the most popular system configuration. By contrast, only 22 percent of the homes in the West region had air conditioning. These observed trends in the presence of air conditioning are consistent with the summer weather conditions experienced in these regions.

The baseline (i.e., prior to Superwindows) window type was consistent within each region; however, the window type

Table 1. Summary of Building Characteristics Participant Homes

Characteristic	East of Cascades N	East of Cascades Mean Value	West of Cascades N	West of Cascades Mean Value	Total Sample N	Total Sample Mean Value
Conditioned Floor Area (sq. ft.)	55	1553	36	1220	91	1421
Number of Occupants	53	2.9	30	3.2	83	3.0
Heating System Type						
Baseboard / Wall Units	1		9		10	
Radiant Panels	2		24		26	
Heat Pump	7		2		9	
Central Forced Air Furnace	45		1		46	
Installed Air Conditioning						
None	0		28		28	
Window / Wall Unit	3		6		9	
Heat Pump	7		2		9	
Central Electric	45		0		45	
Baseline Window Type						
Single	5		32		37	
Double	46		0		46	
Combined	4		4		8	
Pred. Baseline Window Frame Type		metal		metal		metal
Window Percent of Floor Area (%)	55	12.3	36	13.8	91	12.9

varied significantly between the East and West regions. Double glass was the predominant window type in the East region. By contrast, single glass was the predominant window type in the West region. These observed trends are consistent with the winter weather conditions experienced in these regions. In some cases the table shows that the homes had a combination of single and double glass before Superwindows were installed. In each of these cases the analysis of energy savings considered the site specific combination of baseline window types. The final entry in the table shows the window area, expressed as a percent of conditioned floor area, to be about 13 percent across the participant sample. A slight variation is noted across the two regions.

Superwindows Specification

The Superwindows installed in each home were custom manufactured by Viking Industries of Portland, Oregon, under contract to Bonneville. The windows consisted of three panes of glass in a vinyl frame. The windows had a low-emissivity coating on the inner surfaces of the two outer layers. The space between the glazing was also filled with krypton gas. The u-factor of Superwindows was computed to be 0.23 Btu/hr ft^{2}F (or R-value of 4.35 hr ft^{2}F/Btu) using the 1993 ASHRAE Handbook of Fundamentals at a 15 mph wind speed. The u-factor was also computed using the MoWitt Model (Klems & Yazarian 1994) to be 0.21 Btu/hr ft^{2}F (or R-value of 4.76 hr ft^{2}F/btu) at wind and temperature conditions experienced during STEM testing.

Of particular interest to the energy savings analysis was the change in u-factor between the baseline condition (single or double glass) and the Superwindows. The change in u-factor was estimated in three ways for aluminum framed baseline windows. The results are shown in Table 2. First, the standard ASHRAE method was used under an assumed 15 mph wind speed. The change in u-factor was 0.88 Btu/hr ft^{2}F for single glass baseline windows and 0.48 Btu/hr ft^{2}F for double glass baseline windows. The second method was based upon the STEM test results. For this method the change in u-factor was computed in two ways; from the actual STEM test results and by applying the MoWitt model to typically sized windows under the weather (wind speed and tempera-

***Table 2.** Change in Glass Conductance Due to Superwindows*

	Δ Glass U-value (Btu/hr ft F°)				
		STEM Sample		MoWitt Model	
Case	1993 ASPRAE Handbook	Actual Test	MoWitt Model	Typical Portland	Typical Hanford
Single glass to Superwindows	0.88	0.50	0.53	0.69	0.66
Double glass to Superwindows	0.48	0.29	0.30	0.40	0.38

ture) conditions experienced during the STEM tests. The MoWitt model is widely recognized as the most accurate method for estimating the heat loss coefficient in this application. It is the model used in the Windows program. The MoWitt model estimate and STEM test results were found to be in close agreement. The third method involved the application of the MoWitt model to typically sized windows under long-term Portland and Hanford weather conditions. Portland and Hanford weather conditions were used to represent the Western and Eastern Washington climate zones, respectively. The MoWitt model, under these long term weather conditions, estimated a significantly greater change in u-factor than under STEM test conditions. The MoWitt model estimated a significantly lower change in u-factor than the Standard ASHRAE method, due primarily to the impact of the MoWitt model on the u-factor of single glass. These latter MoWitt model estimates, under typical weather, were carried forward into the SUNDAY analysis.

Best Estimate of Net Energy Savings

An independent assessment of net energy savings was performed with the PRISM and SUNDAY models. The alternative estimates of savings produced by these methods were compared and a recommended best estimate of savings was selected for each of the four baseline groups. The recommended best estimates of savings are summarized, by end use, in Table 3. These estimates were based on a sample of 77 participant homes, which accounted for sample attrition due to frequent use of wood for space heating, poor billing data and the removal of outliers. Results from both the PRISM and SUNDAY analyses influenced the recommended savings values. However, in general, the SUNDAY net savings estimates were favored in developing the best estimates because of its superior ability to allocate savings by end use and the much lower variability of the SUNDAY estimates; particularly in the West of the Cascades region.

For both baseline groups in the Western region, the best estimate of space heat savings was selected to be 1.9 kWh/yr/sqft. This value was based upon the SUNDAY estimate for the entire Western region. The SUNDAY estimate of 0.7 kWh/yr/sqft was also selected for the space cooling end use in the Western baseline group with air-conditioning. This cooling value was similar to the 0.5 kWh/yr/sqft value estimated by PRISM.

For the Eastern of the Cascades double glass baseline, the best estimate of savings was taken from the SUNDAY analysis at 1.0 and 0.4 kWh/yr/sqft for the space heating and space cooling end uses, respectively. These values are noted to be very similar to the final PRISM values for these end uses. The PRISM values are 1.10 and 0.46 kWh/yr/sqft for space heating and cooling, respectively. Similar reasoning was applied to the single glass baseline in the Eastern region. The recommended savings estimates of 1.8 and 0.8 kWh/yr/sqft for the space heating and cooling end uses were taken from the SUNDAY analysis. However, these results compared quite favorably to the final PRISM results. The final PRISM values for this final baseline group are 2.1 and 0.8 kWh/yr/sqft for space heating and cooling, respectively.

A comparison of the best estimates of savings across the four baseline groups reveals some expected and unexpected trends. The magnitude of the total building savings varied significantly from 2064 to 3768 kWh/yr across the four baseline groups. The lowest estimate of savings, for both heating and cooling, was found in the Eastern double glass baseline group. This result was expected because this baseline group had the most efficient baseline glazing conditions. The greatest estimate of total building savings (2.6 kWh/yr/sqft) was found in both single glass baseline groups with air-conditioning. No difference in total savings and very small differences in the end use distribution of savings were found between the Eastern and Western regions. This result was unexpected because the Eastern region experiences more severe winter and summer weather conditions. A more detailed analysis of this result was not possible because of the very small samples (3 and 6 cases) in both of these baseline groups. With only three cases in the Eastern sample

Table 3. Best Estimate of Net Savings

	East of Cascades						West of Cascades					
	Single Glass Baseline with A/C (Avg. Area: 1455 ft^2)			Double Glass Baseline with A/C (Avg. Area: 1529 ft^2)			Single Glass Baseline with A/C (Avg. Area: 1320 ft^2)			Single Glass Baseline without A/C (Avg. Area: 1206 ft^2)		
End Use	N	kWh/yr	kWh/yr/ft^2	N	kWh/yr	kWh/yr/ft^2	N	kWh/yr	kWh/yr/ft^2	N	kWh/yr	kWh/yr/ft^2
Space Heat	3	2619	1.8	42	1468	1.0	6	2561	1.9	26	2340	1.9
Space Cooling	3	1149	0.8	42	596	0.4	6	858	0.7	26	N/A	N/A
Total Building	3	3768	2.6	42	206	1.4	6	3419	2.6	26	2340	1.9

glass baseline group, particularly low confidence should be placed on these results.

Economic Analysis

The best estimates of net energy savings for the four baseline groups were used together with invoiced window capital costs ($22.59/sqft of glass in 1993$) and the other economic assumptions to compute the levelized costs (expressed as mills per kWh saved) of Superwindows. The analysis was repeated for the four consecutive years between 1993 and 1996.

The levelized costs for 1993 ranged from 89 to 178 mills/kWh saved (or 8.9 to 17.8¢/kWh saved) across the four baseline groups. In all cases, the computed levelized costs were significantly greater than the 25 mills/kWh target and, therefore, not cost-effective. The cost-effectiveness was consistently worse through the three succeeding years. To achieve cost-effectiveness, a very large market transformation incentive of 95 percent of the 1996 capital cost would be required to reach the 25 mills/kWh saved target.

The results of the incremental cost analysis revealed that, across the participant sample, cost-effectiveness did not improve when only incremental costs and benefits were considered. Although cost-effectiveness did improve somewhat in one of the three relevant baseline groups, its contribution to the overall sample was not sufficient to produce a net improvement in cost-effectiveness.

Market Transformation Assessment

The survey of ten window manufacturers that served the Pacific Northwest and two glass industry trade organizations revealed facts regarding the pricing structure of the window industry that were useful in determining the feasibility of Superwindows as a market transformation technology. The survey also obtained valuable opinions from the window industry on the role that utilities might play in marketing efficient windows and reducing their future costs.

With respect to the feasibility of Superwindows as a market transformation technology, the most disturbing cost-related result from the survey was a consensus among manufacturers that the cost of Superwindows would not decrease appreciably with mass production. In a very competitive market there might be a small reduction from a lower profit margin. However, the manufacturers repeatedly reported that the components of Superwindows are already mass produced and the conversion cost of production from double to triple glass would be negligible. The manufacturers also consistently reported that other options, besides a third pane, result in a window thermal efficiency that approaches triple glass in a more cost-effective manner. Double glass windows with options such as Heat Mirror, low-e coatings and gas fill are, in their opinion, a better alternative to pursue. It is noted that this survey result is in direct conflict with the opinion of manufacturers at the time that the Superwindows glazing configuration was selected. In 1993, the triple glass configuration was selected primarily because it was cheaper than alternative double glass configurations bid by competing manufacturers. Based upon this result and the results of the Superwindows economic analysis discussed above, it is concluded that Superwindows is not a market transformation technology that should be pursued by Bonneville with the current cost-effectiveness threshold set at 25 mills/kWh saved.

The surveyed manufacturers and trade organizations agreed that utilities could provide some assistance in promoting efficient windows and reducing their future cost. Suggestions that resulted from the survey included: (1). Educate builders, rather than consumers, on the benefits of efficient windows.

(2). Provide financial support to industry sponsored research (e.g., improved and less costly production process). (3). Promote more energy efficient energy code (4). Provide customer or builder incentives, such as rebates, zero interest loans or grants. (5). Improve window thermal performance by pursuing high-efficiency coatings as an alternative to a third pane. (6). Treat large and small window manufacturers equally in any assistance that is given.

The industry response to utility involvement in future cost reductions was generally positive. However, much more detailed inquiries must be made before any action is taken.

Customer Satisfaction Survey

The results of the customer satisfaction survey, administered to 87 of the participants, were very encouraging. High levels of satisfaction were found for the windows overall, as well as for the more specific characteristics of operation, clearness, and physical appearance. Ninety percent of the respondents were very satisfied with the new windows in general. Energy savings, reduced noise, appearance, and improved comfort were often given as reasons for satisfaction. The one respondent who was not too satisfied felt that the tinting made the windows look dirty.

A similar degree of satisfaction was found for window operation. Eighty-one respondents (93 percent) were very satisfied with the operation of the window. Those that were only somewhat satisfied stated that the locks did not work and/or that the windows were hard to slide. By contrast, 36 respondents stated that the windows slide easily and 12 respondents noted that they liked the locks.

Satisfaction levels with window clearness and physical appearance were slightly lower with 75 (86 percent) and 74 (85 percent) of the respondents, respectively, indicating that they were very satisfied. While 10 respondents stated that they liked the tint, 11 other respondents noted that they were somewhat dissatisfied with the tint and/or clarity of the windows. The respondent who was not too satisfied with the window appearance stated that the outside trim piece did not match the window. Four other respondents commented on the additional thickness of the windows causing them to either stick out externally or reduce the window sill space internally.

Respondents were asked how much energy they felt the windows were saving. Sixty-three respondents (72 percent) felt that the windows saved some or a lot of energy. Only 7 respondents felt that the windows only saved a little or no energy. Several respondents did not have an opinion on this subject.

Respondents were also asked what recommendations they had for improving the windows. Thirty-eight respondents provided 43 specific recommendations. There were 12 recommendations for improvements in the manufacturing quality and 15 recommendations for more window options in terms of window styles, colors, and tinting. There were 10 recommendations concerning the locks with specific attention to the sliding glass door locks and the number of holes for locking in an open position.

A high degree of customer satisfaction was also found with the pilot program. Ninety percent of the respondents indicated that they were either very or somewhat satisfied with how the program was conducted. Fifty-three respondents stated that they were happy with the utility staff involved. Sixteen respondents stated that they were happy with the installers. Only three respondents were unhappy with the installers. Eleven respondents stated that they were kept well informed. However, four respondents stated that they were not kept well informed. Seven respondents stated that the process took too long, while 2 respondents said that it was done in a timely fashion.

Respondents were asked to indicate their level of satisfaction or dissatisfaction with the quality of the installation. Eighty-six percent stated that they were very or somewhat satisfied with the quality of installation. Nine respondents (10 percent) were not too satisfied with the quality of the installation and 3 respondents (3 percent) were not at all satisfied. Those respondents that were not at all satisfied cited sloppy caulking jobs. In one instance, the installers took longer than necessary.

Respondents were also asked what recommendations they had for improving the Superwindows program. Forty-seven respondents provided 55 recommendations. Faster schedule and improved coordination of scheduling were the most frequently cited recommendations.

Respondents were asked to give reasons for their participation in the program. Saving energy, low cost for new windows, and needed new windows anyway were the three most frequently cited primary reasons for participation. Increased home value and low cost for new windows were the two most frequently cited secondary reasons for program participation.

CONCLUSIONS

From the results of this effort, conclusions were drawn regarding the procedures and important findings of the study. Each of the conclusions is discussed below.

(1) The protocol used in this study to evaluate the feasibility of Superwindows was technically sound and fulfilled the objectives of the study.

(2) Two alternative savings estimation techniques, PRISM and SUNDAY, were used to compute gross and net energy savings from Superwindows. Each of these techniques had advantages and disadvantages for this application that were taken into account in selecting the best estimates of savings.

(3) The analysis showed a significant difference between the gross and net savings estimates for both models, indicating that it was important to conduct a net savings analysis to adjust for energy consumption changes between the pre-and post-periods that were unrelated to the Superwindows.

(4) The Superwindows change in u-factor computed by the Mowitt model was found to be in close agreement with the STEM test results, under weather conditions experienced during the STEM tests.

(5) Both the PRISM and SUNDAY analyses of net energy savings showed significant savings from Superwindows for all four of the baseline groups considered in this study. The best estimate of savings produced by this analysis shows a range in net total building savings of 1.4 to 2.6 kWh/yr/sqft of floor area across the baseline groups. This is equivalent to a range in savings of 2064 to 3768 kWh/yr. Significant variability in savings from these mean values was observed across the building sample. These mean savings represent a significant reduction in total building and end-use consumption from the pre-retrofit condition.

(6) The results of the participant satisfaction survey for the Superwindows shows a high degree of satisfaction for the windows overall, as well as for the more specific characteristics of operation, clearness, and physical appearance. The results of the survey also indicated a high degree of satisfaction with the pilot program and the window installers. The respondents provided suggestions for improving the windows and the pilot program.

(7) The levelized cost of Superwindows, in 1993 dollars, ranged from 89 to 178 mills/kWh saved (or 8.9 to 17.8¢/kWh saved) across the four baseline groups. In all cases the computed levelized costs were significantly greater than the 25 mills/kWh target and, therefore, not cost-effective. The cost-effectiveness was consistently worse in the three succeeding years where it was calculated. To become cost-effective, the window cost in 1996 dollars would have to be reduced by 95 percent. The incremental cost analysis across the participant sample did not improve cost-effectiveness.

(8) A survey of window manufacturers and industry trade organizations indicated that the cost of Superwindows would not decrease appreciably with mass production. Based on this finding and the results of the economic analysis performed in this study, it is concluded that Superwindows is not a market transformation technology that should be pursued by Bonneville for this Pacific Northwest application with the current cost-effective threshold set at 25 mills/kWh saved.

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