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BUILDING TECHNOLOGIES OFFICE

Expert Meeting Report: Windows Options for New and Existing Homes

C. Ojczyk, J. Carmody, and K. Haglund
Northern*STAR*

May 2013

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Expert Meeting Report: Windows Options for New and Existing Homes

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Office of Energy Efficiency and Renewable Energy

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Definitions

DOE	U.S. Department of Energy
EWC	Efficient Windows Collaborative
HVAC	Heating, ventilation, and air conditioning
LBNL	Lawrence Berkley National Laboratory
Low-e	Low-emittance coating
NREL	National Renewable Energy Laboratory
PPD	Predicted percent dissatisfied
SHGC	Solar heat gain coefficient

Executive Summary

The NorthernSTAR Building America Partnership held an expert meeting on Windows Options for New and Existing Homes on November 14, 2011 at the Nolte Building on the University of Minnesota campus in Minneapolis. Featured speakers included John Carmody and Pat Huelman of the University of Minnesota, Charlie Curcija of Lawrence Berkeley National Laboratory, Jim Larson of Cardinal Glass Industries, Peter Yost of Building Green, Peter Baker of Building Science Corporation, and Theresa Weston of DuPont Building Innovations. Audience participation was actively encouraged during each presentation to uncover needs and promote dialog among researchers and industry professionals. Key results from the meeting were:

- A greater understanding of the windows research that Building America partners and national laboratories are engaged in to help professionals and consumers choose best practice strategies
- A greater understanding of the role of comfort in window performance and satisfaction
- A need for research to quantify costs, benefits, and risks of window replacement and window improvement options for existing homes
- Definition of future research needs to be investigated.

Findings from the meeting include:

- The extensive research already being undertaken by the Building America partners has resulted in the development of websites, guides, fact sheets, and other resources to help users make more informed decisions about window options for new and existing homes. The Building America partners continue to develop resources to help users move beyond information gathering to action.
- There is a gap between reported cost information and true costs for materials and installation across all window replacement and retrofit options. There needs to be a greater emphasis on engaging the building industry to provide real cost information (materials and labor) that can be included in the resources that Building America partners are creating for the public.
- More research is needed to quantify the role of windows and window attachments in improving the house as a system. There is a solid understanding of best practices for new construction, but the many variables in existing home situations leave gaps in understanding proposed replacement and retrofit options and their impacts on energy efficiency; heating, ventilation, and air conditioning systems; humidity; durability; and comfort.

The next steps are to define research projects that address the needs uncovered in the windows expert meeting.

1 Background

Windows are critical components of new and existing homes in cost-effectively meeting the Building America energy targets. They have very important impacts on heating, cooling, and air leakage, and provide many benefits such as comfort, increased durability, and increased home value that are harder to quantify than energy consumption.

Although considerable technological development and increased code requirements for windows have occurred in the last 25 years, there is still a need to understand the impacts of window design and installation on the house as a system. Whether a new window is installed in a new or in an existing opening, or whether an insert window, a sash replacement, a refurbished window, or a window attachment is installed, it is necessary to understand impact on the sizing and costs of heating, ventilation, and air conditioning (HVAC) systems and to consider the impacts of the product and installation on overall construction needs, condensation and water infiltration and management, indoor air quality, and window and house durability.

Only recently has there been greater interest in the ability to measure performance and cost effectiveness for refurbishing windows or applying attachments such as shades, blinds, and high performance storm windows.

The question is whether the cost for new technologies and installation processes can be justified through improved energy efficiency, decrease utility costs, improved comfort, and improved durability of the home.

2 Meeting Information

The NorthernSTAR Building America Partnership held an expert meeting on Windows Options for New and Existing Homes on November 14, 2011 at the Nolte Building on the University of Minnesota campus in Minneapolis. The 31attendees included leading researchers, government program managers, and industry experts. Sixteen participants attended via webinar. Seven presenters provided overviews of technologies and issues associated with new and existing windows. Lively discussion and participation occurred during each presentation and a wrap-up discussion was held at the end of the day. A list of participants is included in Table 1.

Table 1. Expert Meeting Participants

Name	Organization	Email Address
Theresa Weston	DuPont Building Innovations	theresa.a.weston@usa.dupont.com
Kohta Oeno	Building Science Corporation	bats22@gmail.com
Peter Yost	Building Green	peter@buildinggreen.com
Kerry Haglund	University of Minnesota	khaglund@umn.edu
John Carmody	University of Minnesota	carmo001@umn.edu
Garrett Mosiman	University of Minnesota	mosi0019@umn.edu
Tom Schirber	University of Minnesota	schir056@umn.edu
Pat Huelman	University of Minnesota	phuelman@umn.edu
Tessa Murray	University of Minnesota	murry009@umn.edu
Charlie Curcija	LBNL[a]	dccurcija@lbl.gov
Pat Donohue	University of Minnesota	pdonahue@nrri.umn.edu
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Tom Kuehn	University of Minnesota	kuehn001@umn.edu
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Kevin Bruce	Marvin Windows and Doors	KevinB@marvin.com
Jeff Christian	Oak Ridge National Laboratory	christianJE@ORNL.gov
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J. Chestnut	J Chestnut	jchesnut4@gmail.com
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Josh Novacheck	Center for Energy and Environment	jnovacheck@mncee.org
Chuck Booten	NREL[b]	chuck.booten@nrel.gov
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Gary Nelson	Energy Conservatory	gnelson@energyconservatory.com
Steve Schirber	Cocoon Solutions	steve@cocoon-solutions.com

[a] LBNL Lawrence Berkeley National Laboratory
[b] NREL National Renewable Energy Laboratory

3 Meeting Objectives and Agenda

The objective of the full-day meeting was to bring together window experts from Building America teams and other related programs and research activities to share information, identify gaps in research activities, and determine future research issues and needs surrounding window technologies, tools, and installatiosn in new and existing homes. The meeting was designed to be interactive and to promote questions and the sharing of experiences to inform the experts from research and industry. The meeting outcomes will help shape the Building America program and the U.S. Department of Energy's (DOE) Windows Glazing Program.

3.1 Research Questions

The NorthernSTAR Partnership created the following questions as a means to guide the presenters and to stimulate conversation and questions from the attendees:

- What are the life cycle costs and benefits of new and retrofit window options?
- What are the tradeoffs between sash replacement and refurbishing or attachments in retrofit situations?
- What are the available tools and information to make cost-effective window choices?
- Are there any new technologies or strategies that make windows more energy efficient or cost effective?
- What are the problems and solutions associated with window installation?

3.2 Agenda

8:30 Welcome and Meeting Introduction

John Carmody, NorthernSTAR Partnership

Chuck Booten, NREL

9:00 Charlie Curcija: Overview of Window Research at LBNL

9:30 John Carmody: Guidelines for Energy Efficient Windows in New Construction

10:45 Break

11:00 James Larsen: The Science of Window Comfort

11:45 Group discussion (led by John Carmody

12:00 Lunch

1:00 Pat Huelman: Window Challenges for Existing Homes

1:30 Peter Yost: Examining Window Retrofit Options

2:00 Peter Baker: Window Repair, Rehabilitation, and Replacement

2:30 Theresa Weston: Windows Retrofit

3:00 Group Discussion To Cover Key Questions and Action Items (led by John Carmody)

4:00 Adjourn meeting

3.3 Presenter Biographies

Dr. Charlie Curcija Dr. Charlie Curcija is a scientist at LBNL in the Energy and Environmental Technologies Division, leading the research in thermal and optical performance of windows and other fenestration systems. He has been working in the area of the performance of buildings and building façades for more than 25 years and earned his Ph.D. at the University of Massachusetts in the field of thermal performance of windows.

John Carmody is the director of the Center for Sustainable Building Research at the University of Minnesota. He has worked in building-related research for 30 years and is the author of several books on building design and construction, including *Window Systems for High-Performance Buildings* with LBNL, and the new edition of *Residential Windows: A Guide to New Technologies and Energy Performance*. John is a co-leader of the NorthernSTAR Building America team.

James Larsen is director of Technology Marketing at Cardinal Glass Industries. He has 20 years experience in glass products R&D. He supports the recognition of energy-efficient windows through state and national codes and provides product support. John serves on the board of directors for the National Fenestration Rating Council.

Pat Huelman is an associate professor in Residential Energy and Building Systems with the University of Minnesota's Department of Bioproducts and Biosystems Engineering and serves as coordinator of the Cold Climate Housing program with the University of Minnesota Extension. He is the lead faculty member for the Residential Building Science and Technology undergraduate degree, a principal investigator for hygrothermal testing at the Cloquet Residential Research Facility, and directs the new NorthernSTAR Building America team. With more than 30 years in the field, Pat has extensive experience and expertise in energy-efficient design, innovative building systems, residential indoor air quality, mechanical ventilation, and moisture management.

Peter Yost is residential program director at Building Green. He brings more than 25 years experience in building, researching, teaching, writing, and consulting on high performance homes to his twin roles as director of residential services for BuildingGreen, and technical director for Taunton Press's GreenBuildingAdvisor.com. Peter has been called on to provide this building science expertise to the nation's leading homebuilding programs, including the National Association of Home Builders Green Building Standard, the U.S. Green Building Council's Leadership in Energy and Environmental Design for Homes, the U.S. Environmental Protection Agency's WaterSense, andDOE's Building America program.

Peter Baker is a senior associate at Building Science Corporation. He provides building forensics and design reviews, sets enclosure design standards, and works as project manager for the Building America program. He conducts field investigations of commercial and residential buildings with assembly or system problems, provides explanations of the identified problems, and develops retrofit recommendations.

Dr. Theresa Weston, DuPont Innovations, leads the building science technology group for DuPont Building innovations. She participates in industry research programs and in standards and codes development. Theresa has more than 20 years experience in materials and fiber development and is an inventor with four U.S. patents. Theresa has a Ph.D. in Chemical Engineering from the CalTech. Theresa is actively involved in industry organizations, including ASHRAE and ASTM, and has chaired technical and standard committees for both.

4 Presentation Summaries

Seven main presentations were given by industry experts describing current windows research, products, and tools for new construction and existing homes. Active discussion was encouraged throughout each presentation to uncover questions and concerns expressed by the attendees. Comments and questions posed by the attendees and presenter responses appear in the summaries in italics to help the reader understand the dynamic exchange of information.

4.1 New Homes

The Building America program has historically focused on improving building technologies, construction systems, and energy efficiency of new homes. Research in this area was presented first to provide a foundation from which to investigate window issues in existing homes.

4.1.1 Charlie Curcija: Overview of Window Research at Lawrence Berkeley National Laboratory

Mr. Curcija began his presentation with thought-provoking numbers on the amount of overall energy consumed in buildings versus the amount consumed by the window component. Buildings consume 39% of total energy in the United States or about 40 quads (1 quad equals 1 quadrillion Btu). The energy attributed to windows is about 4 quads, or 10% of building energy. Of the 4 quads, residential windows represent 2.67 quads, whereas commercial windows consume 1.48 quads. The knowledge that residential windows account for nearly 7% of total building energy consumed presents opportunities for realizing significant total energy savings through improved design.

LBNL is exploring the concept of zero energy building façades where building components supply rather than use energy. In this role, windows would move from being net energy losers to energy producers. This line of thinking raises the question of how to design windows for heating seasons when solar energy balances or exceeds the losses during daylight hours and thermal loss is controlled after dark. During cooling seasons, heat gain from solar radiation is controlled.

One key measurement that indicates potential for a window to become an energy producer is the U-factor, or measurement of a window's ability to resist heat flow. Figure 2 displays the U-factor at which a window moves toward being a net energy producer in a cold climate (a 0.1 or lower U-factor).

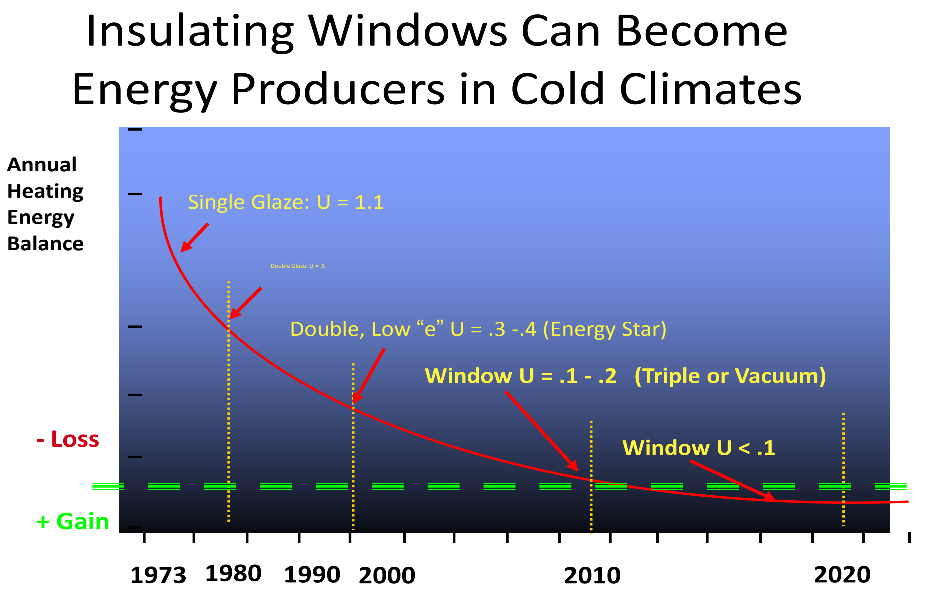


Figure 1. Windows as energy producers

U-factor must be considered alongside solar heat gain coefficient (SHGC) and climate. Figure 3 shows energy graphs of U-factor versus SHGC in Riverside, California. Improved energy performance begins to diminish as U-factor is reduced and SHGC is increased. Reducing U-factor is less important than reducing SHGC in mixed climates.

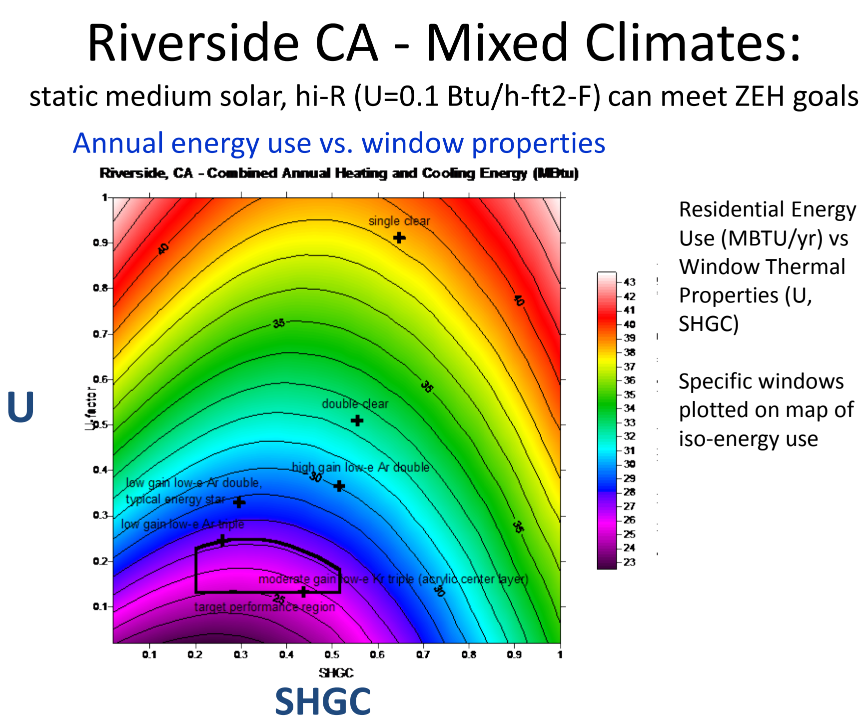


Figure 2. U-Factor and SHGC in mixed climates

LBNL researchers are investigating three main areas to understand the best means for transforming windows into energy producers and balancing U-factor and SHGC:

1. **Highly insulated glazing.** This includes triple- and quadruple-insulated glazings with suspended films or nonstructural center layers, spacers that improve condensation resistance, vacuum glazing with improved metal to glass bonding or innovative pillars, and aerogels.

   Question: Will any of the materials or strategies mentioned above be available soon?

   Response: Nonstructural center glazing seems the closest, but currently the cost outweighs energy savings.

   Comment: An audience member commented that the technologies presented are wonderful, but that other criteria besides energy performance must be considered. These include impact resistance, altitude limits, and wind loads. Special designs, such as arches, can negatively impact performance. With vacuum glazing, performance is greatly impacted by temperature and the product is known to curl in cold weather.

2. **Highly insulated frames.** This research is driven by information collected through the Passive Haus Institute in Germany and its success with zero energy homes. The current highly insulated frames designed to meet Passive Haus standards must be tested against U.S. standards.

   Question: Aren't there measured savings with a better insulated frame?

   Response: Yes, but we need to quantify those savings for our market. We can't just adopt Passive Haus standards and expect similar performance in the different climates we have in the United States.

   Comment: Perhaps we can we improve the insulation of the frame with a jobsite detail rather than build it into the frame.

3. **Dynamic options for solar, control including electrochromic, thermochromic, photochromic, and liquid crystal display technologies, attachments, and shading between the glass.** LBNL is completing the Windows 7/Therm 7 program for complex calculations of performance when a window includes enhancements such as shades, blinds, screens, and vacuum glazing. It developed and has incorporated the Complex Glazing (and shading) Database.

Mr. Curcija reminded the audience that although all these ideas can help windows move to the position of energy producer, research must also focus on understanding the entire window system and how the window interacts with the building system and other potential energy producers.

Comment: NREL will be opening a new facility for testing window durability over wider temperature ranges.

Comment: Oak Ridge National Laboratory will also be embarking on new window research.

4.1.2 John Carmody: Guidelines for Energy-Efficient Windows in New Construction

Mr. Carmody tied his introduction to the message delivered by Mr. Curcija: If the current window stock were upgraded to ENERGY STAR®, there would be an energy savings equivalent to 1 quad. Improving the U-factor further to U = 0.1 using advanced window materials and dynamic controls could yield an energy savings of nearly 2 quads. These are good reasons to keep investing in research related to improved window performance.

Mr. Carmody, Steve Selkowitz, Dariush Arashteh, and Lisa Heschong wrote a book titled, *Residential Windows: A Guide to New Technologies and Energy Performance*. This book provides many levels of information about window selection for new and existing homes.

Mr. Carmody works with LBNL and the Alliance to Save Energy to manage the Efficient Windows Collaborative (EWC). The EWC is composed of window industry manufacturers, suppliers, and affiliates. The EWC provides information on the benefits of energy-efficient windows, how they work, and recommendations for their selection and use. This information is provided through publications and websites. The messages in all the EWC work are:

- Look for the ENERGY STAR label.
- Look for the energy-efficient window properties on the National Fenestration Rating Council label.
- Compare annual energy costs for a typical house.
- Estimate and compare annual energy costs for your house (customized program using the RESFEN software tool).

The EWC website (www.efficientwindows.org) is designed to teach the user how to make informed decisions about window options and how they impact energy performance. Options include window area, shading devices, and frame types. A window selection tool allows the user to choose criteria and then find a window product that meets those characteristics. This helps the consumer to move from information gathering to purchasing. Further assisting the selection process are guideline fact sheets and energy code compliance guides by state. This website averages 50,000 visitors per month.

Question: Does the program address the addition of storm windows on historic homes?

Response: Not currently, but products such as low-e storm windows are addressed in the book.

Mr. Carmody also introduced the current task of the NorthernSTAR Partnership, which is to develop windows measure guidelines for the Building America program. The goal is threefold:

1. Provide guidelines for selecting energy-efficient windows in all U.S. climate zones.

2. Provide cost/benefit information.
   a. Energy Benefits:
      - Operating energy
      - Peak load reduction
      - Mechanical system reduction
   b. Nonenergy benefits:
      - Comfort
      - Condensation resistance

3. Provide energy impacts of design decisions such as window orientation, total glazing area, and shading devices and conditions.

One of the greatest concerns is accurate cost data that can be used in modeling programs such as BeOPT. Although some data are available, industry has responded that the numbers are unrealistically low.

> *Comment: Margins and markups are different for high volume new construction builders and custom remodelers. The DOE Windows Volume Purchase program is not useful for remodeling.*

> *Comment: Installed price is a large component of total window cost, not just window price. Installed price is also affected by the number and variations in size of window openings r in any given home. An estimated cost of $1200/opening is too low. The cost to tear out, insulate weight pockets, replace with a new window, and retrim the opening is closer to $2000 in the Minneapolis market.*

> *Comment: Another missing piece is the energy performance and durability difference between insert units and whole window replacements.*

> *Comment: In new construction, the Building America program for new construction could do delta in material cost as a useful delta, but installed cost of retrofits (and the variability) is huge.*

> *Comment: The most valuable tool would be to create technology that could make window installation more consistent. Then performance would be more measurable.*

> *Comment: People replace windows for many other reasons such as age. Cost data should not just be attributed to energy savings. If someone plans to replace a window anyway, upgrade costs become the right delta.*

4.1.3 Jim Larsen: The Science of Window Comfort

Mr. Larsen's presentation introduced the concept of comfort by discussing the six factors that define the conditions for thermal comfort:

- Metabolic rate
- Clothing insulation (impacted by seasonal change in temperature)
- Air temperature
- Radiant temperature (impacted by window size, occupant's position relative to window, and window surface temperature)
- Air speed
- Humidity.

Given that predicting the factors of each installed window and the variations in individual comfort is impossible, designing a window to address comfort for everyone is nearly impossible. The goal is to move in a direction where most people will experience more comfort.

ASHRAE Standard 55 attempts to address comfort through the ASHRAE comfort tool. Yet ASHRAE Building Code 90.1 and 90.2 suggest a wintertime comfort setting of 68ºF, which falls below the comfort zone suggested by the Standard 55 tool (see Figure 4).

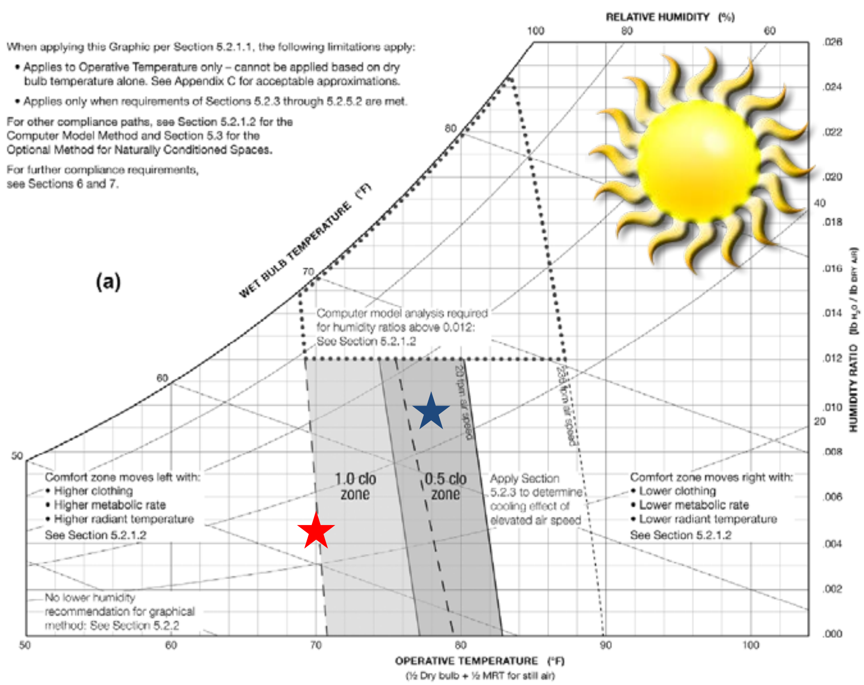
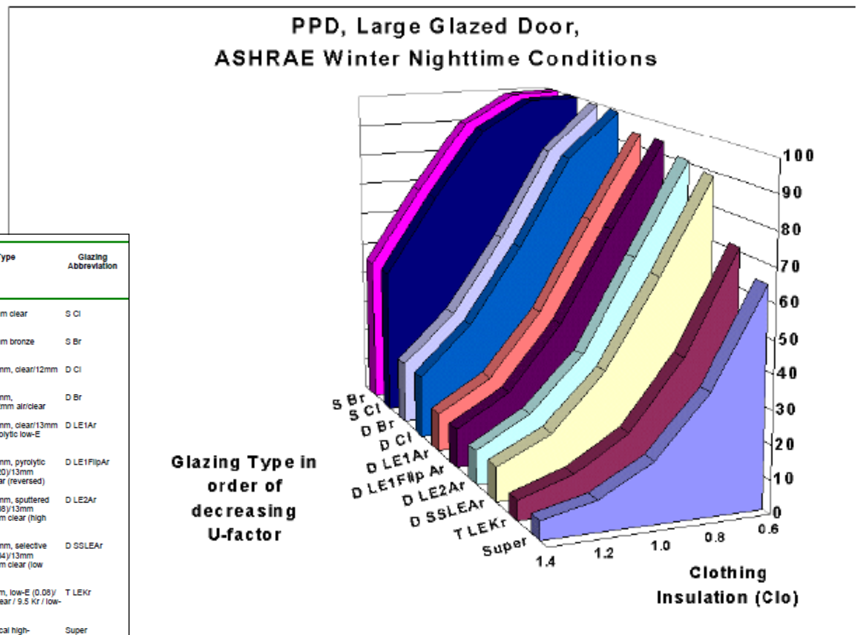


Figure 3. Thermal comfort zones

The graph also shows how thermal comfort for summer and winter months shifts depending on clothing, metabolic rate, and radiant temperature. The ASHRAE 90.1 summer comfort setting is suggested to be 78ºF and falls within the summer comfort zone. Although the standard and the building code align for summer thermal comfort, a key consideration is missing: the impact of solar radiation on the thermal comfort zone. Future research is needed to understand the impact of solar gain on comfort.

Another method for looking at comfort is the PPD or predicted percent dissatisfied measurement, where low values are desired and equate with greater satisfaction. LBNL researchers looked at a variety of window types from single pane clear to high performance against a variety of comfort indicators such as clothing level. As Figure 5 suggests, as the insulating value of a window increases during a winter night, comfort improves.



Glaz-ing No.	Glazing Type	Glazing Abbreviation
1	Single 3mm clear	S Cl
2	Single 3mm bronze	S Br
3	Double 3mm, clear/12mm air/clear	D Cl
4	Double 3mm, bronze/12mm air/clear	D Br
5	Double 3mm, clear/13mm argon/pyrolytic low-E (0.20)	D LE1Ar
6	Double 3mm, pyrolytic low-E (0.20)/13mm argon/clear (reversed)	D LE1FlipAr
7	Double 3mm, sputtered low-E (0.08)/13mm argon/3mm clear (high SHGC)	D LE2Ar
8	Double 3mm, selective low-E (0.04)/13mm argon/3mm clear (low SHGC)	D SSLEAr
9	Triple 3mm, low-E (0.08)/ 9.5 Kr / clear / 9.5 Kr / low-E 0.08	T LEKr
10	Hypothetical high-performance window (low U, low SHGC)	Super

Figure 4. Predicted percent dissatisfied

The LBNL data correlate with EWC data from (Figure 6). As high performance attributes are added to windows, the room-side glass surface temperature moves toward or into the comfort area, even when outside temperatures drop below 0ºF.

Efficient Windows Collaborative

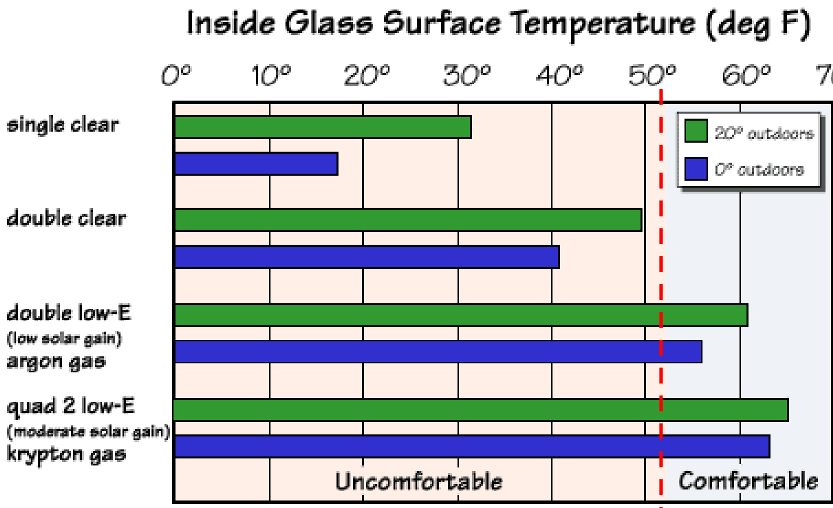


Figure 5. High performance glass and inside glass surface temperature

Further data showed, however, that winter nighttime comfort conditions are completely different than winter sunny conditions and summer sunny conditions. Comfort goes beyond room conditions to the amount of sun passing through glass to heat the room and the temperature of the glass facing the room. It is also a factor of the thermal storage potential of the materials in the building and the ability of temperature to be distributed throughout the spaces.

For example, a field study done in Fort Wayne, Indiana, measured the PPD of a home experiencing a –5°F outside temperature with clear and sunny conditions. The windows were triple glazed high solar gain. The reported PPD numbers were high (toward dissatisfied). Even though solar gain was achieved, the house had big temperature swings from room to room.

Question: Did the study look at the relationship between the field study and the modeling program?

Response: Yes. It is believed the programs overestimate thermal mass in buildings. There is a disconnect between the models and the measured results, especially in winter. Summer months seem to produce a closer agreement.

Mr. Larsen also presented results from his own informal research that examined multiple window options and glazing strategies in multiple geographic locations. As one moves from double pane to triple pane and from high solar gain to low solar gain, the hours of discomfort decrease even as climate changes from cold to hot.

In window comfort analysis a single thermostat set point cannot be used for all seasons in the manner that is used by energy performance modeling. The temperature at which one is comfortable varies from season to season, at different times during the day, and with level of clothing and metabolic rate.

> *Comment: Operative thermostats are available.*
>
> *Comment: One of four people actually use their setback thermostat. (What data are available to prove this statistic?)*
>
> *Question: Do we have the modeling capability to translate comfort information into energy savings?*
>
> *Response: Every hour of measured discomfort is a call to action to develop strategies to improve comfort. 1ºF is 3% change in energy. Reducing temperature 2ºF is a 6% decrease in energy load. Changing comfort changes livability with potential energy improvement. Defining comfort through modeling is difficult because there is no single model for comfort. One would need to combine results from different programs (for example, EnergyPlus will compute long wave infrared but not short wave).*

4.2 Existing Homes

The Building America program recently expanded its research focus to improve building technologies, construction systems, and energy efficiency strategies for the vast stock of existing U.S. homes. Given the many variables in construction techniques from home to home and from climate to climate, predicting performance of window upgrades for existing homes is far more complicated than for new homes. The following presentation summaries and discussions provide a look at the latest research and concerns in the industry.

4.2.1 Pat Huelman: Window Challenges for Existing Homes

Mr. Huelman provided a brief introduction to the afternoon sessions by discussing the complicated nature of window options for existing homes. In new construction, a new window will go into a new opening. Options always need to be considered for that new window, but the choices grow exponentially for existing homes. Choices need to be weighed against conditions of the window, the building envelope, and the home's mechanical systems. Will the whole window be replaced or a new insert added to the frame? Can a new sash be added or the window repaired? Will an interior or exterior attachment be sufficient to improve comfort? Will the current mechanical system be oversized if the new windows and installation create a tighter, more energy-efficient building envelope?

Costs and benefits of each of these strategies need to be weighed against installation, ease of use, and maintenance.

4.2.2 Peter Yost: Examining Window Retrofit Options

Mr. Yost began his presentation by outlining the matrix of considerations that needs to be thought through when contemplating the best method for improving the impact of windows on existing homes.

Options for where the retrofit will be placed need to be considered first:

- Interior attachment (includes blinds, drapes, shades, films)
- Exterior attachment (includes storms, shutters, rollers, screens, landscaping)
- Window replacement (full unit, insert, sash replacement, upgrade/repair).

The secondary areas of consideration are the attributes of those options:

- Thermal (includes insulation, airtightness, solar heat gain, comfort, condensation resistance)
- Visual (includes visual transmittance, views, privacy, aesthetics)
- Use (includes ease of operation, cleaning, repair, adjustability, maintenance, and durability)
- Economics (product and installation costs, energy savings, service life)
- Other (availability of product, ease of install, acoustics, security).

The issue is that little research has been conducted on how best to make decisions about the combination of option and attributes that will result in the best outcome for a particular home.

In some ways it is easy to measure energy efficiency (a thermal attribute) of a specific option but difficult to model the other attributes alongside energy efficiency. Because research and results are lacking, terminology is not consistent in the industry or with consumers. The quality of information posted by manufacturers varies widely and window and attachment interactions do not always produce the desired results. In fact, the orientation of a window and the resulting thermal and solar radiation stress may result in the same type of window in one house experiencing different performance outcomes based on its orientation to the sun. Yet the industry continues to promote the use of one type of window for all window openings in any given home when, in fact, different options and attributes for each window may be a better approach.

To provide professionals and consumers with a better method for choosing window options and attributes, Mr. Yost, his company Building Green, and a team from LBNL were engaged in a research project supported by DOE. Extensive literature reviews, laboratory tests, field testing, and modeling were completed over the course of 18 months.

A field test was completed in Mr. Yost's home during the summer and winter to determine the impact of solar gain and temperature on several baseline windows (double pane, single pane, low-e, argon filled) and various attachments (interior and exterior storm windows, window quilts, solar shades, cellular shades, interior and exterior solar shades). Mr. Yost presented a number of images to demonstrate the findings; Figure 7 and Figure 8 show several key images that highlight the importance of testing to determine the relationships between options and attributes.

Figure 7 shows the resulting infrared image of a single-pane window without an attachment during a winter night.

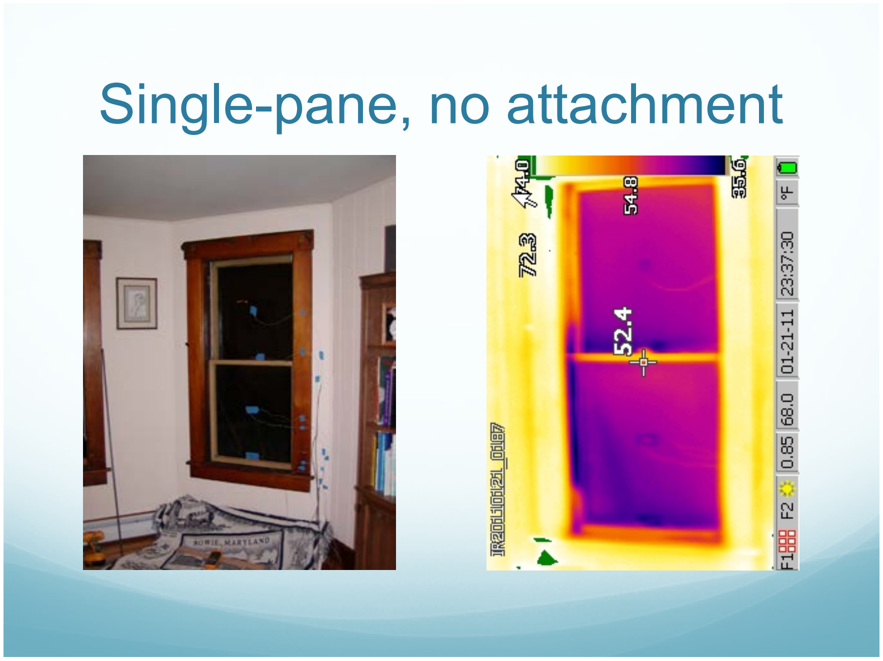
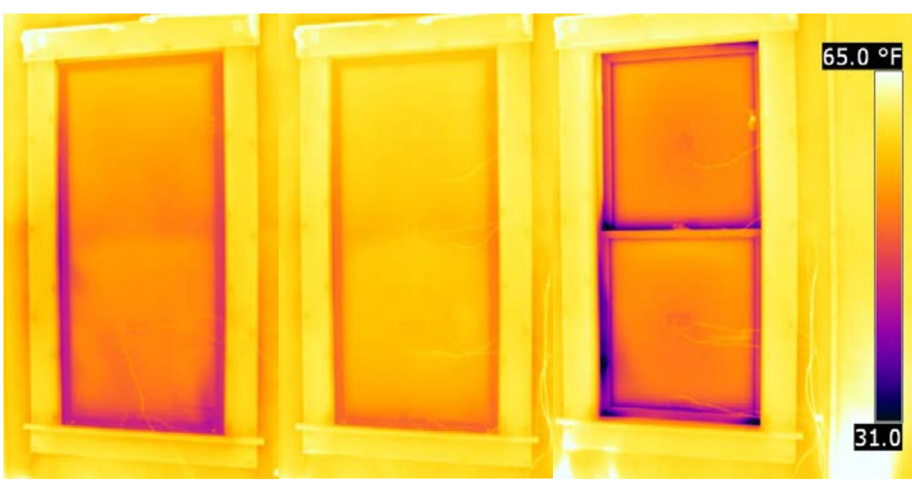


Figure 6. Infrared image of single pane window—winter conditions

The temperature of the interior wall was measured at 72.3ºF; the window glass ranges from 52.4ºF to 35.6ºF. The cold emanating from the window can impact the overall energy needs of the room as well as the comfort of any occupant located near the cold window.

Figure 8 shows the same window opening with three window variables measured during a winter night.

storm double | storm triple | IGU double



interior low-e storm over "vintage" single-pane wood frame double hung | **Interior low-e storm over "base case" double low-e Ar sash inserts** | **"base case" dual glazed low-e Ar double hung sash inserts**

Figure 7. One window opening, three window variables

The left image is the single-pane window covered with an interior low-e storm attachment. The purple color indicates a cold spot on the lower part of the storm frame; the window glass temperature is moving closer to room temperature because of the attachment.

The center image demonstrates what happens to the thermal performance of the window when the window is replaced with a low-e, argon, double-pane sash and then covered with the low-e storm attachment. There are no cold spots and most of the window is moving toward room temperature.

The right image uses the same low-e, argon, double-pane sash as in the center image but without the storm attachment. The sash frame shows an area of cold temperature; the window glass is moving toward room temperature.

In this example, the addition of the storm window or improving the window from single-pane to low-e argon, double-pane sash inserts has improved the thermal performance of the window.

> *Comment: Putting a low-e storm on the interior of the window may be fine for a winter night but may cause excessive solar gain in the room during summer daytime resulting in hot temperatures at the glass surface. Will one attachment require another attachment such as an awning or overhang?*

> *Comment: Interior storm window over single pane window runs the risk of condensation forming on interior side of window. This may be a long-term durability issue.*

> *Response: We did not do much condensation risk testing, but that was meant for testing during the second year. We will also need to look at condensation as a function of window location based on level of home—main floor versus upper floors.*

Additional images highlight the difference between winter versus summer months. Although a window should be insulated to reduce the impact of summer heat on conditioned interior air, excessive solar gain from low-e sashes, films, and storm windows can cause elevated temperatures on the room side of the window glass. This can have a negative impact on energy efficiency and comfort during the cooling months.

The research results were used to create a new website, www.windowattachments.org, to guide consumers in their decision-making process. The DOE fact sheet, "Window Retrofit Options: Deciding What to Do With Existing Windows" has a chart of retrofit options versus performance attributes that are ranked on a scale from potential detriment to greatest benefit. There are additional fact sheets on interior, exterior, and other types of attachments as well as links to resources for sourcing products and services.

The goals of future research are to delve deeper into laboratory and field work and to obtain better cost numbers to improve decision making.

> *Comment: Does the chart or website address embodied energy of new windows and attachments—has anyone done numbers?*

Response: A lot of information on windows is old, not accurate for embodied energy calculations now. Website does not address embodied energy.

Comment: A working group has been established to develop the Product Category Rules to be used with Environmental Product Declarations.) The Product Category Rules will include rules for calculating life cycle analysis and embodied energy of windows.

4.2.3 Peter Baker: Window Repair, Rehabilitation, and Replacement

Mr. Baker's presentation dove deeper into specific retrofits and how to make them more durable and energy efficient. He focused on the product installation system and the connection and interaction details that prevent water infiltration, air infiltration, and interstitial condensation.

The first area of investigation in a retrofit should always be to assess the conditions to identify current water infiltration concerns. There needs to be a determination about whether there is or was a leak and where that leak actually occurred before the type of retrofit option is selected. Common leakage areas that are easy to determine and more easily addressed include infiltration between the glass and the sash and the sash and the frame. The more difficult areas of leakage to assess are those caused by joints in the frame or between the frame and the rough opening. These types of leakage are more difficult to repair and may indicate a full window replacement is needed to better integrate the window into the wall assembly. This is especially true to prevent damage to the building envelope if a wall is insulated or there is intent to insulate.

Air infiltration pathways are similar to water pathways and generally occur between the sash and the frame and at the meeting rails. Air can also leak at the junction of the window frame and rough opening. These areas often include the void caused by weight pockets in older windows or under the sill because of frame geometry. Leakage at the sash and frame can usually be addressed in many retrofit options. But air leakage at the rough opening may require full window replacement with attention to proper air sealing before the installation is complete.

Interstitial condensation is created by uncontrolled air leakage into the space between the window and added coverings such as storms (interior and exterior) and blinds or shades. Reducing the risk of condensation is a function of the fit of the covering to the opening - the tighter the fit the less risk of condensation. Friction-fit storms and window treatments that do not follow a track have a greater risk of condensation than attachments that are measured to fit tightly and permanently into a specific opening: Anything that moves or is removable risks condensation. The interior-most element needs to be as airtight as possible. The exterior-most element should also be as tight as possible but may need to be made incrementally leakier to allow it to dry.

Comment: Are there data on the amount of air leakage in different types of existing windows?

Response: No. The variables are too great. In one house the same type of window experiences different pressures and performance based on solar orientation and occupant use.

Figure 9 shows the impact windows have on the performance of the wall assembly.

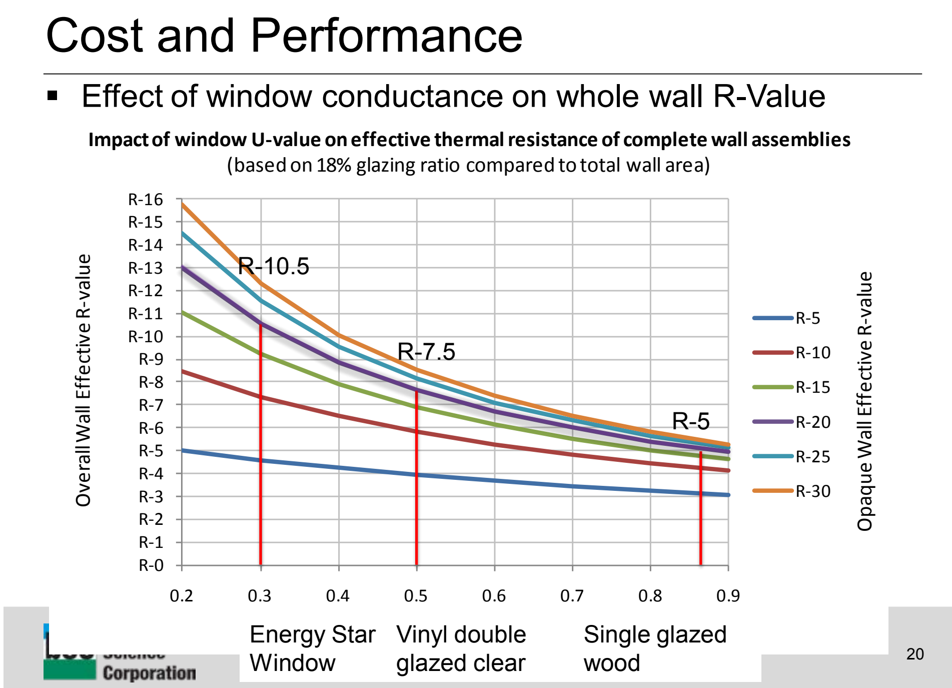


Figure 8. Wall performance as a function of window type

Adding windows into a wall negatively impacts the wall's ability to be an effective insulator. Even with low U-value ENERGY STAR windows, an R-20 wall is performing at half its value because of the window. Any retrofit options need to consider the estimated performance of the new element alongside installation procedures (air sealing) that can improve the overall wall performance.

Baseline window rehabilitation (weather stripping or gasket replacement and sealing) should be done in all measures except full window replacement to minimize air leakage that would impact performance. Existing elements need to be brought up to the same service life as any added elements: rotting wood elements need replacement before the retrofit. Liquid applied waterproof membrane helps reduce water infiltration on window jambs and at the junction of jamb and sill. This is a good option for sash replacements and insert replacement windows.

> *Comment: Is this product readily available and why wouldn't you use existing waterproofing membranes?*
>
> *Response: Many manufacturers make this product. It adds little dimension to the system as opposed to a peel and stick that might make it more difficult to operate the window with added thickness at the jamb and sill.*

In full window replacement, bulk water shedding to the outside of the building and the siding must be addressed. Figure 9 shows a pan flashing detail that Building Science Corporation uses to shed water. The sheet metal layered under the membrane was custom bent on site to fit over the siding.

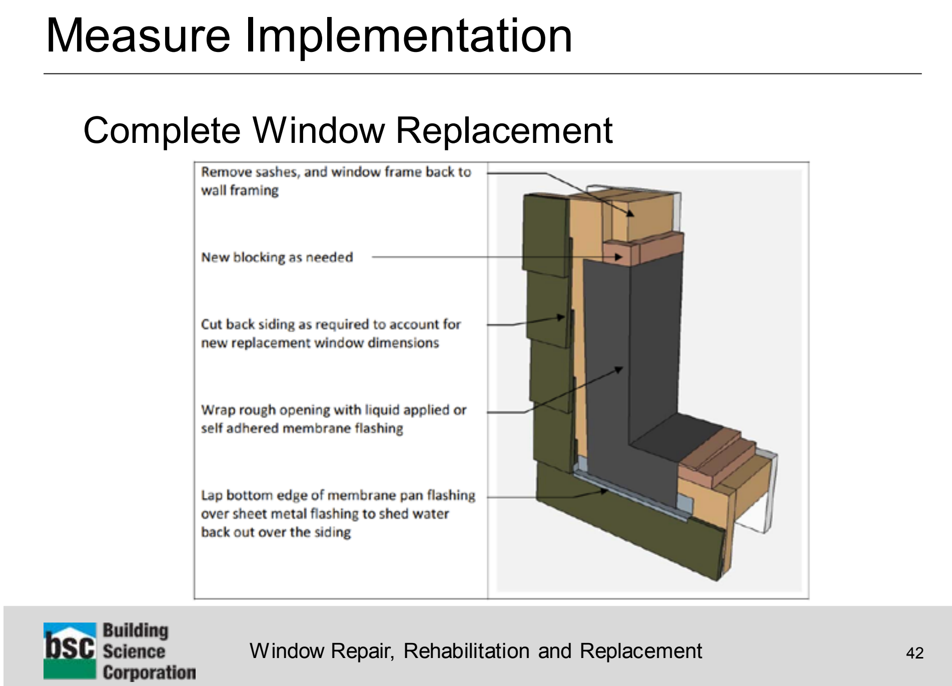


Figure 9. Flashing detail for a window replacement

These detailed slides on best practices per retrofit measure are currently in draft form for a Window Measure Guideline that will soon be available through the Building America program.

4.2.4 Theresa Weston: Windows Retrofit

Dr. Weston presented the work that DuPont Building Innovations, as part of the Building America Retrofit Alliance, has been conducting with Pacific Northwest National Laboratory to develop material for a resource tool to teach building professionals about the best practices for window retrofits. It also teaches the homeowner about the need to hire skilled and experienced installers who understand building science, and how best to integrate new options into existing conditions to maintain or improve occupant safety and building durability during energy upgrades.

The resource tool uses an “arrow” of converging variables to emphasize the custom nature of retrofits. The arrow process is to be used for each window in the home, as different windows may experience different conditions that need special consideration; for example, type of cladding, presence of mold, nonsquare openings, damage or defects in construction area, precipitation level, and actual exposure of the window to precipitation. The arrow engages the user in the practice of creating a best practices plan for improvement. Figure 10 demonstrates this process.

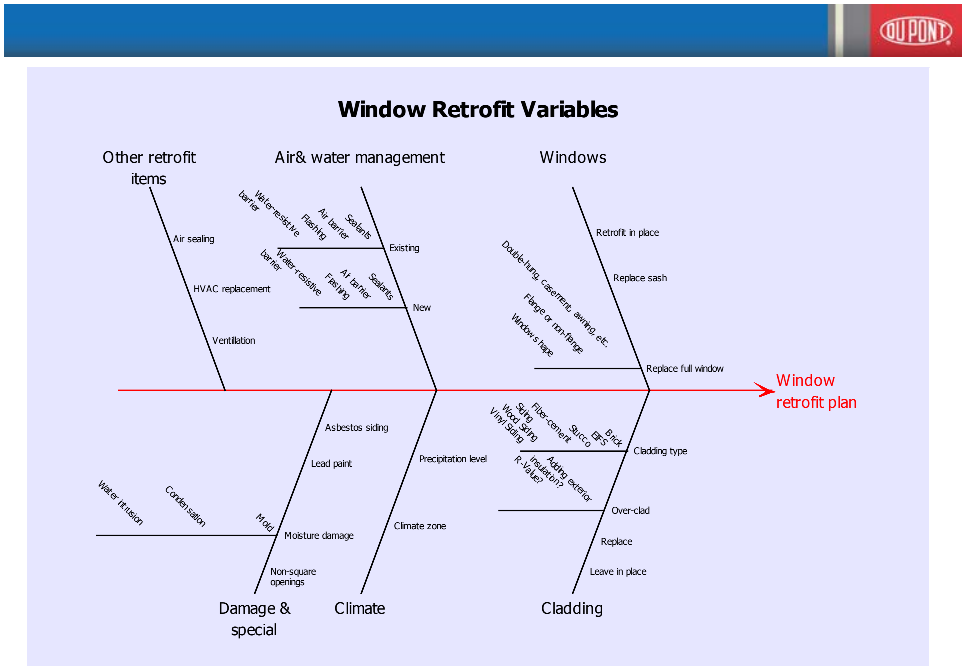


Figure 10. Strategic planning for window replacement

Further into the resource tool are tables of retrofit scenarios that help guide the user in the decision-making process. Will the window retrofit be a full window replacement? If so, is the existing cladding staying or is it to be replaced? The answer leads the user to further information on how best to proceed. A homeowner who is replacing cladding is directed to follow new construction guidelines for window installation.

Dr. Weston used the window retrofit variables arrow tool to show the decision-making process in a Building America Retrofit Alliance demonstration home. The home is brick, has a water-resistive barrier in place, is located in climate zone 2, and all the windows will undergo full replacement with nonflanged windows. The photographs document the steps from development of the retrofit plan to window removal to proposed steps for installation that will occur in the coming weeks.

> *Comment: It often costs more to do a window retrofit than to do full replacement.*

> *Comment: This is where a greater understanding of installation costs per retrofit activity is important to have so that the industry is comparing and selling apples to apples. Full window replacements are very expensive given the cost of the product and all of the installation processes that need to happen, including the repair of interior and exterior elements such as sheet rock, trim, and siding.*

5 Group Discussion to Cover Key Questions and Action Items

The primary purpose of the discussion session at the end of the presentations was to determine key issues that could be framed for future research. Eighteen items were discussed:

1. Case studies are needed to prove that simple payback should not be used alone but combined with value transfer to a new owner. This requires education and coordination with the appraisal and real estate communities.
2. Research is needed to determine how long window retrofits last and how long improvements maintain their value. Also, the necessary maintenance needs to be determined to maintain the value of the retrofit.
3. Research is needed to determine the durability of interior attachments and the impact of condensation.
4. There is a lack of field validation of retrofits and an understanding of why they fail.
5. How can windows that meet Passive Haus standards become more cost effective?
6. What is the life expectancy of windows?
7. Product and installation costs continually dominate the discussion, yet data on true industry costs are lacking. Professionals practicing in the industry need to be encouraged to submit cost and lifetime data to the NREL database.
8. Airflow from windows needs to be quantified. Thermal performance and air leakage need to be included and discussions and investigations need to be held on how window operation impacts air leakage.
9. Partner with industry to provide better cost estimates
10. What are the benefits of following Passive Haus details?
11. An industry guide is needed with expertise on the hierarchy and sequence for building upgrades.
12. How does window replacement impact ventilation?
13. Is there a way to “modularize” window frame design to easily and cost-effectively accommodate future retrofits?
14. The industry needs easy-to-discuss reasons why houses should be tight and ventilated to help remodelers educate homeowners on best practices.
15. We need to communicate that not all remodelers are qualified and they need to learn through experience.
16. Can college curricula be developed to teach window fenestration design, because no school teaches it?
17. Have the benefits and risks of all retrofit options been explored?
18. How can passive solar be done effectively?

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