Product Characterization Report
California Energy Product Evaluation (Cal-EPE) Hub

Technology Sector
Windows

Product Category
Dynamic Glazing

Last Updated
12/14/2018

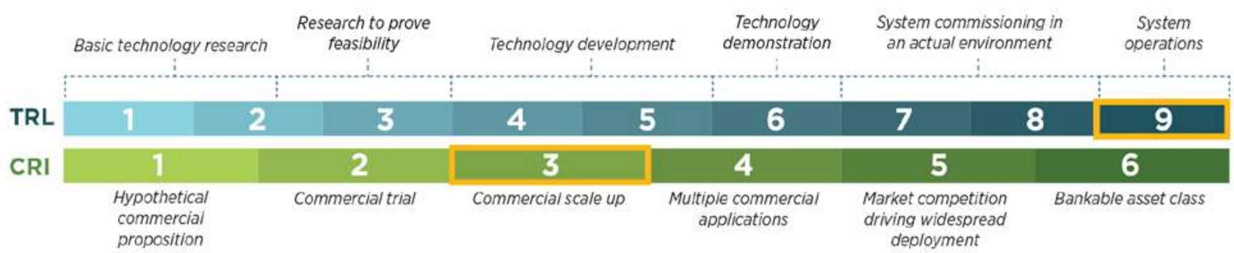
Figure 1: Electrochromic windows with sub-pane zoning. The upper part of the windows is tinted in order to provide glare control; the lower part of the windows is clear in order to provide daylight (source: LBNL).

Product Category Overview

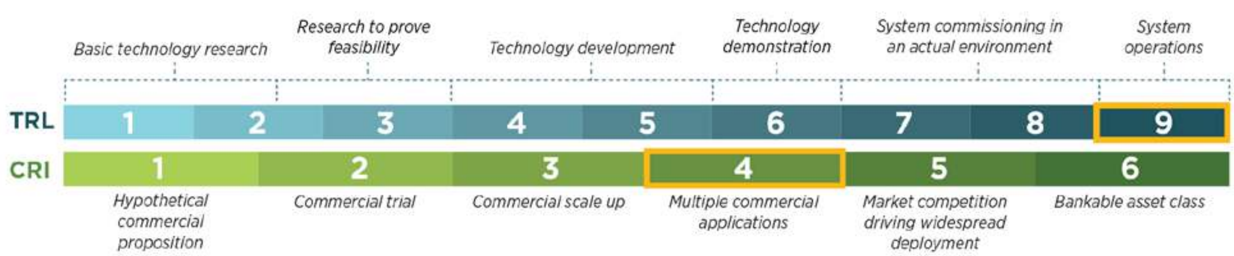
Dynamic glazing systems have glass panes with variable solar-optical properties. In the case of electrochromic glazing, solar-optical properties vary according to an applied electrical potential; in the case of thermochromic glazing, solar-optical properties vary according to the temperature of the glass. Electrochromic windows can be actively controlled, either by an automated system or by the building occupants using wall switches or mobile apps; thermochromic windows operate passively based on ambient conditions. Laboratory and field tests show that, when appropriately controlled, dynamic windows can provide solar and glare control without obstructing the view through the window. In addition, they have the potential to provide greater occupant comfort and satisfaction while enabling other energy-saving measures such as daylight harvesting. To gather the most benefits from this technology, care must be taken to tailor dynamic window control settings to the location and application.

Characterization at a Glance

Thermochromic Windows:



Electrochromic Windows:



Product Category Characterization

Energy Benefits

Through their ability to vary solar-optical properties according to environmental conditions, dynamic windows have the potential to control solar gains while enabling daylight harvesting, thus reducing HVAC and lighting energy consumption. For example, dynamic windows can allow light and heat when desired by going to a lighter state, and block light and heat when not desired by going to a darker state. The ability to reduce glare by going to a darker state can enable daylight harvesting strategies by reducing the need for manually operated shading, which may stay deployed for long periods even when not needed.

Electrochromic windows have the advantage of high flexibility in how they are controlled, and have the greatest potential for energy savings. However, in situations where the window control algorithm for electrochomic windows is not correctly tailored to local conditions, or takes an excessively conservative approach to glare or solar heat gain control, lighting energy use can increase relative to a window with static solar-optical properties. Thermochromic windows operate passively based on ambient temperature and solar gains and are not actively controlled. Solar-optical switching properties of the window material can be tuned for the specific application but cannot be adjusted after installation as is the case with electrochromic windows.

Non-Energy Benefits

Dynamic windows can provide additional benefits besides lower energy consumption. Their ability to control glare and solar heat gains can increase visual and thermal comfort in the space and, by reducing the need for operable shading, provide greater periods of unobstructed view to the outside. When controlling dynamic glazing, care must be taken to balance the need for glare and solar heat gain control with the need for view.

Product Category Differentiation

Dynamic windows covered in this document comprise two different product categories:

- Electrochromic windows. These windows can vary their tint based on an electric potential applied to the glazing. Control can be automatic or manual. Some manufacturers offer windows that are divided in zones that tint independently from each other.
- Thermochromic windows. These windows passively vary their tint based on ambient thermal conditions.

Installation Pathway and Dependencies

Dynamic windows can be used in both new construction and retrofit. Thermochromic windows do not require additional components and the economics are similar to other types of window retrofits. Besides the windows themselves, an electrochromic window installation requires several additional components: (1) wiring to provide power to the windows and for the manual override (usually a wall switch placed in an adjacent wall), (2) control hardware, both local to each window or group of windows and a central controller that controls windows throughout a building, (3) sensors placed indoors, on the façade or on the roof of the building and, for certain installations, (4) communications hardware that allows the manufacturer or other appropriate parties to access the control system remotely. These additional requirements can make electrochromic windows more competitive in new construction applications than in retrofits.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	Model	Type	Differentiating Feature
SageGlass	SageGlass SageGlass Lightzone SageGlass Harmony	Electrochromic	• 4 tint levels. • Daylight mode, glare override, manual override operating modes. • Sub-pane tinting (SageGlass Lightzone). • Sub-pane tinting with spatial gradient (SageGlass Harmony – available in 2019).
View	View dynamic glass	Electrochromic	• 4 tint levels. • Glare mode, daylight maximization mode, solar control mode, manual override operating modes.
Kinestral	Halio	Electrochromic	• 4 tint levels. • Automatic or manual override mode. • Faster tinting/untinting (<3 minutes claimed).
Pleotint	Suntuitive dynamic glass	Thermochromic	• Thermochromic layer integrated into laminate.
RavenWindow	RavenWindow	Thermochromic	• Thermochromic layer positioned on the gap-facing surface of insulated glass unit glass pane.

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review

Location	Application	Results	Reference
Denver, Colorado, USA	Field test, office setting Thermochromics Electrochromics	Thermocromics: projected 22% annual HVAC energy reduction, 47% reduction in peak cooling load, 21% reduction in heating gas use when used in conjunction with low-e glass. Electrochromics: 22% reduction in cooling energy use, 45% reduction in peak cooling load, when using no manual override.	[1]
Portland, Oregon, USA	Field Test, office setting Electrochromics	36% annual lighting energy savings due to daylight; 2% reduction in south zone VAV summer cooling load in normal operating mode; 57% reduction in weekend VAV summer cooling load when in setback mode with fully tinted electrochromics window .	[2]
Sacramento, California, USA	Field test, office setting Electrochromics	Daily HVAC load reduced by 29-65% (0.43-3.48 Wh/ft2); peak HVAC load reduced by 25-58% (1.15-5.63 W/ft2), 62% increase in lighting energy use (probably due to issues specific to this demonstration and not attributable to electrochromics technology as a whole).	[3]
Miramar, California, USA	Field test, office setting Electrochromics	29% reduction in HVAC energy use, 62% reduction in lighting energy use, total building energy savings of 28%.	[4]
Berkeley, California, USA	Laboratory test Electrochromics	19-26% annual peak cooling load reductions, 48%-67% lighting energy use savings.	[5]

References

[1] E. Lee, L. Fernandes, C. Goudey, C. Jonsson, D. Curcija, X. Pang, D. DiBartolomeo and S. Hoffmann, "A Pilot Demonstration of Electrochromic and Thermochromic Windows in the Denver Federal Center, Building 41,Denver, Colorado," General Services Administration, 2013.

[2] E. Lee, L. Fernandes, S. Touzani, A. Thanachareonkit, X. Pang and D. Dickerhoff, "Electrochromic Window Demonstration at the 911 Federal Building, 911 Northeast 11th Avenue, Portland, Oregon," General Services Administration, 2016.

[3] L. Fernandes, E. Lee, D. Dickerhoff, A. Thanachareonkit, T. Wang and C. Gehbauer, "Electrochromic Window Demonstration at the John E. Moss Federal Building, 650 Capitol Mall, Sacramento, California," General Services Administration, 2018.

[4] B. Tinianov, "Demonstration Program for Low-Cost, High-Energy-Saving Dynamic Windows," ESTCP Project EW-201252.

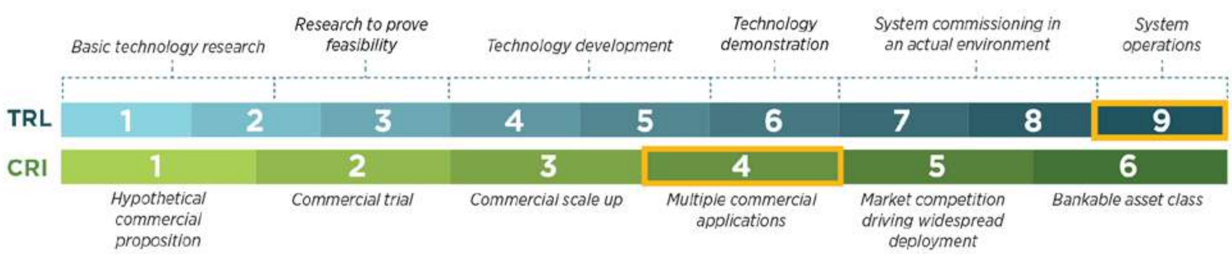
[5] E. Lee, S. Selkowitz, R. Clear, D. DiBartolomeo, J. Klems, L. Fernandes, G. Ward, V. Inkarojrit and M. Yazdanian, "Advancement of Electrochromic Windows," California Energy Commission report no. CEC-500-2006-052, 2006.

Technology Sector Windows Product Category Exterior Shading Last Updated 12/14/2018	 *Figure 1: Exterior shading mounted on a full-scale laboratory testbed (source: LBNL)*

Product Category Overview

Exterior window shading controls solar heat gains by preventing direct solar radiation from reaching the window. Exterior shading technologies can include attachments like louvers, awnings, and architectural/landscaping features such as overhangs or vegetation. Attachments can be static or dynamic, and dynamic attachments can be automated or operated manually. In cooling-dominated climates, exterior shading can be very cost-effective in reducing cooling energy consumption and is suitable for both new construction and retrofits.

Characterization at a Glance



Product Category Characterization

Energy Benefits

The main energy benefit is shielding the building from solar heat gains, therefore reducing cooling loads. For static shading devices, such as overhangs or fixed awnings, this benefit needs to be balanced with the energy penalty incurred during the heating season, when additional solar heat gains reduce the amount of heat that the HVAC system needs to provide. This poses less of an issue for dynamic shading, (such as operable/automated louvers/shutters) or deciduous vegetation. Shading systems, such as some types of shutters, that are placed close to the glazing and that cover its full area can provide additional thermal insulation by reducing airflow near the window.

Non-Energy Benefits

By shielding building occupants from direct sunlight, exterior shading can significantly reduce glare and increase thermal comfort. For systems that can reduce airflow near the window, the increased thermal insulation can reduce condensation on the interior surfaces of the window by decreasing the temperature difference between the interior surfaces of the window and indoor air.

Product Category Differentiation

Exterior shading can be divided into the following major categories of products (architectural features such as overhangs, light shelves, and vegetation are not included in this list):

- Awnings. This type of shading can be made of fabric or a rigid polymer. Fabric awnings can be retractable and/or automated.
- Louver systems (including some types of shutters). Louver systems include fixed louvers and moveable shutter panels (the latter are part of traditional forms of architecture in some parts of the world).
- Rolling shutters. Rolling shutters are comprised of narrow rigid panels that can be lifted and gathered at the top by mechanical action, powered manually or by a motor. When closed, some shutters can constrain air flow, reducing convection heat transfer through the window. Additionally, insulated rolling shutters are available in the market that provide additional thermal insulation.
- Exterior fabric shades (solar screens): These systems comprise fabric shades that can be rolled up or down according to how much of the window area needs to be shaded. They can be motorized and automated.

Installation Pathway and Dependencies

In general, these systems can be installed in both new construction and retrofit applications and are commercially available.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	**Model**	**Type**	**Differentiating Feature**
Warema	Renkhoff SE	Exterior venetian blinds (louver system)	• Choice of slat colors, finishes. • Motorized option available.
Eclipse Shading Systems	Eclipse Premier	Retractable Awning	• Motorized. • Choice of fabrics.
Rollac Rolling Systems	Rollac Retractable Awning	Retractable Awning	• Motorized option available. • Choice of fabrics.
Eclipse Shading Systems	E-zip Retention Cassette	Exterior solar screen	• Motorized with obstruction detection. • Insect-proof. • Choice of fabrics.
Rollac Rolling Systems	ZipShade Solar Shading	Exterior solar screen	• Motorized with obstruction detection. • Insect-proof. • Choice of fabrics.
Rollac Rolling Systems	Rollac SecuraMax	Rolling shutters	• Hurricane-resistant.

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review

Location	**Application**	**Results**	**Reference**
Berkeley, California, USA	Laboratory test Exterior solar screen	12%-24% cooling load reduction on sunny days, 26% reduction in peak summer cooling demand.	[1]
Berkeley, California, USA	Laboratory test Exterior shading	17%-42% energy savings compared to Title 24 2008, 15%-30% energy savings compared to Title 24 2013.	[2]

References

[1] E. Lee, A. Thanachareonkit, S. Touzani, S. Dutton, J. Shackelford, D. Dickerhoff and S. Selkowitz, "Technology Assessments of High Performance Envelope with Optimized Lighting, Solar Control, and Daylighting," PG&E's Emerging Technologies Program ET14PGE8571, LBNL-2001051, 2016.

[2] E. Lee, B. Coffey, L. Fernandes, S. Hoffmann, A. McNeil, A. Thanachareonkit and G. Ward, "High Performance Building Façade Solutions–Phase II," California Energy Commission, Publication number CEC-500-2015-033, 2014.

Technology Sector
Windows
Product Category
Highly Insulating Windows
Last Updated
12/14/2018

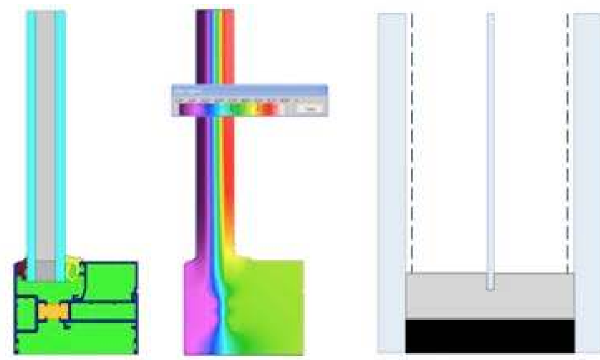


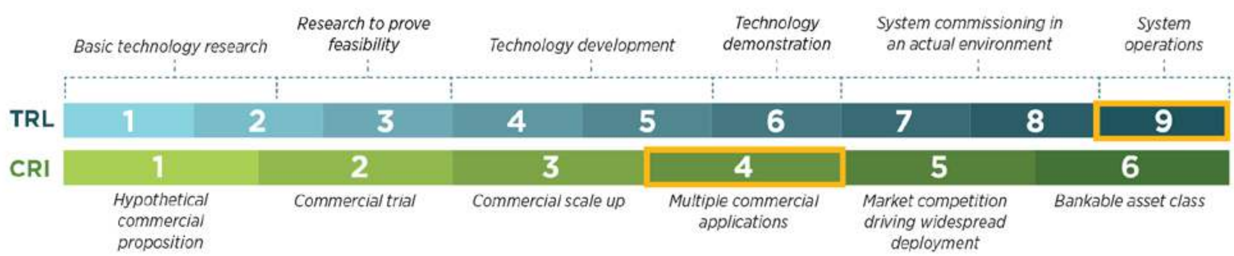
Figure 1: Thermally broken frame (left), thin glass triple window configuration (right) (source: LBNL).

Product Category Overview

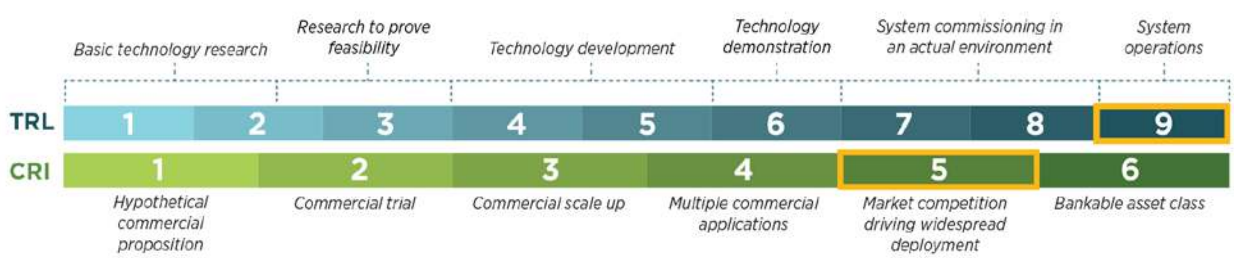
Highly insulating windows reduce energy consumption and increase occupant comfort by reducing transfer through the window when compared with conventional windows. This broad technology type comprises proven technologies such as low-emissivity glazing, suspended infared-reflective films ("heat mirrors"), and thermally broken frames, as well as more recent technologies such as thin-glass triple and vacuum-insulated windows. Secondary glazing systems (a.k.a. storm panels/windows) are another highly insulating option that is often economically attractive in retrofit situations.

Characterization at a Glance

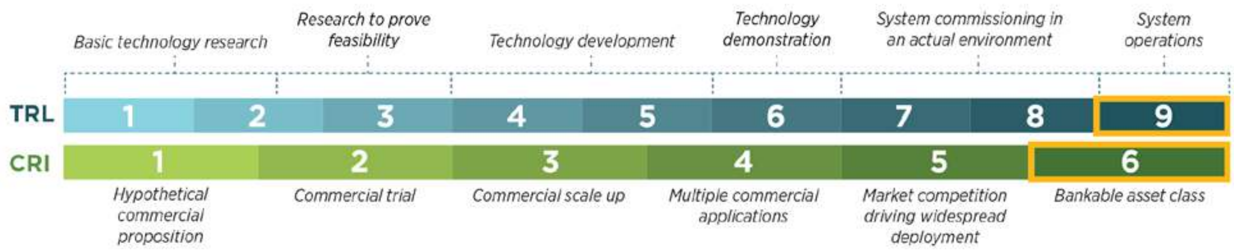
Thin triple glass and vacuum insulated windows:



Suspended film and secondary glazing systems:



All other types:



Product Category Characterization

Energy Benefits

Highly insulating windows comprise a broad range of technology options that can provide reductions in energy use for heating, cooling, and lighting while also increasing the comfort of building occupants.

Low-emissivity (low-e) coatings reduce heat transmission through windows by reducing the amount of heat that each coated glass pane radiates to the neighboring environment. In addition, spectrally-selective low-e coatings can block (in the case of low solar gain spectrally-selective low-e coatings) or allow (in the case of high solar gain spectrally-selective low-e coatings) the transmission of solar infrared radiation for applications in cooling- and heating-dominated climates respectively. In addition to being deposited on the window glass, low-e coatings can also be applied on polymer films suspended inside the between-pane cavity of an integrated glass unit (IGU). This arrangement, commonly referred to as "heat mirror," has the advantage of creating an additional cavity—and therefore providing additional thermal insulation—within the IGU without the added cost, weight, and structural requirements (e.g. thicker frame) of an additional glass pane. Low-e windows, both in conventional and in suspended film configuration, are an established technology with a significant number of manufacturers and commercially available products.

Thin glass triple windows are a more recent development in which a thin, non-structural layer of glass is mounted within the cavity of a standard double-pane IGU. This technology provides an additional option for implementing a double-cavity window that is more lightweight than standard triple-pane IGUs. Another more recent development is vacuum-insulated glazing (VIG). In this type of glazing, thermal conductance of the gap between glass panes is reduced by evacuating it below atmospheric pressure. Spacer elements need to be added to the gap in order to prevent the glass panes from warping. This type of glazing has the potential to insulate even better-than-standard triple-pane IGUs.

Secondary glazing systems (SGS), also known as storm windows or storm panels, are additional window panes that can be retrofit to the interior or exterior of existing windows. In this popular option for retrofits, the air gap between the original window and the new pane provides additional insulation. Low-e SGS are available that provide the insulation and solar control benefits of low-e coatings in addition to the insulation provided by the air gap.

Even if a highly energy-efficient glazing is used, heat transmission through window frames can significantly reduce the overall efficiency of a window if they are made of a highly conductive material such as metal. Metal frames have advantages in strength, durability, and maintenance that make them a popular choice for windows in many different applications. Thermally-broken frames contain insulating elements within the frame that significantly reduce heat flow through the window, thus combining the benefits of metal frames with improved thermal performance.

Non-Energy Benefits

Highly insulating windows can provide additional benefits besides lower energy consumption. Because of the additional insulation, the temperature of the indoor-facing glass pane is closer to the temperature of the indoor air. This increases the thermal comfort of space occupants by reducing drafts due to convection and also reducing the radiative heat exchange between occupants and the window surface. The reduction in temperature difference between interior-facing glass and room air also increases resistance to moisture condensation on the interior surfaces of window glazing and frames.

Product Category Differentiation

Highly insulating windows covered in this document comprise several different product categories:

- Standard low-e IGUs. These are usually double- or triple-pane. The low-e coating can be spectrally selective or not. Spectrally selective low-e coatings can be subdivided into high- and low-solar-gain coatings.
- Suspended film IGUs. They contain one or more suspended films with a low-e coating.
- Thin triple IGUs. These triple windows differ from standard triple IGUs in that the glass pane in the middle is much thinner than conventional glass, bringing the thickness of the IGU much closer to a standard double-pane IGU.
- Vacuum-insulated glazing. These IGUs have an evacuated between-pane gap, as well as structural elements throughout the glazing area that prevent warping due to the pressured difference between the gap and the outside of the IGU.
- Secondary glazing systems. These systems comprise additional panes that can be retrofit to the interior or exterior side of existing windows. They are available with a variety of tints and low-e coatings.
- Thermally-broken frames. The frames contain insulating elements that significantly lowers the thermal conductance of frames made of higher-conductance materials.

Installation Pathway and Dependencies

Most of these window technologies can be installed in both new construction and retrofit applications. Secondary glazing systems are applicable only to retrofit situations, and offer significant first cost advantages over a full window replacement. In some situations, e.g., where the existing frame is relatively well-insulating and has the required depth, it may be possible to achieve performance benefits by replacing the glass only, thus achieving a pathway that is a compromise between SGS and a full window retrofit.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	Model	Type	Differentiating Feature
Pilkington/NSG	SPACIA	Vacuum glazing	• Center pane U-value of 1.10 W/m^{2}K, SHGC is 0.67.
Eastman	Heat Mirror insulating glass	Suspended film	• U-value 0.39-1.72 W/m^{2}K, SHGC up to 0.19-0.55.
Alpen Window	N/A	Thin triple	• N/A
Arconic/Kawneer	Trifab 451UT	Thermally broken framing system	• Dual thermal breaks.

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review

Location	**Application**	**Results**	**Reference**
Berkeley, California, USA	Laboratory test Storm windows	Window U-factor reduced from 4.72 to 2.67-3.32 W/m^2K, SHGC reduced from 0.535 to 0.311-0.394.	[1]
Cook County, Illinois, USA	Field Test Low-e storm windows	21% heating load reduction	[2]
Berkeley, California, USA	Laboratory test Window frames with thermal breaks	Frame U-value in the 0.676 to 1.401 W/m^2K range	[3]
Berkeley, California, USA	Laboratory test Thin triple IGU	Center of glass U-factors as low as 0.57 W/m^2K	[4]

References

[1] J. Klems, "Measured winter performance of storm windows," ASHRAE Transactions 109, Part 2, LBNL-51453, 2002.

[2] S. Drumheller, C. Kohler and S. Minen, "Field evaluation of low-e storm windows," in *Proceedings of the Thermal Performance of the Exterior Envelopes of Whole Buildings X International Conference*, Clearwater Beach, FL, 2007.

[3] A. G. H. Gustavsen, D. Arasteh, S. Uvsløkk, G. Talev, B. Jelle and C. Kohler, "Experimental and numerical examination of the thermal transmittance of high performance window frames," in *Thermal Performance of the Exterior Envelopes of Whole Buildings XI International Conference*, Clearwater Beach, FL, 2010.

[4] D. Arasteh, H. Goudey and C. Kohler, "Highly Insulating Glazing Systems using Non-Structural Center Glazing Layers," in *2008 Annual ASHRAE Meeting, LBNL-611E*, Salt Lake City, UT, 2008.

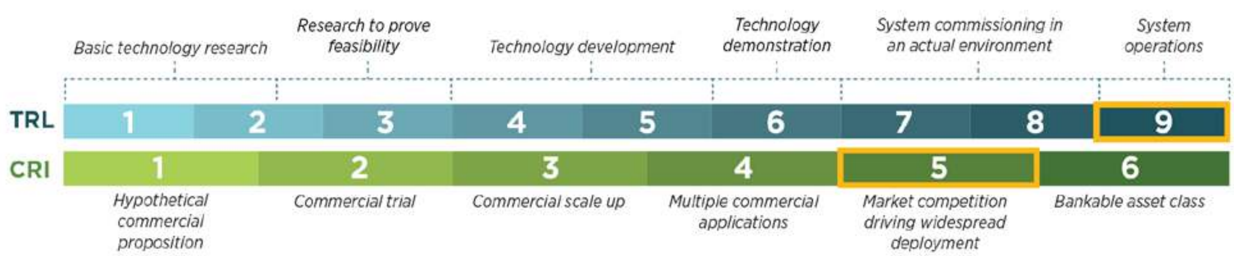
Product Characterization Report
California Energy Product Evaluation (Cal-EPE) Hub

Technology Sector Windows Product Category Retrofit Films Last Updated 12/14/2018	 *Figure 1: Window film being installed (source: http://ipf.msu.edu/green/practices/reflective-window-film.html)*

Product Category Overview

Solar control and low-emissivity (low-e) films can be applied to the exterior or interior surfaces of windows in order to improve their energy performance. Solar control films work mainly by reducing heat gains from direct solar radiation and they are most effective when applied to the exterior surface of windows. Low-e coatings reduce heat transmission through windows by reducing the amount of heat that each coated glass pane radiates to the neighboring environment. Different types of low-emissivity films are available, some aimed at solar control and others targeted at reducing heat losses. Films can provide a very cost-effective retrofit for existing windows.

Characterization at a Glance



Product Category Characterization

Energy Benefits

Retrofit films work by enhancing the solar control and/or thermal insulation properties of existing windows. These existing windows often perform quite poorly from an energy efficiency standpoint and therefore films can significantly improve their performance. Solar control films can reduce solar heat gain through a tint or a low solar gain low-e coating, the latter being the more energy-efficient method. Thermal insulation films reduce heat transfer through the window by means of a high solar gain, low-e coating. In order to minimize annual energy consumption, the properties of the film need to be tailored to the local climate and building characteristics, such as façade orientation and properties of the existing windows so that, for example, the cooling energy reductions in the cooling season are greater than the heating penalties in the heating season.

Non-Energy Benefits

Tinted films can reduce glare to the building occupants by reducing the brightness of the exterior environment as seen from the building interior. By blocking the infrared (IR) portion of direct solar radiation, solar control films can increase thermal comfort during the cooling season for occupants near the window.

Product Category Differentiation

Retrofit films can be divided into the following major categories of products:

- Tinted films. These films provide solar control by absorbing solar radiation. The most basic tinted films do not have low-e coatings. This limits their effectiveness at the thermal part of solar control because a significant part of the absorbed radiation can end up as heat radiated to the building interior.
- Low-e solar control films. This type of film has a coating that is optimized to not only significantly reduce thermal radiation but to also block the IR portion of direct solar radiation. These films can also be tinted in order to provide additional glare control.
- High-gain low-e films. These films are similar to low-e solar control films with the main difference that the low-e coating is optimized to allow solar IR transmission. These films are suitable for situations, such as heating-dominated climates or passive solar architecture, in which solar gains are beneficial.

Installation Pathway and Dependencies

Films are generally aimed at retrofit applications and are usually the least costly type of window retrofit.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	**Model**	**Type**	**Differentiating Feature**
Llumar/Eastman	SpectraSelect VS70 SR CDF	Solar control retrofit film	• Spectrally selective. • 5.0 W/m^{2}K U-value and 0.47 SHGC when installed on 3 mm single-pane clear glass.
3M	Sun Control Window Film Neutral 70	Solar control retrofit film	• 5.8 W/m^{2}K U-value and 0.68 SHGC when installed on 6 mm single-pane clear glass.

Quantification of Performance

A literature search was conducted and a sample of published study results are summarized in Table 2.

Table 2: Summary of results from literature review

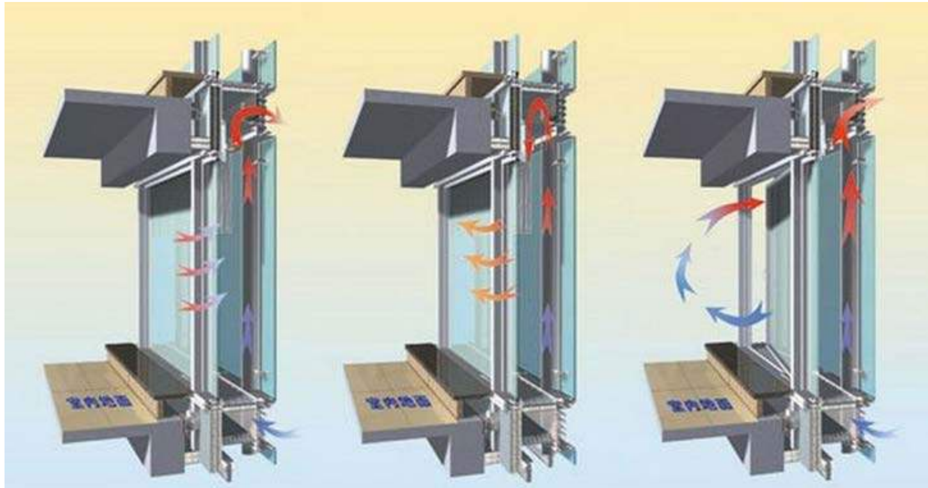
Location	**Application**	**Results**	**Reference**
Dallas, Texas, USA Ogden, Utah, USA	Field test Solar control film	6%-33% annual HVAC energy savings in perimeter zones, depending on the properties of the original window.	[1]
St. Louis, Missouri, USA	Field test Liquid applied solar control film	0%-8% cooling energy savings; net increase in total HVAC energy use due to heating Poor measured performance probably due to issues with particular product, which was an experimental film applied in liquid form; simulations indicate potential 3%-12% annual energy savings, depending on the properties of the original window.	[2]

References

[1] C. Curcija, H. Goudey and R. Mitchell, "Low-e applied film window retrofit for insulation and solar control," General Services Administration, 2017.

[2] C. Curcija, H. Goudey, R. Mitchell, L. Manes and S. Selkowitz, "Liquid-applied absorbing solar control window film retrofit," General Services Administration, 2014.

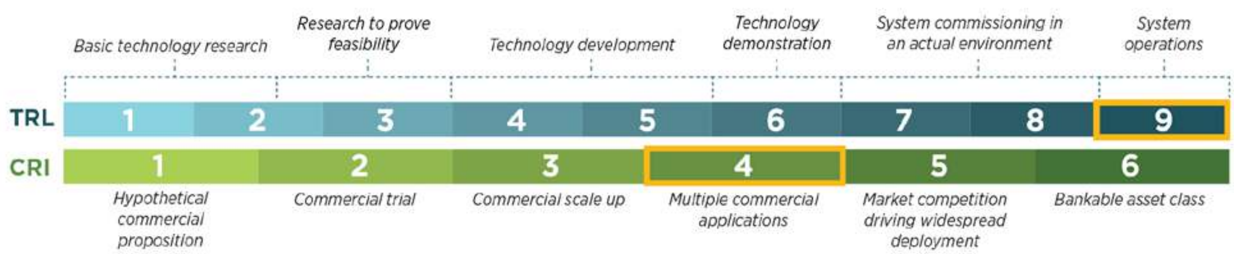
Product Characterization Report
California Energy Product Evaluation (Cal-EPE) Hub

Technology Sector Windows Product Category Ventilation Through the Facade Last Updated 12/17/2018	 *Figure 1: Façade-integrated ventilation (source: https://iitbuildingscience.wordpress.com/2013/10/10/double-skin-facade/)*

Product Category Overview

In mild climates, windows and skylights with integrated automated ventilation have the potential to greatly reduce or even eliminate the need for mechanical cooling. Manually operated windows and skylights have long been in existence. Available automated systems range from mechanical actuators which can be retrofitted to automatically operate existing windows to new windows with built-in automated ventilation.

Characterization at a Glance



Product Category Characterization

Energy Benefits

Ventilation through the façade can provide significant cooling to the interior of buildings. In sufficiently mild climates it can provide all the cooling needs of buildings, which then do not need conventional cooling systems. Before mechanical cooling systems were available, ventilation through the façade was the chief method through which interior thermal conditions were improved in hot weather. With the advent of mechanical HVAC, ventilation through the façade became less used, especially in commercial buildings. Since the fossil fuel crises of the 1970s, interest in ventilation through the façade has increased due to its potential for energy savings. A variety of add-on automated systems that can be retrofitted to existing fenestration have become available in the market, as well as new windows with integrated automation. Façade ventilation systems are also available that include air filtration and/or a degree of energy recovery (e.g. to preheat incoming air in order to reduce heating demand).

Non-Energy Benefits

Ventilation through the façade can increase occupant satisfaction with the interior environment by providing a better psychological connection with the outdoor environment. Significant cost savings can be achieved if ventilation through the façade results in a downsizing of the HVAC equipment.

Product Category Differentiation

Ventilation through the façade products can be divided into the following major categories (conventional, manually-operated windows and skylights are excluded from this list):

- Retrofit motorized systems. These products allow motorizaton of existing windows. Some systems allow automated operation based on schedule or ambient conditions like interior/exterior temperature and incident solar radiation.
- Motorized windows. These are windows that have the ability to open and shut by means of an integrated motor. They can be operated manually or automatically.
- Windows with integrated ventilation. These products are fixed (i.e. non-operable) windows that have integrated ventilation openings. These openings can be operated manually or automatically.
- Façade systems with integrated ventilation. These are used in energy-efficient commercial buildings and are usually highly customized systems; their design and implementation will often require the participation of architects and/or engineers with specialized knowledge.

Installation Pathway and Dependencies

Retrofit motorized systems are aimed at retrofitting existing windows and skylights. Motorized windows and windows with integrated ventilation can be both used in retrofits and new construction. Façade systems with integrated ventilation are more common in new construction, but may be feasible for major retrofits.

List of Products

Table 1: Summary of manufacturers and products for the product category.

Manufacturer	**Model**	**Type**	**Differentiating Feature**
Architectural Applications (A2)	AirFlow Panels	Façade with integrated ventilation	• Opaque façade enthalpy recovery ventilation. • Available in new construction and retrofit configurations.
Schüco	Vent AWS VV	Window-/façade-integrated ventilation	• Available in manually-operated and automated versions.
Amesbury Truth	Marvel Motorized Operators	Power operator for windows and skylights	• Maximum 9.5 inches of chain travel. • Controllable from wall switch/RF remote. • Rain sensor can trigger automatic closing for protection.

Quantification of Performance

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Table 2: Summary of results from literature review

Location	**Application**	**Results**	**Reference**
Stuttgart, Germany	Field/simulation study Window ventilation	No mechanical cooling required.	[1]
California, USA	Simulation Natural ventilation	25%-44% cooling energy savings; 17% total energy savings.	[2]

References

[1] T. Schulze, D. Gürlich and U. Eicker, "Performance assessment of controlled natural ventilation for air quality control and passive cooling in existing and new office type buildings," *Energy and Buildings,* vol. 172, pp. 265-278, 2018.

[2] Linden, P; et al., "Natural Ventilation for Energy Savings in California Commercial Buildings," University of California, San Diego.