Window Technology Pathways

Methodology for Analyzing Certified Product Data

ENERGY STAR Windows, Doors and Skylights

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Executive Summary

This paper proposes a new approach to analyzing product data from the National Fenestration Rating Council (NFRC) Certified Product Directory (CPD). D+R International developed this methodology on behalf of the U.S. Environmental Protection Agency (EPA) to better understand the variety of window technologies that manufacturers have certified and which combinations of technologies are used to achieve different performance levels. In the future, this methodology may be used in conjunction with other data and analyses as part of specification revisions for the ENERGY STAR program for windows, doors, and skylights.

This methodology identifies technology “pathways,” which are defined as distinct combinations of the following components and characteristics: operator type, frame material, spacer system, glass configuration, and gas fill. The methodology will enable EPA to analyze the pathways that can be used to achieve different U-factor and solar heat gain coefficient (SHGC) ratings, the distribution of performance within each pathway, and how common each pathway is compared to other pathways. The main body of this paper describes the methodology; Appendix A: Pathways Methodology Details provides greater detail on how different components were combined into categories; and Appendix B: Sample Heat Maps presents sample performance distributions.

EPA is sharing this methodology with program stakeholders in the spirit of transparency and collaboration, and is interested in feedback on the methodology. The methodology does not expose any proprietary information because it does not identify any specific manufacturers, product lines, or product options.

Background

U.S. building codes require NFRC certification for residential fenestration products. This requirement makes the NFRC’s CPD the definitive source for fenestration product data. The CPD, which is publicly available, houses independently certified data on the configurations, component materials, and performance ratings of every fenestration product on the U.S. market. EPA’s ENERGY STAR Windows, Doors, and Skylights Program also requires products be NFRC certified, and manufacturers must identify product lines that they label with ENERGY STAR as part of NFRC’s Independent Verification Program (IVP). As of December 2015, the CPD contained data on approximately 7.8 million window options from 2,769 distinct ENERGY STAR product lines submitted by 203 manufacturers.

For previous specification revisions, EPA analyzed the CPD to determine whether products could be produced to meet proposed performance levels and what the technical characteristics of those products were. Stakeholders have noted that the CPD includes product lines and options that are not available on the market, and that relying on raw CPD data can skew an assessment of available window technologies. EPA is aware that manufacturers sometimes certify lines and options that they do not currently produce, such as the same product with components from a variety of suppliers, and EPA recognizes that the presence of a particular option in the CPD does not guarantee that the option is available for purchase. However, if an option is certified by the NFRC, then the product is technically feasible and could be manufactured. In addition, if the product line is enrolled in IVP, EPA believes that it is likely that the manufacturer is currently producing some of the options in that line.

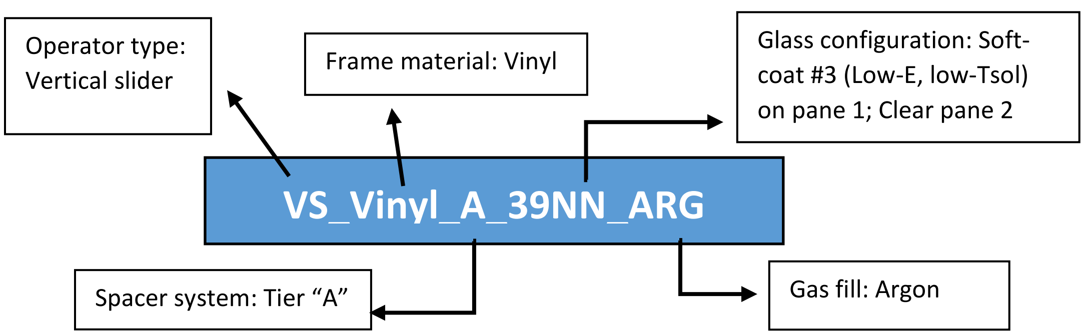
Other ENERGY STAR product categories require that manufacturers report to their certification body all of the individual models that they label. However, EPA recognizes that such a requirement would be especially burdensome for window, door, and skylight manufacturers that offer a large number of product options. EPA believes that the alternative approach described here will be less burdensome for manufacturer partners and serve as a reasonable proxy for product availability.

EPA believes that using this methodology is the best currently available approach to identify the technology pathways that are capable of achieving a given performance level and will help to distinguish common pathways from those that are uncommon. For future specification revisions, EPA intends to supplement this methodology with additional research and seek targeted stakeholder feedback to learn more about particular pathways, including costs and availability of components.

Pathways Methodology

Each pathway represents a unique combination of the following elements: operator type, frame material, spacer system, glass configuration (including low-emissivity coatings), and gas fill. These variables are key drivers of U-factor performance in a window system. Pathways are described with text strings, as shown in Figure 1:

Figure 1: Pathway Anatomy



Pathways were assembled using the following process:

1) In December 2015, EPA requested from NFRC a copy of the CPD data for all ENERGY STAR product lines (product lines identified as having ENERGY STAR certified options as part of the IVP program).
2) EPA analyzed the data to identify similarities among different operator types, frame materials, glass configurations, spacer systems, and gas fills. EPA grouped some variables based on descriptive characteristics and combined other variables based on analysis of performance similarities. [1]
3) Using data queries, EPA assigned each window option in the database to a pathway. EPA also assigned each option to performance bins for U-factor and solar heat gain coefficient (SHGC).

[1] Descriptions of NFRC codes are taken from http://www.nfrc.org/CMA/docs/NFRC-Certified-Products-Directory-Code-Listing-as-of-2012-08-08.pdf

4) Finally, EPA used Microsoft Excel's Power Pivot function to count the number of distinct options at each performance level for each pathway, as well as the numbers of distinct product lines and manufacturers that contain an option at each performance level for each pathway.

The specific methodology for defining categories for each variable is described in greater detail below.

Operator type

NFRC defines 22 window operator types. These operator types were grouped into four categories based on NFRC's descriptions: Casement, Fixed, Horizontal Slider, and Vertical Slider. Casement and projection-style products were combined in the same category because of their similar operation. Doors, skylights, sidelites, transoms, and other specialized operator types, including bay and tilt-and-turn windows, were not included when developing the methodology. See Table 4 in Appendix A for a complete list of operator types by NFRC code and description.

Frame material

NFRC defines 45 frame materials. These were grouped into six categories based on NFRC's description: Aluminum, Composite, Fiberglass, Vinyl, Wood, and Other.

NFRC's codes specify additional distinctions in frame design, including reinforcement, cladding, thermal breaks, and foam filling. These distinctions affect performance to varying degrees; however, EPA understands that differences in frame design among product lines and manufacturers have a greater effect on performance. The CPD does not explicitly measure the thermal properties of the frame, but those properties are implicit in the simulated results for a product line. This methodology enables EPA to see that some pathways have a wide range of performance, despite holding the rest of the variables constant. This is partially a result of differences in frame thermal performance. See Table 5 in Appendix A for a complete list of frame materials by NFRC code and description.

Spacer system

NFRC defines 56 different spacer systems. The critical characteristic of the spacer for the purpose of this methodology is its impact on the thermal performance of the window. Spacers can have a continuous range of thermal conductivity based on their size and other external factors. In the literature, spacer performance is reported as effective conductivity (K_{eff}), equivalent conductivity (λ_{eq}), or both. (Because of different calculation methods, these metrics are not directly comparable).

Drawing on research from Van Den Bergh, et al., EPA grouped spacer systems into performance tiers based on physical descriptions and the cited K_{eff} and λ_{eq} thermal conductivity ratings.[2] EPA matched the product types and brand names from Van Den Bergh with the descriptions provided by NFRC. When an exact match was not available, EPA assigned the thermal conductivity ratings of a spacer system with a similar material and description. EPA sorted the list of available spacer systems into four performance tiers based on thermal conductivity. See Table 6 in Appendix A for a complete list of spacer systems and associated performance ratings and tiers.

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[2] See Table 2 (pp. 15-19) in Van Den Bergh, et al., "Window Spacers and Edge Seals in Insulating Glass Units: A State-of-the-Art Review and Future Perspectives," LBNL-6122E, published in *Energy and Buildings* 58 (2013) 263-280.

Table 1: Spacer System Performance Tiers

Category	Description
Tier A	Nonmetal spacers of different materials with thermal conductivity less than 0.2 W/(mK)
Tier B	U-shaped stainless steel spacers and thermoplastic spacers with thermal conductivity between 0.2 and less than 0.4 W/(mK)
Tier C	Metal spacers, including U-shaped coated steel, with thermal conductivity between 0.4 and 1 W/(mK)
Tier D	Poor-performing metal spacers with thermal conductivity greater than 1 W/(mK).

Glass configuration

The CPD includes certified products with 1-5 panes; however, the majority are double-pane and triple-pane windows. The CPD identifies each glazing layer in a window with a numeric code that can be matched with a glazing material in the International Glazing Database (IGBD). The IGDB provides performance ratings for emissivity, solar transmittance, and visual transmittance, and contained more than 3,000 glazing options as of August 2016.[3] EPA noted that there are glazing materials identified in the December 2015 CPD that are not active in the August 2016 IGDB, likely because the databases are updated on different schedules; therefore, EPA included only those options that were listed in both databases.

EPA grouped glazing materials into performance bins based on three factors: description of the glazing option, minimum emissivity rating, and solar transmittance rating. EPA surveyed the websites of major glazing suppliers and identified descriptions of materials and applications that were common across multiple manufacturers, such as "soft" sputter coatings and "hard" pyrolytic coatings. Using these guideposts, EPA identified distinct differences in the emissivity and solar transmittance of products that met those descriptions. EPA defined performance bins based on those observations and assigned glazing options to one of 12 categories. Table 2 presents a summary of codes, categories, and descriptions.

Table 2: Glass Categories

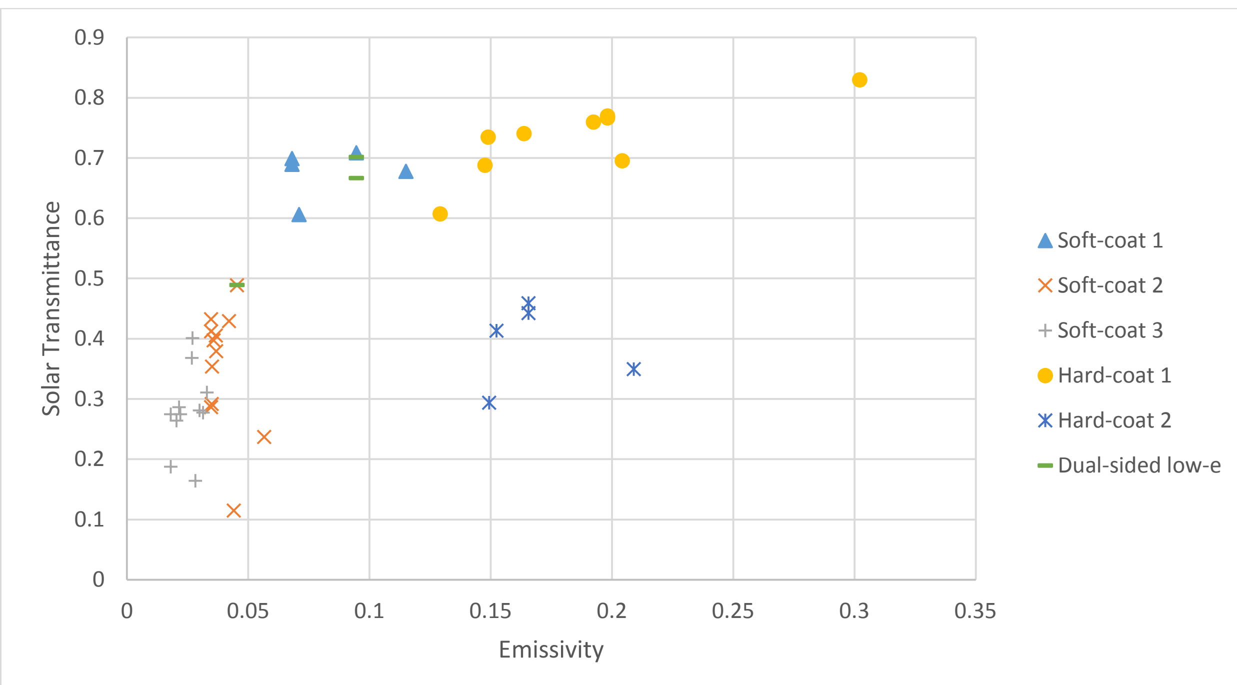
Code	Category Name	Description
1	Soft-coat 1	Soft-coat low-e glass with emissivity between 0.06 and 0.12 and solar transmittance greater than 0.50
2	Soft-coat 2	Soft-coat low-e glass with emissivity between 0.033 and 0.06 and solar transmittance less than 0.50
3	Soft-coat 3	Soft-coat low-e glass with emissivity less than 0.033 and solar transmittance less than 0.50
4	Hard-coat 1	Hard-coat low-e glass with emissivity greater than 0.12 and solar transmittance greater than 0.50; intended for exposed surface applications

[3] Lawrence Berkeley National Laboratories. IGDB Version 49.0. Accessed August 2016 from http://windowoptics.lbl.gov/data/igdb

Code	Category Name	Description
5	Hard-coat 2	Hard-coat low-e glass with emissivity greater than 0.12 and solar transmittance less than 0.50
6	Dual-sided low-e	Specialty glazing with low-e coatings on both sides of the glass
7	Suspended film 1	Internally-mounted low-e film
8	Suspended film 2	Internally-mounted film with low conductivity but high emissivity
9	Clear glass	Glazing with no low-emissivity coating, but may include reinforced, tinted, or colored glass
E	Electrochromic	Glazing that changes shade in response to an electric signal
L	LBNL experimental	Fritted glazing materials used for experimental purposes
T	Thermochromic	Glazing that changes shade in response to temperature
N	No-Glass	No glazing used for the layer

Figure 2: Performance of Glass Options by Category shows the emissivity and solar transmittance of active glass options for some of the categories defined above. Clear glass options, which are not shown, have emissivity ratings greater than 0.80 and a wide range of solar transmittance. To limit duplicates, only glass options with thickness between 2.8 mm and 3 mm were included in the graph. The 'Hard-coat 2' category was an exception because it consisted of products with a wider range of thicknesses; Figure 2 shows all 'Hard-coat 2' options. See Figure 3 in Appendix A for the scatter plot of glass options of all thicknesses.

Figure 2: Performance of Glass Options by Category



After assigning a category code to each glazing option, EPA concatenated the codes into text strings that represent the complete glass configuration for the product. For example, a glass code of 99NN signifies a dual-pane window with clear glass on both panes. 19NN indicates a glass option with a soft-coat 1 on the first pane and a clear glass option on the second pane. This approach does not specify the surface of the low-emissivity coating, but the coating surface can be deduced by the glass category for most applications. For example, soft-coat options are generally used only on non-exposed surfaces; therefore, any double-pane configurations with categories 1, 2, or 3 on the second pane can be assumed to have the low-emissivity coating on surface 3, not surface 4. See Table 7 in Appendix A for the list of all double-pane glass configurations.

Gas fill

There are four general categories of gas fill options in the CPD: air, argon and air mixed, krypton and air mixed, and "AR3" – a mix of air, argon, and krypton. EPA recognizes that within those categories, manufacturers use a variety of fill percentages. EPA combined different fill percentages into aforementioned general categories for simplicity.

Variables not included

By choosing to combine similar components into general categories, EPA excluded some variables that can impact performance. These variables, such as fill percentage, gap width, glass thickness, grids, and tints, are secondary to other design decisions or have a negligible effect on performance. For example, gap width is influenced by the profile of the frame, type and size of the spacer, thickness of the glass, and gas fill (each gas has a different optimal width for thermal performance). Grids and tints – which are aesthetic choices – can reduce SHGC and visual transmittance, but have a minimal impact on U-factor. This data is included in the CPD and can be incorporated in the future if necessary.

U-factor and solar heat gain coefficient

In the CPD, the rated U-factor is given for up to six decimal places for some products; however, ENERGY STAR only specifies two decimal places in its criteria. For this methodology, EPA rounded the rated U-factor for each product option to two decimal places.

To understand the distribution of SHGC at different U-factors, EPA grouped products into four SHGC bins that correspond to the Version 6.0 ENERGY STAR criteria: High SHGC (>0.40), Medium SHGC (0.26 – 0.40), Low SHGC (0.20 – 0.25), and Very Low SHGC (<0.20). The SHGC bins provide another dimension to analyze the performance of different pathways.

Counting options, product lines, and manufacturers

After defining categories for each of the components and characteristics defined above, EPA assigned a complete pathway code to each product option. EPA then used Microsoft Excel's Power Pivot function to count the number of options that manufacturers have certified at each U-factor and SHCG performance level for each pathway.

However, the number of options can be misleading on its own. Manufacturers who simulate many variations within a product line can skew the count of options, giving the impression that a particular pathway or performance level is more common than it actually is. There is no standard approach for simulating product lines – the number of options per product line varies from 1 to more than 180,000.

To control for this variability, EPA also counted the number of distinct product lines and manufacturers at each performance level. Each option in the CPD has only one performance rating, but manufacturers may have multiple options from the same pathway in the same product line. For example, Table 3 shows that there are 38 manufacturers and 103 product lines with a product at U-factor 0.29, but only 3 manufacturers and 4 product lines with the same pathway at 0.25. Comparing the three types of performance distributions can help EPA identify instances where a small number of manufacturers certified the majority of the options at a given performance level.

Table 3: Example Comparison of Performance Distributions for Options, Product Lines, and Manufacturers

	0.25	0.26	0.27	0.28	0.29	0.3	0.31	0.32	0.33	0.34	0.35
Product Options	64	651	1,672	7,053	7,541	5,924	2,574	1,098	746	972	658
Product Lines	4	23	46	103	103	85	60	32	33	26	23
Manufacturers	3	14	19	42	38	33	18	12	14	11	9

Request for Feedback

This methodology will enable EPA to analyze the performance that different combinations of technologies can deliver and to generate tables and graphs that illustrate performance distributions for products with a variety of characteristics.

For potential ENERGY STAR specification revisions in the future, EPA believes that this methodology could be used to assess what pathways are technically feasible at different performance levels. It is reasonable to assume that these products are (or could be) manufactured because the products come from lines that manufacturers have indicated they are currently manufacturing and labeling as ENERGY STAR certified. Furthermore, EPA believes that pathways with many certified options are commonly used by manufacturers. This analysis is not intended to reflect sales or market share; EPA understands that additional research would be needed to confirm that certain products are available in the market. Combining the technology pathways analysis with component cost data and other input from stakeholders can help EPA make better decisions regarding future specification revisions.

EPA intends to develop a complete analysis based on this methodology using available CPD data in 2017. Prior to proceeding with such an analysis, EPA would greatly appreciate feedback on the methodology from stakeholders, including answering the following questions:

- Did EPA combine product characteristics into categories in an appropriate and accurate manner?
- Are there additional key product characteristics that should be included in the pathways?
- In the absence of a complete list of available product options, will this methodology provide a reasonable proxy to assess product availability?

To provide full transparency to the process, EPA can release a spreadsheet analysis with complete performance distributions based on the December 2015 CPD. EPA can also release this type of spreadsheet analysis for future versions of the CPD. As discussed above, the analysis is based on publicly available data and does not expose any proprietary information. However, EPA wants to provide an opportunity for stakeholders to explain any concerns they might have before it releases such an analysis.

Please submit all feedback in writing to windows@energystar.gov by February 3, 2017.

Appendix A: Pathways Methodology Details

The following appendix presents details on how EPA developed component categories for the pathways methodology.

Operator type analysis

Out of 22 window operator types defined by NFRC, 14 operator types had at least one certified window option in the December 2015 CPD.[4] Table 4 provides a complete list of operator type codes and corresponding categories.

Table 4: Operator Type Categories

NFRC Code	NFRC Description	Pathway
CSDV	Casement – Double Vent	CM
CSOX	Casement – Vent/Fixed	CM
CSSV	Casement – Single Vent	CM
PRAW	Projected – Awning	CM
FIGS	Fixed – Multiple shapes	FX
FIXD	Fixed – 4-sided	FX
FXEL	Fixed – Elliptical	FX
FXGS	Fixed – Non-standard shape	FX
FXHR	Fixed – Half-round	FX
HSOX	Horizontal Slider – Fixed/Operable	HS
HSXX	Horizontal Slider – Operable	HS
VSDH	Vertical Slider – Double-hung	VS
VSSH	Vertical Slider – Single-hung	VS
VSUN	Vertical Slider – Unknown	VS

Other window operator types with no active ENERGY STAR product options: CSTH, CSUN, PRFX, PROJ, PRUN, PVHR, PVVT, FIUN, HSUN.

Frame material analysis

Out of 45 frame materials defined by NFRC, 31 had at least one certified window option in the December 2015 CPD. The vast majority (93%) of options fell into either the Wood or Vinyl categories. Table 5 provides a complete list of frame materials available in the CPD and their corresponding pathway category.

[4] All NFRC CPD codes and descriptions referenced in Appendix A are taken from http://www.nfrc.org/CMA/docs/NFRC-Certified-Products-Directory-Code-Listing-as-of-2012-08-08.pdf

Table 5: Frame Material Categories

NFRC Code	NFRC Description	Pathway
AL	Aluminum (non-thermally broken)	Aluminum
AP	Aluminum w/ partial thermal breaks	Aluminum
AT	Aluminum w/ thermal breaks	Aluminum
AU	Thermally-improved aluminum	Aluminum
AV	Aluminum/vinyl composite	Aluminum
AW	Aluminum-clad wood	Wood
CO	Vinyl/wood composite material	Composite
CP	Cellular PVC	Other
CW	Copper-clad wood	Wood
FF	Fiberglass w/ foam-filled insulation	Fiberglass
FG	Fiberglass	Fiberglass
N	Not applicable	Other
OT	Other	Other
PF	ABS plastic w/ foam-filled insulation	Other
PL	ABS plastic (no reinforcement)	Other
PW	ABS plastic-clad wood	Wood
VA	Vinyl w/ all members reinforced	Vinyl
VC	Vinyl-clad aluminum	Aluminum
VF	Vinyl w/ foam-filled insulation	Vinyl
VH	Vinyl w/ horizontal members reinforced	Vinyl
VI	Vinyl w/ interlock members reinforced	Vinyl
VP	Vinyl w/ partial reinforcement	Vinyl
VV	Vinyl w/ vertical members reinforced	Vinyl
VW	Vinyl-clad wood	Wood
VY	Vinyl (no reinforcement)	Vinyl
WA	Aluminum/wood combination	Wood
WC	Composite/wood combination	Wood
WD	Solid wood	Wood
WF	Fiberglass/wood combination	Wood
WP	ABS plastic/wood combination	Wood
WV	Vinyl/wood combination	Wood

Other window frame materials with no active ENERGY STAR product options: AB, AI, AS, BR, BP, BT, PA, PC, PH, PI, ST.

Spacer system analysis

Out of 56 spacer systems defined by NFRC, 26 had at least one certified window option in the CPD as of December 2015. Table 6 provides a complete list of spacer systems and associated performance rating and tiers.

Table 6: Thermal Conductivity Ratings for Spacer Systems

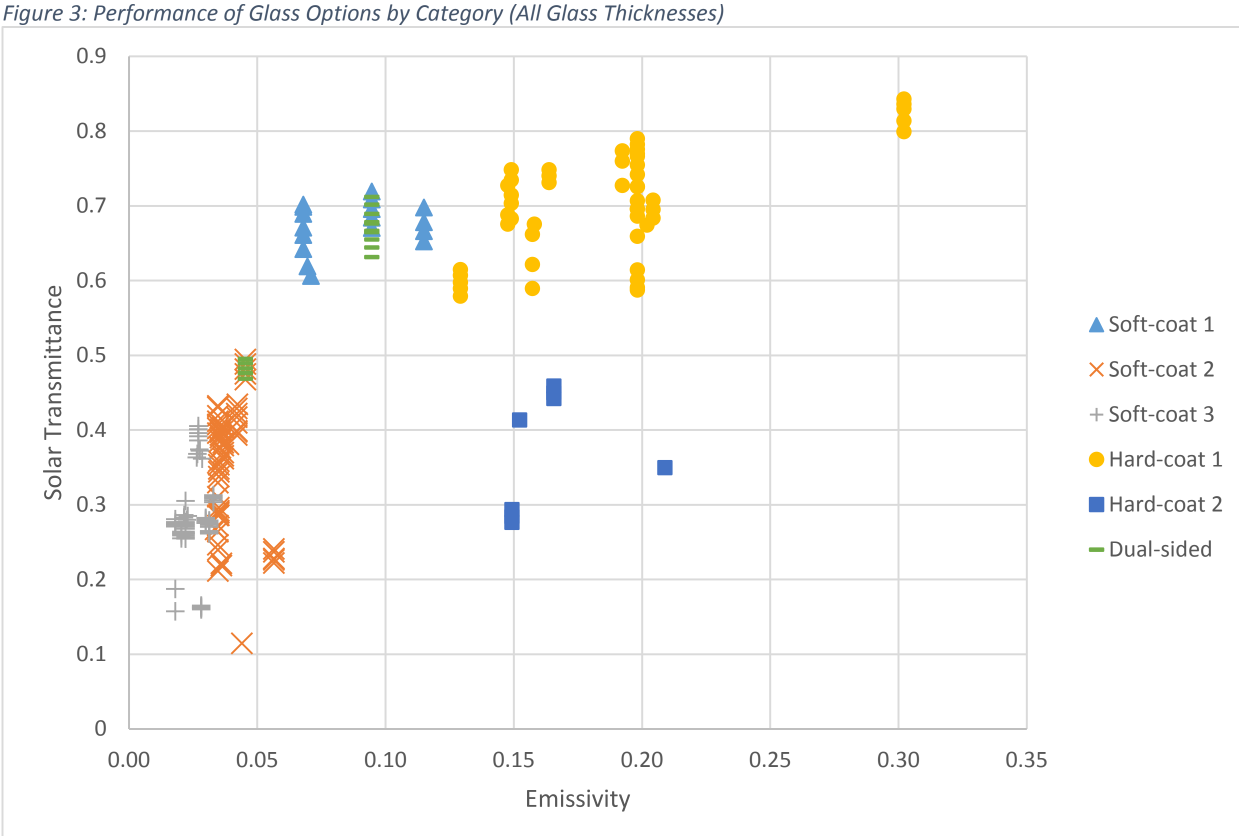
Code	NFRC Description	Category	keff[1] (W/(mK))	λeq[1] (W/(mK))
N	Not applicable	X	-	-
P1-S	Polycarbonate - Butyl Composite - Single Sealed	A	0.08 - 0.13	-
P1-D	Polycarbonate - Butyl Composite - Dual Sealed	A	0.08 - 0.13	-
ZF-S	Silicone Foam - Single Sealed	A	0.16	0.05
ZE-S	Elastomeric Silicone Foam - Single Sealed	A	0.16	0.05
ZF-D	Silicone Foam - Dual Sealed	A	0.16	0.05
ZE-D	Elastomeric Silicone Foam - Dual Sealed	A	0.16	0.05
OF-S	Organic Foam - Single Sealed	A	0.18	0.07
OF-D	Organic Foam - Dual Sealed	A	0.18	0.07
PU-S	Polyurethane Foam - Single Sealed	A	0.18	-
SU-D	Stainless Steel U Shaped - Dual Sealed	B	0.25	-
SU-S	Stainless Steel U Shaped - Single Sealed	B	0.27	0.26
TP-D	Thermoplastic - Dual Sealed	B	0.26 - 0.28	0.21
TP-S	Thermoplastic - Single Sealed	B	0.26 - 0.28	0.21
TS-D	Thermoplastic with stainless steel substrate - Dual Sealed	B	-	0.34
TS-S	Thermoplastic with stainless steel substrate - Single Sealed	B	-	0.34
SS-D	Stainless Steel - Dual Sealed	C	0.40 - 0.80	-
SS-S	Stainless Steel - Single Sealed	C	0.50 - 1.0	-
S6-D	Steel U Channel w/thermal cap - Dual Sealed	C	0.40	-
A8-S	Aluminum Butyl Composite - Single Sealed	C	0.32 - 0.45	-
A8-D	Aluminum Butyl Composite - Dual Sealed	C	0.32 - 0.45	-
A5-D	Aluminum-Reinforced Butyl - Dual Sealed	C	0.57	0.81
CU-D	Coated Steel U Shaped - Dual Sealed	C	0.62	1.8
A5-S	Aluminum-Reinforced Butyl - Single Sealed	C	0.53	-
CU-S	Coated Steel U Shaped - Single Sealed	C	0.56	-
CS-D	Coated Steel - Dual Sealed	D	1.5 - 2.0	-
A1-D	Aluminum - Dual Sealed	D	1.8 - 3.0	-
A1-S	Aluminum - Single Sealed	D	3.0 - 7.6	-

[1] Table 2 (pp. 15-19) in Van Den Bergh, et al., "Window Spacers and Edge Seals in Insulating Glass Units: A State-of-the-Art Review and Future Perspectives," LBNL-6122E, published in *Energy and Buildings* 58 (2013) 263-280.

Glass configuration analysis

The December 2015 CPD referenced 739 different glazing materials for windows, but only 409 were active in the IGDB at the time of the analysis. Approximately 18% of double-pane windows and 8% of triple-pane windows in the CPD used a glazing layer that could not be matched to an active glazing layer in the IGDB. These options were excluded from the pathways analysis at this time. Figure 3 illustrates the performance of the same glass categories shown in Figure 2 but for all available thicknesses.

Figure 3: Performance of Glass Options by Category (All Glass Thicknesses)



Based on the 12 general glazing categories, EPA identified a total of 48 double-pane glass configurations and 95 triple-pane glass configurations active in the CPD. Table 7 provides a complete list of active double-pane configurations.

Table 7: Double-Pane Glass Configurations as of December 2015

Code	Description
11NN	Soft-coat 1 on outside pane; Soft-coat 1 on inside pane
13NN	Soft-coat 1 on outside pane; Soft-coat 3 on inside pane
14NN	Soft-coat 1 on outside pane; Hard-coat 1 on inside pane
19NN	Soft-coat 1 on outside pane; Clear Glass on inside pane
1LNN	Soft-coat 1 on outside pane; LBNL Experimental on inside pane
1TNN	Soft-coat 1 on outside pane; Thermochromic on inside pane
21NN	Soft-coat 2 on outside pane; Soft-coat 1 on inside pane
22NN	Soft-coat 2 on outside pane; Soft-coat 2 on inside pane
23NN	Soft-coat 2 on outside pane; Soft-coat 3 on inside pane
24NN	Soft-coat 2 on outside pane; Hard-coat 1 on inside pane
26NN	Soft-coat 2 on outside pane; Dual-sided Low-e on inside pane
29NN	Soft-coat 2 on outside pane; Clear Glass on inside pane
2LNN	Soft-coat 2 on outside pane; LBNL Experimental on inside pane
2TNN	Soft-coat 2 on outside pane; Thermochromic on inside pane
31NN	Soft-coat 3 on outside pane; Soft-coat 1 on inside pane
32NN	Soft-coat 3 on outside pane; Soft-coat 2 on inside pane
33NN	Soft-coat 3 on outside pane; Soft-coat 3 on inside pane
34NN	Soft-coat 3 on outside pane; Hard-coat 1 on inside pane
35NN	Soft-coat 3 on outside pane; Hard-coat 2 on inside pane
36NN	Soft-coat 3 on outside pane; Dual-sided Low-e on inside pane
39NN	Soft-coat 3 on outside pane; Clear Glass on inside pane
3LNN	Soft-coat 3 on outside pane; LBNL Experimental on inside pane
3TNN	Soft-coat 3 on outside pane; Thermochromic on inside pane
41NN	Hard-coat 1 on outside pane; Soft-coat 1 on inside pane
44NN	Hard-coat 1 on outside pane; Hard-coat 1 on inside pane
49NN	Hard-coat 1 on outside pane; Clear Glass on inside pane
53NN	Hard-coat 2 on outside pane; Soft-coat 3 on inside pane

Code	Description
59NN	Hard-coat 2 on outside pane; Clear Glass on inside pane
91NN	Clear Glass on outside pane; Soft-coat 1 on inside pane
92NN	Clear Glass on outside pane; Soft-coat 2 on inside pane
93NN	Clear Glass on outside pane; Soft-coat 3 on inside pane
94NN	Clear Glass on outside pane; Hard-coat 1 on inside pane
95NN	Clear Glass on outside pane; Hard-coat 2 on inside pane
96NN	Clear Glass on outside pane; Dual-sided Low-e on inside pane
99NN	Clear Glass on outside pane; Clear Glass on inside pane
9LNN	Clear Glass on outside pane; LBNL Experimental on inside pane
9TNN	Clear Glass on outside pane; Thermochromic on inside pane
L1NN	LBNL Experimental on outside pane; Soft-coat 1 on inside pane
L2NN	LBNL Experimental on outside pane; Soft-coat 2 on inside pane
L3NN	LBNL Experimental on outside pane; Soft-coat 3 on inside pane
L4NN	LBNL Experimental on outside pane; Hard-coat 1 on inside pane
L9NN	LBNL Experimental on outside pane; Clear Glass on inside pane
LLNN	LBNL Experimental on outside pane; LBNL Experimental on inside pane
T1NN	Thermochromic on outside pane; Soft-coat 1 on inside pane
T2NN	Thermochromic on outside pane; Soft-coat 2 on inside pane
T3NN	Thermochromic on outside pane; Soft-coat 3 on inside pane
T4NN	Thermochromic on outside pane; Hard-coat 1 on inside pane
T9NN	Thermochromic on outside pane; Clear Glass on inside pane
X	All glass configurations with an unknown glazing layer

Appendix B: Sample Heat Maps

The following section provides illustrative examples of analyses that are possible using the pathways methodology. Using Microsoft Excel conditional formatting, EPA applied shading to the cells to show a darker color when there are more options certified at that performance level. The result is a "heat map" that illustrates the distribution of performance among the different pathways.

EPA would like feedback from stakeholders before releasing a complete analysis using this methodology; therefore, the information shown in the tables below has been altered slightly. Stakeholders should understand these tables to be illustrative examples of possible analyses, rather than actual results.

Table 8 presents a sample of the distribution of certified products by U-factor for wood and vinyl windows when all variables are constant except the spacer category.

Table 8: Sample Spacer System Analysis – Count of Product Options by U-factor

Pathway	0.24	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	>0.35
HS_Vinyl_A_91NN_KRY		64	651	1,672	7,053	7,541	5,924	2,574	1,098	746	972	658	481
HS_Vinyl_B_91NN_KRY			198	598	2,799	3,560	2,997	1,479	665	350	392	312	281
HS_Vinyl_C_91NN_KRY				285	1,530	5,546	7,056	4,982	2,326	1,161	692	509	906
HS_Vinyl_D_91NN_KRY					24	12		64	115	58	28	8	37
HS_Wood_A_91NN_KRY				18	47	104	137	138	128	134	156	60	198
HS_Wood_B_91NN_KRY						12	57	47	6		18		3
HS_Wood_C_91NN_KRY				14	145	1,302	2,573	1,349	525	204	176	256	279
HS_Wood_D_91NN_KRY					7	7	19	17	21	20	6		30

Table 9 holds all variables constant except for gas fill.

Table 9: Sample Gas Fill Analysis – Count of Product Options by U-factor

Pathway	0.24	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	>0.35
VS_Vinyl_B_19NN_AIR							28	407	1,030	3,065	4,485	3,246	5,013
VS_Vinyl_B_19NN_ARG				77	749	2,619	5,087	5,060	2,975	1,335	747	508	945
VS_Vinyl_B_19NN_KRY			16	161	548	1,388	1,194	604	253	103	34	8	76
VS_Vinyl_B_19NN_AR3							18	506	544	116	20	16	40
VS_Wood_B_19NN_AIR						13	24	59	623	1,832	2,561	1,191	2,777
VS_Wood_B_19NN_ARG				29	40	1,175	2,588	2,140	1,004	864	600	735	318
VS_Wood_B_19NN_KRY				3	361	522	566	156	18				
VS_Wood_B_19NN_AR3					183	420	555	297	141	21	3		

Table 10 shows the distribution of certified options for the 10 most common glass configurations among vinyl vertical-sliders with 'A'-tier spacers and argon gas fill. The pathways are sorted by total number of options.

Table 10: Sample Glass Configuration Analysis – Count of Product Options by U-factor

Pathway	0.24	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	>0.35
FX_Vinyl_A_92NN_AIR		4	357	755	3,780	6,761	6,921	5,339	2,213	1,104	1,231	862	744
FX_Vinyl_A_93NN_AIR		64	651	1,672	7,053	7,541	5,924	2,574	1,098	746	972	658	481
FX_Vinyl_A_39NN_AIR		128	833	2,258	5,729	5,534	2,882	1,420	734	519	409	437	602
FX_Vinyl_A_29NN_AIR		4	259	872	2,553	4,187	3,822	1,988	1,172	604	473	362	503
FX_Vinyl_A_34NN_AIR	1,605	3,727	2,998	1,467	1,065	1,281	735	313	27	77	61		36
FX_Vinyl_A_24NN_AIR	722	2,281	2,694	1,472	738	1,259	781	306	52	22	48	2	18
FX_Vinyl_A_33NN_AIR	4	33	329	890	2,694	1,855	810	278	59	136	37	15	6
FX_Vinyl_A_91NN_AIR				38	140	1,139	1,626	1,355	856	292	241	172	277
FX_Vinyl_A_22NN_AIR	8	17	192	374	1,356	2,131	1,126	516	126	155	63	42	4
FX_Vinyl_A_99NN_AIR								1		1			5,334

Table 11 shows the differences in performance distribution among different operator types in the same pathway.

Table 11: Sample Operator Type Analysis – Count of Product Options by U-factor

Pathway	0.24	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	>0.35
CM_Vinyl_B_92NN_ARG	140	2,488	6,713	2,546	1,003	607	440	131	94	39	52	8	18
FX_Vinyl_B_92NN_ARG	626	5,834	7,850	6,019	3,233	1,435	692	1,171	421	403	98	55	242
HS_Vinyl_B_92NN_ARG		42	422	2,390	7,681	6,365	4,796	1,740	591	660	663	273	173
VS_Vinyl_B_92NN_ARG		64	651	1,672	7,053	7,541	5,924	2,574	1,098	746	972	658	481
CM_Wood_B_92NN_ARG			72	96	18	42	314	365	192	227	62	48	126
FX_Wood_B_92NN_ARG		96	226	444	721	895	541	356	253	78	107	84	189
HS_Wood_B_92NN_ARG					36	36	45	29	62	14	20	18	54
VS_Wood_B_92NN_ARG				18	47	104	137	138	128	134	156	60	198

Table 12 and Table 13 show the top five pathways for certified options at 0.27 U-factor for vinyl and wood windows, respectively. Sorting the heat maps by the number of certified options at a given performance level can help in understanding what components and configurations are most commonly certified at that rating.

Table 12: Top 5 Vinyl Vertical Slider Pathways at U-factor 0.27, Count of Product Options by U-factor

Pathway	0.24	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	>0.35
FX_Vinyl_C_93NN_KRY	84	451	582	3,473	2,499	1,053	828	156	137	20	12	23	103
FX_Vinyl_C_34NN_ARG	263	1,604	2,976	2,934	1,583	705	734	354	57	12	26	2	36
FX_Vinyl_D_93NN_KRY		294	325	2,661	3,044	1,157	905	217	180	33	12	17	109
FX_Vinyl_C_26NN_ARG	106	940	2,121	2,296	1,603	744	806	529	127	14	12	6	18
FX_Vinyl_A_39NN_AIR		128	833	2,258	5,729	5,534	2,882	1,420	734	519	409	437	602

Table 13: Top 5 Wood Vertical Slider Pathways at U-factor 0.27, Count of Product Options by U-factor

Pathway	0.24	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	>0.35
FX_Wood_B_24NN_KRY	9	369	1,000	873	361	329	127	112	46	13	6		4
FX_Wood_C_44NN_ARG	46	494	784	368	298	209	151	56	39	32	10	10	10
FX_Wood_B_34NN_AIR			17	275	625	528	269	196	175	104	73	31	47
FX_Wood_C_64NN_AR3		180	209	217	117	33	12						0
FX_Wood_B_14NN_AR3		26	152	207	107	82	26	8	1	2	2		4