Review of different standards for calculation of thermal hemispherical emissivity from measured near-normal IR reflectance data with focus on impact on window U-value

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Abstract

US companies that sell coated glass on the global market are frustrated that they have to present the coating performance differently in different markets. It is confusing for buyers that it looks like you can get a lower emissivity of a product by buying it from a different continent. The National Fenestration Rating Council (NFRC) formed a task group in 2021 to investigate what the impact on window center of glass U-value would be if NFRC switched from the NFRC 301 standard to the EN 12898 standard for calculation of hemispherical emissivity. The result led to everyone in the task group agreeing that a switch was not possible while EN 12898 still keeps the rounding step.

This report documents the discussions and numerical results that led the task group to this unanimous decision. It also contains a review of different standards pertaining to hemispherical emissivity.

Background

You know the E in low-E? That stands for emissivity and considering the impact low-E windows have had on the window market it is obviously an important component. However, even though it is a key component it is not defined consistently in different international standards.

Divergent international standards leads to nothing good. It causes confusion that what one intuitively thinks of as a physical material parameter is not a constant but rather varies depending on in which country you are when you do the calculation. This leads to headaches for manufacturers as they have to present their product differently depending on in which market it is expected to sell. And it causes confusion for people looking to buy glass or who are trying to do calculations/simulations using published data if they think that the same product has different performance in different markets.

The hemispherical emissivity (e_h) is a key factor when calculating the radiative heat transfer component through a window. The black-body radiation from a surface is directly scaled with Ehem, so if a pane is uncoated on one side (e_h = 0.84) and has a coating on the other (e.g. e_h = 0.08) it will radiate 10 times more from the uncoated than the coated. Creating this disparity in the heat flow has a significant impact on the insulating properties of a window.

Terminology

Emittance or emissivity? In some fields of physics there is a difference, but in the window world they are often used interchangeably, and so also in this report. When used in the context of discussing measured properties of transmittance and reflectance it is often written as emittance, but in description of calculation emissivity is used. The argument that emittance is the value measured for a specific sample and emissivity is a fundamental property is sometimes mentioned, but not rigorously followed. (Using Plato's metaphor of the cave, emissivity casts shadows of emittance).

Near-normal reflectance This is the property that is measured using IR spectrophotometery and stored in the International Glazing Database (IGDB). There are other pathways to measure emissivity using other instruments, but this is what is used by the glazing industry for specular glass. This is measured as a function of wavelength and denoted $R_n(\lambda)$.

Near-normal emissivity Also *normal emissivity* this is calculated as 1- $R_n(\lambda)$ for opaque samples such as glass. When written as $e_n(\lambda)$ it is given for each wavelength, but once integrated over a black-body spectrum it loses its wavelength information and is written e_n.

Hemispherical emissivity By integrating the angle-dependence of the emissivity over the outgoing hemisphere it is possible to get a single value to use in radiative heat transfer equations. In window standards this is obtained applying an empirical polynomial to the e_n value. Denoted as e_h.

Corrected emissivity Some standards use this term instead of hemispherical emissivity.

Review of standards

The two newest standards defining calculation of e_h that can be used with spectral data from the IGDB are NFRC 301 (US market) and EN 12898 (EU market). However, there is also an older CEN standard, EN 673, and NFRC 301 was implemented as an ASTM standard in 1993 as ASTM E1585-93. Furthermore there are two ISO standards that deal with hemispherical emissivity ISO 10292 and ISO 15099. ISO 15099 does not include the calculations but rather includes a reference to two different standards. The task group where considering if there might be Korean and Japanese standards but no action was taken to investigate that further or include them in this review.

Looking through the terminology there are questions in every step that can be standardized:

Measured reflectance For what wavelength range and with which step interval should the data be recorded?

Normal emissivity What temperature of the black-body curve should be used?

Hemispherical emissivity Which empirical polynomial should be used with e_n?

Numbers With how many significant digits should a number be recorded?

Standard	**Data range**	**Black body temp.**	**e_h polynomial**	**Precision**
NFRC 301, ASTM E1585	At least 5-25 micron in 1 micron steps	300K	Rubin et al. Different for coated and uncoated	Not specified
EN 12898	Weighted ordinate from 5.5 to 50 micron in 30 ordinals if possible. Exclude ordinals > 23.3 micron if instrument not capable of measuring those values	283K	Fit to EN 672 table	e_n recorded with two decimals
EN 672	Weighted ordinate from 5.5 to 50 micron in 30 ordinals.	Table	Lookup table with 11 e_n values	Not specified

ISO 10292	Weighted ordinate from 5.5 to 50 micron in 30 ordinals.	Table	Lookup table with 11 e_n values	Not specified
ISO 15099	N/A	N/A	N/A	N/A

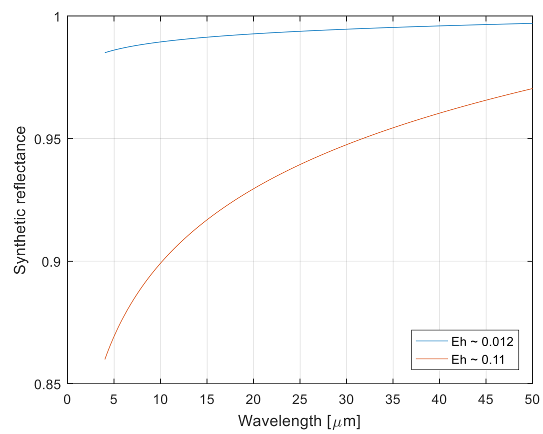
ISO 15099 is listed with N/A in the table as it does not specify the values but rather states that the calculation should be carried out using either ASTM E1585-93 or EN12898.

The numerical details of the difference is not repeated here as the rationale for using the different values is not included in the scope of this report.

One benefit with using weighted ordinate tables for the wavelengths and black body calculation is that the numerical integrating step is clearly defined. The NFRC 301 calculation is implemented using trapezoidal integration in LBNL software but that step is not specified by the standard where only the analytical calculation is described.

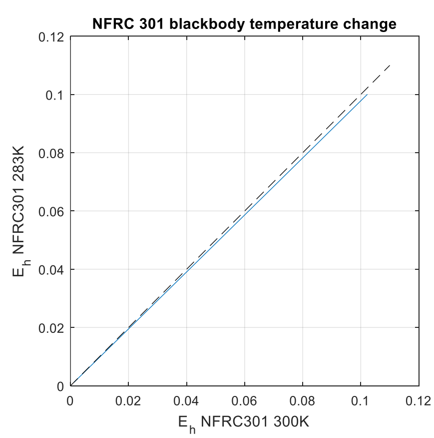
Comparison of resulting e_h calculated according to NFRC301 and EN12898

The method used to investigate the impact of calculation was to generate an ensemble of 100 spectral curves of synthetic reflectance data as a function of wavelength. The figure to the right shows the bounds of that ensemble. The shape of the curves was selected to be exaggerated compared to real low-e spectra that would be flatter. This choice was to allow the theoretical results to bound real impact, i.e. we can conclude that the impact of altering the black-body temperature not larger for real products than for this result.



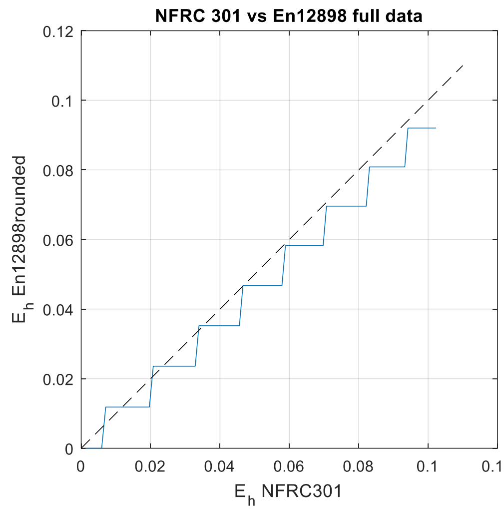
The black-body temperature and the polynomial used to go from e_n to e_h modify the final e_h value in a continuous way and to quite a small degree. These facts were underlying to justify harmonization. A change like this is not taken lightly as even though the numbers are small, as windows that are designed to meet specific U-value target might miss that goal if the underlying data is changed. The smaller the change the smaller the risk of impact, but it is impossible to guarantee that there would be no impact on product U-value no matter how small the change was.

The result of switching NFRC 301 to use the 283K black-body temperature to 300K but keep everything the same is shown in the figure to the right. The x-axis has the e_h value calculated using current NFRC standard and the y-axis shows the result if the black-body temperature was change. The dashed line is plotted as reference to show the current value so that it easy to see the different between new and old. The result would be a slightly lower e_h value, but it would not impact the ranking of products or make any products look worse (lower emissivity is better). Similar graphs where made comparing integration using the weighted ordinate method or trapezoidal



numerical integration and switching from the NFRC 300 to the EN12898 polynomial. They showed the same pattern, i.e. the new result would be a slightly lower e_h value, but it would not impact the ranking of products or make any products look worse.

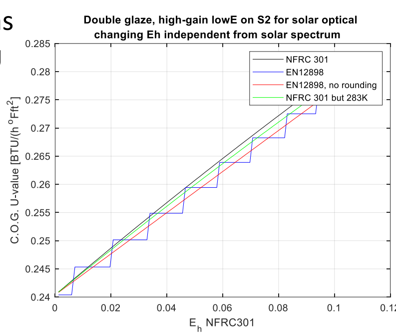
The large impact comes when including the rounding step defined in EN12898. There is a well-defined way to report the normal emissivity (not the hemispherical) using two decimal points, first the calculated e_n number is truncated to three decimal values and then rounded to two. This rounded number is what is used to calculate the e_h value. The result is shown in the graph to the right and there is an obvious step function as the number of different e_n values that go into the graph is reduced by the rounding.

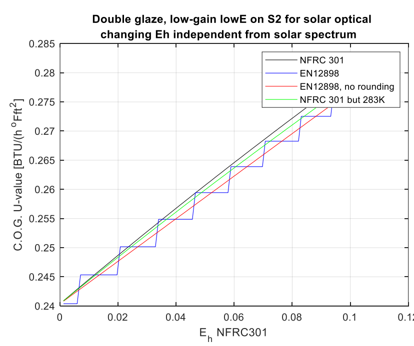


This is the first result where we see that products would get a worse emissivity than their current value. This is especially problematic in the range between ~0.02-0.024 where a lot of the top range products are situated. That they would be equated with products that have an emissivity of 0.03 is not fair. It would also cause a strong incentive to report data so that products with have a low enough value to fall into the 0.01 bin.

Impact on U-value results

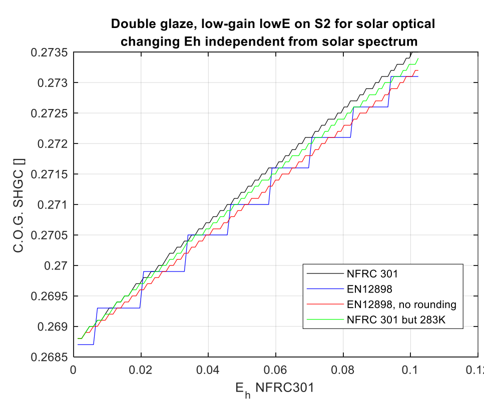
The center of glass (C.O.G.) U-value was calculated for a couple of different IGU compositions to show how the step-function introduced in e_h would translate in U-value.





Again this is synthetic as the solar part of the spectrum was taken from real products but kept constant as the IR spectrum was varied, but as a demonstration of the impact of the calculation change it is sensible.

Both for the high and low-solar gain it is clear that switching to the next step has a high likely hood of changing the rounded U-value by 0.01.



The graphs are in IP units, in SI the same effects are shown but the steps are larger.

There is an impact on SHGC as well but it is much smaller as shown in the graph to the right.

Explanation of the fundamental design difference

The NFRC task group considered it unacceptable that high-performance products would either be equated with lower performance, or separated with a significant step which would impact U-value on a significant level. There was some work trying to figure out why the two standards are so different, which is not easy as the choices resulting in the difference were made over 30 years ago. It is helpful to remember that both systems work on a large scale and they both come with pros and cons.

The NFRC system is based on calculation of product data using IGDB. This is a database of measured product data which acknowledge that the accuracy of the measurement instrument used is not ideal. If samples are tested of a product it is expected that the result should be close to the listed value, but if it came out exactly the same it would be suspicious, because the measurement is not repeatable to more than a couple decimal points but it is often reported with 6 or 8 digits. So when reviewing different data sets for a single product it is expected that data should be close, but not identical. This forces the reviewer to be more knowledgeable to judge what is acceptable, but it also allows the reviewer to spot possible issues in the measurement or the production of the sample. This is especially true if review is done of the measured reflectance data rather than the calculated e_h number.

The EN standard specifies a rounding step and specifies that the e_n number is the result that should be reported. This makes it easy to compare different results as they are either identical or 0.01 different which is significant, it requires very little knowledge of the reviewer to decide if it agrees or not. There is probably a lot more that went into the discussions before EN 12898 adopted the rounding step.

It is also important that the standards were written without the benefit of hindsight, it is unfair to expect that the scientists that were investigating emissivity measurements and writing these standards from scratch would be able to foresee the full impact of their decisions.

Conclusion

There is a difference in design objective between the data measured that goes into the NFRC 301 calculations and the reported emissivity number calculated by EN 12898. While this design goal exist it is hard to see that either standard will be able to change their procedure.