Tubular Daylighting Device
Task Group Status Report
2019 Spring Meeting
March 25, 2019
Baltimore, MD

Chair: Neall Digert
1. Call to Order
   a. Welcome to All Attendees....Cell phones & laptops to silent mode
   b. Antitrust Reminder
   c. NFRC Meeting Guidelines

2. Appoint Recording Secretary (staff if available)

3. Review and Approve Agenda

4. Unfinished Business
   a. None

5. New Business
   a. Current Status of TDD Ratings
   b. Review implementation of NFRC 203 ratings into CA T-24, Washington State, ASHRAE 90.1, ICC IE
      Florida FBC code language.
   c. Proposal for augmenting NFRC 203 to provide Diffuse Sky product ratings.

6. Adjourn
NFRC Tubular Daylighting Device Task Group
Mission: accurately define, rate and label performance characteristics of Tubular Daylighting Devices.

Current Status of TDD Ratings –

1. Test-only Ratings Implemented for:
   a. U-Factor (ANSI/NFRC 100 and NFRC 102)
   b. SHGC (ANSI/NFRC 200 and NFRC 201)
   c. VT\textsubscript{annual} (ANSINFRC 200 and NFRC 203)

2. NFRC BoD Approved Submittal of NFRC 202 and 203 to ANS Standards Committee for review and approval as ANSI Documents.
   a. NFRC 202 & 203 have been submitted for Project Initiation Notification (PIN)
   b. Will be published on March 8, 2019.
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Code Implementation of NFRC 203 ($VT_{\text{annual}}$) and other TDD-related Ratings

a. NFRC 203 (and other NFRC-TDD Ratings) Referenced and Implemented/In-process for

- California T-24 Part 6 – 2019 (Implemented)
- ASHRAE 90.1 (In Process)
- Washington State Energy Code WSEC 2018 (Implemented)
- ICC IECC 2019 (Proposed)
- Florida FBC 2019 (Proposed)
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2018/19 Energy Code Updates

- CA Title 24 Part 6- 2019
  - Updated Definitions to Include TDDs and NFRC 203 Rating Standard for $VT_{annual}$
  - Incorporates Equivalencies for $VT_{annual}$ ratings relative to $VT_{normal}$
  - Updates Table 140.3-B – Minimum Prescriptive Envelope Criteria with new Suitable Minimum $VT_{annual}$ Benchmarks for TDDs (Min. $VT_{annual} = 0.38$)

- ASHRAE 90.1 – 2019
  - Adopts T-24 Prescriptive Requirements for TDDs
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CA T-24 Prescriptive Requirements

<table>
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<tr>
<th></th>
<th>All Climate Zones</th>
<th>Glass, Curb Mounted</th>
<th>Glass, Deck Mounted</th>
<th>Plastic, Curb Mounted</th>
<th>Tubular Daylighting Devices</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Fixed Window</td>
<td>Operable Window</td>
<td>Curtainwall or Storefront</td>
<td>Glazed Doors²</td>
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<tr>
<td></td>
<td>Max U-factor</td>
<td>0.36</td>
<td>0.46</td>
<td>0.41</td>
<td>0.45</td>
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<tr>
<td></td>
<td>Max SHGC</td>
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<td>0.22</td>
<td>0.26</td>
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<td>Area-Weighted Performance Rating</td>
<td>Min VT</td>
<td>0.42</td>
<td>0.32</td>
<td>0.46</td>
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<tr>
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<td>Maximum WWR%</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min VTannual</td>
<td>0.49</td>
<td>0.49</td>
<td>0.64</td>
<td>0.38</td>
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<tr>
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<td>Maximum SRR%</td>
<td>5%</td>
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</tbody>
</table>

*NR* = Not Required

*U.S.* Tubular Daylighting Device Rating

- **Max VTannual:** 0.38
- **Min VTannual:** 0.49
- **Max U-factor:** 0.58
- **Max SHGC:** 0.25
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2018/19 Energy Code Updates

- Washington State Energy Code - 2018
  - Includes all changes to T-24
  - Adds Equivalency Factors for Minimum Daylight Aperture Requirements when using TDD VT\textsuperscript{annual} Ratings

- ICC IECC-2021 & Florida FBC-2020
  - Sets Daylight Aperture Equivalencies for TDDs (Min. Effective Aperture Area = 0.66, Calculated by Eq. 4)
  - Excludes TDDs from ASTM D1003 Haze Factor Ratings Requirements
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IECC Minimum Fenestration

In an enclosed space greater than 2,500 square feet (232 m²) in floor area, directly under a roof with not less than 75 percent of the ceiling area with a ceiling height greater than 15 feet (4572 mm), and used as an office, lobby, atrium, concourse, corridor, storage space, gymnasium/exercise center, convention center, automotive service area, space where manufacturing occurs, nonrefrigerated warehouse, retail store, distribution/sorting area, transportation depot or workshop, the total toplit daylight zone shall be not less than half the floor area and shall provide one of the following:

1. A minimum skylight area to toplit daylight zone of not less than 3 percent where all skylights have a VT of not less than 0.40, or VT-annual of not less than 0.26, as determined in accordance with Section C303.1.3.

2. A minimum skylight effective aperture determined in accordance with Equation 4-4 of:
   1. not less than 1 percent, using a skylight’s VT rating; or
   2. not less than 0.66 percent using a Skylight’s or Tubular Daylighting Device’s VT-annual rating.

\[
\text{SkylightEffectiveAperture} = 0.85 \times \text{Skylight Area} \times \text{Skylight VT} \times \text{WFToplitZone}
\]

\[
\text{Skylight Effective Aperture} = \frac{0.85 \times \text{Skylight Area} \times \text{Skylight VT} \times \text{WFToplitZone}}{\text{Toplit Zone}}
\]

(Equation 4-4)

where:

Skylight area = Total fenestration area of skylights.

Skylight VT = Area weighted average visible transmittance of skylights.

WF = Area weighted average well factor, where well factor is 0.9 if light well depth is less than 2 feet (610 mm), 0.7 if light well depth is 2 feet (610 mm) or greater, or 1.0 for Tubular Daylighting Devices with VT-annual ratings measured according to NFRC 203.

Light well depth = Measure vertically from the underside of the lowest point of the skylight glazing to the ceiling plane under the skylight.
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IECC Haze Factor Exception

C402.4.2.2 Haze factor.

Skylights in office, storage, automotive service, manufacturing, nonrefrigerated warehouse, retail store and distribution/sorting area spaces shall have a glazing material or diffuser with a haze factor greater than 90 percent when tested in accordance with ASTM D1003.

Exception: Skylights and/or tubular daylighting devices designed and installed to exclude direct sunlight entering the occupied space by the use of fixed or automated baffles or the geometry of skylight and light well, or the use of optical diffuser components.
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Proposal for augmenting NFRC 203 to provide Diffuse Sky product ratings
– Expanding the Global Usefulness of NFRC 203.
What is VT\textsubscript{annual}?

- New Certified Product Rating for a product’s \textit{real} Visible Light Transmittance (VT)
- VT\textsubscript{annual} is \textit{Different} from normal VT\textsubscript{normal} – don’t compare them!
- VT\textsubscript{annual} provides a product’s yearly-average Visible Transmittance.
  - Represents \textbf{annual average clear sky} Visible Transmittance for 9:00 AM to 5:00 PM Day
  - Reported for a 40 degree latitude… Think Denver!
Annual Visible Transmittance ($V_{T_{\text{annual}}}$)

- A new, more meaningful rating that accounts for the variable angularity inherent in real-world incidence of solar light at a building site as well as for the precise, selectable, and tunable optics and optical performance of modern, highly-engineered, complex optical fenestration technologies and products.

- The NFRC Tubular Daylighting Device (TDD) Task Group and Lawrence Berkeley National Laboratory developed an annualized visual transmittance rating ($V_{T_{\text{annual}}}$) protocol – NFRC 203-2017, Procedure for Determining Visible Transmittance of Tubular Daylighting Devices.

- NFRC 203 specifies ASTM E1175, Standard Test Method for Determining Solar or Photopic Reflectance, Transmittance, and Absorptance of Materials Using a Large Diameter Integrating Sphere, as the test method for determining (through physical measurement) the visible transmittance (VT) of Tubular Daylighting Devices (TDD) at a set of 18 representative annual solar incidence angle pairs (six solar Altitude angles measured at three Azimutal planes).
Annual Visible Transmittance (VT\textsubscript{annual}) – Cont’d.

- As defined by NFRC 203, the two key elements of the VT\textsubscript{annual} rating are as follows:
  - Visible Transmittance, Annual (VT\textsubscript{annual}): The ratio of visible radiation passing through the fenestration product to the incident visible radiation, expressed as a single dimensionless value between 0 and 1 or as a percentage.
  - Zonal Time, ZT: Zonal Time weighting factors report the percentage of time that the sun spends within each of the 18 specific Sky Zones (Relative Solar Altitudes measured for 20, 30, 40, 50, 60, & 70 Degrees; Relative Solar Azimuth Planes of 0, +/- 30, +/- 60 Degrees), relative to the time that Solar Altitude angles are between 15° and 75°, and Solar Azimuths are between +/- 75° from true south, for a site located in Middle America represented by 40° North Latitude.

- Generated using existing data for the sun’s solar position at 30-second intervals for an entire solar year. (Equations for calculating solar altitude are given in the 2009 ASHRAE Handbook of Fundamentals, Chapter 14).
- Each sky zone ZT is calculated at the specific solar altitude, $\beta$, and surface-solar azimuth, $\gamma$, where each angle represents median of a 10-degree range of solar angles. For example, the range of 15 to 25 degrees is defined as 20 degrees.

- The VT\textsubscript{annual} rating (for a specific latitude) is calculated by summing the products of each measured zonal VT value and the associated Zonal Time Weighting Factor for each of 18 different sky zones.
  - Represents solar zonal time for the traditional 8:00 AM to 5:00 PM period of actual use.
NFRC 203 – A New, Advanced, Dynamic Rating Metric

- NFRC 203 – A Test Apparatus and Methodology for Determining the $VT_{\text{annual}}$ Product Rating for Optically-Complex Tubular Daylighting Devices.
- Represents solar zonal time for the traditional 8:00 AM to 5:00 PM period of actual use.
Annual Visible Transmittance (VT<sub>annual</sub>) – Cont’d.

- VT<sub>annual</sub> is expressed as the sum of 18 different VTs applicable to the sky zones multiplied by ZT weighting factors.

**Equation 1:**

\[
VT_{\text{annual, 40 NLAT}} = (VT_{20,0} \times ZT_{20,0} + VT_{30,0} \times ZT_{30,0} + VT_{40,0} \times ZT_{40,0} + VT_{50,0} \times ZT_{50,0} + VT_{60,0} \times ZT_{60,0} + VT_{70,0} \times ZT_{70,0}) + (VT_{20,30} \times ZT_{20,30} + VT_{30,30} \times ZT_{30,30} + VT_{40,30} \times ZT_{40,30} + VT_{50,30} \times ZT_{50,30} + VT_{60,30} \times ZT_{60,30} + VT_{70,30} \times ZT_{70,30}) + (VT_{20,60} \times ZT_{20,60} + VT_{30,60} \times ZT_{30,60} + VT_{40,60} \times ZT_{40,60} + VT_{50,60} \times ZT_{50,60} + VT_{60,60} \times ZT_{60,60} + VT_{70,60} \times ZT_{70,60})
\]

Where:

- VT<sub>annual</sub> = Total Annual Visible Transmittance of Tested Product
- VT (θ<sub>R</sub>, ϒ) = Visible Transmittance for one of six Solar Altitude Angles (θ<sub>R</sub>) at one of three surface-solar Azimuth Angles (ϒ) for a total of 18 measurements.
- ZT(θ<sub>R</sub>, ϒ) = Zonal Time Factor associated with the Solar Altitude Angle (θ<sub>R</sub>) and Azimuth Angle (ϒ) pair.

**Table 1:** Zonal Time Factors used in NFRC203-2017 for a northern Site Latitude of 40 Degrees.
Annual Visible Transmittance ($VT_{annual}$) – Cont’d.

• $VT_{annual}$ provides a single number that represents a product’s annualized clear-sky visible transmittance given the sun’s actual time-weighted annual movement through the sky and its interaction with a product’s optical system that provides selective daylight harvesting for beneficial portions of the sky vault.
  • While this example was developed to represent the annualized sun’s path in Middle America (40° North Latitude), the 18 core VT data points collected in the test protocol can be used to generate functional, annualized visible light transmittance ratings for any site location in the world.

• The $VT_{annual}$ rating protocol represents a huge advancement in fenestration product ratings that provides meaningful performance data, allowing architects, engineers, code officials, and consumers to make educated product choices based upon a fenestration product’s functional, real-life performance.

• The approach can be further expanded to allow fine tuning of SHGC for more precise trade-offs of energy performance factors.
Extending NFRC 203 for Global Markets (UK and EU)

- Technical review and assessment performed by Fraunhofer Institute for Solar Energy Systems ISE (Dr. Bueno and Dr. Wilson) (Report: EEB3-BB-1809-E01)
  - Reviewed NFRC 203 Testing and Rating Protocols for Suitability to European Climate and Latitudes
    - Developed and applied Clear Sky Zonal Time Weighting Functions for 3 representative Latitudes for assessment of Rating Sensitivity to Northern Latitudes and robustness of NFRC 203 core Dataset.
      - 40° ~ Madrid, Ankara
      - 50° ~ Plymouth, Frankfurt, Prague
      - 60° ~ Oslo, Stockholm, Helsinki
    - Developed extension of Application Protocol to provide Diffuse Sky Ratings using NFRC 203 VT Measurements
Extending NFRC 203 for Global Markets (UK and EU)

- Application of Diffuse Sky Ratings
  - Applies Zonal Time Weighting Function using CIE Overcast Sky Model
    - Assumes luminance across sky is independent of latitude and constant over year.
    - Uses NFRC 203 VT Data Set for a given Fenestration Product
Extending NFRC 203 for Global Markets (UK and EU)

• Calculation of Diffuse Sky Ratings
  – Diffuse Sky Zonal Time Weighting Function:
    • Calculated for each of the 18 Sky Regions as normalized product of their specific luminance and area on the Sky Dome (Equation 1),

\[
ZT_i = \frac{L_i/L_m \cdot S_i}{\sum_{j=1}^{18} L_j/L_m \cdot S_j},
\]

• where:
  \(ZT_i\) is the zonal time weighting factor for a sky region,
  \(L_i\) is the luminance of a sky region,
  \(L_m\) is the average luminance of the sky dome for altitude angles between 15° and 75° and azimuth angles between 0° and 75°, and
  \(S_i\) is the spherical area of the considered sky region.

Note: the overcast sky model is symmetric with respect to a plane described by an azimuth angle of 0°, there is no need to consider negative azimuth angles explicitly.
Extending NFRC 203 for Global Markets (UK and EU)

- Calculation of Diffuse Sky Ratings
  - Diffuse Sky Zonal Time Weighting Function:
    - Calculating CIE Overcast Sky Region Normalized Luminance (Equation 2),
      \[
      \frac{L_i}{L_m} = \frac{6 \left(1 + ae^{b \sin \beta}\right)}{\sum_{k=20}^{70} \left(1 + ae^{b \sin k}\right)}, \tag{2}
      \]
    - where:
      \(\beta\) is the altitude of the sky region \(i\),
      \(a = 4\) and \(b = -0.7\) are gradation parameters [3],
      \(k\) take altitude values from 20° to 70°

Extending NFRC 203 for Global Markets (UK and EU)

- Calculation of Diffuse Sky Ratings
  - Diffuse Sky Zonal Time Weighting Function:
    - Calculating Spherical Area $S_i$ in sky Dome of Sky Region $i$ (Equation 3),

\[ S_i = \Delta \phi (\sin \beta_u - \sin \beta_l), \tag{3} \]

- where:
  - $\Delta \phi$ is the range of azimuth angles of the sky region
  - $\beta_u$ and $\beta_l$ are the upper and lower altitude angle limits of the sky region
Extending NFRC 203 for Global Markets (UK and EU)

• Calculation of Diffuse Sky Ratings
  – Diffuse Sky Zonal Time Weighting Function:

| Altitude | Azimuth  
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<tbody>
<tr>
<td></td>
<td>0°-35°</td>
<td>35°-45°</td>
<td>45°-75°</td>
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<td>15°-25°</td>
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<td>4.4%</td>
<td>4.4%</td>
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– Allows VT\textsubscript{annual,overcast} Ratings to be Calculated using NFRC 203 Product Testing Dataset