

NFRC 101-2026[E0A3]

Procedure for Determining Thermophysical Properties of Materials for Use in NFRC-Approved Software

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National Fenestration Rating Council®

FOREWORD

The National Fenestration Rating Council, Incorporated (NFRC) has developed and operates a uniform rating system for energy and energy-related performance of fenestration products. The Rating System determines the U-factor, Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) of a product, which are mandatory ratings for labeling NFRC certified products, are mandatory ratings for inclusion on label certificates, and are supplemented by procedures for voluntary ratings of products for Air Leakage (AL), and Condensation Resistance. Together, these rating procedures, as set forth in documents published by NFRC, are known as the NFRC Rating System.

The NFRC Rating System employs computer simulation and physical testing by NFRC-accredited laboratories to establish energy and related performance ratings for fenestration product types. The NFRC Rating System is reinforced by a certification program under which NFRC-licensed responsible parties claiming NFRC product certification shall label and certify fenestration products to indicate those energy and related performance ratings, provided the ratings are authorized for certification by an NFRC-licensed certification and Inspection Agency (IA).

The requirements of the rating, certification, and labeling program (Certification Program) are set forth in the most recent versions of the following as amended, updated, or interpreted from time to time:

- NFRC 700 Product Certification Program (PCP).
- NFRC 705 Component Modeling Approach (CMA), Product Certification Program (CMA-PCP).

Through the Certification Program and the most recent versions of its companion programs as amended, updated, or interpreted from time to time:

- The laboratory accreditation program (Accreditation Program), as set forth in the NFRC 701 Laboratory Accreditation Program (LAP).
- The IA licensing program (IA Program), as set forth in NFRC 702 Certification Agency Program (CAP).
- The CMA Approved Calculation Entity (ACE) licensing program (ACE Program), as set forth in the NFRC 708 Calculation Entity Approval Program (CEAP).

NFRC intends to ensure the integrity and uniformity of NFRC ratings, certification, and labeling by ensuring that responsible parties, testing and simulation laboratories, and IAs adhere to strict NFRC requirements.

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In order to participate in the Certification Program, a Manufacturer/Responsible Party shall rate a product whose energy and energy-related performance characteristics are to be certified in accordance with mandatory NFRC rating procedures. At present, a Manufacturer/Responsible Party may elect to rate products for U-factor, SHGC, VT, AL, Condensation Resistance, or any other procedure adopted by NFRC, and to include those ratings on the NFRC temporary label affixed to its products, or on the NFRC Label Certificate. U-factor, SHGC and VT, AL, and Condensation Resistance rating reports shall be obtained from a laboratory that has been accredited by NFRC in accordance with the requirements of the NFRC 701.

The rating shall then be reviewed by an IA which has been licensed by NFRC in accordance with the requirements of the NFRC 702. NFRC-licensed IAs also review label format and content, conduct in-plant inspections for quality assurance in accordance with the requirements of the NFRC 702, and issue a product Certification Authorization Report (CAR), or approve for issuance an NFRC Label Certificate for site-built or CMA products and attachment products. The IA is also responsible for the investigation of potential violations (prohibited activities) as set forth in the NFRC 707 Compliance and Monitoring Program (CAMP).

Ratings for products that are labeled with the NFRC Temporary and Permanent Label, or products that are listed on an NFRC Label Certificate in accordance with NFRC requirements, are considered to be NFRC-certified. NFRC maintains a Certified Products Directory (CPD), listing product lines and individual products selected by the manufacturer/responsible party for which certification authorization has been granted.

NFRC manages the Rating System and regulates the Product Certification Program (PCP), Laboratory Accreditation Program (LAP) and Certification Agency Program (CAP) in accordance with the NFRC 700 (PCP), the NFRC 701 (LAP), the NFRC 702 (CAP), the NFRC 705 (CMA-PCP), and the NFRC 708 (CEAP) procedures, and conducts compliance activities under all these programs as well as the NFRC 707 (CAMP). NFRC continues to develop the Rating System and each of the programs.

NFRC owns all rights in and to each of the NFRC 700, NFRC 701, NFRC 702, NFRC 705, NFRC 707, NFRC 708 and each procedure, which is a component of the Rating System, as well as each of its registration marks, trade names, and other intellectual property.

The structure of the NFRC program and relationships among participants are shown in Figure 1, Figure 2, and Figure 3. For additional information on the roles of the IAs and laboratories and operation of the IA Program and Accreditation Program, see the NFRC 700 (PCP), NFRC 701 (LAP), and NFRC 702 (CAP) respectively.

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Figure 1

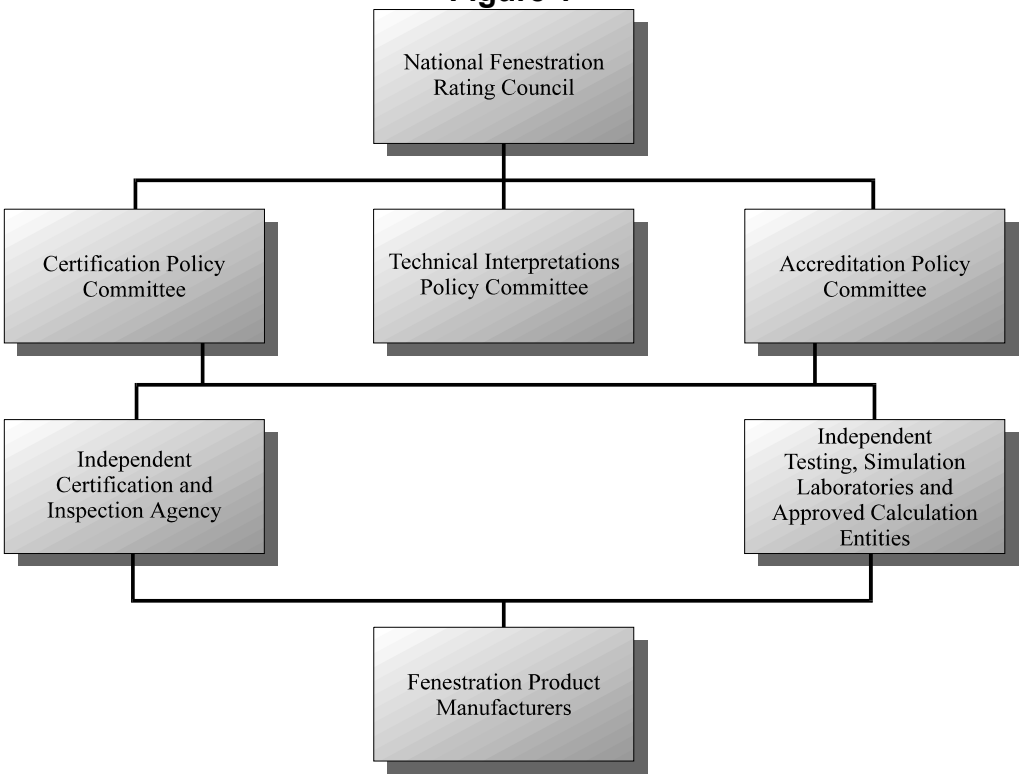
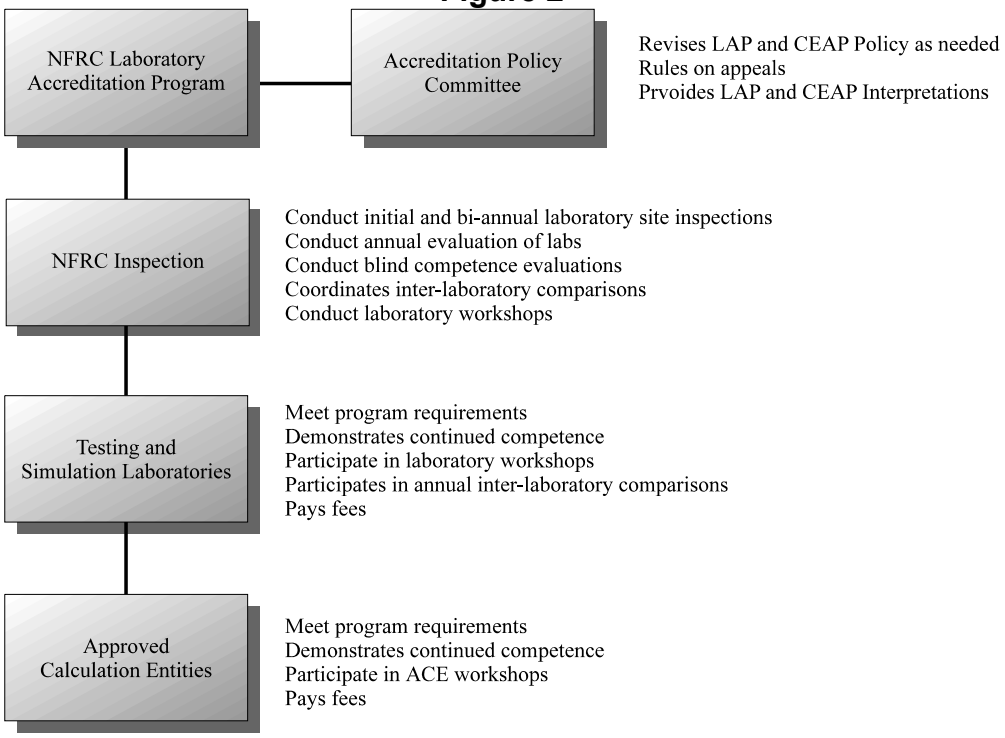
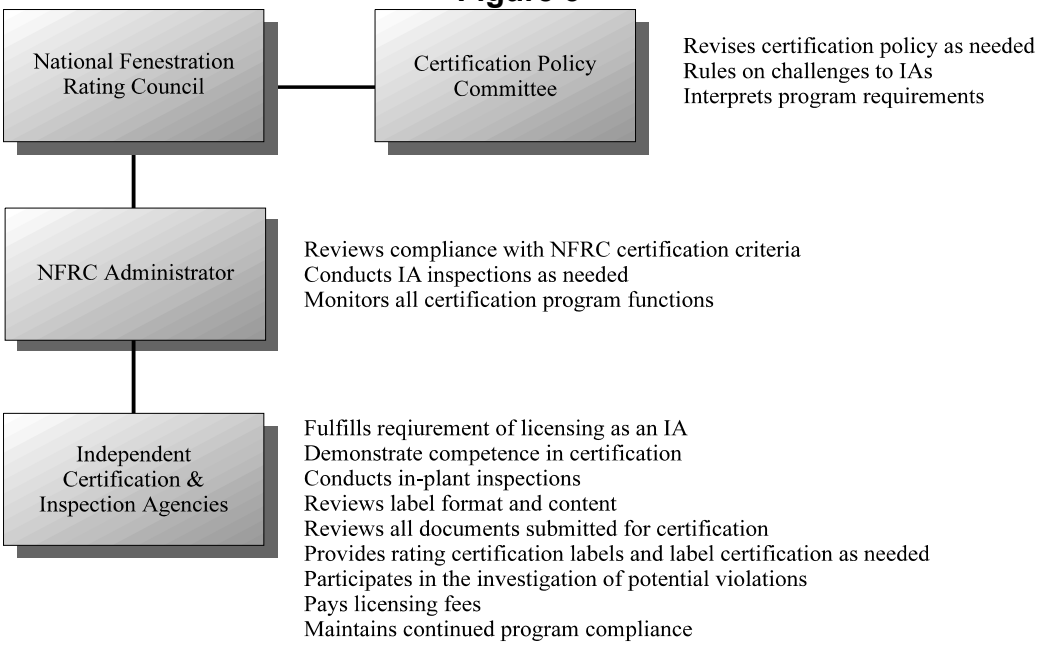


Figure 2



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Figure 3



Questions on the use of this procedure should be addressed to:

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DISCLAIMER

NFRC certification is the authorized act of a Manufacturer/Responsible Party in: (a) labeling a fenestration or related attachment product with an NFRC Permanent Label and NFRC Temporary Label, or (b) generating a site built or CMA label certificate, either of which bears one or more energy performance ratings reported by NFRC-accredited simulation and testing laboratories and authorized for certification by an NFRC-licensed IA. Each of these participants acts independently to report, authorize certification, and certify the energy-related ratings of fenestration and related attachment products.

NFRC does not certify a product and certification does not constitute a warranty of NFRC regarding any characteristic of a fenestration or fenestration-related attachment product. Certification is not an endorsement of or recommendation for any product or product line or any attribute of a product or product line. NFRC is not a merchant in the business of selling fenestration products or fenestration-related products, and therefore cannot warrant products as to their merchantability or fitness for a particular use.

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1. INTRODUCTION

The National Fenestration Rating Council (NFRC) has developed a uniform national rating system for fenestration and fenestration attachment product energy performance.

A product certification program reinforces the rating system by requiring ratings to be determined by NFRC accredited laboratories. The ratings are then reviewed and authorized by NFRC licensed independent certification and inspection agencies (IAs) as conforming to NFRC requirements.

This procedure has been developed to provide uniform and credible tables (libraries) of thermophysical properties of materials used in the construction and manufacture of fenestration and fenestration attachment products for use in approved software tools. The thermophysical properties currently considered are thermal conductivity, long-wave surface emissivity, and solar surface absorptivity.

In this procedure, a table of generic materials and their associated thermophysical properties is provided, as well as a process for introducing new or proprietary materials.

This procedure may involve hazardous materials, operations, and equipment. This procedure does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this procedure to establish appropriate health and safety practices and to determine the applicability of any regulatory limitations prior to use.

The values stated in metric (SI) units shall be regarded as the standard. The inch-pound (IP) units shall be for reference only.

2. PURPOSE AND SCOPE

2.1 Purpose

This procedure is intended to provide a uniform method for determining the thermophysical properties of glazing (thermal conductivity only), framing, and other opaque materials used in the construction and manufacture of fenestration products. These thermophysical properties shall be used in NFRC approved software for the simulation of thermal performance indices of fenestration and fenestration attachment products.

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2.2 Scope

2.2.1 Materials Covered By This Document

A. All frame materials, either single component or composite

B. All glazing materials, thermal conductivity only

C. Applied Film materials, thermal conductivity only

D. All sealants and adhesives

E. Weather-stripping materials

F. Thermal barrier materials

G. Cladding materials

H. Spacer materials

I. Desiccant materials

J. Fill gases

K. Shade/blind slat materials

L. Fabric materials

M. Tubing materials, such as those used in TDDs

2.2.2 Materials and/or Properties Not Covered By This Document

A. Thermal conductivity of finishes

B. Glass coatings

C. Solar-optical properties of glazing and other transparent materials. (See NFRC 300 and NFRC solar-optical database)

3. TERMINOLOGY

Air Leakage (AL):
The volume of air flowing per unit time per unit area through a fenestration system due to air pressure or temperature difference between the outdoor and indoor environment.

Ambient Temperature:
Temperature at a given set of environmental conditions.

Attachment:
See “Dynamic Attachment” or “Fenestration Attachment.”

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Blackbody:
A perfect emitter and absorber of thermal radiation. A blackbody emits radiant energy at each wavelength at the maximum rate possible as a consequence of its temperature and absorbs all incident radiant flux.

Certification:
The affixing by a licensed Responsible Party of an NFRC label on a fenestration product, or on a box/packaging containing an attachment product, or the distribution of an NFRC Label Certificate, for which Certification Authorization has been granted.

Certification Agency Program (CAP):
Set of rules and procedures by which an independent certification and inspection agency becomes licensed and operates.

Certification Authorization Report (CAR):
Certificate listing performance values of NFRC-rated products that is issued by an NFRC-Licensed IA granting the licensee the authority to affix NFRC Labels on a fenestration product or on the box/packaging containing an attachment product, or to obtain an NFRC Label Certificate, upon PCP compliance by the licensee.

Certification Program:
A term often used for the Product Certification Program (PCP or CMA PCP).

Certified Simulator:
Any individual that has attended at least one NFRC-sanctioned Simulation Training Workshop, completed and satisfactorily passed all necessary examinations, participated in NFRC simulation round robins, and is approved by NFRC to use at least one NFRC-approved simulation software tool.

Cladding:
An applied rigid or semi-rigid roll-formed or extruded covering that is placed over or is attached to and follows the contour of the interior or exterior framing member for the primary purpose of protection from environmental elements and/or aesthetics. Cladding adds no structural integrity to the framing member.

Compliance and Monitoring Program:
A program that establishes activities that are prohibited by law and/or contract, and fines associated with such activities.

Computer Simulation:
The process by which a product is analyzed for energy performance characteristics utilizing NFRC-approved computer software and manufacturer

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supplied product specifications and drawings, in accordance with the requirements of the NFRC Rating System.

Condensation Resistance (CR):
A relative indicator of a fenestration product's ability to resist the formation of condensation at a specific set of environmental conditions. The higher the Condensation Resistance value the greater the resistance to the formation of condensation.

Product Condensation Resistance: The lower of CR_f, CR_c, and CR_e.

Curtain Wall, Curtain Wall System:
An external non-load bearing wall that consists of any combination of framing materials, fixed glazing, opaque glazing, operable windows, or other in-fill materials. See "Storefront," "Window Wall."

Divider:
Any bar used to separate glazing into multiple lites or placed in the gap between sheets of glazing. Dividers may be external or internal, may be removable or non-removable, and may be real (true) or simulated. Dividers may also be called grids, grilles, or muntins.

Dynamic Attachment:
Any Fenestration Attachment that incorporates Dynamic Glazing.

Emissivity (ε):
The relative ability of a surface to reflect or emit heat by radiation. Emissivity ranges from 0.00 to 1.00 (Blackbody emissivity is 1.0).

Fenestration:
Products that fill openings in a building envelope, such as windows, doors, skylights, curtain walls, etc., designed to permit or limit the passage of air, light, vehicles, or people.

Fenestration Attachment:
A device (such as, but not limited to, shades, films, or blinds) designed to be physically attached to, incorporated with, or covering a fenestration product.

Fenestration System:
A fenestration is a glazed aperture in a building for the controlled admission of solar radiant heat and light. A fenestration system is an assembly of transparent or translucent glazing infill layers, frames holding the glazing infill, mullions, muntin bars, dividers, and other attachments and/or shading devices. The glazing infill can include glass or plastic sheets that are patterned, corrugated, or otherwise

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optically distorted, so long as some visible light can pass through them. The fenestration system is often referred to as the test specimen in this document.

Finish:
The final treatment or coating of a surface.

Frame:
The enclosing structure of a window, door, or skylight which fits into the wall or roof opening and receives either, glazing, sash, or vents.

Glass:
An inorganic, amorphous substance, usually transparent, composed of silica (sand), soda (sodium carbonate), and lime (calcium carbonate) with small quantities of other materials.

Glazing:
The act of installing the glazing system/glazing in-fill; (n.) The transparent or semi-transparent in-fill material in a glazing system.

Glazing System/Glazing In-fill:
A generic term used to describe an in-fill material, such as glass, plastic, or other transparent or translucent material, or assembly of glazing material, spacer, and desiccant, used to enclose openings in a building created by a specific framing system.

Heat Flux (q):
The heat flow rate through a surface of unit area perpendicular to the direction of heat flow in units of energy per unit time and per unit area.

Individual Product:
Any one specific fenestration product within a product line, specific to weather seals, glazing method, hardware, opening/non-opening configurations, ventilators, weep systems, and sills.

Insulating Glass Unit (IGU), Sealed Insulating Glass Unit:
A preassembled unit comprising lites of glass, which are sealed at the edges and separated by dehydrated space(s). The unit is normally used for windows, window walls, picture windows, sliding doors, patio doors, or other types of fenestration.

Irradiance:
A radiometric term for the radiant flux in any or all directions in a hemispherical solid angle that is incident upon, passing through, or leaving a surface.

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Label:
Permanent and/or temporary marker or device applied to a fenestration product, listing rating information and indicating compliance with certification requirements.

Label Certificate:
A document used in lieu of an NFRC Temporary Label specific to certain products that have received certification authorization (see NFRC 705).

Laboratory Accreditation Program (LAP):
A set of rules and procedures by which a laboratory becomes accredited and operates.

Licensee:
Any entity entering into an NFRC License Agreement and meeting the NFRC PCP requirements.

Opaque (adj.):
Not allowing visible light to pass through.

Product Certification Authorization:
The authority granted by an NFRC-Licensed IA to an NFRC Licensee to affix NFRC Labels, or obtain an NFRC Label Certificate, evidenced by a Certification Authorization Report (CAR) or Label Certificate issued by the IA.

Product Certification Program (PCP):
The NFRC program for granting of authorization to licensees to label products under the NFRC energy rating system.

Radiant Flux:
The time rate of flow of energy in the form of electromagnetic waves or photons.

Radiation:
The transfer of heat in the form of electromagnetic waves or photons from one body to another.

Rating:
Performance values obtained using NFRC-approved procedures used for comparative purposes only (i.e., U-factor, SHGC, VT, etc.).

Rating System:
A system that consists of NFRC simulation and test procedures for determining comparative fenestration product energy performance characteristics, as supported by the Certification Program.

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Responsible Party:
The entity (manufacturer, fabricator, lineal supplier, building owner, architect, door distributor, or other party) that signs an NFRC License Agreement. The responsible party agrees to comply with all applicable program requirements.

Sash:
The portion of a fenestration assembly that is installed in a frame and includes the glazing, stiles, and rails. A sash may be operable or fixed.

Simulation Software:
Any computer software used for Computer Simulation.

Solar (adj):
(1) Referring to radiometric quantities, indicating that the radiant flux involved has the sun as its source or has the relative spectral distribution of solar flux; (2) referring to an optical property, having as its weighting function a standard solar spectral irradiance distribution.

Solar Heat Gain (SHG):
The quantity of incident solar energy passing through a fenestration system. Included are both directly transmitted solar radiation as well as solar energy absorbed by the fenestration system and re-transmitted into the inside space.

Solar Heat Gain Coefficient (SHGC):
The ratio of the solar heat gain entering the space through the fenestration product to the incident solar radiation. NFRC rates SHGC at normal incidence.

Solar Radiation:
Electromagnetic radiation covering the spectral range from 300 to 4000 nm, coming from either natural direct beam solar radiation or from an artificial radiation source having a similar spectral distribution.

Spacer:
The component that separates and maintains the space between the glazing surfaces of an insulating glass unit (IGU), excluding any sealants.

Spectral (adj):
Indicating that the property or quantity was evaluated at a specific wavelength (λ), within a small wavelength interval ($\Delta\lambda$ about λ). Usually indicated by placing the wavelength symbol λ, as a subscript following the symbol for the quantity, as with E_λ, thereby indicating that the flux-related quantity is a concentration of flux at the indicated wavelength, or it may be placed inside parentheses following the symbol

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for the material property, as with α (λ). It is permissible to indicate the wavelength dependence of a flux quantity as follows: E_λ (λ).

Thermal Break, Thermal Barrier:
A component made of material of relatively low thermal conductivity which is inserted between two components having high thermal conductivity in order to reduce heat transfer.

Thermal Bridge:
A path of high thermal conductance from the exterior to interior surfaces of a system that has lower thermal conductance in all other areas. An example would be a metal fastener penetrating an insulating wall or thermally broken frame.

Thermal Conductivity (k):
Heat transfer property of materials expressed in units of energy per time per length per degree temperature difference.

Translucent (adj.):
Permitting light to pass through but with differing degrees of obscuration and diffusion.

Transmittance:
The ratio of the transmitted radiant flux to the incident radiant flux.

Transparent (adj.):
Permitting light to pass through with clear vision.

Visible Transmittance (VT):
The ratio of visible radiation entering the space through the fenestration product to the incident visible radiation, determined as the spectral transmittance of the total fenestration system, weighted by the photopic response of the eye, and integrated into a single dimensionless value. Weighted by a standard solar spectrum.

Weatherstrip:
A flexible component used to reduce air leakage, water penetration, or both between the sash or panels and/or sash or panels and frame.

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4. REPRESENTATIVE THERMOPHYSICAL PROPERTIES

All materials used in the computer simulation of a fenestration or fenestration attachment product shall have either generic thermophysical properties assigned from Appendix A or B, or proprietary thermophysical properties determined by an approved test procedure(s) (see Section 5) and listed in Appendix C.

4.1 Thermophysical Properties of Generic Materials

Those materials determined by NFRC to be generic in nature shall be identified and listed in Appendix A (Basic Set of Generic Materials) or Appendix B (Extended Set of Generic Materials). NFRC may add or remove materials as needed.

Thermophysical properties of generic materials shall be listed in the material libraries of NFRC approved software.

4.1.1 Listing

A material shall be listed in Appendix A when all the following criteria are met:

A. The material is a commodity and readily available from multiple sources.

B. The material's properties are based on data from textbooks, material handbooks, or similar published works (including NFRC 101 Appendix C).

C. The material's properties are a broad average of multiple variations of the same base material.

A material shall be listed in Appendix B when any of the following criteria are met:

A. The material is a specific version of a generic material listed in Appendix A with differing conductivity or emissivity. In this case, the material with the highest conductivity shall be placed in Appendix A and all versions shall be placed in Appendix B.

For example, deciduous and coniferous woods (hardwoods and softwoods) are covered generically in Appendix A. Specific wood species shall be listed in Appendix B.

B. The material is a specific alloy of a metal listed in Appendix A with differing conductivity or emissivity.

C. The material's properties are specific and well defined by an industry, national, or international standard such as, but not

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limited to, the National Institute of Standards and Testing (NIST).

4.1.2 Data Submission and Review

Any interested party may request, in writing, that a material and properties meeting the requirements of Section 4.1.1 be added to Appendix A or B accordingly. The request shall include all supporting data and indicate the source of the data. The data shall be reviewed in accordance with Section 6. Once approved for use the requested material and properties shall be added to the applicable appendix.

For material already listed in Appendix A or B, this process shall be used to request a change to its properties.

Note: The following are considered preferred sources. Submitters are encouraged to use data from these sources where feasible:

A. National Institute of Standards and Testing (NIST)

B. CRC Handbook of Chemistry and Physics

C. American Society of Materials (ASM)

D. Chemical Engineers' Handbook

E. ASHRAE Fundamentals

F. DOE National Laboratories

4.1.3 Use of Appendix A vs. Appendix B

All simulators shall use Appendix A unless the simulator's client requests the use of Appendix B or the material is not represented in Appendix A. If the simulator's client requests the use of material properties from Appendix B, then the client shall provide the simulator with appropriate product drawings and/or material specifications verifying that the requested material properties are representative of the material(s) specified. If such documentation is not provided to the simulator, then the simulator shall use the applicable material property value(s) from Appendix A.

4.1.4 Wood Components

If a wood component's cross-sectional material properties vary randomly along the length of the component, and the client wishes to use material property values from Appendix B, then for purposes of simulation, the cross-section shall be assigned the highest conductivity of all the materials used in that component.

For example, consider a wood frame member composed of multiple individual pieces of wood finger-jointed together along the length of

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the frame member. Some of the wood pieces are Sugar Pine (k=0.100 W/m•K), some are Ponderosa Pine (k=0.110 W/m•K), and some are Radiata Pine (k=0.120 W/m•K). The cross-section for this frame member would be assigned a conductivity of 0.120 W/m•K. See Figure 1.

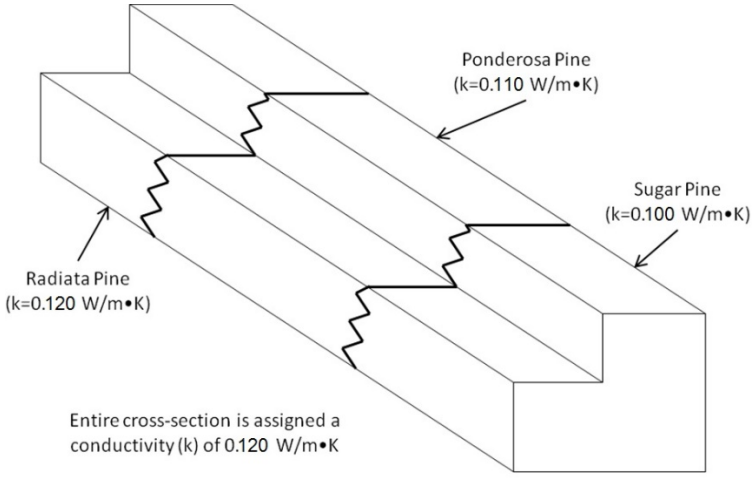


Figure 1

Note: If a product is simulated using material properties from Appendix B, then additional requirements will apply during annual inspections of Product Certification Program licensees. See NFRC 700 for details.

4.1.5 Periodic Review of Appendices A and B

At least once every 24 months, NFRC staff shall review Appendices A and B for completeness, accuracy and currency. NFRC staff shall report to the NFRC 101 Task Group with recommended changes. The NFRC 101 Task Group shall consider staff's recommendations and, if necessary, pursue revisions to Appendices A and B through NFRC's standard revision/ballot process to the Thermophysical Properties Subcommittee (TPPS). Any such revisions, once approved, shall be promptly announced and posted on the NFRC website for retrieval by NFRC-accredited simulation laboratories, NFRC-certified simulators, NFRC IAs, and other interested parties. Each revision shall have its version number clearly identified. NFRC shall post the date(s) when the revised version becomes effective and the previous version becomes obsolete.

4.2 Thermophysical Properties of Proprietary Materials

Thermophysical properties of proprietary materials shall be determined in accordance with the applicable test procedure(s) from Section 5. The

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supplier of the material shall be responsible for providing samples for testing. The supplier may use its own equipment or hire an independent laboratory to determine the thermophysical properties. The supplier shall use an NFRC-approved laboratory.

For unapproved laboratories, they shall obtain approval to provide conductivity testing for material suppliers by meeting one of the following:

(1) Successfully participated in an ILC per Section 7. If the laboratory meets the ILC results criteria, NFRC shall add their company to the list of approved laboratories.

(2) In the absence of an ILC for a particular test method, the new laboratory shall obtain and conduct a test of a NIST traceable standard reference material (SRM) and also conduct a test of a known material from NFRC 101 and/or the Material Property Database (https://www.matweb.com). The results of the testing shall be provided to the NFRC and then will be forwarded to the Accreditation Policy Committee (APC) for review, comment and laboratory approval. See Section 9, Data Verification Process Flowchart for new laboratory approval process.

The supplier shall be responsible for retaining the original test samples for a minimum of 24 months. If the material supplier contracted with a testing laboratory, it is the responsibility of the supplier to coordinate with the laboratory for the storage and retention of the original test samples.

Thermophysical properties of proprietary materials shall be listed through the user-defined section of the material libraries of NFRC approved software.

4.2.1 Listing and Use

A material shall be listed in Appendix C only when the material is unique and proprietary to the supplier. If the material is a variation of a known Appendix A material, then it shall have a conductivity and/or emissivity differing by at least 10% from the properties listed in Appendix A. If the material is a variation of a known Appendix B material, then it shall have a conductivity, and/or emissivity differing by at least 10% from the properties listed in Appendix B.

Three or more materials of the same base type that are listed in Appendix C may be used to establish a new Appendix A or Appendix B generic material if the conductivity and/or emissivity of these three materials differ by less than 10%. In this event the Appendix C listing shall be maintained for use unless withdrawn by the submitting supplier. If the Appendix C listing is maintained, simulators shall be permitted to use either the Appendix C listing or the variation listed in Appendix A or Appendix B, at the discretion of

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the simulator's client. The conductivity, emissivity, and density of the new generic material shall be the average of the materials submitted for consideration.

4.2.2 Data Submission and Review

Any interested party may request, in writing, that a material and properties meeting the requirements of Section 4.2.1 be added to Appendix C. All such requests shall be submitted to NFRC Staff using the approved submission form and signed by a representative of the submitter verifying that measurements were made in accordance with NFRC 101. The approved submission form shall be maintained on the NFRC website. A data review of the submittal shall be conducted per Section 6. Upon a successful review the requested material and properties shall be added to Appendix C.

4.2.3 Periodic Affirmation of Proprietary Materials

Materials and properties listed in Appendix C shall be valid indefinitely provided the material formulation and any additional requirements as deemed necessary by NFRC remain unchanged. The supplier of a proprietary material shall submit a written statement to NFRC staff once every four years, affirming that the material formulation remains unchanged compared to the originally tested samples. The statement shall be signed by an authorized representative of the licensee or the material supplier, and shall be submitted to NFRC staff within 30 calendar days of the listed expiration date in Appendix C.

NFRC staff shall periodically review Appendix C and notify material suppliers in writing of any pending expirations between six and seven months prior to the expiration date.

If written affirmation is not received by NFRC staff within the specified time frame, the proprietary material shall be removed from Appendix C.

If the formulation changes, the material supplier shall be responsible for testing and data submission of the new material.

4.3 Implementation of Changes to Thermophysical Property Values

Any changes to the thermophysical property values in Appendices A, B, or C other than voluntary withdrawal shall be reviewed by the NFRC 101 Task Group. The NFRC 101 Task Group shall consider the potential effects (if any) of such changes and prepare a recommended implementation schedule for consideration by the TPPS, Research and

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Technology Committee and the Board of Directors. See Section 6.5 for voluntary withdrawals.

5. THERMOPHYSICAL PROPERTIES TEST METHODS

Thermophysical properties shall be determined according to appropriate ASTM standards as indicated in this section. A minimum of three samples shall be measured and the mean value reported. The difference between any individual sample value and the average value of all samples shall be no greater than 10% or 0.003 W/(m•K) (0.02 Btu•in/(hr•ft^2•°F)), whichever is greater.

Any revisions to the test methods listed in this section shall be reviewed by the NFRC 101 Task Group. The NFRC 101 Task Group shall consider the potential effects (if any) of such changes to existing Thermophysical property values in Appendices A, B, and C, and prepare a recommended course of action for consideration by the TPPS to the Research & Technology Committee and the Board of Directors.

5.1 Thermal Conductivity

5.1.1 General

For the determination of thermal conductivity, testing shall be conducted according to ASTM C177, C518, C1114, C1363, E1225, E1461, E1530 or E1952, as applicable for the specific material. The test equipment shall be calibrated per the recommendations in the appropriate ASTM document(s), but no less frequently than once every 12 months.

5.1.2 Consideration of Aging Effects

For the following insulation material types that use a blowing agent other than air, the samples shall be aged in accordance with the associated material specification standard prior to determining the thermal conductivity

A. Polyurethane – ASTM C1029

B. Polyisocyanurate – ASTM C1289

C. Expanded Polystyrene (EPS) & Extruded Polystyrene (XPS) – ASTM C578

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5.1.3 Heat Flow Direction

The specimen heat flow shall be measured in the direction intended for final use. The heat flow direction shall be indicated in the test report.

5.1.4 Mean Temperature

Unless otherwise indicated in the applicable test standard, tests shall be conducted at a mean temperature of 2±1ºC (35±2ºF). Actual testing temperatures shall be reported with data submission.

5.1.5 Compressible Materials

Compressible materials shall be tested at the compression percentage specified by the material supplier. The compression percentage used for testing shall be indicated along with thermophysical property values in the appropriate appendix and material library(ies). The thermal conductivity achieved shall be valid only for compression percentages equal to or less than that used for testing.

5.1.6 Rigid and High Conductance Materials and/or Test Specimens

A. An appropriate buffer material shall be placed between the surface of the sample and the testing device surface plates to ensure uniform contact between the two rigid surfaces.

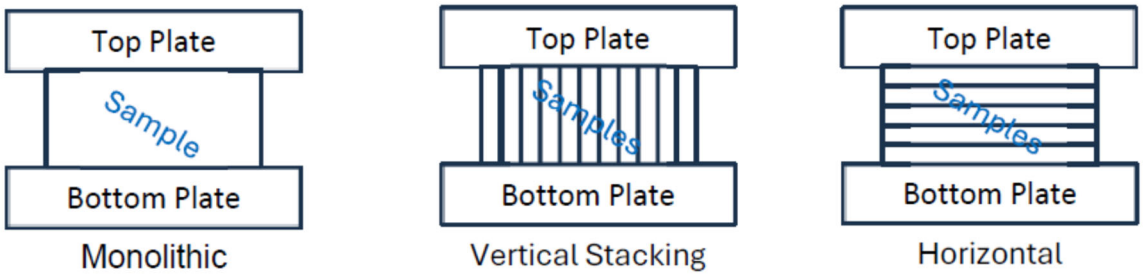
   i. ASTM C177, C518, and C1114 shall require thin foam rubber sheets

   ii. ASTM E1530 – see the test method document for guidance

B. Test Specimen Preparation (applicable only for ASTM C518/C177/C1114)

   i. Monolithic samples are preferred if they accurately represent the structure and heat flow orientation for the intended application. However, to meet the minimum thermal resistance of the test apparatus stacking may be used. If stacking is used, vertical stacking is preferred to horizontal stacking, see image below. In either stacking scenario, each piece of the stacked specimen shall be aligned with the intended heat flow direction.

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ii. Ensure the surfaces of test specimen are flat and parallel for optimal contact.

iii. A thin layer of conductive thermal paste may be applied between layers, if necessary, at the discretion of the testing agency

C. Depending upon the specific standard and device capabilities, additional steps may be necessary.

i. Devices with External Thermocouple Capability

a. External thermocouples shall be mounted on each side of the sample at the center point. Additional thermocouples may be used, placed in the heat flow metering area.

b. These temperatures shall be used to determine the temperature difference across the specimen (ΔT) for use in the thermal conductivity calculations, allowing for direct calculation of the specimen's conductivity.

ii. Devices without External Thermocouple Capability

A separate external temperature measurement shall be used, following the same manner as described above.

a. In this case, thermocouples shall be Type T, special limit, 30 ga or smaller,

b. The thermocouple reader shall comply with C518, which requires that the uncertainty of the measurement of the temperature difference across the specimens shall be within +/- 0.5% of the actual temperature difference.

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Note: For rigid, high thermal conductivity specimens (above 0.1 W/m-K), specimen preparation is recommended as given in ASTM C177, Section 7.2.

iii. Measurements without External Thermocouples

If surface temperature measurements are not used as described above, the thermal resistance of the rubber sheets must be determined and subtracted from the overall test result (which includes rubber sheets and test specimen) as follows. For this option, the rubber sheets shall be neoprene with a thickness between 3mm and 5mm and a minimum density of 140 kg/m3 (8.7 pcf). The neoprene rubber sheets shall have a minimum combined thermal resistance of 0.10 m^2-K/W.

a. Determine the resistance of the rubber sheets using one of the following methods:

1. Using the same device and parameters as for the test specimen, measure the rubber sheets with a NIST-traceable calibration specimen. Determine the resistance of the rubber sheets by subtracting the resistance of the calibration specimen;

2. As an alternative, measure the resistivity of the rubber sheets using ASTM C177 or E1530.

b. Calculate the thermal resistance of the specimen only by subtracting the thermal resistance of the rubber sheets from the thermal resistance of the rubber sheets/specimen.

5.1.7 Special Cases

5.1.7.1 Non-homogeneous Spacer Samples

A. Test Specimen Construction

i. This section applies only to spacer assemblies, where any of the following conditions apply:

a. The spacer material is not capable of being manufactured in a shape suitable for testing.

b. There exist multiple materials within the product which cannot be separately

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analyzed or cannot be simulated as individual materials.

ii. The test specimen shall be assembled of parallel lengths of the sample material with no gaps between the lengths of material that may allow for air within the test specimen assembly. If necessary, the specimen shall be prepared sandwiched between two pieces clear, uncoated, annealed soda lime glass, nominally 2 – 4mm (3/32 – 5/32 in.).

a. Orientation of the test specimen material shall be such that the heat flux in the test assembly is in the same direction across the test specimen assembly.

b. The test specimen assembly construction shall be such that the heat flow is predominantly uniform across the test area and that areas of localized heat flow variation is minimized.

B. Test Method Enhancements

i. Testing shall be conducted per Section 5.1.6, ensuring the use of foam rubber sheets and the appropriate method choice between 5.1.6.B.i, 5.1.6.B.ii or 5.1.6.B.iii.

ii. After determining the thermal resistance of the specimen (glass/spacer assembly), the contribution of the glass (and foam rubber sheets in the case that Method 5.1.6.B.iii was chosen) to the overall specimen shall be calculated and removed to determine the spacer conductivity.

a. Measure actual glass thickness in the assembly and assume glass thermal conductivity of 1.000 W/m-K for this calculation.

b. Calculate the thermal resistance of the spacer material by subtracting the thermal resistance of the glass layers from the thermal resistance of the specimen.

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Note: Test standard EN 675 provides useful background and guidance on testing with rigid glass surfaces and the use of the rubber sheets.

5.1.7.2 Non-homogeneous Vacuum Insulating Glass (VIG) Samples

This section applies to vacuum insulating glass units (VIG) when the pillars or glass separators and vacuum gap are not specified. The test apparatus, dimensions of the specimen and metering area, and measurements shall follow ISO 19916-1, Appendix A, with the following exceptions:

A. The mean temperature shall follow section 5.1.4, herein above.

B. The vacuum gap thermal resistance shall be calculated as follows:

   i. The contribution of the glass to the overall specimen shall be calculated and removed from the measured thermal resistance of the specimen.

   ii. Measure actual glass thickness in the assembly and assume glass thermal conductivity of 1.000 W/m-K for this calculation.

C. Calculate the thermal conductance of the vacuum gap from the thermal resistance of the vacuum gap.

5.1.8 Specimen Thickness

For more specific quantitative information on specimen thickness limitations see References 2, 3, 4 and 6. For materials with conductance higher than the upper limit specified in the applicable standard, sheets of material shall be permitted to be stacked for testing. If the sample cannot be provided with sufficient thickness for a chosen test standard, one of the alternative standards found in Section 5.1.9 shall be applied.

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5.1.9 Test Method Details

5.1.9.1 ASTM C177

For testing in accordance with ASTM C177 the specimen thermal conductance shall be less than 16 W/m^2•K and the temperature difference across the specimen shall not be less than 10 K. The specimen shall be either thermally homogeneous, or non-homogeneous normal to the heat flow direction only (such as layered structures).

5.1.9.2 ASTM C518

For testing in accordance with ASTM C518 the specimen thermal conductance shall be less than 10 W/m^2•K and the temperature difference across the specimen shall not be less than 10 K. The specimen shall be thermally homogeneous.

ASTM C518 is acceptable for obtaining effective thermal conductivity values for materials and components that cannot be simulated and/or provided as a homogeneous specimen for testing. In these cases, specific test specimen construction and test method enhancements are required, as noted in Section 5.1.7, Special Cases.

5.1.9.3 ASTM C1114

ASTM C1114 is applicable to thermally homogeneous, low-conductance specimens only. Apparatus of the type covered by C1114 apply to the study of thermal properties of specimens containing moisture because of the use of small temperature differences and the low thermal capacity of the heat source.

5.1.9.4 ASTM C1363

For testing of specimens with non-homogeneities in the heat flow direction, such as an insulation system with thermal bridges, see ASTM C1363 for guidance.

5.1.9.5 ASTM E1225

For testing in accordance with E1225 the specimen thermal conductivity shall be between approximately 0.2 and 200 W/m•K and the mean sample temperature shall be between approximately 90-1300 K. E1225 uses a steady state technique for the determination of thermal conductivity of homogeneous, opaque solids. To use ASTM E1225 for composites or non-homogeneous systems consisting of slabs or plates bonded together, the

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specimen shall be more than 20 units wide and 20 units thick where a unit is the thickness of the thickest slab or plate.

5.1.9.6 ASTM E1461

ASTM E1461 is a flash diffusivity method used for thin gauge highly conductive, primarily homogeneous, isotropic solid materials such as sheet metals. The specimen thermal diffusivity value shall be between 10^{-7} and 10^{-3} m^2/s and the sample temperature shall be between 75 and 2800 K. ASTM E1461 tests shall be conducted at a mean temperature of 25 ± 1°C (77± 2°F). Any deviation from the required 25 ± 1°C (77± 2°F) mean temperature shall be approved by the NFRC 101 Peer Review Group, preferably prior to testing.

Use of ASTM E1461 requires following specific heat capacity measurement and thermal conductivity measurement techniques per Appendix X2 of ASTM E1461.

5.1.9.7 ASTM E1530

ASTM E1530 is similar in concept to C518 and is especially useful for materials in sheet and similar forms having a thermal conductance of 25 to 500 W/m^2•K over an approximate temperature range of 150 to 600 K. Accuracy may be reduced for specimens thicker than 20 mm (0.8 in) and for thermal conductivities greater than 10 W/m•K.

5.1.9.8 ASTM E1952

E1952 covers the determination of thermal conductivity of homogeneous, non-porous solid materials with conductivity in the range of 0.10 to 1.0 W/m•K by modulated temperature differential scanning calorimeter.

5.1.10 Summary Table

The following table summarizes the features of the aforementioned ASTM standards:

ASTM Standard	Conductivity Range (W/m•K)	Conductance Range (W/m^2•K)	Min ΔT (K)	Remarks
C177		< 16	10	Thermally homogeneous
C518		< 10	10	Thermally homogeneous
C1114			None	Thermally homogeneous, for specimens with moisture
E1225	0.2-200		90-1300	Thermally homogeneous, Opaque

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ASTM Standard	Conductivity Range (W/m•K)	Conductance Range ($W/m^2•K$)	Min ΔT (K)	Remarks
E1461	NA	NA	NA	Primarily homogeneous isotropic solid materials. Thermal diffusivity values ranging from 10^{-7} to 10^{-3} m^2/s; temperature range: 75 to 2800 K (appendix X2 use mandatory)
E1530		25-500	150-600	Thermally homogeneous
E1952	0.1-1.0		None	Thermally homogeneous

5.2 Emissivity

5.2.1 General

See Appendix A or B for emissivity values of generic materials.

For metallic proprietary materials, emissivity shall be determined according to ASTM C1371 or ASTM E1933. For non-metallic proprietary materials, the material supplier shall have the option of determining emissivity according to either ASTM C1371 or ASTM E1933 or assigning a default emissivity of 0.9.

ASTM E1933 requires the specimen to be at a temperature of at least 10 K different than the ambient temperature.

ASTM C1371 provides a comparative means of quantifying the emittance of opaque, highly thermally-conductive materials near room temperature.

5.2.2 Cleanliness of the Surface

ASTM C1371 recommends that the procedure used should ensure minimum alteration of the specimen surface. For example, if the emittance of a dust-covered specimen is desired, the dust shall not be removed. However, if the surface is intended to be clean and free of any residue, it shall be visually inspected for signs of contamination prior to the measurement and, if necessary, cleaned with the appropriate solution and dried.

5.2.3 Finishes

For painted or finished specimens, the paint or finish shall be fully cured and in good contact with the substrate (i.e., no bubbles, peeling, or scratches). For further instructions, see ASTM D3359.

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5.2.4 Default Emissivity

For surface finishes which differ from those noted in Appendices A, B, and C, the manufacturer may choose to accept a default emissivity of 0.9 to represent those finishes.

5.3 Frame Absorptance

See ANSI/NFRC 200 for default frame and divider absorptance values.

5.4 Density

The density of the material shall be determined by dividing its weight by its volume. For compressible materials the density shall be determined at the compression percentage specified by the material supplier. Table 5-1 describes allowable density measurement methods for various materials.

Table 5-1 – Density Standards and Their Applicability

Material	Procedure
Polymer or plastic based materials	ASTM D792, ASTM D1505, ASTM D4883, ISO 1183-1, ISO 1183-2, or ISO 1183-3. For assembled or pre-constructed test specimens, density using a calibrated scale and micrometer, vernier caliper, or tape measure may use the volume ÷ weight formula for measurement.
Timber based	ASTM D2395, Wood Handbook (FPL-GTR-282)
Fine aggregates	ASTM C128
Any other	Must report density measurement standard or procedure used.

5.5 Report Requirements

All reports, regardless of the test method, shall contain at a minimum the information listed in Section 5.5.1. Any additional items required in the specified test method which do not appear below shall also be included.

Additional requirements that pertain to specific test methods are listed in Section 5.5.2.

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5.5.1 Overall Reporting Requirements

General / Laboratory / Conformance

A. The report shall be identified with a unique numbering system to allow traceability to the individual measurements taken during each test performed,

B. Identification of the test organization, responsible-person-in-charge, test operator and the organization for whom the testing is being performed.

C. The specific designation and dated version of the test methods used.

D. Statement of full compliance with the test method, or where circumstances or requirements preclude complete compliance with the procedures of the test, any variations from the test method shall be listed using the phrase, “All requirements of test method XXX have been met with the exception of..." followed by a complete list of the exceptions.

Instrumentation

E. Manufacturer and model of the instrument used,

F. Description of the instrument used for testing.

G. Thermocouple type, size, location and attachment procedures, if applicable.

Specimen Identification, Characteristics, Preparation

H. The generic name and any other pertinent identification required to provide a complete and detailed physical description of the tested material.

I. Specimen shape and size. If the test method used required the assembly of several pieces to create a testable specimen via stacking or adjoining pieces side-by-side, it is required to report how many pieces(parts) were assembled and the dimensions of each.

J. Material source and manufacturer code, if known.

K. Pertinent history of specimen, if known.

L. Description of the specimen and its relationship to the sample, if known.

M. Proprietary and/or brand name, if applicable.

N. For hygroscopic materials, such as concrete or wood, the moisture content shall be given.

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O. Information regarding any specimen preconditioning, including conditioning procedure, method and environment used for conditioning and any thermal or mechanical pretreatment.

P. Total area of the specimen or diameter and length of the specimen, if cylindrical.

Q. Thickness of the specimen as received and as tested (within the metered section)

R. Density of the conditioned specimen as tested and the measurement standard used.

   i. For specimens tested with glass and/or rubber mats, the density of the material evaluated shall exclude the glass or foam materials.

S. Mass loss of the specimen during conditioning and testing, in percentage of conditioned mass, if required.

T. Mass regains of the specimen during test, in percentage of conditioned mass, if required.

U. For loose-fill materials, report the specimen preparation followed.

V. Indicate if specimen stacking was used, and if so, the type and conductivity of the thermal paste used in the specimen construction. A drawing indicating the construction details and dimensions shall be included.

W. Pictures of test specimen(s)

   i. For homogeneous materials, a single photograph of the test specimen showing top and sides is adequate.

      ii. If testing per Section 5.1.7 of this document, then a top and side view photograph of the constructed specimen(s) shall be included.

      iii. Detailed image(s) showing surface condition (flatness) shall be included.

Test Parameters

X. Mean temperature of the test (K or ^{o}C)

Y. Average temperature of the hot and cold specimen surfaces (K or ^{o}C). For non-rigid (compressible) specimens, the plate temperature may be assumed to be the same as the specimen surface temperature. For rigid specimens, the temperature shall be measured at the surface of the specimen.

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Z. Average temperature gradient in the specimen during test as computed from the temperatures of the hot and cold surfaces (K/m).

AA. Direction and orientation of thermal transmission (heat transfer) through the sample. Measurements shall be in the direction intended for final use.

BB. Orientation and position of the heat meter apparatus during test (vertical, horizontal, etc.)

CC. Location of heat flow meter with respect to the hot or cold surface of the specimen

DD. Specimen edge condition: sealed or open to the ambient.

EE. Variables that affect thermal transmission properties and/or environmental surroundings of the specimen (gas type, pressure, etc.), shall be specified when applicable.

FF. Type and thickness of any interface materials (rubber mats) used during the test,

GG. Test start date and time.

HH. Time required for steady temperature conditions, if applicable.

II. Time required to reach steady-state, if applicable.

JJ. Duration and end time of the measurement portion of the test.

KK. Frequency of data collection.

LL. End date and time

Test Measurements

MM. Heat flux amount and direction through the specimen (W/m^2),

NN. The average values as obtained from the test. Standard deviation about that average.

Test Results

OO. Thermal conductance of the specimen, $W/(m^2\text{-}K)$

PP. Thermal conductivity of the specimen, W/(m-K)

QQ. Thermal resistance of the specimen, $m^2\text{-}K/W$ ($h\text{-}ft^2\text{-}°F/Btu$)

RR. The mean value of thermal conductivity for a minimum of three measured samples shall be provided. The difference between each individual sample and the mean shall be reported.

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SS. Results of the thermal resistance test of the glass and/or foam mats used during tests, as applicable.

Calibration

TT. Date of the latest apparatus calibration and/or verification and a description of the procedures used. References for the verification report(s) shall also be included.

UU. Include a statement of laboratory accreditation of the test facility used, including date of latest inspection.

VV. The specimens used in calibration shall be identified as to the type, thermal resistance, date of specimen certification, source of certification, expiration date of calibration, and the certification test number.

Precision & Bias

WW. Estimated or calculated uncertainty.

XX. Any other specifics required by the specified test method(s) are also required.

5.5.2 Specific Reporting Requirements

5.5.2.1 ASTM C518

For direct reading apparatus, the results of the calibration of electronic circuitry and equipment or a statement of compliance including date, and a statement of compliance on linearity requirements.

5.5.2.2 ASTM C177

A. The dimensions of the metered section and guard(s) and their relationship to the overall specimen dimensions (m);

B. Plate emittance;

C. Values for guard loss, back side energy loss and other losses included in the net energy calculation (W/m^2)

5.5.2.3 ASTM C1114

None

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5.5.2.4 ASTM E1225

A. Complete listing of the geometrical dimensions of the system including r_A, r_B, specimen height, meter bar height, and distances between temperature sensors.

B. Column force

C. Meter bar material and source of lM values if other than those listed in Table 1 of ASTM E1225.

D. Complete identification of insulation and source of λI values, gas, and gas pressure

5.5.2.5 ASTM E1461

A. Statement that the response time of the detector, including the associated electronics was adequately checked, and the method used.

B. Energy pulse source.

C. Type of temperature rise detector.

D. Calculated value of thermal diffusivity (at x = 50%, m^2/s in E1461), at the reported temperature.

E. Statement as to whether or not the data was corrected for thermal expansion. If this correction was made, the thermal expansion values used must be reported.

F. Statement of the beam uniformity check, or methods employed to eliminate the need for any.

G. Statements concerning the results of repeat measurements at each temperature.

H. Discussion of errors and correction procedures that were used for heat losses and finite pulse time effects.

5.5.2.6 ASTM E1530

A. Details of temperatures of appropriate surfaces, guard and ambient, °C (°F)

B. Applied load, Pa (psi)

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5.5.2.7 ASTM E1952

A. Thermal diffusivity (mm^2/s);

B. Values for calibrations constant(s)

6. DATA REVIEW

6.1 Peer Review Group (PRG)

The Thermophysical Properties Subcommittee (TPPS) shall establish a Peer Review Group (PRG) which shall include all interested parties, including approved laboratories submitting test data, the chairs of the NFRC 101 Task Group and the TPPS. Staff may also include subject matter experts for each type of material submission as appropriate.

6.2 Initial Review

All submissions shall be submitted to NFRC for an initial review where the submission shall be checked for conspicuous errors, discontinuity, noise, suspicious results, and completeness. The initial review shall be completed within five business days of receipt of the submission by a qualified NFRC technical staff member. If deficiencies are discovered during the initial review, the submitter shall be informed accordingly and provided adequate explanation of items or formats that need to be addressed. The submitter may resubmit data at any time, upon which another initial review shall be conducted.

6.3 Peer Review

Upon successful completion of the initial review, NFRC Staff shall issue the submittal to the PRG for a peer review. The peer review shall last no more than 15 business days from the date the submittal was issued to the PRG. All members of the PRG shall be permitted to question any data submitted. The peer review shall be deemed successful:

A. If no comments are received within the 15-day review period; or

B. When all submitted comments are addressed to the satisfaction of the commenter.

Staff shall retain the right to contact PRG members or subject matter experts that do not reply during a peer review period. Any PRG member that does not reply on three consecutive peer reviews may be removed from the PRG at staff's discretion.

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Any comments that cannot be resolved by the PRG shall be referred to the NFRC 101 Task Group for review and arbitration. Comments not resolved by the NFRC 101 Task Group shall be forwarded to the TPPS for resolution through NFRC's standard consensus process.

6.4 Acceptance and Publication

Upon successful completion of the peer review, NFRC Staff shall notify the submitter within five business days that their new data has been approved for use in NFRC approved software. NFRC 101 shall be updated and published within three weeks following the completion of the peer review and announced via a Technical Bulletin. The published data shall be valid indefinitely unless successfully challenged, voluntarily withdrawn, or replaced. NFRC shall retain on file all data submissions.

6.5 Voluntary Withdrawal

Thermophysical property values of proprietary materials may be withdrawn by the material owner at any time upon written request to NFRC. Upon such request any existing records for that material shall be removed from NFRC 101 and NFRC Certified Simulators should consider removing the materials from their own libraries. Withdrawn values shall not be used in any future simulation work. Any existing simulations completed with withdrawn material shall remain valid until expiration of the associated certification authorization.

6.6 Involuntary Withdrawal

NFRC Staff shall notify material suppliers in writing of pending involuntarily withdraw if affirmation, per Section 4.2.3, is not received prior to the listed expiration date in Appendix C or if the annual thermophysical property participation fee per NFRC 704 is not paid within 45 days following the payment notification date. Material suppliers shall have 15 days to resolve affirmation or nonpayment issues prior to complete withdrawal of proprietary material(s) from Appendix C.

For both voluntary and involuntary withdrawals, NFRC shall issue a Technical Bulletin and send within five (5) business days of the reaffirmation date to announce the publication of a revised NFRC 101 document for withdrawal of proprietary material(s) from Appendix C. The notification shall be sent to all NFRC accredited simulation laboratories, licensed inspection agencies, PRG members, and any other interested party that has requested (in writing) to be included in such notifications.

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7. INTERLABORATORY COMPARISONS (ILC)

NFRC shall sponsor an Interlaboratory Comparison (ILC) at a minimum of once every two years, but preferably once each year.

Assignment of materials to be tested for the ILC shall be recommended by the Board of Directors, Research & Technology Committee, TPPS or NFRC 101 Task Group. Any recommendations shall be reviewed by the NFRC 101 Task Group and then executed by NFRC Staff.

All laboratories that have submitted thermophysical property data shall be invited to participate in ILCs. Any laboratory that has not submitted thermophysical property data shall be permitted to participate in ILCs upon written request to NFRC Staff. Any ILC participant shall be permitted to measure the most recent ILC sample(s) to verify that the measured data is within two standard deviations of the mean of the ILC results. NFRC shall keep ILC data confidential and shall publish only the standard deviation and number of outliers, without disclosing the mean of the ILC measurements for at least one year or until completion of the next ILC.

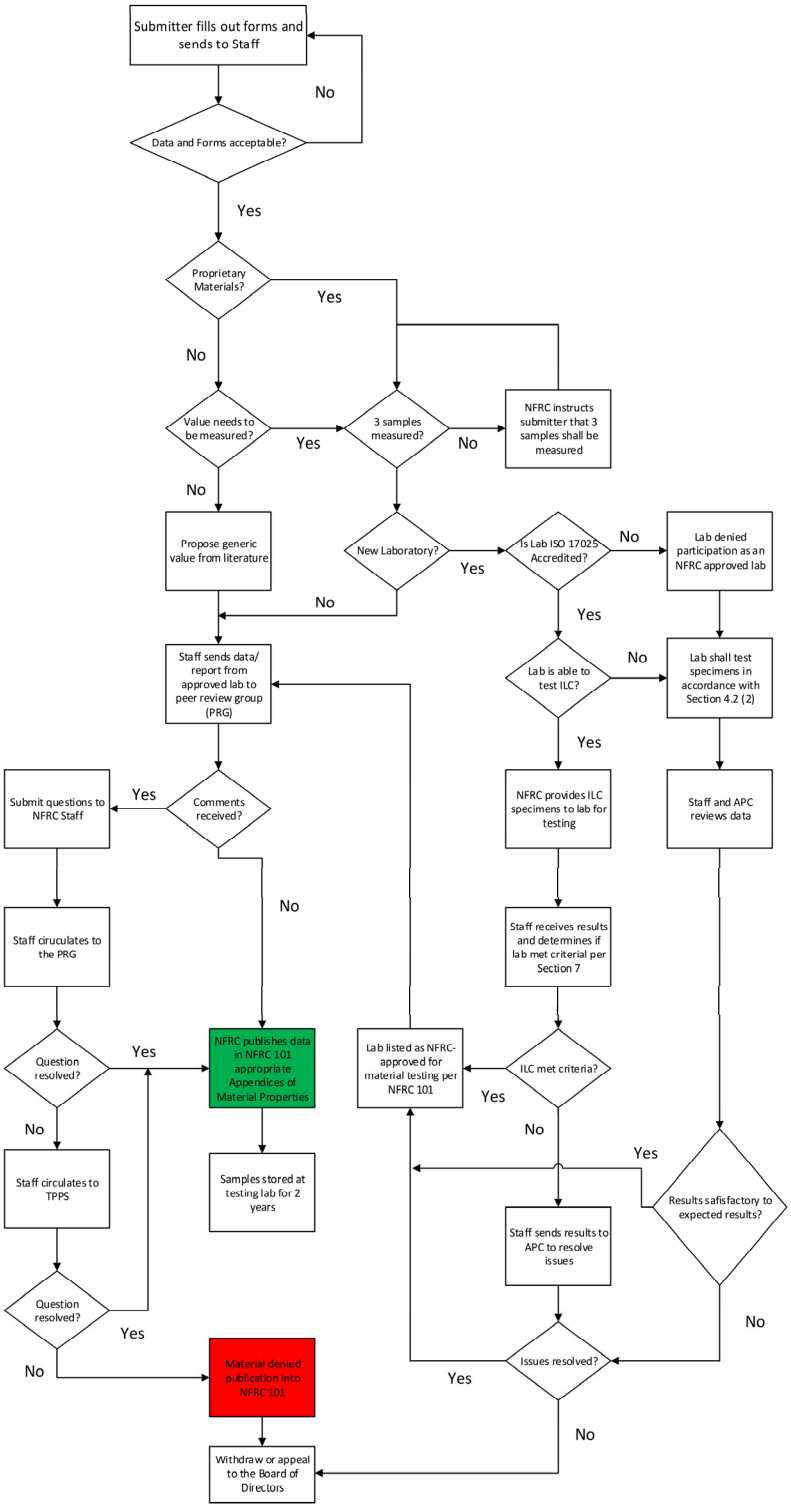
A summary report of the ILC shall be prepared by NFRC and submitted to the NFRC 101 Task Group for review before presentation to the TPPS.

8. CHALLENGE AND APPEALS PROCEDURE

Please refer to NFRC 714 if a challenge or appeal to any NFRC 101 thermophysical property is necessary.

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9. DATA VERIFICATION PROCESS FLOW CHART



Legend: Red = not approved; green = approved

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APPENDIX A BASIC SET OF GENERIC THERMOPHYSICAL PROPERTY VALUES OF MATERIALS

Table A.1: Thermophysical Properties of Solid Materials

Name	Conductivity k			Source[1]	Emissivity ε
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft^2•^{o}F	-	-
Elastomers					
Butadiene	0.250	0.144	1.733	1,15	0.9
Butyl rubber (isobutene, solid/hot melt)	0.240	0.139	1.664	1,3,15	0.9
Expanded rubber (rigid)	0.032	0.018	0.222	2	0.9
Ethylene propylene diene monomer (EPDM)	0.250	0.144	1.733	1,15	0.9
Foam Rubber	0.060	0.035	0.416	1,15	0.9
Hard rubber (ebonite), solid	0.170	0.098	1.179	1,15	0.9
Natural rubber	0.130	0.075	0.901	1,15	0.9
Neoprene (polychloroprene)	0.230	0.133	1.595	1,15	0.9
Polyisobutylene (PIB)	0.200	0.116	1.387	1,15	0.9
Polysulphide	0.400	0.231	2.773	1,15	0.9
Rubber, Neoprene foam	0.036	0.021	0.246	10	0.9
Vulcanized rubber	0.160	0.092	1.109	2	0.9
Polymers					
ABS	0.200	0.116	1.387	20	0.9
Acrylic	0.200	0.116	1.387	1,15	0.9
Cellular Polyvinylchloride (cPVC)	0.067	0.039	0.465	19	0.9
Elastomeric foam, flexible	0.050	0.029	0.347	1,15	0.9
Epoxy resin	0.200	0.116	1.387	1,15	0.9
Phenolic resin	0.300	0.173	2.080	1,15	0.9
PVB	0.224	0.129	1.553	13	0.9
Polyacetate	0.300	0.173	2.080	1,15	0.9
Polyamide (PA 66/Nylon – 25% glass fill)	0.300	0.173	2.080	1,15	0.9
Polyamide (Nylon – no fill)	0.250	0.144	1.733	1,15	0.9
Polycarbonate	0.200	0.116	1.387	1,15	0.9
Polyester resin	0.190	0.110	1.317	1,15	0.9
Polyethylene foam	0.050	0.029	0.347	1,15	0.9
Polyethylene/polythene HD (high density)	0.500	0.289	3.467	1,15	0.9
Polymethylmethacrylate (PMMA)	0.180	0.104	1.248	1,15	0.9
Polypropylene	0.220	0.127	1.525	1,15	0.9

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Name	Conductivity k			Source[1]	Emissivity ε
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft²•°F	-	-
Polypropylene with 25% glass fiber	0.250	0.144	1.733	1,15	0.9
Polystyrene	0.160	0.092	1.109	1,15	0.9
Polytetrafluoroethylene(PTFE)	0.250	0.144	1.733	1,15	0.9
Polyurethane	0.250	0.144	1.733	1,15	0.9
Polyurethane foam	0.050	0.029	0.347	1,15	0.9
Polyurethane foam, closed cell	0.029	0.017	0.201	2	0.9
Polyurethane (urethane) thermal break	0.210	0.121	1.456	1,15	0.9
Polyvinylchloride (PVC) flexible	0.140	0.081	0.971	1,15	0.9
PVC/Vinyl (rigid)	0.170	0.098	1.179	1,15	0.9
Silicone	0.350	0.202	2.427	1,15	0.9
Silicone, filled	0.500	0.289	3.467	1,15	0.9
Composites					
Fiberglass	0.400	0.231	2.774	14	0.9
Timbers					
Coniferous woods (Softwoods)	0.140	0.081	0.971	4	0.9
Deciduous woods (Hardwoods)	0.160	0.092	1.109	4	0.9
Wood based panels					
Cement-bonded particleboard	0.230	0.133	1.595	1,15	0.9
Cement-bonded wood wool panels	0.140	0.081	0.971	1,15	0.9
Fiberboard	0.180	0.104	1.248	1,15	0.9
Particleboard	0.180	0.104	1.248	1,15	0.9
Plywood	0.240	0.139	1.664	1,15	0.9
Oriented strand board (OSB)	0.130	0.075	0.901	1,15	0.9
Metals					
Aluminum	237	136.94	1643.24	8	0.9
Aluminum alloys (mill finish)	160.0	92.446	1109.36	1,12,15	0.05
Aluminum alloys (anodized)	160.0	92.446	1109.36	1,12,15	0.8
Aluminum alloys (painted)	160.0	92.446	1109.36	1,15	0.9
Aluminum bronze	100	57.78	693.35	2	0.9
Bronze	65	37.56	450.68	1,15	0.2
Brass	120	69.34	832.02	1,15	0.2
Copper	380	219.56	2634.72	1,15	0.8
Iron, cast	50	28.89	346.67	9	0.8
Lead	35	20.22	242.67	9	0.8

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Name	Conductivity k			Source[1]	Emissivity ε
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft²•°F	-	-
Tin	66.0	38.130	457.61	9	0.9
Steel (plated)	50.0	28.890	346.67	1,6,15	0.05
Steel (painted)	50.0	28.890	346.67	1,15	0.9
Steel (rolled, ground)	50.0	28.890	346.67	1, 6,15	0.1
Steel (rolled, ground, plated)	50.0	28.890	346.67	1, 6,15	0.2
Steel, low carbon (0.1%C)	59	34.09	409.08	9	0.9
Steel Stainless (oxidized)	17.0	9.822	117.87	1,6,15	0.8
Steel Stainless (buffed)	17.0	9.822	117.87	1,6,15	0.2
Steel-galvanized sheet (0.14%C)	52.0	30.045	360.54	6,16	0.2
Steel-galvanized sheet (0.14%C) (painted)	52.0	30.045	360.54	6,16	0.9
Zinc	110	63.56	762.68	17	0.28
Glazing Materials					
Glass, Soda-Lime (Plate or Float)	1.000	0.578	6.933	1,15	0.84
Glass mosaic	1.200	0.693	8.320	1,15	0.84
Glass-Flint (lead)	1.400	0.809	9.707	2	0.84
Glass-Quartz	1.400	0.809	9.707	1,15	0.9
Acrylic sheet	0.200	0.116	1.387	1,15	0.9
Insulating Materials					
Aerogel – Silica	0.024	0.014	0.166	10	0.9
Cellular glass	0.051	0.029	0.354	2	0.9
Cellulose, sprayed into open cavities	0.040	0.023	0.277	10	0.9
Cellulosic fiber, loose fill	0.046	0.027	0.319	2	0.9
Cotton fiber	0.042	0.024	0.291	2	0.9
Expanded perlite, organic bonded	0.052	0.030	0.361	2	0.9
Expanded Polystyrene (EPS)	0.038	0.022	0.263	1,15	0.9
Extruded Polystyrene (XPS)	0.034	0.020	0.236	1,15	0.9
Felt	0.050	0.029	0.347	2	0.9
Glass fiber, batts	0.048	0.028	0.333	2	0.9
Glass fiberboard	0.035	0.020	0.243	2	0.9
Glass fiber Sheathing (semi-rigid)	0.034	0.020	0.236	2	0.9
Glass fiber (spray applied)	0.042	0.024	0.291	2	0.9
Glass wool	0.033	0.019	0.229	1,15	0.9
Insulation fiberboard	0.049	0.028	0.340	8	0.9
Phenolic foam board with facing	0.023	0.013	0.159	2	0.9
Polyester fiber	0.040	0.023	0.277	1,15	0.9
Polyisocyanurate -foil faced	0.023	0.013	0.159	2	0.9
Polyisocyanurate – unfaced	0.025	0.014	0.173	2	0.9

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Name	Conductivity k			Source[1]	Emissivity ε
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft²•°F	-	-
Polyurethane foam, blown	0.023	0.013	0.159	18	0.9
Rock and slag wool batts	0.037	0.021	0.257	2	0.9
Straw thatch	0.070	0.040	0.485	2	0.9
Vermiculite	0.077	0.044	0.534	10	0.9
Miscellaneous					
Foam glass	0.040	0.023	0.277	1,11,15	0.9
Mohair (polyester) sweep	0.140	0.081	0.971	14	0.9
Desiccated matrix	Use base material				
Desiccant-silica gel	0.130	0.075	0.901	1,14,15	0.9
Desiccant–molecular sieve	0.100	0.058	0.693	14	0.9
Paints	N/A	N/A	N/A	-	0.9
Masonry Materials					
Concrete – high density	2.00	1.156	13.867	1,15	0.9
Concrete -reinforced	2.50	1.444	17.334	1,15	0.9
Brick, Fired clay – high density	1.47	0.849	10.192	2	0.9
Gypsum plasterboard	0.160	0.092	1.109	2	0.9

[1] Numbers listed in this column refer to documents listed in Section 10.2

[2] Values are for 6% moisture content, see Appendix D. This value may be applied to products of any moisture content for the purposes of this document.

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Table A.2: Thermophysical Properties of Gases (Source 5)

	Conductivity $k = a + Bt+Ct^2$ [W/m•K]			**Dynamic Viscosity** $\mu = a + Bt+Ct^2$ [kg/m•s]		
Gas	**Coefficient a** [W/m•K]	**Coefficient b** [W/m•K^2]	**Coefficient c [W/m•K^3]**	**Coefficient a** [kg/m•s]	**Coefficient b** [kg/m•s•K]	**Coefficient c** [kg/m•s•K^2]
Air*	$2.873x10^{-3}$	$7.760x10^{-5}$	0	$3.723x10^{-6}$	$4.94x10^{-8}$	0
Argon	$2.285x10^{-3}$	$5.149x10^{-5}$	0	$3.379x10^{-6}$	$6.451x10^{-8}$	0
Krypton	$9.443x10^{-4}$	$2.826x10^{-5}$	0	$2.213x10^{-6}$	$7.777x10^{-8}$	0
Xenon	$4.538x10^{-4}$	$1.723x10^{-5}$	0	$1.069x10^{-6}$	$7.414x10^{-8}$	0
CO_2	$3.70x10^{-4}$	$2.954x10^{-5}$	0	$-1.16x10^{-6}$	$6x10^{-8}$	0
SF_6	$1.300x10^{-2}$	0	0	$7.214x10^{-7}$	$4.928x10^{-8}$	0
Helium	$4.524x10^{-2}$	$3.6947x10^{-4}$	0	$5.951x10^{-6}$	$4.664x10^{-8}$	0
Neon	$1.567x10^{-3}$	$1.089x10^{-4}$	0	$1.013x10^{-5}$	$7.045x10^{-8}$	0
Octaflouropropane	$-1.578x10^{-3}$	$1.806x10^{-5}$	$10x10^{-8}$	$-2.04x10^{-6}$	$5.475x10^{-8}$	0

*Note: Nitrogen shall be treated as air

	Specific Heat $Cp = a + Bt + Ct^2$ [J/kg•K] -				**Molecular Mass**
Gas	**Coefficient a** [J/kg•K]	**Coefficient b** [J/kg•K^2]	**Coefficient c** [J/kg•K^3]		Mass [kg/kmol]
Air*	1002.74	$1.2324x10^{-2}$	0		28.97
Argon	521.93	0	0		39.948
Krypton	248.09	0	0		83.80
Xenon	158.34	0	0		131.30
CO_2	558.85	1.0496	$-2.3876x10^{-4}$		44.01
SF_6	418.60	0	0		146.10
Helium	5197.00	0	0		4.000
Neon	1030.00	0	0		20.180
Octaflouropropane	634.80	-0.387	$3.122x10^{-3}$		188.019

*Note: Nitrogen shall be treated as air.

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APPENDIX B EXTENDED SET OF GENERIC THERMOPHYSICAL PROPERTY VALUES OF MATERIALS

Table B.1: Thermophysical Properties of Solid Materials

Name[1]	Conductivity (*k*)			Source[2]	Emissivity (ε)
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft²•°F		-
Elastomers					
Vulcanized rubber (any density)	See Appendix A				
Vulcanized rubber, soft (density ≤ 1100 kg/m³)	0.100	0.058	0.693	2	0.9
Polymers					
ABS (any density)	See Appendix A				
ABS (molded)	0.190	0.110	1.318	20	0.9
Polyethylene/polythene (any density)	See Appendix A				
Polyethylene/polythene LD (low density) (density ≤ 920 kg/m³)	0.330	0.191	2.288	1,15	0.9
Polyurethane foam (any density)	See Appendix A				
Polyurethane foam, low density, open cell (density ≤ 10 kg/m³)	0.042	0.024	0.291	2	0.9
Timbers[3]					
Balsa	0.060	0.035	0.416	4	0.9
Birch, yellow	0.160	0.092	1.109	4	0.9
Redwood, old growth	0.110	0.064	0.763	2	0.9
Redwood, new growth	0.100	0.058	0.693	4	0.9
Cedar, Atlantic white	0.090	0.052	0.624	4	0.9
Cedar, Eastern red	0.120	0.069	0.832	4	0.9
Cedar, Northern white	0.090	0.052	0.624	4	0.9
Cedar, Port-Orford	0.110	0.064	0.763	4	0.9
Cedar, Western red	0.090	0.052	0.624	4	0.9
Cedar, yellow	0.120	0.069	0.832	4	0.9
Cypress, bald	0.120	0.069	0.832	4	0.9
Elm, American	0.140	0.081	0.971	4	0.9
Elm, Rock	0.170	0.098	1.179	4	0.9
Elm, Slippery	0.140	0.081	0.971	4	0.9

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Name[1]	Conductivity (*k*)			Source[2]	Emissivity (ε)
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft²•°F		-
Fir, balsam	0.100	0.058	0.693	4	0.9
Fir, white	0.110	0.064	0.763	4	0.9
Douglas-fir, coast	0.130	0.075	0.901	4	0.9
Douglas-fir, interior north	0.130	0.075	0.901	4	0.9
Douglas-fir, interior west	0.130	0.075	0.901	4	0.9
Hemlock, eastern	0.110	0.064	0.763	4	0.9
Hemlock, western	0.120	0.069	0.832	4	0.9
Larch (western)	0.140	0.081	0.971	4	0.9
Mahogany	0.130	0.075	0.901	2,7	0.9
Maple, black	0.150	0.087	1.040	4	0.9
Maple, red	0.140	0.081	0.971	4	0.9
Maple, silver	0.130	0.075	0.901	4	0.9
Maple, sugar	0.160	0.092	1.109	4	0.9
Oak, black	0.160	0.092	1.109	4	0.9
Oak, bur	0.160	0.092	1.109	4	0.9
Oak, Northern red	0.160	0.092	1.109	4	0.9
Oak, Southern red	0.150	0.087	1.040	4	0.9
Oak, white	0.180	0.104	1.248	4	0.9
Pine, Eastern white	0.100	0.058	0.693	4	0.9
Pine, European (Scots/Scotch/Baltic)	0.120	0.069	0.832	21	0.9
Pine, jack	0.120	0.069	0.832	4	0.9
Pine, loblolly	0.140	0.081	0.971	4	0.9
Pine, lodgepole	0.110	0.064	0.763	4	0.9
Pine, longleaf	0.150	0.087	1.040	4	0.9
Pine, pitch	0.130	0.075	0.901	4	0.9
Pine, ponderosa	0.110	0.064	0.763	4	0.9
Pine, Radiata	0.120	0.069	0.832	4	0.9
Pine, red	0.120	0.069	0.832	4	0.9
Pine, shortleaf	0.140	0.081	0.971	4	0.9
Pine, slash	0.150	0.087	1.040	4	0.9
Pine, sugar	0.100	0.058	0.693	4	0.9
Pine, Western white	0.110	0.064	0.763	4	0.9
Spruce, black	0.110	0.064	0.763	4	0.9
Spruce, Engelmann	0.100	0.058	0.693	4	0.9
Spruce, red	0.110	0.064	0.763	4	0.9
Spruce, Sitka	0.110	0.064	0.763	4	0.9
Spruce, white	0.100	0.058	0.693	4	0.9
Yellow-poplar	0.120	0.069	0.832	4	0.9

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Name[1]	Conductivity (k)			Source[2]	Emissivity (ε)
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft²•°F		-
Wood based panels					
Cement-bonded wood wool panels (any density)	See Appendix A				
Cement-bonded wood wool panels (density ≤ 500kg/m³)	0.100	0.058	0.693	1,15	0.9
Fiberboard (any density)	See Appendix A				
Fiberboard (medium density, dry process) (density ≤ 250 kg/m³)	0.070	0.040	0.485	1,15	0.9
Fiberboard (medium density, dry process) (250 < density ≤ 400 kg/m³)	0.100	0.058	0.693	1,15	0.9
Fiberboard (medium density, dry process) (400 < density ≤ 600 kg/m³)	0.140	0.081	0.971	1,15	0.9
Fiberboard (medium density, dry process) (600 < density ≤ 800 kg/m³)	0.180	0.104	1.248	1,15	0.9
Particleboard (any density)	See Appendix A				
Particleboard (density ≤ 300 kg/m³)	0.100	0.058	0.693	1,15	0.9
Particleboard (300 < density ≤ 600 kg/m³)	0.140	0.081	0.971	1,15	0.9
Particleboard (600 < density ≤ 900 kg/m³)	0.180	0.104	1.248	1,15	0.9
Plywood (any density)	See Appendix A				
Plywood (density ≤ 300 kg/m³)	0.090	0.052	0.624	1,15	0.9
Plywood (300 < density ≤ 500 kg/m³)	0.130	0.075	0.901	1,15	0.9
Plywood (500 < density ≤ 700 kg/m³)	0.170	0.098	1.179	1,15	0.9
Plywood (700 < density ≤ 1000 kg/m³)	0.240	0.139	1.664	1,15	0.9
Metals					
Aluminum alloy 195 cast (4.5 Cu)	168	97.07	1164.83	8	0.9
Aluminum alloy 2024 T6 (4.5 Cu,1.5 Mg, 0.6 Mn)	177	102.27	1227.23	8	0.9
Aluminum alloy 1100-O	221.90	128.21	1538.54	2,7	0.9

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Name[1]	Conductivity (k)			Source[2]	Emissivity (ε)
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft²•°F		-
Aluminum alloy 3003-O	163.28	94.34	1132.13	7	0.9
Aluminum alloy 5056-O	117.23	67.73	812.81	7	0.9
Aluminum alloy (96% Al, 1.8% Cu, 0.9% Fe, 0.9% Cr, 0.4% Si)	104.67	60.48	725.73	9	0.9
Aluminum bronze (95% Cu, 5% Al)	82.6	47.73	572.71	9	0.9
Steel, low carbon (0.1% Carbon at 0°C)	59	34.09	409.08	9	0.9
Steel, low carbon (0.2% Carbon at 20°C)	50	28.89	346.67	9	0.9
Steel, high carbon (0.6% Carbon at 20°C)	46.5	26.87	322.41	9	0.9
Tin-Lead Alloy Eutectic Solder (63%Sn - 37%Pb)	50.9	29.4	353	22	0.9
Insulating Materials					
Cellulosic fiber, loose fill (any density)	See Appendix A				
Cellulosic fiber (density ≤ 56 kg/m^3)	0.040	0.023	0.277	2	0.9
Glass fiber, batts (any density)	See Appendix A				
Glass fiber, batts (density ≤ 12 kg/m^3)	0.043	0.025	0.298	2	0.9
Glass fiber, batts (12 < density ≤ 14 kg/m^3)	0.039	0.023	0.027	2	0.9
Mineral fiber-low density (rock, slag, glass) (density ≤ 64 kg/m^3)	0.042	0.024	0.291	2	0.9
Polystyrene expanded (EPS) (any density)	See Appendix A				
Polystyrene expanded, molded beads (EPS), Type I, Type XI (density ≤ 16 kg/m^3)	0.037	0.021	0.257	2	0.9
Polystyrene expanded, molded beads (EPS), Type II, Type VIII (16 < density ≤ 24 kg/m^3)	0.035	0.020	0.243	2	0.9
Polystyrene expanded, molded beads (EPS), Type XI (24 < density ≤ 29 kg/m^3)	0.033	0.019	0.229	2	0.9
Polyester fiber (any density)	See Appendix A				

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Name[1]	Conductivity (*k*)			Source[2]	Emissivity (ε)
	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft²•°F		-
Polyester fiber (density ≤ 25 kg/m³)	0.038	0.022	0.263	1,15	0.9
Polyester fiber (25 < density ≤ 35 kg/m³)	0.036	0.021	0.250	1,15	0.9
Polyester fiber (35 < density ≤ 45 kg/m³)	0.035	0.020	0.243	1,15	0.9
Polyurethane foam, HFC 245fa blown (density ≤ 31 kg/m³)	0.020	0.012	0.139	18	0.9
Polyurethane foam, HFC 134a blown	0.023	0.013	0.159	18	0.9
Polyurethane foam, cyclopentane blown	0.020	0.012	0.139	18	0.9
Masonry Materials					
Concrete (any density)	See Appendix A				
Concrete – medium density (density ≤ 1800 kg/m³)	1.15	0.664	7.974	1,15	0.9
Brick, Fired clay (any density)	See Appendix A				
Brick, Fired clay – low density (density ≤ 1200 kg/m³)	0.45	0.26	3.12	2	0.9
Brick, Fired clay – medium density (1200 < density ≤ 1600 kg/m³)	0.74	0.428	5.131	2	0.9

[1] Densities, where listed, are nominal values and for reference only. Densities of actual materials are permitted to vary and do not need to be verified by NFRC certified simulators.

[2] Numbers listed in this column refer to documents listed in Section 10.2

[3] Values are for 6% moisture content, see Appendix D. This value may be applied to products of any moisture content for the purposes of this document.

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APPENDIX C THERMOPHYSICAL PROPERTY VALUES OF PROPRIETARY MATERIALS

Table C.1: Thermophysical Properties of Solid Materials

Participant	Product	Density	Conductivity			Emissivity	Expiration Date
		kg/m^3	W/m•K	Btu/hr•ft•F	$Btu•in/hr•ft^2•^oF$		
3M™	VHB™ Structural Glazing Tape B23F	720	0.181	0.105	1.26	-	12/31/2029
3M™	VHB™ Structural Glazing Tape G23F	720	0.192	0.111	1.33	-	12/31/2029
3M™	VHB™ Architectural Panel Tape G16F	720	0.152	0.088	1.05	-	12/31/2029
3M™	VHB™ Tape GPH-160	710	0.140	0.081	0.968	-	12/31/2029
Allmetal	3 mil Stainless Steel	7110	15.3	8.83	106	-	12/31/2029
Allmetal	4.5 mil Stainless Steel	7380	14.7	8.47	102	-	12/31/2029
Allmetal	6 mil Stainless Steel	7570	14.9	8.64	104	-	12/31/2029
Allmetal	8 mil Stainless Steel	7690	15.5	8.94	107	-	12/31/2029
AmesburyTruth	Foam-Tite	103.5	0.039	0.022	0.268	-	12/31/2027
Andersen Corporation	CPI Fiberglass Material	1700	0.314	0.181	2.18	-	12/31/2029
Andersen Corporation	Fibrex EZ+	21.8	0.202	0.117	1.40	0.9	12/31/2029
Andersen Corporation	Andersen Extruded Polystyrene Foam	35.8	0.026	0.015	0.183	0.9	12/31/2029
Andersen Corporation	Andersen Extruded Polystyrene Foam 2	30.4	0.026	0.015	0.183	0.9	12/31/2027
Andersen Corporation	Polycarbonate Composite	1310	0.229	0.132	1.588	0.9	12/31/2028
Andersen Corporation	Fibrex IC Material	1430	0.190	0.110	1.32	-	7/1/2029

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Participant	Product	Density	Conductivity			Emissivity	Expiration Date
		kg/m^3	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft^2•^oF		
Andersen Corporation	Composite Subsill	1060	0.292	0.169	2.025	-	12/31/2027
Andersen Corporation	Silicone Backed Graphite Composite (@ 0.200" thick)	1300	0.523	0.302	3.63	-	12/31/2027
Andersen Corporation	Agriculture Fiber Board	588	0.107	0.062	0.744	-	7/1/2029
Azon	Azo-Core 10	157	0.0323	0.0187	0.224	-	12/31/2028
Azon	Azo-Core 13	204	0.032	0.018	0.218	0.9	7/1/2030
Azon	Azo-Core 17	259	0.036	0.021	0.252	0.9	7/1/2030
Azon	Azo-Core 20	335	0.049	0.028	0.337	-	12/31/2028
BASF	Polyurethane Elastomer	1139	0.182	0.105	1.264	-	12/31/2026
BASF	Ultradur® B4040 G11 Natural	1350	0.219	0.127	1.518	-	12/31/2027
BASF	Ultradur® B4040 G11 Green	1427	0.253	0.146	1.754	-	12/31/2027
BASF	KF/F 2000 Series	19	0.029	0.017	0.201	-	12/31/2029
BASF	F5000 (Plus Series)	17	0.028	0.016	0.196	-	12/31/2029
Cardinal Industries	Stainless Steel	7808	14.187	8.197	98.37	-	7/1/2029
Chelsea Building Products	C Core Composite PVC	1586	0.488	0.282	3.384	-	7/1/2029
Colonial Metal	SST	7688	12.933	7.473	89.673	-	12/31/2029
Colonial Metal	Tin Plated Steel	7660	50.2	29.05	348.6	-	12/31/2029
Covestro	Baydur PUL-4800	1120	0.205	0.118	1.419	-	7/1/2028
Deceuninck N.A.	Rovex	2110	0.517	0.299	3.58	-	7/31/2028
Dynamic Fenestration	Carbon Fiber	1560	0.481	0.278	3.34	-	7/1/2030

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Participant	Product	Density	Conductivity			Emissivity	Expiration Date
		kg/m^3	W/m•K	Btu/hr•ft•F	$Btu•in/hr•ft^2•^oF$		
Dynamic Fenestration	Basalt Fiber	2030	0.395	0.228	2.74	-	7/1/2030
Ensinger	Tecafoil LeF Low-E Foil	2193	160	92.4	1109	0.03	7/1/2030
Ensinger	Insulbar® LI + RE-LI	1030	0.213	0.123	1.48	-	12/31/2027
Ensinger	Insulbar® REG + RE	1280	0.280	0.162	1.94	-	12/31/2027
Ensinger	Insulbar® REG + RE GF40	1387	0.378	0.218	2.62	-	7/1/2028
Fenzi North America	Thermoflex Spacer	782	0.118	0.068	0.818	-	7/1/2030
GED	Intercept Ultra Stainless Steel	7473	13.63	7.877	94.52	-	7/1/2029
Glasslam	WorldSpacer/EcoSpacer PU Desiccant Foam	1095	0.191	0.110	1.33	0.9	12/31/2027
Guardian Industries	Corrugated SST	7440	13.87	8.025	96.296	0.9	7/1/2029
H.B. Fuller/ Kömmerling	Kodispace 4SG	1267	0.267	0.154	1.85	-	12/31/2028
H.B. Fuller/ Kömmerling	PIB-7-HSNB	1067	0.168	0.097	1.17	-	12/31/2028
H.B. Fuller/ Kömmerling	PIB-8 HSNB Gray	1094	0.167	0.096	1.16	-	12/31/2028
ICP Construction	Handifoam Open Cell Polyurethane Foam	22	0.034	0.020	0.236	-	12/31/2028
Inline Fiberglass	Fiberglass Pultrusion	1470	0.260	0.150	1.81	-	12/31/2029
JELD-WEN	EPS Door Core Material	18.6	0.033	0.019	0.229	-	12/31/2029
JELD-WEN	JELD-WEN Proprietary Composite	1307	0.227	0.131	1.57	-	12/31/2027
JELD-WEN	Phenolic Foam Core	130	0.046	0.027	0.319	-	12/31/2029
Kalwall	Insulation A	4.81	0.077	0.045	0.536	-	12/31/2029
Kalwall	Insulation B	4.06	0.093	0.054	0.648	-	12/31/2029

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Participant	Product	Density	Conductivity			Emissivity	Expiration Date
		kg/m^3	W/m•K	Btu/hr•ft•F	$Btu•in/hr•ft^2•^oF$		
Kalwall	Insulation C	12.82	0.047	0.027	0.327	-	12/31/2029
Kalwall	Insulation D	38.98	0.032	0.019	0.222	-	12/31/2029
Kalwall	Insulation E	8.0	0.04	0.023	0.277	0.9	12/31/2029
Kenex	Thermoplastic Spacer Sealant (TPPS)	1223	0.248	0.143	1.72	-	12/31/2028
Kingspan Light & Air Fenestration	Translucent Thermal Insulation 15	6.94	0.079	0.046	0.549	0.9	12/31/2029
Kingspan Light & Air Fenestration	Translucent Thermal Insulation 24	4.31	0.098	0.057	0.68	0.9	12/31/2029
Kingspan Light & Air Fenestration	Ultimate Series FRP	1370	0.192	0.111	1.33	0.9	12/31/2029
Kingspan Light & Air Fenestration	10 Light Transmitting Insulation	9.58	0.07	0.041	0.487	-	12/31/2029
Kingspan Light & Air Fenestration	IMG 125 Light Transmitting Insulation	6.92 (at 1.25”)	0.037	0.021	0.258	-	12/31/2029
Kömmerling USA	Profine Threshold - Plastic Composite	1353	0.273	0.158	1.89	-	7/1/2028
Leading Edge	EdgeStar Stainless	7720	13.467	7.781	93.37		7/1/2030
Leading Edge	ThinStar Steel	7147	51.6	29.8	358	-	7/1/2030
LuxWall	Seal Material 1	3587	0.749	0.433	5.19	-	7/1/2028
LuxWall	Seal Material 2	3400	1.137	0.657	7.88	-	7/1/2028
Marvin	ULTREX	1573	0.264	0.152	1.83	-	12/31/2027
Marvin	HLP MGF 47%	1800	0.348	0.201	2.415	-	12/31/2027
Marvin	HDF-FRP-PUR	2055	0.497	0.287	3.45	-	12/31/2027
Marvin	HLP GF 44%	1730	0.273	0.158	1.89	0.9	7/1/2029
Marvin	HLP GF 15%	1540	0.210	0.121	1.68	-	7/1/2029
Marvin	HLP GF 30%	1640	0.242	0.140	1.45	-	7/1/2029
Nan Ya Plastics	Neuma Door-Foam PVC	999	0.082	0.048	0.57	-	12/31/2027

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Participant	Product	Density	Conductivity			Emissivity	Expiration Date
		kg/m^3	W/m•K	Btu/hr•ft•F	$Btu•in/hr•ft^2•^oF$		
Nan Ya Plastics	Neuma Door-Phenolic Foam	740	0.029	0.017	0.201		7/1/2030
Pella Windows and Doors	Duracast (Unpainted)	1784	0.228	0.132	1.58	0.9	12/31/2029
Plastpro	Cellular PVC by JM Eagle	597	0.067	0.039	0.462	-	12/31/2027
Plastpro	PF Frame by JM Eagle	698	0.084	0.049	0.583	-	12/31/2027
Ply Gem Windows	ecoCore Wood Plastic Composite Reinforcement	1002	0.356	0.206	2.47	0.9	7/31/2028
PUcore USA	Polyurethane Foam – RST-200 Series	34.1	0.016	0.0094	0.113	-	12/31/2026
PUcore USA	Injected Polyurethane Foam – RST-970 Series	21.5	0.030	0.017	0.207	0.9	7/1/2027
Quanex Building Products	Super SpacerPremium	634	0.115	0.066	0.795	-	12/31/2027
Quanex Building Products	Super SpacerPremium Plus	648	0.127	0.073	0.877	-	12/31/2028
Quanex Building Products	Super Spacer Standard (EPDM)	793	0.179	0.103	1.24	-	12/31/2028
Quanex Building Products	Super Spacer TriSeal/T-Spacer Premium Plus	686	0.141	0.082	0.980	-	12/31/2028
Quanex Building Products	Super Spacer T-Spacer Premium	767	0.130	0.075	0.899	-	12/31/2027
Quanex Building Products	Butyl 761-71X	1194	0.176	0.102	1.22	0.9	7/15/2029
Quanex Building Products	EnergyCore Fusion Insulated System	134	0.032	0.019	0.225	-	12/31/2029
Quanex Building Products	XTD Composite	493	0.052	0.030	0.362	-	12/31/2029

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Participant	Product	Density	Conductivity			Emissivity	Expiration Date
		kg/m^3	W/m•K	Btu/hr•ft•F	$Btu•in/hr•ft^2•^oF$		
Reynaers Aluminium NV	Nomatec XPE Foam Insulation	34.4	0.036	0.021	0.252	-	12/31/2027
SWISSPACER, Saint Gobain	Advance/Ultimate	1229	0.166	0.096	1.15	-	7/1/2028
SWISSPACER, Saint Gobain	Ultimate Pro	1141	0.145	0.084	1.01	-	7/1/2030
Schuco USA	Polypropylene Foam	32.7	0.031	0.018	0.218	-	12/31/2026
Schuco USA	Polythermid	1027	0.185	0.107	1.28	-	12/31/2027
Schuco USA	Polyutherm	1050	0.193	0.112	1.34	-	12/31/2027
Sun Windows	Weyerhaeuser Moisture Shield Composite Sill	1124	0.311	0.180	2.16	-	7/1/2028
TECHNOFORM	Stainless Steel for SP12, SP13, SP14, SP17, SP20, SP25	7710	14.0	8.09	97.1	0.2	7/1/2029
TECHNOFORM	PA66 GF25	1253	0.284	0.164	1.97	-	12/31/2029
TECHNOFORM	PA66 GF40	1450	0.352	0.204	2.44	-	12/31/2029
Tremco	EnerEDGE Silicone Warm-Edge Spacer, non-white	616	0.113	0.066	0.786	-	12/31/2029
Tremco	EnerEDGE-E (EPDM) Warm-Edge Spacer	726	0.145	0.0838	1.01	-	7/1/2030
Viracon	VTS Thermal Plastic Spacer	1142	0.196	0.113	1.36		12/31/2026
Vision Coatings	Low-e Foam	50	0.0317	0.0183	0.220	0.035	12/312028
Warmframe Technology	Thermal Break Blanket	208	0.019	0.011	0.133	0.9	7/1/2029
WFI Global	U Core Extrusion Fill Foam	39.5	0.029	0.017	0.202	-	7/1/2029
WFI Global	U Core Plus Extrusion Fill Foam	40.5	0.029	0.017	0.203	-	7/1/2029

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Participant	Product	Density	Conductivity			Emissivity	Expiration Date
		kg/m^3	W/m•K	Btu/hr•ft•F	Btu•in/hr•ft^2•^{o}F		
Zola Windows	V1 Foam Insulation	538	0.071	0.041	0.489	-	12/31/2026
Zola Windows	V2 Foam Insulation	205	0.039	0.023	0.270	-	12/31/2026

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APPENDIX D MOISTURE CONTENT OF WOOD

The conductivity data of all wood species in Tables A.1 and B.1 was recalculated at 6% moisture content and then reviewed and approved by an NFRC working group. The working group used the US Department of Agriculture's Wood Handbook (2010, FPL-GTR-190) for the initial table of results for the thermal conductivities of wood species. The data was reviewed by the NFRC 101 Task Group and updated, where applicable, based on the US Department of Agriculture's Wood Handbook (2021, FPL-GTR-282).

It was observed in the Wood Handbook that the wood thermal conductivity data had a variation of as much as ±20%. It was determined that the thermal conductivity for 6% moisture content, with an error band of ±20%, has a range the same or greater than the values from 0% to 12%. As a result of this review by the workgroup, the thermal conductivity for all wood species in Tables A.1 and B.1 is based on 6% moisture content. The wood species' thermal conductivities in Tables A.1 and B.1 are permitted to be used for any moisture content percentage.

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