Asia-Pacific
Economic Cooperation

Advancing Free Trade
for Asia-Pacific Prosperity

Coordinating Standards for Cool Roof Testing and Performance

APEC Energy Working Group

September 2020

APEC Project: EWG 14 2018A

Produced by
Sven Mumme / Kurt Shickman and Bipin Shah
US Department of Energy
Forrestal Building, 1000 Independence Ave,
SW Washington, DC 20585, USA

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

APEC#220-RE-01.10

Contents

Introduction 4
How Cool Surfaces Work 4
Benefits of Increased Deployment of Cool Surfaces 5
Energy 5
Climate and Global Cooling 6
Air Quality 6
Human Health 7
Surface durability 7
Economics and Productivity 8
Effects on Social Equity 8
Cool Roof Testing Standards 9
Establishing Cool Surface Testing Infrastructure 13
Responsibilities of the Certification Governing Body 15
Selecting Cool Roof Product Attributes for Performance Testing and Certification 15
Establishing Minimum Performance Testing and Certification Criteria 16
The Role of Testing Laboratories and Test Farms 17
Requirements for All Accredited Testing Laboratories 17
Ensuring that cool surface products are produced with consistent quality and meet the certified performance requirements 19
Quality Control 19
Random Testing of Rated Products 19
Create a process to label products for the marketplace 19
Cool Roof Product Label Characteristics 20
Technical Annex 1 21
Measurements of Solar Reflectance and Emittance to calculate Solar Heat Gain 21
Detail on Solar Reflectance (SR) and Related Optical Properties of Surfaces 21
Net Solar Heat Gained by a Material Receiving Solar Radiation 22
Air Mass and Optical Processes in the Atmosphere 22
Technical Annex 2 23
Testing Equipment Used for Measurement of Solar Reflectance 24
Measurement of Emittance 29
References 33

Introduction

The use of highly solar reflective, "cool" surfaces (e.g., roofs and walls) has become increasingly common as a means to increase energy efficiency in buildings with air conditioning and to improve thermal comfort in buildings lacking air conditioning. This report, commissioned by the Asia-Pacific Economic Cooperation (APEC), under its Energy Working Group, reviews the characteristics of highly solar reflective, "cool" surfaces, with a focus on the standards currently in place in APEC economies for testing material surface properties. These standards are critical to establishing and enforcing quality products and effective building codes to promote the use of cool surfaces. Differences in standards between APEC economies can add confusion and costs for manufacturers seeking to import and to the end users they are supplying and may contribute to reduced demand or product availability throughout APEC. By gathering and comparing existing standards, this report seeks to provide additional clarity to policymakers and industry, highlight areas of commonality and differences between standards relevant to that audience, offer recommendations to economies who have not yet adopted cool surface testing standards, and inform any future discussions on harmonization of standards.

How Cool Surfaces Work

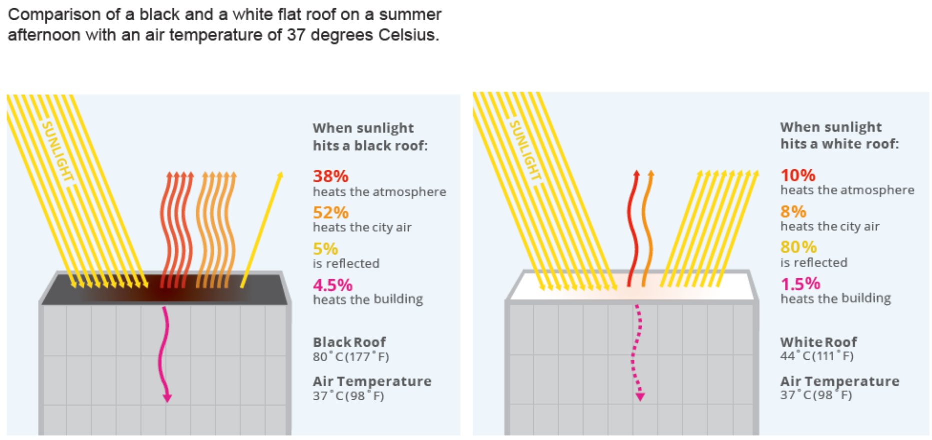
The concept of creating cooler structures using a surface's ability to reflect sunlight and to efficiently emit absorbed heat dates back to ancient construction. Every opaque urban surface (e.g. roofs, walls, pavements) reflects some incoming sunlight and absorbs the rest. Solar radiation absorbed by the exterior surfaces of buildings warms those surfaces. Some of the heat conducts into the building and some raises the outside air temperature. Reflecting solar radiation into the sky, ideally through the atmosphere and into space, can reduce the amount of solar heat gained by buildings, communities, and cities. The effectiveness of so-called "cool surfaces" is measured by the fraction of solar radiation they reflect versus the fraction that they absorb and convert into heat (measured by solar reflectance or SR). SR is measured on a scale between 0 and 1, where 0 represents a pure black surface that reflects no solar energy and 1 is a pure white surface that reflects all solar energy. These values may also be expressed as solar absorptance, which is the inverse of solar reflectivity.

The effectiveness of cool surfaces is also measured by how efficiently and quickly they shed heat. A surface absorbing solar radiation becomes hotter and releases some heat by convection, radiation, and conduction (measured by thermal emittance or TE). Like SR, emittance is measured on a scale from 0 to 1. Non-metallic surfaces are typically characterized by high emissivity (generally in the range of 0.8 to 0.95) while uncoated metallic surfaces tend to have lower thermal emittance performance. Thus, an uncoated metal surface that is as reflective as a non-metallic surface will nonetheless remain warmer because it emits less thermal radiation and absorbs more un-reflected solar heat. Together, SR and TE are sometimes referred to as the radiative properties of a surface.

Building codes may also reference another cooling indicator called the Solar Reflectance Index (SRI). SRI is a combination of a surface's radiative properties in order to simulate roof conditions on a clear, sunny, summer day. SRI is typically a calculated number considering

Solar Reflectance and Solar Emittance, measured from 0 to 100, though it is possible to see negative values for extremely hot surfaces or values over 100 for an exceptionally cool material. The use of SRI as a combined measurement of reflectance and emittance in codes is becoming less common, since it has been shown that two different products with identical SRI values can yield significantly different energy savings results depending on what geographic region they are applied in, and the climatic conditions present in this region.

Figure 1 How cool roofs work



Source: Global Cool Cities Alliance (2012), The Cool Roofs and Pavements Toolkit, https://www.coolrooftoolkit.org/wp-content/pdfs/CoolRoofToolkit_Full.pdf and Lawrence Berkeley National Laboratory.

Benefits[1] of Increased Deployment of Cool Surfaces

Average outdoor air temperatures can be reduced by 0.3°C per 0.10 increase in average solar reflectivity in a city. Peak outdoor air temperature decreases by up to 0.9°C per each 0.10 increase in solar reflectivity.[i] Indoor air temperatures can also be lowered by adopting urban cooling strategies. A pilot outside of Ahmedabad, India found that air temperatures inside a small low-income house with a solar reflective metal roof were 2.5-3.5°C lower than an identical home with an uncoated metal roof.[ii]

The ability of highly solar reflective surfaces to reduce indoor and outdoor air temperatures generates a broad set of benefits for buildings, cities, and the globe.

Energy

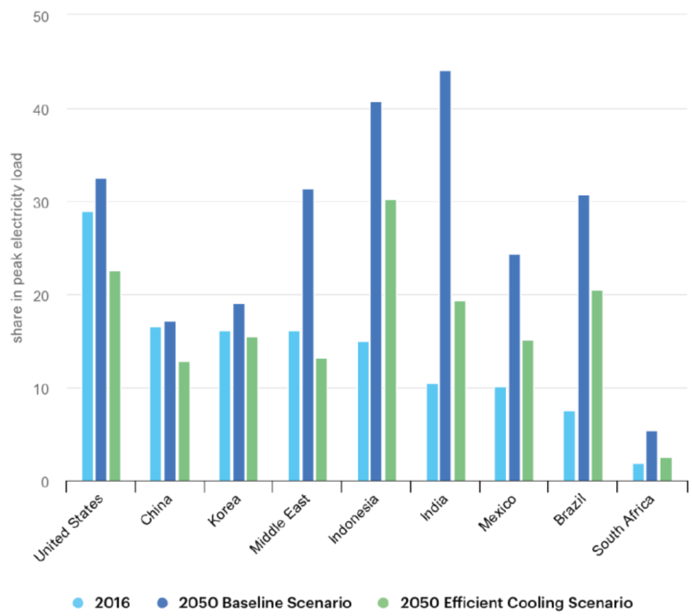
Rising temperatures, and trends of global economic growth, are leading to an increase in the use of air conditioning. Globally, room air conditioners in service are projected to more than triple by 2050 and increase five-fold in developing economies.[iii] This growth in air conditioning is expected to increase energy demand by as much as 58% over the same period.[iv] Solar reflective roofs can reduce cooling energy demand by 10 to 40%. In winter,

[1] The net benefits of increased surface solar reflectivity will depend on climate, building location and orientation, altitude, annual heating load, annual cooling load, peak energy demand, electricity tariffs, occupancy patterns, shading, material availability, market efficiency, urban form and other factors.

heating penalty may range between 5 and 10% as a function of local climate and building characteristics.[v]

During extreme heat events, excess demand for space cooling can overload electricity supply systems and cause power outages.[vi,vii] Cooling demand will make up over 20% of peak load in economies like China and South Korea, around 30% in Mexico and the United States, and over 40% in Indonesia (Figure 2). Increasing the solar reflectance of urban surfaces could reduce maximum peak power demand by up to 7%.[viii]

Figure 2 Expected contribution of cooling on peak energy demand



Source: IEA (2018), The Future of Cooling, IEA, Paris https://www.iea.org/reports/the-future-of-cooling.

Climate and Global Cooling

A large-scale shift toward reflective surfaces could cool the world by 0.01–0.07°C by reducing the amount of heat that is transmitted from the earth's surface and trapped in the atmosphere.[ix] The use of more reflective surfaces in hot cities around the world could cancel the warming effect of 44–57 billion metric tons of carbon dioxide already emitted into the atmosphere[x]—up to 75% above current annual global emissions of carbon dioxide.[2,xi]

Air Quality

Cool surfaces contribute to improved air quality in two ways. First, any energy efficiency gains resulting from the deployment of cool surfaces will reduce greenhouse gas emissions from electric power generation – particularly when electricity is generated by fossil-fuel based power plants located near urban areas. Second, temperature and ground-level ozone

[2] Estimate of 9.5 billion metric tons of carbon emitted (35 billion metric tons of carbon dioxide).

formation are positively correlated, meaning that concentrated deployments of cool surfaces that result in lower air temperatures will also reduce hazardous emissions and smog. Ground-level ozone and smog is a major air-quality concern that significantly contributes to respiratory illness in cities. Currently, over 1 million deaths per year are attributed to extended exposure to ozone pollution, the majority of which occur in India and China.[xii] While research generally supports that cooler air temperatures have a net positive effect on air quality, cooler air temperatures may also cause a slight decrease in air quality by slowing the vertical movement of air from the hot ground level to cooler layers above the city (known as vertical mixing)[xiii]

Human Health

In an average year, heat is the world's deadliest natural disaster and heat-related mortality is expected to dramatically worsen in the coming decades. The World Health Organization estimates that annual heat-related deaths will rise from 100,000 in 2030 to 250,000 by 2050 as extreme heat events grow in frequency, duration, and intensity.[xiv]

Heat stress on humans starts to occur when the human body reaches temperatures above 38°C (or 1°C above its normal temperature of 37°C. Excess heat conditions, along with poor air quality, also exacerbate a number of common health conditions caused by diseases of the heart, lungs, kidney and diabetes.[xv] Indoor air temperatures above 27°C contribute to increased mental stress and sleeping difficulty.[xvi]

City-scale implementation of cool surfaces reduces air temperatures and can save lives on dangerously hot days. One study evaluated the effect of increases in the average solar reflectance of roofs in Chicago and Boston (hot summer, cold winter climates) and found that both cities would experience an average air temperature reduction of 1.5°C. The resulting cooler air temperatures could reduce mortality during dangerous heat events by 8.1% and 9.2% in Boston[3] and by 2.5% to 10% in Chicago.[xvii] Beyond saving lives, cooler temperatures promote outdoor activity, social interaction, and enhance quality of life, leading to improved mental health.

Surface durability

Roof surfaces that absorb a lot of solar radiation (i.e., hot roofs) widen the roof surface's diurnal temperature range—daytime high minus nighttime low—and the resulting stress of thermal expansion and contraction can reduce material stability. Any resulting fatigues can cause the roof substrate to crack or tear, producing water leakages and shortening of a roof's useful life.

[3] The low end of the mortality reduction range assumes a 0.15 SR increase in average roof albedo. The upper end of the range assumes a 0.25 SR increase.

Economics and Productivity

The negative effects of excess heat have substantial implications for urban economies. A study of 1,692 cities worldwide finds that the effects of excess urban heat and local climate change will reduce the annual economic output of the median city by 5.6% by 2100 and by up to 11% in the worst-affected cities.[xviii] Other studies examine the negative economic effects of heat including reduced productivity,[xix] power outages, and transport disruptions.[xx] Financial losses from a 2009 heatwave in southeast Australia were estimated to be US$521 million, largely from disruptions to the power grid and transportation system.[xxi]

Combinations of urban passive cooling solutions, primarily solar reflective and permeable surface solutions, generate between $1.50 and $15.20 in net benefits for each $1.00 invested, according to a study covering 1,692 cities worldwide (Figure 3).[xxii]

Figure 3 Benefit and Cost Effects of Cool and Permeable Surfaces

Source: World Bank Group (2020), "Primer on Cool Cities: Reducing Excessive Urban Heat" based on data from Estrada et al (2017), "A global economic assessment of city policies to reduce climate change impacts," Journal Nature Climate Change, https://www.nature.com/articles/nclimate3301.

Effects on Social Equity

Without exception, the negative effects of heat described above are disproportionately borne by poor and marginalized populations. The effect of rising heat is particularly dire for the 680 million people living in hot, economically impoverished, urban areas who lack access to air conditioning and must find other solutions to deliver the thermal comfort needed to live and thrive.[xxiii] People living in lower-income and less vegetated areas have a 5% greater chance to die due to heat than those living in wealthier, shadier areas.[xxiv]

Cool Roof Testing Standards

Policy makers and the public are becoming more aware of the substantial benefits possible from the implementation of cool surfaces. This has led to an increase in their use in many APEC economies, with some adopting incentives or requirements to spur market growth. Standards to test radiative properties are essential to ensure effective policies and informed purchasing decisions. This section reviews the existing standards in APEC economies for testing the radiative properties of cool surfaces. Table 1 summarizes the existing standards used to test the solar reflectance of building envelope products (primarily roofs). Table 2 summarizes the existing standards for testing thermal emittance. Table 3 reorganizes the standards to show which standards are active by APEC economy.

Table 1: Testing Standards for Solar Reflectance of Surfaces in APEC Economies

Standard	Title	Comments
ASTM C1549	Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer	Testing method
ASTM C 903	Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres	Testing method
ASTM E 1918	Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field	Testing method
ASTM C1864	Standard Test Method for Determination of Solar Reflectance of Directionally Reflective Material Using Portable Solar Reflectometer	Testing method
ASTM E 1980	Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces	Calculation method based on measured Reflectance and Emittance
ANSI/CRRC S100	Standard Test Methods for Determining Radiative Properties of Materials	Testing requirements and procedure
GB/T 31389	Technical Requirements and Evaluation Methods of Solar Reflective Materials for Exterior Walls and Roofs	Apendix A and B of the standard mention the method used for measurement of Reflectance, similar to ASTM C 903 and C 1549 respectively
JGJ/T287	Testing Standard for Solar Heat Reflecting Insulation Coatings for Buildings	Testing method

JGJ/T 359	Technical Specification for Application of Architectural Reflective Thermal Insulation Coating	Specification standard
JG/T235	Architectural Reflective Thermal Insulation Coating	Specification standard
JIS K 5602	How to Determine Solar Reflectance of Coating	IS K 5602: measurement method using a spectrophotometer, established 2008-09-20, investigated by Japanese Industrial Standards Committee, published by Japanese Standards Association
JIS K 5675	High Solar Reflectance Paint for Roof	JIS K 5675: measurement method using a spectrophotometer, defined by the near-infrared solar reflectance, established 2011-07-20, investigated by Japanese Industrial Standards Committee, published by Japanese Standards Association. Retention of the near-infrared solar reflectance 24 months after outdoor exposure is measured in JIS K 5675
JSTM J 6151	Measuring Method for Solar Reflectance of Flat Roof in the Field	measurement method by pyranometer using white and black standard plates, published 2014-09-16 by Japan Testing Center for Construction Materials
JIS R 3106	Testing Method On Transmittance, Reflectance and Emittance of Flat Glasses and Evaluation of Solar Heat Gain Coefficient	Industry in Thailand are using this standard for Reflectance measurement. However, they are planning to switch to JIS K 5062.
NMX-U-000-SCFI-2015	Building Industry -Buildings-Roof Surfaces with High Solar Reflectance Index-Specifications and Test methods	Mexico Test and Specification Industry standard.
QCVN 09:2017/BXD	National Technical Regulation on Energy Efficiency Buildings	Viet Nam building standard -Specifies $OTTV_m$ and $OTTV_T$ = Overall Thermal Transfer Value for Roof and Exterior walls. This considers the Solar Gain which requires the measurement of Reflectance and Emittance
ISO 6946	Building Components and Building Elements — Thermal Resistance and Thermal Transmittance — Calculation Methods	Used by Viet Nam in conjunction with TCVN 4605 and TCVN 9258.
TCVN 4605	Heating Techniques - Insulating Components - Design Standard	
TCVN 9258	Heat Protection for Residential Buildings - Design Guide	

Table 2: Thermal Emittance Test Standards in APEC Economies

Standard	Title	Comments
ASTM C1371	Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers	Testing method
ASTM C 903	Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres	Testing method
ANSI/CRRC S100	Standard Test Methods for Determining Radiative Properties of Materials	Testing requirements and procedure
GB/T 31389	Technical Requirements and Evaluation Methods of Solar Reflective Materials for Exterior Walls and Roofs	Appendix A and B of the standard mention the method used for measurement of Reflectance, similar to ASTM C 903 and C 1549 respectively
JIS R 3107	Calculation of Thermal Transmittance of Glazing	established 1998-03-20, revised 2019-03-20, investigated by Japanese Industrial Standards Committee, Standards Board for ISO area, Technical Committee on Architecture, published by Japanese Standards Association. Currently used for opaque material also in Laboratory
JIS R 3106	Testing Method on Transmittance, Reflectance and Emittance of Flat Glasses and Evaluation of Solar Heat Gain Coefficient	Industry in Thailand are using this standard for Reflectance measurement. However, they are planning to switch to JIS K 5062.
NMX-U-000-SCFI-2015	Building Industry -Buildings-Roof Surfaces with High Solar Reflectance Index-Specifications and Test methods	Mexico Test and Specification Industry standard.
QCVN 09:2017/BXD	National Technical Regulation on Energy Efficiency Buildings	Viet Nam building standard -Specifies $OTTV_m$ and $OTTV_T$ = Overall Thermal Transfer Value for Roof and Exterior walls. This considers the Solar Gain which requires the measurement of Reflectance and Emittance
ISO 6946	Building components and building elements — Thermal resistance and thermal transmittance — Calculation methods	Used by Viet Nam in conjunction with TCVN 4605 and TCVN 9258.
TCVN 4605	Heating Techniques - Insulating Components - Design Standard	
TCVN 9258	Heat Protection for Residential Buildings - Design Guide	

Table 3: Testing standards for radiative properties by APEC economy

APEC Members	Standards Used	Comment
Australia	ASTM E1549, ASTM E1371, ASTM E1980, ASTM E903, AS/NZ 4859-1	n/a
Brunei Darussalam	Currently no standard for Testing Reflectance or Emittance of cool roof.	Table for Reflectance and Emittance are provided in the economy’s building code standard
Canada	ASTM E1549, ASTM E1371, ASTM E1980, ASTM E903	n/a
Chile	Currently no standard for Testing Reflectance or Emittance of cool roof.	n/a
People's Republic of China	GBT 31389, JGJ287, JGJ359, JGT235-2014	GBT 31389 specifies the testing standard for Reflectance and Emittance. JGJ and JGT are standards product performance
Hong Kong, China	No specific standard for testing Reflectance or Emittance	Uses OTTV and OTTR in the economy’s building code. The appendix has a table listing of material Reflectance and Emittance
Indonesia	Currently no standard for Reflectance or Emittance of cool roof.	Table for Reflectance and Emittance are provided in the economy’s Building Code standard
Japan	JIS_K_05602, JIS_K_05675, JSTM-J-7601, JSTM-J-7602, JSTM-J-6151, JIS-R-3107	JIS R 3107 is standard for measuring Glazing product Emittance and is used for measuring opaque surface also
Republic of Korea	Information not Available	
Malaysia	Currently no standard for Reflectance or Emittance of cool roof.	The economy’s code MS1525 requires calculation of RTTV, however does not reference testing procedure. Table for Reflectance and Emittance are provided in the economy’s building standard
Mexico	NMX-U-000-SCFI-2015	Difference from USA methodology is that coatings are tested over standard QUV exposure and at manufacturer’s recommended thickness. Measure over contrast leneta, in order to asses “extended or solar” contrast ratio
New Zealand	ASTM E1549, ASTM E1371, ASTM E1980, ASTM E903, AS/NZ 4859-1	n/a
Papua New Guinea	Currently no standard for Reflectance or Emittance of cool roof.	n/a
Peru	Currently no standard for Reflectance or Emittance of cool roof.	n/a

The Philippines	Currently no standard for Reflectance or Emittance of cool roof.	The economy's Building Energy code is under public review.
Russia	ASTM E903, ASTM E1371,	Standards are used for determining Reflectance and Emittance of Glass but not specifically for cool roofs
Singapore	Information not Available	There is no known testing standard for Reflectance and Emittance measurement
Chinese Taipei	Same as China	n/a
Thailand	ASTM E 903-82, JIS R 3106 1998, ASTM E 1980-01, ASTM C 1371-98, BS EN 12898	Currently the tests for the reflectance of coating have been done in compliance with JIS R 3106. However, changing to JIS K 5602: 2008 is under consideration
The United States	ANSI-CRRC_S100-2016, ASTM E1549, ASTM E1371, ASTM E903, E1918, ASTMD751, ASTM C1864	n/a
Viet Nam	QCVN 09:2017/BXD	Specifies Reflectance and Emittance requirements for calculating Resistance. However, there are no Testing standard for Reflectance and Emittance measurement

Establishing Cool Surface Testing Infrastructure

Based on reviewing the good practices established in the U.S. (Cool Roof Rating Council) and the European Union (European Cool Roofs Council), this section explores the steps necessary to establishing an effective testing, rating, and labeling program for cool surfaces. A number of APEC economies do not currently have standards for testing the radiative properties of materials. These economies may choose to adopt the testing standards recommended in this document and also a product certification program to manage the testing, certification, and labeling of roofing products.

Cool surface testing infrastructure refers to an interconnected system of public and private stakeholders that allow for accurate and reliable materials testing in accordance with local requirements and standards. These stakeholders include:

- Accredited Independent Testing Laboratories (AITLs)– facilities where the surface (radiative) properties of the materials are tested. In some cases, these labs may also perform aging and weathering tests. The laboratories are accredited by recognized accreditation bodies in the economy.
- Test Farms – facilities where product samples are installed outside and monitored over a period of months or years to determine changes in radiative properties resulting from exposure (i.e., aged ratings).

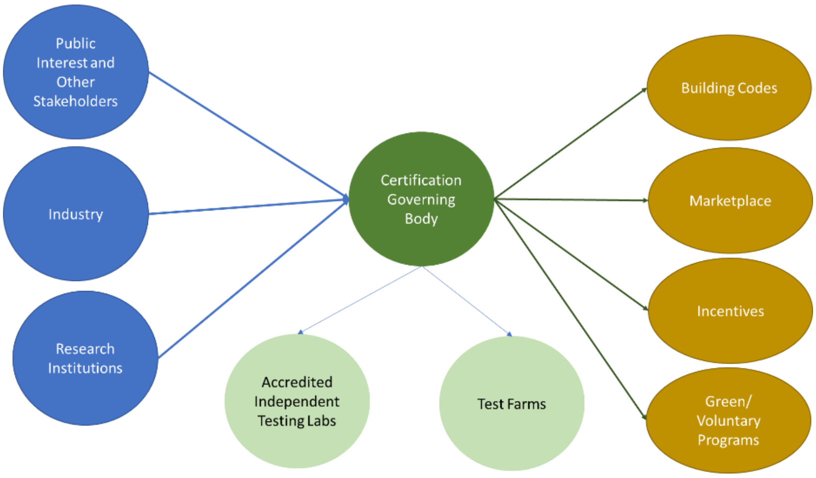
- Laboratory Accreditation Bodies – agencies or organizations (typically affiliated with economy governments) that evaluate lab procedures, staff, and equipment to ensure proper protocols and standards;
- Standards Organizations – economy and international bodies that publish standards and facilitate the process for establishing and modifying those standards over time.
- Code bodies – local, regional, or economy bodies that adopt requirements for building safety, energy use, and/or sustainability.

Establishing an independent *Certification Governing Body* (Governing Body) is important to oversee and manage the testing and certification process, update procedures, validate and verify the accuracy of results from testing laboratories and weathering facilities, maintain databases of product testing results, and produce the results and labels for product packaging. The Governing Body should be made up of a collection of manufacturers, suppliers, testing laboratories, and advocacy groups including consumer interests, governmental organizations and educational institutions. The Governing Body should have a Board of Directors and administrative office to manage the day-to-day operations. The Board of Directors should be a balanced and representative mix of all types of participants so every aspect of the industry (e.g., manufacturers, testing laboratories, consumer groups, research institutions, technical experts, and policy groups) has input.

The Governing Body would hold periodic meetings to discuss issues related to certification program and create voluntary task groups to work on technical and certification issues on behalf of the organization. One of the primary roles of the Governing Body is to develop policies and manage a uniform program for the certification and labeling of cool roof products, and maintain a database of all certified products for the public to access. The executive office will comprise of staff members who will be responsible for executing: 1) the Board of Directors' policy; 2) financials and accounting; 3) technical and quality control.

Establishing a Governing Body for cool surfaces is the first step that should be taken in a process to develop a viable cool roof testing, and certification program. This Governing Body should be independent (preferably a not-for-profit), and all duties, responsibilities, and elections should be completely voluntary. Figure 4 describes an effective structure for such a governing body.

Figure 4: Governance structure for testing organizations



Responsibilities of the Certification Governing Body

The Governing Body should undertake several activities to establish an effective testing and certification regime including:

1. Selecting cool surface product attributes for testing and certification
2. Establishing the minimum performance testing and certification criteria for cool surfaces;
3. Ensuring that cool surface products are produced with consistent quality and meet the certified performance requirements;
4. Create a process to label products for the marketplace.

Each of these activities is described in more detail below.

Selecting Cool Roof Product Attributes for Performance Testing and Certification

When considering which characteristics and attributes to include in performance testing, the Governing Body should select those that the cool roof industry is familiar with and for which there are industry-accepted testing protocols developed and test equipment available. It will also have to consider which tests to make mandatory for certification and reporting and which attributes will be considered optional. While the Governing Body will primarily be interested in establishing a testing and certification program for radiative properties, attributes and tests may not be limited to energy or thermal performance and may include:

- The water infiltration performance of a cool roof is a measure of the resistance, under standard condition, a cool roof product can resist before failing.
- Scratch resistance of the cool roof surface
- Fire resistance of the cool coating and surfaces
- Elasticity of the cool roof product membrane to account for seasonal expansion and contraction due to thermal temperature cycling.

The Governing Body will need to consider a number of program details in consultation with industry, building science experts, and other stakeholders. These program details include:

- How long can the test results be used for certification and thus how often does a manufacturer need to retest and recertify cool roof products?
- What physical changes to a cool roof product can be made without triggering the need for retesting?
- How will test results be reported for each attribute including units (e.g., SI or IP), the number of decimal places reported, and where and what order the attributes are listed on a label?
- Are the attributes and the metrics for those attributes appropriate for all of the use cases and climatic conditions in the jurisdiction covered by the testing entity?
- What exact equipment will be needed by testing labs and is there ae straightforward and unambiguous process for a testing laboratory to acquire and set up test apparatus, to calibrate testing equipment and conduct the tests efficiently across a number of cool roof products (multiple product types in market place, paints, membranes, shingles, tiles and etc.) from multiple manufacturers.
- What is the cost for testing and certification and how does that impact the price of the end product to the consumer? Could that cost be passed along from all manufacturers to the consumer? If so, are the costs comparable across all manufacturers?
- Are there international standards, experience and examples that can be drawn upon for establishing the attributes, and the testing protocols, and is this experience applicable to the economy?

In 1998, the Cool Roof Rating Council (CRRC) was founded to develop accurate and credible methods for evaluating and labeling the solar reflectance and thermal emittance (radiative properties) of roofing products sold in the United States and to disseminate the information to all interested parties. Many of the required tests by the CRRC rely on standards or protocols promulgated by the ASTM International (www.astm.org), International Standard Organization (ISO) and the American National Standards Institute (ANSI) (www.ansi.org) and are articulated in the ANSI S100 Standard. The actual testing protocol and calibration of the apparatus is set forth in standards promulgated by the International Organization for Standardization (www.iso.org), American Nation Standards Institute (http://www.ansi.org) and the International Electrotechnical Commission (www.iec.ch).

European Cool Roofs Council (ECRC) was also established on similar structure as the CRRC in the USA and have adopted similar testing and certification standards.

Establishing Minimum Performance Testing and Certification Criteria

One of the first actions of the Governing Body is to define the minimum performance rating and certification attributes cool roof products. These attributes and the levels at which they are set according to government requirements (e.g., codes and standards) should ensure that cool roofs provide a high level of cost-effective thermal performance.

Beyond establishing the radiative performance of cool surface materials, the testing and certification process should result in:

- Cool roof products applied to the roof that preserve reflectance and emittance properties of the surface within an acceptable range over the life of the product;
- A production process of the Age performance of the cool roof products being certified to follow certain specific quality control and recordkeeping requirements;
- The cool roof product meets – at a minimum – thermal (energy) performance characteristics plus other selected attributes (with identified metrics of those attributes) important to the consumer and consumer comfort;
- The manufacturing facility being certified to produce cool roof products consistently meeting the certified performance characteristics and maintain quality control.

The Role of Testing Laboratories and Test Farms

While the Governing Body establishes the testing program, the actual testing is undertaken by Accredited Independent Testing Laboratories (AITL) and Approved Test Farms. This section reviews good practices for setting requirements for AITLs and Test Farms.

An AITL is a testing laboratory that is accredited for compliance with ISO/IEC Standard 17025 to test roofing products and is completely independent from any roofing product manufacturer or roofing product seller. Accredited shall be defined as achieving third-party evaluation accreditation by an organization accredited to ISO 17011.

Requirements for All Accredited Testing Laboratories

Testing required by the certification program must be conducted by an AITL. Four good practices for testing laboratory accreditation include:

- The laboratory must submit a completed application to the Governing Body for consideration as a recognized Accredited Testing Laboratory and pay the required fees. Laboratory should also meet all ISO/economy accreditation requirement and provide necessary proof to Governing Body
- At least one employee of the Accredited Testing Laboratory must participate in a laboratory training workshop organized by the Governing Body. All testing for the purpose of organizational certification shall be performed or supervised by this person, who shall certify the test results which are reported according to set requirements.
- The laboratory must demonstrate ongoing competency to the certification governing body by testing reference samples upon request;

Round Robin Testing

As part of ongoing compliance with accreditation, AITLs and Testing Farms shall be provided with prepared test samples from the Governing Body, without advanced notice, and shall test and report the findings on those samples to the certification governing body in accordance to set criteria. The intent of the periodic evaluation is to ensure consistency and competency of the testing laboratory by evaluating the test results against pre-determined test results of those same samples. The executive office shall notify the testing laboratory of the results at the completion of each test, and shall notify the testing laboratory of any corrective actions that may be necessary.

Weathering Tests

A weathering farm should be accredited for compliance with ISO/IEC Standard 17025 to weather and test roofing products, and shall be independent from any roofing product manufacturer or roofing product seller. Accredited Independent Testing Laboratories are also responsible to report testing results of radiative properties after a period of aging and weathering outdoors (often referred to as aged radiative properties). Age testing is done at approved test farm which may be operated by AITL. Such a program helps evaluate the performance of a material under normal usage conditions. AITLs forward product samples for weathering exposure directly to Approved Test Farms after testing for initial radiative properties. After testing samples for aged radiative properties, AITLs are responsible for holding weathered product samples for a period of 90 days or until aged radiative properties are approved by the organization. AITLs must use the most current test method applicable to the roofing product type for measuring the solar reflectance and thermal emittance of aged products.

Specific Requirements for Accredited Independent Testing Laboratories

The Governing Body will have the responsibility of selecting which AITL's are included in the program. It is recommended that the governing body require an AITL to demonstrate certification under either ISO-17025 or ISO25 through submission of the following information:

- Evidence of certification by an accrediting entity listed by the Governing Body as complying with ISO Guide 58. This list should be published by the organization for public access.
- A listing of test methods that the accrediting entity has found the AITL capable of performing. The AITL may only use such tests for the purpose of this certification Program.
- An AITL must provide a statement of independence that shows it has no significant ownership or commercial interest in a supplier or roofing product company and is not owned by such a company.

Specific Requirements for Test Farms

In order to participate in the testing program established by the Governing Body, a test farm should meet the following criteria:

- A Test Farm should demonstrate certification under ISO 17025.
- A Test Farm must have exposure locations as specified by the certification governing body. Generally, these are chosen to reflect the range of climatic and exposure conditions that roofing materials would likely be installed in.
- A Test Farm should produce a list of exposure methods that an accrediting body has found the Test Farm capable of performing.
- A Test Farm must provide a statement that shows it has no significant ownership or commercial interest in a supplier or roofing product company and is not owned by such a company.

Ensuring that cool surface products are produced with consistent quality and meet the certified performance requirements

The second key task of the Governing Body will be to ensure that products tested by the program are of consistent quality to meet the performance requirements. The Governing Body should work with the AITLs and Test Farms to ensure quality control and undertake random testing of products already rated by the program,

Quality Control

Cool roof product manufacturer and sellers shall have an appropriate quality control plan in place that ensures its roofing products maintain the radiative properties at or above the values they received from the certification program. A manufacturer shall designate at least one employee as quality control manager at each plant, and shall provide the certification governing body with the name and contact information of each of these individuals. All quality control records and the quality control plan shall be made available to the Governing Body upon written request.

Random Testing of Rated Products

As part of its quality assurance program, the Governing Body should periodically select rated roofing products, obtain them from the marketplace or from the point of manufacturing, and have them tested by an AITL. The percentage of products to be tested each year will be established by the Governing Body. Products are considered to fail periodic testing if the tested radiative properties from the accredited testing laboratory are more than 0.05 lower than the certified radiative properties.

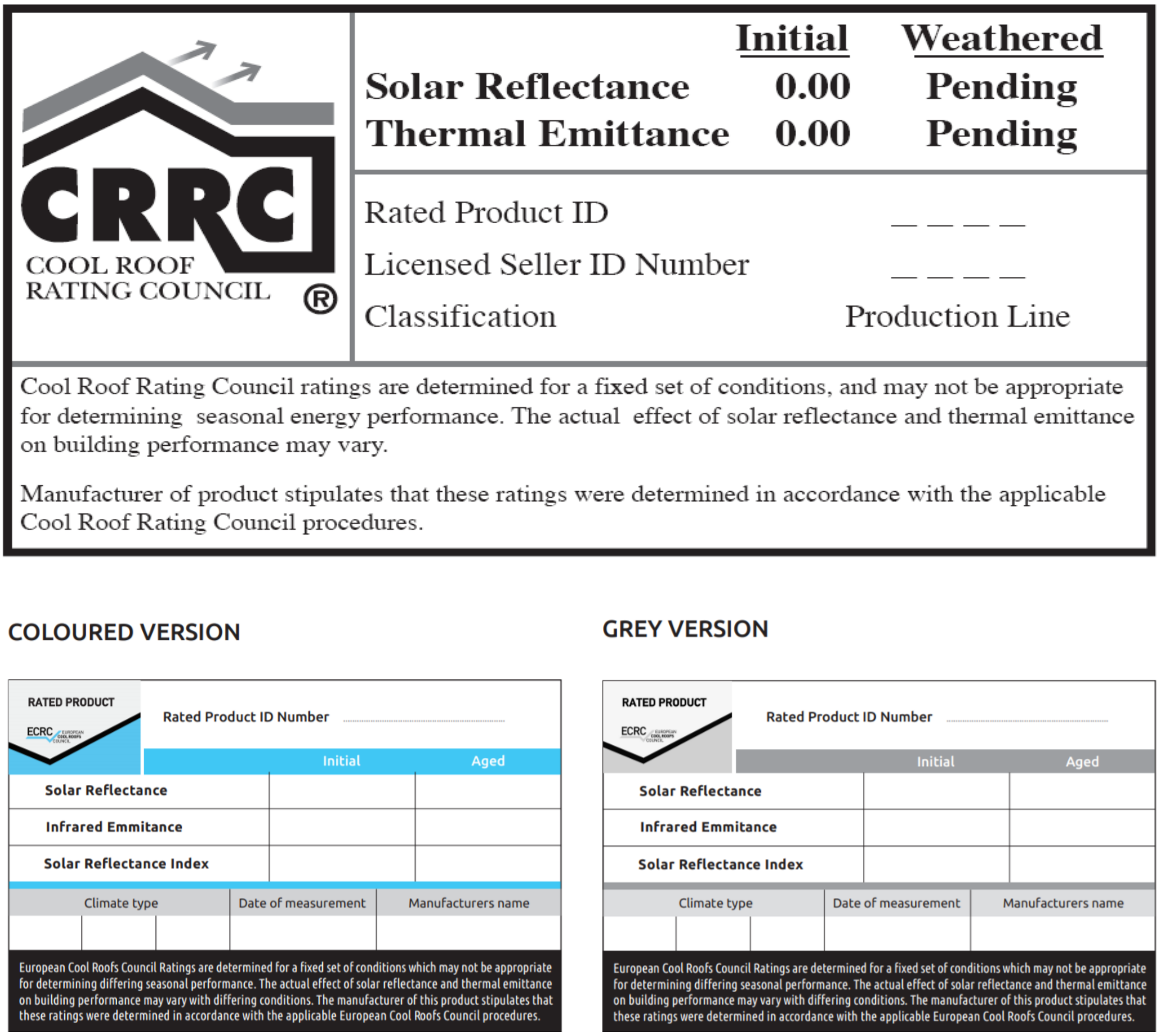
Manufacturer shall provide information to the Governing Body regarding where the office can obtain samples of their product for periodic testing. Each manufacturer shall provide a list of distributors or contractors, and this information shall be provided with each application for product rating. The information will be updated annually at the time of application for product renewal. Parties listed by the manufacturer shall agree to provide samples to executive office at no cost and upon request by the Governing Body. Requests for samples shall be made no more frequently than once a year, unless a product fails the first test and must be retested. Manufacturer shall also agree to have samples collected from their point of manufacturing in conjunction with their routine quality control inspections. Roofing product manufacturers shall provide a one-page instruction sheet on how to collect or prepare the sample. This instruction sheet shall be included with the application for product rating.

Create a process to label products for the marketplace

A third key role for the Governing Body is to create a means for educating the market on the test results for each product – primarily through the use of a visible label on product packaging. Beyond informing the marketplace, labeling also facilitates the inclusion of radiative properties into building codes, voluntary programs, and incentive schemes. Visible certification showing that a credible laboratory verified the product met established attributes provides purchasers of cool roof with important assurances about their investment in energy-efficient products.

The label should include the results of all of the tests certified by the Governing Body and be consumer-friendly, easily identifiable and legible. An example from the U.S. Cool Roof Rating Council and European Cool Roofs Council are shown in Figure 5.

Figure 5: Examples of Product Labels for Roofing Products



Labels should contain the manufacturer, model number and the results of the tests for the selected attributes in units familiar to the consumer. The means should be developed to trace the original certification that indicates the standard which the product was tested, a name (to provide traceability) the manufacturing facility, the performance level achieved, the series or model name of the product and other information pertinent to that product. This label information can be cross-referenced with the certified products database kept by the Governing Body and a third-party certifying entity.

Cool Roof Product Label Characteristics

Characteristics of the label include:

- The official logo of the Governing Body certifying the cool roof product and the web address of the governing body;

- Disclaimers about the cool roof label/labeling process from the Governing Body;
- Appearance of all the test results of the attributes required by the Governing Body and – as an option - any test results that are considered optional by the Governing Body; and
- Date the product received the certifications.

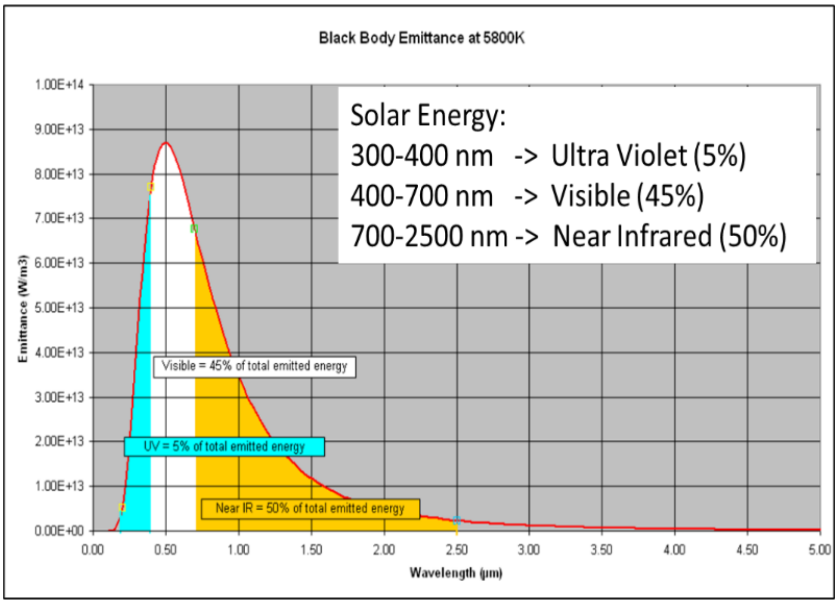
The label information should match the data in the certified products database maintained by the Governing Body. The Governing Body provides the template for the labels to the manufacturer with guidance on when, where, and how long it is to be affixed. The Governing Body will formally inform the manufacturer when all tests and certifications have been received. The manufacturer can create and attach the label at that time.

Technical Annex 1

Measurements of Solar Reflectance and Emittance to calculate Solar Heat Gain

The possibility of having a high solar reflectance over the range of solar wavelengths and a low emittance (and reflectance) over long wavelength thermal infrared ones is called *spectral selectivity*, making possible both high solar reflectance and high thermal infrared radiant emission from surfaces with this selectivity property. Such surfaces can be cooler than otherwise when exposed to the sun outdoors.

Detail on Solar Reflectance (SR) and Related Optical Properties of Surfaces



Any packet of radiant solar flux is composed of photons, each having energy associated with its wavelength λ in nanometers (nm). Those photons incident upon a surface are either reflected, absorbed, or transmitted. Below are the definitions of the fractional portions of the packet of photons (each carrying energy associated with the wavelength λ) which are reflected, absorbed, and transmitted:

Spectral reflectance **r(λ):** probability that an incident photon of wavelength λ is reflected
Spectral absorptance **a(λ):** probability that the photon is absorbed by the surface
Spectral transmittance **t(λ):** probability the photon is transmitted through the surface

These properties are related according to this equation

$r(\lambda) + a(\lambda) + t(\lambda) = 1$ (1)

For opaque surfaces $t(\lambda) = 0$ and the solar spectral absorptance for opaque surfaces is

$a(\lambda)=1- r(\lambda)$ (2)

Kirchhoff's law states that for most ordinary materials, the absorptance equals the emittance, $a(\lambda) = \varepsilon(\lambda)$. This is generally true for specific wavelength ranges, in which case the total values over such a specific wavelength range for each would obey $a = \varepsilon$.

Net Solar Heat Gained by a Material Receiving Solar Radiation

The net solar radiant heat gained (absorbed) by a material is the quantity of solar flux in Watts that is retained by that material due to absorption, after the portion of that gain which is re-emitted back into the air through which the solar radiation travelled is subtracted.

When we think of solar radiation incident upon a wall or roof, we usually speak of the *irradiance* of the incident radiation, point for point across that surface. Irradiance is the flux per unit area in W/m^2 propagating from the sun onto the surface. The portion of the incident solar irradiance admitted as solar heat gain per unit area we call E_{ad}, in W/m^2. This is the incident solar irradiance E_s multiplied by the solar absorptance a_m of the material, following the notation of equations (1) and (2), integrated over the relevant wavelength range:

$E_{ad} = a_m \cdot E_s$ (3)

The main process causing some of this admitted solar heat to be lost back out is the radiant emission as irradiance Eradiated due to the increased temperature of the surface (from T_1 to T_2) produced by the solar heat gained, given by

$E_{radiated} = \varepsilon\sigma(T_2^4 – T_1^4)$ (4)

Where ε is the emittance (or emissivity) of the surface, σ is the Stefan-Boltzmann Constant (5.67×10^{-8} Watt per square meter and per degree Kelvin to the 4th power or $W \cdot m^{-2} \cdot K^{-4}$), and T is the absolute temperature of the surface in degrees Kelvin.

The final net solar heat gained, therefore, is given by

$E_{SHG} = E_{ad} – E_{radiated} = E_s \cdot a_m – \varepsilon\, \sigma\, (T_2^4 – T_1^4)$ (5)

Air Mass and Optical Processes in the Atmosphere

Due to the large distance between the sun and the earth, a beam of solar radiation reaching the top of the atmosphere is almost parallel. (Solar disk angular diameter is 0.533 degree, 31’27” of arc, & 6.807×10^{-5} sr of solid angle, so the angular divergence or spread of rays approaching the atmosphere from the sun has these relatively small values.)

When the sun is directly overhead (at the zenith in the sky) the atmospheric depth (thickness) is at a minimum for that condition (occurs only at lower latitudes, below about 23 degrees). The atmosphere is defined to have what is called a Relative Air Mass of 1.0 for the zenith position in the sky (straight up). As the sun moves down towards the horizon, the air mass increases to approximately 38 at the horizon. Air mass can be less than one at an elevation greater than sea level. The effects of absorption and scattering are correspondingly greater for large air mass values and the spectral distributions of both solar flux and diffuse sky radiation are altered.

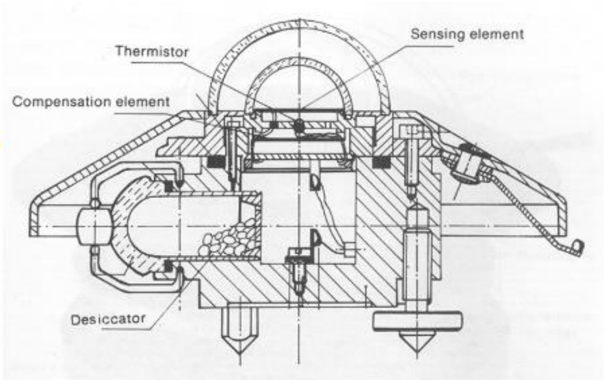
The wavelengths of terrestrial (close to the Earth) solar radiation range from high photon energy ultraviolet (UV) radiation through the ‘visible’ (VIS) part of the spectrum (~360 nm to ~830 nm), to the lower photon energy ‘near’ infrared (NIR) region. The maximum intensities are found in the visible part of the spectrum, with wavelengths between 400 and 700 nm. The intensities in the UV and NIR regions of the spectrum are much lower. Being very hot, the sun emits no‘far’ infrared radiation (FIR). The much cooler Earth does emit both IR and FIR radiation, especially when heated by solar radiation. The Earth’s emitted IR radiation is partially absorbed and re-radiated by gases, particles and clouds in the atmosphere. Daytime-absorbed solar heat radiates at night into deep space, less so when the night sky is cloudy and humid, so absorbs some of the Earth’s radiated heat. (Mornings after a clear night sky tend to have cooler air temperatures because night radiation from the earth into the sky is less absorbed in the drier atmosphere during clear sky conditions.)

When passing through the atmosphere, some incident solar radiation reaches the Earth’s surface mostly undisturbed and some is scattered or absorbed by air molecules, aerosol particles, water droplets and/or ice crystals in clouds and aircraft contrails. Gaseous molecules and aerosols cause most of the absorption. Scattering of solar radiation by larger particles like water droplets and ice crystals takes place over the whole spectral range, and is much less wavelength-selective (making clouds white), whereas the much smaller molecules predominantly scatter solar radiation greater at short wavelengths (blue part of visible spectrum) and at larger angles of scattering (making the clear sky blue).. Large aerosol particles including water droplets mainly scatter at lesser angles of scattering.

Multiple repeated scatterings of light produce a wider angular spreading of the scattered light. These processes significantly affect the spectrum of radiation that reaches the Earth’s surface. The stronger scattering of short wavelength (blue) sky light is responsible for the blue color of clear-sky daylight. Sunset light is more reddish in color, due to the blue having been removed by the greater distance sunlight travels when low in the sky and that longer wavelengths in the red end of the spectrum remain strong when the sun nears the horizon, making the rising and setting sun orange to red in color.

Technical Annex 2

Testing Equipment Used for Measurement of Solar Reflectance



Pyranometer: A pyranometer is a thermal-electrical instrument that measures solar irradiance, E in W/m^2. Its sensor is a black disk backed by a thermopile for measuring temperature difference. Output voltage is proportional to the temperature rise of the black disk in sunlight. Glass dome(s) over the sensor inhibits convective heat transfer and blocks FIR radiation which could contaminate the measurement. Such an instrument has a nearly hemispherical solid angle field of view, so can measure incident or reflected radiation, composed of a narrow beam (solar) or broadly diffuse (sky) flux or both together.

The sun and sky radiation received from a hemispherical solid angle of 2π steradians (sr) on a horizontal surface is referred to as global radiation. This includes radiation received directly from the small solid angle of the sun's disk (6.807×10^{-5} sr), as well as the 2π sr of incoming diffuse sky radiation from the hemispherical whole sky that has been scattered in traversing the atmosphere. A well designed and fabricated pyranometer is the proper instrument for measuring solar radiation received from a solid angle of 2π sr onto a plane surface and over a spectral range from 300 to 3,000 nm. (The sky radiation component does not have to be present, usually eliminated by a cylindrical blackened tube placed in front of the pyranometer's sensing element.) Pyranometers are sometimes used to measure solar radiation on surfaces oriented in a horizontal position to measure incoming solar radiation and then in the inverted position to measure reflected global radiation, as from the ground or roof. When measuring just the diffuse sky component of solar radiation, the direct solar component can be blocked from reaching the pyranometer through the use of a shading or occulting disk.

Pyranometers normally use thermo-electric, photoelectric, pyro-electric or bimetallic elements as sensors. Since pyranometers are usually exposed continually in all weather conditions they must be robust in design and resist wind loads, driving rain, and the corrosive effects of humid air (especially near the sea). The receiver should be hermetically sealed inside its casing, or the casing must be easy to take off so that any condensed moisture can be removed. Where the receiver is not permanently sealed, a desiccator is usually fitted in the base of the instrument to absorb moisture, preventing problems like condensation on the glass elements. The properties of a pyranometer of most concern when evaluating the uncertainty and quality of its measurement are: response sensitivity, stability, response time, cosine (angular) response, azimuthal (angular) response, linearity, temperature response, thermal offset, zero irradiance signal, and spectral response.

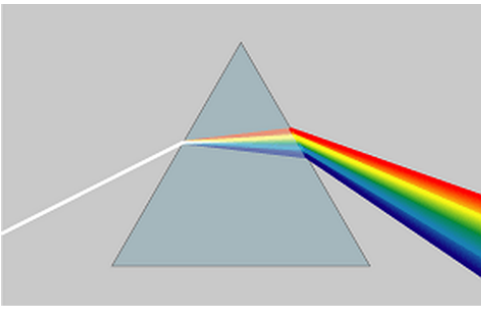
Installation of pyranometers for measuring global radiation. A pyranometer should be securely attached to whatever mounting stand is available, using the holes provided in the tripod legs or in the baseplate. Precautions should always be taken to avoid subjecting the instrument to mechanical shocks or vibration during transport and installation. This operation is best effected as follows. First, the pyranometer should be oriented so that the emerging leads or the connector are located poleward of the receiving aperture (See ASTM E 1918). This minimizes heating of the electrical connections by the sun. Instruments with Moll-Gorcynski thermopiles should be oriented so that the line of thermo-junctions (the long side of the rectangular thermopile) points east-west. This constraint sometimes conflicts with the first, depending on the type of instrument, and should have priority since the connector could be shaded, if necessary.

When towers are nearby, the instrument should be situated on the side of the tower towards the Equator, and as far away from the tower as practical, to prevent shadowing.
Radiation reflected from the ground or the base should not be allowed to irradiate the instrument body from underneath. A cylindrical shading device can be used, but care should be taken to ensure that natural ventilation still occurs and is sufficient to maintain the instrument body at ambient temperature.

The pyranometer should then be secured lightly with screws or bolts and levelled with the aid of the levelling screws and spirit-level provided. After this, the retaining screws should be tightened, taking care that the setting is not disturbed so that, when properly exposed, the receiving surface is horizontal, as indicated by a spirit-level.

The stand or platform should be sufficiently rigid so that the instrument is protected from severe shocks and the horizontal position of the receiver surface is not changed, especially during periods of high winds and strong solar energy.

The cable connecting the pyranometer to its recorder should have twin conductors and be waterproof. The cable should be firmly secured to the mounting stand to minimize rupture or intermittent disconnection in windy weather. Wherever possible, the cable should be properly buried and protected underground if the recorder is located at a distance. The use of shielded cable is recommended with the pyranometer, cable and recorder being connected by a very low resistance conductor to a common ground. As with other types of thermo-electric devices, care must be exercised to obtain a permanent copper-to-copper junction between all connections prior to soldering. All exposed junctions must be weatherproof and protected from physical damage. After identification of the circuit polarity, the other extremity of the cable may be connected to the data-collection system in accordance with the relevant instructions.

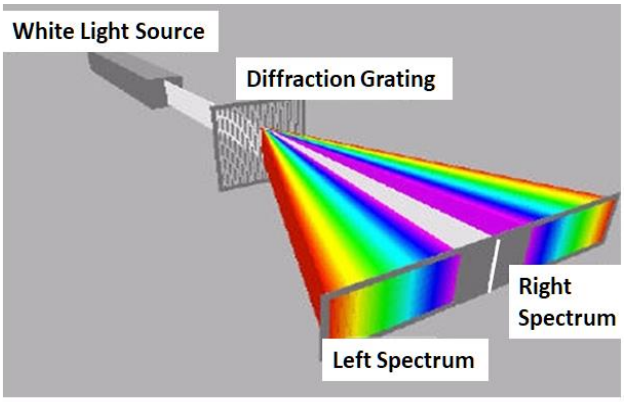


In a dispersive prism, material dispersion (a wavelength-dependent refractive index) causes different colors to refract at different angles, splitting white light into a spectrum. The technology extends beyond the visible range into both UV and IR ones, if the prism material is sufficiently transmissive over the spectral range of interest.

Spectrophotometer: A *spectrophotometer* is composed of a *spectrometer* to angularly spread a beam of radiation into its component wavelengths, for separate measurement, as illustrated to the right and below, including additional components described further.

Spectrometer: Any instrument which receives a beam of electromagnetic radiation and "disperses" the radiant flux into a continuum of spectral flux at different wavelengths, separated spatially for human observation (as in the eyepiece of old glass prism spectrometers or using electrical flux detectors to produce measurement results) of the strength or magnitude of the flux at different wavelengths over the spectral range of interest. This spreading of spectral flux produces what is called a "spectrum." The term is also applied to the graphical representation of the observations or measurements of the spectral flux over a wavelength scale presented graphically on paper or electronically on a computer screen.

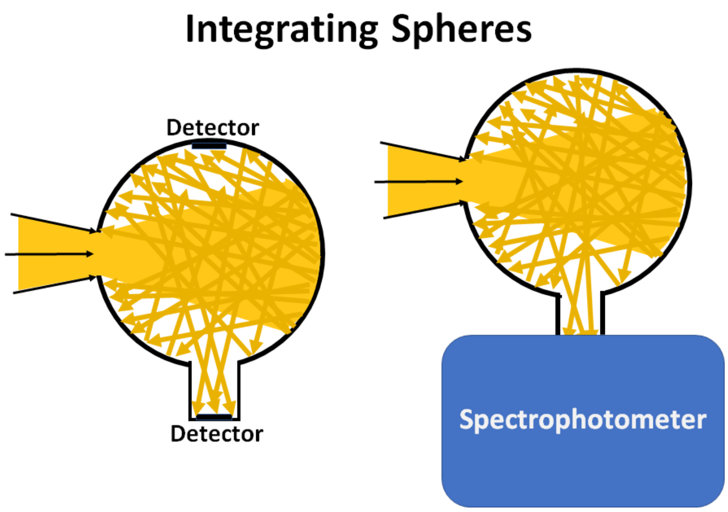
Optical Dispersing Devices: Components physically separating the beam of flux into its frequency or wavelength components and sending them to the detection device(s). The primary dispersion devices are glass prisms and ruled or holographically created diffraction gratings.



A transmissive ruled diffraction grating causes different colors to diffract at different angles, splitting white light into several separate beams, called "diffraction orders" angularly separated. Each contain the same spectrum. If the grating is "blazed," (also called an echelette grating from French *échelle* = ladder) it's rulings are shaped to direct more flux to one order, optimized to achieve maximum grating efficiency putting more flux into that order.

Examples include a **glass prism** and a ruled reflective **diffraction grating** (or its older transmissive version), an optical component with a periodic structure that splits and diffracts light into several beams travelling in different directions, each beam called a *diffraction order*. The directions of these beams depend on the spacing of the rulings in the grating and the wavelength of the light so that the grating acts as the dispersive element.

Detection Devices: To quantify the relative amounts of flux at each different wavelength range selected for measurement, an *optical radiation detector* is used. These devices produce an electrical current proportional to the electromagnetic flux incident upon their front surfaces. A linear array of such detectors is placed in the output beam from a prism or one of the orders emerging from a grating dispersion device. The signals from these are sent to multichannel analyzers which convert the radiant flux on each detector into an electrical current output proportional to the flux received by the detector and this is measured for each detector covering a small wavelength range of interest. Alternatively, the spectrum can be physically scanned across a single detector or the detector moved across the output spectrum sending its signal to the recording system which outputs and/or stores the resulting absolute flux measurement for documenting the results numerically.



Integrating Sphere; To gather radiation having angular spread from little to substantial, the integrating sphere is commonly used. It is a thin metallic sphere whose interior surface is having both a highly diffuse and highly reflective white material, spreading reflected radiation over a large angular range. Many multiple reflections within the sphere render the interior flux very travelling in all directions. A small circular hole is cut into the sphere to admit the incident beam of flux. At 90^{O} to this entrance port a detector is placed to measure the flux scattered from the wall of the sphere. Alternatively, the detector can be placed outside the sphere but inside a short cylinder so that it receives diffuse radiation mostly from the opposite wall of the sphere. Another alternative is to replace the detector with the entrance port of a spectrometer, so as to measure a large number of wavelengths in the incident beam separately. Such a sphere can also be used to convert a beam into diffuse radiation having a large angular spread.

Laboratory Grade Spectrophotometers: Complete, commercially available, instruments capable of relatively automated measurements of glass reflectance over the full solar spectral range, for glass and other surfaces are available in a variety of packages and capabilities from several manufacturers. Searches on *solar spectral reflectance instruments*, should provide information on the most appropriate laboratory and field-portable instruments for determining these properties. Scrolling down through these and similar search returns will reveal information from manufacturers and tutorial information on the topics of the searches.

ASTM E 903 is a standard test method for solar absorptance, reflectance, and transmittance of materials using integrating sphere spectrophotometers which describes generically the use of a sophisticated laboratory instrument for measuring the spectral reflectance for direct beam incidence and hemispherical solid angle collection of reflected flux, on a wavelength-by-wavelength basis over the relevant solar spectral region of 300 to 2500 nm. Lawrence Berkeley National Laboratory uses a Perkin-Elmer Lambda 1050 UV-VIS-NIR spectrometer with a Labsphere integrating sphere attachment to make these spectral reflectance measurements.

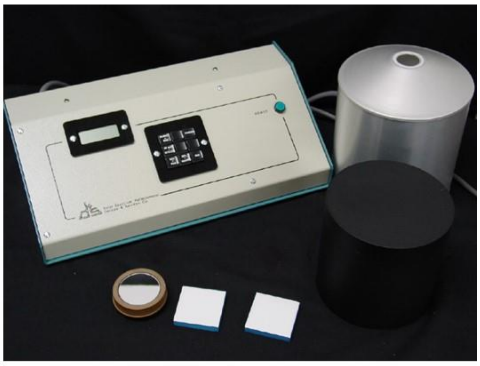
Solar Spectrum Reflectometer (SSR): Rapid, accurate, and repeatable measurements of solar reflectivity are possible with a less expensive specialty instrument called a Solar Spectrum Reflectometer (SSR). The unit, consisting of measurement head and associated electronics, features a direct digital readout of total solar reflectivity with resolution to 0.001 and repeatability of +/- 0.003 reflectivity units.

Drift compensation and automatic zeroing is designed into the device to minimize the requirements for periodic calibration by the user, thus making the instrument ideal for quality control and R&D. Other features include the use of a single tungsten-halogen light source, and a four-detector combination (new version has six-detectors which help the measurement to be more accurate and closer to Spectrophotometer measurements in accordance with ASTM E903). The SSR provides a measurement spectrum that closely approximates a standard AM1 solar spectrum. Other terrestrial solar spectra can be set by the user.

The model SSR-ER version 6 features a selectable solar measurement spectrum matched to a variety of standard global and beam normal solar irradiance models. The SSR provides accurate measurements on both diffuse and specular materials, even second surface reflectors up to 0.25 inches (6.4 mm) thick.

Apparatus

The test method described here applies to the determination of directional hemispherical solar reflectance using a commercial portable reflectometer. The instrument utilizes the principles of an integrating sphere for performing optical reflectance measurements in the spectral region from 335 to 2,500 nm. The instrument consists of two units, the Measurement Head and the Command Module (Fig. 1).



410-Solar-i Reflectometer by Surface Optics Corporation, left, and Solar Spectrum Reflectometer Model SSR V6 by Devices and Services Company, right.

Measurement Head. The Measurement Head is constructed around an integrating sphere for measurements of directional-hemispherical reflectance. Light from a tungsten halogen lamp enters the integrating sphere through an internal beam port at a 20° angle of incidence and illuminates the test specimen placed over the sample port of the integrating sphere. The flux reflected from the sample multiply and diffusely reflects around the interior of the sphere and becomes uniformly diffused. A portion of that light reaches the detector arrays which are used to measure the directional-hemispherical in-band reflectance. Optical filters and detector arrays cover seven spectral bands in the wavelength range of 335 to 2,500 nm (335-380, 400-540, 480-600, 590-720, 700-1,100, 1,000-1,700, and 1,700-2,500 nm). A rubber ring protects the measured surface from contact with the metal surface of the integrating sphere and provides a non-skid surface to press against the sample surface.

Command Module. The Command Module provides:

- Computer processing
- Electrical power
- Structural support for the Measurement Head

The housing of the Command Module contains the

- Trigger,
- Battery Cartridge
- a small Personal Digital Assistant (PDA) type computer
- Light Emitting Diode (LED) & Vibrator Motor indicators
- Secure Digital (SD) card port
- Measurement Head mechanical and electrical connections
- Input / Output port
- safety strap.

The computer is located at the top of the handle with a touch screen display that faces the user during operation. The user controls the unit by selecting various software functions from the touch screen interface and pressing the trigger when a measurement is to be made.

Calibration Coupon. Calibration of the reflectometer is accomplished with a manufacturer-supplied calibration coupon. The reflectance values of the provided coupon are stored on the supplied SD card. Zero reflectance is measured with no sample present at the sample port of the integrating sphere. The Measurement Head must be pointed away from artificial light sources such as fluorescent lighting or into a darkened black box, during the Zero measurement.

During the calibration process (and during each sample measurement cycle), the instrument automatically makes an additional measurement of the light beam reflected from a specific location on the wall of the integrating sphere.

A ratio of the electrical signal generated by the detector when the beam illuminates the sample to that when the beam illuminates the reference point on the integrating sphere is used in the calculation of sample reflectance values.

This normalization process eliminates most of any instrument drift that might be caused by thermal or electrical system instabilities.

Test Specimens. Specimens to be tested can be flat, concave (inner diameter larger than 15 cm), or convex (outer diameter larger than 8 cm), and may have specular or diffuse characteristics. The sample is illuminated with an elliptical spot of about 12 mm at the major axis and 6 mm at the minor axis. The sample port of the integrating sphere is pressed flush against the measured surface, which must have a minimum dimension of 13 mm.

Measurement of Emittance

Emittance of a surface is the ratio of the actual radiant emission of thermal radiant flux from a surface to that emitted by what is called a *perfect blackbody* emitter, at the same temperature. Symbol ε. (The term *emissivity* generally applies to the same property for a material substance rather than an actual object.) Infrared radiation emitted from warm to moderately hot materials generally has wavelengths in the infrared region of the electromagnetic spectrum, those above about 800 nanometers. At any wavelength (or over a defined range of wavelengths), a low emittance surface generally has high reflectance. In consequence, a low infrared emittance surface can help reduce the fraction of incident solar heat gained by such a surface, as well as the resulting material stresses and failures and the rate of interior heating from that surface.

Most conventional roofing materials (excepting bare metals like aluminum or steel) have a fairly high infrared emittance and consequently low reflectance, producing higher solar heat gain than one might otherwise like.

Good convective heat transfer away from a surface heated by the sun is also desirable, helping to carry away the solar heat absorbed by that surface into the outside air. In some roofing systems air can circulate underneath the outer roofing material (e.g., vented tile and wood shake systems, or vented corrugated metal roofing). Attic venting also can be used to carry away heated air before it penetrates into the conditioned space.

Measurements of emittance can be done in several ways. The most direct method involves forming an object (made of the same material as the sample to be measured) into the shape of a cavity, in such a way that near-blackbody radiation is emitted inside the cavity. A small hole in this object is made to allow the interior radiation out. A measurement is then made to compare the radiation from within the formed cavity to radiation from a flat, outside surface of the same test material, presumably at the same temperature (Sparrow et al., 1973). The cavity can be given the form of a cylinder, cone, or sphere.

Care must be taken that the specimen is isothermal (same temperature throughout) and that the reflected radiation is measured and compared from the two objects. The definitive measurements of several materials, such as tungsten (DeVos, 1954), were determined in this fashion. The significant advantage in this direct method is that it is relative, depending on neither absolute radiometry nor thermometry, but only requiring that the radiometer or spectroradiometer be linear over the dynamic range of the measurement. This linearity is also determinable by relative measurements.

If a variable-temperature blackbody simulator and a suitable thermometer are available, the specimen can be heated to the desired temperature T_s and the blackbody simulator temperature T_{bb} can be adjusted such that its (spectral) radiance matches that of the specimen. Then the (spectral) emittance is calculable using the following equations for spectral emittance ε(λ) and emittance ε (for a graybody only).

$$\varepsilon(\lambda) = \left(e^{C_2/\lambda * T_s}\right) - 1 / \left(e^{C_2/\lambda * T_{bb}}\right) - 1 \qquad (6)$$

$$\varepsilon = {T_{bb}}^4 / {T_s}^4 \qquad (7)$$

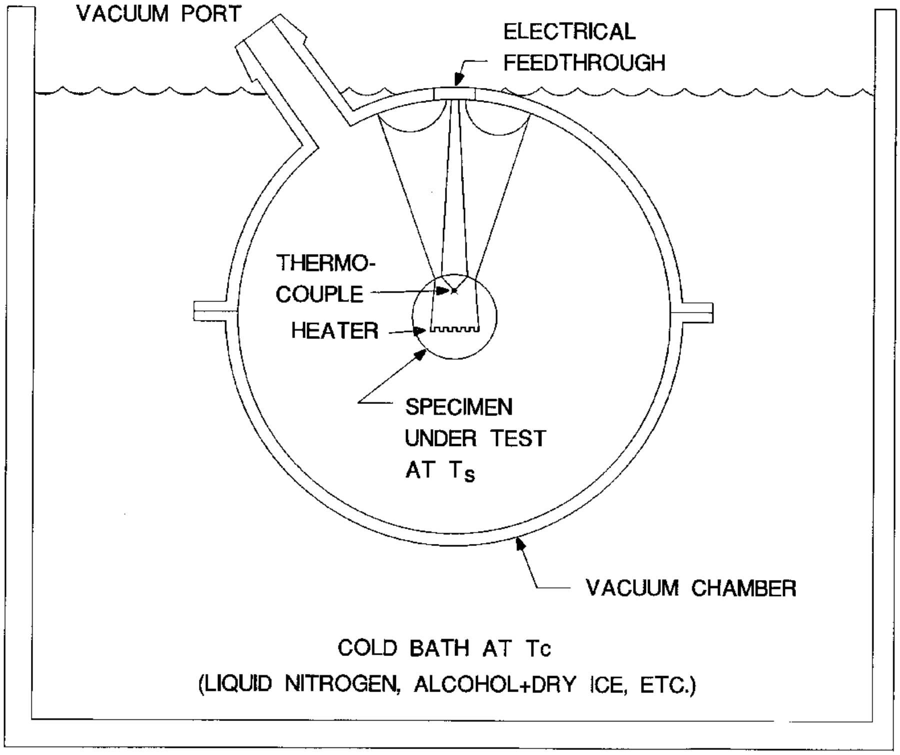


Figure 6: Calorimetric measurement of total hemispherical emittance

If an absolutely calibrated radiometer and a satisfactory thermometer are available, a direct measurement can be made, as L_b is calculable if the temperature is known. Again, the reflected radiation must be considered included.

Simple ‘‘inspection meter’’ techniques have been developed, and instrumentation is commercially available to determine the hemispherical emittance over a limited range of temperatures surrounding the ambient temperature. These instruments provide a single number, as they integrate both spatially and spectrally. A description of the technique can be found in ASTM E408.

Measurements of spectral emittance are most often made using spectral reflectance techniques, invoking Kirchhoff's law along with the assumption that the transmittance is zero. A review of early work is found in Dunn et al (1966a) and Millard and Streed (1969). The usual geometry of interest is directional-hemispherical. This can be achieved by either hemispherical irradiation-directional collection or using Helmholtz reciprocity (Clarke and Perry, 1985), (directional irradiation-hemispherical collection). Any standard reflectometry technique is satisfactory.

A direct method for the measurement of total (integrated over all wavelengths) hemispherical emittance can use a calorimeter as shown in Fig. 8. A heated specimen is suspended in the center of a large, cold, evacuated chamber. The vacuum minimizes gaseous conduction and convection. If the sample suspension is properly designed, the predominant means of heat transfer is radiation. The chamber must be large to minimize configuration factor effects between the chamber and the specimen. The chamber is cooled to T_c to reduce radiation from the chamber to the specimen. Being cold minimizes external radiation or conduction contaminations of the process.

The equation used to determine emittance ε is

$$\varepsilon = \frac{P}{\sigma * A * (T_s^4 - T_c^4)} \qquad (8)$$

where P is the power input to the specimen heater necessary to maintain an equilibrium with specimen temperature T_s and A is the specimen area. The equation has been simplified with the aid of the following assumptions: (1) no thermal conduction from the specimen to the chamber, (2) no convective losses, (3) equilibrium has been achieved, and (4) the specimen area is much less than the chamber area. The power can be supplied electrically by means of a known heater or optically via a window in the chamber. In the latter case, a direct measurement of the ratio of solar absorptance α_S to thermal emittance ε_T can be directly obtained if the optical source simulates solar radiation. By varying the input power, the emittance can be determined as a function of temperature. There are numerous small corrections to account for geometry, lead conduction, etc. Details can be found in ASTM C835, ASTM E434, Edwards (1970), and Richmond and Harrison (1960).

ASTM E1371 is currently used by the industry and building codes in the USA and many APEC economies as means to measure surface emissivity.

Laboratory Grade FTIR Spectral Emittance Measurement Devices

Searches on *spectral emissivity measuring instruments* and *Instruments for measuring IR emissivity of surfaces* should provide information on the most appropriate laboratory and field-portable instruments for determining both spectral and broadband properties. Scrolling down through these and similar search returns will reveal information from manufacturers and tutorial information on the topics of the searches and manuals describing the correct operation of the relevant instruments. “FTIR” refers to “Fourier Transform InfraRed” measurements. Instead of a prism or grating spectrometer, a version of the Michelson interferometer is used. Source radiation travels through a 45 degree angled beam splitter. One beam goes to a fixed mirror while the other of equal flux level to a movable mirror. Upon returning to the beam-splitter, the two beams are combined as they emerge and sent to a radiation detector. All wavelengths are present. However, each wavelength produces oscillations between the brightness of constructive interference when that wavelength of the radiation from both beams is in phase and the darkness of destructive interference when the movable mirror produces destructive interference (zero flux in the combined beam at that wavelength emerging from the beam-splitter. This apparently jumbled mess is separated out by recording the emerging radiant flux as the movable mirror is scanned through a suitable distance. The emerging flux will be varying differently at each wavelength. By applying a formula based on the Fourier mathematical transform, the true spectrum can be elucidated. The first commercially available instrument using this method for infrared measurements was offered for sale in 1969.

References

Akbari H., H.D. Matthews and D. Seto (2012), "The long-term effect of increasing the albedo of urban areas," *Environmental Research Letters* 7: 10 pp.

Akbari, H., S. Menon and A. Rosenfeld (2009), "Global cooling: increasing world-wide urban albedos to offset CO2," Climatic Change 94:275–286.

Añel, J., M. Fernández-González, X. Labandeira, X. Lopez-Otero, L. de la Torre Ramos (2017), "Impact of Cold Waves and Heat Waves on the Energy Production Sector" *Atmosphere*, 8. 209. 10.3390/atmos8110209.

Campbell, I., A. Kalanki and S. Sachar (2018), "Solving the Global Cooling Challenge," http://rmi.org/wp-content/uploads/2018/11/Global_Cooling_Challenge_Report_2018.pdf.

Chhetri, P., A. Hashemi, F. Basic, A. Manzoni and G. Jayatilleke (2012), "Bushfire, Heat Wave and Flooding Case Studies from Australia," Report from the International Panel of the Weather project funded by the European Commission's 7th framework programme. Melbourne, March 2012.

Epstein, S.A., L., Sang-Mi, A.S. Katzenstein, M. Carreras-Sospedra, X. Zhang, S.C. Farina, P. Vahmani, P.M. Fine and G. Ban-Weiss (2017) "Air-quality Implications of Widespread Adoption of Cool Roofs on Ozone and Particulate Matter in Southern California," Proceedings of the National Academy of Sciences USA 114(34) 8991-8996 doi 10.1073/pnas.1703560114

Estrada, F., W. Botzen and R. Tol (2017), "A global economic assessment of city policies to reduce climate change impacts," Journal Nature Climate Change, DOI: 10.1038/NCLIMATE3301.

Kalkstein, L., F. Klink, K. Shickman, S. Schneider, M. Egolf and D. Sailor (2020) "The Potential Impact of Cool Roof Technologies Upon Heat Wave Meteorology and Human Health in Boston and Chicago," Roofing Research and Standards Development: 9th Volume, ASTM International, https://doi.org/10.1520/STP1621-EB

Le Quere C. et al. (2013), "The global carbon budget 1959—2011," Earth System Science Data 5:165–185.

Malley, C., D. Henze, J. Kuylenstierna, H. Vallack, Y. Davila, S. Anenburg, M. Turner, and M. Ashmore (2017), "Updated Global Estimates of Respiratory Mortality in Adults >= 30 Years of Age Attributable to Long-Term Ozone Exposure," *Environmental Health Perspectives*, August 28, 2017, https://doi.org/10.1289/EHP1390.

Perera, E., T. Sanford, J. White-Newsome, L. Kalkstein, J. Vanos, and K. Weir (2012), "Heat in the Heartland: 60 Years of Warming in the Midwest," Union of Concerned Scientists, https://www.ucsusa.org/resources/heat-heartland-60-years-warming-midwest.

Pomerantz, M. (2018) “Are cooler surfaces a cost-effect mitigation of urban heat islands?” Urban Climate, 24, 393-397, https://escholarship.org/uc/item/49m3n3c3.

Sahoo, S. and H. Mittal (2013), “Cool Roof for Low Income Group Housing” CEPT University Report, https://coolrooftoolkit.org/knowledgebase/cool-roof-pilot-on-affordable-houses-in-ahmadabad/.

Salamanca et al. (2014), “Anthropogenic heating of the urban environment due to air conditioning,” Journal of Geophysical Research: Atmospheres Volume 119, Issue 10.

Santamouris, M. (2014), "Cooling the cities–a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments," Solar Energy 103: 682-703.

Schinasi, L., T. Benmarnhia and A. De Roos (2017), “Modification of the association between high ambient temperature and health by urban microclimate indicators: A systematic review and meta-analysis,” Environ Res. 2018 Feb;161:168-180. doi: 10.1016/j.envres.2017.11.004. Epub 2017 Nov 14.

Sustainable Energy for All (2020), “Financing Access to Cooling Solutions,” https://www.seforall.org/publications/financing-access-to-cooling-solutions.

The World Health Organization (2018), “Health and Sustainable Development: Air Pollution.” http://www.who.int/sustainable-development/cities/health-risks/air-pollution/en/.

United States Environmental Protection Agency (2008), “Reducing urban heat islands: Compendium of strategies,” https://www.epa.gov/heat-islands/heat-island-compendium (accessed May 20, 2020).

van Raalte, L., M. Nolan, P. Thakur, S. Xue, N. Parker (2012), “Economic Assessment of the Urban Heat Island Effect,” in: AECOM (Ed.). AECOM Australia Pty Ltd., Melbourne, https://www.melbourne.vic.gov.au/SiteCollectionDocuments/eco-assessment-of-urban-heat-island-effect.pdf.

van Ruijiven, B., E. De Cian and I. Wing (2019), “Amplification of future energy demand growth due to climate change.” *Nature Communications* 10, 2762. June 24, 2019.

Zander, K., W.J. Botzen, E. Oppermann, T. Kjellstrom, S.T. Garnett (2015), “Heat stress causes substantial labour productivity loss in Australia,” Nature Climate Change 5, 647-651.

---

i (Santamouris, M., 2014)
ii (Sahoo, S. and H. Mittal, 2013)
iii (Campbell, I., A. Kalanki and S. Sachar, 2018)
iv (van Ruijiven, B., E. De Cian and I. Wing, 2019)
v (Salamanca et al., 2014)
vi (Añel, J. et al., 2017)

vii (U.S. Environmental Protection Agency, 2008)
viii (Pomerantz, M., 2018)
ix (Akbari H., H.D. Matthews and D. Seto, 2012)
x (Akbari, H., S. Menon and A. Rosenfeld, 2009)
xi (Le Quere C et al., 2013)
xii (Malley, C., et al, 2017)
xiii (Epstein et al , 2017)
xiv (The World Health Organization, 2018)
xv (Perera, E. et al., 2012)
xvi (van Raalte, L., M. Nolan, P. Thakur, S. Xue, N. Parker, 2012)
xvii Kalkstein et al (2020)
xviii (Estrada F., W. Botzen and R. Tol, 2017)
xix (Zander, K. et al., 2015)
xx (Hsiang, S., 2010), (Chhetri, P. et al., 2012)
xxi (Chhetri, P., et al., 2012)
xxii (Estrada et al 2017)
xxiii (Sustainable Energy for All, 2019)
xxiv (Schinasi, L., T. Benmarnhia and A. De Roos, 2017)