Title

The Advancement of Cool Roof Standards in China from 2010 to 2015

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Disclaimer

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Abstract

Since the initiation of the U.S.-China Clean Energy Research Center-Building Energy Efficiency (CERC-BEE) cool roof research collaboration between the Lawrence Berkeley National Laboratory Heat Island Group and Chinese institutions in 2010, new cool surface credits (insulation trade- offs) have been adopted in Chinese building energy efficiency standards, industry standards, and green building standards. JGJ 75-2012: Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Zone became the first national level standard to provide cool surface credits. GB/T 50378-2014: Assessment Standard for Green Building is the first national level green building standard that offers points for heat island mitigation. JGJ/T 359-2015: Technical Specification for Application of Architectural Reflective Thermal Insulation Coating is the first industry standard that offers cool coating credits for both public and residential buildings in all hot-summer climates (Hot Summer/Cold Winter, Hot Summer/Warm Winter). As of December 2015, eight provinces or municipalities in hot-summer regions have credited cool surfaces credits in their residential and/or public building design standards; five other provinces or municipalities in hot-summer regions recommend, but do not credit, the use of cool surfaces in their building design standards. Cool surfaces could be further advanced in China by including cool roof credits for residential and public building energy efficiency standards in all hot-summer regions; developing a standardized process for natural exposure and aged-property rating of cool roofing products; and adapting the U.S.-developed laboratory aging process for roofing materials to replicate solar reflectance changes induced by natural exposure in China.

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Note to reader

In this report, solar absorptance is written as ρ, solar reflectance is written as α, and thermal transmittance is written as U to match the nomenclature of Chinese building energy efficiency standards.

1 Introduction

1.1 Cool roofs

Roofs that can stay cool under the sun by minimizing solar absorption and maximizing thermal emission are called "cool" roofs. Replacing a conventional dark roof with a cool roof decreases cooling electricity use, cooling power demand, and cooling equipment capacity requirements. Cool roofs can also lower summertime citywide ambient air temperature, which can slow the formation of ozone and increase human comfort (Akbari & Levinson, 2008). Cool roofs typically have high solar reflectance (SR) and high thermal emittance (TE). Solar reflectance is the fraction of the incident solar energy that is reflected by a surface. Thermal emittance is the efficiency with which a surface emits thermal radiation, shedding heat to its environment (LBNL, 2016).

1.2 Background of U.S.-China Clean Energy Research Center - Building Energy Efficiency (CERC-BEE) Cool Roof Project

In 2010, the Heat Island Group at Lawrence Berkeley National Laboratory (LBNL) started collaborating with Chinese institutions and government authorities to study cool roof applications and standards in China. Cool roofs are a mature industry in the United States, supported by extensive research, a product rating system, voluntary incentives, and code requirements (Gao, et al., 2014; CRRC, 2016c; Akbari & Levinson, 2008). However, prior to this project, China did not have the infrastructure needed to promote the appropriate use of cool roofs, such as cool roof provisions in national energy efficiency standards, incentive programs, and a cool roof product rating system. The U.S.-China Clean Energy Research Center–Building Energy Efficiency (CERC-BEE) cool roof project investigates how cool roofs can be adapted to Chinese climates, urban designs, and building practices. The team has quantified potential energy and environmental benefits of cool roofs in China, especially carbon reduction. The team has also collaborated with policymakers to develop the infrastructure (including building standards and rating systems) needed to promote the appropriate use of cool roofs in China.

The roles of key partners in CERC-BEE cool roof project are summarized in Table 1.

Table 1. Key Chinese partners working on cool roof related codes and standards and their roles in CERC BEE cool roof projects in China.

Name	**Position**	**Role**
Changqing LIN	Department Head, Research Institute of Standards and Norms (RISN), of Ministry of Urban-Rural Development (MOHURD)	Initiate and lead the development of cool roof standards and codes at the national level. Lead cool roof material aging related research studies. Lead eight Chinese research institutions on natural aging trials to study how cool materials are naturally aged in China. ● Jiangsu Research Institute of Building Science ● Guangdong Provincial Academy of Building Research Group ● China Building Materials Academy (China Building Materials Test & Certification Group) ● Xiamen Academy of Building Research Group ● Sichuan Institute of Building Research ● Xinjiang Construction Research Institute ● Shaanxi Institute of Building Research ● Shenzhen Institute of Building Research
Shichao YANG	Vice President, Guangdong Provincial Academy of Building Research Group (GPABR)	Lead cool roof research at GPABR. He is one of the most active experts working on cool roof codes and standards with Changqing LIN. GPABR is one of the eight Chinese research institutions conducting natural aging trials. It is working with LBNL to develop a proof-of-concept accelerated aging process using 12 months of natural exposure data gathered in Guangzhou.
Yafeng GAO	Professor, Chongqing University	Conduct collaborative cool surfaces related research with LBNL. He is the lead author of the first collaborative publication: *Cool roofs in China: Policy review, building simulations and proof-of-concept experiments* (Gao, et al., 2014).

2 Background of building energy efficiency design standards system in China

2.1 Overview of China's standard system

China has three major categories of standards: national, industry, and enterprise. National standards provide uniform technical instructions across the country. Industry standards provide uniform technical instructions across one sector. National standards take priority over industry standards, and newly introduced national standards replace existing industry standards in the same area. Local governments can introduce their own standards, but they need to be more stringent than any pre-existing national standards or national-level industry standards. In the absence of both national and industry standards, manufacturers can draft enterprise standards to serve as the criteria for production. Where national or industry standards have been formulated, the government shall encourage manufacturers to formulate enterprise standards that are more stringent than national or industry standards (State Council, 1989).

2.2 National Building Energy Efficiency Design Standards

In the building design area, there are four national building energy efficiency (BEE) design standards, as listed in Table 2. For public buildings, there is only one BEE standard for the whole country, while for residential buildings, BEE standards are introduced based on climate zone: Hot Summer/Warm Winter, Hot Summer/Cold Winter, Cold, and Severe Cold. There is no national BEE design standard for the Temperate zone.

Building developers and construction companies are required to follow the national BEE standards in the climate zones of the construction site. National BEE standards set a minimal requirement for buildings to follow. Some provincial or local governments introduce their own BEE standards, which are stricter than national BEE standards. Provincial or local governmental BEE Standards (if existed) have priority over national BEE standards. Please refer to Figure 1 for climate zones in BEE standards.

Figure 1. Climate zones referenced in Chinese building energy efficiency standards. Adapted from (Gao, et al., 2014).

2.3 Industry standards

Building developers follow local (if available) or national industry standards when applying certain building technologies, such as cool roofs. All buildings should satisfy the requirements in relevant national BEE standards. Developers should also use technology-specific industry standards.

3 Cool surface credits in current national energy efficiency standards

Experiments and simulations have indicated that cool roofs reduce annual source energy use in Hot Summer/Warm Winter and Hot Summer/Cold Winter Chinese climates (Gao, et al., 2014). Since the initiation of CERC-BEE in 2010, cool surfaces (roof and wall) have been given credits in the national residential design standard for Hot Summer/Warm Winter climate zone. In the context of a prescriptive standard, a “credit” is a trade-off that allows greater flexibility in design of the building. For example, a cool roof credit might permit the use of less insulation in the roof assembly. Cool surface credits in national BEE standards are summarized in Table 2.

Table 2. National energy efficiency design standards and cool surface credits.

Climate zone	Standard	do cool roofs provide energy savings?[1]	Cool surface credit
Public buildings			
All	Design standard for energy efficiency of public building GB 50189-2015 (MOHURD, 2015)	In hot-summer climate zones	None
Residential Buildings			
Severe Cold and Cold	Design standard for energy efficiency of residential buildings in severe cold and cold zones JGJ 26-2010 (MOHURD, 2010b)	No	None
Hot Summer/Cold Winter	Design standard for energy efficiency of residential buildings in hot summer and cold winter zone JGJ 134-2010 (MOHURD, 2010a)	Yes	None
Hot Summer/Warm Winter	Design standard for energy efficiency of residential buildings in hot summer and warm winter zone JGJ 75-2012 (MOHURD, 2012)	Yes	Roofs and walls with solar absorptance $\rho < 0.6$ are assigned additional thermal resistance ($m^2 \cdot K/W$): 0.20 if $\rho < 0.4$ 0.15 if $0.4 \leq \rho \leq 0.6$

[1] According to (Gao, et al., 2014)

4 Advancement of cool surface provisions in Chinese standards from 2010 to 2015

4.1 Advancements in national standards

Since 2010, MOHURD has introduced cool surface credits in the national residential design standard for Hot Summer/Warm Winter regions. In this standard, cool surface credits are given in the form of equivalent thermal resistance as described in Table 2. The 2015 revision to the national public building design standard in (GB 50189-2015: Design Standard for Energy Efficiency of Public Buildings) did not credit cool surfaces; please refer to Section 7.3 for further discussion.

4.2 Advancements in provincial or local design standards

By December 2015, eight provinces or municipalities in hot-summer regions had adopted cool surfaces credits in their residential and/or public building design standards (Table 3).

Table 3. Cool surface credits in standards at the provincial and municipal levels.

Region	Climate Zone	Building Type	Year of Adoption
Chongqing (Municipality)	Hot Summer/Cold Winter	Public Residential	2013 2010
Sichuan Province	Hot Summer/Cold Winter Cold Temperate	Residential	2012
Hubei Province	Hot Summer/Cold Winter	Residential	2009
Fujian Province	Hot Summer/Cold Winter Hot summer/Warm Winter	Residential	2014
Guangdong Province	Hot Summer/Warm Winter	Public	2007
Guangxi Province	Hot Summer/Warm Winter Hot Summer/Cold Winter	Residential	2013
Guangxi Province	Hot Summer/Warm Winter Hot Summer/Cold Winter	Public	2013
Shanghai (Municipality)	Hot Summer/Cold Winter	Residential Public	2011 2012
Hainan Province	Hot Summer/Warm Winter	Residential	2005

By December 2015, five provinces or municipalities in hot-summer regions had recommended using cool surface materials in their residential and/or public building design standards. Yunnan province, which is in the temperate zone, also recommended cool surfaces. Cool surface credits in provincial and municipal levels are listed in Table 4.

Table 4. Cool surfaces recommended in provincial and municipality level standards.

Region	Climate Zone	Building Type	Year of Adoption
Henan Province	Hot Summer/Cold Winter;	Residential	2012
	Cold	Commercial or Public	2006
An'hui Province	Hot Summer/Cold Winter	Residential	2010
Jiangxi Province	Hot Summer/Cold Winter	Residential	2014
Guizhou Province	Hot Summer/Cold Winter	Residential	2008
	Hot Summer/Warm Winter		
	Temperate		
Zhejiang Province	Hot Summer/Cold Winter	Residential	2015
		Commercial or Public	2007
Yunnan Province	Temperate	Residential	2011

Appendix A summarizes the cool surface credits in both national and local design standards.

4.3 Assessment standard for green building

In GB/T 50378-2014: Assessment Standard for Green Building, mitigation of the heat island effect is given four points in the Outdoor Environment Category. This was the first time that surfaces with high solar reflectance were given points in a Chinese national green building standard. The heat island effect section is described below:

Heat island effect: 4 points in the outdoor environment category

1. If outdoor environment has trees or other shading measurement that covers at least 10% of the outdoor area, 1 point. Covers at least 20% of the outdoor area, 2 points

2. Solar reflectance of pavement and building roofs is at least 0.4 for at least 70% of the surface area, 2 points.

4.4 Advancement in national industry standard

National industry standard JGJ/T 359-2015: Technical Specification for Application of Architectural Reflective Thermal Insulation Coating (MOHURD, 2015) was introduced to guide building developers and construction companies in the application of architectural reflective thermal insulation coatings. JGJ/T 359-2015 offers cool coating credits (insulation trade-offs) for both public and residential buildings in all hot-summer Chinese climates (Hot Summer/Cold Winter; Hot Summer/Warm Winter). For more detail, please see Appendix B: Cool surface credits in JGJ/T 359 – 2015; Appendix C: Calculation of solar reflectance with pollution factor in JGJ/T 359 –2015; and Appendix D: Equivalent thermal resistance for applying solar reflective heat insulation materials in JGJ/T 359 – 2015.

5 Cool surface credits in JGJ/T 359-2015: Technical Specification for Application of Architectural Reflective Thermal Insulation Coating

5.1 Standard summary

We summarize JGJ/T 359-2015 in Table 5.

Table 5. Summary of standard JGJ/T 359-2015: Technical Specification for Application of Architectural Reflective Thermal Insulation Coating (MOHURD, 2015).

Standard Name	JGJ/T 359 – 2015: Technical Specification for Application of Architectural Reflective Thermal Insulation Coating
Publication Date	2015-06-30
Implementation Date	2016-02-01
Publication Agency	China Architecture & Building Press on behalf of Ministry of Housing and Urban-Rural Development (MOHURD)
Standard Application Region	National Industry Standard
Application Level	Optional
Author of the standard	Technical Leads: Fujian Academy of Building Research, Fuzhou, Fujian Province Hengyi Group, Fujian Province (a multi-business stream enterprise with core business in building development and construction) Other participating organizations include five research institutions, two universities, and 17 building material and construction companies.
Target audience	All building developers, construction companies, and materials companies shall follow this standard if they intend to apply architectural reflective thermal insulation coating to walls or roofs.
Major sections	Materials Requirements Architectural Structural Design Architectural Thermal Performance Design Construction Acceptance of Construction Quality
Development of the standard	The development of the standard was initiated by MOHURD's Research Institute of Standards and Norms (RISN) to regulate and provide engineering application guidance for the application of architectural reflective thermal insulation coatings. The goal of the standard is to ensure construction quality, safety, and economical feasibility for applying architectural reflective thermal

	insulation coatings. The standard encourages the application of the most advanced technologies and methods when applying architectural reflective thermal insulation coating.
Definition of architectural reflective thermal insulation coating	Coating is made of synthetic resin, with the addition of functional pigments and other additives. The coating has high solar reflectance, high near-infrared reflectance, and high thermal emittance.

5.2 Main relevant standards referenced in JGJ/T 359-2015

JC/T 235-2014: Architecture Reflective Thermal Insulation Coating (MOHURD, 2014a)

- Standard JC/T 235-2014 is by far the most comprehensive standard on architectural reflective thermal insulation coatings. JGJ/T 359-2015 references JC/T 235-2014 for the definition of architectural reflective thermal insulation coating. JGJ/T 359-2015 also references the laboratory aging practice in JC/T 235-2014.

JGJ/T 287-2014: Standard for Energy Efficiency Test of Solar Heat Reflecting Insulation Coatings of Buildings (MOHURD, 2014b)

- Standard JGJ/T 359-2015 references JGJ/T 287-2014 for measurement of initial and aged solar reflectance. JGJ/T 287-2014 also references a laboratory aging practice in GB/T 9780-2013: Test Method for Dirt Pickup Resistance and Stain Removal of Film of Architectural Coatings and Paint (MOHURD, 2013).

GB/T 9780-2013: Test Method for Dirt Pickup Resistance and Stain Removal of Film of Architectural Coatings and Paint (MOHURD, 2013)

- JGJ/T 359-2015 references a laboratory aging process in GB/T 9780-2013, and presents a “pollution correction” formula based this laboratory aging process. Please refer to Section 6.2 for a detailed description.

Figure 2 illustrates the relationship between the standards.

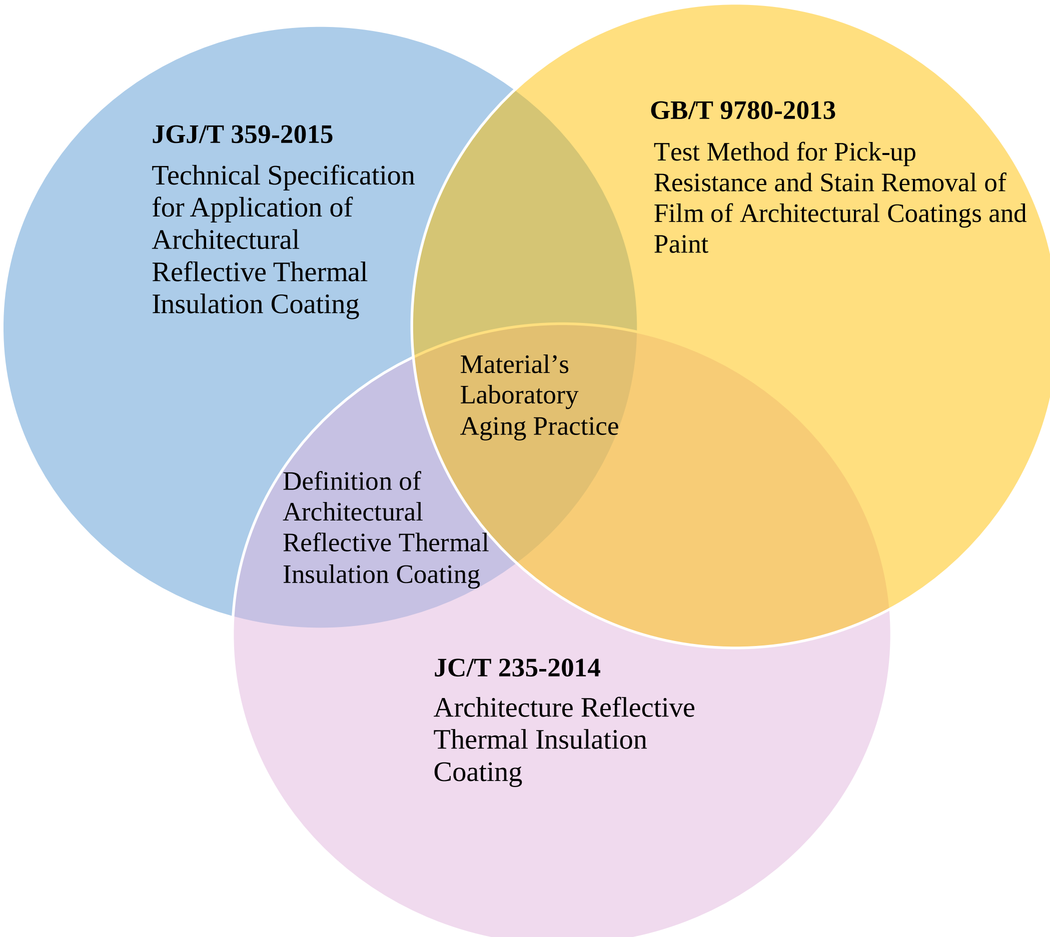

Figure 2. Material's laboratory aging practice sections in JGJ/T 359-2015 and JC/T 235-2014 come from GB/T 9780-2013. The definition of architectural reflective thermal insulation coating comes from JC/T 235-2014 (MOHURD, 2014a; MOHURD, 2014b; MOHURD, 2013).

5.3 Cool surface credits in JGJ/T 359-2015

For simplicity, cool surfaces are given "equivalent thermal resistance" values (insulation trade- offs) in this standard. This includes both walls and roofs for public and residential buildings in the two hot-summer climate zones. Simulated energy uses of multi-level residential buildings in four cities in the Hot Summer/Warm Winter zone and four cities in the Hot Summer/Cold Winter zone (Table 6) were used to calculate equivalent thermal resistances followings Eqs. (1) through (5). Calculation inputs and outputs are shown in Table 7.

Table 6. Cities used for equivalent thermal resistance calculation in each climate zone.

Hot Summer/Cold Winter	**Hot Summer/Warm Winter**
Shanghai	Guangzhou
Chongqing	Haikou
Nanchang	Fuzhou
Hangzhou	Hechi

In this standard, the "equivalent thermal resistance" is determined by the "annual energy consumption index" method. The DeST (Tsinghua University, 2016) or DOE (Hirsch, 2016) building energy simulation tool is used to calculate annual conditioning (heating + cooling) site electricity use per unit of floor area (energy intensity) of the typical building. The standard refers to this property as the building's "annual energy consumption index". Each climate-specific value of annual energy consumption index (E) is related to properties of the roof or wall using the linear regression

$$E = C_0 + C_1\, U_0 + C_2\, U_0\, \rho_0 + C_3\, \rho_0 \tag{1}$$

where

- E is annual heating and cooling electricity use per unit floor area of the typical building (referred to as annual energy consumption index) (kWh/m^2);
- U_0 is thermal transmittance of roof or wall (W/m^2·K);
- ρ_0 is solar absorptance (-);
- C_0 is the constant term in the linear regression (kWh/m^2);
- C_1 is the coefficient for the term U_0 (kh·K);
- C_2 is the coefficient for the term $U_0 \cdot \rho$ (kh·K); and
- C_3 is the coefficient for the term ρ_0 (kWh/m^2).

When E remains the same, Eqs. (2) through (4) can be used to calculate the coefficient C_d, which in turn is used to calculate equivalent thermal resistance.

$$C_d = \frac{U'}{U} \tag{2}$$

$$U' = \frac{E - C_0 - C_3 \cdot \rho_c}{C_1 + C_2 \cdot \rho_c} \tag{3}$$

$$U = \frac{E - C_0 - C_3 \cdot \rho_{r0}}{C_1 + C_2 \cdot \rho_{r0}} \tag{4}$$

where

- C_d is ratio of thermal transmittance of walls or roofs with architectural thermal insulation coating to those of original surfaces without the coating;
- U is the actual thermal transmittance of roof or wall without architectural thermal insulation coating ($W/m^2 \cdot K$);
- U' is the equivalent thermal transmittance of roof or wall with architectural thermal insulation coating ($W/m^2 \cdot K$);
- ρ_c is the solar absorptance of the surface with architectural reflective thermal insulation coating, after pollution correction; and
- ρ_{r0} is the solar absorptance of a typical surface without architectural reflective thermal insulation coating (no pollution correction applied).

"Equivalent thermal resistance" can be calculated as

$$R_{eq} = \left(\frac{1}{C_d} - 1\right) \times R \tag{5}$$

where

- R_{eq} is the equivalent thermal resistance of the building surface (roof or wall) that uses an architectural reflective thermal insulation coating ($m^2 \cdot K/W$); and
- R is the actual thermal resistance of the building surface (roof or wall) that does not use an architectural reflective thermal insulation coating ($m^2 \cdot K/W$)

In each city, coefficients C_0 through C_3 were computed from six case studies via linear regression. A sample calculation of the coefficient C_d for residential buildings in Shanghai is illustrated in Table 7. In this example, C_0, C_1, C_2, C_3 and C_d are calculated from the values of ρ_0, U_0, and E simulated in cases 1 through 4, yielding $C_0 = 12.69$, $C_1 = 4.41$, $C_2 = -1.59$, $C_3 = 3.63$, and $C_d = 0.77$ (MOHURD, 2015).

Table 7. Calculations for coefficients based on a residential building in Shanghai.

Case number	Solar absorptance ρ_0	Thermal transmittance U_0 (W/m^2·K)	Heating electricity use (kWh/m^2)	Cooling electricity use (kWh/m^2)	Conditioning (heating + cooling) electricity use E (kWh/m^2)
1	0.20	1.0	7.86	15.62	23.48
2	0.40	1.0	7.55	16.32	23.87
3	0.80	1.0	6.94	17.78	24.72
4	0.55	1.2	8.23	16.92	25.15
5	0.55	1.0	7.33	16.86	24.19
6	0.55	0.8	6.39	16.80	23.19

5.4 Aged solar reflectance value application in the standard

Aged SR value refers to a product's steady long-term solar reflectance value after it is naturally exposed outside for a period until SR value stabilizes. The standard GB/T 9780-2013: Test Method for Dirt Pickup Resistance and Stain Removal of Film of Architectural Coatings and Paint GB/T 9780-2013 (MOHURD, 2013) is followed to provide laboratory simulated aged SR. A standard dirt mixture is applied on building surface coating specimens. The dirt composition is fine coal fly ash with particle diameter smaller than 0.045 mm (Reference Material P.R. China, 2015). A formula to quickly calculate aged SR value is developed by measuring solar reflectance before and after applying the dirt pick-up test. In this standard, the formula is referred to as the "pollution correction" formula (see Appendix C) (MOHURD, 2015).

5.5 The importance of the cool coating credit standard

Standard JGJ/T 359-2015 is the first standard that offers cool coating credits (insulation trade-offs) for both public and residential buildings in all hot-summer Chinese climates (Hot Summer/Cold Winter; Hot Summer/Warm Winter).

6 Solar reflectance and thermal emittance measurement practices in the U.S. and China

6.1 Overview

6.1.1 Solar reflectance and thermal emittance measurement practices in the U.S.

Major building energy efficiency standards in the U.S., such as 2013 California Code of Regulations (CCR), Title 24: California Building Standards Code (CRRC, 2016c), ASHRAE 90.1-2013: Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE, 2013), and 2015 IECC: International Energy Conservation Code (IECC, 2015), specify that the radiative properties of roofing products shall be obtained following ANSI/CRRC Standard CRRC-1, now called ANSI/CRRC S100: Standard Test Methods for Determining Radiative Properties of Materials (CRRC, 2016b). S100 permits measurement of solar reflectance following ASTM C1549 (2014): Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer (ASTM, 2014); CRRC-1 Test Method #1 (a random-sampling application of ASTM C1549) (CRRC, 2005), ASTM E903 (2012): Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres (ASTM, 2012); or ASTM E1918 (2015): Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field (ASTM, 2015b). It also permits measurement of thermal emittance following ASTM C1371 (2015): Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers (ASTM, 2015a) for products that have high thermal conductance, or the Slide Method variation on ASTM C1371 (Devices & Services, 2011) for those that do not. As of June 2016, over 99% of product reflectances reported in the Rated Products Directory of the Cool Roof Rating Council were measured following ASTM C1549 or CRRC-1 Test Method#1 (CRRC, 2016c).

ASTM C1549 specifies the use of a solar spectrum reflectometer made by Devices & Services (Dallas, Texas, U.S.) to measure solar reflectance. ASTM E903 describes the use of a solar (UV-vis-NIR) spectrophotometer with integrating sphere to measure solar spectral reflectance, and how to weight this result with solar spectral irradiance to compute solar reflectance. ASTM 1918 specifies how to measure solar reflectance with a first-class pyranometer (or a pair of first-class pyranometers). An earlier work details the physics and accuracy of each of these three solar reflectance test methods (Levinson, Akbari, & Berdahl, 2010).

ASTM C1371 describes the use of a portable emissometer made by Devices & Services to measure thermal emittance (efficiency which a surface emits thermal infrared radiation). The Slide Method variant on C1371 moves the emissometer along the test surface to minimize radiant heating of specimens whose temperatures cannot be regulated with a heat sink.

6.1.2 Solar reflectance and thermal emittance measurement practices in China

JGJ/T 287-2014: Standard for Energy Efficiency Test of Solar Heat Reflecting Insulation Coatings of Buildings (MOHURD, 2014b) guides solar reflectance and thermal emittance measurements.

6.1.2.1 Solar reflectance

JGJ/T 287-2014 specifies three instruments that can be used to measure solar reflectance:

1. a solar (UV-vis-NIR) spectrophotometer (minimum detection wavelength range 350 to 2500 nm);

2. a fiber optic spectrometer (minimum detection wavelength range 350 to 2500 nm) with a halogen-lamp light source; and

3. a solar reflectometer that complies with ASTM C1549-09.

The measurement can either use an absolute method (specimen is placed in the center of integrating sphere without a calibration standard) or a relative method. In the absolute method, solar reflectance α_s is computed from spectral reflectance following Eq (6).

$$\alpha_s = \frac{\sum_{i=1}^{n} \alpha_{1\lambda_i} \, E_s(\lambda_i) \, \Delta\lambda_i}{\sum_{i=1}^{n} E_s\,(\lambda_i) \, \Delta\lambda_i} \tag{6}$$

In relative measurement method (with calibration standard), solar reflectance α_s can be computed from spectral reflectance following Eq (7).

$$\alpha_s = \frac{\sum_{i=1}^{n} \alpha_{0\lambda_i} \, \alpha_{1\lambda_i} \, E_s(\lambda_i) \, \Delta\lambda_i}{\sum_{i=1}^{n} E_s\,(\lambda_i) \, \Delta\lambda_i} \tag{7}$$

where

- i is calculation point in the wavelength range 350 to 2500 nm;

- λ_i is the wavelength (nm) corresponding to point i;

- $\Delta\lambda_i = (\lambda_{i+1} - \lambda_{i-1})/2$ is the wavelength interval (nm) around measurement point i

- n = 96 is number of calculation points;

- $\alpha_{0\lambda i}$ is the reflectance of calibration standard at wavelength λ_i (There is a table in the Appendix of JGJ/T 287-2014 that provides the value of $\alpha_{0\lambda i}$);

- $\alpha_{1\lambda i}$ is the measured reflectance of tested surface at wavelength λ_i measured with standard white board as calibration standard; and

- $E_s(\lambda_i)$ is hemispherical solar spectral irradiance at wavelength λ_i ($W/m^2 \cdot nm$), obtained from Appendix C of Standard JGJ/T 287-2014, which in turn cites GB/T 17683.1-1999: Solar Energy – Reference Solar Spectral Irradiance at the Ground at Different Receiving Conditions – Part 1: Direct Normal and Hemispherical Solar Irradiance for Air Mass 1.5 and 37° Tilted Surface (MOHURD, 1999).

Outdoor SR measurements should use a fiber optic spectrometer (MOHURD, 2014b).

6.1.2.2 Thermal Emittance (TE)

JGJ/T 287-2014 specifies two instruments that can be used to measure thermal emittance: a portable emissometer, or an infrared spectrometer (minimum wavelength range 2.5 to 25 μm).

Portable emissometer measurement range should be between 0.03 and 0.95. When using an infrared spectrometer, hemispherical thermal emittance ε should be calculated as

$$\varepsilon = 1 - \sum_{4.5\mu m}^{25\mu m} G(\lambda)\, \rho(\lambda) \tag{8}$$

where

- $\rho(\lambda)$ is the specimen's spectral reflectance; and
- $G(\lambda)$ is the ratio of the monochromatic hemispherical emissive power at wavelength λ ($W/\mu m \cdot m^2$) to the total hemispherical emissive power (W/m^2) at 293 K (There is a table in the Appendix of the standard JGJ/T 287-2015 that provides value of $G(\lambda)$ based on wavelength value) (MOHURD, 2014b).

6.2 Initial and aged SR and TE measurement procedure in China

As of spring 2016, there are 30 China Metrology Accreditation (CMA) certified laboratories in China that can measure the solar reflectance and thermal emittance of cool surface materials (Yang, 2015).[2] CMA is a mandatory accreditation system designed to assess the metrology capabilities of testing or calibration laboratories that test products being sold into the Chinese market (NIMTT, 2014). Manufacturers must send their cool surface products for SR and TE testing to CMA labs. JGJ/T 287-2014: Standard for Energy Efficiency Test of Solar Heat Reflecting Insulation Coatings of Buildings is referenced for measuring and testing materials for both initial and aged SR and TE.

6.3 Assessing aged solar reflectance and thermal emittance in the U.S.

The aged solar reflectance and thermal emittance of a roofing product in the U.S. can be accessed through natural aging or laboratory aging.

[2] Metrology is the science of measurement.

6.3.1 Natural aging

Laboratory aging of roofing products in the U.S. follows ASTM Standard D7897: Laboratory Soiling and Weathering of Roofing Materials to Simulate Effects of Natural Aging on Solar Reflectance and Thermal Emittance. The scope of this ASTM standard is as follows:

> Practice D7897 applies to simulation of the effects of field exposure on the solar reflectance and thermal emittance of roof surface materials including but not limited to field-applied coatings, factory-applied coatings, single-ply membranes, modified bitumen products, shingles, tiles, and metal products. The solar reflectance and thermal emittance of roof surface materials can be changed by exposure to the outdoor environment. These changes are caused by three factors: deposition and retention of airborne pollutants; microbiological growth; and changes in physical or chemical properties. This practice applies to simulation of changes in solar reflectance and thermal emittance induced by deposition and retention of airborne pollutants and, to a limited extent, changes caused by microbiological growth. (ASTM, 2015)

This practice can simulate three-year exposure in Phoenix, Miami, or Cleveland, or directly mimic the U.S.-average changes in solar reflectance and thermal emittance.

6.4 Issue with current aged solar reflectance application in standard JGJ/T 359-2015

In a personal communication, Zhi SUN of RISN (who works for Changqing LIN) related that the dirt pick-up test standard GB/T 9780-2013 was developed to test the change in building material properties when picking up dirt. The fly ash mixture was used in this test in all of China due to its stability in material property. The developers of GB/T 9780-2013 did not claim that materials undergoing this dirt pick up practice will have the same aged solar reflectance as naturally exposed materials. Therefore, GB/T 9780-2013 cannot be utilized to measure and report aged SR. The LBNL research team recommends that Chinese cool coating products undergo natural exposure to determine how materials age in Chinese environments. A laboratory aging process can then be developed from these results.

7 Future cool surface standards

7.1 Development of natural aging and laboratory aging practice

Changqing LIN from RISN is leading a natural aging experiment in China to support later development of a proper laboratory aging process. Eight laboratories across China are participating in a natural aging experiment in which coating materials are exposed outside for three years. Natural aging provides a foundation to develop a laboratory aging process in China.

Shichao YANG, the vice president of Guangdong Provincial Institute of Building Research, has suggested that a China-specific laboratory aging process developed in the future can be included in a future revision of ASTM D7897. Thereafter, Chinese laboratory aging processes would be able to reference ASTM D7897 for laboratory aging (Yang, 2015).

7.2 Waterproofing solar reflective materials

In 2015, Chinese waterproofing companies started to develop solar reflective PVC PPO (polyvinyl chloride polyphenyleneoxide) composite solar reflective waterproofing materials due to the inclusion of heat island points in the 2014 Chinese national standard GB/T 50378-2014: Assessment Standard for Green Building.

Previously, waterproofing companies or experts did not participate in the standard development process of solar reflective building materials. In spring 2016, Huasheng SHANG of the Chinese National Building Waterproofing Association indicated his interest in contributing to the high solar reflective building material related standard development process (Shang, 2016).

7.3 Potential revision of design standards

The national residential building standard for the Hot Summer/Warm Winter zone is the only Chinese national building energy standard that credits cool surfaces. Experiments and simulations have indicated that cool roofs reduce annual source energy use in both Hot Summer/Warm Winter and Hot Summer/Cold Winter Chinese climates (Gao, et al., 2014). The research team therefore suggests that cool roof credits should also be included in the national residential building design standard for the Hot Summer/Cold Winter zone as well as in the national public building design standard for all hot-summer regions.

In China, a committee approach is used for developing a new standard. The lead author organization creates the committee that makes standards. The lead author organization can take recommendations from other committee members on what goes into the standard, but the lead author organization makes the final decision. This helps explain why the 2012 BEE design standard for Hot Summer/Warm Winter zone (JGJ 75-2012) credited cool surfaces while the 2015 revision of the design standard of public buildings did not. The co-lead author organization of the Hot Summer/Warm Winter building energy efficiency design standard (JGJ 75-2012) is our CERC project's collaborator, Guangdong Provincial Academy of Building Research (GPABR). Our partner, Dr. Shichao YANG, plays a key role in developing this standard and recognizes the energy saving potential of cool surfaces. Therefore, he included cool surface credits in JGJ 75-2012.

The 2015 public building design standard's lead author organization is the China Academy of Building Research, and their experts have expressed doubts about the energy saving benefits of aged cool roofs (Lin, 2016). Therefore, despite recommendations from Shichao YANG and others to including cool roof credits, the 2015 public building energy efficiency standard GB 50189-2015 does not credit cool roofs. The long-term natural aging experiment is therefore very important – it provides long term concrete data that can persuade lead author organizations to credit cool surfaces in building design standards (Lin, 2016).

8 Summary and recommendations

Over the past five years, cool surface adoption has greatly advanced in Chinese BEE design standards, industry standards, and green building standards.

JGJ 75-2012: Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter zone became the first national level standard to provide cool surface with credits.

By December 2015, eight provinces or municipalities in hot-summer regions have given cool surfaces credits in their residential and/or public building design standard. Five other provinces or municipalities in hot-summer regions have recommended the use of cool surfaces in either their residential or public building design standard, or in both. Some of the provinces or municipalities in the Hot Summer/Cold Winter zone have offered cool surface credits, even though no cool surface credits have been offered for buildings in the Hot Summer/Cold Winter zone's national standard.

GB/T 50378-2014: Assessment Standard for Green Building is the first national-level green building standard to offer points for solar reflective surfaces, encouraging the waterproofing industry to develop solar reflective waterproofing materials.

JGJ/T 359-2015: Technical Specification for Application of Architectural Reflective Thermal Insulation Coating is the first standard that offers cool coating credits (insulation trade-offs) for both public and residential buildings in all hot-summer Chinese climates (Hot Summer/Cold Winter; Hot Summer/Warm Winter).

Potential future improvements to the current Chinese standard system include the development of a solar reflective material natural aging system and a revision of the laboratory aging process. In addition, given the demonstrated energy saving benefits for both public and residential buildings in hot-summer regions, we recommend that cool surface credits be included in future revisions of national and local design standards. It is also recommended that waterproofing material experts and companies participate in the standard development process for cool surface related standards, helping foster a market for develops cool waterproofing materials.

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Appendix A: Cool surfaces related credits in Chinese building energy efficiency standards by province

Provinces

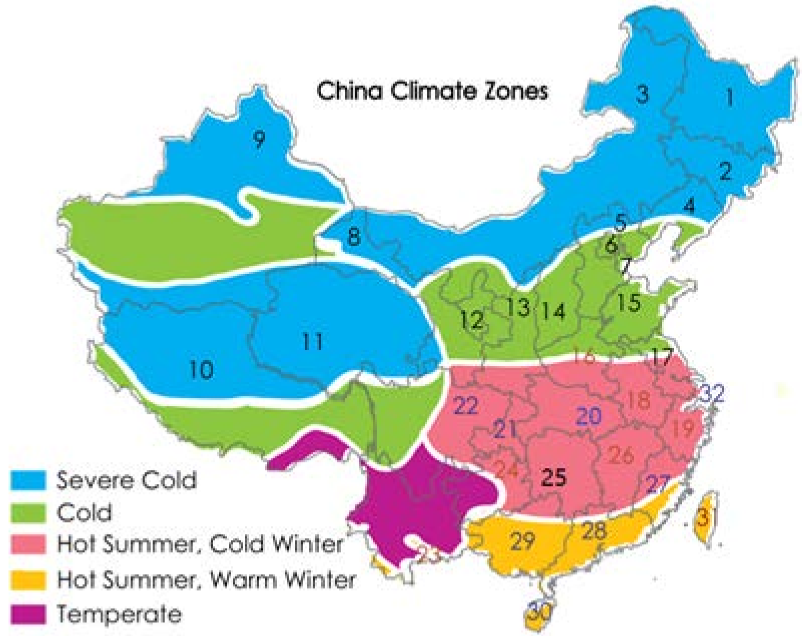
1. Heilongjiang 黑龙江
2. Jilin 吉林
3. Neimenggu 内蒙古
4. Liaoning 辽宁
5. Hebei 河北
6. Beijing 北京
7. Tianjin 天津
8. Gansu 甘肃
9. Xinjiang 新疆
10. Xi'zang 西藏
11. Qinghai 青海
12. Ningxia 宁夏
13. Shann'xi 陕西
14. Shanxi 山西
15. Shandong 山东
16. Henan 河南
17. Jiangsu 江苏
18. An'hui 安徽
19. Zhejiang 浙江
20. Hubei 湖北
21. Chongqing 重庆
22. Sichuan 四川
23. Yunnan 云南
24. Guizhou 贵州
25. Hunan 湖南
26. Jiangxi 江西
27. Fujian 福建
28. Guangdong 广东
29. Guangxi 广西
30. Hainan 海南 (Residential builing only)
31. Taiwan 台湾
32. Shanghai 上海

Color Coding

Blue – The region's standard includes cool surface credits.

Brown – The region's standard does not include cool surface credits, but recommends cool surfaces.

Black – The region's standard neither credits nor recommends cool surfaces.



Building types defined in the new public building standards (GB50189-2015: Design standard for energy efficiency of public buildings)	
Type A (New):	If individual building’s footprint area is over 300 m^2 or individual building’s footprint area is smaller than 300 m^2 but total building community’s construction area is over 1,000 m^2.
Type B (New):	If individual building has footprint area smaller or equal to 300 m^2
Building types defined in old public building standards (before the implementation of GB50189-2015)	
Type A:	Floor area exceeds 20,000 m^2, or entire building is air conditioned.
Type B:	Floor area is less than 20,000 m^2, or some or all of the building is not air conditioned.
Type C:	Building is not air conditioned, or is not air conditioned during peak electrical demand hours in both summer and winter.

Table 8. Public building type definition defined in standard.

Table 9. Cool surface credits or recommendations in national and provincial standards.

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
JGJ75-2012: Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Zones (2012), 夏热冬暖地区居住建筑节能设计标准 (MOHURD, 2012)	0.9 If $0.4 \leq U \leq 0.9$: thermal inertia D must be at least 2.5	Roof with solar absorptance $\rho < 0.6$ assigned additional thermal resistance ($m^2 \cdot K/W$): 0.20 if $\rho < 0.4$ 0.15 if $0.4 \leq \rho \leq 0.6$ Roof with vegetation credited with additional thermal resistance 0.9	Hot Summer/Warm Winter	2012
JGJ134-2010: Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zones (2010) 夏热冬冷地区居住建筑节能设计标准 (MOHURD, 2010a)	If shape factor $S \leq 0.4$: If thermal inertia $D \leq 2.5$: 0.8 else: 1.0 If $D \leq 2.5$: 0.5 else: 0.6	None, but light-colored surfaces recommended for “heat insulation”; roofs with vegetation or surface coatings recommended for the southern regions	Hot Summer/ Cold Winter	2010

Standard	Maximum roof thermal transmittance *U* ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
JGJ26-2010: Design Standards for Energy Efficiency of Residential Buildings in Cold and Severe Cold Zones(2010) 寒冷地区居住建筑节能设计标 (MOHURD, 2010b)	If number of floors ≤ 3: • 0.20 in Severe Cold zone A • 0.25 in Severe Cold zone B • 0.30 in Severe Cold zone C • 0.35 in Cold zone A • 0.35 in Cold zone B If number of floors is 4 – 8: • 0.25 in Severe Cold zone A • 0.30 in Severe Cold zone B • 0.40 in Severe Cold zone C • 0.45 in Cold zone A • 0.45 in Cold zone B If number of floors ≥ 9: • 0.25 in Severe Cold zone A • 0.30 in Severe Cold zone B • 0.40 in Severe Cold zone C • 0.45 in Cold zone A	None	Cold	2010

Standard	Maximum roof thermal transmittance *U* ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
	• 0.45 in Cold zone B			
GB50189-2015: Design standard for energy efficiency of public buildings 公共建筑节能标准 (MOHURD, 2015)	Type A (New) Building: • If Shape Factor $S \leq 0.3$ • 0.28 in Severe Cold zone A, B • 0.35 in Severe Cold zone C • 0.45 in Cold zone If Shape Factor $0.3 \leq S \leq 0.5$ • 0.25 in Severe Cold zone A, B • 0.28 in Severe Cold zone C • 0.40 in Cold zone If thermal inertia $D \leq 2.5$ • 0.40 in Hot Summer/Cold Winter zone • 0.50 in Hot Summer/Warm Winter zone • 0.50 in Temperate zone If thermal inertia $D > 2.5$ • 0.50 in Hot Summer/Cold Winter	None	All	2015

Standard	Maximum roof thermal transmittance *U* ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
	zone • 0.80 in Hot Summer/Warm Winter zone • 0.80 in Temperate zone Type B (New) Building: • 0.35 in Severe Cold zone A, B • 0.45 in Severe Cold zone • 0.55 in Cold zone • 0.70 in Hot Summer/Cold Winter zone • 0.90 in Hot Summer/Warm Winter zone			
GB/T 50378-2014: Assessment standard for green building 绿色建筑评价标准 (MOHURD, 2014c)		Heat island effect: 4 points in the outdoor environment category 1. If outdoor environment has trees or other shading measurement that covers at least 10% of the outdoor area, 1 point. If it covers at least 20% of the outdoor area, 2 points. 2. Solar reflectance of pavement and building roofs is at least 0.4 for at least 70% of the surface area, 2 points.	All climate zones	2014

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
DBJ50-052-2013: Design Standards on Public building energy saving (green buildings)-Chongqing 重庆市工程建设标准-公共建筑节能（绿色建筑）设计标准 (CMCURD, 2013)	0.7	Roof and walls are recommended to use light colored reflective material to reduce surface solar absorption. When roof and wall's physical characteristics for solar reflective insulation coating satisfy the requirements in DBJ/T50-076: Technical Specification for External Thermal Insulation Composite System Based on Reflective Thermal Insulating Coating on Building (Chongqing), roof and wall's thermal transmittance should be corrected as follows: $U_m = \beta \cdot U_m'$ U_m is average thermal transmittance of the roof and wall with solar reflective coating U_m' is average thermal transmittance of the roof and wall without solar reflective coating β is correction factor: should reference the value below 0.85 if $U_m' > 1.3$; 0.90 if $1.0 < U_m' \leq 1.30$ 0.95 if $U_m' \leq 1.0$ According to DBJ/T50-067: Technical Specification for Planted Roofs, when vegetation covers at least 70% of the roof, the equivalent thermal resistance of the vegetative roofing layer is 0.50 $m^2 \cdot K/W$.	Hot Summer/Cold Winter	2013

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
DBJ 50-071-2010: Design Standard for Energy Efficiency (65%) of Residential Buildings in Chongqing (2010), 重庆市 65%居住建筑节能设计标准 (CMCURD, 2010a)	If shape factor $S \leq 0.4$: If thermal inertia $D < 2.5$: 0.6 Else: 0.8 Else: If thermal inertia $D < 2.5$: 0.5 Else: 0.6	Thermal transmittance U' of light-colored external wall is multiplied by 0.85 if $U' > 1.3$ 0.90 if $1.0 < U' \leq 1.3$ 0.95 if $U' \leq 1.0$	Hot Summer/Cold Winter	2010

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
DBJ50-102-2010: Design Standard for Energy Efficiency (50%) of Residential Buildings in Chongqing (2010), 重庆市 50%居住建筑节能设计标准 (CMCURD, 2010b)	If shape factor $S \leq 0.4$: If thermal inertia $D < 2.5$: 0.6 Else: 1.0 Else: If thermal inertia $D < 2.5$: 0.5 Else: 0.8	Thermal transmittance U' of light-colored external wall is multiplied by 0.85 if $U' > 1.3$ 0.9 if $1.0 < U' \leq 1.3$ 0.95 if $U' \leq 1.0$	Hot Summer/Cold Winter	2010
DGJ32/J71-2014: Design Standard of Thermo-Environment & Energy Conservation for Residential Buildings in Jiangsu Province 江苏省居住建筑热环境和节能设计标准 (JPDHURD, 2014)	Hot Summer/Cold Winter zone: If thermal inertia $D \geq 3$ (buildings with fewer than 6 stories): 0.5 If thermal inertia $D \geq 2.5$ (buildings with 6 or more stories) 0.6	None	Hot Summer/Cold Winter, and Cold.	2014
DBJ52/49-2008: Design Standard for	If in Temperate zone or Hot Summer/ Warm Winter zone:	None, but light colors are recommended for roofs and walls.	Hot Summer/Cold Winter ,	2008

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
Energy Efficiency of residential buildings of Guizhou (Revision version) 贵州居住建筑节能设计标准（修订版） (GPDHURD, 2008)	1 If in Hot Summer/Cold Winter zone: 0.7		Hot Summer/Warm Winter , Temperate	
DB42/T559—2013: Design Standard for Energy Efficiency of Residential Buildings in Hubei 湖北省低能耗居住建筑设计标准 (HPDHURD, 2013)	If thermal inertia $D \geq 3.0$ (buildings with above 4 floors): 0.5 If thermal inertia $D \geq 3.0$ (buildings with below 3 floors): 0.4	When solar absorptance $\rho > 0.70$, maximum allowed thermal transmittance value of light-colored external wall or roof is multiplied by 0.9. Vegetative roof is assigned a solar absorptance value of 0.86. The standard includes a table of solar reflectance values for each type of building material.	Hot Summer/Cold Winter	2013
DB33/1015-2015: Design standard for energy efficiency of residential buildings in Zhejiang (Final review version) 浙江省居住建筑节能设计标准 (报批稿) (ZPDHURD, 2015)	For thermal inertia $D \leq 2.5$: If shape factor $S \leq 0.40$: 0.6 Else: 0.5 For thermal inertia $2.5 < D \leq 3.0$:	None, but roofs and walls are recommended to adopt light colored roofs.	Hot Summer/Cold Winter	2015

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
	If shape factor $S \leq 0.40$: 0.7 Else: 0.6 For thermal inertia $D > 3.0$: If shape factor $S \leq 0.40$: 0.8 Else: 0.7			
DB33/1038-2007: Design standard for energy efficiency of public buildings 浙江省公共建筑节能设计标准 (ZPDHURD, 2007)	Type A: 0.5 Type B: 0.7 Type C: 1.0	None, but walls are recommended to use light colors. Vegetative roofs are recommended for flat roofs.	Hot Summer/Cold Winter	2007
DBJ/T45-001-2013: Design standard for energy efficiency of residential buildings in Guangxi Zhuang	Hot Summer/Warm Winter zone: For thermal inertia $D \geq 2.5$: 0.9	Solar reflective surfaces are recommended. Vegetative roofs are recommended. Roof with solar absorptance $\rho < 0.6$ is assigned additional thermal resistance	Hot Summer/Warm Winter , Hot Summer/Cold Winter	2013

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
Autonomous Region 广西壮族自治区居住建筑节能设计标准 (BQTSGZAR, 2013a)	Else: 0.4 Hot Summer/Cold Winter zone: For shape factor $S \leq 0.4$: If thermal inertia $D \leq 2.5$: 0.8 Else: 1.0 For shape factor $S > 0.4$: If thermal inertia $D \leq 2.5$: 0.5 Else: 0.6	($m^2 \cdot K/W$): 0.20 if $\rho < 0.4$ 0.15 if $0.4 \leq \rho \leq 0.6$ Pollution correction factor for solar absorptance: $\theta = 11.384\ \rho^{-0.6241}$ $\rho' = \theta \cdot \rho$ where • ρ is original solar absorptance; • ρ' is adjusted solar absorptance; • θ is pollution coefficient. Note: when $\rho < 0.5$, use this equation to calculate θ; otherwise, set θ to 1.		
DBJ45-003-2012: Design standard for energy efficiency of public buildings in Guangxi Zhuang Autonomous Region 广西壮族自治区公共	Hot Summer/Warm Winter zone: If thermal inertia $D \geq 2.5$: 0.9 Else: 0.4	Hot Summer/Warm Winter zone: Additional thermal resistance ($m^2 \cdot K/W$) assigned: If $0.45 \leq$ solar absorptance $\rho < 0.5$: 0.12	Hot Summer/Warm Winter , Hot Summer/Cold Winter	2013

Standard	**Maximum roof thermal transmittance *U* (W/m²·K)**	**Cool surface credits**	**Climate zone**	**Year**
建筑节能设计标准 (DHURDGZAR, 2012)	Hot Summer/Cold Winter zone: If thermal inertia $D \geq 2.5$: 0.7 Else: 0.4	If $0.4 \leq \rho < 0.45$: 0.14 If $\rho < 0.4$: 0.16 Hot Summer/Cold Winter zone: Additional thermal resistance ($m^2 \cdot K/W$) assigned: If $0.45 \leq \rho < 0.5$ 0.10 If $0.4 \leq \rho < 0.45$ 0.115 If $\rho < 0.4$ 0.13		
DBJ13-62-2014: Design standard for energy efficiency of residential buildings in Fujian Province 福建省居住建筑节能设计标准	Hot Summer/Cold Winter zone: If thermal inertia $D \geq 2.5$: 0.8 Hot Summer/Warm Winter zone: If thermal inertia $D \geq 2.5$:	Roof with solar absorptance $\rho < 0.6$ assigned additional thermal resistance ($m^2 \cdot K/W$): • 0.20 if $\rho < 0.4$ • 0.15 if $0.4 \leq \rho \leq 0.6$ Pollution correction factor for solar absorptance:	Hot Summer/Warm Winter, Hot Summer/Cold Winter	2014

Standard	Maximum roof thermal transmittance *U* (W/m²·K)	Cool surface credits	Climate zone	Year
(HURDF, 2014)	0.9 Else: 0.4 City of Fuzhou and Xiamen If thermal inertia $D \geq 2.5$: 0.8 Else: 0.4	$\theta = 11.384\ \rho^{-0.6241}$ $\rho' = \theta \cdot \rho$ where • ρ is original solar absorptance; • ρ' is adjusted solar absorptance; • θ is pollution coefficient. Note: when $\rho < 0.5$, use this equation to calculate θ; otherwise, set θ to 1.		
DGJ08-205-2011: Design standard for energy efficiency of residential buildings Shanghai 上海居住建筑节能设计标准 (SURDTC, 2011)	If light-weight roof (< 200 kg/m²): 0.7 If normal-weight roof (≥ 200 kg/m²): 0.8	For solar reflectance of the wall $0.80 \leq \alpha < 0.90$, Thermal transmittance U will be multiplied by: 0.90 if $U \geq 1.4$ 0.91 if $1.1 \leq U < 1.4$ 0.92 if $U < 1.1$ For solar absorptance of the wall $\alpha \geq 0.90$, Thermal transmittance U will be multiplied by:	Hot Summer/Cold Winter	2011

Standard	Maximum roof thermal transmittance U (W/m^2·K)	Cool surface credits	Climate zone	Year
		0.85 if $U \geq 1.4$ 0.86 if $1.1 \leq U < 1.4$ 0.87 if $U < 1.1$		
DGJ08-107-2012, J12068-2012: Design standard for energy efficiency in public buildings Shanghai 上海公共建筑节能设计标准 (SURDTC, 2012)	Type A: If light weight roof (< 200 kg/m^2): 0.4 If normal weight roof (≥ 200 kg/m^2): 0.5 Type B: If light weight roof (< 200 kg/m^2): 0.5 if normal weight roof (≥ 200 kg/m^2): 0.6	Vegetative roofs are recommended for flat roofs. When solar reflectance of the roof or wall is greater than 0.80, thermal transmittance U can be modified by the following equation: $U_m = \frac{U_p F_p + U_{B1} F_{B1} + U_{B2} F_{B2} + U_{B3} F_{B3}}{F_p F_{B1} F_{B2} F_{B3}} \times C_1$ where • U_m is new thermal transmittance (W/m^2·K); • U_p is original thermal transmittance (W/m^2·K), calculated according to GB 50176-93: Civil Thermal Design Specification of the Chinese National Standard; • F_p is area of the main wall/roof (m^2); • C_1 is correction factor for solar reflectance; • U_{B1}, U_{B2}, U_{B3} is thermal transmittance of the thermal bridge	Hot Summer/Cold Winter	2012

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
		($W/m^2 \cdot K$) ; • F_{B1}, F_{B2}, F_{B3} is area of the thermal bridge (m^2). The correction factor C_1 is shown as follows: For solar reflectance $\alpha < 0.80$: $C_1 = 1.0$ For $0.80 \leq \alpha < 0.90$: $C_1 = 0.90$ if $U_p \geq 1.4$ $C_1 = 0.91$ if $1.1 \leq U_p < 1.4$ $C_1 = 0.92$ if $U_p < 1.1$ For $\alpha \geq 0.90$: $C_1 = 0.85$ if $U_p \geq 1.4$ $C_1 = 0.86$ if $1.1 \leq U_p < 1.4$ $C_1 = 0.87$ if $U_p < 1.1$		
DB51/5027 -2012, J10147-2012: Design Standard for Energy Efficiency of Residential Buildings in Sichuan Province 四川省居住建筑节能	Cold zone: If ≤ 3 stories: 0.30 If 4-8 stories:	If solar absorptance of the wall < 0.5, thermal inertia D of the wall will be multiplied by: 1.20 if $D > 3.0$ 1.15 if $2.0 < D \leq 3.0$ 1.05 if $D \leq 2.0$	Hot Summer/Cold Winter , Cold, Temperate	2012

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
设计标准 (SPDHURD, 2012)	0.40 If ≥ 9 stories: 0.40 Hot Summer/Cold Winter zone, Temperate zone: If thermal inertia $D \leq 2.5$: 0.8 Else: 1.0			
DB34/xxx-2010: Design Standard for Energy Efficiency of Residential Buildings in Anhui Province (Final review version) 安徽省居住建筑节能设计标准（报批稿） (APDHURD, 2010)	If light weight roof (>200 kg/m^2): If shape factor $S \leq 0.4$: 0.8 Else: 0.5 If normal weight roof: If $S \leq 0.4$: 1.0	None, but roofs and walls are recommended light colored surfaces or coating to reduce solar absorption. Vegetative roofs are recommended.	Hot Summer/Cold Winter	2010

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
	Else: 0.6			
Design Standard for Energy Efficiency of Residential Buildings in Jiangxi Province 2014 (Final review version) 江西省居住建筑节能设计标准 （报批稿） (JPDHURD, 2014)	If thermal inertia $D \leq 2.5$: If shape factor $S \leq 0.4$: 0.8 Else: 0.5 If $D > 2.5$: If $S \leq 0.4$: 1.0 Else: 0.6	None, but light colored or solar reflective coatings are recommended because they help reduce summer air-conditioning use. They can reflect solar radiation and emit heat from the buildings in the evenings. Vegetative roofs are recommended, and one can calculate equivalent heat resistance for vegetative roof according to the actual design.	Hot Summer/Cold Winter	2014

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
DBJ41/071-2012: Henan Province design standard for energy efficiency of residential buildings (Hot Summer and Cold Winter Zone) (Final review version) 河南省居住建筑节能设计标准（夏热冬冷地区）（报批稿） (HPDHURD, 2012)	If thermal inertia $D \le 2.5$, If shape factor $S \le 0.4$, 0.8 Else, 0.5 If $D > 2.5$, If $S \le 0.4$, 1.0 Else, 0.6	None, but light colored or solar reflective coatings are recommended for walls.	Hot Summer/Cold Winter	2012
DBJ41/0-xxx-2006: Henan Province design standard for energy efficiency of public buildings (Final review version from) 河南省公共建筑节能设计标准 （报批稿） (HPDHURD, 2006)	Hot Summer/Cold Winter zone: 0.7	Light colored paint or bricks for roofs and walls are recommended to reduce solar radiation absorption for exterior surface.	Hot Summer/Cold Winter , Cold	2006

Standard	Maximum roof thermal transmittance *U* ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
DBJ-2007: Guangdong Province design standard for energy efficiency of public buildings (Final review version) 广东省公共建筑节能设计标准（报批稿） (DHURDGP, 2007)	Hot Summer/Cold Winter zone: If thermal inertia $D < 2.5$: 0.4 Else: 0.7 Hot Summer/Warm Winter zone： If thermal inertia $D < 2.5$: 0.4 Else: 0.9	Walls or roof with solar absorptance < 0.6 are assigned equivalent heat resistance of 0.2 $m^2 \cdot K/W$. Vegetative roof has equivalent heat resistance of 0.5 $m^2 \cdot K/W$.	Hot Summer/Warm Winter	2007
DBJ 03-2006: Design standard for energy efficiency of public buildings in Hainan 海南省公共建筑节能设计标准 (HPDHURD, 2006)	0.9	None.	Hot Summer/Warm Winter	2006

Standard	Maximum roof thermal transmittance U ($W/m^2 \cdot K$)	Cool surface credits	Climate zone	Year
JDJ01-2005: Design Standard for Energy Efficiency of Residential Buildings in Hainan Province(2005) 海南省居住建筑节能设计标准 (HPDHURD, 2005)	If thermal inertia $D \geq 2.5$: 1.0 Else: 0.5	Thermal resistance value is increased by 0.2 for light-colored external wall or roof, 0.3 to 0.5 for roofs that include one or more of the following measures: radiant barrier; roof covered by water storage, green plants, or shades; 0.3 for east/west walls covered by plants	Hot Summer/Warm Winter	2005
DBJ 53/T-39-2011： Design Standard for Energy Efficiency of Civil Buildings in Yunnan Province(2011), 云南省居住建筑节能设计标准 (YPDHURD, 2011)	If thermal inertia $D \geq 3$: 1.8 If $2.5 \leq D < 3$: 1.5 Else: 1.2	None, but light-colored surfaces, vegetation recommended for roofs and east/west walls.	Temperate	2011

Appendix B: Cool surface credits in JGJ/T 359 – 2015 (Original Text)

5.1 General requirement

5.1.3 Polluted (or aged) SR value should reference Appendix B in JCJ/T 359-2015.

5.3 Energy Saving Design

5.3.1 When using architectural reflective thermal insulation coating on roofs or walls, one can follow performance standard to design energy efficient building.

5.3.2 When using prescriptive standard, the energy saving impact of cool surfaces should be calculated as a basis of equivalent thermal resistance. One should follow formula (1) to calculate new thermal transmittance:

$$U' = \left[\frac{1}{R_{\mathrm{eq}} + \frac{1}{U}} \right] \qquad (1)$$

where,

- *U*' is new thermal transmittance of surfaces that applied architectural reflective thermal insulation coating;
- *U* is thermal transmittance of surfaces without architectural reflective thermal insulation coating; and
- R_{eq} is equivalent thermal resistance of walls or roofs that use architectural reflective thermal insulation coating ($m^2 \cdot K/W$).

Appendix C: Calculation of solar reflectance with pollution factor in JGJ/T 359 –2015 (Original Text)

When calculating solar reflectance corrected with pollution factor, the Equation B.0.1-1, B.0.1-2, and B.0.1-3 should be used.

$$\rho_c = \rho \cdot m \qquad \text{Eq B.0.1-1}$$

$$\rho_c = 1 - \alpha \qquad \text{Eq B.0.1-2}$$

$$m = 11.384 \cdot (\rho \cdot 100)^{-0.6241} \qquad \text{Eq B.0.1-3}$$

where,

- ρ_c is solar absorptance corrected with pollution factor;
- α is original solar reflectance;
- ρ is original solar absorptance;
- m is pollution correction factor

Solar absorptance corrected with pollution factor should follow the equation (B.0.2).

$$\rho_c = 1 - \alpha_c \qquad \text{Eq B.0.2}$$

Note: α_c is solar reflectance corrected with pollution factor should be determined following clause 3.0.1, which references standard JG/T 235-2014: Architectural reflective thermal insulation coating (MOHURD, 2014a).

Appendix D: Equivalent thermal resistance for applying solar reflective heat insulation materials in JGJ/T 359 – 2015 (Original Text)

Equivalent thermal resistance for reflective walls

C.0.1. In Hot Summer/Warm Winter zone and Hot Summer/Cold Winter zone, one should follow Table C.0.1 for equivalent thermal resistance value for walls that use reflective thermal insulation materials.

Table C.0.1. Equivalent thermal resistance of Hot Summer/Warm Winter zone and Hot Summer/Cold Winter zone for applying solar reflective coating on walls. U is thermal transmittance of the wall without solar reflective thermal insulation coating. Units: W/m^2·K.

Solar absorptance corrected with pollution factor			$\rho_c \leqslant 0.3$	$0.3 < \rho_c \leqslant 0.4$	$0.4 < \rho_c \leqslant 0.5$	$0.5 < \rho_c \leqslant 0.6$
Hot Summer/Cold Winter zone (north region)	Equivalent thermal resistance R_{eq} (m^2·K/W)	$1.2 < U \leq 1.5$	0.19	0.16	0.12	0.07
		$1.0 < U \leq 1.2$	0.24	0.20	0.15	0.09
		$0.7 < U \leq 1.0$	0.28	0.23	0.18	0.11
		$U \leq 0.7$	0.40	0.34	0.25	0.16
Hot Summer/Warm Winter zone (north region)	Equivalent thermal resistance R_{eq} (m^2·K/W)	$2.0 < U \leq 2.5$	0.17	0.13	0.07	0.04
		$1.5 < U \leq 2.0$	0.21	0.17	0.09	0.06
		$U \leq 1.5$	0.29	0.22	0.12	0.07
		$U \leq 0.7$	0.61	0.48	0.25	0.16
Hot Summer/ Warm Winter zone (south region)	Equivalent thermal resistance R_{eq} (m^2·K/W)	$2.0 < U \leq 2.5$	0.27	0.17	0.10	0.04
		$1.5 < U \leq 2.0$	0.33	0.21	0.13	0.06
		$U \leq 1.5$	0.44	0.29	0.17	0.07
		$U \leq 0.7$	0.95	0.61	0.36	0.16

Equivalent thermal resistance for reflective roofs

In Hot Summer/Warm Winter zone and Hot Summer/Cold Winter zone, one should follow table C.0.2 for equivalent thermal resistance value for walls that use reflective thermal insulation materials.

Table C.0.2. Equivalent thermal resistance of Hot Summer/Warm Winter zone and Hot Summer/Cold Winter zone for applying solar reflective coating on roofs. U is thermal transmittance of the roof without solar reflective thermal insulation coating. Units: $W/m^2 \cdot K$.

Solar absorptance corrected with pollution factor			$\boldsymbol{\rho_c \leqslant 0.3}$	$\boldsymbol{0.3 < \rho_c \leqslant 0.4}$	$\boldsymbol{0.4 < \rho_c \leqslant 0.5}$	$\boldsymbol{0.5 < \rho_c \leqslant 0.6}$
Hot Summer/Cold Winter zone (north region)	Equivalent thermal resistance R_{eq} ($m^2 \cdot K/W$)	$0.8 < U \leq 1.0$	0.43	0.33	0.25	0.18
		$0.6 < U \leq 0.8$	0.54	0.42	0.31	0.22
		$0.4 < U \leq 0.6$	0.71	0.56	0.42	0.29
		$U \leq 0.4$	1.07	0.83	0.63	0.44
Hot Summer/Warm Winter zone (north region)	Equivalent thermal resistance R_{eq} ($m^2 \cdot K/W$)	$0.8 < U \leq 1.0$	0.67	0.43	0.25	0.18
		$0.6 < U \leq 0.8$	0.83	0.54	0.31	0.22
		$0.4 < U \leq 0.6$	1.11	0.71	0.42	0.29
		$U \leq 0.4$	1.67	1.07	0.63	0.44
Hot Summer/Warm Winter zone (south region)	Equivalent thermal resistance R_{eq} ($m^2 \cdot K/W$)	$0.8 < U \leq 1.0$	1.00	0.67	0.43	0.18
		$0.6 < U \leq 0.8$	1.25	0.83	0.54	0.22
		$0.4 < U \leq 0.6$	1.67	1.11	0.71	0.29
		$U \leq 0.4$	2.50	1.67	1.07	0.44