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# Status of cool roof standards in the United States

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ABSTRACT

Since 1999, several widely used building energy efficiency standards, including ASHRAE 90.1, ASHRAE 90.2, the International Energy Conservation Code, and California's Title 24 have adopted cool roof credits or requirements. We review the technical development of cool roof provisions in the ASHRAE 90.1, ASHRAE 90.2, and California Title 24 standards, and discuss the treatment of cool roofs in other standards and energy-efficiency programs. The techniques used to develop the ASHRAE and Title 24 cool roof provisions can be used as models to address cool roofs in building energy standards worldwide.

## 1. INTRODUCTION

Roofs that have high solar reflectance (high ability to reflect sunlight) and high thermal emittance (high ability to radiate heat) stay cool in the sun. The same is true of low-emittance roofs with exceptionally high solar reflectance. Roofs that stay cool in the sun are referred to as "cool roofs."

Low roof temperatures lessen the flow of heat from the roof into the building, reducing the need for electricity for space cooling in conditioned buildings. Since building heat gain through the roof peaks in mid-to-late afternoon, when summer electricity use is highest, cool roofs can also reduce peak electricity demand. Energy savings are greatest for buildings located in climates with long cooling and short heating seasons, particularly those buildings that have distribution ducts in the plenum (Akbari 1998; Akbari et al. 1999; Konopacki and Akbari 1998).

Cool roofs transfer less heat to the outdoor environment than do warm roofs (Taha 2001). The resulting lower outside air temperatures can slow urban smog formation and improve human health and outdoor comfort. Reduced thermal stress may also increase the lifetime of cool roofs, lessening maintenance and waste (Akbari et al. 2001).

Many studies have measured daily air-conditioning energy savings and peak power demand reduction from the use of cool roofs on nonresidential buildings in several warm-weather climates, including California, Florida, and Texas. Cool roofs typically yielded measured summertime daily air-conditioning savings and peak demand reductions of 10% to 30%, though values have been as low as 2% and as high as 40% (Konopacki et al. 1998). For example, Konopacki et al. (1998) measured summer daily air-conditioning savings of 67, 39, and 4 $Wh/m^2$ (18, 13, and 2%) for three California nonresidential building. Hildebrandt et al. (1998) measured summer daily air-conditioning savings of 23, 44, and 25 $Wh/m^2$ (17, 26, and 39%) in an office, a museum, and a hospice in Sacramento, CA. Konopacki and Akbari (2001) estimated summer daily cooling average energy savings of 39 $Wh/m^2$ (11%) and peak power reduction of 3.8 $W/m^2$ (14%) in a large retail store in Austin, TX. Parker et al. (1998) measured summer daily energy savings of 44 $Wh/m^2$ (25%) and a peak power reduction of 6.0 $W/m^2$ (30%) for a school building in Florida. Parker et al. (1997) measured summer daily energy savings of 81 $Wh/m^2$ (25%) and peak power reduction of 6.4 $W/m^2$ (29%) in seven retail stores within a Florida strip mall.

Building energy efficiency standards typically specify both mandatory and prescriptive requirements. Mandatory requirements, such as practices for proper installation of insulation, must be implemented in all buildings covered by the standard. A prescriptive requirement typically specifies the characteristics or performance of a single component of the building (e.g. the thermal resistance of duct insulation) or of a group of components (e.g., the thermal transmittance of a roof assembly).

All buildings regulated by a particular standard must achieve either prescriptive or performance compliance. A proposed building that meets all applicable mandatory and prescriptive requirements will be in prescriptive compliance with the standard. Alternatively, a proposed building can achieve performance compliance with standard if (a) it satisfies all applicable mandatory requirements and (b) its annual energy use does not exceed that of comparable design (a.k.a. standard design) building that achieves prescriptive compliance.

Prescribing the use of cool roofs in building energy efficiency standards promotes the cost-effective use of cool roofs to save energy, reduce peak power demand, and improve air quality. Another option is to credit, rather than prescribe, the use of cool roofs. This can allow more flexibility in building design, permitting the use of less energy-efficient components (e.g., larger windows) in a building that has energy-saving cool roofs. Such credits are energy neutral, but may still reduce peak power demand and improve air quality. They may also reduce the first cost of the building.

This paper reviews the technical steps in developing the cool roof provisions in the ASHRAE 90.1, ASHRAE 90.2, and California Title 24 building energy efficiency standards, and discusses the treatment of cool roofs in several other standards and energy-efficiency programs.

## 2. DEVELOPMENT OF STANDARDS

### *2.1 ASHRAE Standard 90.1*

Recognizing the potential for cool roofs to reduce the conditioning energy use of commercial buildings, the ASHRAE Standard 90.1 committee organized a task force in 1997 to analyze the energy-saving benefits of cool roofs in different climates, and to propose modifications to the standard to account for the effect of roof solar reflectance (Akbari et al. 1998).

A cool roof reduces the flow of heat from the roof into the building's conditioned space. This can decrease the need for cooling energy in summer, and increase heating-energy use in winter. The winter heating-energy penalty is usually smaller than the summer cooling-energy savings, because in winter the sun is low, the days are short, the skies are often cloudy, and most heating occurs either in early morning hours or early evening hours. Roof insulation also impedes the flow of heat between the roof and the conditioned space, slowing both heating of the building when the roof is warmer than the inside air and cooling of the building when the roof is cooler than the inside air. One can develop an energy-neutral tradeoff between the roof's solar reflectance and the thermal resistance of its insulation.

ASHRAE Standard 90.1 permits both prescriptive and performance ("energy cost budget") compliance. ASHRAE Standard 90.1-1999 includes two forms of credits for a cool roof, defined as one with a minimum initial solar reflectance of 0.70 and a minimum thermal emittance of 0.75. For performance compliance, a cool roof on a proposed building is assigned a solar absorptance of 0.55 (solar reflectance of 0.45). (We believe this may be a typographical error, because the analysis used to develop this standard assigned to a cool roof an aged solar absorptance of 0.45 [aged solar reflectance of 0.55]). A noncool roof on a proposed building and the roof on the design building are each assigned a solar absorptance of 0.70 (solar reflectance of 0.30).

For prescriptive compliance, ASHRAE Standard 90.1-1999 increases the maximum acceptable thermal transmittance of a roof assembly under a cool roof surface. This has the effect of reducing the required thermal resistance of insulation beneath a cool roof. The standard includes the following adjustment to the thermal transmittance of the roof assembly with a cool surface:

$$U_{\text{roof adj}} = U_{\text{roof proposed}} \times F, \qquad (1)$$

where $U_{\text{roof adj}}$ is the adjusted roof thermal transmittance for use in demonstrating compliance; $U_{\text{roof proposed}}$ is the thermal transmittance of the proposed roof, as designed; and $F$ is the roof thermal transmittance multiplier from Table 1.

ASHRAE Standard 90.1-2001 (ASHRAE 2001) retains the same provisions for cool roof credits. The current version of this standard, ASHRAE Standard 90.1-2004 (ASHRAE 2004a) tabulates thermal transmittance multipliers by U.S. climate zones (see Table 2).

Table 1. Roof thermal transmittance (U-factor) multipliers for cool roofs (Table 5.3.1.1B of ASHRAE 90.1-1999).

| HDD65[a] | (HDD18)[b] | Roof U-Factor Multiplier |
|---|---|---|
| 0-900 | (0-500) | 0.77 |
| 901-1800 | (501-1000) | 0.83 |
| 1801-2700 | (1001-1500) | 0.85 |
| 2799-3600 | (1501-2000) | 0.86 |
| > 3600 | (>2000) | 1.00 |

a. Heating-Degree-Days based on 65ºF
b. Heating-Degree-Days based on 18ºC

Table 2. Roof thermal transmittance (U-factor) multipliers for cool roofs (Table 5.5.3.1 of ASHRAE 90.1-2004).

| Climate Zone | Roof U-Factor Multiplier |
|---|---|
| 1 | 0.77 |
| 2 | 0.83 |
| 3 | 0.85 |
| 4 - 8 | 1 |

### *2.2 ASHRAE Standard 90.2*

The procedure for incorporating the effect of roof solar reflectance in the ASHRAE Standard 90.2 residential standards was similar to that followed for ASHRAE Standard 90.1 (Akbari et al. 2000). ASHRAE Standard 90.2-2004 permits both prescriptive and performance ("energy cost budget") compliance. The standard includes two form of credits for cool roofs, defined as a roof with either (a) a minimum initial solar reflectance of 0.65 and a minimum thermal emittance of 0.75, or (b) a solar reflectance index (SRI) of at least 75 calculated in accordance with ASTM Standard E1980 under medium wind speed conditions (ASTM 1998). SRI is defined to be 0 for a clean black roof (solar reflectance 0.05, thermal emittance 0.90) and 100 for a clean white roof (solar reflectance 0.80, thermal emittance 0.90); thus, warm surfaces have low SRI, and cool surfaces have high SRI. For performance compliance, a cool roof on a proposed building is assigned its actual solar absorptance, or possibly a solar absorptance of 0.35; the standard's language is ambiguous. A noncool roof on a proposed building and the roof on the design building are each assigned a solar absorptance of 0.20 (solar reflectance of 0.80). However, the authors believe the latter to be a typographical error; the logical value would be a solar absorptance of 0.80 (solar reflectance of 0.20).

For prescriptive compliance, ASHRAE Standard 90.2-2004 increases the maximum acceptable thermal transmittance of the ceiling under a cool roof surface. (The authors believe that ceiling may actually mean roof assembly.) This has the effect of reducing the required thermal resistance of insulation beneath a cool roof. The standard includes the following adjustment to the thermal transmittance of the ceiling under a cool roof:

$$U_{\text{ceiling adj}} = U_{\text{ceiling proposed}} \times F, \qquad (2)$$

where $U_{\text{ceiling adj}}$ is the adjusted ceiling thermal transmittance for use in demonstrating compliance; $U_{\text{ceiling proposed}}$ is the thermal transmittance of the proposed ceiling, as designed; and $F$ is the ceiling thermal transmittance multiplier from Table 3.

Table 3. Ceiling thermal transmittance (U-factor) multiplier for cool roofs (Table 5.5 of ASHRAE 90.2-2004).

| Zone | Ceilings with Attics | Ceilings without Attics |
|---|---|---|
| 1 | 1.50 | 1.30 |
| 2 | 1.25 | 1.30 |
| 3 | 1.20 | 1.20 |
| 4 | 1.15 | 1.20 |
| 5 | 1.10 | 1.10 |
| 6,7,8 | 1.00 | 1.00 |

The current version of this standard, ASHRAE Standard 90.2-2007 (ASHRAE 2007), retains the same cool roof credits for compliance performance. However, the cool roof credits for prescriptive compliance have been modified. Rather than specify ceiling thermal transmittance multipliers, the new standard prescribes reduced thermal resistances in climate zones 1 – 3 for ceilings under cool roofs (Table 4).

Table 4. Ceiling thermal resistances [$ft^2$ h F $BTU^{-1}$] prescribed by ASHRAE Standard 90.2-2007 for ceilings with attics under conventional (noncool) and cool residential roofs, derived from Tables 5.2 and 5.6.1 of ASHRAE Standard 90.2-2007 (ASHRAE 2007).

| | ceilings with attics | | | |
|---|---|---|---|---|
| | wood frame | | steel frame | |
| climate zone | conventional roof | cool roof | conventional roof | cool roof |
| 1 | 30 | 20 | 30 | 20 |
| 2 | 30 | 24 | 30 | 24 |
| 3 | 30 | 27 | 30 | 27 |
| 4 | 38 | 38 | 38 | 38 |
| 5 | 43 | 43 | 43 | 43 |
| 6 | 49 | 49 | 49 | 49 |
| 7 | 49 | 49 | 49 | 49 |
| 8 | 52 | 52 | 52 | 52 |

### *2.3 California Title 24 standards*

In 2001, cool roof credits were added to California's Title 24 Building Energy Efficiency Standards for Residential and Nonresidential Buildings. The Title 24 Standards were upgraded in 2005 to prescriptively require cool roofs on nonresidential buildings with low-sloped roofs. The California Energy Commission is currently (2007) considering adding prescriptive cool roof requirements for all other buildings to the 2008 Standards.

In January 2001, the state of California followed the approach of ASHRAE Standards 90.1 and 90.2 by adding cool roof credits to Title 24 (CEC 2001). Roofs are considered cool if they have an initial solar reflectance not less than 0.70 and a thermal emittance not less than 0.75. An exception lowers this minimum initial solar reflectance requirement to 0.40 for tile roofs. Cool roofs were not incorporated in the prescriptive standards. For performance compliance, a cool roof on a proposed building was assigned a solar absorptance of 0.45 (solar reflectance of 0.55). The roof of a standard (design) building was assigned a solar absorptance of 0.70 (solar reflectance of 0.30), as was the roof of a proposed building with a noncool roof.

**Low-sloped roofs on non-residential buildings.** In 2002, the Berkeley Lab Heat Island Group began to investigate the possible prescriptive requirement in Title 24 of cool roofs for nonresidential buildings with low-sloped roof. The analysis approach was similar to that used to develop ASHRAE Standards 90.1 and 90.2. Steps included reviewing the physics of the cool roofs; reviewing measurements of cool-roof energy savings reported in the literature; investigating the market availability of cool roofs; surveying cost premiums (if any) for cool roofs; reviewing roofing material durability; investigating environmental consequences of cool roofs; and; performing hourly simulations of building energy use to estimate the energy and peak demand savings potentials of cool roofs (Levinson et al. 2005).

A cool roof was defined as a roof with either (a) an initial thermal emittance not less than 0.75 and an initial solar reflectance not less than 0.70, or (b) an initial thermal emittance ($\varepsilon_{\text{initial}}$) less than 0.75 and an initial solar reflectance not less than $0.70 + 0.34 \times (0.75 - \varepsilon_{\text{initial}})$. The second term in this expression is the solar-reflectance premium required to ensure that the aged (soiled) temperature of a low-emittance roof under ASTM E1980 medium wind speed conditions will not exceed that of an aged (soiled) high-emittance cool roof.

DOE-2.1E building energy simulations performed in California's 16 climate zones indicated that the use of a cool roof on a prototypical California Title 24 nonresidential building with a low-sloped roof yielded average annual cooling energy savings of 3.2 kWh/m$^2$, average annual natural gas deficits of 5.6 MJ/m$^2$, average source energy savings of 30 MJ/m$^2$, and average peak power demand savings of 2.1 W/m$^2$. Total savings—initial cost savings from downsizing cooling equipment plus the 15-year net present value (NPV) of energy savings with time dependent valuation (TDV)—ranged from 1.90 to 8.30 \$/m$^2$.

The typical cost premium for a cool low-sloped roof is 0.00 to 2.20 \$/m$^2$. Cool roofs with premiums up to \$2.20/m$^2$ are expected to be cost effective in California Climate Zones 2 through 16; those with premiums not exceeding \$1.90/m$^2$ are expected to be also cost effective in climate zone 1. Therefore, the year-2005 Title 24 standard for nonresidential buildings with low-sloped roofs adopted a cool-roof prescriptive requirement in all California climate zones. Nonresidential buildings with low-sloped roofs that do not meet this new prescriptive requirement may still achieve performance compliance.

In 2005, we began to investigate the merits of adding to the 2008 Title 24 standards prescriptive requirements for the use of cool roof of all other types of buildings, including nonresidential buildings with steep-sloped roofs, residential buildings with steep-sloped roofs, and residential buildings with low-sloped roofs. The methodology was similar to that used to consider the prescriptive requirement in the 2005 standards of cool low-sloped roofs for nonresidential buildings. In these 2008-cycle analyses, MICROPAS was used to simulate the hourly energy use of prototypical residential and small nonresidential buildings (Akbari et al. 2006; Wray et al. 2006).

**Proposed steep-sloped roofs on non-residential buildings.** We simulated the energy use of a prototypical building with conventional and cool versions of three different steep-sloped roofs: fiberglass asphalt shingle, concrete tile, and polymer-coated metal. Each conventional product had a solar reflectance of 0.10. The cool shingle had solar reflectance of 0.25, while the cool tile and cool metal products had solar reflectances of 0.40. All products were assigned a thermal emittance of 0.90.

Total savings—initial cost savings from downsizing cooling equipment plus the 30-year NPV of TDV energy savings—ranged from 2.5 to 10.3 \$/m$^2$ across California's 16 climate zones. The typical cost premium for a cool steep-sloped roof is 0.00 to 2.20 \$/m$^2$. Cool roofs with premiums up to \$2.20/m$^2$ are expected to be cost effective in all 16 climate zones. At the time of writing this manuscript, California is considering the inclusion in its year-2008 Title 24 code of a prescriptive cool-roof requirement for nonresidential buildings with steep-sloped roofs in all climate zones.

**Proposed low-sloped roofs on residential buildings.** We simulated the energy use of a residential prototype building with conventional ($\rho$=0.10) and cool ($\rho$=0.55) versions of a low-sloped (horizontal) built-up roof. While the 2005 Title 24 Standard for residential buildings prescriptively requires a sub-roof radiant barrier in some climate zones (2, 4, and 8 - 15), radiant barriers are not usually installed in pre-2000 houses with low-sloped roofs. Without a radiant barrier, total savings—initial cost savings from downsizing cooling equipment plus the 30-year NPV of TDV energy savings—ranged from -1.3 to 10.9 $/m^2$ across California's 16 climate zones. With a radiant barrier, the NPV TDV savings range from -2.5 to 3.0 $/m^2$. The negative savings occur in coastal California climate zones with minimal summertime cooling requirements. Also, the presence of a roof radiant barrier reduces cool roof energy savings, just as the presence of a cool roof reduces radiant-barrier energy savings.

The typical cost premium for a cool roof is 0.00 to 2.20 $/m^2$. Cool roofs with premiums up to $2.20/m^2$ are expected to be cost effective in some climates zones. At the time of writing this manuscript, California is considering the inclusion in its year-2008 Title 24 code of a prescriptive cool-roof requirement for residential buildings with low-sloped roofs in hot Central Valley climates.

**Proposed steep-sloped roofs on residential buildings.** We simulated energy use of a residential prototype building with conventional and cool versions of three different steep-sloped roofs: fiberglass asphalt shingle, concrete tile, and polymer-coated metal. Each conventional product had a solar reflectance of 0.10. The cool shingle had a solar reflectance of 0.25, while the cool tile and cool metal products had solar reflectances of 0.40. All products were assigned a thermal emittance of 0.90.

The 2005 Title 24 Standard for residential buildings prescriptively requires a sub-roof radiant barrier in some climate zones, but they are not present in most existing houses built before 2000. Without a radiant barrier, total savings—initial cost savings from downsizing cooling equipment plus the 30-year NPV of TDV energy savings—ranged from -1.7 to 14.8 $/m^2$ across California's 16 climate zones. For steep-sloped roof houses with radiant barriers, the NPV TDV savings range from -1.3 to 8.8 $/m^2$. Cool shingles induced smaller savings (and penalties) than did cool tiles and cool metal products because the solar reflectance of the cool shingle was only 0.15, rather than 0.30, higher than that of the conventional shingle. The negative savings occur in coastal California climate zones with minimal summertime cooling requirements. Also, the presence of a roof radiant barrier reduces cool roof energy savings, just as the presence of a cool roof reduces radiant-barrier energy savings.

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## 3. COOL ROOF PROVISIONS IN OTHER STANDARDS AND PROGRAMS

Many U.S. states have adopted building codes from ASHRAE Standard 90.1 or the International Energy Conservation Code (IECC). Other U.S. cities, states and territories have developed custom provisions for cool roofs in their energy codes. Aside from California, these include Atlanta, GA; Chicago, IL; Florida; Georgia; Guam; and Hawaii. Cool roof requirements have also been developed by several voluntary energy-efficiency programs, including the U.S. Environmental Protection Agency (EPA) Energy Star™ label, the Leadership in Energy and Environmental Design (LEED) Green Building Rating System, and the cool roof rebate programs offered by the state of California and its utilities. Cool roof provisions in these standards and programs through the year 2003 are reviewed by Eley Associates (2003).

### *3.1 Energy standards adopted by U.S. states*

The adoption as of May 2007 of IECC and/or ASHRAE standards by individual U.S. states is detailed in Figure 1 (commercial building codes) and Figure 2 (residential building codes).

The 2003 IECC does not explicitly address the use of cool roofs. However, a provision allows commercial buildings to comply with the 2003 IECC by satisfying the requirements of ASHRAE Standard 90.1, which in turn offers cool roof credits. There are neither direct nor indirect cool roof credits for residential buildings (IECC 2003).

The 2006 IECC retains the link to ASHRAE Standard 90.1 for commercial buildings, and explicitly offers cool roof credits for residential buildings through performance compliance. IECC Table 404.5.2(1) assigns to the roof on the standard reference design residential building a solar absorptance of 0.75 (solar reflectance of 0.25) and a thermal emittance of 0.90, while the roof on the proposed design building is assigned its proposed values of solar absorptance and thermal emittance (IECC 2006).

### *3.2 U.S. EPA Energy Star™ label*

To qualify for its Energy Star™ label, the U.S. EPA currently requires that low-sloped roofing products (ratio of rise to run 2:12 or less) have initial and three-year-aged solar reflectances not less than 0.65 and 0.50, respectively. Steep-sloped roofing products (ratio of rise to run greater than 2:12) must have initial and three-year-aged solar reflectances not less than 0.25 and 0.15, respectively (EPA 2007).

### *3.3 LEED Green Building Rating System*

LEED Green Building Rating System assigns one rating point for the use of a cool roof in credit 7.2. The current version of LEED (2.2) uses SRI to qualify a non-vegetated cool roof (GBC 2005). LEED Version 2.2 requires a cool roof to either (a) cover at least 75% of its surface with products that a minimum SRI of 78 (low-sloped roofs) or 29 (steep-sloped roofs); (b) have at least 50% of its surface covered by vegetation; or (c) use a combination of high-SRI materials and vegetation that satisfy a particular formula.

## 5. CONCLUSIONS

Since the late 1990s, the quantification of energy savings offered by the use of cool roofs has led both ASHRAE and the state of California to add cool roof credits and/or requirements to their energy efficiency standards for both residential and nonresidential buildings. Many U.S. states have adopted cool roof credits from ASHRAE Standard 90.1 (1999 or later), IECC 2003, or IECC 2006. Several U.S. cities and states other than California have developed and added custom cool roof provisions to their energy standards. Voluntary energy-efficiency programs, such as the U.S. EPA Energy Star label, the LEED Green Building Rating System, and rebate programs offered by California and its utilities, have established qualifications for cool roofs.

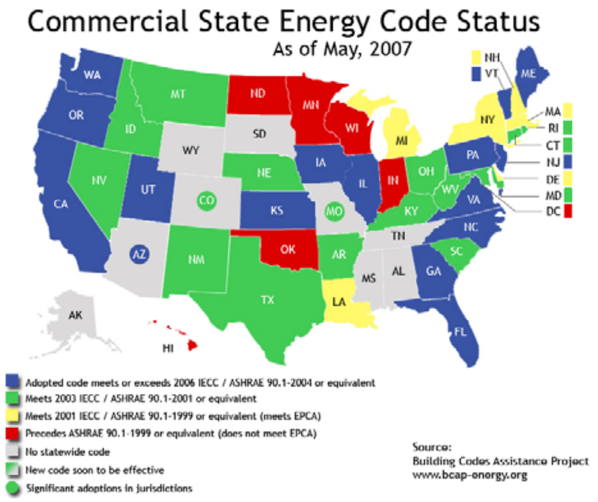


Figure 1. Adoption of commercial building energy codes by U.S. states as of May 2007. Courtesy Building Codes Assistance Project (BCAP 2007).

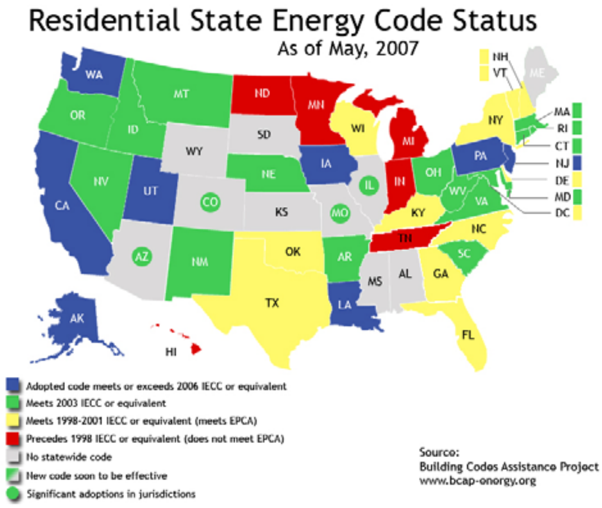


Figure 2. Adoption of residential building energy codes by U.S. states as of May 2007. Courtesy Building Codes Assistance Project (BCAP 2007)

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