CODE CHANGE PROPOSAL

2008 Title 24 Building Energy Efficiency Standards Update

# *Inclusion of Solar Reflectance and Thermal Emittance Prescriptive Requirements for Steep-Sloped Nonresidential Roofs in Title 24*

(Revised May 18, 2006)

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# Overview

## Description

The current (2005) Title-24 standards prescribe minimum values of solar reflectance and thermal emittance for low-sloped roofs (i.e., roofs with a ratio of rise to run not exceeding 2:12) on nonresidential buildings. This report proposes adding prescriptive requirements for the solar reflectance and thermal emittance of roofs to California's Title-24 standards for nonresidential buildings with steep-sloped roofs (i.e., roofs with a ratio of rise to run exceeding 2:12). We also propose the specification of three-year-aged, rather than initial, values of solar reflectance and thermal emittance for nonresidential buildings with steep-sloped roofs and nonresidential buildings with low-sloped roofs.

The proposed measure advocates minimum requirements for the solar reflectance and thermal emittance of roofs to reduce cooling energy usage and peak electrical power demand in air-conditioned buildings regulated by Title 24. Such buildings include but are not limited to small offices, small retail stores, health care facilities, schools, and universities. Attachment 1 lists building and occupancy types covered by the existing and the proposed standards. Prior research has indicated that savings per unit floor area are greatest for buildings located in climates with long cooling seasons and short heating seasons, particularly those buildings that have distribution ducts in the attic and/or low rates of attic ventilation (Akbari et al., 2005; Akbari and Konopacki 2005; Akbari *et al.*, 1999; Konopacki and Akbari, 1998).

## Benefits

Many existing roofing products (e.g., dark-colored fiberglass asphalt shingles) have low solar reflectance (ability to reflect sunlight) and high thermal emittance (ability to radiate heat). Increasing the solar reflectance of a roof without reducing its thermal emittance lowers its surface temperature in the sun.[1] This proposal advocates the prescription of minimum requirements for

[1] A measure that decreases thermal emittance while increasing solar reflectance (e.g., substitution of a bare metal surface for a non-metallic surface) may or may not reduce the surface temperature of the roof. Virtually all roofing products with nonmetallic surfaces (including painted metals) have high thermal emittance (about 0.80 to 0.90). Under standard summer afternoon conditions (Levinson et al. 2005a), variations in thermal emittance within that range have little effect on roof temperature. For example, decreasing thermal emittance to 0.80 from 0.85 increases the temperature of a roof with solar reflectance 0.55 by about 0.5K. However, a bare metal roofing product can exhibit very a low thermal emittance (about

the solar reflectance and thermal emittance of roofs to reduce their daytime surface temperatures.[2]

Reducing roof temperature decreases heat flow from the roof into the building, which in turn reduces cooling power demand in an air-conditioned building. Because roof temperatures peak in the afternoon, when summer electricity use is highest, reducing roof temperature can also lower peak electricity demand.

Reducing roof temperature decreases the amount of heat transferred to the outdoor air. This would result in lower air temperatures that can slow urban smog formation and increase human health and outdoor comfort. Reducing roof temperature may also increase roof lifetime by reducing thermal stress, lessening maintenance and waste.

## Environmental Impact

Lowering roof temperature is expected to have both positive and negative environmental impacts. Benefits include increased human comfort, slowed smog formation, and mitigation of urban heat islands in summer. Waste from disposal of roofs would also decrease. Penalties include slightly higher wintertime heating energy use and degraded wintertime urban air quality because of higher heating energy use.

### *Environmental Benefits*

Reducing roof temperature decreases the amount of heat transferred to the outdoor air. This would result in lower air temperatures that can slow urban smog formation and increase human comfort both outdoors and in unconditioned buildings. On a clear summer afternoon, the air temperature in

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0.05 to 0.30) that can significantly increase roof temperature if used to replace a high-emittance product. For example, decreasing thermal emittance to 0.20 from 0.85 increases the temperature of a roof with solar reflectance 0.55 by about 11K.

[2] To maintain an equal temperature under the sun, a surface with low thermal emittance requires a higher solar reflectance than does a surface with high thermal emittance. Under standard summer afternoon conditions, a 4 point (0.04) decrease in thermal emittance has about the same effect on the temperature of a weathered white roof (aged solar reflectance 0.55, aged thermal emittance 0.85) as a 1 point (0.01) decrease in solar reflectance (Levinson et al. 2005a). Hence, we propose a higher minimum aged solar reflectance for surfaces with low aged thermal emittance (less than 0.75) than for surfaces with high aged thermal emittance (not less than 0.75).

a typical North American urbanized area can be about 2 to 9 °F hotter than that in the surrounding rural area. The additional air-conditioning use induced by this urban air temperature elevation is responsible for 5 to 10% of urban peak electric demand, at a direct cost of several billion dollars annually in the U.S. At the community scale, increasing the solar reflectance of roofs can effectively and inexpensively mitigate an urban heat island (Akbari *et al.,* 2001).

Air temperature also has a significant influence on the formation of urban smog. Measurements and computer simulations of the effect of temperature on Los Angeles smog formation show that a significant reduction in ozone concentration is achieved by lowering the ambient temperature. The simulations predict a reduction in population-weighted smog (ozone) of 10 to 20% resulting from a 3 to 4 °F cooling in ambient temperature. Decreases in roof temperature contribute about one-third of this reduction. For some scenarios, a 10 to 20% reduction in ozone is comparable to that obtained by replacing all gasoline on-road motor vehicles with electric cars (Rosenfeld *et al.,* 1995).

It is also important to note that reduced peak air conditioning load reduces power plant emissions at exactly the time when pollutants of all kinds have the most deleterious impact. This effect—reduced peak power plant emissions–happens independently of the urban heat island phenomenon. Hence, reducing the surface temperature of roofs offers the following three air quality benefits:

- it reduces heat flow from the roof into a conditioned building, decreasing daily and peak air conditioning energy use and power plant emissions;
- it decreases ambient air temperature, reducing daily and peak air conditioning energy use and power plant emissions by decreasing the temperature difference across the building envelope; and
- it reduces ambient air temperature, slowing the temperature-dependent formation of smog.

Lowering roof temperature may also increase roof lifetime by reducing thermal stress. Thus, if applied in the course of either new construction or regularly scheduled roof replacement (i.e., once every 10 to 25 years), measures that reduce roof surface temperature would reduce waste and the need for landfill.

### *Environmental Penalties*

Reducing roof temperature tends to increase consumption of building heating energy. Of particular concern is the potential to increase gas-furnace emissions into local air districts where winter air pollution may be problematic. That is, if a building is cooled with remotely generated electric power, and heated with locally burned natural gas, lowering roof temperature may increase annual local emissions even while reducing annual energy consumption.

There are no requirements by the EPA or the Cool Roof Rating Council (CRRC) to wash roofs. Some manufacturers will void the warranty of a roof if the roof is washed (Miller 2005).

## Type of Change

### *Existing Title 24 Code*

California's Title 24 Energy Code, "Building Energy Efficiency Standards for Residential and Non-Residential Buildings," defines a cool roof as a "roofing material with high thermal emittance and high solar reflectance, or low thermal emittance and exceptionally high solar reflectance as specified in Section 118 (i) that reduces heat gain through the roof." Title 24 specifies rules for certification and labeling of roofing product solar reflectance and thermal emittance. The 2005 Title 24 Code includes cool roofs in the prescriptive requirements for non-residential building envelopes with low-sloped roofs.

In the nonresidential-building overall envelope approach, the roof's solar reflectance is factored into the building heat gain equation via specification of roof solar absorptance. (For an opaque surface like that of a roof, absorptance = 1 – reflectance.) The solar absorptance of a low-sloped nonresidential cool roof is set to 0.45 (solar reflectance 0.55), while that of a low-sloped nonresidential standard roof is fixed at 0.70 (solar reflectance 0.30).

The Residential and Nonresidential Alternative Calculation Method (ACM) Approval Manual for performance-based compliance also assigns reduced solar absorptance (increased solar reflectance) to cool roofs. The prescribed aged cool roof absorptance is 0.45 (reflectance 0.55), while the standard roof absorptance is 0.70 (reflectance 0.30)] for low-sloped nonresidential buildings. For the steep-sloped nonresidential buildings, the proposed cool roof absorptance is also 0.45 (reflectance 0.55), while the default (when there is no CRRC label) roof absorptance is 0.90 (reflectance 0.10). Section 118(f) of the Standards sets reflectance and emittance requirements for cool roofs. Clay tiles and concrete tiles must have a minimum initial solar reflectance of 0.40

and a minimum thermal emittance of 0.75 to be considered cool, while all other cool roofing products are required to have a minimum initial solar reflectance of 0.70 and a minimum thermal emittance of 0.75.

### *Code Change Proposal*

In this report, we propose the prescription of minimum values of the solar reflectance and the thermal emittance of roofs in the 2008 California Title 24 Code for both nonresidential buildings with low-sloped roofs and nonresidential buildings with steep-sloped roofs. The proposed measures will promote the use of cool roofs with increased solar reflectance to reduce cooling energy usage and peak electrical power demand in air-conditioned (cooled) buildings regulated by Title 24. Such buildings include but are not limited to small offices, small retail stores, health care facilities, schools, and universities (see Attachment 1). In a parallel study, we also propose the prescription of minimum values of solar reflectance and thermal emittance of roofs in the 2008 California Title 24 code for residential buildings with steep-sloped roofs and residential buildings with low-sloped roofs.

The proposed change adds a prescriptive requirement that establishes a minimum thermal emittance and minimum aged solar reflectance[3] for roof materials in each of California's 16 climate zones (Figure 1).

For nonresidential buildings with steep-sloped roofs, we propose that

- any roofing product with a three-year-aged thermal emittance not less than 0.75 shall have a minimum three-year-aged minimum solar reflectance that varies by roofing material: 0.25 for fiberglass asphalt shingle, and 0.40 for all other roofing products, including but not limited to concrete tile, clay tile, and coated metal; and
- any roofing product with a three-year aged thermal emittance $\varepsilon_{aged}$ less than 0.75 shall have a minimum 3-year aged solar reflectance of $0.40 + 0.31 * (0.75 - \varepsilon_{aged})$.

For nonresidential buildings with low-sloped roofs, we propose that

[3] To stay cool, a surface with low thermal emittance requires a higher solar reflectance than does a surface with high thermal emittance. Hence, the minimum aged solar reflectance for cool roof is thermal-emittance dependent.

- any roofing product with a three-year-aged thermal emittance not less than 0.75 shall have a minimum three-year-aged minimum solar reflectance of 0.55; and
- any roofing product with a three-year aged thermal emittance $\varepsilon_{aged}$ less than 0.75 shall have a minimum 3-year aged solar reflectance of 0.55 + 0.24* (0.75 - $\varepsilon_{aged}$).

Roofing products are described in Table 2.

Three-year-aged values of solar reflectance and thermal emittance are determined as follows.

1. If the product's three-year-aged values of solar reflectance and thermal emittance have been certified and labeled by the Cool Roof Rating Council (CRRC), these CRRC-certified and labeled three-year-aged values must be used.
2. If the CRRC has certified and labeled the product's initial values of solar reflectance and thermal emittance, but has not certified and labeled the product's three-year-aged values of solar reflectance and thermal emittance, the product's three-year-aged solar reflectance $\rho_{aged}$ and three-year-aged thermal emittance $\varepsilon_{aged}$ are estimated from its CRRC-certified and labeled values of initial solar reflectance $\rho_{initial}$ and initial thermal emittance $\varepsilon_{initial}$ using the following two formulas:
$$\rho_{aged} = 0.2 + 0.7 * (\rho_{initial} - 0.2)$$
$$\varepsilon_{aged} = \varepsilon_{initial}$$
3. If neither three-year-aged nor initial values of the product's solar reflectance and thermal emittance have been certified and labeled by the CRRC, the product will be assigned a default three-year-aged solar reflectance of 0.10 and a default three-year-aged thermal emittance of 0.75.

Requirements for three-year-aged thermal emittance and three-year-aged solar reflectance are based on an estimated life-cycle cost (LCC) analysis for roofs on nonresidential buildings.[4]

[4] Our simulations for determination of cost effectiveness assume that both the higher- and lower-reflectance prototype roofs have high thermal emittance (a three-year-aged thermal emittance of 0.85). In those climate zones for which we propose minimum three-year-aged values of solar reflectance and thermal emittance, we suggest requiring a minimum three-year-aged thermal emittance of 0.75, rather than 0.85. We do so because (a) roofing materials usually have either a high thermal emittance (0.80 – 0.90) or a low thermal emittance (0.05 – 0.30); (b) there is an uncertainty of about ±0.05 when measuring thermal emittance; and (c) we wish to avoid disqualification-by-measurement-error of products with high thermal emittance.

Requirements are considered cost effective if the life-cycle time-dependent-valuation (TDV) savings were at least $0.20/ft$^2$ (the maximum expected cost premium for materials meeting the requirements.)

Since definite LCC savings were found in all climate zones (even with low-emittance foil-skrim-kraft-faced insulation at the underside of the roof), the same minimum thermal emittance and aged solar reflectance would be required for all of these climate zones. By establishing these prescriptive values, performance approach calculations would result in compliance credits or penalties, depending on the product performance rating relative to the prescriptive requirement.

The proposed change modifies both compliance options, as described below. Revisions will be necessary to the Standards, Nonresidential Manual, Nonresidential ACM, and compliance forms to reflect the changes.

**Prescriptive Compliance.** Adopt requirements in all climate zones for the minimum three-year-aged values of solar reflectance and thermal emittance of steep-sloped roofs on nonresidential buildings. This would expand the list of prescriptive envelope requirements, since the 2005 revisions to Title 24 do not include such requirements in the prescriptive compliance approach for steep-sloped nonresidential roofs.

**Performance Compliance.** The 2001 revisions allow the inclusion of cool roofs as a compliance option for credit. The 2005 revisions do not address cool roof requirements for steep-sloped roofs in nonresidential buildings. The proposed 2008 revisions will use newly established prescriptive requirements for steep-sloped roofs on nonresidential buildings and the newly created attic model (Niles et al. 2006) to determine the energy budget for performance compliance calculations, resulting in potential compliance credits or penalties that depend on the product performance rating relative to the prescriptive requirement. Our analysis methodology and assumptions are described later in this report (“Methodology” section, p.18).

**Overall Envelope Approach.** TO BE UPDATED.

# Technology Measures

## *Measure Availability and Cost*

### Technologies

The daytime surface temperature of a roof is raised by absorption of solar radiation and lowered by thermal radiation to the sky. Solar heating is proportional to solar absorptance (absorptance = 1 – reflectance), while radiative cooling is proportional to thermal emittance. Hence, other factors (e.g., incident solar radiation, convective cooling, and conductive cooling) being equal, a roof with high solar reflectance and high thermal emittance can stay cooler than a roof with a low solar reflectance and/or low thermal emittance.

Virtually all construction materials except bare, shiny metals have high thermal emittance. [5] Since 95% of solar radiation arrives at the earth's surface in the visible and near-infrared (NIR) spectra,[6] a roof with a non-metallic surface and high visible and/or NIR reflectance will be cool. Light-colored surfaces are cool because they have high visible reflectance, high NIR reflectance, and high thermal emittance. Dark-colored surfaces colored with conventional (NIR-absorbing) pigments are warm because they have low visible reflectance and low NIR reflectance. A surface with a dark-colored "cool" coating system[7] has low visible reflectance and high NIR reflectance, and is described as a cool color surface. It is cooler than a conventionally pigmented dark-colored surface but warmer than a light-colored surface. Shiny metals typically have high visible and NIR reflectances, but low thermal emittances, and thus stay warmer than a non-metallic surface of comparable solar reflectance. However, a low-emittance surface can stay as cool as a high-emittance surface if the low-emittance surface has a higher solar reflectance. For brevity, the terms

[5] Non-metallic construction materials typically have thermal emittances in the range of 0.80 to 0.95. A bare, shiny metal (e.g., aluminum foil) may have an emittance as low as 0.03, while a roof coating formed with metal flakes may have an intermediate emittance (around 0.5).

[6] 43% of the energy in the standard air-mass 1.5 solar spectrum (300-2,500 nm) lies in the visible range (400-700 nm). Another 52% is in the near-infrared range (700-2,500 nm), and 5% is in the ultraviolet range (300-400 nm).

[7] The top layer in a dark-colored cool coating system is colored with pigments that have high visible absorptance, low NIR absorptance, and possibly strong NIR backscattering (ability to reverse the direction of light). If the topcoat has weak NIR backscattering, it must be applied over a basecoat with high NIR reflectance (e.g., a white coating), or over a substrate with high NIR reflectance (e.g., zincalume steel, clay tile).

reflectance (ρ), absorptance (α), and emittance (ε) will be used hereafter to denote solar reflectance, solar absorptance, and thermal emittance, respectively.

Products that are installed on steep-sloped roofs typically include asphalt shingles, concrete tiles, clay tiles, fiber-cement tiles, slate, wood shakes/shingles, architectural metal panels, and individual metal roof components. Products that are typically installed on low-sloped surfaces include single-ply membranes, built-up-roofs (BUR), modified bitumen, spray polyurethane foam, roof coatings, and standing-seam profiled metal. Some products that are typically installed on low-sloped roofs may also be installed on steep-sloped roofs (e.g., single-ply membranes and roof coatings) (EPA, 2006).

As Table 1 shows, there are warmer and cooler options available for nearly all roofing products. Steep-sloped and low-sloped roofing technologies are described in Table 2.

Market

Table 2 lists data from the National Roofing Contractors Association (NRCA 2003) that characterize roofing material shares of the combined residential and commercial 2002 markets in the Pacific region states (California, Oregon, and Washington). For steep-sloped roofs, which accounted for about 50% of sales dollars in these three states, sales were dominated by asphalt shingle (44% new construction, 55% reroofing), tile (21% new construction, 13% reroofing), and metal (18% new construction, 12% reroofing) products. For low-sloped roofs, sales were dominated by single-ply membrane (43% new construction, 34% reroofing), modified bitumen (20% new construction, 24% reroofing), and BUR (17% new construction, 21% reroofing) products.

*Western Roofing Insulation and Siding* magazine projected that the total roof construction sales in 2005 was $6.7 billion for non-residential buildings in the 14-state western U.S. market (Western Roofing 2006). California roof sales accounted for 37% ($1.7 billion) of the 14-state combined nonresidential new construction and reroofing markets (personal communication with M. Dodson, 2005)[8]. Three classes of roofing materials—built-up roofing (BUR, 28%), modified bitumen (31%), and single-ply membrane (24%) — collectively accounted for 83% of sales dollars in the western

[8] Product shares in the western-region roofing market are not necessarily representative of those in California.

U.S. non-residential building market[9]. Metal (5%), shingles (3%), liquid applied coatings (3%), polyurethane foam (2%), and other materials made up the remainder. Tile roofs were only 0.2% of the market. These data, together with the NRCA data, suggest that the majority of non-residential roofs are low-sloped, but some are steep-sloped.

Using the steep-slope market share sales data reported by the NRCA, and the relative median material costs listed in Table 1, we estimate that the dominant steep-sloped roof materials based on roof *area* fractions of annual new roof construction and reroofing are: asphalt shingles (56% of new construction, 66% of reroofing), metal (11% of new construction, 6% of reroofing), and tile (9% of new construction, 5% of reroofing) – totals of 80% and 83% respectively for new roofs and reroofing. Similarly for the remaining approximately 20% of steep-sloped roof area, we estimate that the dominant materials are liquid applied coatings (11% of new construction, 2% of reroofing), BUR (4% of new construction, 4% of reroofing), and modified bitumen (3% of new construction, 4% of reroofing). These last three products are typically used only on roofs with slopes not exceeding 3:12.

The Energy Information Agency's Commercial Buildings Energy Consumption Survey (EIA 2003) reported that of the 64.8 billion $ft^2$ of floor area in U.S. commercial buildings, 40% was contained in one-story buildings, 25% was contained in two-story buildings, and the remaining 35% was contained in buildings of three or more stories. The total roofing area was estimated to be 38.7 billion $ft^2$. The California Energy Commission (CEC) reported that the total floor area of the state's commercial building stock was 6.2 billion $ft^2$ in 2005, and is expected to grow by 118 million $ft^2$ each year (CEC 2005). One- and two-story buildings account for about three quarters of the total commercial building floor area. Based on these data, we estimate that the ratio of overall roofing area to floor area is approximately 0.66 and that the total roofing area in California's commercial buildings in 2005 was approximately 4.1 billion $ft^2$, with an annual addition of 78 million $ft^2$ of new roofing in new construction.

F.W. Dodge (2003) data indicate that the Pacific region states accounted for 460 million $ft^2$ of new roofing and 1.77 billion $ft^2$ of reroofing. The total roofing area was 2.2 billion $ft^2$, which was about 13% of the total U.S. new and reroofing area in 2003. The ratio of reroofing area to new roofing area was therefore about 3.85 for the Pacific region. Applying this ratio to the California non-

[9] The 14 western states included in this market are Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming.

residential building market, we estimate that the annual re-roofing area of commercial buildings in California would be about 3.85*78 = 300 million $ft^2$. The total area of new roofing and reroofing in California's commercial building would therefore be 378 million $ft^2$ in 2005.

Based upon the survey results of roof sales markets by NRCA and *Western Roofing Insulation and Siding Magazine*, we estimate that for California's commercial buildings, the steep-sloped roof areas accounted for about 20% of the new and reroofing area. If we assume that 90% of the steep-sloped roof area would ordinarily be built with a non-cool roof, then the total area of steep-sloped roofs to which cool roof materials could be applied is 70 million $ft^2$ (14 million $ft^2$ new and 56 $ft^2$ million reroofed).

Manufacturers

There are over 200 companies manufacturing roofing products in the United States. Most manufacturers specialize by type of roofing material. However, firms that manufacture asphalt-based roofing products, such as asphalt shingles, built-up roofing, and/or modified bitumen, may offer all three. Companies that specialize in asphalt-based roofing have the largest sales volumes. Table 3 lists major roofing manufacturers and their primary products.

Distribution

Roofing manufacturers sell most of their roofing products through distributors. The distributors generally contact the manufacturers to obtain materials, although some manufacturers also use representatives to sell products.

Though more profitable for the manufacturer, factory-direct sales make up a smaller portion of the roofing market than does distribution, and are usually used only for large-quantity purchases. Manufacturers distribute most of their products through local outlets such as independent wholesale distributors and company-owned distribution centers.

From the distributor, there are three main channels to the end-user: lumber yards (45 to 50% of sales), direct sales to large contractors or home builders (40%), and retail establishments such as home improvement centers and hardware stores (10 to 15%) (Freedonia Group 1997).

Availability

The EPA EnergyStar® roof program lists approximately 180 Roof Product Partners in the U.S. on its web site (EPA 2006). The EPA program allows manufacturers to self-certify their products' performance criteria and does not include a minimum emittance requirement for eligible roofing products.

According to the EPA program, steep-sloped roofs must have an initial solar reflectance that is at least 0.25. Three years after installation under normal conditions, the solar reflectance must be at least 0.15. Low-sloped roofs must have an initial solar reflectance that is at least 0.65. After 3 years, the solar reflectance must be at least 0.50. Each company's roof product warranty for reflective roof products must be equal in all material respects to the product warranty offered by the *same company* for comparable non-reflective roof membrane products. A company that sells *only* reflective roof products must offer a warranty that is equal in all material respects to the standard *industry* warranty for comparable non-reflective roof products.

The Cool Roof Rating Council has rated the initial solar reflectance and initial thermal emittance of about 680 roofing products as of May 2006 (CRRC 2006).

"Cool" products for low-sloped roofs (primarily white single-ply membranes and white elastomeric coatings) are widely available and have been used to meet the 2005 Title 24 prescriptive requirements for minimum levels of solar reflectance and thermal emittance of a low-sloped roof on a nonresidential building.

The "cool" products market for steep-sloped roofs is very young. However, cool color technologies have been demonstrated for clay tile, concrete tile coating, metal, and fiberglass asphalt shingle products, and are commercially available from a limited number of manufacturers (Akbari et al. 2006). We expect that adoption of prescriptive requirements for the solar reflectance and thermal emittance of steep-sloped roofing materials will stimulate wider production.

Cost

Products that meet the aforementioned requirements for three-year-aged solar reflectance (0.55 for low-sloped roofs, 0.25 for fiberglass asphalt shingle steep-sloped roofs, and 0.40 for all other steep-sloped roofs) and three-year-aged thermal emittance (0.75 for all roofs, with allowance made for products that have exceptionally high solar reflectance) are available for most types of low- and steep-sloped roofing. We propose the use of roofs that meet these requirements for new construction and for reroofing in those climate zones for which they are cost effective. In estimating cost effectiveness, we consider only the incremental initial cost of changing the reflectance of the roof from a low value to a high value. Additional expenditure might be required if a building owner wished to maintain the roof's reflectance at its initial, rather than three-year-aged, value. That additional cost has not been factored into the LCC analysis because the simulated energy savings are based on three-year-aged reflectances that assume no additional maintenance.

Material and labor costs for roofing projects vary from one contractor to another. Table 4 lists estimates of incremental combined costs obtained from interviews of manufacturers, contractors, owners, and specifiers.

### *Useful Life and Persistence*

Table 5 lists life expectancies for various roof materials. For steep-slope materials, the life expectancies are 15 to 30 years for shingle roofs, 20 to 50 years for metal roofs, and 50 years for tile roofs. The wide ranges occur because life expectancy depends on material quality, installation procedures, and climate.

Roof reflectance may change over time from aging, weathering, and soiling.  In a recent study, Cheng and Miller et al (2006) report the effects of exposure on the solar reflectances of steep-sloped roofing products—coated metal, glazed clay tile, and coated concrete tile samples— at seven sites in California. The fractional reduction in solar reflectance was about 6% over 2.5 years of exposure, and solar reflectance stabilized after about 2 years. The effect of roof slope appears to have more of an effect on lighter color roofs whose solar reflectance exceeds 0.50 and that exhibit visible contamination. However, precipitation and or wind sweeping helps restore most of the initial solar reflectance. The thermal emittance remained invariant with time and location and was therefore not affected by climatic soiling.

A study monitoring the effects of aging and weathering on 10 low-sloped roofs in California found that the reflectance of cool materials with an initial value of 0.70 can decrease by as much as 0.15, mostly within the first year of service (Bretz and Akbari 1997). Another study at LBNL has found similar reflectance degradations for an assortment of single-ply membrane low-sloped roofs sited around the United States (Akbari et al. 2005a; Levinson et al. 2005b). Once the membranes were cleaned, their reflectances approached those of fresh roofing materials.

ASHRAE Standard 90.1 (non-residential buildings, section 5.3.1.1) assigns credits to "cool" roofs with a minimum reflectance of 0.70 (ASHRAE, 2001) (no distinction is made between the steep-sloped and low-sloped nonresidential roofs). However, the credits are calculated based on an aged reflectance of 0.55 (Akbari *et al.*, 1998c). Like the ASHRAE calculations, the 2005 Title 24 code assigns a degraded reflectance of 0.55 to a cool low-sloped roof on a nonresidential building. The 2005 Title 24 code does not address cool roof requirements for steep-sloped roofs on nonresidential buildings.

Lowering roof temperature reduces the thermal stress that results from diurnal temperature change. This is commonly believed to extend product life (Berdahl et al. 2006). However, potential product-lifetime increases have not been factored into cost-effectiveness calculations because long-term studies of this effect are not available.

## Performance Verification

The three-year-aged or initial values of solar reflectance and thermal emittance are to be certified and labeled by the CRRC. There are no additional performance verification or commissioning activities required to ensure proper installation and performance of roof products.

## Cost Effectiveness

Cost effectiveness can be estimated by quantifying three parameters: net present value (NPV) with time dependent valuation (TDV) of net energy savings (annual decrease in space-cooling-related electricity consumption minus annual increase in space-heating-related gas consumption), first cost savings from downsizing cooling equipment (generally applicable to new construction only), and the cost premium for a cool roof. Three other parameters can yield benefits, but are excluded in this determination of cost-effectiveness: expenditure decrease from participation in a load curtailment program, expenditure decrease from participation in a reflective-roof rebate program, and savings in material and labor costs from extended life of roofing materials.

We simulated buildings with steep-sloped roofs that used lower- and higher-reflectance versions of fiberglass asphalt shingle, concrete tile, and metal products. The lower-reflectance products typify conventional dark roofs, while the higher-reflectance versions typify “cooler” versions of these roofs that meet the proposed requirements for three-year-aged values of solar reflectance and thermal emittance.

All lower-reflectance products were assigned a three-year-aged solar reflectance of 0.10. Higher-reflectance asphalt shingles were assigned a three-year-aged solar reflectance of 0.25, while higher-reflectance concrete tile and metal products were assigned a three-year-aged solar reflectance of 0.40. All products were assigned a three-year-aged thermal emittance of 0.85.[10]

Based on our simulations of lower- and higher-reflectance shingle, tile, and metal steep-sloped non-residential roofs on a Title-24 prototypical new building (results shown in Figures 2 through 5), we estimate that substituting a higher-reflectance roof for a lower-reflectance roof yields energy savings (30-year NPV with TDV) ranging from \$0.21 to 2.18/$ft^2$ of roof area (average \$1.05/$ft^2$) with time dependent valuation (TDV).

Total savings exceeded \$0.20/$ft^2$ of roof area for all materials in climate zones 1 through 16 (even with low-emittance foil-skrim-kraft-faced insulation at the underside of the roof). Since the typical cost premium for a higher-reflectance roof is \$0.20/$ft^2$ or less, higher-reflectance roofs are expected to be cost effective in all climate zones for air-conditioned nonresidential buildings with steep-sloped roofs in all climate zones. On a building without air-conditioning, increasing the solar reflectance of a roof will not save cooling energy use and may actually increase heating energy use (see Figure 2); the annual heating penalty varies with climate zone and ranges from 1.2 to 13.1 therms/1000 $ft^2$ of roof area, which is worth \$0.02 to \$0.26/$ft^2$ with time dependent valuation.

## Analysis Tool

The building energy simulation program MICROPAS (Enercomp 2005) was the primary analysis tool used to quantify energy savings and peak demand. The version of MICROPAS that we used was 7.24p, which includes a major improvement in energy calculation algorithms. MICROPAS can now model the complex convective and radiant heat transfer processes that are characteristic of attics containing ducts (Niles 2006). MICROPAS has other merits: it is based on known and published heat transfer algorithms; just prior to the addition of the attic model, it was certified as an alternative calculation method for use in 2005 Title 24 residential performance-based compliance analyses; and it has since been validated for many test cases, lending confidence to its use.

DOE-2.1E, which is the primary non-residential compliance tool, was not used because its radiation exchange algorithms use a constant, combined convection and radiation coefficient to couple the surface temperature to that of the zone air, which makes its estimation of the effect of cool roofs on building energy use too low, particularly for buildings with an attic. It also does not account for

[10] The thermal emittance of a nonmetallic roof surface (including a painted metal) is typically in the range of 0.80 to 0.90.

duct radiation heat transfer, which can be significant when ducts are located in the attic. In a study of school buildings in Sacramento, DOE-2.1E simulations of energy and peak power savings were 37% and 57% below measured values (Akbari, 1993).

## Relationship to Other Measures

Reducing roof temperature can permit downsizing of cooling and air-handling equipment.

- Reducing roof temperature could reduce the peak building cooling load by 0.1 to 0.6 W/ft$^2$ of roof area, depending on building type, roof insulation, and climate zone. Hence, the cooling unit can potentially be downsized.
- A building's air-handling unit (AHU) is typically designed to accommodate the summer peak cooling load. A lower summer peak cooling load can reduce the size of the AHU and save electricity. The smaller AHU can also operate more efficiently and use less electricity during the heating season.

Reducing roof temperature may also permit downsizing of roof and ceiling insulation[11].

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This study was directed by Hashem Akbari of LBNL, with assistance from Craig Wray, Tengfang Xu, and Ronnen Levinson of LBNL.

[11] Reducing roof temperature can also reduce the need for roof and ceiling insulation for an energy neutral case. When a building is cooled, the energy savings yielded by reducing roof temperature are inversely proportional to the level of insulation. At the current prescriptive requirements, total building energy use is reduced by reducing roof temperature, and this installation is cost effective (Akbari et al. 1998).

# Methodology

## Overview

The cost effectiveness of minimum requirements for the solar reflectance and thermal emittance of roofs was estimated by comparing the cost premiums and cost savings associated with substituting roofing products of higher solar reflectance for roofing products of lower solar reflectance. Premiums were based on interviews of manufacturers, contractors, owners, and specifiers, while savings were estimated using building energy simulations. The MICROPAS building energy model was used to estimate the effects of cool roofs on space cooling and heating energy use by a prototypical Title-24 compliant non-residential building for each of California's 16 climate zones. Finally, the simulated savings (normalized per 1000 ft$^2$ of cool roof area) were combined with projections of annual new roof and reroofing area additions to predict statewide savings.

## Simulated Building Energy Savings

For each of the 192 variations of the prototypical building that we simulated (16 climate zones, three roofing materials, two solar reflectances, two roof insulation types), MICROPAS estimated annual source and 30-year TDV-weighted space cooling electricity use and space heating natural gas use, as well as peak power demand for space cooling.

The prototype building is a non-directional one-story office building with a conditioned floor area of 2,000 ft$^2$ and a steep-sloped hip roof with a slope of 5:12. Building envelope, interior mass, thermostat setpoint, occupancy, internal gain, and water heating characteristics are consistent with the Title 24 Nonresidential Building Standards Alternative Calculation Method Approval Manual. This prototype is derived from the one used in previous analyses of lay-in insulation changes proposed for the Title 24 Standards (PG&E 2003).

Space conditioning is provided by a SEER 13 split-system air-conditioner and a 78% AFUE natural gas furnace. This space conditioning system is attached to "sealed" supply and return air ducts that are located in the attic (4% leakage for each of the supply and return duct sections). The ducts have R-4.2 insulation as prescribed by the Standards. A setback thermostat is specified with cooling setpoints of 73°F for hours 6 through 18 and 77°F for hours 1 through 5 and 19 through 24[12], and

[12] Hour 1 begins at midnight and ends at 1:00 am.

heating setpoints of 70°F for hours 8 through 18, 65°F for hours 6, 7 and 19; and 60° F for hours 1 through 5 and 20 through 24.

The building envelope has a specific leakage area (SLA) of 4.9, which is derived from Title 24 specifications for similarly-constructed residences that have not been tested using a blower door. The building has continuous, balanced mechanical ventilation as required by Title 24. The 195 cfm flow is based on the ventilation requirement of 15 cfm per person, 20 occupants for a 2,000 $ft^2$ office building, and the maximum occupancy fraction in the Title 24 occupancy office schedule (65%). The ventilation fan power is 0.24 W/cfm, assuming that it is similar to an air-handler operating at low-speed in heating mode.

Floor and ceiling areas are identical. The floor is slab-on-grade construction, and is fully covered with carpet. The slab in climate zone 16 has R-7 exterior edge insulation. The ceiling (attic floor) is an uninsulated, suspended acoustic-tile T-bar type. The specified thermal conductance of the ceiling includes an additional conductance of 0.005 Btu/(h-$ft^2$-°F) to account for leaky ceiling tiles, as specified in Joint Appendix IV of Title 24. The 9 foot high walls are stucco exterior, gypsum-board interior, wood-frame construction with cavity insulation. Wall insulation levels are R-11 in climate zones 2 through 13, and R-13 elsewhere. Windows are evenly distributed on all four faces of the building (20% WWR).

The amount of interior mass is derived from Section 2.3.1.5 of the Title 24 Non-Residential ACM, which indicates that furniture and equipment should be modeled as "heavy"[13] furniture that covers 85% of the floor area. Assuming that the specific heat capacity ($C_p$) of the mass is 0.3 Btu/(lb-°F), then the heat capacity per unit floor area is 20 x 0.85 x 0.3 = 5.1 Btu/($ft^2$-°F).

The attic is unvented and is insulated using fiberglass batts at the underside of the roof deck. Insulation levels are R-11 in climate zones 6 through 9 and R-19 elsewhere. For every climate zone, two insulation types were simulated: "unfaced" and "FSK-faced"[14], with an emittance on the side facing into the attic of 0.9 and 0.05 respectively.

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[13] The 2005 ACM states that the interior mass of furniture and equipment should be modeled in DOE-2 as "heavy" furniture and suggests that this mass is 80 lb per SQUARE foot. Section 2.3.4.1 of the DOE-2 Engineers Manual (LBL 1982), however, states that "heavy" furniture is 80 lb per CUBIC foot and 20 lb per SQUARE foot, and has a specific heat capacity ($C_p$) of 0.3 Btu/(lb-°F). We used 20 lb/$ft^2$ in our analyses.

[14] FSK is foil-skrim-kraft, which has a low-emittance surface that serves as a radiant barrier. Note that we are not simulating vapor barriers per se, but rather are exploring the effect of a radiant barrier on the energy savings achieved by increasing roof solar reflectance. Radiant barriers are not required in the 2005 T24 building code for non-residential buildings with steep-slope roofs.

Three different roofing materials were simulated: fiberglass asphalt shingles, concrete tiles, and standing-seam metal panels. We expect that the thermal performance of a building with a clay tile roof is similar to that of a building with a concrete tile roof. The properties of the roof assemblies were as follows:

***Asphalt Shingle Roof***

Overlapping asphalt shingles are installed (nominally two layers thick) directly over one layer of No. 15 asphalt-saturated roofing felt, all over nominal 1/2" plywood.

The shingle characteristics are based on an average derived from data for two commercially available products (shingles A and B), which have dimensions of 13-1/4" x 39-3/8". The manufacturer's installation manual calls for a 5-5/8" exposure. Our measurements of a product sample indicate that the shingles are about 0.10 in thick (shingle A) and 0.12 in thick (shingle B), which means that the average installed thickness of the overlapped shingle "layer" is about 0.26 in. Our measurements also indicate that a bundle weighs about 64 lb and we counted 22 shingles (shingle A) and 16 shingles (shingle B) in each bundle, which equates to about 3 and 4 bundles respectively installed per roofing square (100 $ft^2$). The dimensions and weight suggest a shingle density of about 95 $lb/ft^3$ (shingle A) and 112 $lb/ft^3$ (shingle B), which is greater than the 2005 ASHRAE Handbook of Fundamentals value for asphalt shingles (70 $lb/ft^3$), and suggest an installed weight per square of about 190 lb (shingle A) and 260 lb (shingle B). The installed weight per square is consistent with information listed on a GAF Master Elite Contractor's website (VRI 2006). The 2005 Title 24 Joint Appendix IV and 2005 ASHRAE Handbook of Fundamentals list the thermal resistance and specific heat ($C_p$) of shingles (presumably for the entire layer of installed shingles) as R-0.44 and 0.30 Btu/(lb-°F), respectively.

Our recent measurements of a sample a commercially available No. 15 asphalt-saturated roofing felt indicate that it is 0.03 in thick and a 432 $ft^2$ roll weighs about 53 lb. The dimensions and weight suggest a saturated felt density of about 49 $lb/ft^3$ (no density listed by ASHRAE), and an installed weight per square of about 12 lb (ignoring the 2 in overlap of adjacent sheets). The 2005 Title 24 Joint Appendix IV and 2005 ASHRAE Handbook of Fundamentals list the thermal resistance for building paper and permeable felt respectively as R-0.06. No specific heat data are listed, and likely are not important for the simulations (the saturated felt is very light compared to the shingles above and plywood below).

The nominal 1/2" thick plywood sheathing is assumed to actually be 15/32" thick (sanded thickness). The 2005 Title 24 Joint Appendix IV and 2005 ASHRAE Handbook of Fundamentals list the thermal resistance, density, and specific heat of nominal 1/2" plywood as R-0.62 (the Joint Appendix states R-0.63), 34 lb/ft$^3$, and 0.29 Btu/(lb-°F) respectively. The corresponding installed weight per square is 133 lb. We assumed that the saturated felt and plywood can be modeled as a single R-0.68, 34 lb/ft$^3$, 0.29 Btu/(lb-°F) layer.

***Concrete Tile Roof***

Overlapping, flat, lightweight concrete tiles are installed on horizontal nominal 1" x 2" wood battens (actually 3/4" x 1-1/2") over two layers of overlapped No. 30 asphalt-saturated roofing felt, all over nominal 1/2" plywood.

The tiles are based on a commercially available product, which is listed as 16-1/2" x 13" with a 1-1/4" side overlock and nailing holes 1-1/2" from the tile top. The installation manual calls for a 3" head lap. Published specifications for weight are 596 lb per square (lightweight tiles) and about 88 tiles installed per square. We assumed that the tiles are 1/2" thick (not critical because the resistance of the tiles is low compared to the rest of the roof deck resistance). The dimensions and weight suggest a tile density of about 120 lb/ft$^3$ (consistent with 2005 ASHRAE Handbook of Fundamentals values for lightweight concrete). The 2005 ASHRAE Handbook of Fundamentals lists the thermal resistance of lightweight concrete as R-0.11 to R-0.16 per inch. This means that the 1/2" tile is about R-0.08. The specific heat listed in the 2005 ASHRAE Handbook of Fundamentals for lightweight concrete is 0.20 Btu/(lb-°F).

We calculated the thermal resistance of the layer comprised of battens and the airspace between the tiles and roof deck using a parallel heat flow path method and assuming a 1/2" to 3/4" thick airspace at a 45 degree slope (averaged values for heat flow up and down cases). Thermal resistance data for the airspace and wood battens are from the 2005 ASHRAE Handbook of Fundamentals. The effective thermal resistance for the batten-airspace layer is R-0.99.

Our recent measurements of a sample of a commercially available No. 30 asphalt-saturated roofing felt indicate that it is 0.057 in thick and a 216 $ft^2$ roll weighs about 52 lb. The dimensions and weight suggest a saturated felt density of about 50 $lb/ft^3$ (no density listed by ASHRAE), and an installed weight per square of about 48 lb (24 lb per layer). The 2005 Title 24 Joint Appendix IV and 2005 ASHRAE Handbook of Fundamentals list the thermal resistance for building paper and permeable felt respectively as R-0.06. We assumed that one layer of No. 30 felt is double this value, which means two layers of No. 30 felt is about R-0.24. No specific heat data are listed, and likely are not important for the simulations.

The nominal 1/2" thick plywood sheathing characteristics are described above for the shingle roof (R-0.62). We assumed that the saturated felt and plywood can be modeled as a single R-0.86, 34 $lb/ft^3$, 0.29 Btu/(lb-°F) layer. The felt mass (48 lb/square) is not trivial compared to the plywood (133 lb/square), but probably is not important thermally other than it introduces a slight dampening and time lag in the heat transfer.

***<u>Standing-Seam Architectural Metal Roof</u>***

Non-overlapped, standing-seam architectural galvanized steel panels are installed directly over one layer of rosin-sized paper (slip sheet) and one layer of No. 30 asphalt-saturated roofing felt, all over nominal 1/2" plywood.

The metal panel thickness is based on a commercially available G-90 galvanized steel panel, which has a standard thickness of 0.025 in (24 ga, US Standard Gauge). The 2005 ASHRAE Handbook of Fundamentals lists mild steel as 489 $lb/ft^3$. We expect that the very thin layer of zinc on each side of the panel (0.9 $oz/ft^2$) probably will not change this density by more than about 10%. Together, the thickness and density suggest an installed weight per square of about 103 lb. This weight with a 10% increase for the zinc coating (total of 113 lb) is consistent with information in the 2003 NRCA Roofing and Waterproofing Manual, which lists 24 ga galvanized steel as 116 lb/square. The 2005 ASHRAE Handbook of Fundamentals lists the thermal conductivity and specific heat of mild steel as 26.2 Btu/(h-ft-°F) and 0.30 Btu/(lb-°F) respectively. The corresponding thermal resistance is R-(8 x $10^{-5}$).

One manufacturer lists red-rosin paper as 14 lb per 501 $ft^2$ roll. The 2005 ASHRAE Handbook of Fundamentals lists paper as 58 $lb/ft^3$, which together with the area and weight per roll suggest a thickness of 0.006 in. and an installed weight per square of 3 lb. The 2005 ASHRAE Handbook of Fundamentals also lists the thermal conductivity and specific heat of paper as 0.075 Btu/(h-ft-°F) and 0.32 Btu/(lb-°F) respectively. The corresponding thermal resistance is R-0.007.

No. 30 saturated felt characteristics are described above for the tile roof (only one layer though for the metal roof; R-0.12) and nominal 1/2" thick plywood sheathing characteristics are described above for the shingle roof (R-0.62). We assumed that the rosin-sized paper, felt, and plywood can be modeled as a single R-0.75, 34 lb/ft$^3$, 0.29 Btu/(lb-°F) layer.

In each case, annual energy and peak power savings were determined by simulating the building twice: once with a higher-reflectance roof ($\rho$=0.25 for shingle steep-sloped roofs, and $\rho$=0.40 for concrete tile and metal steep-sloped roofs), and once with a lower reflectance roof ($\rho$=0.10 for shingle, concrete tile, and metal steep-sloped roofs). This corresponds to a solar reflectance difference of $\Delta\rho_0$ = 0.15 for shingle roofs, and 0.30 for concrete tile and metal roofs, with unchanged thermal emittance ($\varepsilon$ =0.85 for all cases).[15] Because savings are linearly proportional to the change in roof solar reflectance (Akbari *et al.,* 1998), savings for some other solar reflectance difference $\Delta\rho_1$ can be calculated from:

$$\text{savings}_{\Delta\rho_1} = \left(\Delta\rho_1 / \Delta\rho_0\right) \times \text{savings}_{\Delta\rho_0}$$

The net present value (NPV) of savings ($/1000 ft$^2$ of roof area) was calculated in two ways: (1) with time dependent valuation (TDV); and (2) without TDV.

1. The TDV method assigns 30-year unit values of NPV to electricity ($/kWh) and natural gas ($/therm) that vary with hour of year and climate zone. These hourly multipliers are used to calculate the NPV of savings achieved in each of the 8,760 hours in a year. Summing these hourly savings yields the TDV NPV ($) (Energy and Environmental Economics 2006).

2. The non-TDV method converts annual electricity savings and annual natural gas savings to NPV $ using NPV multipliers ($2.10/kWh and $12.64/therm), which are based on 30-year

[15] The thermal emittance of a nonmetallic roofing surface (including a painted metal) is typically in the range of 0.80 to 0.90.

projections of statewide annual average electricity and gas prices. The same multipliers are used in every climate zone (Eley Associates 2002).

In our analyses, air-conditioner equipment cost savings were added to energy savings to determine total savings. To determine the "purchased" equipment savings associated with increasing roof reflectance, the estimated peak demand savings need to be converted to equipment capacity savings at rating conditions. For an air-conditioner, the energy-efficiency ratio (EER) is the equipment capacity (evaporator output, Btu/h) divided by the electrical power input (Watts) for the condensing unit and evaporator fan. For an air-conditioner with a rated EER of 10 (COP 2.9), 1 ton of evaporator output (12,000 Btu/h) corresponds to a 1.2 kW power input. At peak, higher outdoor temperatures than rating conditions can reduce the EER and capacity of the system. For example, in a hot climate like zone 15, our MICROPAS simulations indicate that the EER for the SEER 13 system that we simulated is about 6 at peak and the evaporator capacity is about 10% less than at rating conditions. This means that the evaporator output is reduced to 0.9 ton, which requires about 1.8 kW of power with an EER of 6. Conversely, a nominal 1 kW peak input power saving with an EER of 6 is a 6,000 Btu/h peak output saving, which is a 6,667 Btu/h (0.6 ton) rated capacity requirement reduction including the 10% capacity loss between rating and peak conditions.

For a split-system air-conditioner, RS Means (2006) suggests a $1,650/ton increase for a 3 to 4 ton rated capacity increase and a $550/ton increase for a 4 to 5 ton increase. Conservatively using $550/ton capacity as the rated capacity increase cost premium, an EER reduction to 6 at peak, and a capacity loss of 10% at peak, 1 kW of peak input power savings is worth: [(1 kW x 1000 W/kW) x EER 6 Btu/Wh / 0.9) x [$550/ton / 12,000 Btu/(ton-h)] = $306. Higher EERs and less capacity loss at peak would result in larger cost savings.

## Measured Building Energy Savings

Many studies have measured daily air conditioner energy savings and peak power demand reduction from increased roof solar reflectance on commercial buildings in several warm-weather climates, including California, Florida, and Texas. Daily energy savings measured after increasing roof reflectance were annualized by multiplying daily savings (kWh/day) by the number of cooling days per year. Energy and peak-demand savings were also lowered to account for reflectance reduction resulting from roof weathering. Degraded annual energy savings (kWh) and peak demand reduction (kW) were normalized per 1000 $ft^2$ of roof area for comparison with simulated results (kWh/1000 $ft^2$ and kW/1000 $ft^2$). This study uses the measured data as practical evidence that increasing roof reflectance provides energy and peak power savings, but relies solely on MICROPAS simulation results for the cost-effectiveness analysis.

## Projected Statewide Energy Savings for Nonresidential New Construction

If the annual savings (energy, demand, or $) per unit roof area in climate zone i is $S_i$, and the total floor area of nonresidential new buildings in climate zone i is $A_i$, then the statewide savings can be estimated as

$$\text{State-Wide Savings} = C \times \text{Sum of } (S_i \times A_i), \text{ for } i = 1 \text{ to } 16.$$

The savings $S_i$ are the combined estimated savings for each roof material type applied in a climate zone, with the savings for each material type (shingles, tile, and metal) weighted by the corresponding fraction of roof area that uses that material type. The coefficient C translates floor area to roof area. The material fractions and coefficient C are based on the data described earlier in the "Market" section of this report. Data that we obtained from the CEC (Gorin 2006) describe the distribution of nonresidential floor area by climate zone, and were used to estimate and define $A_i$. Dividing $A_i$ for each zone by the total floor area defines the "Roof Area Fractions" listed in Table 6.

# Results

## Simulated Building Energy Savings for New Construction

Simulated savings in each climate zone for each of the 6 scenarios (three roofing materials and two insulation types) are illustrated in Figures 2 through 6. The following summarizes those results for all of the scenarios and all 16 climate zones[16]:

[16] The minimums, maximums, and averages of TDV-weighted values summarized here represent the range of values for "individual" buildings and are not weighted based on roof area and material type distributions throughout California. Statewide saving estimates, which are described later in the report, provide weighting based on roof area and material type distributions.

- Annual space-cooling-related TDV-weighted electricity savings:

| Data: Figures 2 (a through f) | Savings (kWh/1000 ft$^2$) | | |
|---|---|---|---|
| Insulation Type | Min | Max | Average |
| Unfaced | 477 | 3,144 | 1,688 |
| FSK-Faced | 421 | 2,709 | 1,497 |

- Annual space-heating-related TDV-weighted natural gas deficits:

| Data: Figures 2 (a through f) | Savings (therm/1000 ft$^2$) | | |
|---|---|---|---|
| Insulation Type | Min | Max | Average |
| Unfaced | 1.2 | 13.1 | 5.8 |
| FSK-Faced | 1.2 | 12.1 | 5.4 |

- Annual total TDV-weighted net source energy savings:

| Data: Figures 2 (a through f) | Savings (MBtu/1000 ft$^2$) | | |
|---|---|---|---|
| Insulation Type | Min | Max | Average |
| Unfaced | 1.13 | 10.14 | 5.18 |
| FSK-Faced | 0.98 | 8.79 | 4.57 |

- Peak power demand savings:

| Data: Figures 3 (a through f) | Savings (kW/1000 ft$^2$) | | |
|---|---|---|---|
| Insulation Type | Min | Max | Average |
| Unfaced | 0.07 | 0.29 | 0.16 |
| FSK-Faced | 0.06 | 0.24 | 0.14 |

- Cooling equipment cost savings:

| Data: Figures 6 (a through f) | Savings ($equip/1000 ft$^2$) | | |
|---|---|---|---|
| Insulation Type | Min | Max | Average |
| Unfaced | 20 | 88 | 50 |
| FSK-Faced | 17 | 74 | 44 |

- Thirty-year net present value energy savings (with TDV):

| Data: Figures 4 (a through f) | Savings ($/1000 ft$^2$) | | |
|---|---|---|---|
| Insulation Type | Min | Max | Average |
| Unfaced | 243 | 2,181 | 1,113 |
| FSK-Faced | 211 | 1,890 | 982 |

- Thirty-year net present value energy savings (without TDV):

| Data: Figures 4 (a through f) | Savings ($/1000 ft$^2$) | | |
|---|---|---|---|
| Insulation Type | Min | Max | Average |
| Unfaced | 320 | 2,481 | 1,329 |
| FSK-Faced | 279 | 2,150 | 1,172 |

- Total savings (equipment cost savings + 30-year NPV energy savings, with TDV):

| Data: Figures 5 (a through f) | Savings ($/1000 ft$^2$) | | |
|---|---|---|---|
| Insulation Type | Min | Max | Average |
| Unfaced | 264 | 2,270 | 1,163 |
| FSK-Faced | 228 | 1,955 | 1,026 |

- Total savings (equipment cost savings + 30-year NPV energy savings, without TDV):

| Data: Figures 5 (a through f) | Savings ($/1000 ft$^2$) | | |
|---|---|---|---|
| Insulation Type | Min | Max | Average |
| Unfaced | 340 | 2,569 | 1,379 |
| FSK-Faced | 296 | 2,2150 | 1,216 |

The largest annual savings occurred in the south and central, mostly inland areas (climate zones 6 through 10 and 13 through 15). Slightly less than average savings occurred in the more northern, inland areas (climate zones 2, 4, 11, and 12). The smallest savings were found along the cooler north and central coast (zones 1, 3, and 5), and in the mountains (zone 16).

Source energy savings are not shown in Figures 2 through 5. To facilitate comparisons of simulated energy saving predictions with measured savings, the following summarizes the source energy savings for all of the scenarios and all 16 climate zones:

- Annual space-cooling-related source electricity savings:

| | Savings (kWh/1000 ft²) | | |
|---|---|---|---|
| **Insulation Type** | **Min** | **Max** | **Average** |
| Unfaced | 170 | 1,201 | 653 |
| FSK-Faced | 149 | 1,032 | 577 |

- Annual space-heating-related natural gas deficits:

| | Savings (therm/1000 ft²) | | |
|---|---|---|---|
| **Insulation Type** | **Min** | **Max** | **Average** |
| Unfaced | 0.7 | 7.8 | 3.4 |
| FSK-Faced | 0.7 | 7.2 | 3.2 |

- Annual total TDV-weighted source energy savings:

| | Savings (MBtu/1000 ft²) | | |
|---|---|---|---|
| **Insulation Type** | **Min** | **Max** | **Average** |
| Unfaced | 0.28 | 3.76 | 1.88 |
| FSK-Faced | 0.23 | 3.39 | 1.65 |

## Measured Building Energy Savings

Increasing the solar reflectance of nonresidential 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%. For example:

- Konopacki *et al.* (1998b) measured daily summer air conditioning savings of 6.3, 3.6, and 0.4 kWh/1000 ft² (18, 13, and 2%) for three California commercial buildings—two medical offices in Davis and Gilroy and a retail store in San Jose. Corresponding demand reductions were 0.31, 0.22, and 0.15 kW/1000 ft² (12, 8, and 9%). Estimated annualized air conditioner savings were 590, 340, and 60 kWh/1000 ft², assuming an increase in the aged solar reflectance (post-retrofit minus pre-retrofit) of about 0.35.
- Hildebrandt *et al.* (1998) measured daily air conditioner savings (annual savings / number of cooling days per year) of 2.1, 4.1, and 2.3 kWh/1000 ft² (17, 26, and 39%) in an office, a museum and a hospice in Sacramento. Estimated annualized air conditioner savings were 120, 240, and 200 kWh/1000 ft², assuming an increase in the aged solar reflectance (post-retrofit minus pre-retrofit) of about 0.35.

- Konopacki and Akbari (2001) estimated daily cooling energy savings of 3.6 kWh/1000 $ft^2$ (11%) and peak power reduction of 0.35 kW/1000 $ft^2$ (14%) in a large retail store in Austin, TX. Estimated annualized air conditioner savings were 630 kWh/1000 $ft^2$, assuming an increase in the aged solar reflectance (post-retrofit minus pre-retrofit) of about 0.45.
- Parker *et al.* (1998b) measured daily energy savings of 4.1 kWh/1000 $ft^2$ (25%) and a peak power reduction of 0.56 kW/1000 $ft^2$ (30%) for a school building in Florida. Estimated annualized air conditioner savings were 440 kWh/1000 $ft^2$ for an estimated 0.35 to 0.40 increase in the solar reflectance of the roofs.

We do not have measured energy and/or peak demand savings data for small non-residential buildings with steep-sloped roofs. However, energy and peak demand savings have been measured for residential buildings (Parker et al 1998a and Miller et al 2006). (We have documented these results in a parallel CASE study for residential buildings.)

## Statewide Projected Savings for New Construction

- annual TDV electricity savings of 15 GWh (unfaced insulation), 13 GWh if FSK-faced;
- annual TDV natural gas deficit of 42 ktherm (unfaced insulation), 39 ktherm if FSK-faced;
- annual TDV net source energy savings of 46 GBtu (unfaced insulation), 40 GBtu if FSK-faced;
- annual peak power demand savings[17] of 1.4 MW (unfaced insulation), 1.2 MW if FSK-faced;
- annual equipment savings of $0.4M (unfaced or FSK-faced insulation);
- TDV NPV energy savings of $10M (unfaced insulation), $9M if FSK-faced;
- TDV total savings (equipment + NPV energy) of $10M (unfaced insulation), $9M if FSK-faced;
- non-TDV NPV energy savings of $12M (unfaced insulation), $10M if FSK-faced; and
- non-TDV total savings (equipment + NPV energy) of $12M (unfaced insulation), $11M if FSK-faced.

## Statewide Projected Savings including Roof Replacement

- annual TDV electricity savings of 69 GWh (unfaced insulation), 61 GWh if FSK-faced;
- annual TDV natural gas deficit of 196 ktherm (unfaced insulation), 182 ktherm if FSK-faced;
- annual TDV net source energy savings of 214 GBtu (unfaced insulation), 189 GBtu if FSK-faced;
- annual peak power demand savings of 6.3 MW (unfaced insulation), 5.7 MW if FSK-faced;

[17] "Annual" power savings refer to reductions in the annual need for power plant construction.

- annual equipment savings of $1.9M (unfaced insulation), $1.7M if FSK-faced;
- TDV NPV energy savings of $46M (unfaced insulation), $41M if FSK-faced;
- TDV total savings (equipment + NPV energy) of $48M (unfaced insulation), $42M if FSK-faced;
- non-TDV NPV energy savings of $54M (unfaced insulation), $48M if FSK-faced; and
- non-TDV total savings (equipment + NPV energy) of $56M (unfaced insulation), $49M if FSK-faced.

# Recommendations

## Proposed Standards Language

See Attachment 2 (Proposed Standards Language for Residential and Nonresidential Cool Roofs 2008).

# Bibliography and Other Research


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***Table 1. Warmer and cooler options for low- and steep-sloped roofs. Shown are ranges of typical values for initial solar reflectance, initial thermal emittance, and estimated material plus labor cost.***

| Warmer Roof Options | | | | Cooler Roof Options | | | |
|---|---|---|---|---|---|---|---|
| *Roof Type* | *Reflectance* | *Emittance* | *Cost ($\$/ft^2$)* | *Roof Type* | *Reflectance* | *Emittance* | *Cost ($\$/ft^2$)* |
| **Built-up Roof** | | | **1.2 – 2.1** | **Built-up Roof** | | | **1.2 – 2.15** |
| with dark gravel | 0.08 – 0.15 | 0.80 – 0.90 | | with white gravel | 0.30 – 0.50 | 0.80 – 0.90 | |
| with smooth asphalt surface | 0.04 – 0.05 | 0.80 – 0.90 | | with gravel and cementitious coating | 0.50 – 0.70 | 0.80 – 0.90 | |
| with aluminum coating | 0.25 – 0.60 | 0.20 – 0.50 | | smooth surface with white roof coating | 0.75 – 0.85 | 0.80 – 0.90 | |
| **Single-Ply Membrane** | | | **1.0 – 2.0** | **Single-Ply Membrane** | | | **1.0 – 2.05** |
| black (PVC) | 0.04 – 0.05 | 0.80 – 0.90 | | white (PVC) | 0.70 – 0.78 | 0.80 – 0.90 | |
| | | | | color with cool pigments | 0.40 – 0.60 | 0.80 – 0.90 | |
| **Modified Bitumen** | | | **1.5 – 1.9** | **Modified Bitumen** | | | **1.5 – 1.95** |
| with mineral surface capsheet (SBS, APP) | 0.10 – 0.20 | 0.80 – 0.90 | | white coating over a mineral surface (SBS, APP) | 0.60 – 0.75 | 0.80 – 0.90 | |
| **Metal Roof** | | | **1.8 – 3.7** | **Metal Roof** | | | **1.8 – 3.75** |
| unpainted, corrugated | 0.30 – 0.50 | 0.05 – 0.30 | | white painted | 0.60 – 0.70 | 0.80 – 0.90 | |
| dark-painted, corrugated | 0.05 – 0.08 | 0.80 – 0.90 | | color with cool pigments | 0.40 – 0.70 | 0.80 – 0.90 | |
| **Asphalt Shingle** | | | **0.5 – 2** | **Asphalt Shingle** | | | **0.6 - 2.1** |
| black or dark brown with conventional pigments | 0.04 – 0.15 | 0.80 – 0.90 | | "white" (actually light gray) | 0.25 – 0.27 | 0.80 – 0.90 | |
| | | | | medium gray or brown with cool pigments | 0.25 – 0.27 | 0.80 – 0.90 | |
| **Liquid Applied Coating** | | | **0.5 – 0.7** | **Liquid Applied Coating** | | | **0.6 – 0.8** |
| smooth black | 0.04 - 0.05 | 0.80 – 0.90 | | smooth white | 0.70 – 0.85 | 0.80 – 0.90 | |
| | | | | smooth off-white | 0.40 – 0.60 | 0.80 – 0.90 | |
| | | | | rough white | 0.50 – 0.60 | 0.80 – 0.90 | |
| **Concrete Tile** | | | **1 - 6** | **Concrete Tile** | | | **1 - 6** |
| dark color with conventional pigments | 0.05 – 0.35 | 0.80 – 0.90 | | color with cool pigments | 0.40 – 0.50 | 0.80 – 0.90 | |
| | | | | white | 0.70 | 0.80 – 0.90 | |
| **Clay Tile** | | | **3 -5** | **Clay Tile** | | | **3 - 5** |
| dark color with conventional pigments | 0.20 | 0.80 – 0.90 | | terracotta (unglazed red tile) | 0.40 | 0.80 – 0.90 | |
| | | | | color with cool pigments | 0.40 – 0.60 | 0.80 – 0.90 | |
| | | | | white | 0.70 | 0.80 – 0.90 | |
| **Wood Shake** | | | **0.5 - 2** | **Wood Shake** | | | **0.5 - 2** |
| painted dark color with conventional pigments | 0.05 – 0.35 | 0.80 – 0.90 | | bare | 0.40 – 0.55 | 0.80 – 0.90 | |

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- **Note: The existence of certain roofing material, e.g., BUR, in the table does not necessarily imply significant shares in the steep-slope roofing market (NRCA 2003).**

*Table 2. Steep-sloped roofing technologies and their market shares in three Pacific Region states (NRCA, 2002-2003)*

| | | | PACIFIC[b] (steep-sloped) | |
|---|---|---|---|---|
| **Technology** | **Description** | **Median Cost[a] ($/ft²)** | **New Sales** | **Retrofit Sales** |
| **Built-up Roof (BUR)** | A continuous, semi-flexible multi-ply roof membrane, consisting of plies (layers) of saturated felts, coated felts, fabric, or mats, between which alternate layers of bitumen are applied. (Bitumen is a tarlike hydrocarbon mixture often including nonmetallic hyrocarbon derivatives; it may be obtained naturally or from the residue of heat-refining natural substances such as petroleum.) Built-up roof membranes are typically surfaced with roof aggregate and bitumen, a liquid-applied coating, or a granule-surfaced cap sheet. | **1.7** | **3.9%** | **4.4%** |
| Examples | (1) Asphalt | | 3.0% | 2.5% |
| | (2) Coal Tar | | - | 0.2% |
| | (3) Coal Process | | 0.9% | 1.7% |
| **Modified Bitumen** | (1) A bitumen modified through the inclusion of one or more polymers (e.g., atactic polypropylene and/or styrene butadiene styrene).<br>(2) Composite sheets consisting of a polymer modified bitumen often reinforced and sometimes surfaced with various types of mats, films, foils, and mineral granules. It can be classified into two categories: thermoset, and thermoplastic. A thermoset material solidifies or sets irreversibly when heated; this property is usually associated with cross-linking of the molecules induced by heat or radiation. A thermoplastic material softens when heated and hardens when cooled; this process can be repeated provided that the material is not heated above the point at which decomposition occurs. | **1.7** | **3.4%** | **4.9%** |
| Examples | Styrene-butadiene styrene (SBS) is an elastomeric modifier containing high molecular weight polymers with both thermoset and thermoplastic properties. It is formed by the block copolymerization of styrene and butadiene monomers. These polymers are used as modifying compound in SBS polymer modified asphalt-roofing membranes to impart rubber-like qualities to the asphalt. | | 1.6% | 3.6% |
| | Atactic polypropylene (APP) is a thermoplastic modifier containing a group of high molecular weight polymers formed by the polymerization of propylene. Used in modified bitumen as a plastic additive to permit heat fusing (torching). | | 1.8% | 1.3% |
| **Single-Ply Membrane** | A roofing membrane that is field applied using just one layer of membrane material (either homogeneous or composite) rather than multiple layers. The principal roof covering is usually a single-layer flexible membrane, often of thermoset, thermoplastic, or polymer-modified bituminous compounds. Roofing membranes can be torch-applied or hot-mopped with asphalt during application. | **1.5** | **1.3%** | **1.4%** |
| Examples | Polyvinyl chloride (PVC) is a synthetic thermoplastic polymer prepared from vinyl chloride. PVC can be compounded into flexible and rigid forms through the use of plasticizers, stabilizers, fillers, and other modifiers. Flexible forms are used in the manufacture of sheeting and roof membrane materials. | | 1.3% | 1.1% |
| | EPDM | | - | - |
| | TPO | | - | - |
| | Other Single Ply | | - | 0.3% |

| | | | | |
|---|---|---|---|---|
| **Metal** | Metal roofs can be classified as *architectural* or *structural*. | **2.8** | **17.8%** | **11.6%** |
| Examples | Architectural (hydrokinetic-watershedding) standing-seam roof systems are typically used on steep slopes with relatively short panel lengths. They usually do not have sealant in the seam because they are designed to shed water rapidly. They do not provide structural capacity or load resistance, and their installation is less labor-intensive because they have a solid substrate platform that makes installation easier. | | 7.5% | 6.3% |
| | Structural (hydrostatic-watershedding) standing-seam roof systems are versatile metal panel systems that can be used on both steep- and low-slope roofs and are designed to be water-resistant. Most structural standing-seam systems include a factory-applied sealant in the standing seams to help ensure water tightness. These panel systems provide structural capacity and load resistance. | | 10.3% | 5.3% |
| **Fiberglass Asphalt Shingle** | Asphalt is a dark brown to black cementitious material, solid or semisolid, in which the predominant constituents are naturally-occurring or petroleum-derived bitumens. It is used as a weatherproofing agent. The term asphalt shingle is generically used for both fiberglass and organic shingles. There are two grades of asphalt shingles: (1) standard, a.k.a. 3-tab, and (2) architectural, a.k.a. laminated or dimensional. Asphalt shingles come in various colors | **1.3** | **43.8%** | **55.4%** |
| Examples | Fiberglass shingles, commonly known as "asphalt shingles," consist of fiber mats that are coated with asphalt and then covered with granules. Granules, a.k.a. mineral granules or ceramic granules, are opaque, naturally or synthetically colored aggregates commonly used to surface cap sheets and shingles. | | 43.8% | 55.4% |
| | Organic shingles have a thick cellulose base that is saturated in soft asphalt. This saturation makes them heavier than fiberglass shingles, and less resistant to heat and humidity, but more durable in freezing conditions. | | - | - |
| **Fiber-cement Shingle** | Fiber-cement shingles contain wood fibers that can soak up water and add an extra weight load to a house. Sometimes color is only on the surface and may need repainting after wear. | **4** | **0.3%** | **1.0%** |
| **Wood-shingles /Shakes** | Organic shingles have a thick cellulose base that is saturated in soft asphalt. This saturation makes them heavier than fiberglass shingles, and less resistant to heat and humidity, but more durable in freezing conditions. | **1.3** | **3.4%** | **3.7%** |
| **Slate** | Slate is a fine-grained, homogeneous, sedimentary rock composed of clay or volcanic ash which has been metamorphosed (foliated) in layers (bedded deposits). Slate can be made into roofing shingles because it has two lines of breakability: cleavage and grain. | **10** | **1.0%** | **1.1%** |
| **Tile** | Usually made of concrete or clay, tile is a combination of sand, cement, and water; the water fraction depends on the manufacturing process. Concrete tiles are either air-cured or auto-claved, whereas clay tiles are kiln-fired. Color is added to the surface of the tile with a slurry coating process, or added to the mixture during the manufacturing process. | **4** | **20.8%** | **13.4%** |
| **Polyure-thane Foam (SPF)** | A foamed plastic material, formed by spraying two components (Polymeric Methelene Diisocyanate [PMDI] and a resin) to form a rigid, fully adhered, water-resistant, and insulating membrane. | **0.7** | **-** | **2.2%** |
| **Liquid Applied Coatings** | These are used as a surfacing on roofs of various types, especially built-up and metal roofs. They are available in different colors, and may be divided on the basis of reflectivity into black, aluminum, white, and tinted coatings. | **0.6** | **4.1%** | **0.7%** |
| **Other** | All other roofing materials that are not covered under the categories mentioned above. | **1** | **0.3%** | **0.2%** |

*a*. LBNL estimates of the typical costs are approximate from previous work - Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements (Revised August 2002, PG&E).

*b.* The NRCA's Pacific-region figures are derived from responses from 57 contractors compared to a total of 430 responses from over 4000 contractors to whom the survey was sent in the nation. Since the Roof Contactors Association of California reports that there are approximately 5000 active roofing contractors statewide in 2002, the NRCA figures may lack statistical validity (Hoffner, 2002).

*Table 3. Leading roofing product manufacturers (The Freedonia Group, 1997; Builder, 1995).*

| Company | Market Share | Leader In | Product Mix | Sales |
|---|---|---|---|---|
| Owens Corning | 8% | asphalt-based roofing | multi-product building materials | local dealer/distributor and factory-direct |
| GAF Materials Corporation | 7% | asphalt-based roofing | multi-product building materials | no information |
| France-based Saint-Gobain (via CertainTeed) | 6% | asphalt-based roofing | multi-product building materials | local dealer/distributor |
| Jim Walter (via Celotex) | 3-4% | asphalt-based roofing, coatings | multi-product building materials | local dealer/distributor |
| GS Roofing Products | 3-4% | asphalt-based roofing | specialty | local dealer/distributor |
| Johns Manville | 3-4% | asphalt-based roofing | multi-product building materials | local dealer/distributor and factory-direct |
| Carlisle Companies (via Carlisle SynTec) | 3-4% | elastomeric roofing | multi-line rubber products; metal roofing | no information |
| Japan-based Bridgestone (via Firestone Building Products) | 3-4% | elastomeric roofing | multi-line rubber products; building materials | no information |
| Tamko Roofing Products | <3% | asphalt-based roofing | specialty | local dealer/distributor |
| United Dominion Industries (via AEP Span and Varco-Pruden Buildings) | <3% | metal roofing | specialty pre-engineered buildings | no information |
| Gulf States Manufacturers | <3% | metal roofing | specialty pre-engineered buildings | no information |
| NCI Building Systems | <3% | metal roofing | specialty pre-engineered buildings | no information |
| Australia-based Boral (via US Tile and Lifetile) | <3% | tile | no information | local dealer/distributor |
| Clarke Group of Canada | <3% | cedar shingles and shakes; fiber cement roofing | no information | no information |
| Elcor (via Elk) | <3% | asphalt shingles | no information | local dealer/distributor |
| GenCorp | <3% | thermoplastic and rubber membrane roofing | no information | no information |
| Hood Companies | <3% | asphalt shingles and roll roofing | no information | no information |
| Redland of the UK (via Monier Roof Tile) | <3% | tile | no information | local dealer/distributor |
| Tremco | <3% | built-up and membrane roofing | no information | no information |

*Table 4. Cost premiums for cooler varieties of common steep-sloped roofing products.*

| Roofing Product | Cool Variety | Cost Premium ($/ft$^2$) |
|---|---|---|
| ballasted BUR | use white gravel | up to 0.05 |
| BUR with smooth asphalt coating | use cementitious or other white coatings | 0.10 to 0.20 |
| BUR with aluminum coating | use cementitious or other white coatings | 0.10 to 0.20 |
| single-ply membrane (EPDM, TPO, CSPE, PVC) | choose a white color | 0.00 to 0.05 |
| modified bitumen (SBS, APP) | use a white coating over the mineral surface | up to 0.05 |
| metal roofing (both painted and unpainted) | use a white or cool color paint | 0.00 to 0.05 |
| roof coatings (dark color, asphalt base) | use a white or cool color coating | 0.00 to 0.10 |
| concrete tile | use a white or cool color | 0.00 to 0.05 |
| cement tile (unpainted) | use a white or cool color | 0.05 |
| red clay tile | use cool red tiles | 0.10 |

*Table 5. Life expectancies of roof materials (NRCA, 1998; Lufkin and Pepitone, 1997).*

| Roofing material | Life expectancy (yr) |
|---|---|
| wood shingles and shakes | 15 to 30 |
| tile[a] | 50 |
| slate[b] | 50 to 100 |
| sheet metal[c] | 20 to 50+ |
| BUR/asphalt[d] | 12 to 25 |
| BUR/coat and tar[d] | 12 to 30 |
| single-ply modified bitumen | 10 to 20 |
| single-ply thermoplastic | 10 to 20 |
| single-ply thermoset | 10 to 20 |
| asphalt shingle | 15 to 30 |
| asphalt overlay | 25 to 35 |

*a*. Depends on quality of tile, thoroughness of design, and climate

*b*. Depends on grade.

*c*. Depends on gauge of metal, quality of coating, thoroughness of design and application.

*d*. Depends on materials and drainage; coatings will add to life span.

***Table 6 (a and b). Distribution of steep-sloped roof area for non-residential buildings; plus simulated new roof annual energy, peak power, cooling equipment cost, and net present value (NPV) savings, with and without time dependent valuation (TDV). Savings are weighted by the fraction of total roof area in each California climate zone, and by the fraction of new roof area for each material.***

| (a) Area- and Material-Weighted Savings for Steep-Sloped Shingle (56%), Tile (9%), and Metal (11%) Roofs [Heavy Interior Mass, Unfaced Insulation] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Annual TDV Energy/Mft2 | | | Peak Power/Mft2 | | TDV NPV/Mft2 | | non-TDV NPV/Mft2 | |
| Zone | Roof Area Fraction | Cooling MWh | Heating ktherm | Total MBtu | kW | k$equip | k$energy | k$total | k$energy | k$total |
| 1 | 0.002 | 0.9 | -0.009 | 2.1 | 0.13 | 0.0 | 0.4 | 0.5 | 0.6 | 0.6 |
| 2 | 0.012 | 9.5 | -0.053 | 27.3 | 1.05 | 0.3 | 5.9 | 6.2 | 7.3 | 7.6 |
| 3 | 0.096 | 59.7 | -0.325 | 171.4 | 5.93 | 1.8 | 36.9 | 38.7 | 48.3 | 50.1 |
| 4 | 0.069 | 54.2 | -0.207 | 164.2 | 6.24 | 1.9 | 35.3 | 37.2 | 43.6 | 45.5 |
| 5 | 0.013 | 9.0 | -0.046 | 26.0 | 0.93 | 0.3 | 5.6 | 5.9 | 7.5 | 7.8 |
| 6 | 0.069 | 85.4 | -0.214 | 269.9 | 5.69 | 1.7 | 58.0 | 59.8 | 69.0 | 70.8 |
| 7 | 0.032 | 35.6 | -0.084 | 113.0 | 2.24 | 0.7 | 24.3 | 25.0 | 33.1 | 33.8 |
| 8 | 0.106 | 148.7 | -0.303 | 477.3 | 12.93 | 4.0 | 102.6 | 106.6 | 118.3 | 122.3 |
| 9 | 0.067 | 95.4 | -0.186 | 307.0 | 8.66 | 2.6 | 66.0 | 68.7 | 75.3 | 78.0 |
| 10 | 0.122 | 126.7 | -0.294 | 402.8 | 11.83 | 3.6 | 86.6 | 90.2 | 97.7 | 101.3 |
| 11 | 0.026 | 23.8 | -0.072 | 74.1 | 2.77 | 0.8 | 15.9 | 16.8 | 17.5 | 18.4 |
| 12 | 0.132 | 113.6 | -0.407 | 347.0 | 11.83 | 3.6 | 74.6 | 78.2 | 86.3 | 89.9 |
| 13 | 0.040 | 40.4 | -0.101 | 127.8 | 4.33 | 1.3 | 27.5 | 28.8 | 33.7 | 35.0 |
| 14 | 0.130 | 148.0 | -0.499 | 455.2 | 14.03 | 4.3 | 97.9 | 102.2 | 109.5 | 113.8 |
| 15 | 0.060 | 79.9 | -0.070 | 265.8 | 6.38 | 1.9 | 57.2 | 59.1 | 65.1 | 67.1 |
| 16 | 0.024 | 17.6 | -0.144 | 45.8 | 2.31 | 0.7 | 9.8 | 10.5 | 11.5 | 12.2 |
| Total | 1.000 | 1049 | -3.01 | 3277 | 97 | 30 | 705 | 734 | 824 | 854 |

| (b) Area- and Material-Weighted Savings for Steep-Sloped Shingle (56%), Tile (9%), and Metal (11%) Roofs [Heavy Interior Mass, FSK-Faced Insulation] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Annual TDV Energy/Mft2 | | | Peak Power/Mft2 | | TDV NPV/Mft2 | | non-TDV NPV/Mft2 | |
| Zone | Roof Area Fraction | Cooling MWh | Heating ktherm | Total MBtu | kW | k$equip | k$energy | k$total | k$energy | k$total |
| 1 | 0.002 | 0.8 | -0.009 | 1.8 | 0.11 | 0.0 | 0.4 | 0.4 | 0.5 | 0.6 |
| 2 | 0.012 | 8.6 | -0.049 | 24.3 | 0.96 | 0.3 | 5.2 | 5.5 | 6.5 | 6.8 |
| 3 | 0.096 | 53.1 | -0.305 | 150.7 | 5.34 | 1.6 | 32.4 | 34.0 | 42.6 | 44.2 |
| 4 | 0.069 | 48.6 | -0.192 | 146.8 | 5.62 | 1.7 | 31.6 | 33.3 | 38.9 | 40.6 |
| 5 | 0.013 | 8.0 | -0.044 | 22.9 | 0.84 | 0.3 | 4.9 | 5.2 | 6.6 | 6.9 |
| 6 | 0.069 | 73.3 | -0.197 | 230.6 | 4.32 | 1.3 | 49.6 | 50.9 | 59.0 | 60.3 |
| 7 | 0.032 | 30.6 | -0.078 | 96.6 | 1.94 | 0.6 | 20.8 | 21.4 | 28.3 | 28.9 |
| 8 | 0.106 | 128.3 | -0.285 | 409.4 | 11.22 | 3.4 | 88.0 | 91.5 | 101.6 | 105.0 |
| 9 | 0.067 | 82.5 | -0.174 | 264.0 | 7.40 | 2.3 | 56.8 | 59.0 | 64.9 | 67.1 |
| 10 | 0.122 | 114.0 | -0.277 | 361.4 | 10.77 | 3.3 | 77.7 | 81.0 | 87.5 | 90.8 |
| 11 | 0.026 | 21.5 | -0.066 | 66.7 | 2.53 | 0.8 | 14.3 | 15.1 | 15.8 | 16.5 |
| 12 | 0.132 | 102.5 | -0.374 | 312.4 | 10.80 | 3.3 | 67.2 | 70.5 | 77.4 | 80.7 |
| 13 | 0.040 | 36.5 | -0.092 | 115.3 | 3.98 | 1.2 | 24.8 | 26.0 | 30.4 | 31.6 |
| 14 | 0.130 | 133.5 | -0.462 | 409.4 | 12.84 | 3.9 | 88.1 | 92.0 | 98.5 | 102.4 |
| 15 | 0.060 | 72.4 | -0.066 | 240.3 | 5.81 | 1.8 | 51.7 | 53.4 | 58.9 | 60.7 |
| 16 | 0.024 | 15.8 | -0.133 | 40.7 | 2.10 | 0.6 | 8.7 | 9.4 | 10.2 | 10.8 |
| Total | 1.000 | 930 | -2.80 | 2893 | 87 | 26 | 622 | 649 | 727 | 754 |

***Table 6(c and d). Distribution of steep-sloped roof area for non-residential buildings; plus simulated reroofing annual energy, peak power, cooling equipment cost, and net present value (NPV) savings, with and without time dependent valuation (TDV). Savings are weighted by the fraction of total roof area in each California climate zone, and by the fraction of reroofed roof area for each material.***

| (c) Area- and Material-Weighted Savings for Steep-Sloped Shingle (66%), Tile (5%), and Metal (6%) Roofs [Heavy Interior Mass, Unfaced Insulation] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Annual TDV Energy/Mft2 | | | Peak Power/Mft2 | | TDV NPV/Mft2 | | non-TDV NPV/Mft2 | |
| Zone | Roof Area Fraction | Cooling MWh | Heating ktherm | Total MBtu | kW | k$equip | k$energy | k$total | k$energy | k$total |
| 1 | 0.002 | 0.9 | -0.009 | 2.0 | 0.12 | 0.0 | 0.4 | 0.5 | 0.6 | 0.6 |
| 2 | 0.012 | 9.1 | -0.050 | 26.1 | 1.00 | 0.3 | 5.6 | 5.9 | 7.0 | 7.3 |
| 3 | 0.096 | 57.2 | -0.307 | 164.3 | 5.68 | 1.7 | 35.3 | 37.1 | 46.3 | 48.0 |
| 4 | 0.069 | 51.9 | -0.196 | 157.3 | 5.96 | 1.8 | 33.8 | 35.7 | 41.8 | 43.6 |
| 5 | 0.013 | 8.6 | -0.044 | 25.0 | 0.89 | 0.3 | 5.4 | 5.6 | 7.2 | 7.5 |
| 6 | 0.069 | 81.7 | -0.203 | 258.6 | 5.32 | 1.6 | 55.6 | 57.2 | 66.1 | 67.7 |
| 7 | 0.032 | 34.1 | -0.079 | 108.3 | 2.15 | 0.7 | 23.3 | 24.0 | 31.7 | 32.3 |
| 8 | 0.106 | 142.4 | -0.286 | 457.3 | 12.36 | 3.8 | 98.4 | 102.1 | 113.4 | 117.2 |
| 9 | 0.067 | 91.3 | -0.176 | 294.1 | 8.29 | 2.5 | 63.2 | 65.8 | 72.2 | 74.7 |
| 10 | 0.122 | 121.2 | -0.279 | 385.6 | 11.29 | 3.4 | 82.9 | 86.4 | 93.6 | 97.0 |
| 11 | 0.026 | 22.7 | -0.068 | 70.8 | 2.65 | 0.8 | 15.2 | 16.0 | 16.8 | 17.6 |
| 12 | 0.132 | 108.6 | -0.387 | 331.9 | 11.28 | 3.4 | 71.4 | 74.8 | 82.5 | 86.0 |
| 13 | 0.040 | 38.6 | -0.096 | 122.2 | 4.12 | 1.3 | 26.3 | 27.5 | 32.3 | 33.5 |
| 14 | 0.130 | 141.5 | -0.473 | 435.6 | 13.39 | 4.1 | 93.7 | 97.8 | 104.8 | 108.9 |
| 15 | 0.060 | 76.4 | -0.066 | 254.0 | 6.09 | 1.9 | 54.6 | 56.5 | 62.3 | 64.1 |
| 16 | 0.024 | 16.9 | -0.137 | 43.8 | 2.20 | 0.7 | 9.4 | 10.1 | 11.0 | 11.6 |
| Total | 1.000 | 1003 | -2.85 | 3137 | 93 | 28 | 675 | 703 | 789 | 818 |

| (d) Area- and Material-Weighted Savings for Steep-Sloped Shingle (66%), Tile (5%), and Metal (6%) Roofs [Heavy Interior Mass, FSK-Faced Insulation] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Annual TDV Energy/Mft2 | | | Peak Power/Mft2 | | TDV NPV/Mft2 | | non-TDV NPV/Mft2 | |
| Zone | Roof Area Fraction | Cooling MWh | Heating ktherm | Total MBtu | kW | k$equip | k$energy | k$total | k$energy | k$total |
| 1 | 0.002 | 0.8 | -0.008 | 1.7 | 0.10 | 0.0 | 0.4 | 0.4 | 0.5 | 0.5 |
| 2 | 0.012 | 8.2 | -0.047 | 23.3 | 0.92 | 0.3 | 5.0 | 5.3 | 6.2 | 6.5 |
| 3 | 0.096 | 50.8 | -0.289 | 144.5 | 5.11 | 1.6 | 31.1 | 32.6 | 40.8 | 42.4 |
| 4 | 0.069 | 46.5 | -0.182 | 140.6 | 5.36 | 1.6 | 30.2 | 31.9 | 37.2 | 38.9 |
| 5 | 0.013 | 7.7 | -0.041 | 22.0 | 0.81 | 0.2 | 4.7 | 5.0 | 6.4 | 6.6 |
| 6 | 0.069 | 70.2 | -0.187 | 221.0 | 4.05 | 1.2 | 47.5 | 48.8 | 56.5 | 57.8 |
| 7 | 0.032 | 29.3 | -0.074 | 92.6 | 1.86 | 0.6 | 19.9 | 20.5 | 27.1 | 27.7 |
| 8 | 0.106 | 122.9 | -0.270 | 392.3 | 10.72 | 3.3 | 84.4 | 87.6 | 97.3 | 100.6 |
| 9 | 0.067 | 78.9 | -0.164 | 252.9 | 7.08 | 2.2 | 54.4 | 56.5 | 62.1 | 64.3 |
| 10 | 0.122 | 109.1 | -0.262 | 346.0 | 10.27 | 3.1 | 74.4 | 77.5 | 83.7 | 86.9 |
| 11 | 0.026 | 20.5 | -0.063 | 63.8 | 2.41 | 0.7 | 13.7 | 14.4 | 15.1 | 15.8 |
| 12 | 0.132 | 98.0 | -0.354 | 298.9 | 10.30 | 3.1 | 64.3 | 67.4 | 74.0 | 77.2 |
| 13 | 0.040 | 34.9 | -0.087 | 110.3 | 3.79 | 1.2 | 23.7 | 24.9 | 29.0 | 30.2 |
| 14 | 0.130 | 127.7 | -0.438 | 391.8 | 12.28 | 3.8 | 84.3 | 88.0 | 94.2 | 98.0 |
| 15 | 0.060 | 69.1 | -0.063 | 229.6 | 5.54 | 1.7 | 49.4 | 51.1 | 56.3 | 58.0 |
| 16 | 0.024 | 15.1 | -0.126 | 39.0 | 2.00 | 0.6 | 8.4 | 9.0 | 9.7 | 10.4 |
| Total | 1.000 | 890 | -2.65 | 2770 | 83 | 25 | 596 | 621 | 696 | 722 |

*Table 7(a,b). Estimated annual state-wide new and reroofed steep-sloped roof area for non-residential buildings; plus simulated statewide cool-roof annual energy, peak power, cooling equipment cost, and net present value (NPV) savings, with and without time dependent valuation (TDV).*

**(a) State-Wide Savings for Steep-Sloped Shingle, Tile, and Metal Roofs [Heavy Interior Mass, Unfaced Insulation]**

| | Mft² applicable roof area | Annual TDV Energy | | | Peak Demand | | TDV NPV | | non-TDV NPV | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | GWh | ktherm | GBTU | MW | M$equip | M$energy | M$total | M$energy | M$total |
| **New** | 14 | 15 | -42 | 46 | 1.4 | 0.4 | 10 | 10 | 12 | 12 |
| **Reroof** | 54 | 54 | -154 | 169 | 5.0 | 1.5 | 36 | 38 | 42 | 44 |
| **Total** | 68 | 69 | -196 | 214 | 6.3 | 1.9 | 46 | 48 | 54 | 56 |

**(b) State-Wide Savings for Steep-Sloped Shingle, Tile, and Metal Roofs [Heavy Interior Mass, FSK-Faced Insulation]**

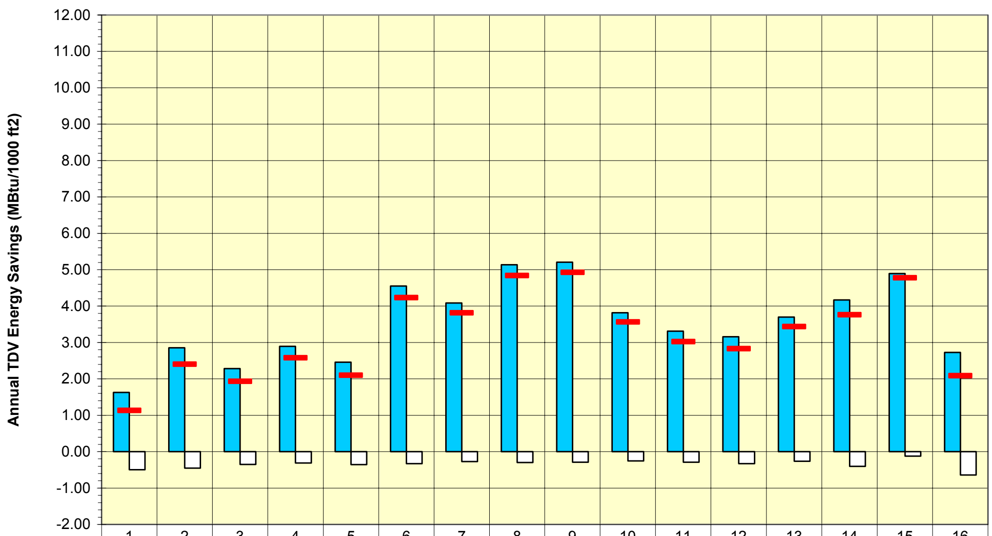
| | Mft² applicable roof area | Annual TDV Energy | | | Peak Demand | | TDV NPV | | non-TDV NPV | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | GWh | ktherm | GBTU | MW | M$equip | M$energy | M$total | M$energy | M$total |
| **New** | 14 | 13 | -39 | 40 | 1.2 | 0.4 | 9 | 9 | 10 | 11 |
| **Reroof** | 54 | 48 | -143 | 149 | 4.4 | 1.4 | 32 | 33 | 37 | 39 |
| **Total** | 68 | 61 | -182 | 189 | 5.7 | 1.7 | 41 | 42 | 48 | 49 |

*Figure 1. Locations of the 16 California climate zones (courtesy Eley Associates).*

*Figure 2 (a through f). Annual TDV-weighted energy savings (MBTU/1000 ft²) versus California climate zone, simulated for a prototypical Title-24 building.*

(a)

**Shingle (Leaky T-Bar Ceiling, Heavy-Mass Interior, Unfaced Insulation)**

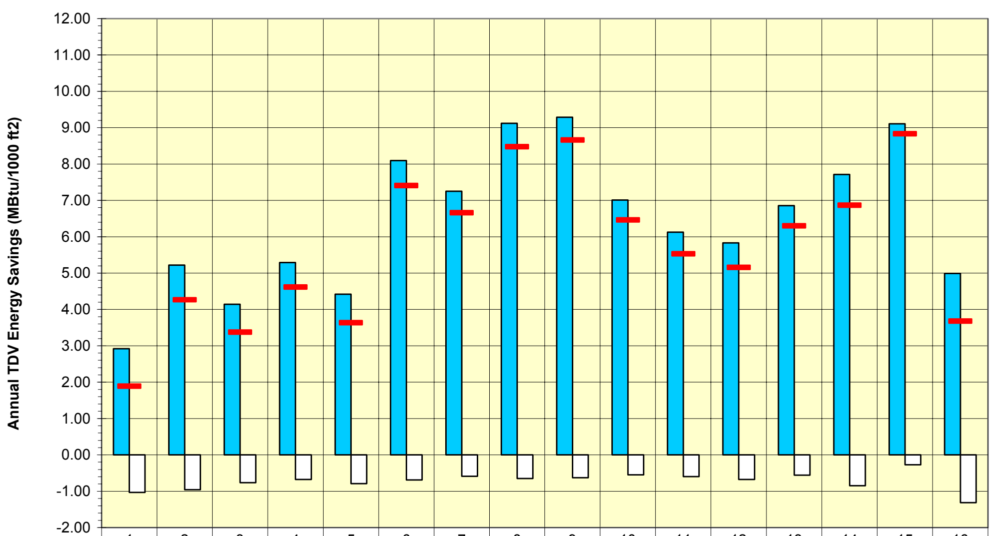



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cooling | 1.63 | 2.85 | 2.28 | 2.89 | 2.46 | 4.55 | 4.09 | 5.14 | 5.21 | 3.82 | 3.31 | 3.16 | 3.70 | 4.17 | 4.90 | 2.73 |
| Heating | -0.49 | -0.45 | -0.35 | -0.31 | -0.36 | -0.32 | -0.27 | -0.30 | -0.29 | -0.25 | -0.29 | -0.33 | -0.26 | -0.40 | -0.12 | -0.64 |
| Total | 1.13 | 2.40 | 1.93 | 2.58 | 2.10 | 4.23 | 3.82 | 4.84 | 4.92 | 3.57 | 3.02 | 2.83 | 3.44 | 3.77 | 4.77 | 2.08 |

California Climate Zone

(b)

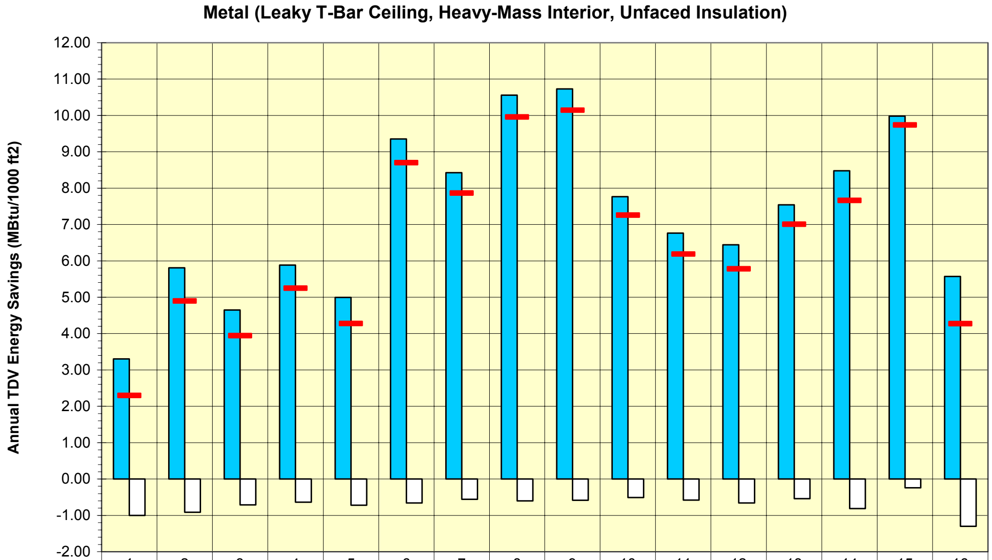
**Tile (Leaky T-Bar Ceiling, Heavy-Mass Interior, Unfaced Insulation)**




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cooling | 2.92 | 5.22 | 4.14 | 5.29 | 4.42 | 8.10 | 7.25 | 9.12 | 9.29 | 7.01 | 6.13 | 5.83 | 6.85 | 7.71 | 9.11 | 4.99 |
| Heating | -1.03 | -0.96 | -0.76 | -0.68 | -0.79 | -0.69 | -0.59 | -0.65 | -0.63 | -0.55 | -0.59 | -0.67 | -0.56 | -0.85 | -0.27 | -1.31 |
| Total | 1.89 | 4.26 | 3.38 | 4.61 | 3.63 | 7.41 | 6.66 | 8.47 | 8.66 | 6.46 | 5.53 | 5.15 | 6.30 | 6.87 | 8.83 | 3.68 |

California Climate Zone

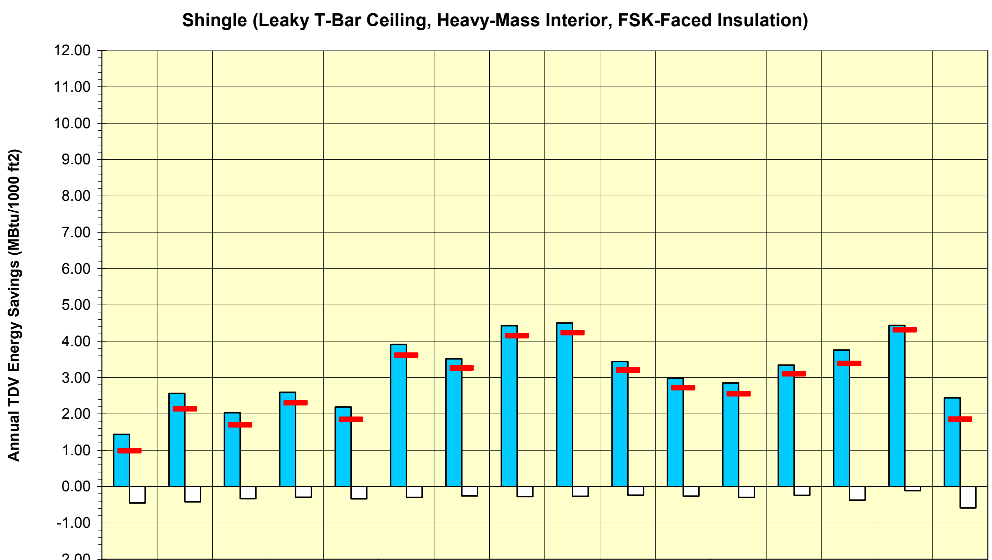
(c)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cooling | 3.30 | 5.81 | 4.65 | 5.88 | 4.99 | 9.36 | 8.42 | 10.55 | 10.73 | 7.77 | 6.76 | 6.44 | 7.54 | 8.48 | 9.98 | 5.57 |
| Heating | -1.00 | -0.91 | -0.71 | -0.64 | -0.72 | -0.66 | -0.56 | -0.60 | -0.58 | -0.51 | -0.58 | -0.66 | -0.54 | -0.81 | -0.24 | -1.30 |
| Total | 2.30 | 4.90 | 3.94 | 5.25 | 4.27 | 8.70 | 7.87 | 9.95 | 10.14 | 7.26 | 6.18 | 5.78 | 7.01 | 7.66 | 9.73 | 4.27 |

California Climate Zone

(d)

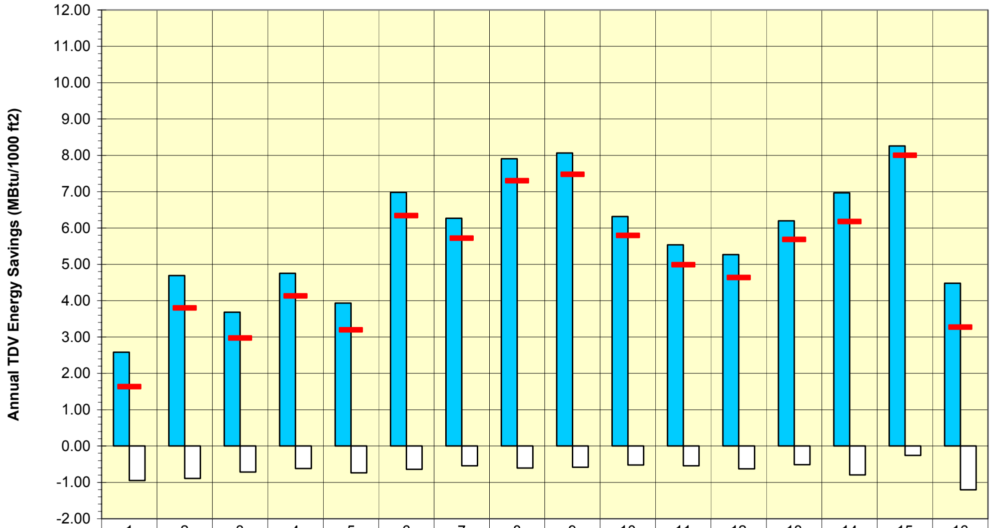



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cooling | 1.44 | 2.56 | 2.03 | 2.60 | 2.19 | 3.91 | 3.52 | 4.43 | 4.50 | 3.44 | 2.99 | 2.85 | 3.34 | 3.76 | 4.43 | 2.44 |
| Heating | -0.45 | -0.42 | -0.33 | -0.29 | -0.34 | -0.30 | -0.26 | -0.28 | -0.27 | -0.24 | -0.26 | -0.30 | -0.24 | -0.37 | -0.12 | -0.59 |
| Total | 0.98 | 2.14 | 1.70 | 2.30 | 1.85 | 3.61 | 3.26 | 4.15 | 4.23 | 3.20 | 2.72 | 2.55 | 3.10 | 3.39 | 4.32 | 1.85 |

California Climate Zone

(e)

**Tile (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)**

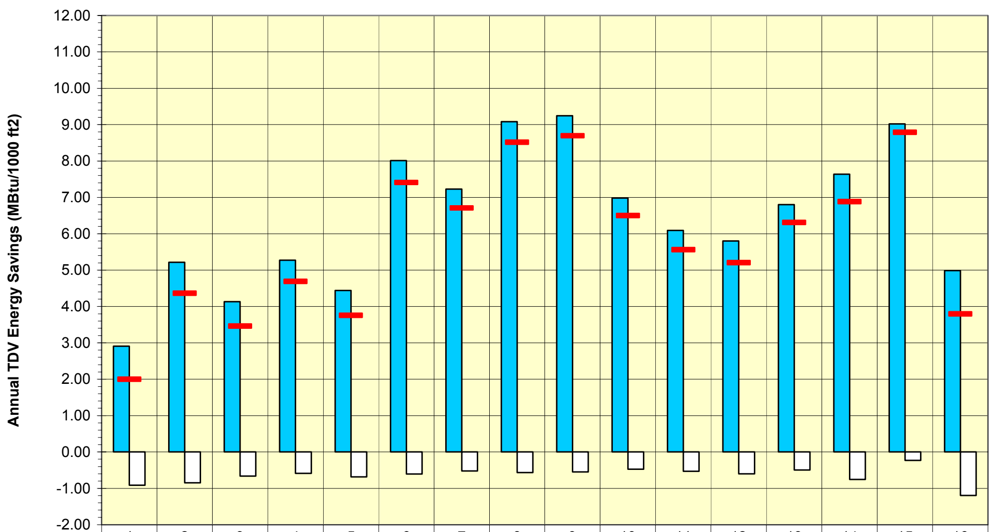



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cooling | 2.58 | 4.69 | 3.69 | 4.75 | 3.93 | 6.98 | 6.27 | 7.91 | 8.06 | 6.32 | 5.54 | 5.27 | 6.20 | 6.97 | 8.26 | 4.48 |
| Heating | -0.95 | -0.89 | -0.72 | -0.62 | -0.74 | -0.64 | -0.54 | -0.61 | -0.59 | -0.52 | -0.55 | -0.63 | -0.51 | -0.79 | -0.26 | -1.21 |
| Total | 1.63 | 3.80 | 2.97 | 4.13 | 3.20 | 6.34 | 5.72 | 7.30 | 7.48 | 5.80 | 4.99 | 4.64 | 5.68 | 6.18 | 8.00 | 3.27 |

**California Climate Zone**

(f)

**Metal (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)**

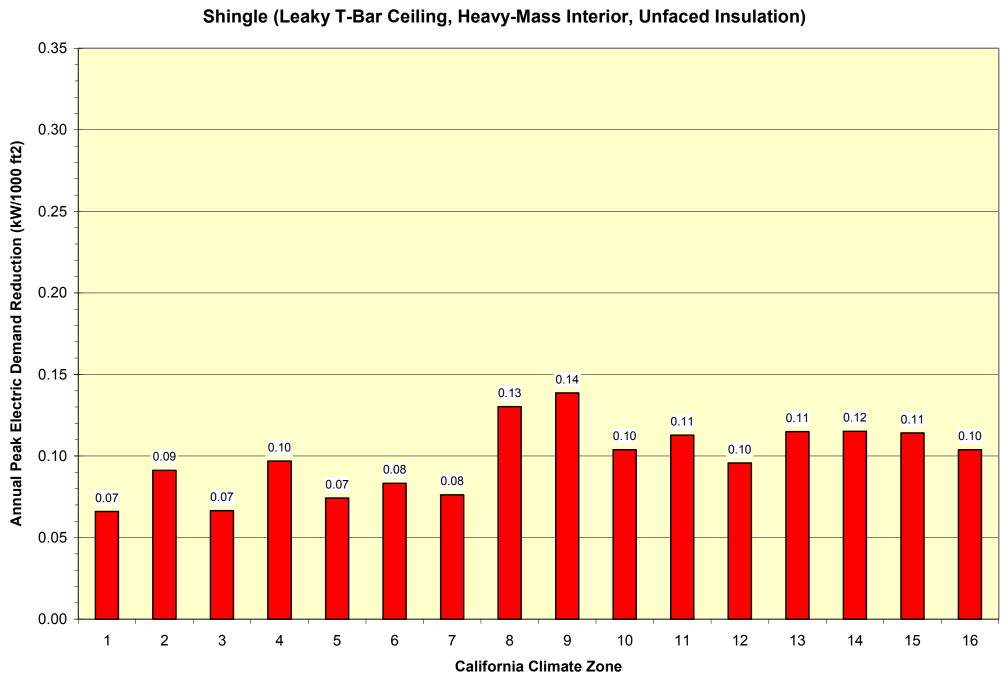



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cooling | 2.91 | 5.21 | 4.13 | 5.28 | 4.44 | 8.01 | 7.23 | 9.08 | 9.24 | 6.98 | 6.09 | 5.80 | 6.80 | 7.63 | 9.02 | 4.99 |
| Heating | -0.91 | -0.85 | -0.67 | -0.59 | -0.68 | -0.61 | -0.52 | -0.56 | -0.55 | -0.48 | -0.53 | -0.60 | -0.49 | -0.75 | -0.23 | -1.19 |
| Total | 2.00 | 4.36 | 3.46 | 4.69 | 3.76 | 7.41 | 6.71 | 8.52 | 8.70 | 6.50 | 5.56 | 5.20 | 6.31 | 6.88 | 8.79 | 3.79 |

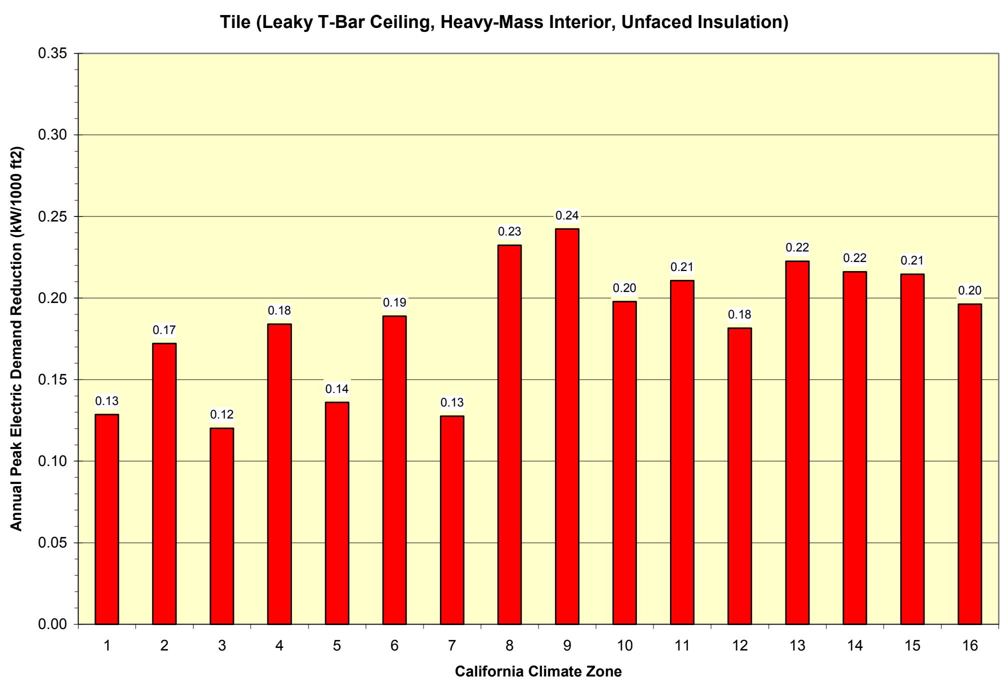
**California Climate Zone**

*Figure 3 (a through f). Annual peak electric demand reduction (kW/1000 ft²) versus California climate zone, simulated for a prototypical Title-24 building.*

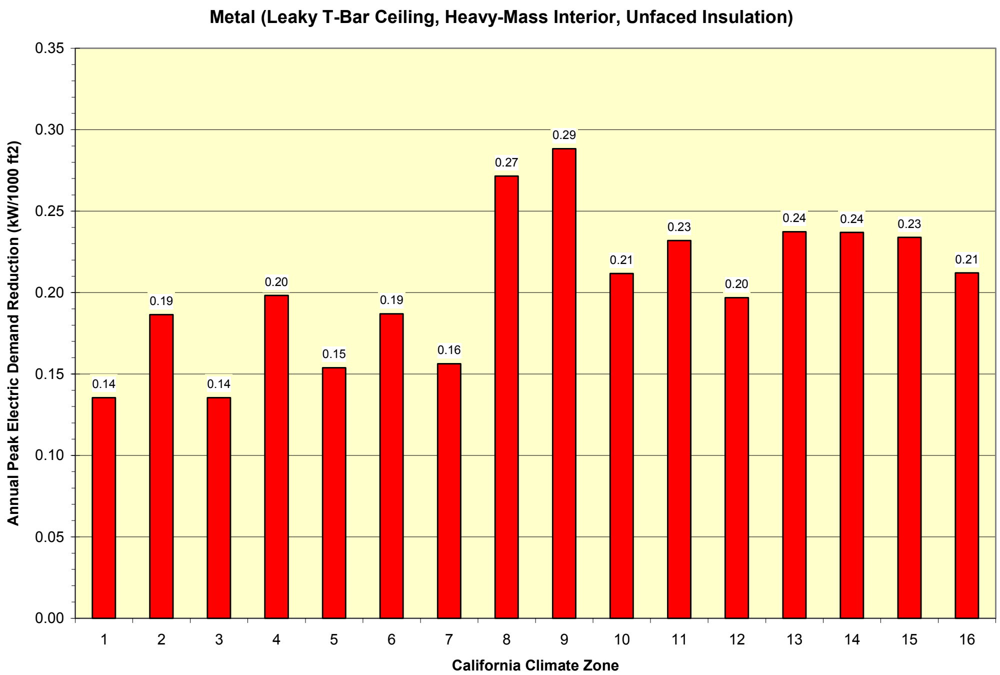
(a)



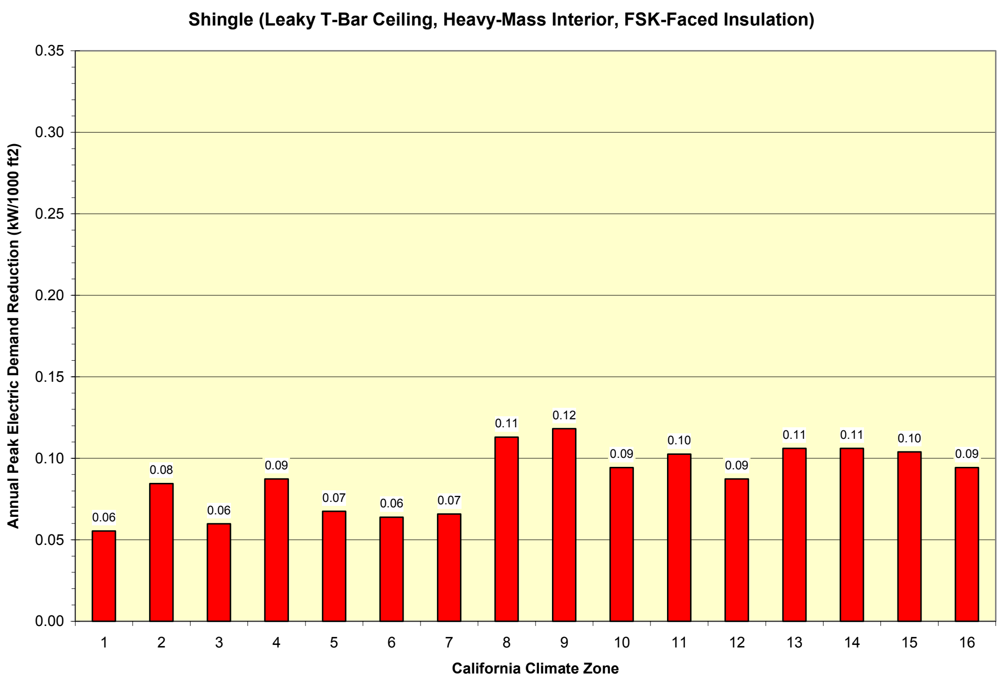

(b)



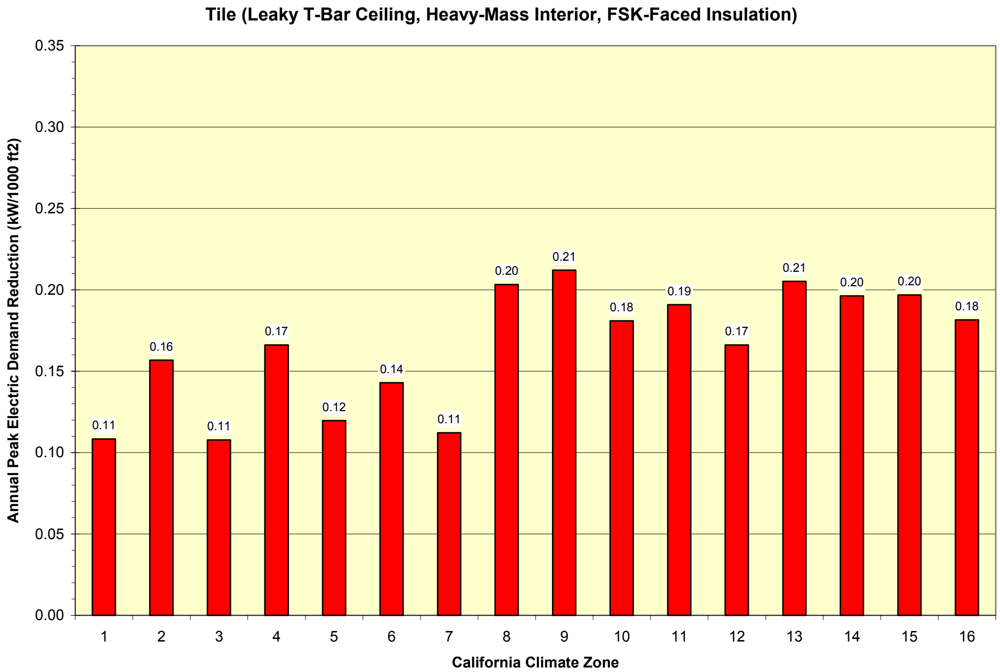
(c)


Metal (Leaky T-Bar Ceiling, Heavy-Mass Interior, Unfaced Insulation)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.14
0.19
0.14
0.20
0.15
0.19
0.16
0.27
0.29
0.21
0.23
0.20
0.24
0.24
0.23
0.21
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

(d)


Shingle (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.06
0.08
0.06
0.09
0.07
0.06
0.07
0.11
0.12
0.09
0.10
0.09
0.11
0.11
0.10
0.09
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

(e)


Tile (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.11
0.16
0.11
0.17
0.12
0.14
0.11
0.20
0.21
0.18
0.19
0.17
0.21
0.20
0.20
0.18
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

(f)

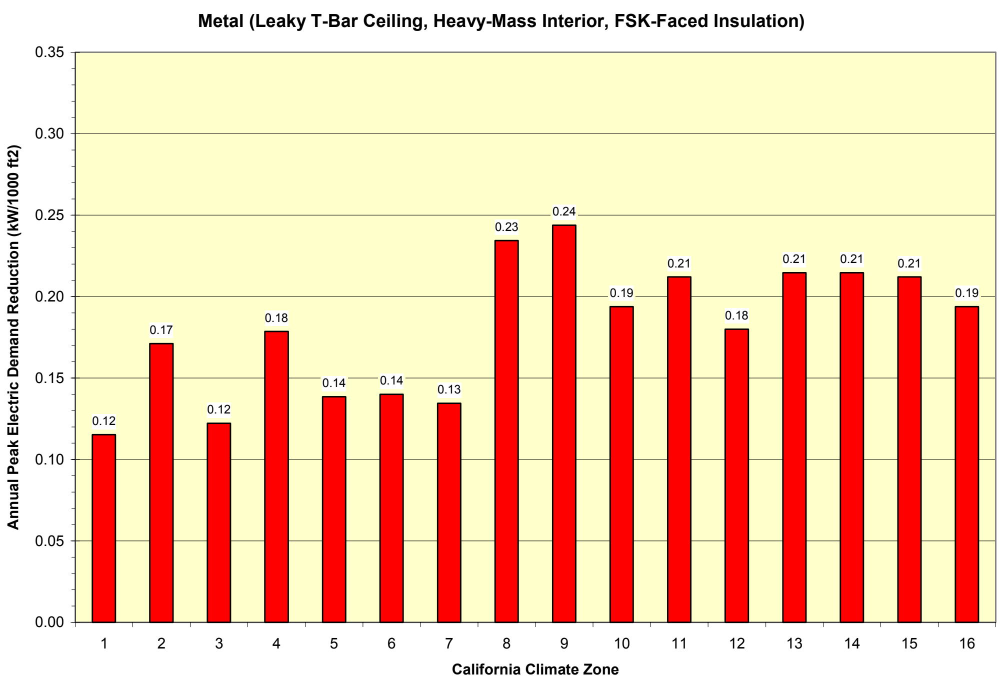
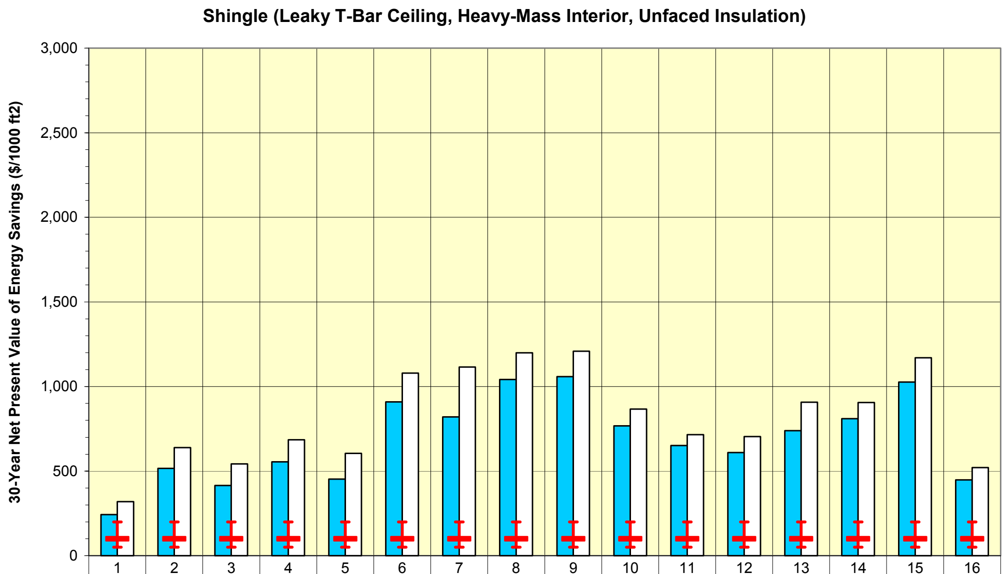

Metal (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.12
0.17
0.12
0.18
0.14
0.14
0.13
0.23
0.24
0.19
0.21
0.18
0.21
0.21
0.21
0.19
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

***Figure 4 (a through f). 30-year net present value (NPV) of energy savings ($/1000 ft²) versus California climate zone, simulated for a prototypical Title-24 building. NPV is calculated with and without time dependent valuation (TDV). Material cost premiums (0.05, 0.10, and 0.20 $/ft²) are overlaid on the NPV data.***

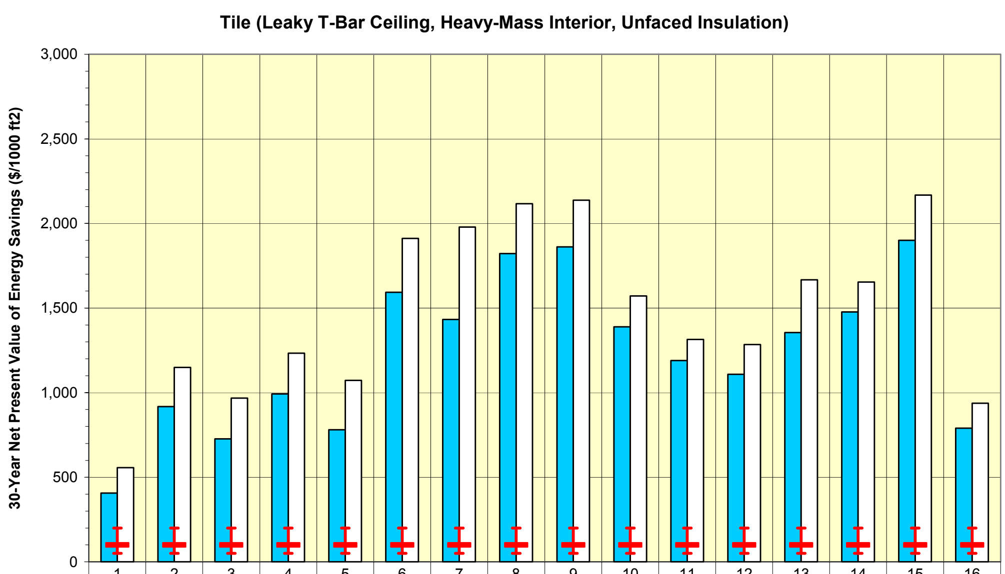
(a)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 243 | 517 | 415 | 555 | 452 | 909 | 821 | 1,041 | 1,059 | 767 | 650 | 609 | 739 | 810 | 1,027 | 448 |
| Non-TDV | 320 | 639 | 543 | 685 | 605 | 1,080 | 1,115 | 1,199 | 1,208 | 866 | 716 | 704 | 907 | 906 | 1,171 | 521 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

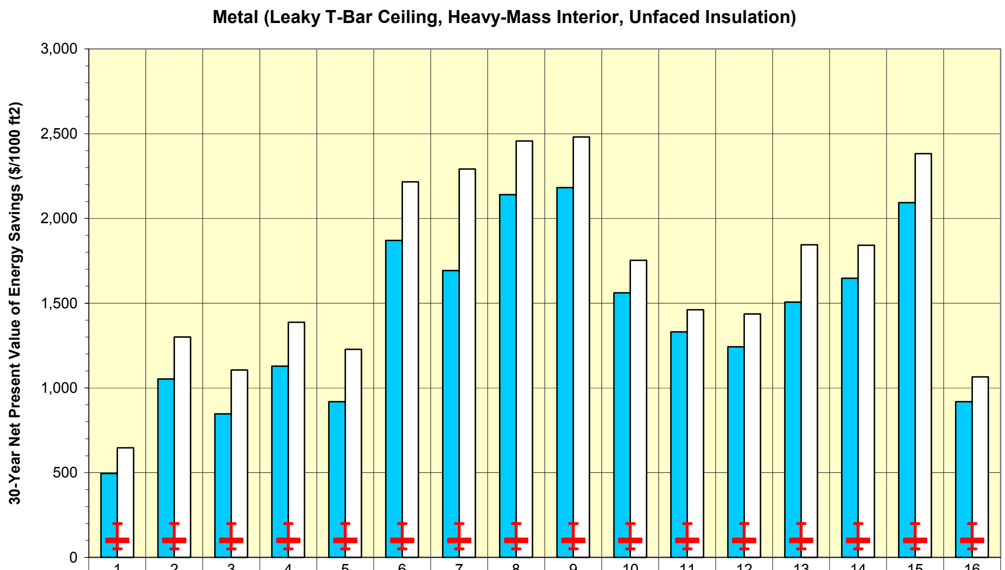
(b)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 406 | 917 | 726 | 992 | 781 | 1,593 | 1,432 | 1,822 | 1,862 | 1,390 | 1,190 | 1,109 | 1,355 | 1,477 | 1,900 | 791 |
| Non-TDV | 557 | 1,149 | 968 | 1,233 | 1,072 | 1,912 | 1,979 | 2,117 | 2,137 | 1,571 | 1,314 | 1,284 | 1,667 | 1,654 | 2,168 | 937 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

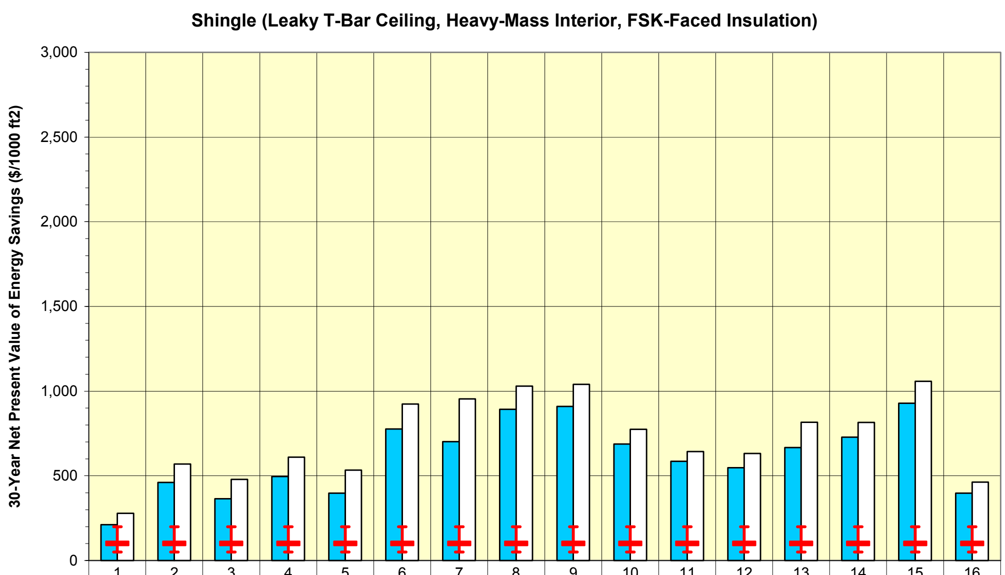
California Climate Zone

(c)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 495 | 1,053 | 847 | 1,128 | 919 | 1,870 | 1,692 | 2,141 | 2,181 | 1,561 | 1,330 | 1,243 | 1,507 | 1,648 | 2,093 | 918 |
| Non-TDV | 647 | 1,301 | 1,105 | 1,387 | 1,228 | 2,216 | 2,291 | 2,457 | 2,481 | 1,753 | 1,460 | 1,436 | 1,844 | 1,841 | 2,383 | 1,065 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

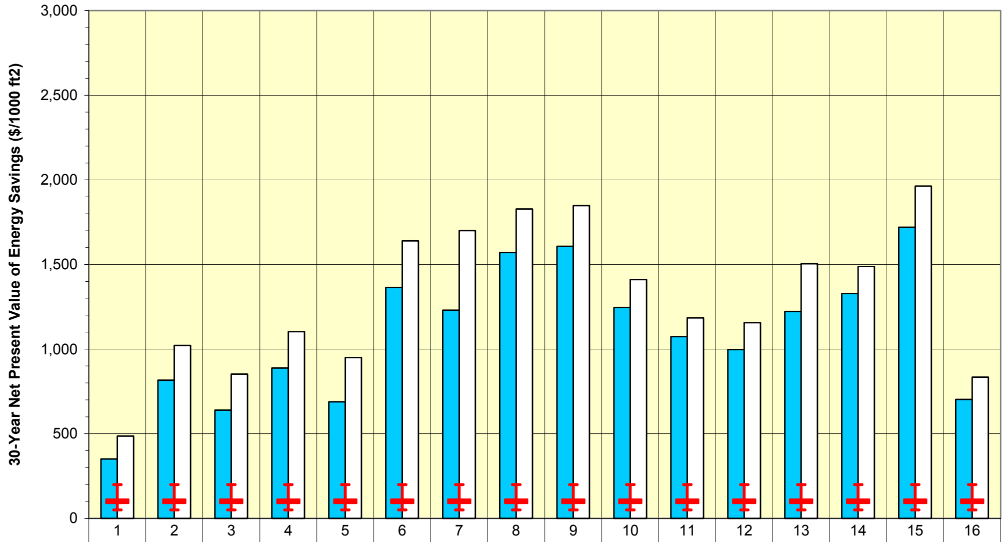
(d)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 211 | 460 | 365 | 496 | 398 | 777 | 701 | 893 | 911 | 689 | 586 | 549 | 667 | 729 | 928 | 398 |
| Non-TDV | 279 | 570 | 479 | 610 | 534 | 924 | 954 | 1,029 | 1,040 | 775 | 643 | 631 | 816 | 815 | 1,058 | 463 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

(e)

Tile (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)

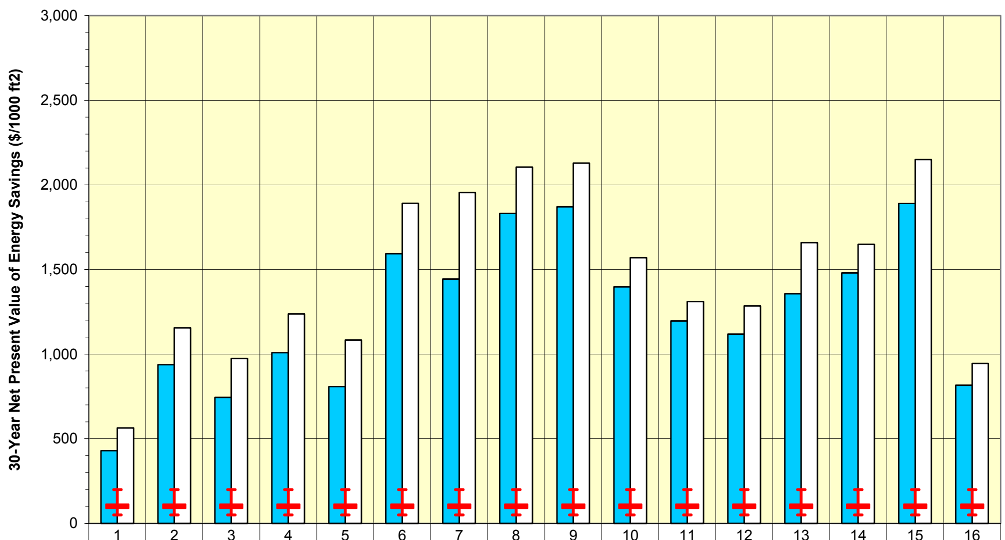



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 351 | 817 | 639 | 889 | 688 | 1,364 | 1,230 | 1,570 | 1,608 | 1,247 | 1,073 | 998 | 1,222 | 1,328 | 1,720 | 703 |
| Non-TDV | 487 | 1,022 | 852 | 1,103 | 949 | 1,639 | 1,700 | 1,827 | 1,848 | 1,410 | 1,185 | 1,156 | 1,504 | 1,489 | 1,963 | 834 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

(f)

Metal (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)

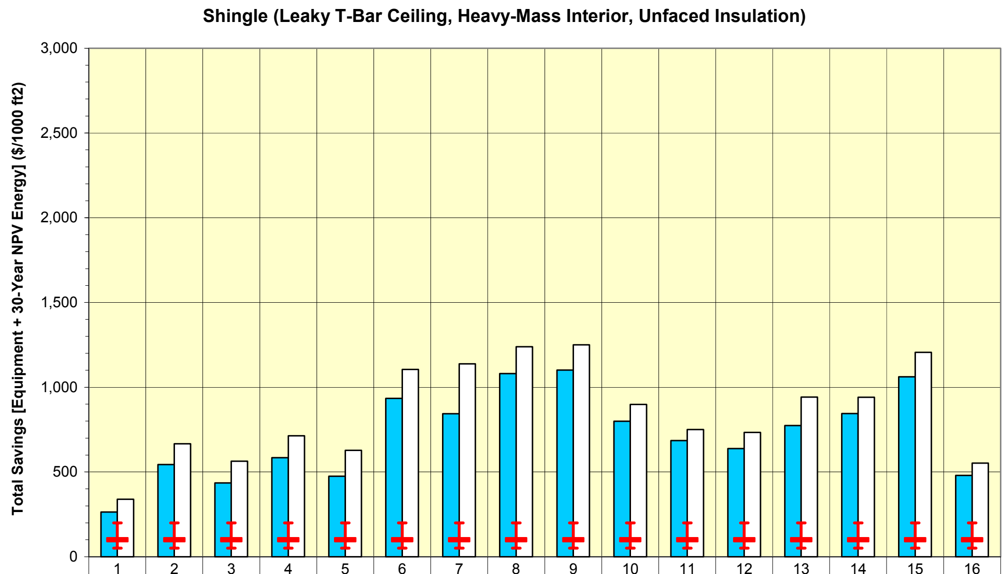



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 429 | 938 | 745 | 1,008 | 808 | 1,593 | 1,443 | 1,831 | 1,870 | 1,398 | 1,196 | 1,119 | 1,357 | 1,480 | 1,890 | 816 |
| Non-TDV | 563 | 1,155 | 974 | 1,237 | 1,083 | 1,891 | 1,955 | 2,105 | 2,129 | 1,569 | 1,310 | 1,285 | 1,659 | 1,649 | 2,150 | 945 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

***Figure 5 (a through f). Total savings (cooling equipment savings plus 30-year NPV of energy savings) in $/1000 ft² versus California climate zone, simulated for a prototypical Title-24 building. NPV is calculated with and without time dependent valuation (TDV). Material cost premiums (0.05, 0.10, and 0.20 $/ft²) are overlaid on the NPV data.***

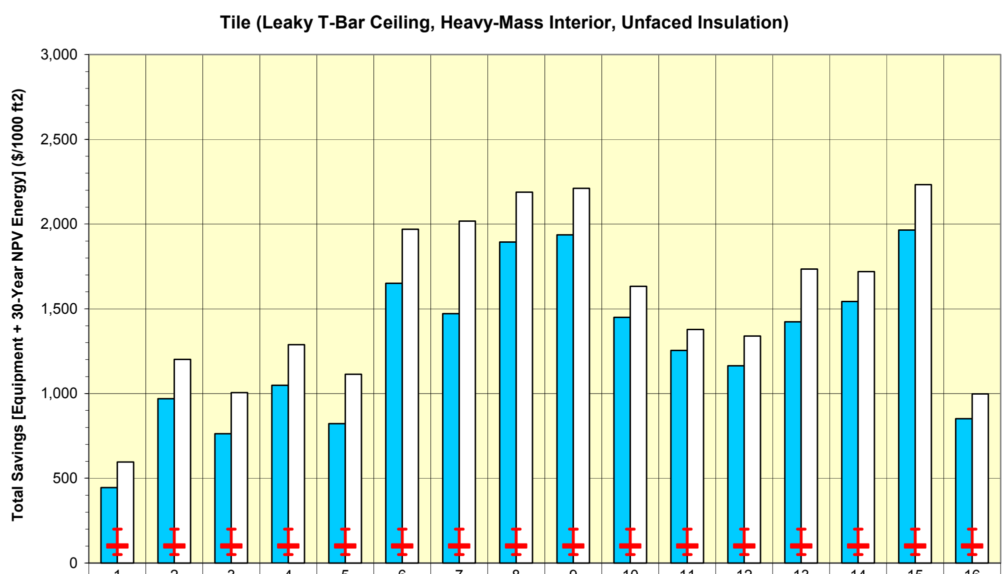
(a)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 264 | 545 | 436 | 584 | 475 | 935 | 844 | 1,081 | 1,101 | 799 | 685 | 638 | 774 | 845 | 1,062 | 480 |
| Non-TDV | 340 | 667 | 563 | 714 | 627 | 1,105 | 1,138 | 1,239 | 1,251 | 898 | 750 | 733 | 942 | 941 | 1,205 | 552 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

(b)

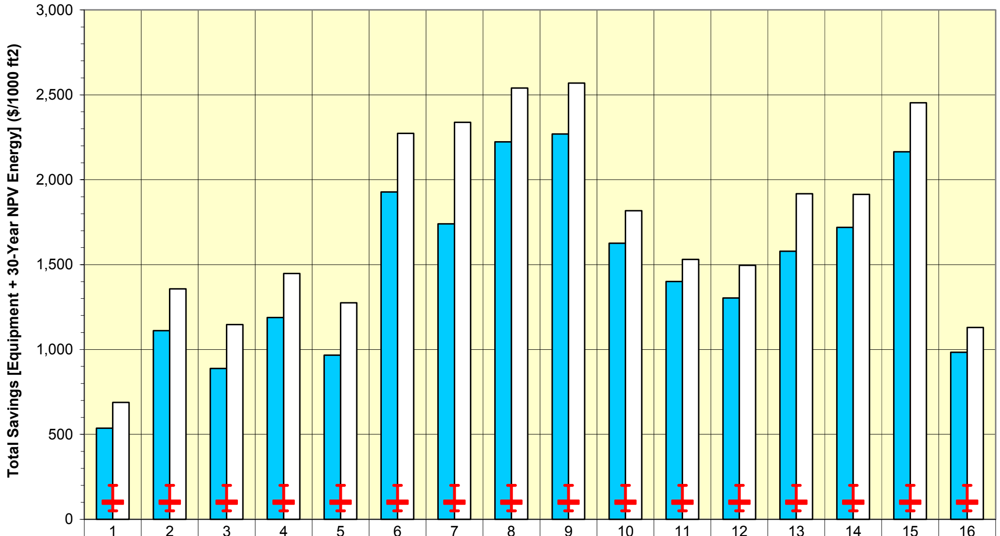



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 445 | 970 | 763 | 1,048 | 823 | 1,651 | 1,471 | 1,893 | 1,936 | 1,450 | 1,254 | 1,164 | 1,423 | 1,543 | 1,966 | 851 |
| Non-TDV | 597 | 1,201 | 1,005 | 1,289 | 1,114 | 1,970 | 2,018 | 2,188 | 2,211 | 1,632 | 1,379 | 1,339 | 1,735 | 1,720 | 2,233 | 997 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

(c)

**Metal (Leaky T-Bar Ceiling, Heavy-Mass Interior, Unfaced Insulation)**

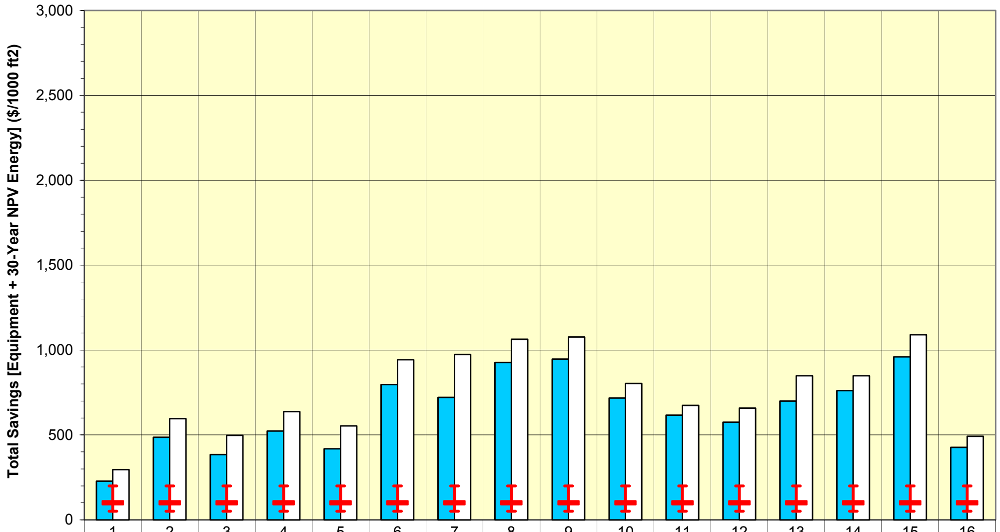



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 536 | 1,110 | 889 | 1,189 | 966 | 1,928 | 1,740 | 2,224 | 2,270 | 1,626 | 1,401 | 1,303 | 1,579 | 1,720 | 2,165 | 983 |
| Non-TDV | 688 | 1,358 | 1,147 | 1,447 | 1,275 | 2,273 | 2,339 | 2,540 | 2,569 | 1,818 | 1,531 | 1,496 | 1,917 | 1,914 | 2,454 | 1,129 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

(d)

**Shingle (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)**

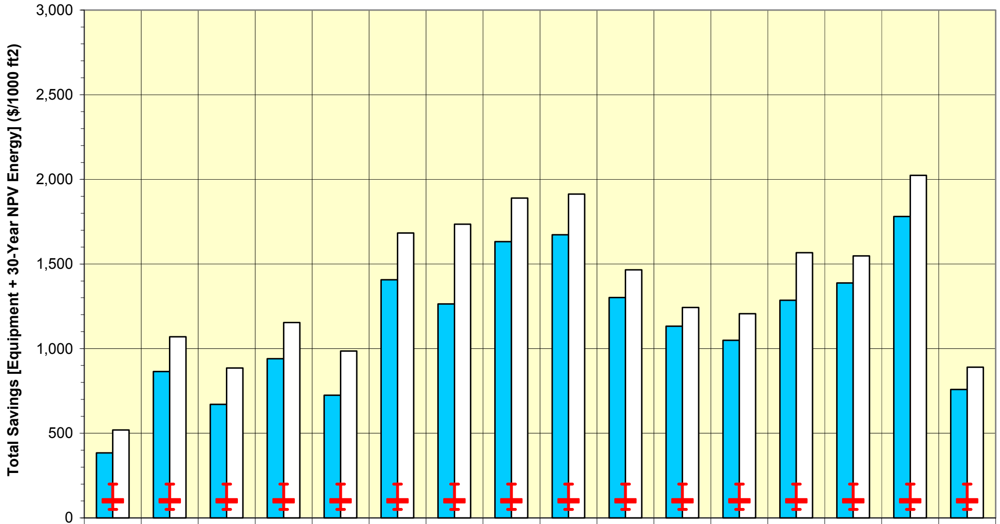



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 228 | 486 | 384 | 522 | 418 | 797 | 722 | 927 | 947 | 717 | 617 | 575 | 700 | 761 | 960 | 427 |
| Non-TDV | 296 | 595 | 497 | 637 | 554 | 943 | 974 | 1,064 | 1,076 | 803 | 675 | 658 | 849 | 848 | 1,090 | 491 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

(e)

**Tile (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)**

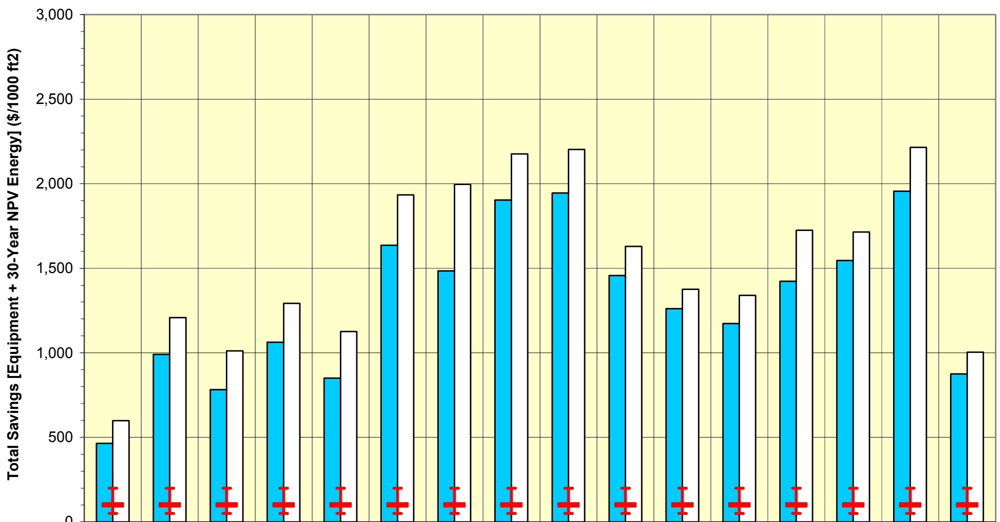



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 384 | 864 | 671 | 939 | 724 | 1,408 | 1,265 | 1,632 | 1,673 | 1,302 | 1,132 | 1,048 | 1,285 | 1,388 | 1,780 | 759 |
| Non-TDV | 520 | 1,070 | 885 | 1,154 | 986 | 1,683 | 1,735 | 1,889 | 1,913 | 1,466 | 1,243 | 1,207 | 1,567 | 1,549 | 2,023 | 890 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

(f)

**Metal (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)**

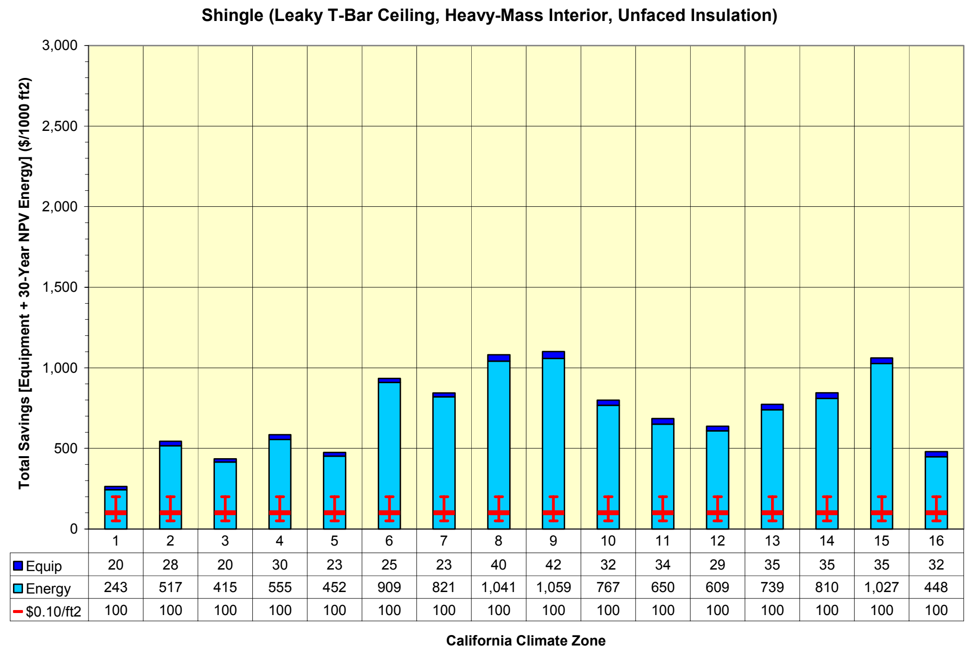



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDV | 464 | 990 | 782 | 1,063 | 850 | 1,636 | 1,484 | 1,903 | 1,945 | 1,457 | 1,261 | 1,174 | 1,423 | 1,546 | 1,955 | 875 |
| Non-TDV | 598 | 1,207 | 1,012 | 1,292 | 1,125 | 1,934 | 1,996 | 2,177 | 2,203 | 1,629 | 1,375 | 1,340 | 1,725 | 1,715 | 2,215 | 1,004 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

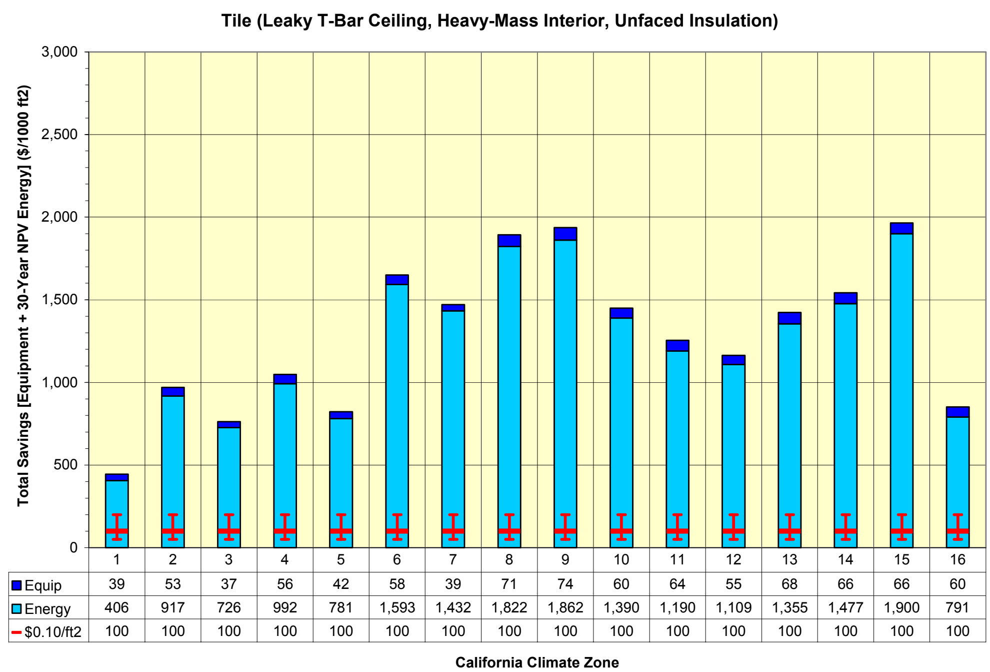
***Figure 6 (a through f). Total savings (stacked-bar chart of 30-year NPV of energy savings plus cooling equipment savings) in $/1000 ft² versus California climate zone, simulated for a prototypical Title-24 building. NPV is calculated with time-dependent valuation (TDV). Material cost premiums (0.05, 0.10, and 0.20 $/ft²) are overlaid on the NPV data.***

(a)



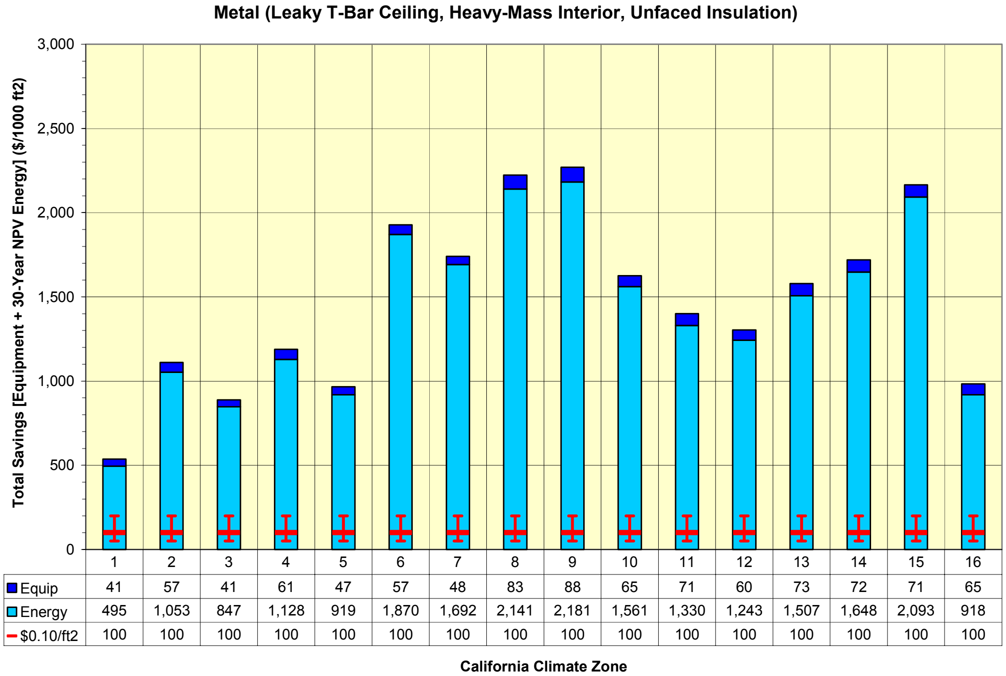

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equip | 20 | 28 | 20 | 30 | 23 | 25 | 23 | 40 | 42 | 32 | 34 | 29 | 35 | 35 | 35 | 32 |
| Energy | 243 | 517 | 415 | 555 | 452 | 909 | 821 | 1,041 | 1,059 | 767 | 650 | 609 | 739 | 810 | 1,027 | 448 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

(b)



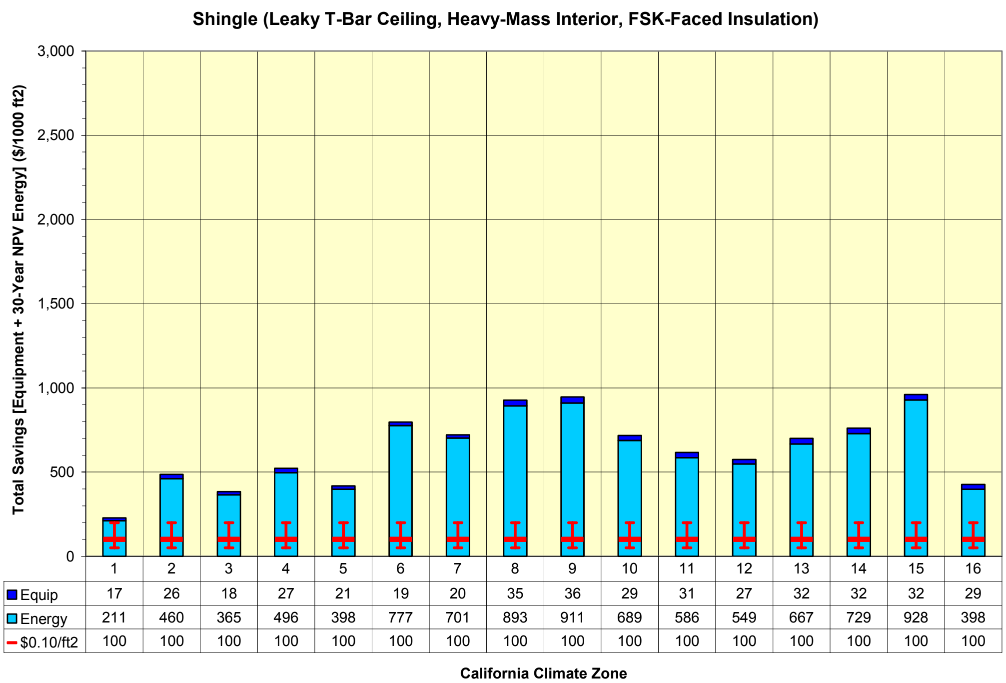

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equip | 39 | 53 | 37 | 56 | 42 | 58 | 39 | 71 | 74 | 60 | 64 | 55 | 68 | 66 | 66 | 60 |
| Energy | 406 | 917 | 726 | 992 | 781 | 1,593 | 1,432 | 1,822 | 1,862 | 1,390 | 1,190 | 1,109 | 1,355 | 1,477 | 1,900 | 791 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

(c)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equip | 41 | 57 | 41 | 61 | 47 | 57 | 48 | 83 | 88 | 65 | 71 | 60 | 73 | 72 | 71 | 65 |
| Energy | 495 | 1,053 | 847 | 1,128 | 919 | 1,870 | 1,692 | 2,141 | 2,181 | 1,561 | 1,330 | 1,243 | 1,507 | 1,648 | 2,093 | 918 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

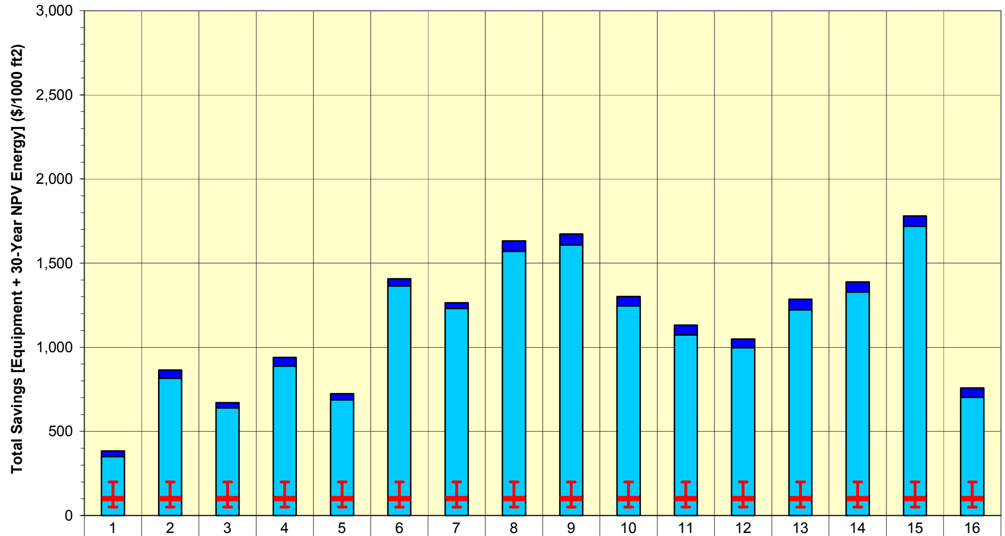
(d)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equip | 17 | 26 | 18 | 27 | 21 | 19 | 20 | 35 | 36 | 29 | 31 | 27 | 32 | 32 | 32 | 29 |
| Energy | 211 | 460 | 365 | 496 | 398 | 777 | 701 | 893 | 911 | 689 | 586 | 549 | 667 | 729 | 928 | 398 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

(e)

Tile (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)

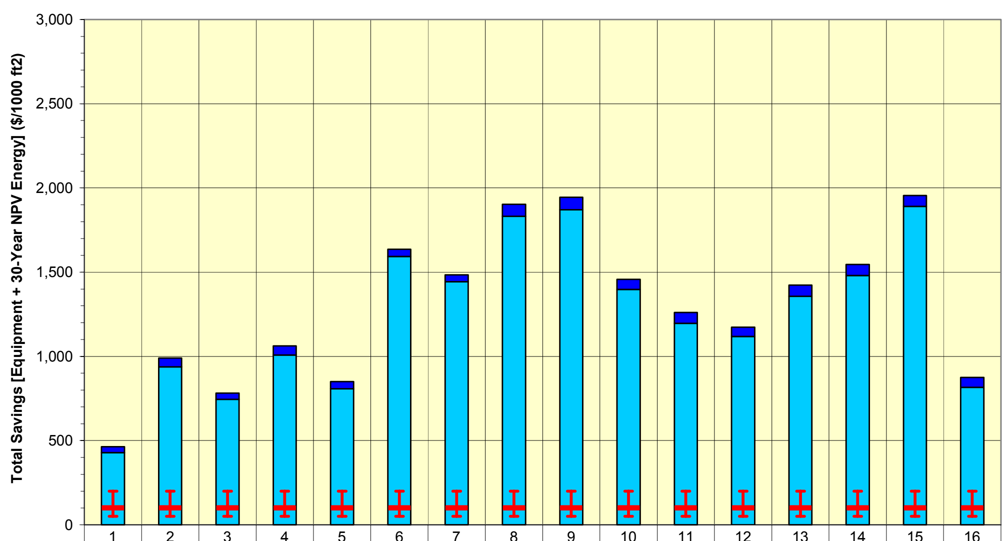



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equip | 33 | 48 | 33 | 51 | 37 | 44 | 34 | 62 | 65 | 55 | 58 | 51 | 63 | 60 | 60 | 55 |
| Energy | 351 | 817 | 639 | 889 | 688 | 1,364 | 1,230 | 1,570 | 1,608 | 1,247 | 1,073 | 998 | 1,222 | 1,328 | 1,720 | 703 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

(f)

Metal (Leaky T-Bar Ceiling, Heavy-Mass Interior, FSK-Faced Insulation)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equip | 35 | 52 | 37 | 55 | 42 | 43 | 41 | 72 | 74 | 59 | 65 | 55 | 66 | 66 | 65 | 59 |
| Energy | 429 | 938 | 745 | 1,008 | 808 | 1,593 | 1,443 | 1,831 | 1,870 | 1,398 | 1,196 | 1,119 | 1,357 | 1,480 | 1,890 | 816 |
| $0.10/ft2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

California Climate Zone

# Attachment 1

## Types of buildings subject to California's 2005 Title 24 cool roof requirements:

Note: Qualifying historic buildings are exempt from any cool roof regulations.(Source: CBC, Title 24, Part 2, Chapter 3)

*Group A – Assembly*

Building or structure, or portion thereof, for the gathering of 50 or more persons for purposes such as civic, social or religious functions, recreation, instruction, food or drink consumption, or awaiting transportation. Examples: restaurants, arenas, churches, theaters.

*Group B – Business*

Building or structure, or portion thereof, for office, professional or service-type transactions; includes storage of records and accounts and restaurants with occupant load less than 50. Examples: animal hospitals, kennels, automobile showrooms, banks, barber shops, outpatient clinic and medical offices, educational occupancies above the 12th grade, fire stations, florists and nurseries, testing and research labs, print shops, radio and TV stations

*Group E – Educational (through 12th grade)*

Building or structure, or portion thereof, for educational purposes through 12th grade for more than 12 hours per week or 4 hours in any one day. Examples: schools, nonresidential buildings used for daycare for more than six children, residential buildings used as daycare for more than 14 persons.

*Group F – Factory (low- and moderate-hazard)*

Building or structure, or portion thereof, for fabricating, manufacturing, packaging, processing, etc. Examples: furniture manufacturing, bakeries, food processing plants, paper mills, printing or publishing facilities, refuse incineration, shoe factories, dry cleaning facilities.

*Group H – Hazardous facilities*

Building or structure, or portion thereof, that involves the manufacturing, processing, generation or storage of materials that constitute a high fire, explosion, or health hazard. Examples: manufacturing plants for explosives, blasting agents, fireworks, flammable gases; storage facilities for such products.

*Group M – Mercantile (sale of merchandise)*

Building or structure, or portion thereof, for the display and sale of merchandise. Examples: department stores, shopping centers, wholesale and retail stores, markets.

*Group S – Storage facilities*

Building or structure, or portion thereof, for storage not classified as a hazardous occupancy. Examples: storage of beer or wine in metal, glass, or ceramic containers, of cement in bags, of foods in noncombustible containers, of gypsum board, of stoves, washers, and dryers.

*Group U – Utility facilities*

Private garages, carports, sheds, agricultural buildings, and towers.

## Types of buildings which are exempt from California's 2005 Title 24 cool roof requirements but would be required to have cool roofs under the proposed standards:

*Group I – Institutions*

Hospitals, sanitoriums, nursing homes with nonambulatory patients with more than 5 patients; nursing homes for ambulatory patients; mental hospitals, jails, prisons; nurseries for the full-time care of at least 5 children under the age of 6.

## Types of buildings that under the 2005 Title 24 cool roofs are optional — not prescriptive — (with this CASE study, we are proposing cool roofs prescriptive requirements for some building types):

- Unconditioned warehouses and other buildings

- “Process spaces” – not meant for human occupancy, held at temperatures less than 55°F or greater than 90°F
- Buildings cooled by swamp coolers/evaporative coolers
- High-rise residential buildings (4 stories and more) (Will require to have cool roofs under a proposed standard for residential buildings)
- Hotels and motels (Will require to have cool roofs under the proposed standard)
- Any roof with slope greater than 2:12 (Will require to have cool roofs under a proposed standard for residential buildings)

*Attachment 2*

## Proposed Standards Language: Solar Reflectance and Thermal Emittance of Residential and Nonresidential Roofs 2008

In two parallel studies, we have analyzed the consequences of prescribing minimum values for the solar reflectance and thermal emittance of roofs on residential and non-residential buildings. The following proposed standards language modifies solar reflectance and thermal emittance requirements for all building types (both residential and non-residential).

The proposed standards language prescribes for all buildings with a steep-sloped roof a minimum 3-year-aged reflectance that varies with 3-year-aged thermal emittance. If the three-year-aged thermal emittance is greater than or equal to 0.75, the required 3-year-aged solar reflectance is 0.25 for fiberglass asphalt shingles, and 0.40 for other roofing materials, including but not limited to concrete tile, clay tile, and metal. If the three-year-aged thermal emittance $\varepsilon_{aged}$ is less than 0.75, the required 3-year-aged solar reflectance is $0.40 + 0.31 * (0.75 - \varepsilon_{aged})$ for all roofing products.

The proposed standards language prescribes for all buildings with a low-sloped roof a minimum 3-year-aged reflectance that varies with 3-year-aged thermal emittance. If the three-year-aged thermal emittance is greater than or equal to 0.75, the required 3-year-aged solar reflectance is 0.55 for all roofing products. If the three-year-aged thermal emittance $\varepsilon_{aged}$ is less than 0.75, the required 3-year-aged solar reflectance is $0.55 + 0.24 * (0.75 - \varepsilon_{aged})$ for all roofing products.

The proposed language changes the standard to use the reflectances and emittance described above. All proposed buildings shall use the CRRC-certified values for 3-year-aged solar reflectance and 3-year-aged thermal emittance (or a default 3-year-aged solar reflectance of 0.10 and a default 3-year-aged thermal emittance of 0.75 if CRRC values are unavailable).

The prescriptions for roofing products are revised to replace requirements for initial values of solar reflectance and thermal emittance with requirement for the three-year-aged values of these properties.

California Title 24 AB 970
Energy Efficiency Standards for Residential and Nonresidential Buildings (<u>October 1, 2005</u>)

**Proposed additions are <u>underlined</u> and deletions are ~~struck~~.**

*Section 101 – Definitions and Rules Of Construction*

<u>STEEP-SLOPED ROOF is a roof that has a ratio of rise to run exceeding 2:12.</u>

*Section 118 – Mandatory Requirements for Insulation<u>, Roof Solar Reflectance, and Roof Thermal Emittance</u> ~~and Cool Roofs~~*

**(i) Mandatory Requirements for ~~Cool~~ Roof <u>Solar Reflectance and Thermal Emittance</u>. ~~In order to qualify for compliance credit as a cool roof or meet the requirements of Section 143 (a) 1 or 149 (b) 1 B, a cool roof~~ <u>A roof</u> shall be certified and labeled according to the requirements of Section 10-113 and meet conditions 1 or 2 and, for liquid applied roofing products, 3 below.**

~~**1. Any roofing product with an initial thermal emittance greater than or equal to 0.75 when tested in accordance with CRRC-1 shall have a minimum initial solar reflectance of 0.70 when tested in accordance with CRRC-1.**~~

~~**EXCEPTION to Section 118 (i) 1: For low-rise residential buildings, concrete tile (as defined in ASTM C55) and clay tile (as defined in ASTM C1167) roofing products shall have a minimum initial thermal emittance of 0.75 and a minimum initial solar reflectance of 0.40 when tested in accordance with CRRC-1.**~~

~~**2. Any roofing product with a minimum initial thermal emittance $\varepsilon_{initial}$ less than 0.75 when tested in accordance with CRRC-1, including but not limited to roof products with metallic surfaces, shall have a minimum initial solar reflectance of 0.70 + 0.34 * (0.75 - $\varepsilon_{initial}$) when tested in accordance with CRRC-1.**~~

**1. <u>For all buildings with low-sloped-roofs:</u>**

**<u>a. any roofing product with a 3-year aged thermal emittance greater than or equal to 0.75 as determined by Section 118 (i) 4 shall have a minimum 3-year aged solar reflectance of 0.55 as determined by Section 118 (i) 4..</u>**

b. any roofing product with a 3-year aged thermal emittance less than 0.75 as determined by Section 118 (i) 4 shall have a minimum 3-year aged solar reflectance of
$0.55 + 0.24 * (0.75 - \varepsilon_{aged})$ as determined by Section 118 (i) 4.

2. For all buildings with steep-sloped roofs:

a. for any roofing product with a 3-year aged thermal emittance greater than or equal to 0.75 as determined by Section 118 (i) 4:

i. fiberglass asphalt shingles shall have a minimum 3-year aged solar reflectance of 0.25 as determined by Section 118 (i) 4.

ii. all other roofing products including but not limited to metal, concrete tile, and clay tile shall have a minimum 3-year aged solar reflectance of 0.40 as determined by Section 118 (i) 4.

b. any roofing product with a 3-year aged thermal emittance less than 0.75 when tested in accordance with CRRC-1 shall have a minimum 3-year aged solar reflectance of $0.40 + 0.31 * (0.75 - \varepsilon_{aged})$ as determined by Section 118 (i) 4.

EXCEPTION to Section 118 (i) 1: For low-rise residential buildings with low-sloped roofs, the prescriptive requirements for solar reflectance and thermal emittance are waived in California Climate Zones 1 through 9 and 12. For low-rise residential buildings with steep-sloped roofs, the prescriptive requirement for solar reflectance and thermal emittance are waived in California Climate Zones 1 through 8.

4. Three-year-aged values of solar reflectance and thermal emittance are determined as follows.

a. If the product's three-year-aged values of solar reflectance and thermal emittance have been certified and labeled according to CRRC-1, these values must be used.

b. If the product's initial values of solar reflectance and thermal emittance have been certified and labeled according to CRRC-1, but the product's initial values of solar reflectance and thermal emittance have not been certified and labeled according to CRRC-1, the product's three-year-aged solar reflectance $\rho_{aged}$ and three-year-aged thermal emittance $\varepsilon_{aged}$ are estimated from its CRRC-1 compliant values of initial solar reflectance $\rho_{initial}$ and initial thermal emittance $\varepsilon_{initial}$ using the following two formulas:

$$\rho_{aged} = 0.2 + 0.7 * (\rho_{initial} - 0.2)$$

$$\varepsilon_{aged} = \varepsilon_{initial}$$

c. If neither three-year-aged nor initial values of the product's solar reflectance and thermal emittance have been certified and labeled according to CRRC-1, the product will be assigned a default three-year-aged solar reflectance of 0.10 and a default three-year-aged thermal emittance of 0.75.

### *Section 143 – Prescriptive Requirements for Building Envelopes*

A building complies with this section by being designed with and having constructed and installed either (1) envelope components that comply with each of the requirements in Subsection (a) for each individual component and the requirements of Subsection (c) where they apply, or (2) an envelope that complies with the overall requirements in Subsection (b) and the requirements of Subsection (c) where they apply. When making calculations under Subsection (a) or (b), all of the rules listed in Section 141 (c) 1, 4, and 5 shall apply.

(a) Envelope Component Approach.

1.**Exterior roofs and ceilings.** Exterior roofs and ceilings shall:

A. For nonresidential buildings with low-sloped roofs, meet the requirements of either 118 (i) 1 or 118 (i) 2 and for liquid applied roof coatings, Section 118 (i) 3; and

~~**EXCEPTION to Section 143 (a) 1 A:** Any roofing product with a minimum initial thermal emittance $\varepsilon_{initial}$ less than 0.75 when tested in accordance with CRRC-1, including but not limited to roof products with metallic surfaces, if that roofing product has a minimum initial solar reflectance of 0.70 + 0.34 * (0.75 - $\varepsilon_{initial}$) when tested in accordance with CRRC-1.~~

(b) Overall Envelope Approach

2. Overall heat gain

EQUATION (1-D)—STANDARD BUILDING HEAT GAIN EQUATION

$$
\begin{aligned}
HG_{std} = & \sum_{i=1}^{nW}\left(A_{Wi}\times U_{Wi_{std}}\times TF_i\right)\\
& +\sum_{i=1}^{nF}\left(A_{Fi}\times U_{Fi_{std}}\times TF_i\right)\\
& +\sum_{i=1}^{nR}\left(A_{Ri}\times U_{Ri_{std}}\times TF_i\right)\\
& +\sum_{i=1}^{nG}\left(A_{Gi}\times U_{Gi_{std}}\times TF_i\right)\\
& +\sum_{i=1}^{nS}\left(A_{Si}\times U_{Si_{std}}\times TF_i\right)\\
& +\sum_{i=1}^{nG}\left(WF_{Gi}\times A_{Gi}\times RSHG_{Gi_{std}}\right)\times SF\\
& +\sum_{i=1}^{nS}\left(WF_{Si}\times A_{Si}\times SHGC_{Si_{std}}\right)\times SF
\end{aligned}
$$

$$
+\sum_{i=1}^{nR}\left(WF_{Ri}\times A_{Ri}\times U_{Ri_{std}}\times \cancel{\left[1-\left(0.2+0.7\left[\rho_{Ri_{std}}-0.2\right]\right)\right]}\ \underline{[1-\rho_{Ri_{std}}]}\right)\times SF
$$

$\rho_{Ri_{std}}$ = ~~Initial~~ Three-year aged solar reflectance of the roofing product for the corresponding $A_{Ri}$. The roof of the standard building has ~~an initial~~ a 3-year-aged solar reflectance of ~~0.70~~ 0.55 for ~~nonresidential~~ all buildings with low-sloped roofs, ~~and an initial solar reflectance of 0.30 for nonresidential buildings with high-sloped roofs, for high-rise residential buildings, and for guest rooms of hotel/motel buildings.~~ a 3-year-aged solar reflectance of 0.25 for steep-sloped fiberglass asphalt shingle roofs, and a 3-year-aged solar reflectance of 0.40 for all other types of steep-sloped roofs (including but not limited to steep-sloped metal, concrete tile, and clay tile roofs).

EQUATION (1-E)—PROPOSED BUILDING HEAT GAIN EQUATION

$$
\begin{aligned}
HG_{prop} = & \sum_{i=1}^{nW}\left(A_{Wi}\times U_{Wi_{prop}}\times TF_i\right) \\
& +\sum_{i=1}^{nF}\left(A_{Fi}\times U_{Fi_{prop}}\times TF_i\right) \\
& +\sum_{i=1}^{nR}\left(A_{Ri}\times U_{Ri_{prop}}\times TF_i\right) \\
& +\sum_{i=1}^{nG}\left(A_{Gi}\times U_{Gi_{prop}}\times TF_i\right) \\
& +\sum_{i=1}^{nS}\left(A_{Si}\times U_{Si_{prop}}\times TF_i\right) \\
& +\sum_{i=1}^{nG}\left(WF_{Gi}\times A_{Gi}\times RSHG_{Gi_{prop}}\right)\times SF \\
& +\sum_{i=1}^{nS}\left(WF_{Si}\times A_{Si}\times SHGC_{Si_{prop}}\right)\times SF
\end{aligned}
$$

$$
+\sum_{i=1}^{nR}\left(WF_{Ri}\times A_{Ri}\times U_{Ri_{prop}}\times \left[1-\left(0.2+0.7\left[\rho_{Ri_{prop}}-0.2\right]\right)\right][1-\rho_{Rj_{prop}}]\right)\times SF
$$

$\rho_{Rj_{prop}}$ = The ~~initial~~ 3-year-aged solar reflectance of the proposed design roofing product for the corresponding $A_{Rj}$, as determined by Section 118 (i) 4. If the roofing product has an emittance less than 0.75 the value shall be calculated by the following equation:

[Charles Eley and LBNL to work to update the following equation.]

$\rho_{Rj_{prop}}$ = -0.448 + 1.121 * R + 0.524 * E

Where

R = reflectance of the roofing product

E = emittance of the roofing product

The calculated value of $\rho_{Rj_{prop}}$ from the above equation shall not be larger than R or less than 0.10.

~~If the proposed design roofing product used has not been certified and labeled according to the requirements of 10-113 and/or does not meet the requirements of Section 118 (i) 3, the proposed design initial~~ 3-year-aged ~~solar reflectance shall be~~

~~0.10 for nonresidential buildings with low-sloped roofs, or 0.30 for nonresidential buildings with high-sloped roofs, high-rise residential buildings, and guest rooms in hotel/motel buildings~~.

*Section 149 – Additions, Alterations, and Repairs to Existing Buildings That Will Be Nonresidential, High-Rise Residential, and Motel/Hotel Occupancies*

(b) Alterations

1. Prescriptive Approach

B. Replacements, recovering or recoating of the exterior surface of existing nonresidential low-sloped <u>and steep sloped</u> roofs shall meet Subsection i or ii where more than fifty percent of the roof or more than 2,000 square feet of roof, whichever is less, is being replaced, recovered or recoated.

*SECTION 152 – ENERGY EFFICIENCY STANDARDS FOR ADDITIONS AND ALTERATIONS IN EXISTING BUILDINGS THAT WILL BE LOW-RISE RESIDENTIAL OCCUPANCIES*

[LBNL needs help to write the corresponding language for the residential addition and alteration. The new section should parallel section 149 (b) 1 B.]

## Proposed ACM Language

*Nonresidential Alternative*
*Calculation Approval Method*

2.3.2.3 Solar Reflectance and Thermal Emittance

Description

The combination of solar reflectance and thermal emittance are the reflective and radiative properties of exterior surfaces. With the performance method any combination of reflectance and emittance is recognized for credit or penalty. A cool roof, as defined in the Standards,

a. for low-sloped roofs, has a minimum ~~initial~~ <u>3-year-aged</u> solar reflectance of 0.55 and minimum ~~initial~~ <u>3-year-aged thermal</u> emittance of 0.75

b. for steep-sloped roofs:

1. asphalt shingles: 3-year-aged solar reflectance of 0.25 and minimum 3-year-aged thermal emittance of 0.75,

2. all other roofing products including but not limited to metal, concrete tile, and clay tile: 3-year-aged solar reflectance of 0.40 and minimum 3-year-aged thermal emittance of 0.75,

*Modeling Rules for Reference Design (All):*

Nonresidential low -sloped roofs - the initial roof absorptance of the standard design shall be 0.30 (initial reflectance of 0.70). The emittance in the standard design shall be 0.75.

Other nonresidential roofs, high-rise residential and hotel/motel roofs – the initial roof absorptance of the standard design shall be 0.70. The emittance in the standard design shall be 0.75.

For all other roofs as well as walls and floors, the default reflectance and emittance shall be used.

The reference method shall use an aged absorptance value to model the proposed design roof. The ACM shall calculate the aged absorptance, $\alpha_{aged}$ , from the following equation:

Equation N2 -2 aged = 0.8 + 0.7 ( init – 0.8)

where init is the initial absorptance of the roofing product. The aged emittance shall be equal to the initial emittance.

There are two compliance cases, one for nonresidential roofs with low -slopes and the second for other nonresidential roofs, high -rise residential and hotel/motel roofs.

Other nonresidential roofs, high-rise residential and hotel/motel roofs – roofs that meet the requirements of Section 118 (i) 3 qualify for a compliance credit. ……. bare metal, galvanized steel and aluminum coating.