Energy Savings in High-Rise Buildings Using High-Reflective Coatings

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Executive Summary:

"Nevertheless, the simulation analyses showed that when designing a building for low energy consumption, even in cold climates, high-reflectance coatings should be specified for walls, window frames and roofing."

Architectural Energy Corp., (AEC) performed simulation analyses on a high-rise building to evaluate the energy saving potential of high-reflectance coatings on three surface types – walls, window frames and roofs – in a variety of climates.

Using the DOE 2.2 (the simulation engine of eQUEST®), AEC simulated the energy performance of a generic eight-story office building in 12 North American cities. Surface reflectance was set between 5 percent and 70 percent for all three surface types, then compared to a baseline building, which had reflectances set at 5 percent across all three surface types.

The AEC analyses showed that high-reflectance coatings reduced energy costs significantly in warm and hot climates, and less so in the coldest climates, as would be expected. Other findings:

- *When wall reflectance was increased to 70 percent from 5 percent, energy savings as a percentage of total building energy cost ranged from 0.4 to 2.4 percent, depending on location.*
- *When reflectance for window frames was similarly adjusted, energy savings as a percentage of total building energy cost ranged from 0.4 to 1.2 percent.*
- *When roof reflectance was increased to 70 percent, savings ranged from zero to 0.8 percent. Cool roof savings also are limited in comparison to other surface areas, because on tall buildings, a well-insulated roof only accounts for a small portion of its surface area. It should also be noted that higher surface reflectances reduce design airflow in all cases.*

Building configuration, HVAC system type, and local climate all are significant factors in determining a building's potential energy savings. Nevertheless, the simulation analyses showed that when designing a building for low energy consumption, even in cold climates, high-reflectance coatings should be specified for walls, window frames and roofing.

Introduction:

Buildings account for 39 percent of the energy consumed in the United States, according to the U.S. Energy Information Administration (EIA, 2010). With current concerns over global warming and the associated impacts of energy consumption, energy efficiency has become a critical part of building design. The U.S. Department of Energy has a goal of achieving net-zero energy commercial buildings that will be commercially marketable by 2025.

Improving the energy efficiency of buildings involves a wide variety of approaches and design options, including:

- *Building orientation and configuration for solar control*
- *Increased wall and roof insulation*
- *Air sealing to reduce infiltration*
- *Improved windows to optimize solar heat gain and visible light, while reducing air leakage and heat loss*
- *Improved lighting system design*
- *Daylighting controls and occupancy sensors*
- *Reduced plug loads and controls to turn off equipment*
- *Improved HVAC system designs*

In addition to these strategies, so-called "white roofs" have become standard practice in many applications. These roofs feature high reflectance values to reduce the heat gain from solar radiation falling on the roof. White membrane roofs are widely used, particularly in warmer climates, and on warehouse and big-box buildings.

To increase the aesthetic options available to architects and building owners, PPG has introduced a line of coatings in a wide range of colors that yield high surface reflectances. These "cool" coatings can be applied to exterior walls, window frames and roofing. This paper describes the approach and results of a project to evaluate the energy savings potential of high-reflectance coatings by PPG in a variety of climates.

Approach:

AEC conducted a simulation analysis to evaluate the energy consumption effects of high-reflectance coatings on a generic eight-story office building using eQUEST/DOE 2.2, the most accurate building energy modeling software available in the United States. Details of the modeling are described on page 3.

Simulations were run with reflectance values of 0.05, 0.25, 0.35, 0.55, 0.65 and 0.70 on the walls, window frames and roofs. The resulting energy consumption was compared to the baseline building, which has reflectance on all three surface types set at 0.05.

In order to examine the impact of climate on the results, simulations were performed using weather data for 12 cities in a representative range of climates. The cities and weather files were:

City	Weather File
Atlanta	Hartsfield-Jackson Int'l Airport TMY3
Boston	Logan Int'l Airport TMY2
Chicago	Midway International Airport TMY3
Denver	Denver International Airport TMY3
Houston	George Bush Intercontinental Airport TMY3
Los Angeles	Los Angeles International Airport TMY3
Mexico City	Mexico City 1991
Ottawa	Ottawa CWEC
Philadelphia	Philadelphia International Airport TMY3
Phoenix	Sky Harbor International Airport TMY3
Seattle	Seattle-Tacoma International Airport TMY3
St. Louis	Lambert-St. Louis International Airport TMY3

Results are presented using a number of metrics including: energy cost savings, energy cost percentage savings, and simulation auto-sized design airflow capacity.

Modeled Building:

The generic eight-story office building was modeled with 241,000 square feet of floor area and a slightly rectangular footprint, with five zones per floor. Wall insulation was varied by location, based on the minimum requirements of ASHRAE Standard 90.1-2007. Roof insulation was R-20 continuous insulation, as specified by Standard 90.1-2007 for all of the modeled locations. Table 1 provides additional details on the building envelope. Table 2 provides details on internal loads of the building. Table 3 describes the heating and cooling systems.

Energy costs were found using U.S. average rates for commercial customers, as of September 2009, as provided by EIA. Electricity cost is $0.1051/kWh and natural gas is $0.898/therm.

Table 1 – Envelope Data

Glass Type	Double-pane, low-e coated or tinted
Glass SHGC	0.32
Glass U-Value (w/o framing)	0.35 Btuh/ft^2/°F
Window Frame Type & U-value	Thermally broken aluminum (1.25 Btuh/sf-F)
Window Frame Width	2.5” (9% of gross window area)
Window to Wall Ratio	30% of 14’ floor-floor wall area

AEC assumed the use of thermally broken frames to produce conservative savings estimates. Frames *without* a thermal break have default U-values that are double those of the frames modeled in this analysis. Thermal-break frames are common in cold climates but less so in warm climates, where heat gain reduction from low-reflectance coatings is most valuable.

Table 2 – Internal Load Data

Occupancy	200 ft^2/person
Lighting Power	1.0 W/ft^2
Plug Loads	1.0 W/ft^2
Infiltration Rate	0.3 AC/hr in perimeter zones when the building is unpressurized (unoccupied)
Ventilation Rate	20 cfm/person

Table 3 – HVAC Systems

System Type	VAV-Reheat
Cooling Source	Centrifugal Chiller
Cooling Efficiency	0.576 kW/ton
Heating	Hot-Water Reheat
Heating Source	Gas Boiler
Heating Efficiency	80% at full load
Economizer	Differential Enthalpy
VAV Box Minimum	30% of Design
Minimum Design Airflow	0.85 cfm/gsf
Supply Air Temperature Control	55ºF, reset up to a maximum of 60ºF below 55ºF outdoor air
Operating Hours	5 full days and two half-days per week. Fan cycles to meet zone thermostat set up/back at other hours

Results for Walls:

Table 4 below shows the annual energy cost savings for increasing wall reflectance, and Table 5 shows these savings as a percentage of total building energy cost.

Table 4 – Energy Cost Savings for Increasing Wall Reflectance

Wall Reflectance	5%	25%	35%	55%	65%	70%
Atlanta	$0	$1,175	$1,624	$2,680	$3,178	$3,443
Boston	$0	$334	$533	$951	$1,120	$1,232
Chicago	$0	$336	$545	$977	$1,167	$1,283
Denver/Boulder	$0	$191	$493	$1,060	$1,357	$1,559
Houston	$0	$2,217	$3,335	$5,358	$6,464	$6,918
Los Angeles	$0	$950	$1,452	$2,399	$2,842	$3,061
Mexico City	$0	$1,478	$2,254	$3,848	$4,709	$5,147
Ottawa	$0	$344	$536	$882	$1,076	$1,178
Philadelphia	$0	$547	$815	$1,505	$1,789	$1,941
Phoenix	$0	$2,120	$3,314	$5,934	$7,288	$7,886
Seattle	$0	$440	$672	$1,160	$1,383	$1,510
St. Louis	$0	$524	$792	$1,306	$1,615	$1,770

Table 5 – Energy Cost Percentage Savings for Increasing Wall Reflectance

Wall Reflectance	5%	25%	35%	55%	65%	70%
Atlanta	0.00%	0.39%	0.53%	0.88%	1.04%	1.13%
Boston	0.00%	0.12%	0.19%	0.33%	0.39%	0.43%
Chicago	0.00%	0.11%	0.18%	0.33%	0.39%	0.43%
Denver/Boulder	0.00%	0.07%	0.17%	0.36%	0.47%	0.53%
Houston	0.00%	0.68%	1.02%	1.64%	1.98%	2.12%
Los Angeles	0.00%	0.34%	0.51%	0.85%	1.01%	1.09%
Mexico City	0.00%	0.50%	0.76%	1.31%	1.60%	1.75%
Ottawa	0.00%	0.11%	0.18%	0.29%	0.36%	0.39%
Philadelphia	0.00%	0.19%	0.28%	0.51%	0.61%	0.66%
Phoenix	0.00%	0.63%	0.98%	1.76%	2.16%	2.33%
Seattle	0.00%	0.16%	0.25%	0.43%	0.51%	0.56%
St. Louis	0.00%	0.17%	0.26%	0.43%	0.53%	0.58%

The price difference between standard fluoropolymer coatings and heat-reflective coatings on metal walls is relatively minor, yet the small premium paid for heat-reflective coatings pays for itself many times over in energy savings for the building owner. This is true even in cold climates, where the modeled energy savings are smaller than for warmer locales.

Table 6 shows the design airflow reduction. Combined with other measures, air handling unit (AHU) sizing could be reduced, or design fan speed and fan brake horse power (BHP) could be reduced within the same AHU. As expected, the reductions are greatest in hot, sunny climates.

Table 6 – Design Airflow Reduction for Increasing Wall Reflectance

Wall Reflectance	5%	25%	35%	55%	65%	70%
Atlanta	0.00%	0.90%	1.31%	2.12%	2.54%	2.75%
Boston	0.00%	0.53%	0.81%	1.36%	1.65%	1.79%
Chicago	0.00%	0.50%	0.75%	1.28%	1.54%	1.68%
Denver/Boulder	0.00%	0.61%	0.92%	1.57%	1.91%	2.09%
Houston	0.00%	1.50%	2.25%	3.73%	4.44%	4.76%
Los Angeles	0.00%	0.73%	1.11%	1.86%	2.25%	2.45%
Mexico City	0.00%	1.01%	1.51%	2.45%	2.95%	3.21%
Ottawa	0.00%	0.59%	0.89%	1.51%	1.84%	2.01%
Philadelphia	0.00%	0.57%	0.86%	1.46%	1.77%	1.93%
Phoenix	0.00%	1.48%	2.25%	3.69%	4.44%	4.82%
Seattle	0.00%	0.62%	0.93%	1.60%	1.94%	2.11%
St. Louis	0.00%	0.52%	0.78%	1.32%	1.59%	1.73%

Results for Window Frames:

Table 7 below shows the annual energy cost savings for increasing window frame reflectance, and Table 8 shows these savings as a percentage of total building energy cost.

Table 7 – Energy Cost Savings for Increasing Window Frame Reflectance

Frame Reflectance	5%	25%	35%	55%	65%	70%
Atlanta	$0	$892	$1,238	$1,964	$2,364	$2,545
Boston	$0	$331	$524	$925	$1,096	$1,184
Chicago	$0	$359	$534	$889	$1,117	$1,196
Denver/Boulder	$0	$511	$747	$1,294	$1,582	$1,749
Houston	$0	$902	$1,288	$2,214	$2,687	$2,894
Los Angeles	$0	$747	$1,163	$1,982	$2,390	$2,594
Mexico City	$0	$1,031	$1,572	$2,662	$3,179	$3,478
Ottawa	$0	$317	$514	$874	$1,046	$1,107
Philadelphia	$0	$505	$746	$1,338	$1,659	$1,789
Phoenix	$0	$914	$1,345	$2,328	$2,809	$3,055
Seattle	$0	$426	$622	$1,067	$1,320	$1,429
St. Louis	$0	$475	$702	$1,248	$1,470	$1,611

Table 8 – Energy Cost Percentage Savings for Increasing Window Frame Reflectance

Frame Reflectance	5%	25%	35%	55%	65%	70%
Atlanta	0.00%	0.29%	0.41%	0.64%	0.78%	0.84%
Boston	0.00%	0.12%	0.18%	0.32%	0.38%	0.41%
Chicago	0.00%	0.12%	0.18%	0.30%	0.37%	0.40%
Denver/Boulder	0.00%	0.18%	0.26%	0.44%	0.54%	0.60%
Houston	0.00%	0.28%	0.39%	0.68%	0.82%	0.89%
Los Angeles	0.00%	0.26%	0.41%	0.70%	0.85%	0.92%
Mexico City	0.00%	0.35%	0.53%	0.90%	1.08%	1.18%
Ottawa	0.00%	0.11%	0.17%	0.29%	0.35%	0.37%
Philadelphia	0.00%	0.17%	0.25%	0.45%	0.56%	0.61%
Phoenix	0.00%	0.27%	0.40%	0.69%	0.83%	0.90%
Seattle	0.00%	0.16%	0.23%	0.40%	0.49%	0.53%
St. Louis	0.00%	0.16%	0.23%	0.41%	0.48%	0.53%

The price difference between standard fluoropolymer coatings and heat-reflective coatings on metal window frames is relatively minor, yet the small premium paid for heat-reflective coatings pays for itself many times over in energy savings for the building owner. This is true even in cold climates, where the modeled energy savings are smaller than for warmer locales.

Table 9 shows the design airflow or fan sizing reductions that can be achieved. While individually small, these become significant when combined with other measures.

Table 9 – Design Airflow Reduction for Increasing Window Frame Reflectance

Frame Reflectance	5%	25%	35%	55%	65%	70%
Atlanta	0.00%	0.69%	1.03%	1.64%	1.95%	2.11%
Boston	0.00%	0.54%	0.82%	1.38%	1.66%	1.81%
Chicago	0.00%	0.51%	0.77%	1.30%	1.58%	1.71%
Denver/Boulder	0.00%	0.58%	0.88%	1.49%	1.80%	1.95%
Houston	0.00%	0.63%	0.95%	1.61%	1.95%	2.12%
Los Angeles	0.00%	0.61%	0.92%	1.56%	1.88%	2.05%
Mexico City	0.00%	0.73%	1.11%	1.84%	2.19%	2.36%
Ottawa	0.00%	0.58%	0.88%	1.48%	1.79%	1.95%
Philadelphia	0.00%	0.56%	0.85%	1.43%	1.72%	1.87%
Phoenix	0.00%	0.64%	0.97%	1.65%	2.00%	2.18%
Seattle	0.00%	0.62%	0.93%	1.58%	1.89%	2.05%
St. Louis	0.00%	0.51%	0.78%	1.31%	1.58%	1.72%

Results for Roofs:

Table 10 below shows the energy cost savings for increasing roof reflectance, and Table 11 shows these savings as a percentage of total building energy cost. Because the building is tall, the ratio of roof to surface or floor area is small, and increased roof reflectance is less significant than the increased reflectance of other surfaces. The surprising small negative savings for Denver/Boulder results from a penalty in cold, sunny weather, which is more common there. Also, at these very small savings, simulation non-linearities cause some inflection points in the savings.

Table 10 – Energy Cost Savings for Increasing Roof Reflectance

Roof Reflectance	5%	25%	35%	55%	65%	70%
Atlanta	$0	$541	$708	$1,032	$1,269	$1,393
Boston	$0	$62	$47	$131	$90	$82
Chicago	$0	$116	$190	$359	$367	$385
Denver/Boulder	$0	-$113	-$32	$119	$184	$210
Houston	$0	$646	$917	$1,499	$1,797	$1,939
Los Angeles	$0	$348	$518	$736	$811	$828
Mexico City	$0	$841	$1,225	$1,869	$2,105	$2,219
Ottawa	$0	$101	$117	$123	$61	$39
Philadelphia	$0	$193	$364	$591	$696	$730
Phoenix	$0	$734	$1,107	$1,955	$2,410	$2,629
Seattle	$0	$120	$130	$177	$163	$143
St. Louis	$0	$274	$432	$653	$821	$884

Table 11 – Energy Cost Percentage Savings for Increasing Roof Reflectance

Roof Reflectance	5%	25%	35%	55%	65%	70%
Atlanta	0.00%	0.18%	0.23%	0.34%	0.42%	0.46%
Boston	0.00%	0.02%	0.02%	0.05%	0.03%	0.03%
Chicago	0.00%	0.04%	0.06%	0.12%	0.12%	0.13%
Denver/Boulder	0.00%	-0.04%	-0.01%	0.04%	0.06%	0.07%
Houston	0.00%	0.20%	0.28%	0.46%	0.55%	0.59%
Los Angeles	0.00%	0.12%	0.18%	0.26%	0.29%	0.29%
Mexico City	0.00%	0.29%	0.42%	0.63%	0.71%	0.75%
Ottawa	0.00%	0.03%	0.04%	0.04%	0.02%	0.01%
Philadelphia	0.00%	0.07%	0.12%	0.20%	0.24%	0.25%
Phoenix	0.00%	0.22%	0.33%	0.58%	0.71%	0.78%
Seattle	0.00%	0.04%	0.05%	0.07%	0.06%	0.05%
St. Louis	0.00%	0.09%	0.14%	0.21%	0.27%	0.29%

Table 12 shows the modeled design airflow reduction. These are much smaller than other airflow reductions because the roof area is small in proportion to the wall and window area.

Table 12 – Design Airflow Reduction for Increasing Roof Reflectance

Roof Reflectance	5%	25%	35%	55%	65%	70%
Atlanta	0.00%	0.04%	0.07%	0.11%	0.13%	0.15%
Boston	0.00%	0.03%	0.05%	0.08%	0.10%	0.10%
Chicago	0.00%	0.03%	0.04%	0.07%	0.08%	0.09%
Denver/Boulder	0.00%	0.04%	0.05%	0.09%	0.12%	0.13%
Houston	0.00%	0.04%	0.06%	0.10%	0.12%	0.13%
Los Angeles	0.00%	0.03%	0.05%	0.08%	0.10%	0.11%
Mexico City	0.00%	0.05%	0.07%	0.13%	0.16%	0.17%
Ottawa	0.00%	0.03%	0.05%	0.09%	0.11%	0.12%
Philadelphia	0.00%	0.03%	0.05%	0.08%	0.10%	0.10%
Phoenix	0.00%	0.05%	0.07%	0.12%	0.15%	0.16%
Seattle	0.00%	0.03%	0.05%	0.09%	0.11%	0.11%
St. Louis	0.00%	0.03%	0.04%	0.08%	0.09%	0.10%

Results for Walls, Window Frames and Roofs with 70% Reflectance:

In addition to the analyses where high-reflectance coatings were applied to the walls, window frames and roof individually, the building was also analyzed with reflectance for all three surface types set to 70 percent. These results are shown in Table 13. As expected, combined savings are higher than savings for a single low-reflectance surface.

Table 13 – Savings for Walls, Window Frames and Roof Reflectance at 70% vs. 5%

Combined High-Reflectance Surfaces	Cost Savings	% Cost Savings	% Cooling Load Reduction	% Airflow/fan Size Reduction
Atlanta	$7,554	2.48%	2.90%	4.71%
Boston	$2,514	0.88%	2.05%	3.70%
Chicago	$2,782	0.93%	3.10%	3.30%
Denver/Boulder	$3,782	1.30%	4.57%	4.16%
Houston	$11,208	3.43%	3.75%	6.59%
Los Angeles	$6,055	2.15%	3.85%	4.17%
Mexico City	$10,746	3.65%	6.59%	5.45%
Ottawa	$2,001	0.66%	2.13%	3.87%
Philadelphia	$4,242	1.44%	2.33%	3.82%
Phoenix	$13,619	4.03%	5.16%	6.88%
Seattle	$2,942	1.09%	4.57%	4.17%
St. Louis	$4,329	1.43%	2.70%	3.51%

Conclusion:

As expected, the addition of high-reflectance coatings to building surfaces reduces heat gain through those surfaces. In cooler climates, there is a trade-off between increased heating load and decreased cooling load but reflective coatings still yield an advantage. The overall effect on energy consumption is dependent on the climate of the building. In hot climates, such as Atlanta, Houston, Los Angeles, Mexico City and Phoenix, significant energy savings can be achieved.

Similarly, AHUs typically are sized for the sensible cooling load and these units, as indicated by the design airflow, may also be downsized or the fan size decreased.

The results of these analyses indicate that significant energy savings from high-reflectance surface coatings are achievable not only with cool roofing products but also on vertical surfaces such as wall panels and window frames. These coatings also provide reductions in cooling loads and design airflows, potentially allowing equipment downsizing and first cost reductions.

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