# Effectiveness of Cool Roof Coatings with Ceramic Particles

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Cool roofs, coating, ceramic particles, solar reflectance, thermal emittance, thermal conductivity

## Abstract

Liquid applied coatings promoted as cool roof coatings, including several with ceramic particles, were tested at Oak Ridge National Laboratory (ORNL), Oak Ridge, Tenn., for the purpose of quantifying their thermal performances. Solar reflectance measurements were made for new samples and aged samples using a portable reflectometer (ASTM C1549**,** Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer) and for new samples using the integrating spheres method (ASTM E903, Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres). Thermal emittance was measured for the new samples using a portable emissometer (ASTM C1371, Standard Test Method for Determination of Emittance of Materials Near Room

Temperature Using Portable Emissometers). Thermal conductivity of the coatings was measured using a FOX 304 heat flow meter (ASTM C518, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus). The surface properties of the cool roof coatings had higher solar reflectance than the reference black and white material, but there were no significant differences among coatings with and without ceramics.

The coatings were applied to EPDM (ethylene propylene diene monomer) membranes and installed on the Roof Thermal Research Apparatus (RTRA), an instrumented facility at ORNL for testing roofs. Roof temperatures and heat flux through the roof were obtained for a year of exposure in east Tennessee. The field tests showed significant reduction in cooling required compared with the black reference roof (~80 percent) and a modest reduction in cooling compared with the white reference roof (~33 percent). The coating material with the highest solar reflectivity (no ceramic particles) demonstrated the best overall thermal performance (combination of reducing the cooling load cost and not incurring a large heating penalty cost) and suggests solar reflectivity is the significant characteristic for selecting cool roof coatings.

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## 1. Introduction

Cool roof system requirements are appearing in more building codes to promote energy-efficient buildings. Although there are various ways to design a cool roof system, one relatively simple way is based on highly reflective surface coatings. These coatings often appear white in the visible spectrum and have high solar reflectance values. One feature of cool roof coatings is the addition of ceramic particles to the coating mixture. Claims have been made that the ceramic particles improve the thermal performance of the coatings. The current work was initiated to answer a question regarding the significance of ceramic beads in a cool roof coating. Laboratory tests of surface properties and thermal conductivity were conducted; and a yearlong test of coatings exposed to outdoor weather conditions was completed March 2011.

## 2. Experimental Procedures and Data

All the materials tested are available commercially. The materials appeared bright white and initially were in liquid form and dried after application. Following is a list of coating materials and brief descriptions:

- Sample A—acrylic coating with various sizes of ceramic particles (as prepared)
- Sample B—latex/acrylic coating with ceramic particles (as prepared)

- Sample C—acrylic coating (same as Sample E) with ceramic particles added (prepared on site)
- Sample D—highly reflective acrylic coating without ceramic particles
- Sample E—acrylic coating without ceramic particles

## 2.1 Laboratory Tests

To conveniently run laboratory tests on the coatings, 12- by 12-inch pieces of galvanized sheet metal and EPDM membrane were coated with each of the materials. Care was taken to apply the coating at the recommended thickness—15 to 20 mils. Sample A is thinner than desired because of limited coating material and difficulties obtaining additional amounts.

| Sample | Coating thickness on metal (mils) | Coating thickness on EPDM (mils) |
|---|---|---|
| A | 6 | 9 |
| B | 21 | 21 |
| C | 24 | 23 |
| D | 17 | 19 |
| E | 13 | 21 |

Table 1. Thickness of coatings

Thermal Emittance **-** One characteristic important for evaluating the thermal performance of a roof coating thermal performance is thermal emittance. A high thermal emittance is desirable to improve a roof system's ability to reject heat. The Devices & Services model AE device was used to measure emittance and is based on ASTM C1371. One method for using the device is based on the coating and substrate having relatively high thermal conductivity. Coatings were applied to a thin sheet of galvanized steel (high thermal conductivity) and an EPDM membrane and emittance measurements were made for both surfaces.

| Sample | Base Material | Emittance from Oak Ridge National Laboratory | Emittance from Cool Roof Rating Council |
|---|---|---|---|
| A | Metal | 0.89 | 0.91 |
| | EPDM | 0.86 | |
| B | Metal | 0.87 | 0.88 |
| | EPDM | 0.83 | |
| C | Metal | 0.92 | N/A |
| | EPDM | 0.88 | |
| D | Metal | 0.89 | 0.87 |
| | EPDM | 0.86 | |
| E | Metal | 0.89 | 0.88 |
| | EPDM | 0.89 | |

Table 2. Thermal emittance measurements for sample pieces (not installed on the roof) using the Devices & Services emissometer

The emittance measurements generally were slightly lower for EPDM compared with sheet metal. Also, the values were in reasonable agreement with measurements made by the Cool Roof Rating Council (CRRC, 2010). All emittance values fell within a relatively narrow band, with sample C having a slightly higher emittance than the other samples. For comparison, emittance for the TPO (thermo-plastic polyolefin used as the white reference material) and the EPDM (black reference material) were 0.90 as reported in Desjarlais et al. (2007).

Solar Reflectance–Solar reflectance is another important factor when evaluating roof systems' thermal performances. The initial solar reflectance from ORNL is measured according to ASTM C1549 using the Design & Services (D & S) portable reflectometer. The data from ORNL is noted as initial solar reflectance because the same method is used later to measure solar reflectance for the materials exposed to outdoor conditions during the year of testing. The ORNL measurements are based on the version 6 calibration for the D&S reflectometer. The CRRC solar reflectance measurements are made with the D&S device but based on the version 5 calibration. The solar reflectance values from Lawrence Berkeley National Laboratory (LBNL) are explained in a subsequent paragraph and based on the integrating spheres method.

| Sample | Base Material | Initial Solar Reflectance from ORNL | Solar Reflectance from CRRC | Solar Reflectance from LBNL |
|---|---|---|---|---|
| A | Metal | 0.815 | 0.83 | 0.83 |
| | EPDM | 0.810 | | |
| B | Metal | 0.776 | 0.83 | 0.77 |
| | EPDM | 0.776 | | |
| C | Metal | 0.788 | N/A | 0.79 |
| | EPDM | 0.786 | | |
| D | Metal | 0.874 | 0.92 | 0.88 |

| | | | | |
|---|---|---|---|---|
| | EPDM | 0.876 | | |
| E | Metal | 0.814 | 0.83 | 0.81 |
| | EPDM | 0.814 | | |

Table 3. Solar reflectivity measurements for samples coatings (ORNL data based on D&S reflectometer with version 6 calibration, CRRC data based on D&S reflectometer with version 5 calibration, and LBNL data based on integrating spheres method)

Sample D has the highest measured solar reflectance value based on all three measurement methods. Solar reflectance values found on the CRRC website are higher than the values measured at ORNL. One of the contributing factors is the move to the newer calibration version 6 (D&S Tech Notes, 2010), which was used in the ORNL measurements but not used at the time of the CRRC measurements. The change in calibration was initiated based on the study by Levinson et al. (2010) that demonstrated solar reflectivity of “cool colors” tends to be overpredicted when using previous calibrations. The solar reflectance measured on EPDM and metal are nearly the same with no standard bias.

The measurements of solar reflectivity made by the D&S device are based on measurements at four wavelengths in the ultraviolet (UV), visible and near-infrared ranges. A proper weighting of the reflectivity at these wavelengths yields solar reflectivity. To investigate the possibility that liquid applied coatings with ceramics have unusual reflectivity characteristics at wavelengths other than the four measured with the portable device, a measurement over all solar wavelengths was performed. Solar reflectivity as a function of wavelength was measured at LBNL according to ASTM E903 (integrating spheres method). For this test, reflectance is measured at 5 nanometer (nm) wavelength increments. The solar reflectance is calculated based on the G calibration with 5 percent of solar radiation in the UV range (300-400 nm), 43 percent in the visible range (400-700 nm) and 52 percent in the near-infrared range (700-2500 nm). The samples consisted of coating material applied at the thicknesses listed in Table 1 to 2- by 2-inch pieces of sheet metal.

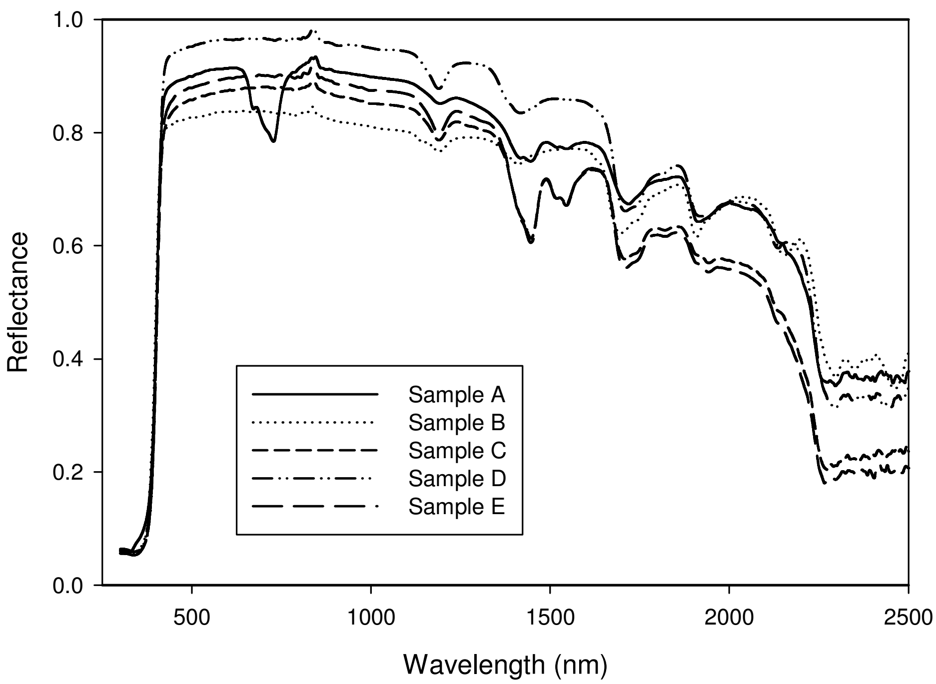


Figure 1. Solar reflectivity of coatings as a function of wavelength

All coatings (with and without ceramic particles) demonstrated similar signatures of reflectivity as a function of wavelength, and the ceramic beads do not have a significant effect in a particular wavelength band that was missed by the D&S reflectometer. The solar reflectivity based on all wavelengths is similar to the value from the D&S reflectometer. Sample C and E provide an interesting comparison. Sample E is a bright white coating material, and Sample C is the same material with ceramic particles added.

In Figure 1, Sample C (short dashes) has a slightly lower reflectance in the visible and lower wavelengths of near-infrared compared to Sample E. After 1700 nm, the trend reverses and Sample C has a slightly higher solar reflectance. Over all wavelengths, the addition of ceramic beads slightly reduced the solar reflectance for Sample C.

**Thermal Conductivity**

Thermal conductivity of the coating materials was measured according to ASTM C518, which is based on a Fox 305 Heat Flow Meter. As the thickness of the coatings is on the order of 20 mils, the thermal resistance values were anticipated to be quite small. The following procedure was used to obtain thermal resistance values for the coating material and then estimate the coating's thermal conductivity. The thermal resistance for two extruded polystyrene boards with an EPDM membrane coated with a sample materials was measured. A sandwich of the polystyrene boards and EPDM (no coating) was also tested. The difference in thermal resistance between the two cases was the thermal resistance due to the coating. The coating's thickness is relatively thin, resulting in small changes in resistance and at the limit the device can measure accurately. At least three trials to measure thermal conductivity were made for each coating.

| Sample | Average Thermal Conductivity (Btu in/hrft$^{2o}$F) | Standard Deviation of Thermal Conductivity (Btu in/hrft$^{2o}$F) | R-value of Coating for Actual Thickness Applied (ft$^{2o}$Fhr/Btu) | R-value if 20 mils (0.020 in.) Applied* (ft$^{2o}$Fhr/Btu) |
|---|---|---|---|---|
| A | 6.736 | 4.32 | 0.0015 | 0.0030 |
| B | 0.880 | 0.11 | 0.0244 | 0.0227 |
| C | 2.112 | 0.80 | 0.0116 | 0.0095 |

| | | | | |
|---|---|---|---|---|
| D | 3.354 | 0.68 | 0.0060 | 0.0060 |
| E | 5.284 | 1.54 | 0.0038 | 0.0038 |

Table 4. Thermal conductivity for the coating layers (*20 mils falls in the range of recommended thickness for all coatings)

The standard deviations of the trials demonstrate the thermal conductivity values measured are not tightly bounded. In fact, using analysis of variance, it is not possible to conclude one material has lower thermal conductivity than another with a reasonable level of confidence. In a paper by Raghu and Philip (2006), the thermal conductivity for four commercially available coatings of black paint was measured. The thermal conductivity values were in the range of 10.06 to 3.95 Btu in/hr ft$^{2o}$F and the coatings tested in the current study fall in nearly the same range. While conclusions on which is the better insulating coating are not possible, the data does demonstrate the thermal conductivity values for all these coating materials provides a very small thermal resistance for the typical application thickness. The R-value (units of ft$^{2o}$Fhr/Btu) for the RTRA roof system (consisting of a membrane of EPDM, 1.5 inches of wood fiber board, and metal deck) is about 4, and even on this relatively poorly insulated roof, the coating's thermal resistance is less than 1 percent of the total roof thermal resistance. The coatings each had a recommended thickness of application of 15-20 mils. When preparing samples, it was difficult to meet this thickness precisely. The last column in Table 4 was included to demonstrate that using the recommended thickness of coating will not provide a significant addition to a roof's thermal resistance.

### 2.2 Exposure Tests

Tests of the coatings were conducted on the RTRA, which is a small building with space for eight 4- by 4-foot horizontal roof systems to be installed and tested. The building's interior is maintained at a uniform temperature of 71$^{o}$ F. The roof construction for each of the test roofs consisted of 22-gauge sheet metal nearest the interior and 1.5 inches of wood fiber board. For the coatings, A-D, the coating was applied to EPDM, which was installed on top of the wood fiber board. The white and black reference panels had the same construction, but the white reference was TPO and the black reference was EPDM with no coating. (Note: Sample E was included in the small scale tests but was not part of the larger scale exposure tests due to limited space.)

The roof panels were instrumented with thermocouples located at the material interfaces and near the center of the 4- by 4-foot panels (see Figure 2). A heat flux transducer was installed between the wood fiber boards. The data acquisition system took data at 15-minute intervals. A weather station above the building has instrumentation to measure solar heat flux, infrared radiation to the panels and outdoor temperature.

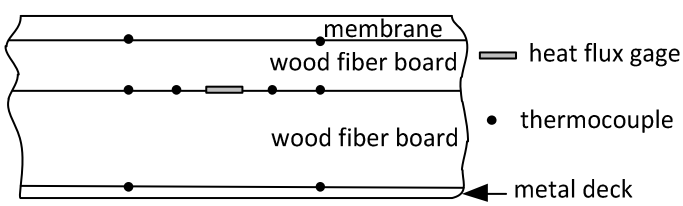


Figure 2. Schematic of roof cross-section with instrumentation locations

Figure 3 shows the average temperature measured by the thermocouples mounted between the membrane and wood fiber board during 48 hours. During hot or sunny conditions, these thermocouples will experience temperatures near the roof surface temperature. Clouds passed by on the first day, resulting in large spikes in the data. The second day was relatively clear, and a general parabolic temperature plot occurs. The temperature curves for most of the coating samples fall within a relatively narrow band except for the black sample, which is a significantly higher curve. Black roof temperatures reach nearly 160$^{o}$F while the white roofs stay below 100$^{o}$F. The data shown in this figure does not provide the complete story regarding performance and was only selected to demonstrate the type of data collected.

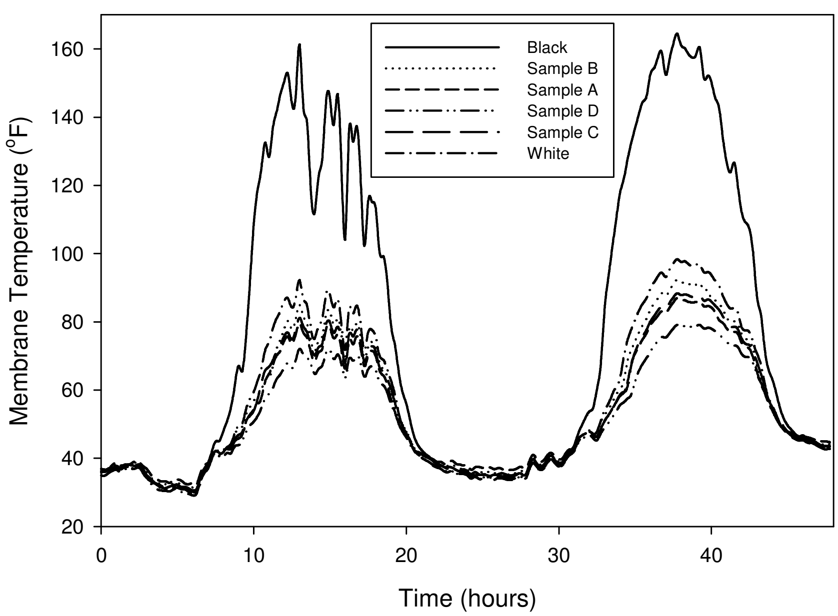


Figure 3. Example of membrane temperature measured for two days in April 2010

The D&S portable reflectometer was used to measure solar reflectance for the test and reference roof panels. Measurements were made after one month of exposure and then every three months thereafter. The solar reflectivity has continued to drop after ten months of exposure because of dirt and dust accumulation. The sample panels decreased in solar reflectivity, ranging from 7 to 17 percent and no conclusions regarding solar reflectivity degradation between coatings with ceramics and without can be made.

| Sample | Initial Solar Reflectivity (Table 2) | Solar Reflectivity after One Month (April) | Solar Reflectivity after Four Months (July) | Solar Reflectivity after Seven Months (October ) | Solar Reflectivity after Ten Months (January) | Percentage Change (Initial to Ten Month Value) |
|---|---|---|---|---|---|---|
| A | 0.810 | 0.789 | 0.740 | 0.716 | 0.700 | 13.6 |
| B | 0.776 | 0.755 | 0.696 | 0.670 | 0.645 | 16.9 |
| C | 0.786 | 0.769 | 0.753 | 0.740 | 0.727 | 7.5 |
| D | 0.876 | 0.853 | 0.822 | 0.798 | 0.795 | 9.2 |
| White reference | -- | 0.691 | 0.678 | 0.664 | 0.650 | -- |
| Black reference | -- | 0.053 | 0.055 | 0.055 | 0.053 | -- |

Table 5. Solar reflectivity measured on the RTRA after exposure to outdoor conditions

**Heat Flux**

Heat flux through the RTRA's sample panels is measured and reported in Figure 4 and Table 6 below. The data shown are from March 5, 2010 through March 10, 2011, slightly over one year. Heat flux lost through the roof is heat that must be provided to maintain a room temperature of 71°F and is summed over the year to obtain the yearly heating requirement. Heat gained through the roof must be removed through cooling and is summed over the year to obtain the yearly cooling requirement. The black roof system had significant cooling requirements—three to four times larger than the test roofs. None of the test coatings provided dramatically better performance than another. Sample D (no ceramics) with the high solar reflectivity has the lowest cooling requirement but by a modest margin. Sample B (with ceramics), which has the lowest solar reflectivity, has the highest cooling requirement. Coating C (with ceramics) has the smallest heating penalty and was followed closely by Coating B (with ceramics).

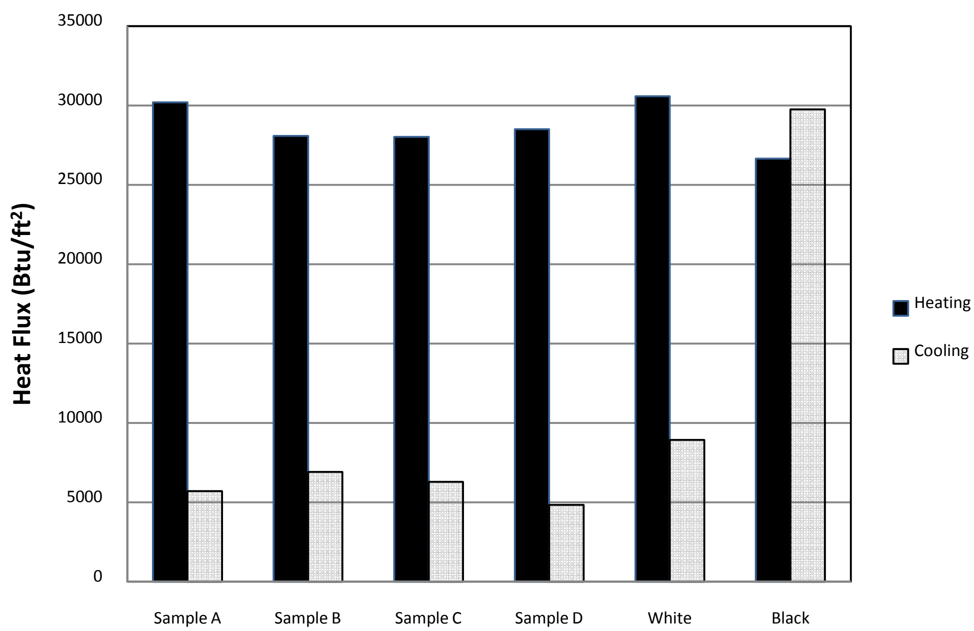


Figure 4. Heating and cooling flux for the roofs from March 5, 2010 until March 10, 2011

| Sample | Yearly Heating Required (Btu/ft$^2$) | Percentage Increase in Heating Compared to Black | Yearly Cooling Required (Btu/ft$^2$) | Percentage Decrease in Cooling Compared to Black | Yearly Energy Cost ($/ft$^2$) |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| | | Ref.* | | Ref.* | |
| A | 30192 | 13.3 | 5706 | 80.8 | 0.463 |
| B | 28079 | 5.4 | 6915 | 76.8 | 0.445 |
| C | 28023 | 5.2 | 6291 | 78.9 | 0.438 |
| D | 28496 | 6.9 | 4845 | 83.7 | 0.432 |
| White reference | 30575 | 14.7 | 8925 | 70.0 | 0.467 |
| Black reference | 26649 | --- | 29750 | --- | 0.630 |

Table 6. Heat flux data from RTRA and roof energy cost for March 5, 2010, until March 10, 2011

An energy cost estimate (Table 6) for each roof was calculated by assuming the following: Heat is provided by a natural gas furnace with an efficiency of 0.83, the heating value of natural gas is 1030 Btu/ft$^3$ and natural gas costs $11.65/1000 ft$^3$; the cooling is accomplished by an air-conditioning unit with a seasonal energy efficiency ratio of 13; and electricity cost is $0.1168/kilowatt-hour. The highly reflective coating without ceramic beads, Sample D, had the lowest yearly energy cost; but it was not significantly better than Samples A-C (coatings with ceramic particles). Ceramic particles did not improve thermal performance of cool roof coatings as tested on roof panels under east Tennessee weather conditions.

**3. Summary**

All roof coatings tested significantly reduced the cooling required compared with the black EPDM roof system. Considering the benefits of the high solar reflectivity during hot, sunny months and heating penalty during cold months by estimating energy costs to heat and cool the building, the costs for all samples tested were significantly less than the black reference roof system and showed a modest improvement compared with the white reference roof system.

The coatings with ceramic particles did not demonstrate thermal performance superior to a cool roof coating without particles. The coatings with ceramics had slightly higher thermal emittance and slightly lower solar reflectance compared to Sample D. The solar reflectance over all wavelengths (see Figure 1) did not show significant difference among coatings without particles (D and E) and with particles (A, B and C). Thermal conductivity of the coatings was measured, and the thin coating layers would have negligible effect on the overall thermal resistance even for the low-resistance roof used on the test facility.

The results from the tests of roof panels exposed to weather conditions over a year showed slightly better thermal performance (lower energy cost per square foot) for Sample D, a cool roof coating with no ceramic particles. Surface properties (solar reflectance and thermal emittance) are the dominant characteristics for cool roof coatings and should be the basis for selecting cool roof coatings.

## 4. References

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## 5. Acknowledgements

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