Paper No. 03-3931

Reductions in Traffic Sign Retroreflectivity Caused by Frost and Dew

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A study of in-service traffic signs was undertaken to quantify the average effects of frost and dew on their retroreflective capabilities. The results were then compared with proposed minimum retroreflectivity standards recently developed by FHWA-sponsored research for inclusion in the *Manual on Uniform Traffic Control Devices.* Although the effects of frost and dew were found to be variable, average reductions in retroreflectivity levels of 79% and 60%, respectively, were found. None of the different colored signs sampled with Type I (engineering grade) sheeting was found to meet the proposed minimum levels when covered in frost or dew (with the exception of signs with white backgrounds covered in dew), even though all signs were in like-new condition. Signs sampled with Type III (high intensity) sheeting had mixed results. The findings are significant enough that they should be considered in the development of the final version of the FHWA national standards. Furthermore, those jurisdictions subject to frequent cycles of frost and dew should review usage guidelines governing the grade of sign materials used, allowing for expected loss of retroreflectivity.

The FHWA has expended a considerable amount of effort since 1993 revising a series of proposed minimum in-service retroreflectivity levels for traffic signs. The intent is to provide standards that will be included as an addendum to Section 2A.09 of the *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*). These recommended standards will establish the minimum level of retroreflectivity considered adequate for nighttime drivers and will be used as a benchmark to govern the selection of sheeting materials and the replacement of older and faded signs. Minimum proposed levels have evolved to include factors such as vehicle type, headlight design, driver visual capabilities, roadway type, traffic speed, and the necessary driver response dictated by a sign message (P. Carlson, unpublished data, Oct. 2002).

The standards do not specifically account for a reduction in the nighttime legibility of traffic signs when the sign face is covered with either dew or frost. This can be particularly problematic in areas where the formation of dew or frost is frequent and typically occurs at night, when retroreflective qualities are needed. If the standards are to have any meaningful or practical application, they should account for, or at least recognize the effect of, climatic conditions, if they occur regularly enough.

This study has quantified typical overall reductions in retroreflectivity levels resulting from the formation of frost and dew and compared the residual values to proposed minimum values recently developed through an FHWA-sponsored research study (P. Carlson, unpublished data, Oct. 2002). The primary objective was to determine whether relatively new signs can still provide adequate retroreflectivity under dew or frost conditions using the proposed minimum standards as a baseline.

The study was conducted on in-service traffic signs in the province of New Brunswick, in eastern Canada. The northern latitude of New Brunswick and its proximity to the Atlantic Ocean creates conditions favorable for the frequent formation of dew or frost. In fact, it is possible for frost to form on 200 to 275 days of the year throughout the province, depending on factors such as humidity, cloud cover, and wind. Many of the northern U.S. states would experience similar frequencies of frost–dew cycles.

BACKGROUND

A 1992 U.S. Congress Transportation Appropriations Act stipulated that "the Secretary of Transportation shall revise the MUTCD to include a standard for minimum levels of retroreflectivity that must be maintained for traffic signs and pavement markings which apply to all roads open to public travel" (*2*). To this end, the FHWA has been working toward the development of standards to govern the performance of in-service markings and signing. A set of minimum standards was first drafted by the FHWA (*3*) and later revised (*2, 4*) following consultation with a number of groups, including AASHTO.

The most recent version of these proposed standards developed through FHWA-sponsored research undertaken by the Texas Transportation Institute has only recently been released. The research was undertaken in preparation for draft rulemaking and has incorporated a series of consultative workshops conducted through AASHTO's policy-resolution process. These standards are meant to create a baseline for the selection and replacement of traffic signs to ensure that signs and markings provide a minimal amount of performance for nighttime drivers.

As proposed, the standards reflect different sign colors and vary depending on the size of the symbol or text and on the sign's position. Currently, the only guidelines for nighttime visibility of signs are in the MUTCD (*1*), which was produced by the FHWA. This manual stipulates simply that all warning and regulatory signs be "retroreflective or illuminated to show the same shape and similar color by both day and night" (*1*).

A computer model called Computer Analysis of Retroreflectorized Traffic Signs, which includes several submodels, facilitated the initial development of these standards. The most recent work undertaken by the Texas Transportation Institute employed even more robust modeling of retroreflective sheeting performance. One submodel of the system accounted for traffic speed, sign size, sign legend, material type, and sign placement. Another was used to determine the sign luminance and retroreflective requirements to establish the distance at which traffic signs were

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visible under varying conditions. Factors in this submodel included visual characteristics of the driver, characteristics of the vehicle, the geometry of the road and surrounding area, and sign size and placement. The final submodel was used to create a standard value of retroreflection for the different material types from different manufacturers. A limitation with the computer model and the resulting standards was that it did not take into account climatic factors, such as frost and dew. However, weather conditions fluctuate with geographic regions and have varying effects on the retroreflective values of traffic signs. This makes it difficult to provide a uniform national retroreflectivity reduction factor for road signs.

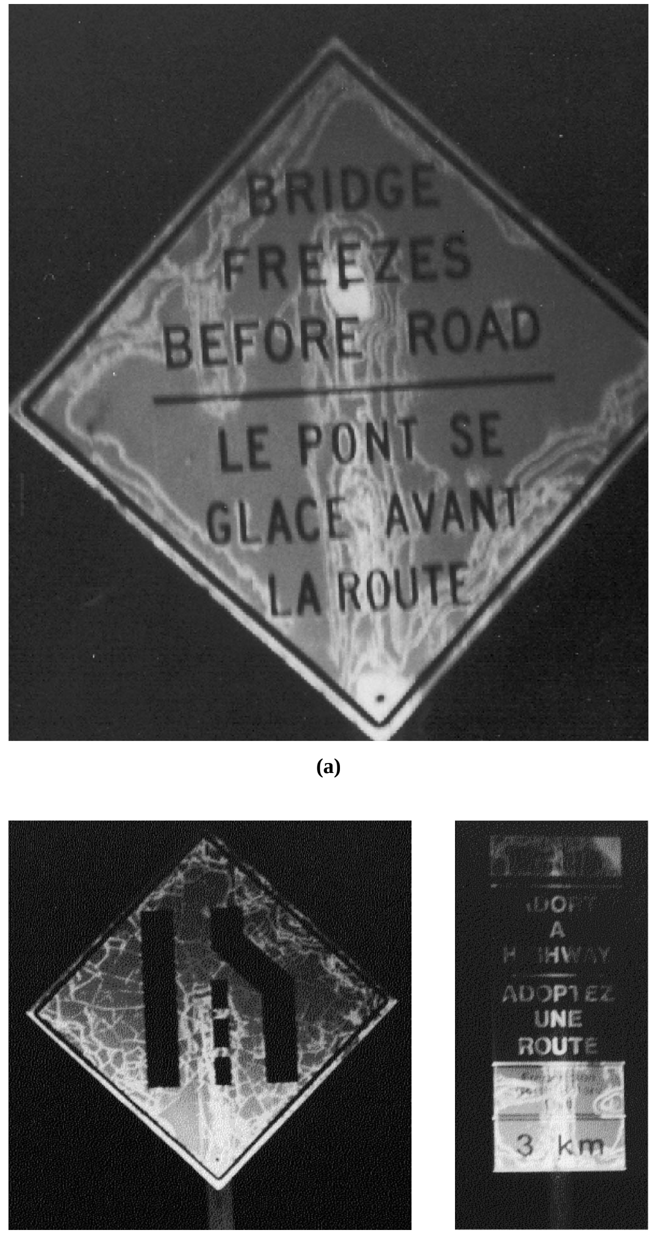
When traffic signs and pavement markings are illuminated, they have the ability to reflect light back to the driver so they appear bright, thereby providing good guidance and target value. This ability, known as retroreflectivity, is usually accomplished using one of two technologies. Traditionally, tiny glass beads are applied to sign sheeting materials or mixed with pavement markings. Newer signing materials use manufactured prismatic reflectors consisting of cube-corner elements. Thus, when light is directed onto the sign face (by a headlamp), the sign will redirect light back to the driver and appear as a large emitting source of light. The measurement of light from a source with some discernable dimensions is luminance, in units of candelas per square meter (cd/m^2). The capability of a sign to redirect light back to the source is referred to as retroreflectivity, which is a ratio of the reflected light versus incident light. Retroreflection is measured in candelas per lux per square meter (cd/lux/m^2).

A number of studies have examined climatic effects on retroreflectivity, but most tend to focus on the long-term degradation of sign materials. The limited studies that have addressed frost and dew specifically have concentrated on reducing the susceptibility of sign material to these conditions rather than quantifying the reduction in retroreflectivity.

Previous studies that specifically address sign performance under dew and frost conditions focused on the physical formation of frost and dew with the objective of developing measures to limit their formation (*5, 6*). Studies were constructed on test beds involving one or two signs with several sheeting and lettering combinations. The reports did not quantify retroreflectivity reduction but acknowledged a degree of reduction in retroreflectivity associated with frost and dew. Hutchinson and Pullen's study subjectively ranked material types relative to one another according to viewers' perceived reduction in retroreflectivity (*5*). Advances in signing materials and the ability to empirically measure retroreflectivity provide the underpinnings for this study.

A sign's ability to be retroreflective can deteriorate over time. This has provided the impetus for the FHWA to develop minimum in-service retroreflectivity levels. The standards, however, assume normal field conditions. Frost and dew are known to significantly reduce a sign's ability to be retroreflective, yet the standards do not consider these conditions.

Conditions affecting frost and dew on a road sign include sign orientation and proximity to shelter as well as geographic location and weather patterns. Signposts have been identified as possible heat reservoirs or sinks (possibly drawing heat from the road bed or embankment). This explains why, on some signs, frost and dew are present in reduced quantities in a band the width of the signpost (*6*). This phenomenon is illustrated in Figure 1. The brighter areas, which are frost free due to the heat provided by the posts, are contrasted against the remainder of the sign face.



(a)

(b) (c)

FIGURE 1 Effects of frost on the retroreflective qualities of three traffic signs.

STUDY METHODOLOGY

Tests for retroreflectivity of 130 in-service traffic signs under normal and dew conditions were completed from September to November 2001. Tests of the same signs under frost conditions were completed during nights throughout January, February, and March 2002. The signs sampled were selected such that they were in excellent condition, so they would represent new or near-new sheeting materials.

Retroreflective materials are made by several manufacturers and are currently divided into nine ASTM D 4956-01 classifications according to retroreflectivity, daytime luminance factor, color, and rigidity of the sheeting material (*7*). Previous taxonomies only segregated signing materials into four categories (*3*), however, with the recent development of specialized and more advanced materials, further delineation was required.

For the purpose of this project, only Type I (commonly referred as engineering grade) and Type III (high intensity) sheeting were surveyed. These two are the most common material types used for traffic signs in the province of New Brunswick. The signs sampled had background colors of: white, red, yellow, green, blue, and orange of both material types, where possible. All signs used in this project were ground mounted and located in speed zones of 70 km/h (43.5 mph) or less. Signs in these zones were the easiest and safest to reach by the observer with the equipment employed.

Retroreflectivity levels were collected for in-service signs using a hand-held retroreflectometer (Model 920 produced by Advanced Retro Technology, Inc.). Consistent with current North American practice, the instrument measures retroreflectivity levels (in candelas per lux per square meter) based on an entrance angle of –4° and an observation angle of 0.2°. Before taking measurements at each sign, the operator calibrated the instrument using a reference template of known retroreflectivity similar to the sign material being measured.

Signs were first tested under dry conditions, and then the same signs were remeasured when dew or frost was present. The retroreflectivity of each sign was measured at a minimum of seven locations around the sign face to account for variability due to cleanliness, physical marks or defects, areas that may have faded slightly, or lack of uniformity of frost or dew coverage. The individual locations measured on each sign face were selected to provide coverage of all regions of the sign regardless of patterns of dew or frost formation. Similar coverage patterns were repeated for subsequent sampling of the same signs.

Care was taken to ensure that the pattern of dew or frost was not disturbed during the recording of the retroreflectivity. If the pattern was changed in any way, the reading was discarded. Dew will form when the temperature of the traffic sign's face approaches the dew point of the surrounding air. Atmospheric conditions such as cloud cover, wind speed, and moisture combine to influence the formation of dew. Frost will form when the dew point falls below the freezing point of water.

While frost and dew formation can vary in density, sufficient signs were sampled over many different nights to ensure averaged values would be reflective of the full range of conditions. The intent is not to establish reproducible laboratory results but rather to demonstrate the relative magnitude of the average effect of dew or frost on a traffic sign's retroreflectivity. By including a large sample of in-service signs and sampling over the course of several months, a range of conditions were included in the survey. A sign's final legibility, or functionality, may depend on whether only a portion of the sign face is obscured by the frost or dew. Conditions may sometimes exist where patchy coverage exists on a single sign face, so a direct link cannot always be drawn between average retroreflectivity levels and legibility or functionality.

RESULTS

Average measured retroreflectivity levels were determined for each sign under normal, dew, and frost conditions. The results were then grouped by color and sign-material type and compared with the minimum standards currently recommended by FHWA-sponsored research (P. Carlson, unpublished data, Oct. 2002). The minimum levels currently being proposed are summarized in Table 1. The values for yellow and orange signs are the same. A minimum value of 50 cd/lux/m^2 was used for yellow and orange sheeting since all signs sampled for this project had a bold black symbol for a message (signs with fine symbols or text have a recommended minimum retroreflectivity level of 75 cd/lux/m^2). All other delineation of the standards based on sign size or speed zone has been removed from this latest version of the recommended standards.

Blue signs are not considered in the proposed minimum retroreflective standards. Since blue signs are reserved by most jurisdictions for tourist information signs and symbols, they may not be considered as vital from a safety perspective as the other colors. They were included in this project, however, for comparison with the other colors.

The variability of retroreflectivity levels in Table 2 was shown to increase for those readings taken under dew and frost conditions. This was expected given the naturally occurring variability of frost and dew coverage. The coefficient of variation ranged from 7% to 30% for each of the different colors under normal conditions. These values increased to a range of 16% to 80% for dew and 16% to 48% for frost-covered signs. Nevertheless, surveys were conducted over a period of several months to ensure a range of environmental conditions. The values listed as Like New Condition in Table 2 are for calibration swatches used with the retroreflectometer and can be considered representative of new sheeting materials that have not weathered due to in-service use.

With only one exception (red, Type III), the presence of frost is shown to degrade retroreflectivity more than the presence of dew. Reductions in retroreflectivity levels due to frost range from 73% to

Frost is worse than dew

TABLE 1 Proposed Minimum Retroreflectivity Levels (*2*)

Background Color	Retroreflectivity (cd/lx/m^2)	Special Conditions
Yellow or Orange	50	Bold symbol or Text Sign ≥48"
Yellow or Orange	75	Fine Symbol or Text Sign ≤48"
Red (with white text/symbols)	Red=7 / White=35	Minimum Contrast Ratio 3:1
White	50	
Green (with white text/symbols)	Green=15 / White=120 Green=15 / White=250	Ground Mounted Overhead Mounted

TABLE 2 Effect of Frost and Dew on Retroreflectivity

Sign Material and Background Color	Like New Condition	Field Condition			Proposed Minimum Standard (FHWA Research)
		Normal	Dew	Frost	
Type I (Eng. Grade)					
White	125	103	53	23	50
Red	29	18	4	3	7
Yellow	73	69	28	14	50 *
Green	16	13	6	3	15
Blue	9	6	2	2	n.a.
Type III (High Intensity)					
White	312	298	233	82	50
Red	62	52	7	11	7
Yellow	201	201	115	26	50
Green	63	57	7	7	15

*The current proposed standards do not recommend the use of Type I sheeting for yellow/orange. However, the value is listed for comparative purposes.

• frost & dew build up show no correlation w/ type/grade

87% and average 79% for all colors combined. Reductions in retroreflectivity resulting from dew are generally less severe, averaging 60%; however, they are shown to range from 22% to 87%. The degree of reduction in retroreflectivity shows no correlation with the type or grade of sheeting material. These findings contradict those of Hutchinson and Pullen, who found that all tested combinations of "materials appeared to be less affected by frost than dew" (*5*). That study, however, only subjectively evaluated sign legibility and did not use any objective means to measure retroreflectivity properties.

Comparing the results in Table 2 with the minimum retroreflectivity levels recommended by FHWA research (P. Carlson, unpublished data, Oct. 2002), it is evident that several situations exist where minimum values cannot be attained, even with signs that are relatively new. All Type I sign-sheeting types are shown to provide substandard retroreflective properties under both dew and frost conditions, except for white, which barely exceeds the minimum value when dew is present. Furthermore, high-intensity yellow (Type III) does not meet the proposed minimum retroreflectivity level when frost is present, and Type III green was shown to be substandard given the presence of both dew and frost.

Figure 2 better illustrates the degradation caused by the sign face being covered in either dew or frost. The minimum in-service standards currently proposed by FHWA research are plotted as a broken line for reference.

Frost reduced by 79%

CONCLUSIONS

Frost was shown to reduce the retroreflectivity levels of the sampled in-service traffic signs by an average of 79%. This resulted in a reduction significant enough to normally lower the average retroreflectivity of relatively new signs with Type I sheeting below the minimum values recommended by FHWA research. Those signs with red or white Type III sheeting were just able to meet the FHWA values, despite being degraded significantly due to frost. Signs with yellow or green Type III sheeting did not meet proposed minimum levels when covered with frost.

Dew reduced by 60%

In-service signs covered with dew were found to have an average reduction in retroreflectivity of 60%, although the range was large between different colors (22% to 80%). Only white Type I sheeting was shown to meet the proposed minimum values when covered in dew. All Type III colors except green were shown to meet minimum retroreflectivity levels given dew conditions.

DISCUSSION OF RESULTS

The results of this study indicate that frost- and dew-covered traffic signs have a greatly diminished ability to return incident light to the driver. While there are no current standards, those being recommended based on FHWA research to govern the selection of materials and replacement of in-service signs serve as a baseline. Jurisdictions in which dew, frost, or both are prevalent should be aware that the effectiveness of signs is severely compromised when dew or frost is present. Consideration should be given to this issue in the development of national standards and particularly when developing operational practice. For example, it may be prudent to use higher-grade sign-sheeting materials for key signs installed in regions that are prone to the frequent formation of frost or dew. Policies governing the use of different grades of materials should be revisited in light of these findings. Although national standards cannot reflect localized effects, the formation of dew (and frost in the northern United States) is prevalent enough that the minimum levels should consider reflecting these effects.

It may be possible to develop techniques to mitigate the formation of frost and dew through advanced sign materials, heat sinks, or other technologies. The fundamental conditions necessary for the formation of dew or frost include a drop in temperature below the dew point, still air, and moisture. Countermeasures would have to either address one or more of these elements to prevent the formation of dew or frost or work in such a way as to mitigate the effect on retroreflectivity once it does form. Earlier work by Hutchinson and Pullen found that "observed decreases in sign legibility and target value because of dew and frost formation were always more pronounced on the plywood-backed sign panel than on the plain aluminum panels" (*5*). Furthermore, Woltman suggested that internal heat storage may be possible or that dew specifically could be countered with a chemical surfactant to convert dew particles to a film (*6*). These findings hint at the notion that more advanced backing materials or composites might be developed to minimize the formation of dew or frost.

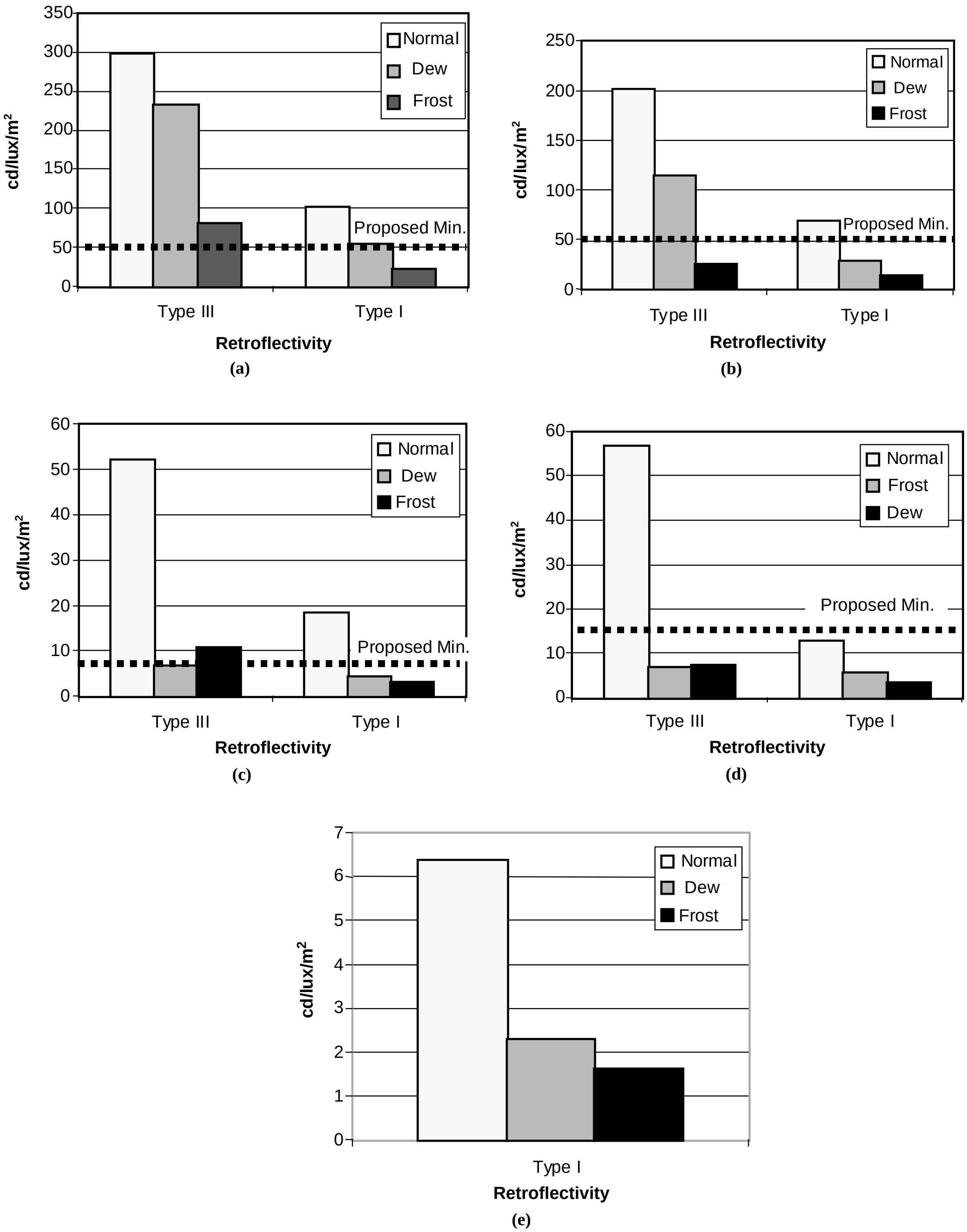


FIGURE 2 Reduction in retroreflectivity caused by frost and dew: (*a*) white sheeting, (*b*) yellow sheeting, (*c*) red sheeting, (*d*) green sheeting, and (*e*) blue sheeting.

ACKNOWLEDGMENTS

The author is indebted to Patrick Stamper, who undertook the fieldwork necessary for this project. Appreciation is also extended to Trevor Hanson, who provided valuable research assistance in the preparation of this paper. Comments received by Greg Schertz of FHWA to shape the final version of this paper are also greatly appreciated. Paul Carlson of the Texas Transportation Institute was kind enough to provide the most recent proposed minimum retroreflectivity levels while they were still in final draft format. Finally, the comments received by those on the TRB review committee have been incorporated and are appreciated.

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Publication of this paper sponsored by Committee on Visibility.