TRAFFIC SIGN RETROREFLECTIVITY AND THE CANADIAN ENVIRONMENT

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INTRODUCTION

The Manual of Uniform Traffic Control Devices for Canada (MUTCD-C) states that traffic signs "must be illuminated or reflectorized to show the same shape and colours by night as by day" (1). The criterion laid out in the U.S. version of this document is almost identical (2). Unfortunately, neither manual currently provides much guidance to road authorities concerning the replacement of worn traffic signs due to diminished reflectivity characteristics.

The U.S. Federal Highway Administration (FHWA) has been working to address this issue and have recently proposed minimum levels of retroreflectivity for in-service traffic signs. These retroreflectivity levels were initially intended to serve as national minimum standards, however, they are currently only classified as recommended values to guide authorities with the replacement of traffic signs that are approaching, or that have surpassed, their service lives (3).

The recommended minimum in-service retroreflectivity levels introduced in the U.S. will likely be utilized by most states to help meet the nighttime visibility requirements of drivers. Furthermore, given the close harmonization of North American traffic standards, there is a strong possibility that comparable guidelines will be introduced in Canada as well.

Unfortunately, the U.S. standards were established without much consideration given to the negative impact that dew and frost have on the retroreflective performance of traffic sign sheeting. Dew and frost typically form during the nighttime, coincident with the period that retroreflectivity is most important. Road authorities that rely on these recommended values may be unaware that some types of sign materials may not meet the guidelines during dew and frost conditions. Consequently, there is a need to better understand the effects that dew and frost have on traffic sign retroreflectivity before Canada considers adopting minimum retroreflectivity levels since dew and frost conditions are prevalent in many parts of the country.

The overall goal of this study was to gain a better understanding of the impact that dew and frost have on the retroreflective performance of traffic signs. Much of the work involved measuring retroreflectivity levels of various traffic sign colours and sheeting material grades under varying weather conditions. The results were then compared with the proposed FHWA minimum retroreflectivity levels. Testing took place during the autumn and winter of 2003/04 in Fredericton, New Brunswick, Canada.

BACKGROUND

Retroreflection is a property of a material that enables it to return light back in the general direction of the source. It is measured in units of candelas per lux per square-meter ($cd/lx/m^2$). Retroreflection is most commonly used to enhance road safety by utilizing the property with items such as traffic signs, roadway channelizers, pavement markings, and tapes for heavy-vehicles in order to increase the conspicuity of these objects at night. Traffic signs retroreflect light from a vehicle's headlamps, or incident light, back toward the vehicle. Although the light is retroreflected toward the vehicle headlamps, the driver is able to see much of this returned light because of their relative position. The result is that these objects appear brighter than they otherwise would, and thus, more conspicuous. Retroreflective materials are effective under ideal conditions, however, there are many factors that impede the full return of light (4). Some of the common hindrances to traffic sign retroreflection include weather (rain, snow, fog, etc.), damage to the sign, cleanliness of the sign (dirt, snow, salt, etc.), and the presence of dew or frost on the sign's face.

The American Society for Testing and Materials (ASTM) has grouped retroreflective sheeting into nine categories which include applications for traffic signs, barrier delineators, cones, and other traffic control devices (5). The most common types of retroreflective sheeting used for traffic signs in Canada, in order of increasing performance, include: Type I (Engineering), Type III (High Intensity), and Type VII and IX (Prismatic).

The U.S. Federal Highway Administration (FHWA) has strived to improve road safety during nighttime driving conditions by working to identify the visibility needs of drivers, understand the variables that influence sign visibility, and recommending sign maintenance procedures for States to follow (6). One of the objectives of their mission has been to establish minimum retroreflectivity levels that could be used to trigger the replacement of traffic signs. The intention has been to include these values in the U.S. version of the Manual on Uniform Traffic Control Devices (MUTCD) for transportation agencies to follow. Additional pressure was placed on the FHWA in 1993 when the United States Congress mandated that the MUTCD be revised to include minimum levels of retroreflectivity for traffic signs and pavement markings.

The MUTCD has not yet been updated to include minimum levels of retroreflectivity; however, Section 2A.09 was added in 2000 with the intention that minimum levels will be included sometime in the future after additional research addresses some remaining issues. The 2003 report by Carlson et al. (7) explained the development of the most recent set of minimum levels and identified several areas that require further examination. Some of the proposed research areas include: the impact of weathering on the variation of retroreflectivity, rural versus urban driving environments, improving nighttime visibility measurement options, along with a number of other topics. In addition to addressing the lack of knowledge available for certain aspects of this topic, the FHWA has been working to address some of the concerns voiced by public and private transportation agencies. For instance, some roadway agencies are concerned with their exposure to tort liability if minimum retroreflectivity levels are legislated (3).

The background research that the FHWA standards are based on did not include the negative effect that the presence of dew or frost have on a sign's ability to return light to the driver. Although researchers have conceded that frost and dew does reduce the retroreflectivity capabilities of traffic signs, there has not been an abundance of research undertaken to quantify this impact. Two separate research projects were conducted in the 1960's and 1970's to evaluate the impact of dew and frost on traffic signs (8,9). Researchers subjectively noted the impact that dew and frost had on various retroreflective sheeting grades and sign backing materials based on visual observations. Research conducted at UNB in 2001 employed a more quantitative method of measuring this impact by using a retroreflectometer (10). This study indicated that the FHWA minimum retroreflectivity levels may not be met under dew and frost conditions, particularly when using lower grade sign sheeting.

The science of dew and frost formation is complex since their development relies on many isolated climatic conditions such as temperature, humidity, wind, and cloud formation (11). These conditions differ between geographic regions, thus, the frequency of dew and frost formation is highly variable. This is one of the main reasons why the influence of dew and frost was not incorporated into the development of national standards. Even sites close to one another can encounter different conditions depending on factors such as elevation, shelter from other objects, and sign orientation. As a general rule, dew and frost is most likely to occur when there is a clear sky, a still atmosphere, and high humidity (8).

An object’s material type and its location also play a role in determining whether dew and frost will form on the object (11). Different material types will lose heat to radiation faster than others. An object that quickly loses heat due to radiation will cool quicker and, thus, will more readily reach the dew point temperature than objects that can retain their heat. A traffic sign’s susceptibility to dew and frost formation depends largely on the material type used for the sign backing. Studies have shown that dew and frost form on signs with plywood backing earlier and last longer than on signs with aluminum backing (8,9). Objects also lose more heat to radiation when there is less cloud cover, which means that dew and frost is more likely to occur on a clear night. Finally, objects closer to the ground or in a valley are generally exposed to cooler temperatures because cool air is denser than warm air and, thus, lies closer to the ground’s surface.

STUDY METHODOLOGY

In order to build upon the previous research, this study collected data using both in-service signs and a test deck built specifically for this project. Retroreflectivity levels were collected for twelve different sign types, encompassing a range of sign sheeting grades and colours. The sign types studied are listed in Table 1.

Most of the retroreflectivity data collected for this study was gathered using the test deck. There are several advantages to collecting retroreflectivity research data using a single test site rather than testing numerous in-service signs. First, more data can be collected in a shorter period of time. Several sign sheeting grades and colours can be tested at a single location without the travel time that would otherwise be required to find a variety of sign types. Second, the sheeting materials are new and are less likely to be damaged through vandalism, snow plowing, or by being struck by a vehicle, considering they are situated on private property. Finally, the weather conditions will be the same for each sign type. It is difficult to make comparisons between in-service signs based on sheeting type or colour alone, since individual signs may experience different weather conditions because of differences in geographic location or sign orientation.

Various colours of Type I (Engineering), Type III (High Intensity), and Type VII (Prismatic) sheeting grades were used on the test deck, as shown in Figure 1. Each sample of sign sheeting material was 30.5 cm by 61 cm (1 ft by 2 ft) in size. The test deck was oriented facing the north and positioned in an area exposed to weather conditions. This was done to permit the replication of typical dew and frost conditions that occur on in-service signs.

Retroreflectivity data was collected each time dew or frost was observed on the sign face. This required that the test deck be checked regularly between dusk and dawn. Only one set of measurements was taken for each occurrence of dew or frost because the meter disturbs the moisture pattern after each reading is taken. Measurements were taken periodically under normal conditions, which are defined as conditions when the sign is free of dew, frost, or any other moisture. This data was used as a baseline for calculating the average reduction in retroreflectivity levels experienced when dew or frost are present on a sign. Having several sets of data for normal conditions over the course of the study also helped detect whether the performance of the sign materials had degraded due to weathering or the accumulation of dirt on the sign face.

Retroreflection was measured at six locations on each of the twelve material types. Marks were delineated throughout the material sample, which allowed the measurements to be taken at the same six locations each time. This was done so that the spatial and temporal variations in retroreflectivity caused by dew and frost could be obtained rather than the natural variations in retroreflectivity that exist across the sign sheeting.

Spatial variance affects the overall readability of the traffic sign. There are a number of factors that can contribute to spatial variance in sign retroreflection, including: inconsistencies in sign sheeting performance, the challenge of taking retroreflectivity measurements at the exact same location each time, dirt forming on the sign face, and non-uniform deterioration of the sign sheeting. Additional spatial variations in retroreflectivity levels are introduced with the natural variations in dew and frost coverage across the sign face each time. In addition, traffic sign posts have been known to inhibit the formation of dew or frost along certain sections of traffic signs. It is believed that the heat that the post draws from the ground prevents dew or frost from forming along the sections of sign that the post comes in contact with.

Temporal variance is a measure of the degree of dew and frost formation on the sign sheeting from day-to-day. Temporal variance is influenced by the challenge of taking retroreflectivity measurements at the exact same location each time, dirt forming on the sign face, and any deterioration of the sign sheeting that may have taken place throughout the testing period. Dew and frost formation can greatly influence the temporal variation in sign retroreflectivity since the degree in coverage varies between dew and frost events.

Retroreflectivity data for in-service signs under normal, dew, and frost conditions were also collected to quantify the average reduction and variance of retroreflectivity levels experienced by typical in-service signs. The signs chosen were in like-new or good condition so that the variance in readings would not be a result of any degradation or damage to the sign. Six or seven measurements were taken at random points on each sign, depending on the area of retroreflective sheeting present on the sign. A sketch of each sign, which includes the location of the measurement points, was drawn to ensure that the readings were taken on the same location on the sign each time they were measured under different conditions.

A Model 920 Advanced Retro Technology (ART) retroreflectometer was used to measure the retroreflectance of the sign sheeting tested in the study. Retroreflectometers are designed to replicate the light from a vehicle's headlamps striking a traffic sign. A light source and a receiver located within the meter are used to measure the proportion of light that a point on a traffic sign can retroreflect.

The weather information for Fredericton was retrieved from the Environment Canada website (12) for the dates when dew and frost had formed on the test deck. This was used in order to identify the climate conditions consistent with dew and frost formation. The Fredericton weather station is located at the Fredericton Airport, which is approximately 14km from the test site in this study. Although weather conditions can vary between geographic locations, this weather data was deemed to be sufficient for the purposes of this study.

RESULTS

The sign material samples on the test deck were measured 6 different days under normal conditions, 13 times under dew conditions, and on 21 occasions when frost had formed. Since the test deck was inspected almost every morning and night for dew or frost formation, the number of recorded measurements would be expected to closely correspond to the number of times dew and frost had formed on the test deck during the 5-month study period.

Retroreflectivity Levels

Figures 2 and 3 illustrate the effect dew and frost had on the retroreflectivity of the various sign samples on the test deck. In each case the dew or frost was wiped off the left half of each sign sheeting type to reveal a surface that was representative of a sign under normal conditions. As expected, the sign under normal conditions (left side) is brighter than the sign with dew or frost (right side) since the light from the camera flash is diffused by these elements. The contrast in brightness between normal and dew conditions is less obvious for a few of the higher performance signs since the level of retroreflectivity is high in both cases. When comparing the effects of dew and frost it is apparent that the sections of sign with frost are dimmer than the sections of sign with dew, which illustrates that frost had a greater impact on retroreflectivity than dew.

There was a noticeable difference in the coverage of frost between each event, whereas dew appeared to have a more consistent coverage each time. It is not clear whether this phenomenon is due to the dynamics in weather conditions, the characteristics of the test deck, or a combination of both. It is important to understand both the degree to which frost reduces sign retroreflectivity levels and how overall sign readability is lowered due to variance in coverage. Therefore, in order to facilitate a direct comparison between full dew and frost coverage two distinct types of frost were delineated for analysis purposes. The first frost type included data collected during all frost events (including highly variable or patchy coverage) while the second analysis only included readings when frost had almost fully covered the sign sheeting (approximately greater than 90% of the sheeting area).

The overall average retroreflectivity levels were calculated for each of the twelve sign sheeting types under normal, dew, and frost conditions. Figure 4 compares the average retroreflectivity levels for each of the sign samples under normal, dew, frost, and full-coverage frost conditions. The percentage that the retroreflectivity levels were reduced under each condition is shown for the different materials on each plot. In almost every case frost was shown to degrade retroreflectivity more than dew. The overall reductions in retroreflectivity levels caused by dew ranged from 41% to 88%, whereas the reductions associated with frost ranged from 59% to 82%. For full-coverage frost conditions the reductions in retroreflectivity levels ranged from 69% to 95%, depending on the sign sheeting type.

Higher-grade sign materials experienced a disproportionate reduction in retroreflectivity levels, as the data in Figure 5 show. There were even a few instances where the Type VII (Prismatic) sheeting actually had lower overall retroreflectivity levels than the same colour of Type III (High Intensity) sheeting under frost conditions. In general, the higher-grade sheeting outperformed lower grades in average retroreflectance under both dew and frost conditions.

The data in Table 2 provides a comparison of the proposed FHWA minimum levels with the average retroreflectivity levels under normal, dew, and frost conditions. This illustrates how the various sign sheeting types performed in comparison to the proposed guidelines. There are only a select number of sign colours included in the proposed standards and some colours may have different minimum levels depending on their intended application (e.g., roadside versus overhead mounted sign). All of the 17 proposed minimum retroreflectivity levels were met under normal weather conditions; however, many of the sign types were not able to meet the proposed standards given dew or frost conditions. As the data show, seven standards were not met under dew conditions, six were not met under frost conditions, and twelve were not met under full-coverage frost conditions.

Variability of Retroreflectivity Levels

The spatial variances of retroreflectivity levels observed under each weather condition are summarized in Figure 6. Perhaps not surprisingly, frost was shown to have a greater spatial variance than dew. The spatial coefficient of variation under dew conditions averaged 5.3% (range: 1.7% to 11.6%) for the different sign material types, while it averaged 14.4% (range: 2.5% to 23.9%) under frost conditions. For full-coverage frost conditions the spatial coefficient of variation averaged 11.8% (range: 2.0% to 28.3%). Figure 7 illustrates how frost sometimes only formed on portions of the sign. In this photograph, only the middle portions of the test deck had significant frost formation leaving the fringes of the test deck free of frost. This would have yielded overall higher spatial coefficients of variation.

The temporal variance of each sign sample is shown in Figure 8. Overall, retroreflectivity levels were shown to vary significantly more temporally under frost than dew conditions. The temporal coefficient of variation averaged 39.0% (range: 20.7% to 56.3%) during dew conditions, 83.8% (range: 48.0% to 121.2%) for all frost events, and 46.7% (range: 28.3% to 79.6%) for full-coverage frost conditions.

Study findings regarding variability of retroreflectivity levels are significant because there is likely a direct correlation to sign legibility. Even though average reductions are greater under frost conditions, the higher variability of coverage may conceivably serve to improve recognition or legibility of the sign.

In-Service Signs

In-service signs were also measured for changes in retroreflectivity levels under dew and frost conditions in order to supplement/validate the data collected from the test deck. The results of these tests are synthesized in Figure 9. Since the number of sampled weather events was somewhat smaller for the in-service signs, the results cannot be regarded with the same degree of confidence. Nevertheless, the results provide an interesting comparison to those derived from the test deck. Although average reductions in retroreflectivity levels were similar, the in-service signs yielded readings with a larger average spatial coefficient of variation under dew and frost conditions. This likely reflects the influence of the sign post (as a heat sink or transmitter) on the uniformity of moisture coverage across the sign face.

Weather

After analyzing the environmental data, it was apparent that weather conditions recorded each time dew and frost had formed had consistent patterns. Some of the variables that remained consistent were: temperature approached dew point, the humidity approached 100%, the wind was calm, and the sky was clear. There were a number of instances where frost had formed on the windshields of vehicles but not on the test deck which was only a few metres away. This exemplified how different materials can be more susceptible than others to dew and frost formation.

CONCLUSIONS AND DISCUSSION

There were a number of significant findings from this research, including:

- Dew and frost significantly reduce the retroreflectivity levels of traffic signs.
- In general, frost degraded retroreflection more than dew.
- There are several of the FHWA proposed minimum guidelines that cannot be met under dew and frost conditions if conventional material types are used. In many cases deficiencies can be overcome if higher-grade materials are selected (e.g., substitute Type III material where Type I is traditionally used).
- Many of the FHWA proposed minimum guidelines cannot be met when a full coverage frost condition exists regardless of the sign material grade used.
- Although higher-grade sign materials generally outperformed lower sheeting grades they experienced a disproportionate reduction in retroreflectivity levels under dew or frost conditions.
- In general, the spatial and temporal variations in retroreflectivity levels were higher under frost than dew conditions.

The formation of dew or frost on traffic signs was shown to greatly diminish the ability to return incident light to the driver. Even the superior Type VII (Prismatic) sheeting fell short of the minimum guidelines proposed by the FHWA for white letters/symbols used on overhead guide signs. The findings are significant enough that they should be considered in future revisions to the proposed FHWA minimum retroreflectivity levels, as well as any future development of national standards in the U.S. or Canada. Furthermore, jurisdictions subject to frequent cycles of dew and frost should review usage guidelines governing the grade of sign materials used allowing for expected loss of retroreflectivity. It would be appropriate for authorities to substitute higher-grade materials for the more critical signs.

The driver’s ability to detect and understand a traffic sign is not solely related to it’s retroreflectivity characteristics. Further research is needed to better understand the negative impact that frost and dew have on a sign’s legibility.

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Table 1 – Sign Types Included in Study

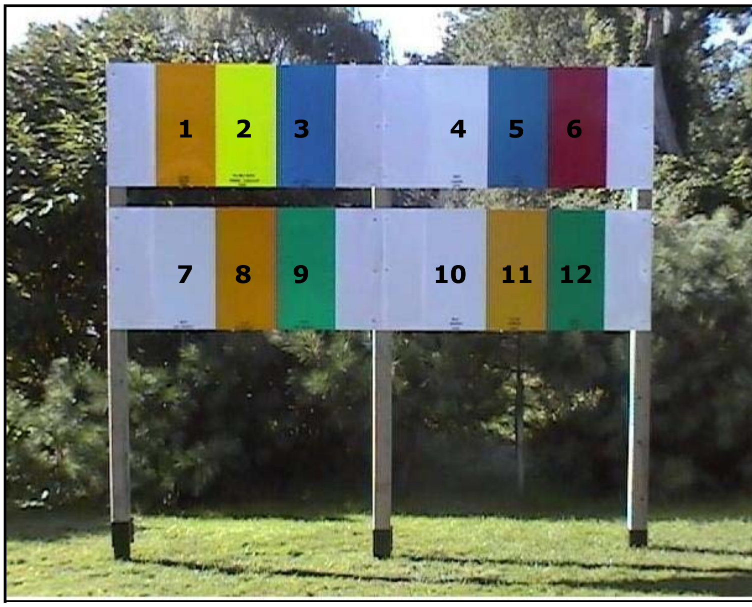
Test Deck	**Type I**	White, Yellow, Blue, & Green
	Type III	White, Yellow, Blue, Green & Red
	Type VII	White, Yellow, Yellow-Green
In-Service Signs	**Type I**	White (2) & Yellow (3)
	Type III	White (4)
	Type VII	Yellow (2) & Yellow-Green

Table 2 – Compliance with Proposed FHWA Minimum Retroreflectivity Levels – 2002 Revisions

Sign Type	**Application** (Legend / Background)	**Proposed Minimum Value** (cd/lx/m^2)	**Normal** (cd/lx/m^2)		**Dew** (cd/lx/m^2)		**Frost** (cd/lx/m^2)		**Frost (full coverage only)** (cd/lx/m^2)	
Type I - White	White / Red	35	71	✓	29	X	22	X	13	X
	Black / White	50		✓		X		X		X
Type I - Green	White / Green	7	20	✓	8	✓	8	✓	5	X
Type III - White	White / Red	35	292	✓	82	✓	95	✓	52	✓
	Black / White	50		✓		✓		✓		✓
	White / Green (shoulder sign)	120		✓		X		X		X
Type III - Red	White / Red	7	65	✓	19	✓	20	✓	10	✓
Type III - Yellow	Black / Yellow (bold symbol or text signs $\geq$ 48")	50	200	✓	54	✓	53	✓	34	X
	Black / Yellow (fine symbol or text signs < 48")	75		✓		X		X		X
Type III - Green	White / Green (overhead sign)	25	48	✓	14	X	16	X	9	X
	White / Green (shoulder sign)	15		✓		X		✓		X
Type VII - White	White / Red	35	1158	✓	175	✓	178	✓	67	✓
	Black / White	50		✓		✓		✓		✓
	White / Green (shoulder sign)	120		✓		✓		✓		X
	White / Green (overhead sign)	250		✓		X		X		X
Type VII - Yellow	Black / Yellow (bold symbol or text signs $\geq$ 48")	50	931	✓	131	✓	168	✓	49	X
	Black / Yellow (fine symbol or text signs < 48")	75		✓		✓		✓		X

✓ – meets proposed FHWA minimum retroreflectivity levels

X – does not meet proposed FHWA minimum retroreflectivity levels



	Colour	Sheeting Grade
1.	Yellow	Type VII (Prismatic)
2.	Yellow/Green	Type VII (Prismatic)
3.	Blue	Type III (High Intensity)
4.	White	Type VII (Prismatic)
5.	Blue	Type I (Engineering)
6.	Red	Type III (High Intensity)
7.	White	Type III (High Intensity)
8.	Yellow	Type III (High Intensity)
9.	Green	Type III (High Intensity)
10.	White	Type I (Engineering)
11.	Yellow	Type I (Engineering)
12.	Green	Type I (Engineering)

Figure 1 – Test Deck

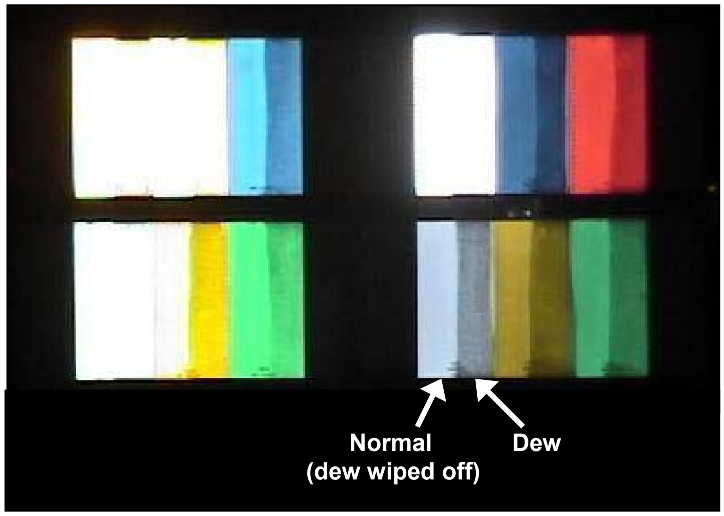


Figure 2 - Test Deck with Dew Present

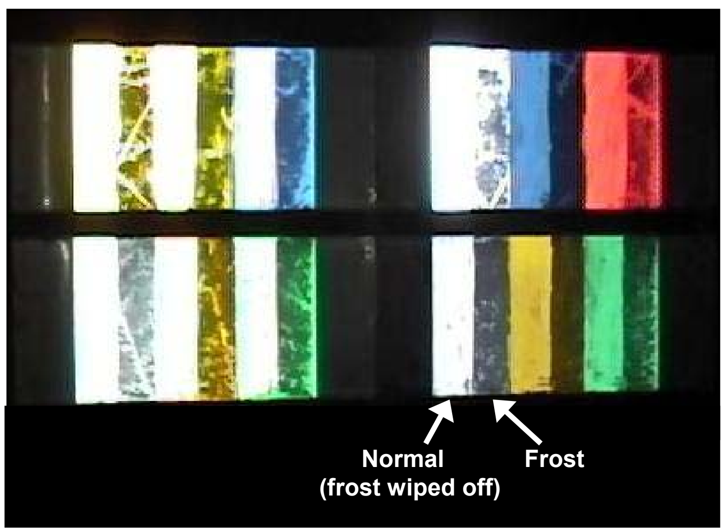


Figure 3 - Test Deck with Frost Present

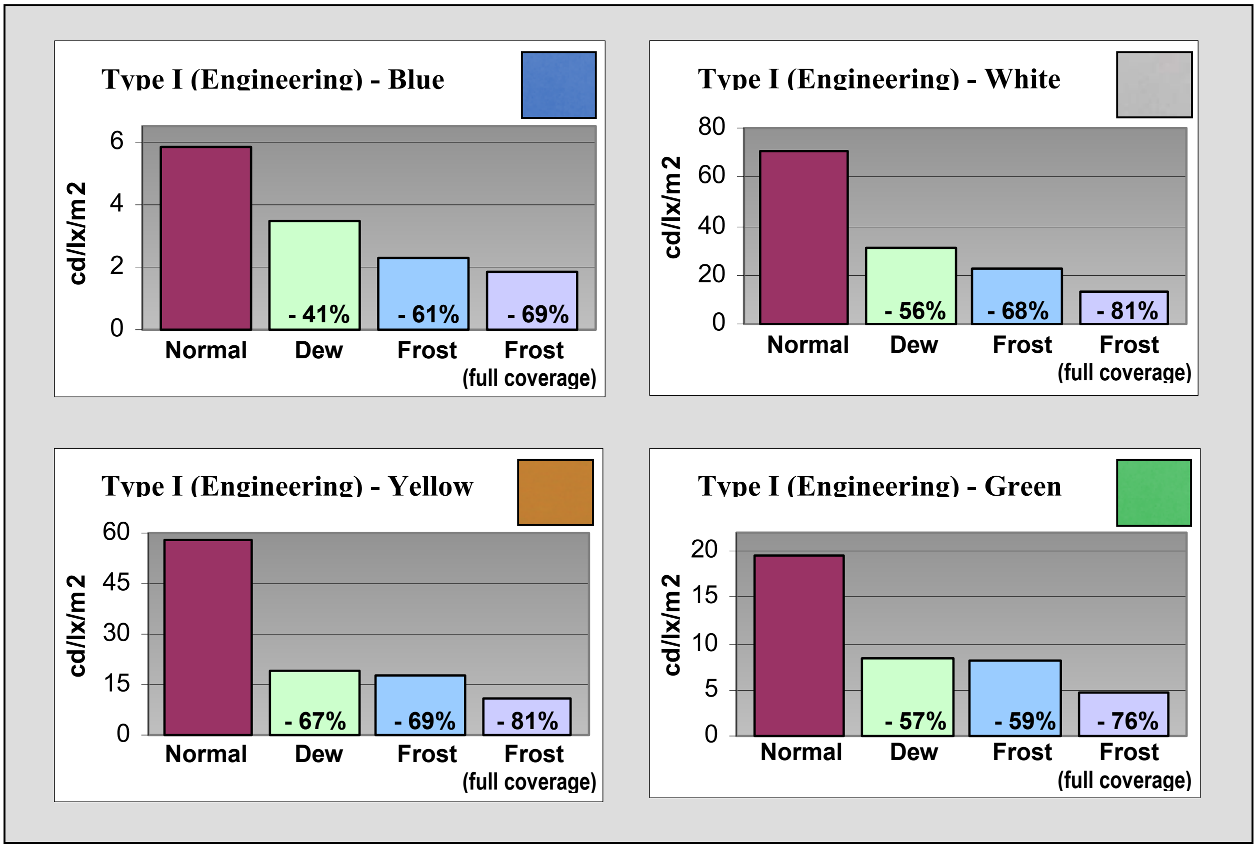


Figure 4a - Reduction in Retroreflectivity Levels Caused by Dew and Frost for Type I (Engineering) Sheeting

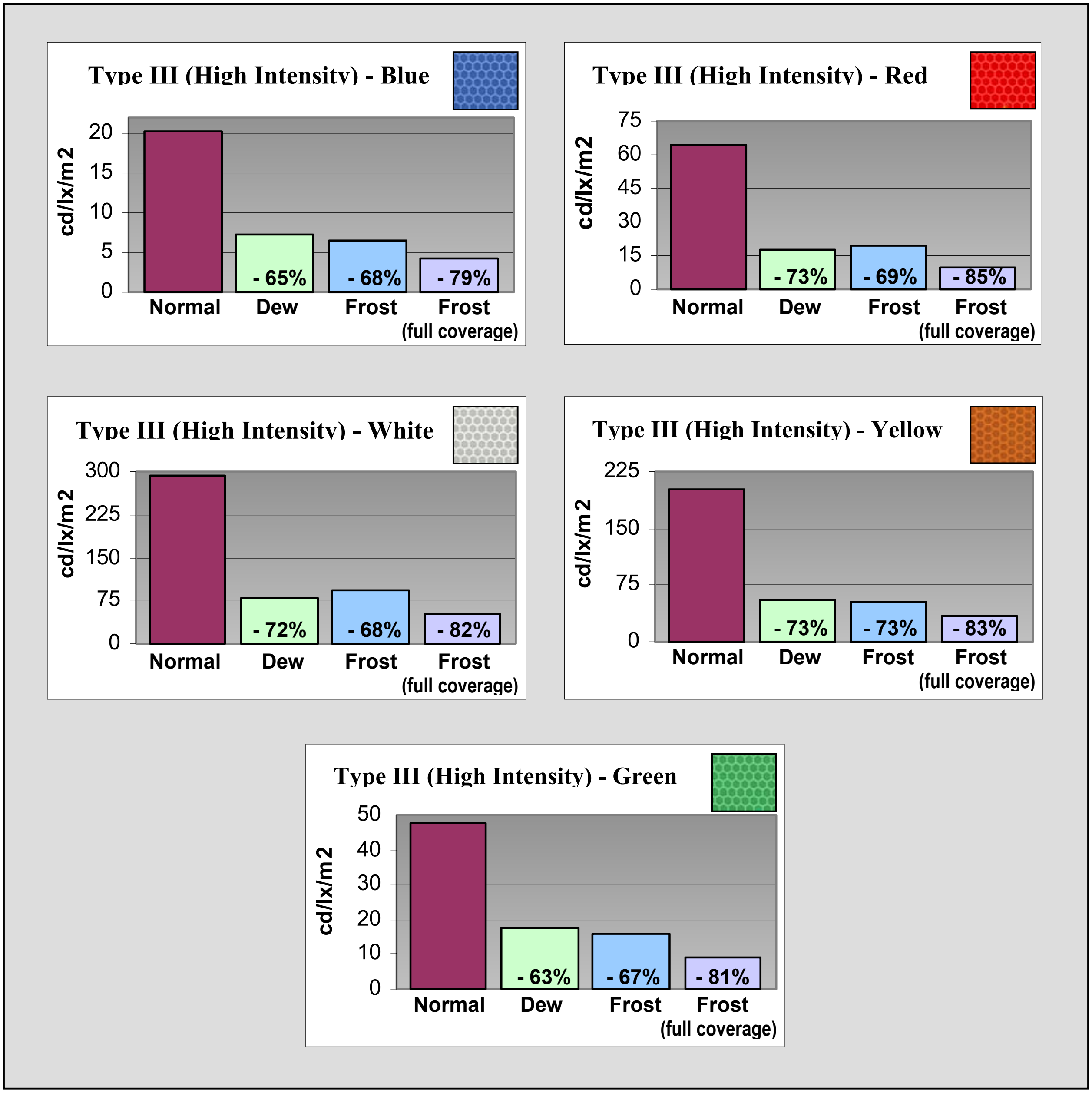


Figure 4b - Reduction in Retroreflectivity Levels Caused by Dew and Frost for Type III (High Intensity) Sheeting

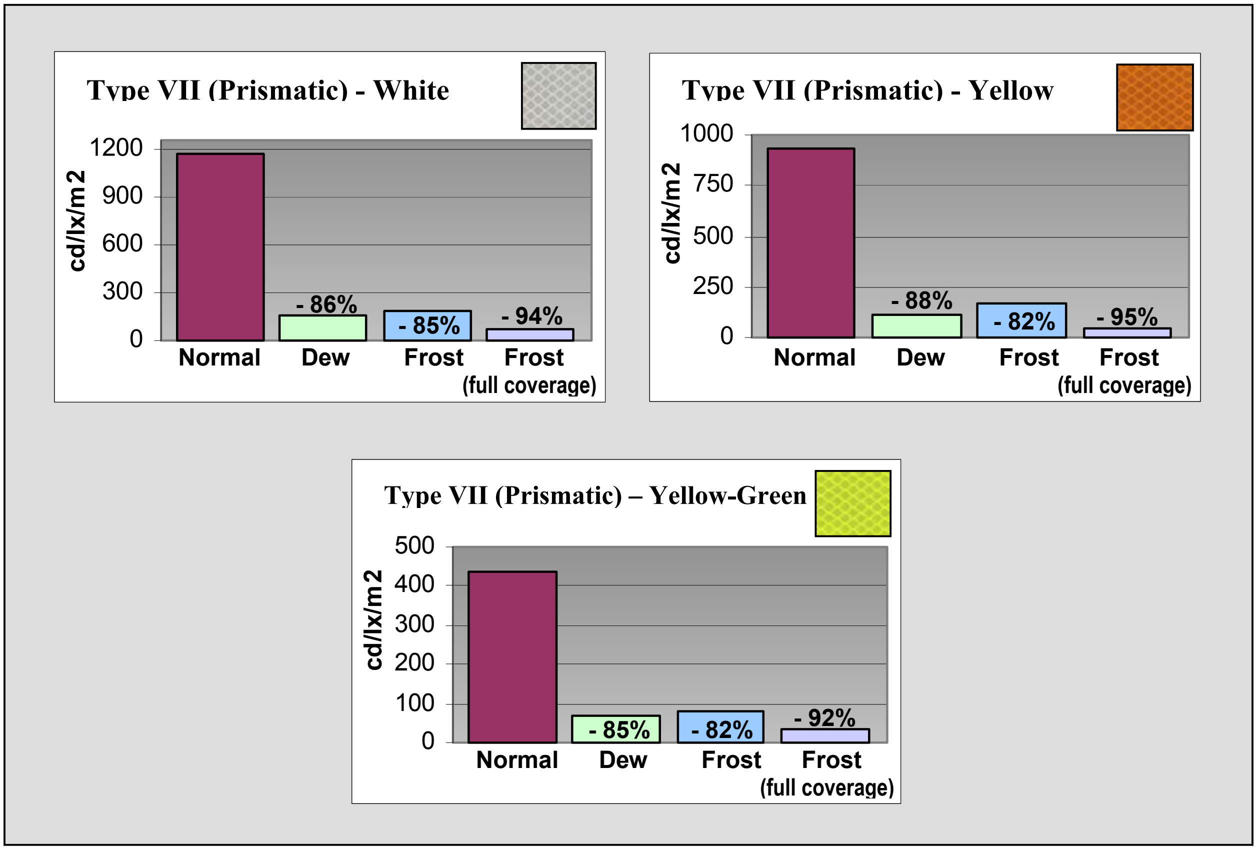


Figure 4c - Reduction in Retroreflectivity Levels Caused by Dew and Frost for Type VII (Prismatic) Sheeting

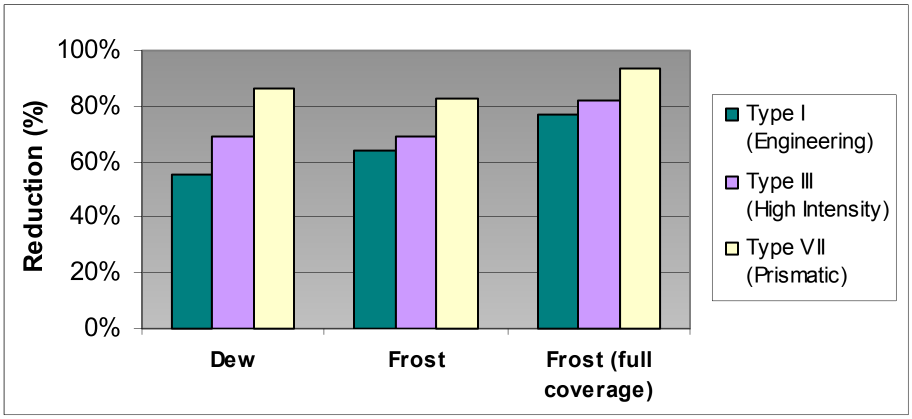


Figure 5 - Reduction in Retroreflectivity Levels by Material Type

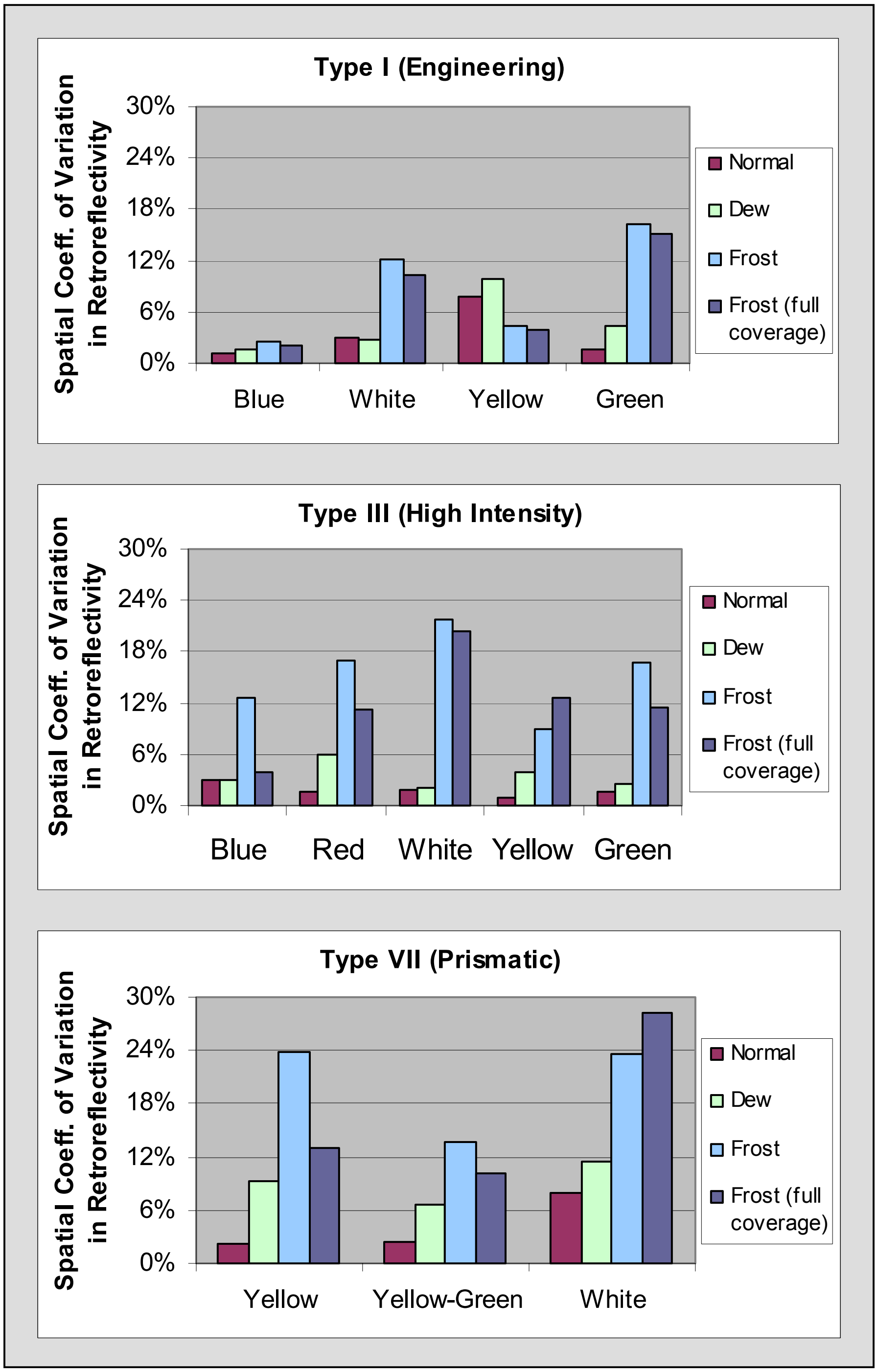


Figure 6 - Spatial Variance in Retroreflectivity Levels

Figure 7 - Partial Frost Coverage

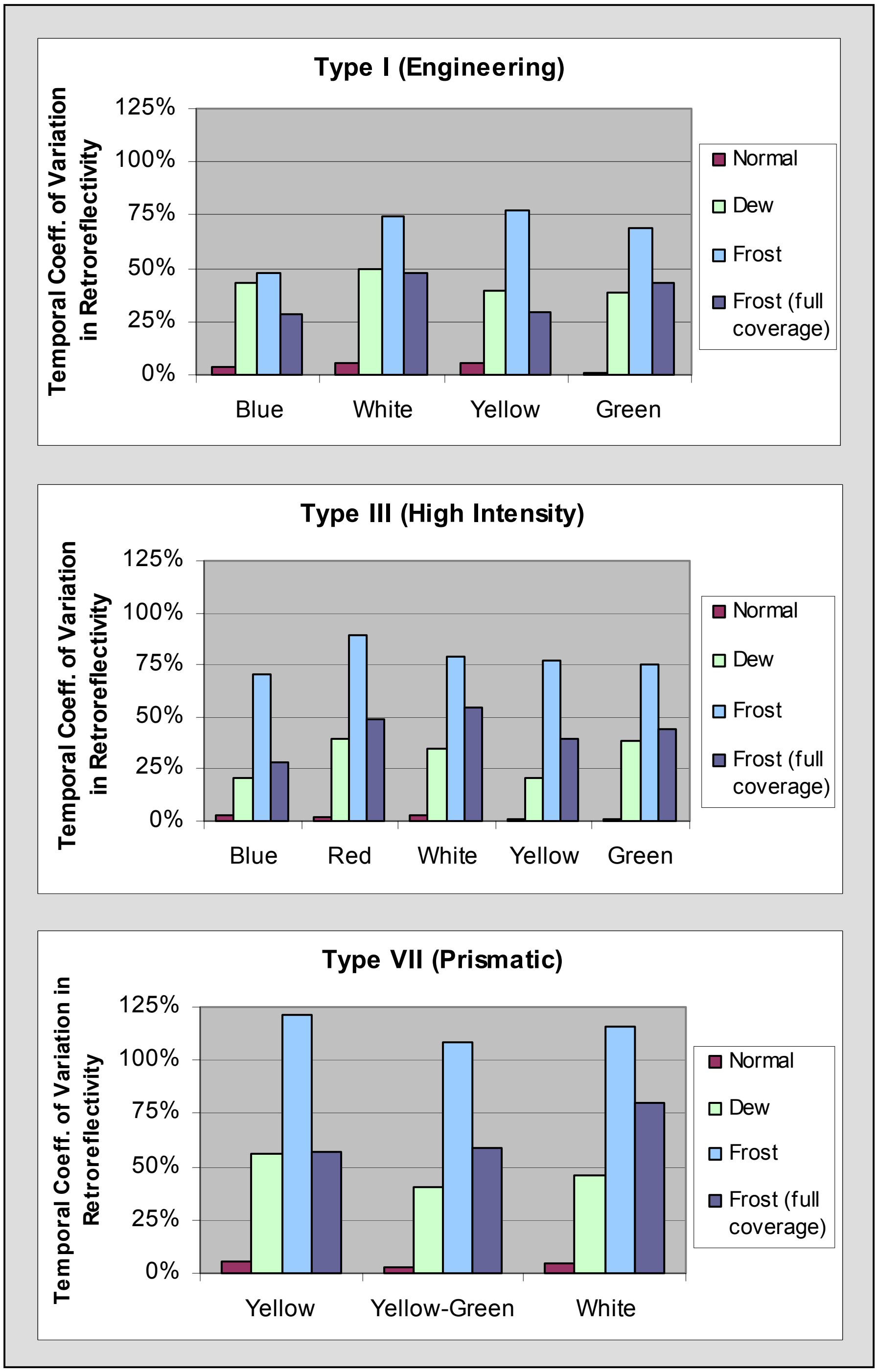


Figure 8 - Temporal Variance in Retroreflectivity Levels

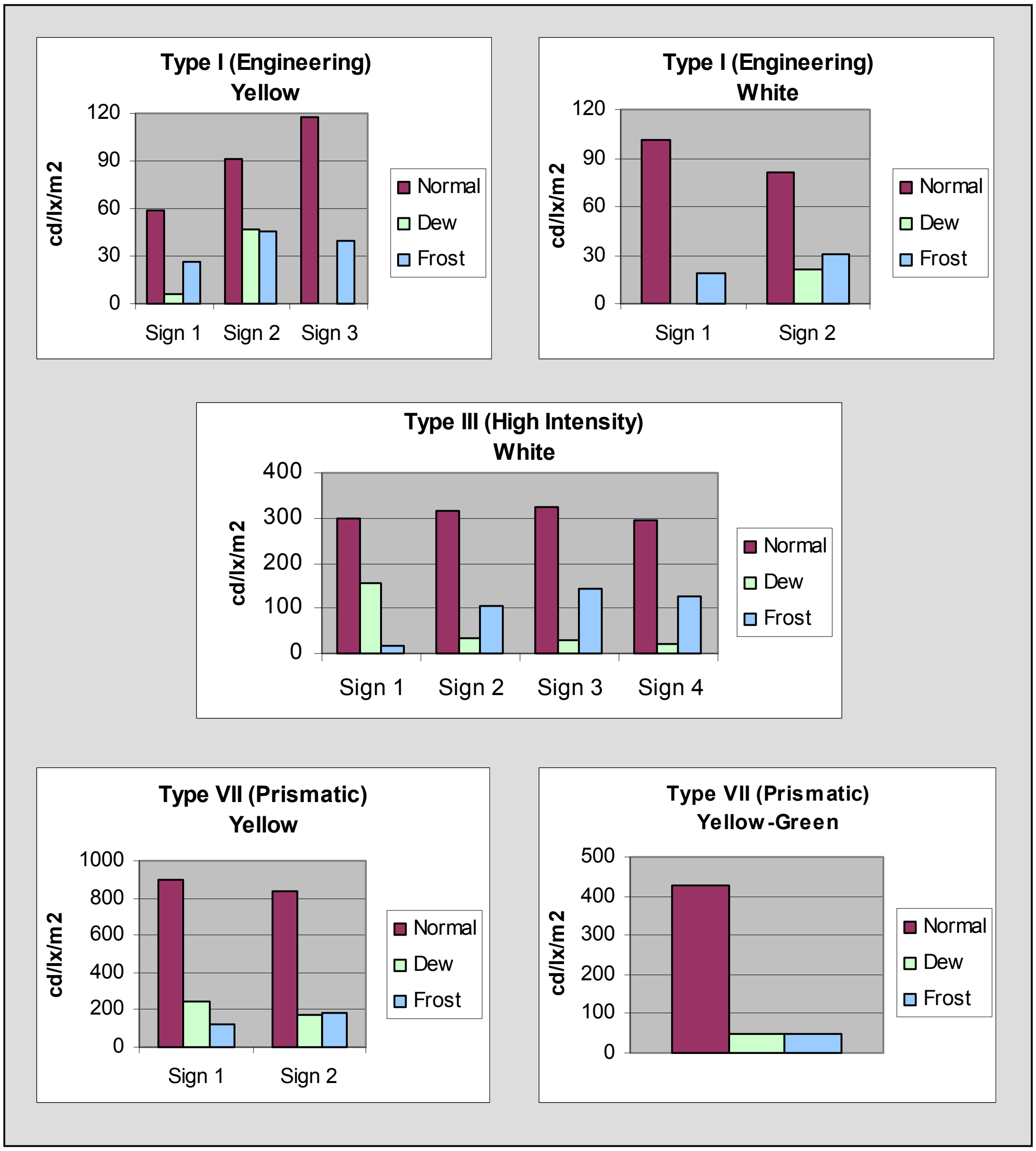


Figure 9 - Reduction in Retroreflectivity Levels of In-Service Signs Caused by Dew and Frost