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Analysis of Road Lighting Quantity and Quality in Varying Weather Conditions

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Abstract—This article focuses on road lighting measurements and calculations. Road lighting measurements are made to study the definition of appropriate road surface luminance levels during different weather conditions. Measurements took place in five pilot locations where the effects of snow, rain and fog on road luminances were examined. Through the measurement results, the effects of weather on road luminances are introduced and analyzed. The characterization and investigation of different weather conditions and their effects on visual conditions in driving offer new ways to optimize intelligent road lighting control and to make it more efficient. With an effective road lighting control system and real-time luminance measurements, electricity can be saved without adversely affecting either the safety of driving or the quality of road lighting.

Keywords—road lighting, luminance measurement, luminance photometer, weather conditions, intelligent road lighting control

1 INTRODUCTION

Road lighting is a practical tool in providing efficient and safe traffic movement and making driving conditions more comfortable. It is estimated that the successful implementation of road lighting reduces night-time accidents by 20 to 40 percent [FNRA 2006]. The impact of road lighting on reducing night-time fatal accidents is even higher [FNRA 2004]. So far, road surface luminances have been based on standardized lighting classes, using certain static luminance levels in certain road types (for example 2.0 cd/m^2, 1.5 cd/m^2, 1.0 cd/m^2 or 0.5 cd/m^2) [EN 13201–2 2003]. In practice, however, luminance levels of road surfaces are usually very dynamic and depend to large extent on weather conditions. Recent increases in the cost of electrical energy have caused actions to minimize energy costs. Activities of technological research and

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development have been carried out in order to find solutions and coherent guidelines for intelligent road lighting control. The main purpose of an intelligent road lighting control system is to save electricity without adversely affecting either the safety of driving or the quality of road lighting [Bjelland 2007; Van Tien 2005].

In this work road lighting measurements are made to study the choice of the luminance levels during different states of weather. Through the measurement results intelligent road lighting control can be optimized by taking into account different weather conditions and their effects on road luminances. Measurements are made in several pilot locations during different seasons and weather conditions (dry, wet, snowy, foggy) [Bassett 1998; CIE 1979; McNair 1997]. The main hypothesis is that in Finland during wintertime the intensity of road lighting is often excessive in relationship to the standard requirements because of higher surrounding and road surface reflectances [EN 13201–2 2003]. The measurements and analysis are made using the ProMetric 1400 luminance photometer and Radiant Imaging ProMetric and Road LumiMeter computer programs [RII 2001].

2 MEASUREMENT METHOD AND EQUIPMENT

The ProMetric 1400 luminance photometer is a computer controlled CCD-based imaging photometer and it is applicable for luminance measurements and analysis in indoor and outdoor lighting. The photometer consists of a 2-stage Peltier cooled 14-bit CCD camera, a photopic filter and a choice of lenses [RII 2001]. A CCD matrix is used as a sensor. The measurement range of the ProMetric 1400 is from 0.005 cd/m^2 to 10^{10} cd/m^2. The photometer is controlled by Radiant Imaging ProMetric software. The system accuracy for luminance measurements is ± 3 percent [RII 2001].

Road lighting calculations and measurements in Europe follow the European Standard EN 13201–3 which differs from American National Standard for roadway lighting [EN 13201–3 2003; IESNA 2000]. In this work measurements and calculations are done according to the European standard, except the observer locations. The main reason for different observer locations is that on the real roads the luminance meters of the intelligent road lighting control system cannot be placed according to the standard in the center of driving lane because of the traffic. It has to be put on the side of the carriageway or for example attached on a bridge. Either way, the location of the meter and the measurement area has to be optimized and calculated specifically for different cases.

In this work road luminances of pilot locations are measured using exactly the same method during different seasons and weather conditions. Thus the measurement results are comparable and relative calculations for different weather conditions can be made.

The longitudinal road surface measuring area of the pilot locations is taken from the first luminaire to the following one on the same side of the road. The transverse road surface measuring area is defined by borders of a carriageway. The observation point is placed 1.5 m above the road surface and luminance measurement points are taken so that the viewing angle of the observer lies between 0.5° and 1.5°. The average luminances as well as the overall and longitudinal luminance uniformities are calculated from the measured values. Average luminances and overall uniformities are calculated for the entire carriageway, whereas longitudinal luminance uniformities are calculated for each lane separately.

The utilization of an imaging luminance photometer instead of a conventional spot meter eases the luminance measurements and gives many new possibilities in analyzing the luminance distributions [Eloholma 2004]. The captured image of ProMetric 1400 consists of 500x500 pixels and in the measuring process the luminances of individual pixels are captured simultaneously. The image is transformed into numerical data, which can be correlated to photometric values. In this way a luminance map from the image can be built and luminances over the captured scene analyzed. At the HUT Lighting Laboratory, a Matlab-based program Road LumiMeter has been developed for road lighting measurements. It calculates the EN-13201–3 road lighting parameters from the photometer's measurement results.

3 PILOT LOCATIONS

In this work five different pilot locations were used for road luminance measurements. The parameters of the pilot locations are presented in Table 1. The measurements were done during January, March, June and October between 11 pm and 2 am.

TABLE 1.
Pilot Locations of Luminance Measurements in Different Weather Conditions

Test Road	Location	Lamp Type	Road Type	Weather Conditions
VT3	Haaga	MH	Highway	dry, slightly snowy, wet
VT3	Kaivoksela	HPS	Highway	dry, slightly snowy, wet
Jakokunnantie	Pakila	HPS	Local street	dry, snowy, wet
Leppälinnunrinne	Leppäsilta	HPS	Local street	dry, very snowy, wet
Ring Road III	Vuosaari	HPS	Highway	dry, snowy, snowy and foggy, wet

Highway VT3 is a major road from Helsinki to Vaasa with very heavy traffic flow and high driving speeds. It consists of two carriageways separated by a central reservation of five meters width. Each carriageway consists of two traffic lanes. On VT3 new road lighting has been installed on road section from Haaga to Ring Road III. It consists altogether of 442 luminaires of which 102 are equipped with metal halide lamps (MH 150 W) and 330 with high pressure sodium lamps (HPS 150 W). The pole height is 12 m and pole spacing 46 m. On VT3 the weather measurements were made in two different pilot locations, in Kaivoksela and in Haaga. Road section in Haaga is lit with MH lamps and the section in Kaivoksela with HPS lamps. On VT3 the road maintenance level is high and winter salting and snow clearance at wintertime is efficient.

Leppälinnunrinne is a local street located in Leppäsilta, Espoo. It consists of two traffic lanes and is lit with HPS lamps. Traffic flow on Leppälinnunrinne is very low and maintenance level adequate.

Jakokunnantie is a two lane local street located in Pakila, Helsinki. Like Leppälinnunrinne it has minor traffic volume and low driving speeds. Jakokunnantie is lit with HPS lamps. Leppälinnunrinne and Jakokunnantie were chosen as pilot locations because they offer good opportunities to study the effect of snowy conditions on road luminance levels and driver's visual conditions.

Ring Road III is an important highway in southern Finland. It is the outermost of the three beltways in the Helsinki region. It lies within four municipalities - Kirkkonummi, Espoo, Vantaa, and Helsinki. As an arch in shape, the road is about 50 km long. It consists of two carriageways separated by central reservation and is mostly four lanes wide. On Ring Road III the weather measurements were made on a recently built extension section which is not yet used by traffic. In this pilot location road lighting installation is new and consists of HPS lamps with pole spacing of 54 m. The main problem of this pilot location is that there is no road maintenance. Also because of the lack of traffic, snow wearing caused by automobiles is quite minimal. However, as a pilot location Ring Road III is very suitable for studying extreme weather conditions.

4 RESULTS OF THE WEATHER MEASUREMENTS

Results of the road luminance measurements in various weather conditions are shown in Fig. 1 - 5. The results are shown in isocolor presentations. Each figure represents one pilot location measured in different weather conditions. Colors and palettes show the luminance distribution. The unit of the palette values is cd/m^2. For each measurement, the average luminance, overall luminance uniformity and longitudinal luminance uniformities were calculated.

The luminances of the VT3 in Haaga are presented in Fig. 1. Figure 1a shows the luminance distribution and calculated luminance values of a dry road surface. Figure 1b shows the same measurement area, measured from the same

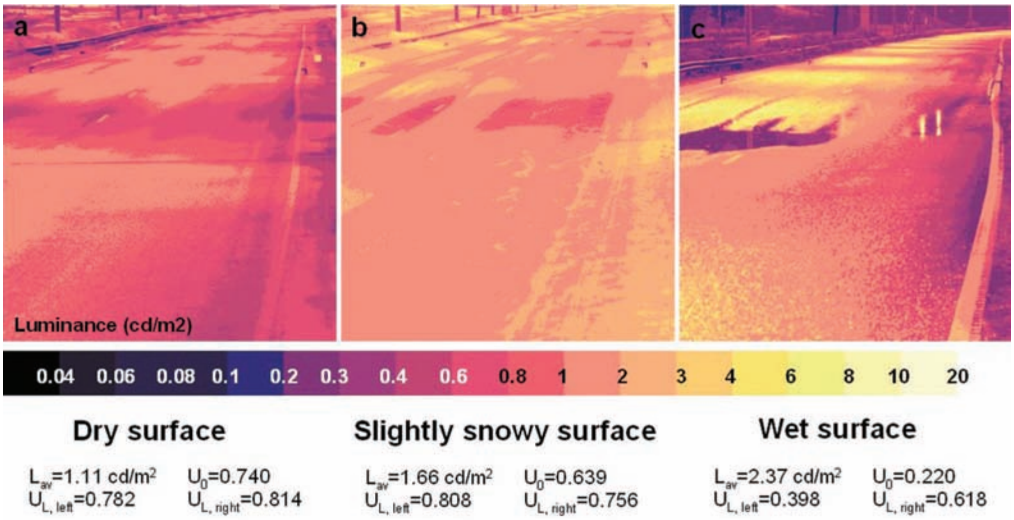


Fig. 1. Luminance distributions of the pilot location in Haaga on highway VT3 measured with the luminance photometer ProMetric. Average luminance L_{av}, overall luminance uniformity U_o and longitudinal luminance uniformities for the left, $U_{L,left}$, and right, $U_{L,right}$, lanes. The road lighting is provided by 150 W MH lamps.

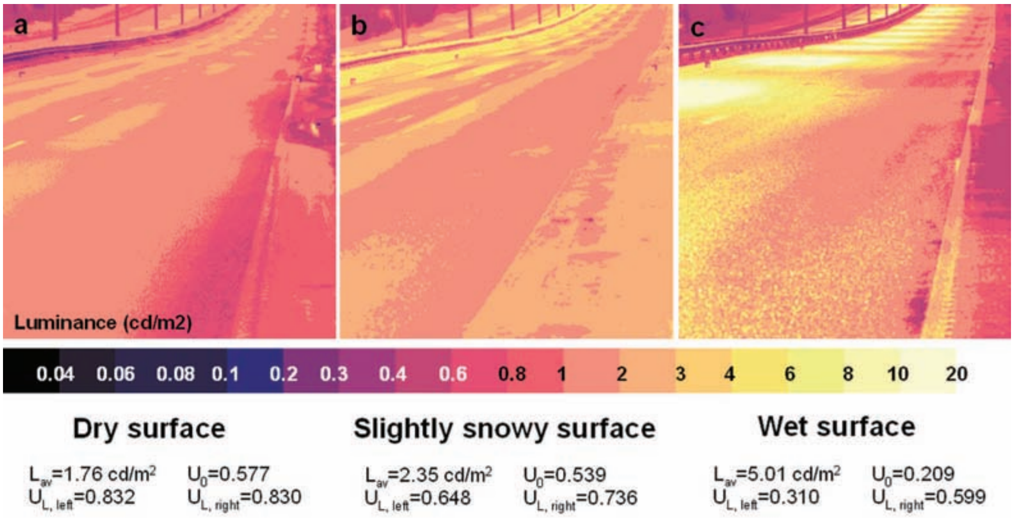


Fig. 2. Luminance measurement results measured on VT3 in Kaivoksela. Dry, partly snowy and wet road surfaces. The road section is lit with 150 W HPS lamps.

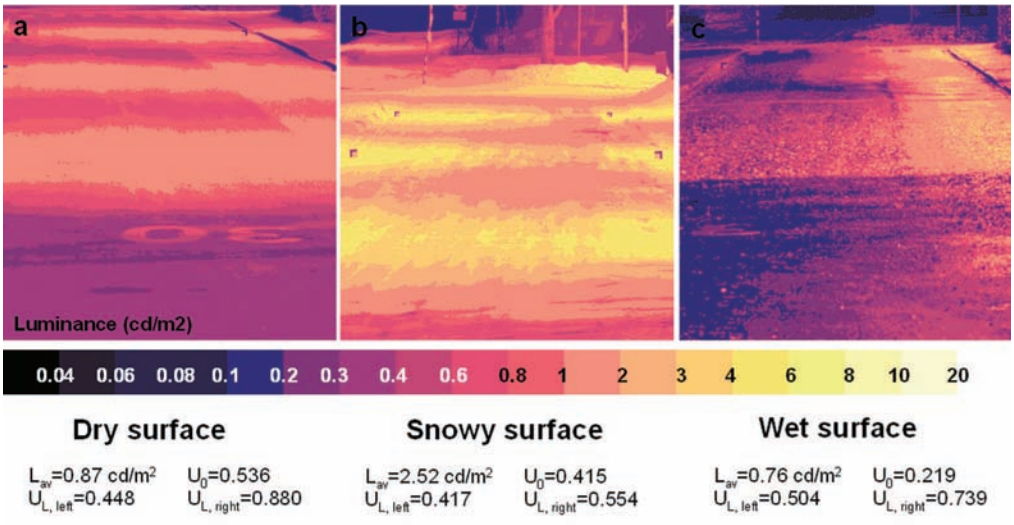


Fig. 3. Luminance distributions of the pilot location in Kaivoksela during different weather conditions. The road lighting is provided by HPS lamps.

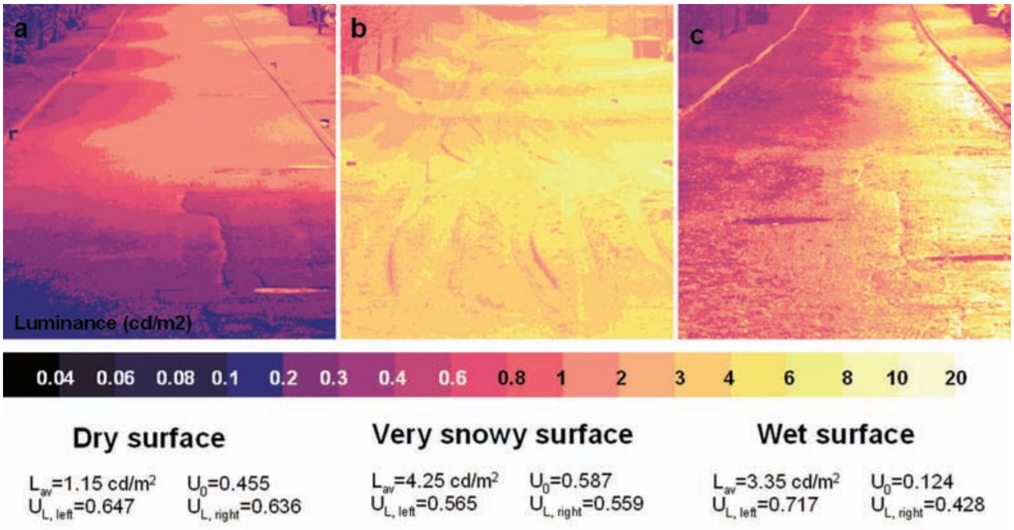


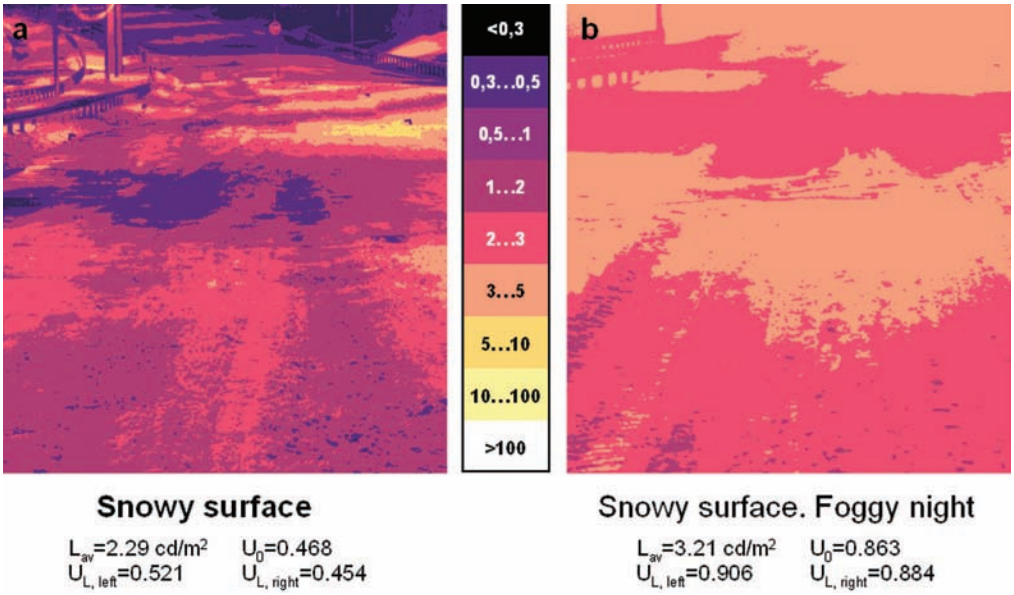
Fig. 4. Measurements results of the local street Leppälinnunrinne. Dry, very snowy and wet road surfaces. The road lighting is provided by HPS lamps.

observer location with slightly snowy road surface. The measurement is made at winter one week after the dry road surface measurement presented in Fig. 1a. Thus the seasonal circumstances are quite similar. Wet road surface measurement was done in October and the results are presented in Fig. 1c.

On VT3 the recommended average roadway luminance is 1.0 cd/m^2, minimum overall luminance uniformity value 0.4 and minimum longitudinal uniformity value 0.6 (class MEW3 [EN 13201–2 2003]). For wet road surface condition the recommended minimum overall luminance uniformity value is 0.15. As can be seen from Fig. 1a all the road surface luminance requirements are fulfilled in dry weather conditions. The overall and longitudinal luminance uniformities of snowy road surface are slightly lower but still adequate for the standard requirements. The results show that even with slightly snowy road surface the average road surface luminance is 50 percent higher than the recommended level.

Figure 1b with partly snowy road surface represents quite ordinary winter conditions in Finland. On the major roads there is usually not much snow

Fig. 5. Measurement results measured on the extension section of Ring Road III. Snowy weather conditions compared to snowy and foggy weather conditions. The road section is lit with HPS lamps.



because of salting and snow clearance. However road surroundings are covered with snow which increases the overall brightness of night-time driving conditions. As shown in Fig. 1a and 1b, the average luminance of slightly snowy surface is 1.5 times higher compared to the dry one although road surface is almost clear from snow. And the more snow there is the more luminous it gets. Thus with road lighting that is dynamically adjusted to the prevailing conditions, there is a lot of potential to achieve considerable energy savings without adversely affecting the quality of lighting.

Road surface luminances in wet conditions (Fig. 1c) are more than two times higher than in normal dry conditions. The overall and longitudinal uniformities are as expected very low but, however, compared to the standard EN-13201–2 requirements for wet road surfaces (U_0=0.15) sufficient enough [EN 13201–2 2003]. The longitudinal luminance uniformity measured from the left lane is clearly lower compared to the one measured from the right lane.

Figure 2 shows weather measurement results measured on VT3 in Kaivoksela in the HPS lamp installation. The measurement set-up is similar to the one presented in Fig. 1. The road surface luminance levels in the HPS installation (Fig. 2) were higher compared to the MH lamp installation (Fig. 1). In the HPS lamp installation the average luminance of the lightly snowy surface was 34 percent higher than in dry conditions and the overall and longitudinal luminance uniformities were a little bit lower. The average luminance in wet conditions (5.0 cd/m^2) was way too excessive with regard to the actual need. The wet surface, however, reduces the luminance uniformities substantially. In all situations all road lighting quality requirements were met.

In wet conditions the luminance levels of parts of the surface are lower than in dry conditions, whereas in areas with specular reflection towards the driver they increase significantly. For example in dry conditions (Fig. 2a) the average luminance in the HPS installation was 1.76 cd/m^2. Again in wet conditions (Fig. 2c) the luminances in the bright area were between 10. . . 30 cd/m^2 towards the observer, which is about ten times higher than in dry conditions. The luminances of the darker areas of the road were however slightly decreased. This results in very low luminance uniformities. Bright areas with specular reflection may also cause discomfort glare.

The biggest problem in wet conditions is the high reflection factor of the road surface which might result in causing discomfort glare [Eloholma 2004]. It is also very difficult to upkeep good quality of lighting on wet road surface because of its dynamic characteristics. The road surface luminances are very unstable because the surface is usually either becoming more wet or dries. Luminance uniformities are poor and also as shown in Fig. 1c reflections from ponds can disturb driver's visibility. However, the average luminances are usually quite high (Fig. 2c) and with efficient road lighting control based on real-time measurements of luminance there are possibilities to benefit from high luminance levels.

Luminance distributions of the local street Jakokunnantie are presented in Fig. 3. Figures 3a and 3b show that if there is snow on the road, average luminances can easily be three times higher than in dry road surface conditions. On major roads this could for example represent a situation when it has recently snowed.

The road luminance measurements in Leppäsilta focused on more extreme weather conditions (Fig. 4). Figure 4b shows the measurement results of very snowy road surface. The measurement was done right after it snowed and before any snow clearance was done. The measured average luminance of the snowy road surface was 4.25 cd/m^2 which is even four times higher than the average luminance on dry road surface (1.15 cd/m^2). For a local street this kind of luminance level is very high. Fig. 4c presents the same pilot location with very wet road surface. The average luminance is quite high but the overall uniformity is inadequate. In wet conditions the left lane is quite dark while the luminances of the right lane are about five times higher than in dry conditions.

Figure 5 shows weather measurement results measured on the extension section of Ring Road III. Figure 5a presents the luminance distribution of snowy road surface. Again the substantial effect of the snow on road luminances can be seen as the average luminance is 130 percent higher than the recommended level 1.0 cd/m2 (MEW3). Figure 5b shows the effect of fog on road luminances while the surface is covered with snow. The average road surface luminance in foggy conditions is 40 percent higher and luminance uniformities are almost doubled compared to the bare snowy surface. Despite the increased average luminance and luminance uniformities the fog may, however, result in substantially decreased driver's visibility conditions. Thus, in order to optimize the control strategies in intelligent road lighting control systems, other input data (weather conditions, traffic flow etc.) should also be collected in addition to road luminances.

5 DISCUSSION

According to the weather measurements in night-time periods when snow covers roads, the need for light is lower and the illumination levels can be reduced. However, minimizing energy costs should not be done by turning every second luminaire off because that reduces lighting quality and driving safety. To be able to save electricity, and at the same time upkeep the required lighting quality level, dynamic road lighting is required.

The objective of intelligent road lighting control should be to provide road lighting that is adequate in quantity and quality for the prevailing circumstances (traffic density, weather, etc.). Dynamic control should be based on real-time measurements of luminance. Luminance meters can monitor the luminance level on the road surface and compare it to the required level. The control system tries to keep the luminance level of the road sufficient for each traffic and visibility conditions.

In intelligent road lighting control system the location of the luminance meter and the measurement area on the road has to be selected and calculated specifically for different cases. Luminance meter should be placed so that the meter's observation location is as similar to the driver's position as possible. The meter should measure the road surface between one luminaire spacing and in the transverse direction the area should be defined by borders of a carriageway.

The analysis of the reliability of the luminance measurements results has been divided according to the measurement equipment and method used. Major sources of error in the luminance measurements are estimated to be external factors such as sky-glow, moonlight, external buildings and so on. Because the measurements were done at different times of the year these factors play a role. The system measurement error for luminance measurements according to the manufacturer's certificate is ± 3 percent.

6 CONCLUSIONS

The road luminance measurement results in different weather conditions show that by taking weather effects on road luminances into account there is potential to achieve considerable energy savings. Luminances of snowy road surfaces can be multiple times higher than in dry and so called "normal" conditions. And even if there is a minor amount of snow and snow clearance is done, luminance levels are still about 50 percent higher compared to conditions without any snow. The overall and longitudinal luminance uniformities of snowy road surfaces are usually slightly lower than in dry conditions but still adequate for the standard requirements. Also in some situations snowy and especially icy road surface illuminated by the headlamps of an oncoming vehicle can cause discomfort and disability glare and reduce visibility conditions of the driver.

In wet conditions the luminance distributions of road surfaces change significantly compared to the dry conditions. Road surface areas with specular refection towards the observation point become very bright and may cause discomfort glare. On the other hand, the luminances of the darker areas of road surface decrease. This results in lower luminance uniformities and in worse driver's visibility conditions. However, average luminances of wet road surfaces are usually higher than in normal, dry conditions.

In wet conditions on well illuminated roads the luminances of the bright areas can be over ten times higher compared to the dry conditions. When light levels are reduced luminance levels of the bright areas are 5. . . 8 times higher than in dry conditions. However, together with the cumulative effect of oncoming vehicle headlights reflecting from the wet road surface, reducing light levels might even worsen the glare effect. Also in foggy conditions, despite the increased average luminance and luminance uniformities, the fog may result in substantially decreased driver's visibility. Also rain or snowfall that is illuminated by the headlamps of a vehicle may reduce visibility conditions.

To be able to take into account and benefit from the prevailing weather conditions, an intelligent road lighting control based on real-time measurements of luminance is needed. Luminance levels of road surfaces are usually very dynamic and especially on wet road surfaces it is difficult to upkeep good road lighting quality. However, the luminance measurements in different weather conditions so far have been promising and in order to efficiently take advantage of the varying weather conditions, there is need to develop and investigate the possibilities of intelligent road lighting control.

The findings of the paper indicate that it is reasonable to use road surface luminance as one of the control parameters for intelligent road lighting control. However, although the weather measurements show great luminance differences in varying weather conditions and according to the measurements there is potential to achieve energy savings, in real applications the intelligent road lighting control system may not detect the luminance differences due to the effects of traffic flows. In intelligent road lighting the placement of luminance meter should be considered carefully, because different positions of the meter result in varying road surface luminance results. In practice, this usually means a compromised position where the disturbances of traffic can be minimized.

The luminance measurements presented in this work do not represent any specified standard conditions of snowy and wet road surfaces. However, they do indicate remarkable changes which these conditions can have on the luminance distributions of road lighting.

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