



REPORT

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Date 2016-04-08 Reference MTK5P08986-2 Page 1 (33)

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Traffic-compensated luminance measurement – complementary addition

(2 appendices)

Summary

The document describes the findings from a study, performed as a complementary addition to previous work on Traffic compensated luminance estimation, as reported in MTK4P06467-2, *Final report - Traffic compensated luminance estimation (2015-06-24)*.

During the test period the L_{seq} camera registered many scenes with extraordinary luminance distributions, caused by sun illuminated cloud edges and direct sun in the camera field of view. In the report, we discuss the influence of saturated pixels, field of view of the L_{seq} camera and the intra-day variation of the visibility of objects in the tunnel opening. Moreover, we show that the luminance value is highly dependent on the centring of the field of view. A rotation of the camera (or diode-based sensor) of approximately 1 degree will – for this particular scene and time of year – result in an average L_{20} luminance error of 5 percent.

One of the principal objectives of the original project was to estimate the impact of active traffic compensation to reduce the influence of traffic on road surface luminance estimation for lighting control. European standard EN 13201 dictates that the luminance should be measured from the road surface – and not the roof tops of the vehicles. In order to achieve this, we need to continuously keep track of the vehicles (using e.g. computer vision techniques) and make sure that, every time we sample a road patch, it is free from occluding vehicles.

The basic technology for active traffic compensation was evaluated in the original project. However, the technical evaluation was performed during a time of year when high-density traffic did not coincide with twilight or nocturnal conditions - the conditions of most interest for lighting control. In this complementary project, however, we have utilised the same set of camera prototypes to acquire data under highly relevant conditions.

The results show that, at peak traffic hours between 7am and 8am, the mean relative error between the compensated and uncompensated signals may exceed 60 %. The data clearly indicates a correlation between relative luminance errors and traffic flow - where high errors are more likely at times of high traffic flow. Based on these results, we believe that active traffic compensation should be a requirement to maintain errors at a reasonable level allowing lighting control while maintaining traffic safety.

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In addition to the above, we study the impact of various weather conditions on the road surface luminance. Under conditions with fog and/or snow, our results show that the average surface luminance may double thereby providing opportunities for significant energy savings through active dimming of light sources.

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1. Background

This document describes the results of the study financed by Trafikverket, as a complementary addition to the work reported in MTK4P06467-2 *Final report – Traffic compensated luminance estimation*¹, dated 2015-06-24. The work presented here was proposed in the document ML150916-1rev1, entitled *Projektförslag Trafikkompenserad luminansmätning komplettering*².

In the proposal, the following work was proposed:

Table 1. Description of work performed.

AP	Work description	Result	Presentation
1.2	Additional data storage purchase	Complete	The storage has been used for the additional image data collected.
1.6	Implement adaptive logging of image data	Complete	An adaptive logging which collects image data more frequently when high L_{seq} values are noted has been implemented for the CIE 88 system
1.7	Collection and annotation of image data (EN 13201 ⁵ and CIE 88 ⁴)	Complete	Image data has been collected and used for the evaluation reported here
4.7	Study the effect of changed sampling frequency when calculating L_{seq}	Complete	The results are reported in section 2
4.9	Evaluate image material from fall 2015 in terms of L_{seq}	Complete	The results are reported in section 2
10.3	Evaluation of collected image data (EN 13201 ⁵)	Complete	The results are reported in section 0
10.7	Search for particularly interesting lighting conditions. Analysis and visualization of these (EN 13201 ⁵)	Complete	The results are reported in section 0
10.8	Calculation of relation between angular distance and pixel distance for an instrument placed above the road surface	Complete	The results are reported in section 3
11.1	Project management	Complete	
11.6	Presentation of results	Complete	Presented at Trafikverket 2016-01-13

2. Luminance data from L_{seq} - camera

Data from the luminance camera looking into North entrance of Gnistängstunneln was collected during the period 2015-10-06 until 2015-11-21.

L_{seq} was calculated every 10 seconds and the intensity values for each segment in the L_{seq} grid were saved but the underlying camera images were only saved if L_{seq} values were high or the change in L_{seq} since last observation was big. Figure 1 shows L_{seq} observations when these criteria were fulfilled. Thus, for every L_{seq} observation in the graph, there is a corresponding luminance image available for further analysis.

By inspecting Figure 1 we find high daily maximum L_{seq} values on October 25 and November 8, 12, 14, 15, 18. Tone mapped images of the luminance distributions for these days are shown in Figure 2 and a summary of the conditions can be found in Table 2.

Table 2. Description of the scenarios with high L_{seq} observations. L_{seq} is calculated from luminance data with a saturation level of 225000 cd/m^2 .

Date	L_{seq}	Sky	Sun	Road
2015-10-25	427	10 % light clouds	Direct	Wet
2015-11-08	439	10 % light clouds	Direct	Dry
2015-11-12	496	10 % light clouds	Direct	Dry
2015-11-14	461	10 % light clouds	Direct	Wet
2015-11-15	504	Clear sky	Direct	Dry
2015-11-18	520	10 % light clouds	Direct	Dry

The luminance images were saturated at 225000 cd/m^2 , so all scenarios correspond to a higher L_{seq} value than given in Figure 1 and Table 2 because of saturated pixels. However, the measurement error is maybe not as big as one might first think, because the optical components of the camera will smear out the extremely high intensity levels from the sun to cover a larger area of the camera sensor chip. This imaging error will in some way compensate for the inability to measure the exact value.

The luminance of the solar disc³ is probably in the range of 100 – 1000 Mcd/m^2 , but the diameter of the solar disc is about 0.5° , so the contribution to L_{seq} from a patch in one of the outer rings containing the sun, should not be unreasonably high.

A rough estimation gives that the L_{seq} contribution from an outer patch containing the sun with an average solar disc luminance of 1000 Mcd/m^2 could be about 800 cd/m^2 . During the test period the L_{seq} camera measured individual patch contributions in the range of 100 cd/m^2 , and total L_{seq} values of about 500 cd/m^2 when direct sun was in the field of view. Therefore it is reasonable to assume that the measurement error estimates to a factor of just 2 – 3, even for extreme situations with direct sun in the field of view.

The luminance images in Figure 2 are shown with different tone mapping for the upper and lower part. The upper part mainly contains the sky with high luminance levels, and the lower part contains lower luminance levels. By using different white points for the two areas, it is possible to see if there are clouds on the sky or where the sun is located in the upper part of the image and at the same time resolve contrasts in the lower part of the same image. Otherwise

the sky would have been white with no details visible or the lower part of the image would have appeared very dark.

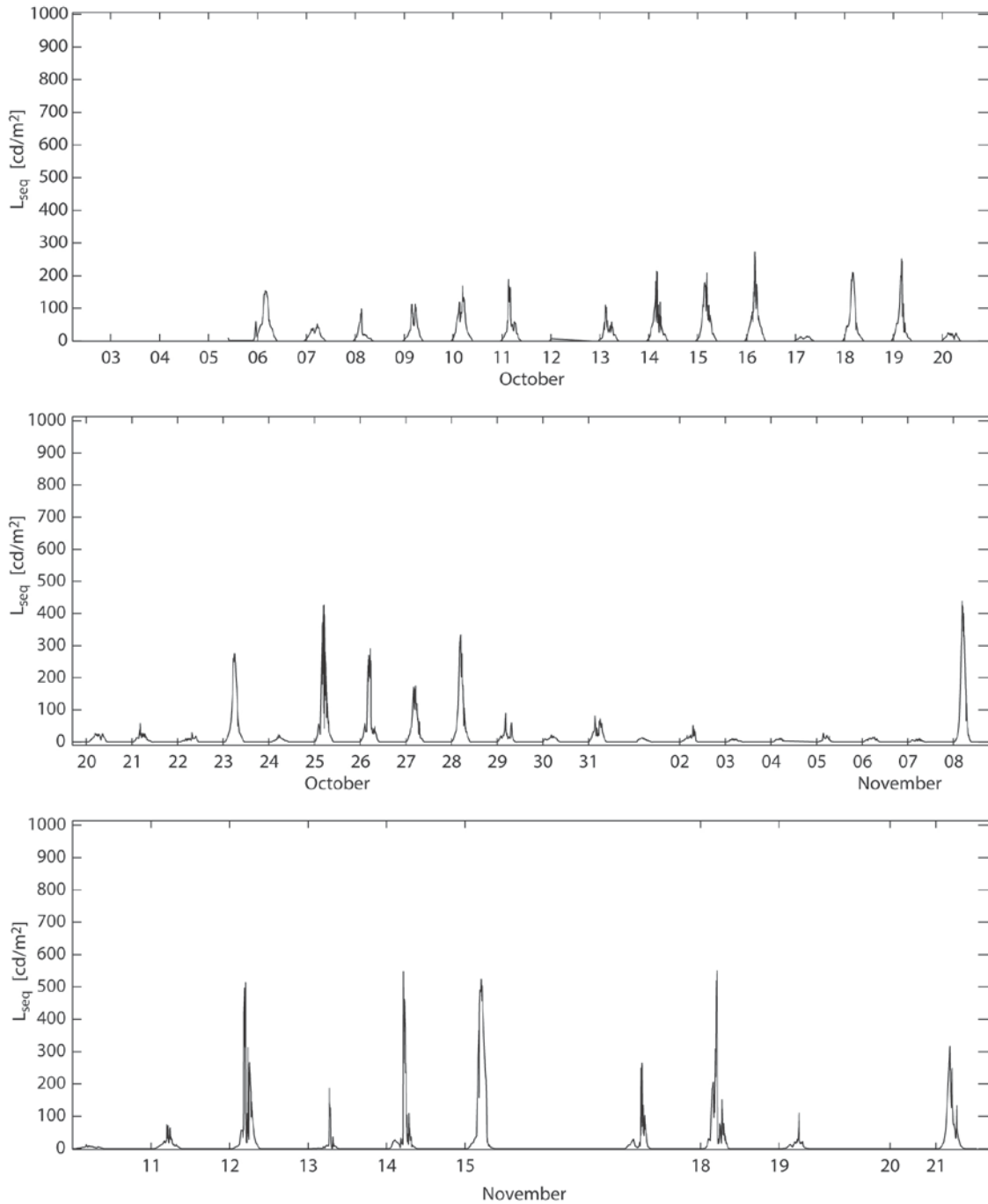


Figure 1. L_{seq} observations during 2015-10-03 to 2015-11-21 at North entrance of Gnistingstunneln.

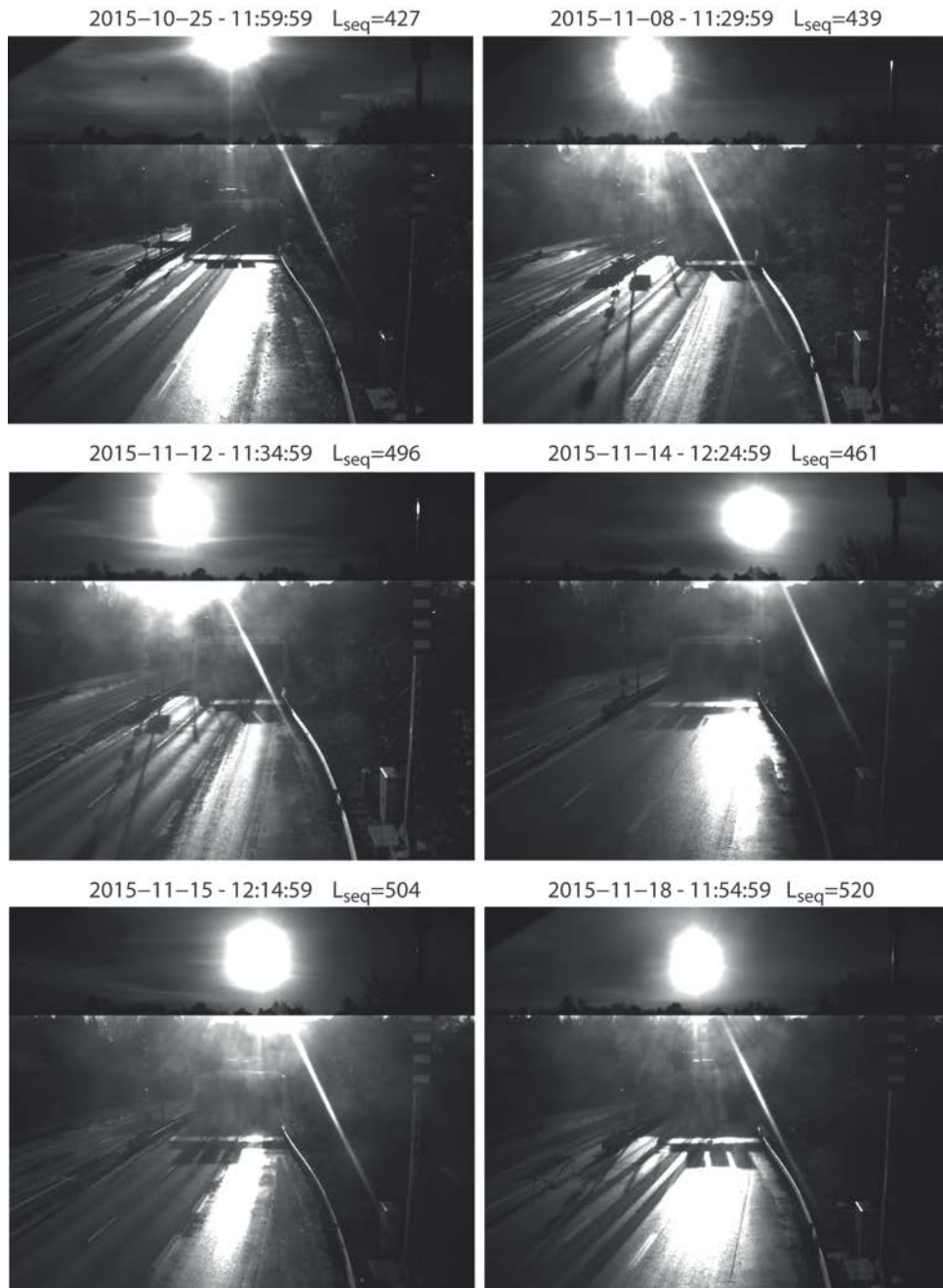


Figure 2. Tone mapped luminance images of scenarios with high L_{seq} values.

2.1. Estimation of the visibility of an object in the tunnel opening

A rough estimate of the visibility of an object in the tunnel opening is the ratio between the veiling luminance, L_{seq} , and the mean luminance in the 2° central ring, L_2 , of the L_{seq} grid. The higher luminance in the tunnel opening, the more visible will an object on the road become. However, the veiling luminance will reduce the contrasts of an object and the bigger the veiling luminance compared to the local mean luminance, the more it will influence the contrasts. Therefore, L_{seq} / L_2 is an estimate of the visibility of an object.

Figure 3 shows the variation of L_{seq} / L_2 over the test period. The maximum value is near 0.2 for almost all days. An example of the intraday variations is shown in Figure 4.

By inspecting how the L_{seq} grid is located in the tunnel opening, c.f. Figure 8, it appears that L_2 measures the luminance on the road about ten meters inside the tunnel. Therefore L_2 is not exactly the same as the threshold luminance L_{th} .

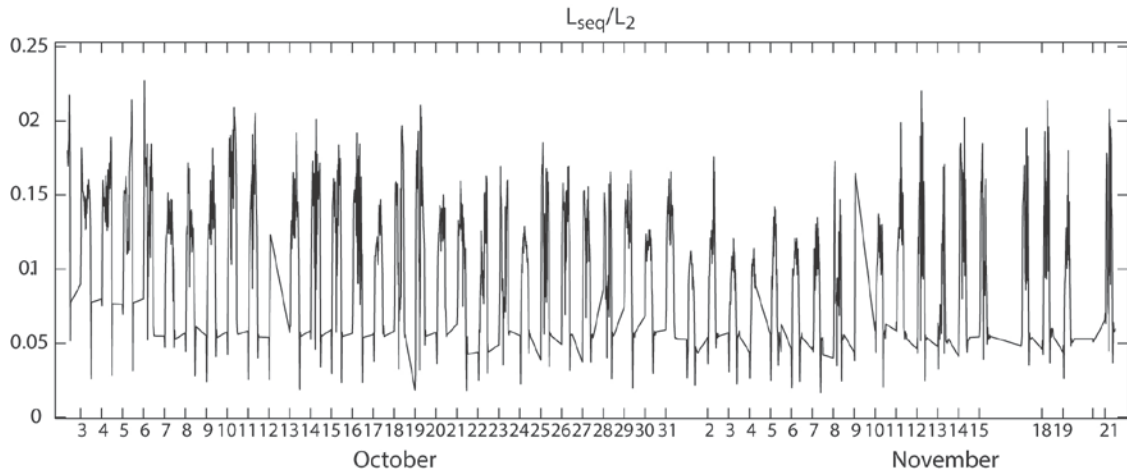


Figure 3. The ratio L_{seq} / L_2 estimates the visibility of an object in the tunnel opening and is here plotted for the whole test period.

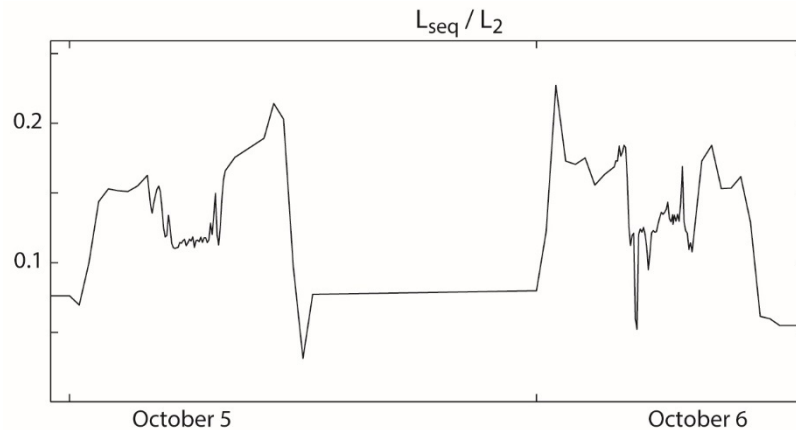


Figure 4. An example of intraday variations of L_{seq} / L_2 for October 5 and 6. By inspecting the exact time stamps it was found that the maximum values occurred 17:29 and 07:59, respectively.

The maximum value of ratio L_{seq} / L_2 doesn't coincide with the maximum value of L_{seq} , as shown in Figure 4 and in more detail in Figure 5 where L_{seq} / L_2 graph is shown superimposed on the L_{seq} graph. Generally, it seems that L_{seq} / L_2 is high in the morning and in the evening. In Figure 4, the maximum occurred at 17:29 on October 5 and at 07:59 on October 6. The luminance distributions at these times are shown in Figure 6. The same pattern repeats even on days with direct sun above the tunnel at noon, like 2015-11-08, c.f. Figure 2.

This observation indicates that the poorest visibility in the tunnel opening might occur for other luminance distributions than we might expect, i.e. not when the luminance levels are the highest at mid-day. One reason could be that for this particular tunnel portal, the roof is of raster type and that it works particularly well at mid-day luminance distributions. Further investigations are needed for full understanding of this phenomena, for example by investigating from where the road is illuminated at different times of the day.

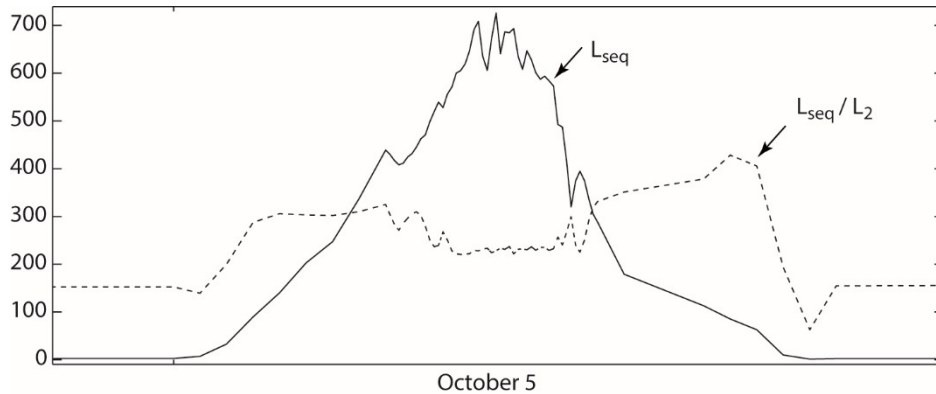


Figure 5. Variation of L_{seq} (solid line) on October 5 with the graph of ratio L_{seq} / L_2 (dotted line) superimposed. The maximum value of L_{seq} / L_2 does not coincide with maximum levels of L_{seq} .

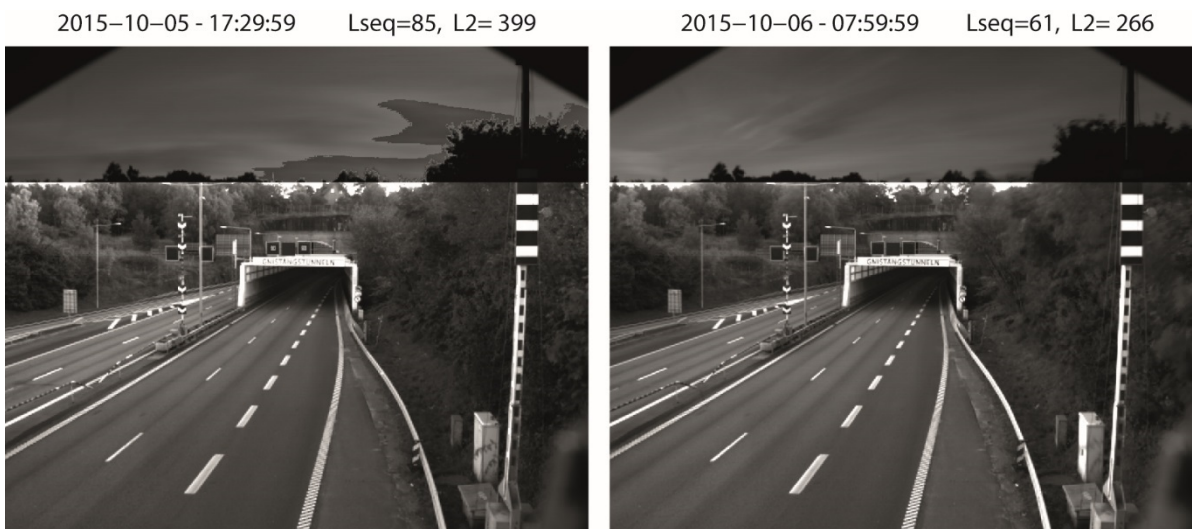


Figure 6. Luminance images from two occasions on October 5 and 6 when the ratio L_{seq} / L_2 was high.

2.2. Contribution from highest and lowest patches of L_{seq} grid

In CIE 88:2004⁴ page 11 there is a statement saying that the veiling luminance contributions from the two highest and the two lowest patches in the L_{seq} grid should not be taken into account because these patches are out of the field of vision. The reason is not given, but we might assume that the authors believe that the roof of the vehicle will block these parts of the field of view. However, modern cars tend to have large windscreens and trucks and buses have very little shielding from the roof in these areas, so it is far from certain that those patches should be excluded.

In an attempt to estimate the amount of contribution from these patches we calculated the fractional contribution to L_{seq} from the highest and lowest two patches respectively for all recorded luminance images during the test period. The result is presented in the histogram plots in Figure 7. We see that for most luminance distributions the two highest patches contribute with 10-15% to L_{seq} . The two lowest patches contribute with about 1-3% to L_{seq} and are more or less negligible. For some luminance distributions the two highest patches

contribute to over 40% of L_{seq} , which turned out to be because of direct sun, or illuminated cloud edges, in these areas, see Figure 8. Two other examples of luminance distributions where the contribution to L_{seq} from the highest patches are 25% and 10% respectively, are also given in Figure 8.

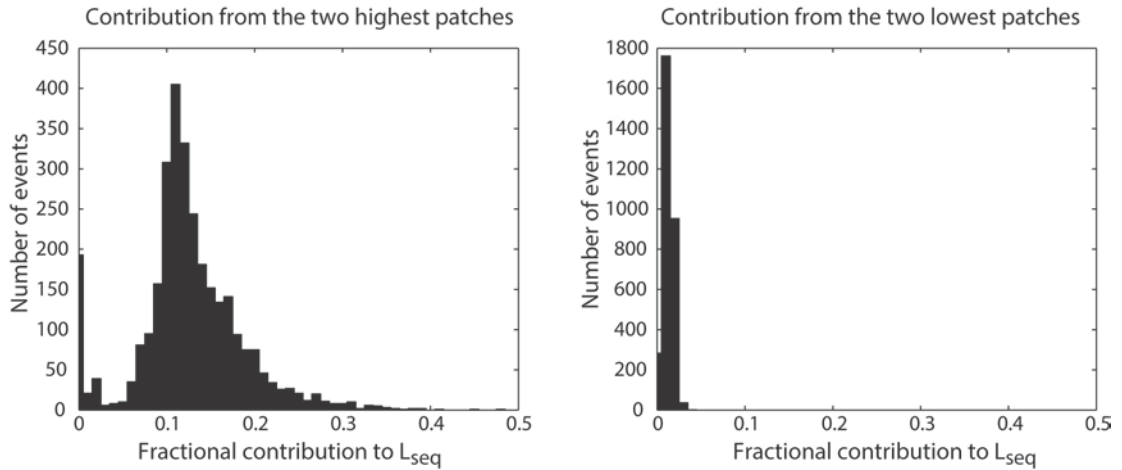


Figure 7. Histogram showing the contribution from the two highest patches (left) and the two lowest patches (right) in the L_{seq} grid.

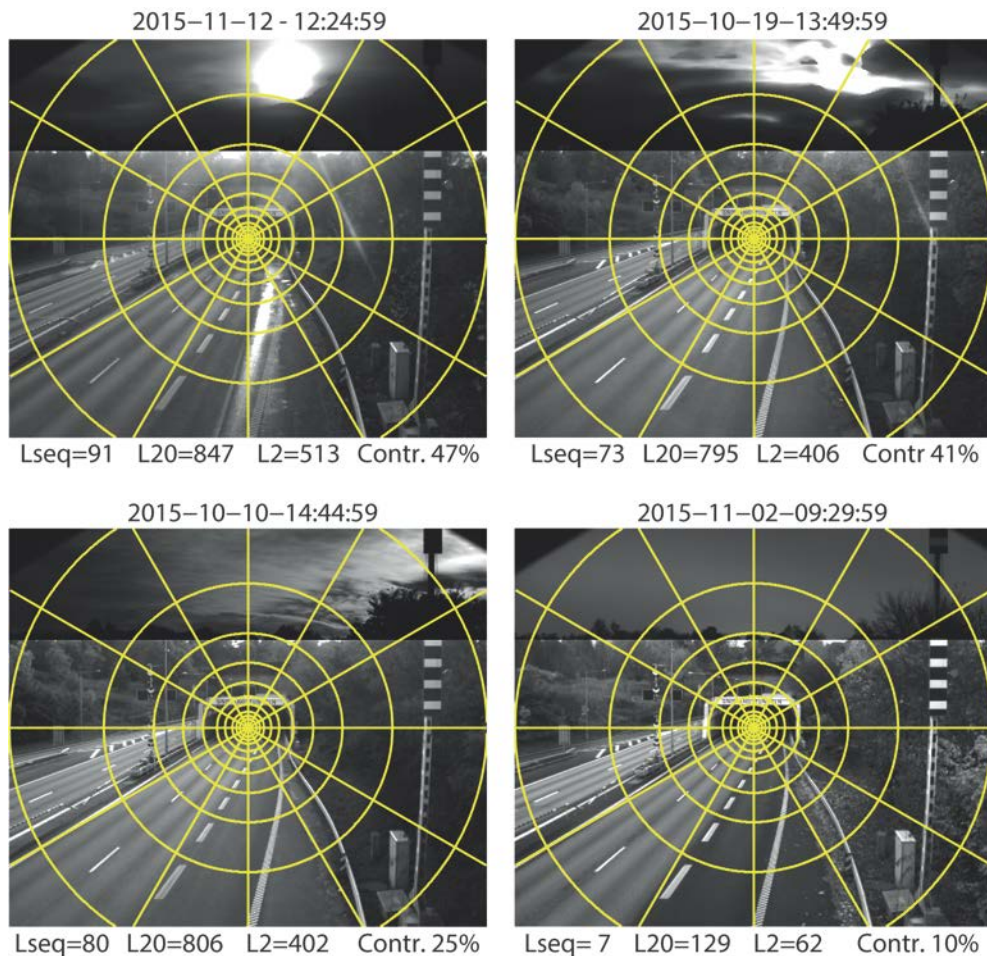


Figure 8. Some examples of luminance distribution scenarios when the contributions to L_{seq} from the two highest patches in the L_{seq} grid vary between 47% - 10%.

3. Centring the field of view

As dictated in CIE 88:2004⁴, the L_{20} field of view should be centred vertically at 25 percent of the distance from the road surface to the tunnel ceiling. Similarly, the L_{seq} field of view should be centred vertically at 50 percent of the distance. In the original TKLM study, we investigated the impact of the centring of the L_{20} field-of-view on the luminance values. We concluded that shifting the L_{20} field of view from 25 to 50 percent of the distance (i.e. using the L_{seq} centre point as opposed to the L_{20} centre point) would offset the luminance values by 5 percent on average over a longer period of time. In this study, the re-centring of the L_{20} measurement region was performed by shifting the L_{20} circle within the image region. Below we compute the angle corresponding to the shift distance in pixels for Test Site 2.

The relationship between the pixel shift and the camera rotation angle is expressed as follows:

$$\beta = \arctan \left[\frac{2d}{y} \tan \left(\frac{\alpha}{2} \right) \right]$$

where α is the camera aperture, d is the pixel shift in the image space, and y is the image height in pixels. These distances and angles are illustrated in Figure 9.

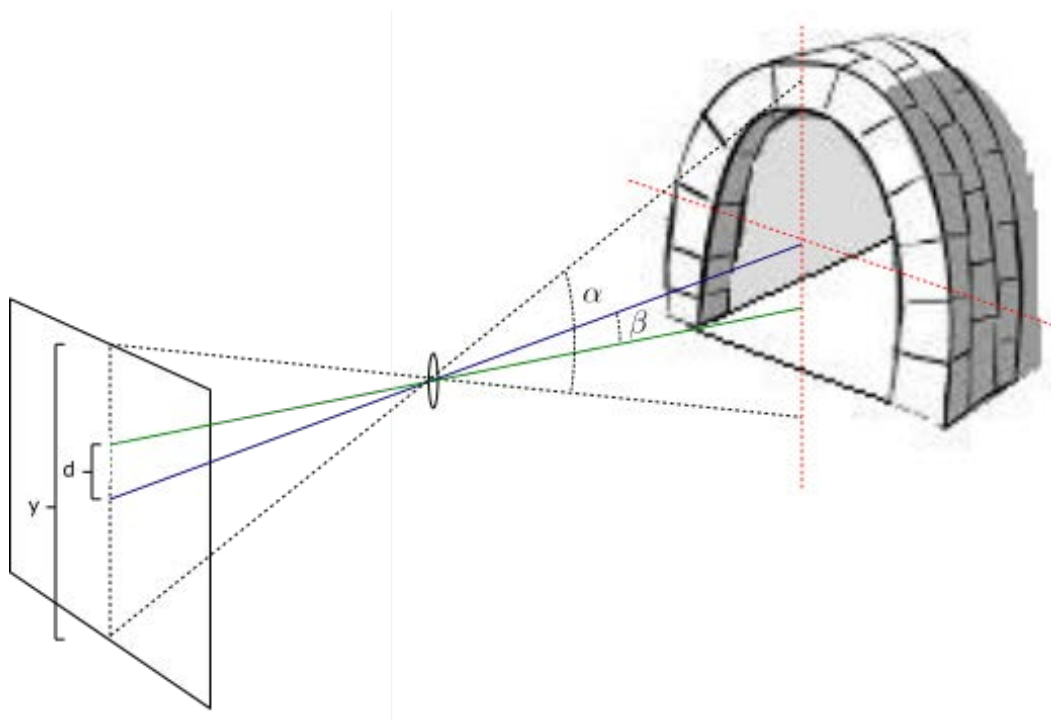


Figure 9. Relationship between pixel shift and camera rotation angle.

For Test Site 1, we have $d = 12$ pixels, $y = 600$ pixels and $\alpha = 47.4$ degrees. Thus, we get $\beta = 1.01$ degrees. In other words, a rotation of the camera (or diode-based sensor) of approximately 1 degree will – for this particular scene and time of year – result in an average L_{20} luminance error of 5 percent.

4. Road Surface Luminance Data Analysis

In this section, we present an analysis of the road surface luminance data acquired at TKLM Test Site 2 where EN 13201 measurements have been performed during October and November 2015, and January 2016. This includes some overall statistics, a categorisation of the measurement periods, a study of the impact of traffic compensation on luminance estimation, and an investigation into the influence of various weather conditions on the road surface luminance.

Some of the key observations made in this analysis are:

- At peak traffic hours between 7am to 8am, the highest mean relative errors between the compensated and uncompensated luminance signals exceed 50 % in October and 60 % in November.
- The data clearly indicates a correlation between relative luminance errors and traffic flow – where high errors are more likely at times of high traffic flow.
- In our study, as expected, we cannot see a clear relationship between relative luminance error and luminance level, e.g. a high error does not necessarily correspond to a high (or low) luminance level.
- In general, the road surface luminance is higher in the left lane than in the right lane. This is probably due to the positioning of the light sources in the centre of the road.
- In general, the relative luminance error is higher in the right lane compared to the left lane. The reason is probably a combination of higher average traffic flow and lower road surface luminance in the right lane.
- In wet conditions, the luminance level is significantly higher in the left lane than the right lane. This may be due to the positioning of the light sources, the viewing angle of the camera and the relative abilities of the two lanes to drain water from the road surface.
- Fog can cause an increase in the average road surface luminance of 50 percent. Fog in combination with snowy conditions can double the road surface luminance.
- During the measurement period, the lowest mean luminance was 0.4 cd/m^2 – far below the 1 cd/m^2 requirement for the road class ME3. The typical mean luminance during a dry night was around $0.5 - 0.6 \text{ cd/m}^2$. However, we are probably underestimating the road surface luminance value due to the greater angle between the camera optical axis and the road surface compared to the standard observer.

4.1. General measurement statistics

In Table 3 and Table 4, we list road surface luminance error statistics for October 2015. We show the mean and median relative errors between the traffic compensated and uncompensated luminance values. The relative error ε between a traffic compensated value L_t and the corresponding uncompensated value L_u is computed as follows:

$$\varepsilon = (L_t - L_u)/L_t$$

Also, we show the standard deviation of the luminance errors, and the minimum/maximum errors. In Table 3, we show error statistics for the time period 7pm to 7am and for the right lane only. In Table 4, we show the corresponding statistics for the morning traffic between 7am and 8am. In both tables, the three highest mean errors are highlighted in red. For some nights (e.g. 2015-10-19 – 2015-10-20), measurements are not available due to technical problems.

As can be seen in Table 3, the highest mean error between 7pm and 7am exceeds 15 %. In the high-density period between 7am and 8am, the highest mean error exceeds 50 %.

Table 3. October relative luminance error ϵ , 7pm – 7am, right lane.

Measurement Night	Mean	Median	Std dev	Min	Max
2015-10-01 – 2015-10-02	0,1220	0,0169	0,2766	0,0000	2,6660
2015-10-02 – 2015-10-03	0,0823	0,0161	0,1834	0,0000	1,6191
2015-10-03 – 2015-10-04	0,0973	0,0164	0,2294	0,0000	3,4208
2015-10-04 – 2015-10-05	0,1154	0,0109	0,4274	0,0000	9,5896
2015-10-05 – 2015-10-06	0,1170	0,0147	0,2472	0,0000	2,7510
2015-10-06 – 2015-10-07	0,1193	0,0147	0,2550	0,0000	2,5299
2015-10-07 – 2015-10-08	0,1342	0,0164	0,2912	0,0000	2,9802
2015-10-08 – 2015-10-09	0,1407	0,0314	0,3416	0,0000	3,1946
2015-10-09 – 2015-10-10	0,0906	0,0152	0,1820	0,0000	2,1078
2015-10-10 – 2015-10-11	0,0950	0,0164	0,1951	0,0000	1,5773
2015-10-11 – 2015-10-12	0,1282	0,0111	0,2804	0,0000	2,2011
2015-10-12 – 2015-10-13	0,1498	0,0140	0,4484	0,0000	8,4536
2015-10-13 – 2015-10-14	0,1474	0,0169	0,3415	0,0000	3,7199
2015-10-14 – 2015-10-15	0,1450	0,0188	0,2931	0,0000	2,0898
2015-10-15 – 2015-10-16	0,1414	0,0186	0,2803	0,0000	2,0941
2015-10-16 – 2015-10-17	0,1069	0,0150	0,2839	0,0000	3,2283
2015-10-17 – 2015-10-18	0,0874	0,0185	0,1724	0,0000	1,4384
2015-10-18 – 2015-10-19	0,1394	0,0124	0,3123	0,0000	3,2010
2015-10-19 – 2015-10-20	N/A	N/A	N/A	N/A	N/A
2015-10-20 – 2015-10-21	N/A	N/A	N/A	N/A	N/A
2015-10-21 – 2015-10-22	N/A	N/A	N/A	N/A	N/A
2015-10-22 – 2015-10-23	0,1541	0,0334	0,3627	0,0000	3,2098
2015-10-23 – 2015-10-24	0,1073	0,0171	0,2281	0,0000	1,6557
2015-10-24 – 2015-10-25	0,0659	0,0213	0,1693	0,0000	1,9866
2015-10-25 – 2015-10-26	0,1254	0,0114	0,2764	0,0000	2,2081
2015-10-26 – 2015-10-27	0,1157	0,0129	0,2798	0,0000	2,6588
2015-10-27 – 2015-10-28	0,1137	0,0172	0,2309	0,0000	1,7656
2015-10-28 – 2015-10-29	N/A	N/A	N/A	N/A	N/A
2015-10-29 – 2015-10-30	0,0851	0,0174	0,1543	0,0001	0,9915

Table 4. October relative luminance error ϵ , 7am - 8am, right lane.

Measurement Night	Mean	Median	Std dev	Min	Max
2015-10-01 – 2015-10-02	0,1569	0,1070	0,1510	0,0000	0,8253
2015-10-02 – 2015-10-03	0,0479	0,0395	0,0542	0,0000	0,4263
2015-10-03 – 2015-10-04	0,0429	0,0355	0,0412	0,0000	0,2670
2015-10-04 – 2015-10-05	0,1022	0,0776	0,0870	0,0000	0,4179
2015-10-05 – 2015-10-06	0,1358	0,0949	0,1241	0,0000	0,5563
2015-10-06 – 2015-10-07	0,1538	0,1061	0,1495	0,0000	0,7232
2015-10-07 – 2015-10-08	0,1942	0,1156	0,2823	0,0000	1,3626
2015-10-08 – 2015-10-09	0,2588	0,2075	0,2821	0,0000	1,7243
2015-10-09 – 2015-10-10	0,0473	0,0363	0,0478	0,0000	0,3697
2015-10-10 – 2015-10-11	0,0435	0,0257	0,0920	0,0000	0,6922
2015-10-11 – 2015-10-12	0,2021	0,1423	0,2087	0,0000	1,2246
2015-10-12 – 2015-10-13	0,2117	0,1143	0,2361	0,0000	1,0828
2015-10-13 – 2015-10-14	0,3075	0,1776	0,4309	0,0000	2,2595
2015-10-14 – 2015-10-15	0,2542	0,1613	0,3081	0,0000	1,6865
2015-10-15 – 2015-10-16	0,3502	0,1841	0,4652	0,0000	2,0205
2015-10-16 – 2015-10-17	0,1178	0,0411	0,2638	0,0000	1,4229
2015-10-17 – 2015-10-18	0,1197	0,0439	0,3895	0,0000	2,1774
2015-10-18 – 2015-10-19	0,4563	0,2545	0,6041	0,0000	2,5803
2015-10-19 – 2015-10-20	N/A	N/A	N/A	N/A	N/A
2015-10-20 – 2015-10-21	N/A	N/A	N/A	N/A	N/A
2015-10-21 – 2015-10-22	N/A	N/A	N/A	N/A	N/A
2015-10-22 – 2015-10-23	0,5317	0,3317	0,5904	0,0000	3,2465
2015-10-23 – 2015-10-24	0,1395	0,0539	0,3426	0,0000	1,9255
2015-10-24 – 2015-10-25	0,0358	0,0318	0,0246	0,0000	0,1081
2015-10-25 – 2015-10-26	0,0981	0,0930	0,0648	0,0000	0,2926
2015-10-26 – 2015-10-27	0,1335	0,1078	0,0977	0,0000	0,4455
2015-10-27 – 2015-10-28	0,1536	0,1000	0,1597	0,0000	0,8324
2015-10-28 – 2015-10-29	N/A	N/A	N/A	N/A	N/A
2015-10-29 – 2015-10-30	N/A	0,0850	N/A	0,0000	N/A

In Table 5 and Table 6 we list road surface luminance error statistics for November 2015. As for October, we show the mean and median relative errors between the traffic compensated and uncompensated luminance values. Also, we show the standard deviation of the luminance errors, and the minimum/maximum errors. In Table 5, we show error statistics for the time period 5pm to 7am and for the right lane only. In Table 6 we show the corresponding statistics for the morning traffic between 7am and 8am. In both tables, the three highest mean errors are highlighted in red. For one night (2015-11-11 – 2015-11-12), measurements are not available due to technical problems.

As can be seen in Table 5, the highest mean error between 5pm and 7am exceeds 10 %. In the high-density period between 7am and 8am, the highest mean error exceeds 60 %.

Table 5. November relative luminance error ϵ , 5pm – 7am, right lane.

Measurement Night	Mean	Median	Std dev	Min	Max
2015-11-01 – 2015-11-02	0,0599	0,0155	0,1097	0,0000	0,7543
2015-11-02 – 2015-11-03	0,0969	0,0198	0,1650	0,0000	1,0504
2015-11-03 – 2015-11-04	0,0990	0,0262	0,1784	0,0000	2,0055
2015-11-04 – 2015-11-05	0,0913	0,0219	0,1448	0,0001	0,8290
2015-11-05 – 2015-11-06	0,0939	0,0392	0,1551	0,0001	2,0420
2015-11-06 – 2015-11-07	0,0906	0,0357	0,1553	0,0001	2,5990
2015-11-07 – 2015-11-08	0,0855	0,0370	0,1374	0,0000	1,3401
2015-11-08 – 2015-11-09	0,0967	0,0316	0,1555	0,0000	0,9001
2015-11-09 – 2015-11-10	0,0781	0,0214	0,1391	0,0000	1,0125
2015-11-10 – 2015-11-11	0,0980	0,0326	0,1765	0,0000	2,1006
2015-11-11 – 2015-11-12	N/A	N/A	N/A	N/A	N/A
2015-11-12 – 2015-11-13	0,0895	0,0264	0,1514	0,0000	1,3563
2015-11-13 – 2015-11-14	0,0880	0,0328	0,1516	0,0001	1,4310
2015-11-14 – 2015-11-15	0,0740	0,0180	0,1379	0,0000	0,8910
2015-11-15 – 2015-11-16	0,0771	0,0159	0,1430	0,0000	1,2006
2015-11-16 – 2015-11-17	0,0721	0,0258	0,1265	0,0000	1,2631
2015-11-17 – 2015-11-18	0,0982	0,0290	0,1689	0,0000	2,2075
2015-11-18 – 2015-11-19	0,0944	0,0401	0,1404	0,0000	1,2043
2015-11-19 – 2015-11-20	0,1087	0,0287	0,1728	0,0000	1,1254
2015-11-20 – 2015-11-21	0,0878	0,0186	0,1602	0,0000	1,1053
2015-11-21 – 2015-11-22	0,0743	0,0178	0,1432	0,0000	1,1836
2015-11-22 – 2015-11-23	0,0770	0,0172	0,1395	0,0000	1,0985
2015-11-23 – 2015-11-24	0,0663	0,0206	0,1377	0,0000	1,5300
2015-11-24 – 2015-11-25	0,1094	0,0479	0,1675	0,0000	1,5090
2015-11-25 – 2015-11-26	0,0910	0,0315	0,1432	0,0000	1,3411
2015-11-26 – 2015-11-27	0,0723	0,0266	0,1123	0,0001	1,1229
2015-11-27 – 2015-11-28	0,0813	0,0377	0,1251	0,0000	0,9817
2015-11-28 – 2015-11-29	0,0768	0,0349	0,1212	0,0000	0,9778
2015-11-29 – 2015-11-30	0,0859	0,0414	0,1260	0,0001	1,1625

Table 6. November relative luminance error ϵ , 7am - 8am, right lane.

Measurement Night	Mean	Median	Std dev	Min	Max
2015-11-01 – 2015-11-02	0,1173	0,0978	0,1055	0,0000	0,5387
2015-11-02 – 2015-11-03	0,1153	0,0897	0,1076	0,0000	0,4919
2015-11-03 – 2015-11-04	0,1202	0,0821	0,1115	0,0000	0,5320
2015-11-04 – 2015-11-05	0,1518	0,1274	0,1226	0,0000	0,6483
2015-11-05 – 2015-11-06	0,1277	0,0678	0,1388	0,0000	0,6499
2015-11-06 – 2015-11-07	0,0508	0,0340	0,0486	0,0000	0,2684
2015-11-07 – 2015-11-08	0,0354	0,0334	0,0324	0,0000	0,2311
2015-11-08 – 2015-11-09	0,1453	0,0958	0,1486	0,0000	0,6304
2015-11-09 – 2015-11-10	0,1364	0,1191	0,0986	0,0000	0,5151
2015-11-10 – 2015-11-11	0,1543	0,1141	0,1850	0,0000	0,9582
2015-11-11 – 2015-11-12	N/A	N/A	N/A	N/A	N/A
2015-11-12 – 2015-11-13	0,2392	0,0948	0,3928	0,0000	2,4040
2015-11-13 – 2015-11-14	0,0688	0,0486	0,0895	0,0000	0,4234
2015-11-14 – 2015-11-15	0,0403	0,0275	0,0458	0,0000	0,2451
2015-11-15 – 2015-11-16	0,2264	0,1946	0,1939	0,0000	0,7998
2015-11-16 – 2015-11-17	0,1860	0,1427	0,1606	0,0000	0,6650
2015-11-17 – 2015-11-18	0,1773	0,1199	0,2542	0,0000	1,7594
2015-11-18 – 2015-11-19	0,2070	0,1178	0,2283	0,0000	1,0934
2015-11-19 – 2015-11-20	0,1855	0,1182	0,1977	0,0000	0,8900
2015-11-20 – 2015-11-21	0,0636	0,0379	0,1407	0,0000	1,0234
2015-11-21 – 2015-11-22	0,0644	0,0129	0,1526	0,0000	0,8030
2015-11-22 – 2015-11-23	0,2355	0,1557	0,2379	0,0000	1,0439
2015-11-23 – 2015-11-24	0,6034	0,3884	0,6281	0,0000	2,1888
2015-11-24 – 2015-11-25	0,3543	0,2700	0,3157	0,0000	1,4714
2015-11-25 – 2015-11-26	0,3055	0,2127	0,2953	0,0000	1,4352
2015-11-26 – 2015-11-27	0,3522	0,1736	0,4078	0,0000	1,4504
2015-11-27 – 2015-11-28	0,1104	0,0590	0,1272	0,0000	0,4833
2015-11-28 – 2015-11-29	0,1098	0,0406	0,2712	0,0000	1,6147
2015-11-29 – 2015-11-30	0,3326	0,2176	0,4074	0,0000	1,9833

The luminance recorded for the period is reported in Table 7 – Table 8. The lowest values are highlighted in red.

Table 7. October luminance statistics (traffic compensated, L_t), 7pm - 7am, right lane.

Measurement Night	Mean	Median	Std dev	Min	Max
2015-10-01 – 2015-10-02	0,5804	0,5493	0,2557	0,2954	3,8807
2015-10-02 – 2015-10-03	0,5620	0,5439	0,2357	0,2440	3,1892
2015-10-03 – 2015-10-04	0,5426	0,5563	0,1361	0,2480	1,6222
2015-10-04 – 2015-10-05	0,5554	0,5566	0,1216	0,2342	1,7116
2015-10-05 – 2015-10-06	0,5489	0,5444	0,0955	0,2453	0,9434
2015-10-06 – 2015-10-07	0,5478	0,5474	0,0937	0,2837	0,8295
2015-10-07 – 2015-10-08	0,5501	0,5510	0,0943	0,2653	0,9150
2015-10-08 – 2015-10-09	0,4021	0,4072	0,0909	0,1665	0,5925
2015-10-09 – 2015-10-10	0,5155	0,5499	0,1165	0,2412	0,6781
2015-10-10 – 2015-10-11	0,5141	0,5408	0,1193	0,2409	0,6608
2015-10-11 – 2015-10-12	0,5296	0,5403	0,1015	0,2621	1,1704
2015-10-12 – 2015-10-13	0,5952	0,5487	0,7277	0,2873	12,8410
2015-10-13 – 2015-10-14	0,5341	0,5346	0,1361	0,2929	1,8320
2015-10-14 – 2015-10-15	0,5356	0,5423	0,0982	0,2325	0,7653
2015-10-15 – 2015-10-16	0,5334	0,5423	0,1010	0,2704	1,1978
2015-10-16 – 2015-10-17	0,5216	0,5480	0,1143	0,2489	0,6605
2015-10-17 – 2015-10-18	0,5037	0,5329	0,1204	0,2254	0,6556
2015-10-18 – 2015-10-19	0,5079	0,5202	0,0993	0,2224	0,8217
2015-10-19 – 2015-10-20	N/A	N/A	N/A	N/A	N/A
2015-10-20 – 2015-10-21	N/A	N/A	N/A	N/A	N/A
2015-10-21 – 2015-10-22	N/A	N/A	N/A	N/A	N/A
2015-10-22 – 2015-10-23	0,4204	0,4470	0,0934	0,1656	0,5904
2015-10-23 – 2015-10-24	0,5111	0,5391	0,1148	0,2346	0,7427
2015-10-24 – 2015-10-25	0,4604	0,4543	0,1284	0,1078	1,5236
2015-10-25 – 2015-10-26	0,5555	0,5470	0,1567	0,2811	2,1755
2015-10-26 – 2015-10-27	0,5265	0,5384	0,1128	0,2749	1,5432
2015-10-27 – 2015-10-28	0,4827	0,4858	0,1063	0,1452	0,9158
2015-10-28 – 2015-10-29	N/A	N/A	N/A	N/A	N/A
2015-10-29 – 2015-10-30	0,6176	0,5887	0,0981	0,5436	1,4870

Table 8. November luminance statistics (traffic compensated, L_t), 5pm - 7am, right lane.

Measurement Night	Mean	Median	Std dev	Min	Max
2015-11-01 – 2015-11-02	0,5183	0,5054	0,0631	0,4472	0,7721
2015-11-02 – 2015-11-03	0,6455	0,6266	0,1005	0,5489	1,1601
2015-11-03 – 2015-11-04	0,6389	0,5802	0,1536	0,5066	2,6590
2015-11-04 – 2015-11-05	0,6484	0,6188	0,1022	0,5435	1,0590
2015-11-05 – 2015-11-06	0,5960	0,5920	0,1410	0,4161	1,1780
2015-11-06 – 2015-11-07	0,5783	0,5202	0,1331	0,3931	1,0054
2015-11-07 – 2015-11-08	0,5223	0,4838	0,1006	0,4008	0,8350
2015-11-08 – 2015-11-09	0,5823	0,5715	0,1128	0,3911	0,9331
2015-11-09 – 2015-11-10	0,5916	0,5656	0,0992	0,4703	0,9825
2015-11-10 – 2015-11-11	0,5825	0,5053	0,1445	0,4486	1,3701
2015-11-11 – 2015-11-12	N/A	N/A	N/A	N/A	N/A
2015-11-12 – 2015-11-13	0,6559	0,6433	0,1097	0,4906	1,1265
2015-11-13 – 2015-11-14	0,5332	0,4708	0,1274	0,3766	0,8590
2015-11-14 – 2015-11-15	0,6358	0,6573	0,0812	0,4590	0,8024
2015-11-15 – 2015-11-16	0,6542	0,6104	0,0817	0,5509	1,0727
2015-11-16 – 2015-11-17	0,5269	0,5036	0,0852	0,3948	0,7795
2015-11-17 – 2015-11-18	0,6123	0,6108	0,1360	0,4097	0,9977
2015-11-18 – 2015-11-19	0,5590	0,5115	0,1261	0,4009	1,0195
2015-11-19 – 2015-11-20	0,7192	0,6803	0,1123	0,5332	1,1734
2015-11-20 – 2015-11-21	0,6665	0,6411	0,0920	0,5192	1,0315
2015-11-21 – 2015-11-22	0,5937	0,5901	0,0648	0,4633	0,7423
2015-11-22 – 2015-11-23	0,5071	0,4912	0,0578	0,4392	0,8414
2015-11-23 – 2015-11-24	0,5034	0,4821	0,0597	0,4417	0,7742
2015-11-24 – 2015-11-25	0,5817	0,5171	0,1413	0,4266	1,1139
2015-11-25 – 2015-11-26	0,5971	0,5458	0,1373	0,4231	1,0337
2015-11-26 – 2015-11-27	0,5336	0,5154	0,0890	0,4412	0,8950
2015-11-27 – 2015-11-28	0,5623	0,5258	0,0965	0,4471	1,0005
2015-11-28 – 2015-11-29	0,5572	0,5218	0,1142	0,4304	0,9678
2015-11-29 – 2015-11-30	0,5859	0,5755	0,1043	0,4254	0,8774

4.2. Categorisation of the measurement periods

In Table 9, we categorise each of the nights in October and November based on the behaviour of the luminance data. The categories are: “Nothing To Report” (NTR), “Rain”, “Dark” and “Spike”. The first two categories are self-explanatory. The category “Dark” indicates a night with lower than normal luminance levels. The category “Spike” indicates significant deviations in the luminance signal at specific points in time. The reader is referred to the full listing of luminance graphs in the appendices for more detailed information. In the following sections, we show some highlights from these measurement periods illustrating the different categories. The entries shown in red colour in Table 9 are illustrated in the following sections.

Table 9. Categorization of measurement periods, October and November.

Measurement Night	Days	October	November
2015-1X-01 – 2015-1X-02	Thu-Fri	NTR	Rain
2015-1X-02 – 2015-1X-03	Fri-Sat	NTR	NTR
2015-1X-03 – 2015-1X-04	Sat-Sun	NTR	Spike @ 8.20pm
2015-1X-04 – 2015-1X-05	Sun-Mon	NTR	NTR
2015-1X-05 – 2015-1X-06	Mon-Tue	NTR	Rain
2015-1X-06 – 2015-1X-07	Tue-Wed	NTR	Rain
2015-1X-07 – 2015-1X-08	Wed-Thu	NTR	Rain
2015-1X-08 – 2015-1X-09	Thu-Fri	Rain	Rain in morning
2015-1X-09 – 2015-1X-10	Fri-Sat	Spike @ 9.40pm	Rain
2015-1X-10 – 2015-1X-11	Sat-Sun	NTR	Rain
2015-1X-11 – 2015-1X-12	Sun-Mon	NTR	NTR
2015-1X-12 – 2015-1X-13	Mon-Tue	Spike @ 8.20pm	NTR
2015-1X-13 – 2015-1X-14	Tue-Wed	Spike @ 8.30pm	Rain
2015-1X-14 – 2015-1X-15	Wed-Thu	NTR	NTR
2015-1X-15 – 2015-1X-16	Thu-Fri	NTR	NTR
2015-1X-16 – 2015-1X-17	Fri-Sat	NTR	Rain
2015-1X-17 – 2015-1X-18	Sat-Sun	NTR	Rain in morning
2015-1X-18 – 2015-1X-19	Sun-Mon	NTR	Rain
2015-1X-19 – 2015-1X-20	Mon-Tue	NTR	NTR
2015-1X-20 – 2015-1X-21	Tue-Wed	NTR	NTR
2015-1X-21 – 2015-1X-22	Wed-Thu	NTR	NTR
2015-1X-22 – 2015-1X-23	Thu-Fri	Rain	NTR
2015-1X-23 – 2015-1X-24	Fri-Sat	Spike @ 6am	Rain
2015-1X-24 – 2015-1X-25	Sat-Sun	Rain	Rain
2015-1X-25 – 2015-1X-26	Sun-Mon	NTR	Rain in morning
2015-1X-26 – 2015-1X-27	Mon-Tue	NTR	NTR
2015-1X-27 – 2015-1X-28	Tue-Wed	NTR	Rain
2015-1X-28 – 2015-1X-29	Wed-Thu	NTR	Rain
2015-1X-29 – 2015-1X-30	Thu-Fri	NTR	Rain

4.3. The impact of traffic compensation

To investigate the impact of traffic flow on luminance estimation in detail, we plotted the relative luminance error as a function of traffic flow for one morning in November. The traffic flow data was obtained from the regional database of the National Transport Administration and expresses the number of vehicles per hour. The resulting plot is shown in Figure 10. As can be seen in the figure, there is a correlation between luminance errors and traffic flow – high errors are more likely to appear in high flow. On this particular morning from 5am to 8am, all errors above 50 % occur at traffic flows above 1000.

However, it is difficult to study the relationship between luminance errors and traffic flow in isolation since, at this time of day, the luminance level is also changing rapidly. Since the traffic compensation algorithm has a built-in inertia meaning that it will not adapt directly to

quickly changing light levels, the error between the compensated and uncompensated signals will be partly due to traffic and partly due to the slower adaptation rate of the compensated signal.

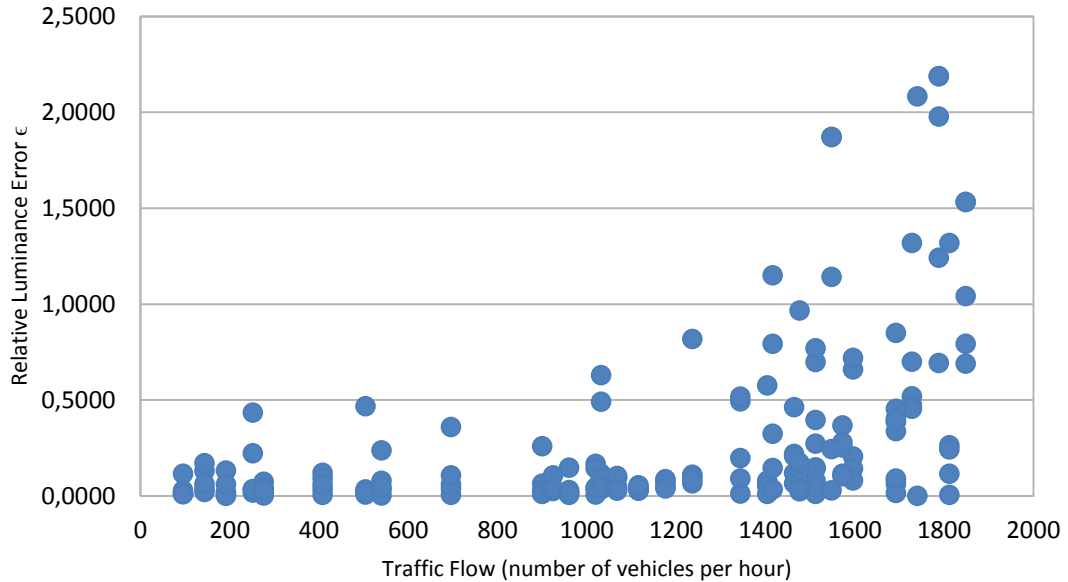


Figure 10. Relative luminance error ϵ as function of traffic flow, 2015-11-24 5am to 8am.

We have also investigated the relationship between relative luminance error and traffic compensated luminance level. This is shown in Figure 11. From this measurement period, it is difficult to draw conclusions regarding the relationship – a high error does not necessarily correspond to a high luminance level.

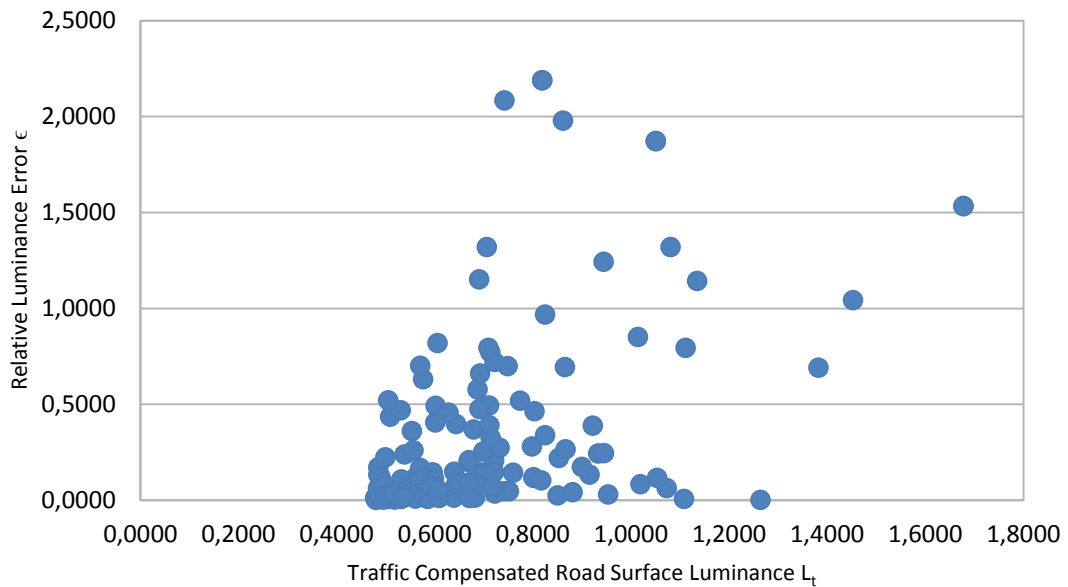


Figure 11. Relative luminance error ϵ as function of road surface luminance L_t (cd/m^2), 2015-11-24 5am to 8am.

In Figure 12, we show the mean road surface luminance (compensated and uncompensated) and the relative error as functions of time for this measurement period. In Figure 13, we show the traffic flow for the same period. As can be seen in Figure 13, the traffic flow is steadily increasing. The light levels starts rising from just before 7am. The intense traffic in combination with quickly rising light levels result in large deviations between the compensated and uncompensated signals.

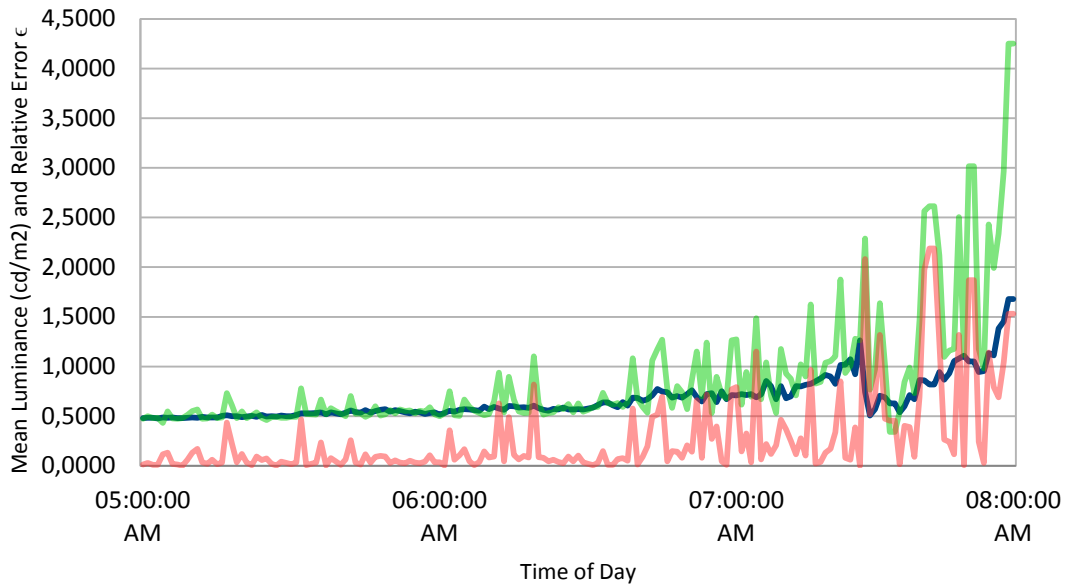


Figure 12. Mean luminance (traffic compensated L_t in dark blue, uncompensated L_u in green, cd/m^2) and relative error ϵ (red, no unit) as functions of time of day, 2015-11-24 5am to 8am.

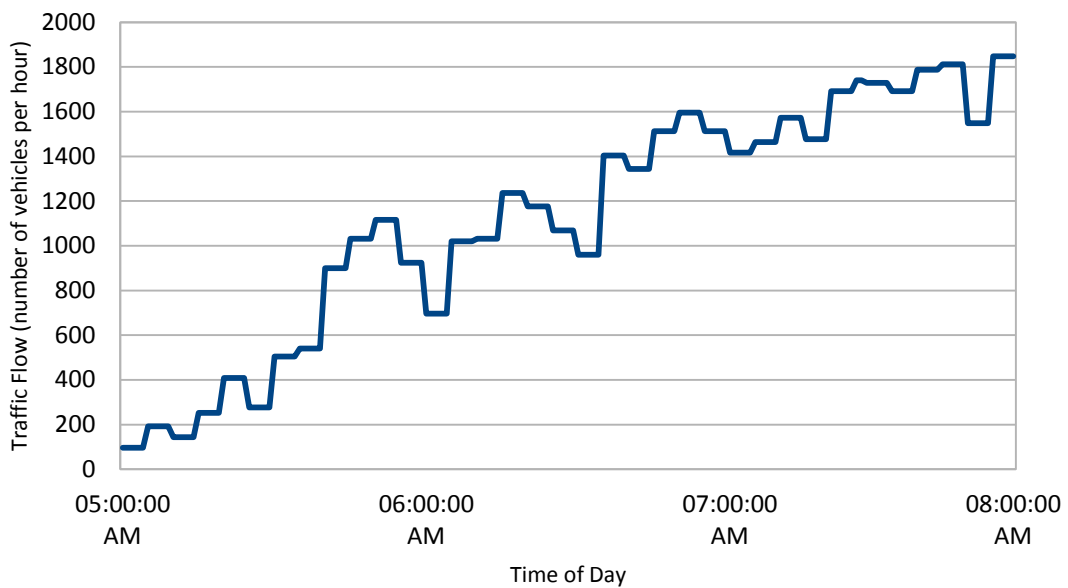


Figure 13. Traffic flow as function of time of day, 2015-11-24 5am to 8am.

In an attempt to isolate the relationship between relative luminance error and traffic flow, we selected another day and time period where the light levels are more or less constant. This is shown in Figure 14. During the chosen three hour period the light level was between 1.0 and 1.1 cd/m² all the time. Also in this figure the high errors appear more common at high traffic flows.

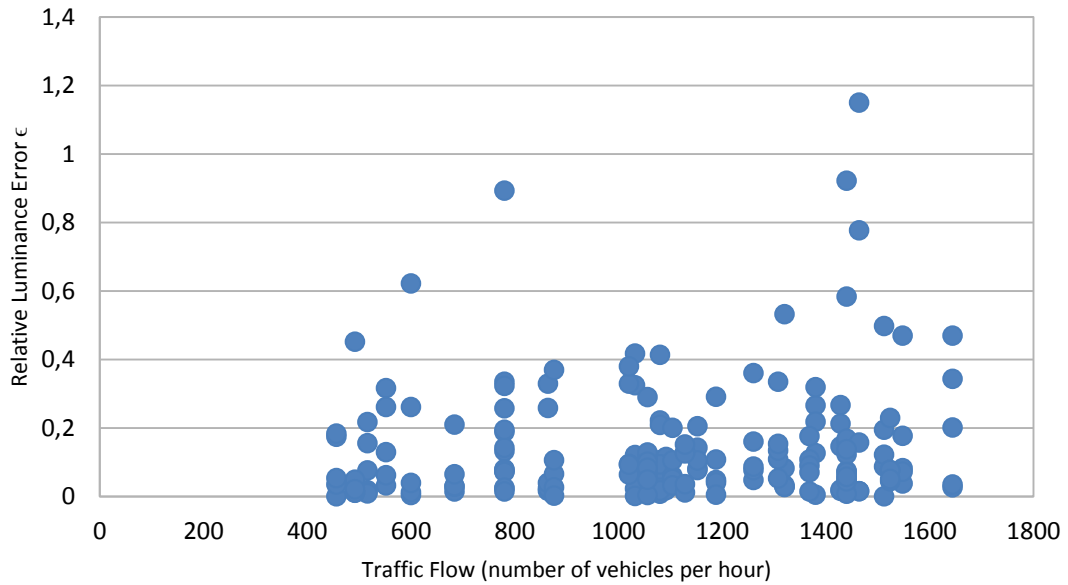


Figure 14. Relative luminance error ϵ as function of traffic flow, 2015-11-23 4.30pm to 7.30pm

In Figure 15, we show the relationship between relative luminance error and traffic flow for a third day and time period. In this case, it is a Saturday evening between 5pm and 8pm and the traffic flow is significantly lower than in previous time periods. At this low level of traffic flow, the relationship between luminance error and flow is less clear.

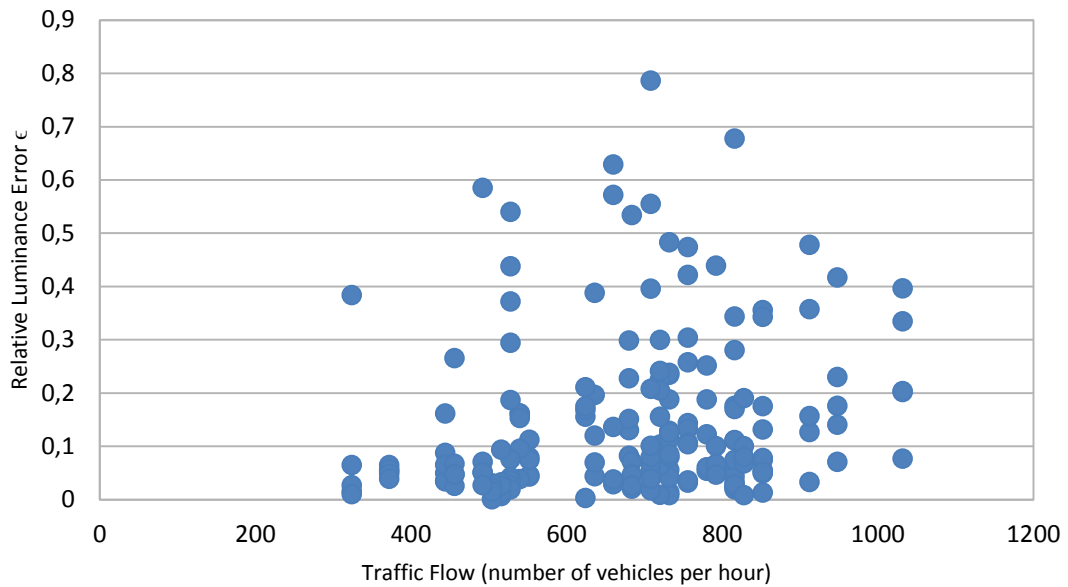


Figure 15. Relative luminance error ϵ as function of traffic flow, 2015-11-14 5pm to 8pm.

4.4. Relative luminance error distributions

In Figure 16, we show the distributions of relative luminance errors for one night (October 4 to 5) and for the left and right lanes, separately. The summary statistics for the two periods 7pm to 7am and 7am to 8am are also shown in the figure. As can be seen in the figure, most of the errors are relatively small but the distribution has a long tail. These error distributions are representative for many of the nights during October and November.

Note that the right lane errors are higher than the left lane errors which is probably due to higher average traffic flow in the right lane.

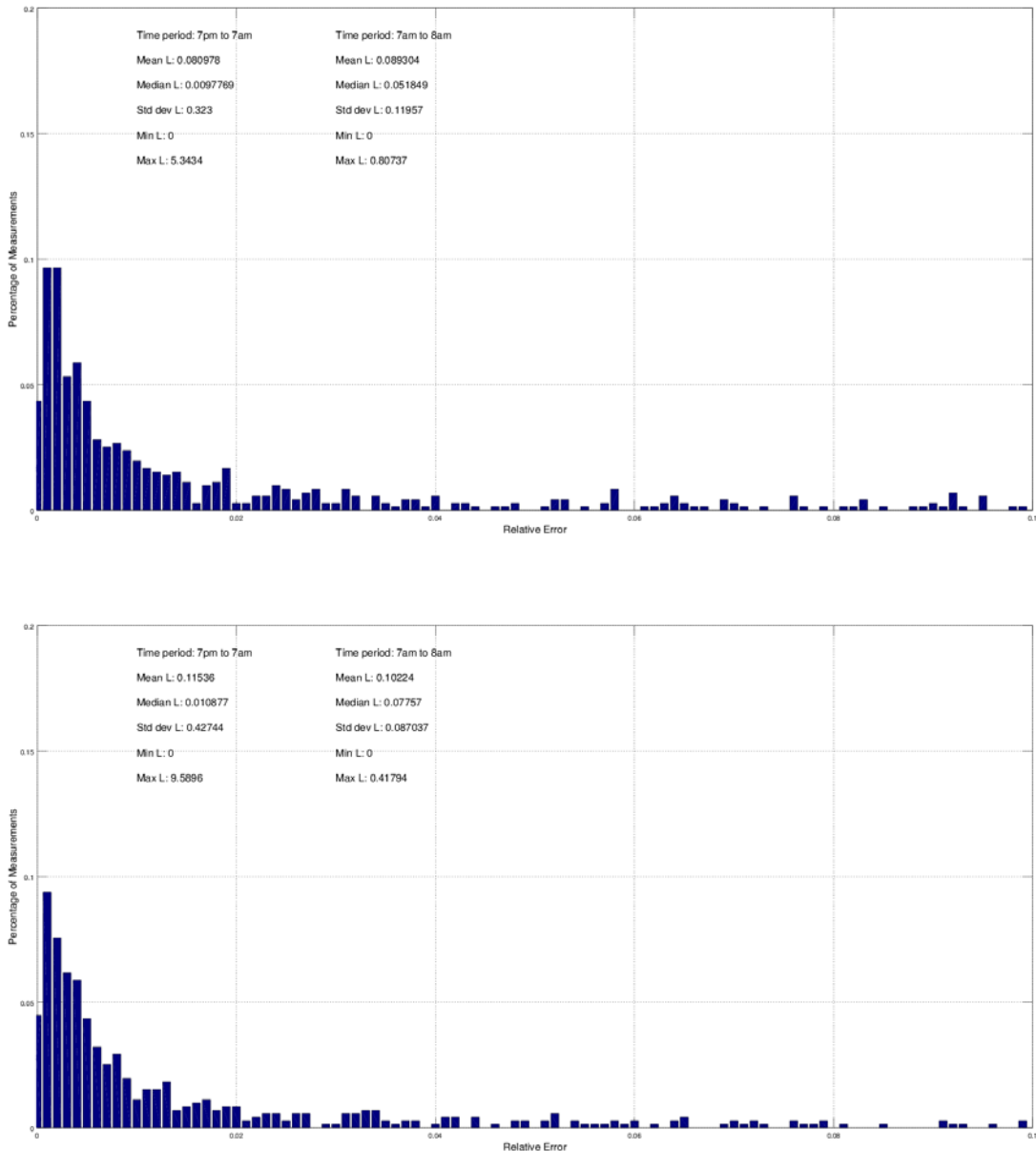


Figure 16. Relative luminance error distributions, October 4 to 5. Top row is left lane and bottom row is right lane.

4.5. The impact of weather conditions

In Figure 17, we show an example of a night where it starts to rain during the night. As can be seen in the figure, the luminance level is significantly higher in the left lane than the right lane when the road surface is wet. This can also be seen in the luminance images shown in Figure 18 – the left one was taken before the rain and the right one during the rain. This may be due to the positioning of the light sources, the viewing angle of the camera and the relative abilities of the two lanes to drain water from the road surface.

Note that the EN 13201-system uses high-dynamic range images composed from two exposure times but, in Figure 18, we only show a single exposure time (where some of the image regions are saturated).

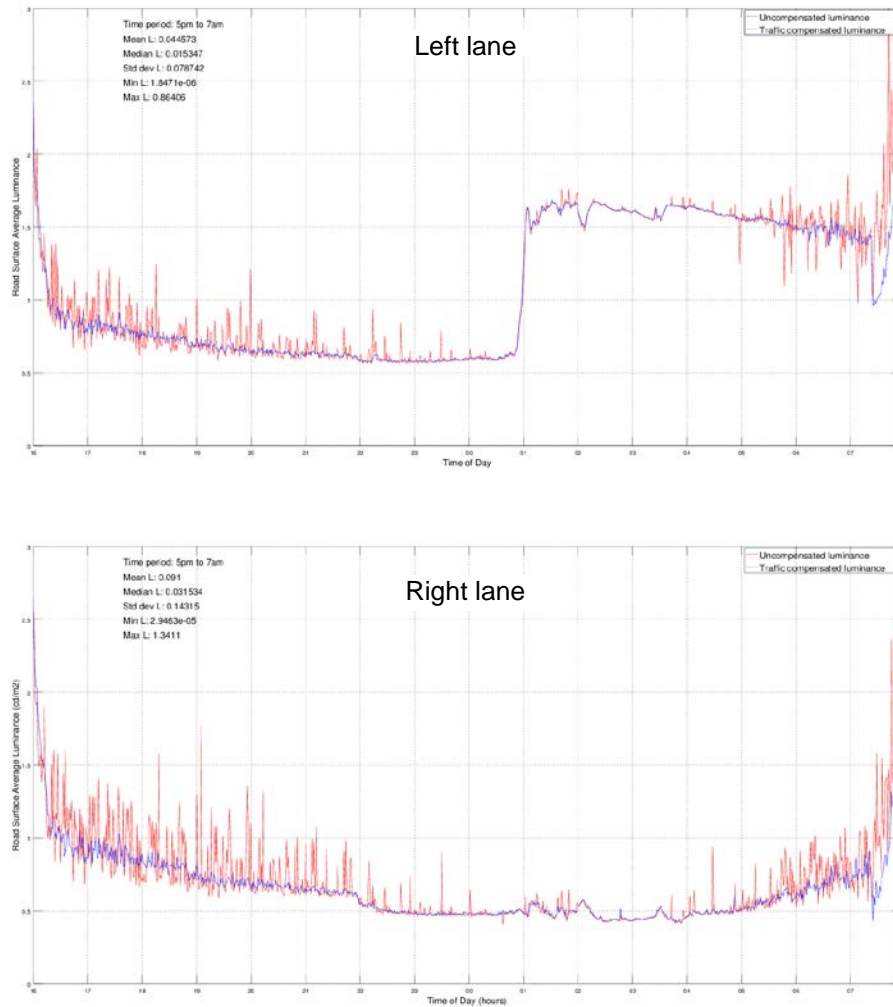


Figure 17. EN 13201 average surface luminance: November 25, 5pm, to November 26, 8am. Top row is left lane and bottom row is right lane. Uncompensated L_u in red, compensated L_t in blue.

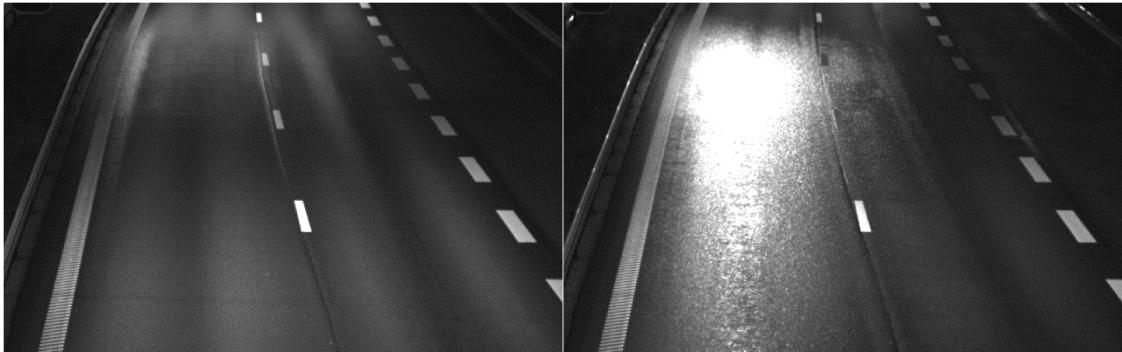


Figure 18. Images taken 2015-11-25 at 12pm (left) and 2015-11-26 at 3am (right). One out of two exposure times only.

In Figure 19, we show another example of a rainy night. Luminance images just before and after the sharp rise in mean road surface luminance at just after 9pm on November 16 are shown in Figure 20.

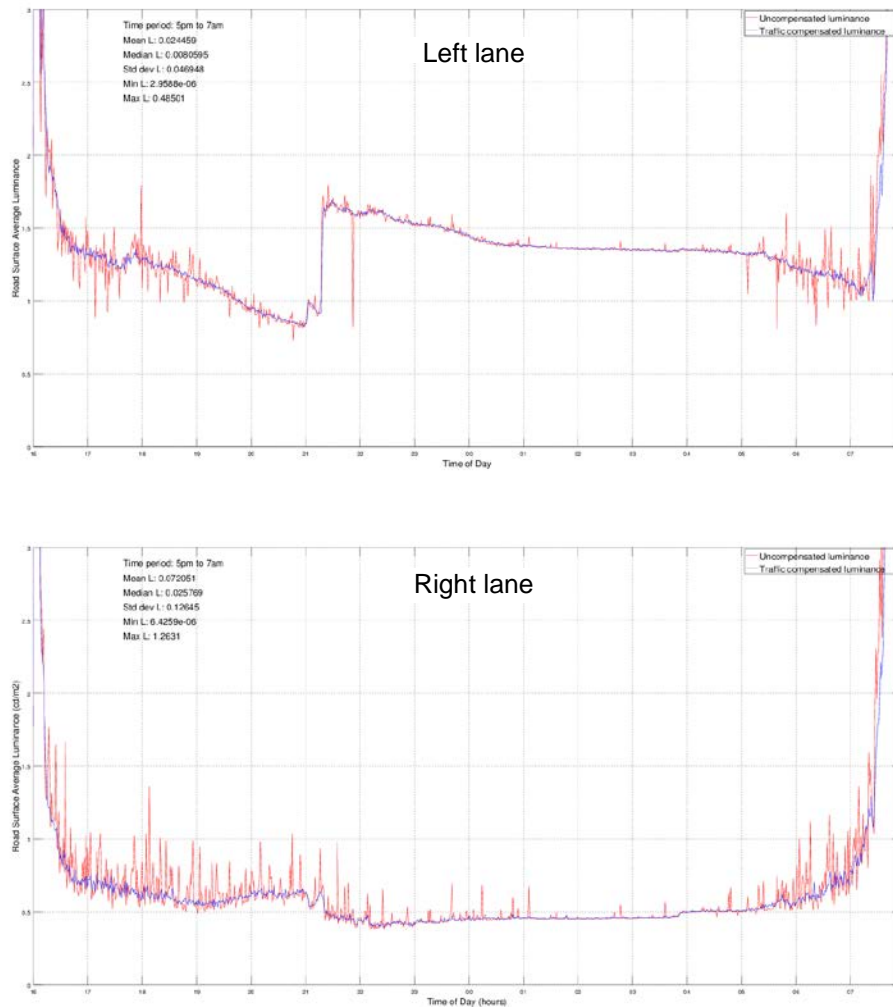


Figure 19. EN 13201 average surface luminance: November 16, 5pm, to November 17, 8am. Top row is left lane and bottom row is right lane. Uncompensated L_u in red, compensated L_t in blue.

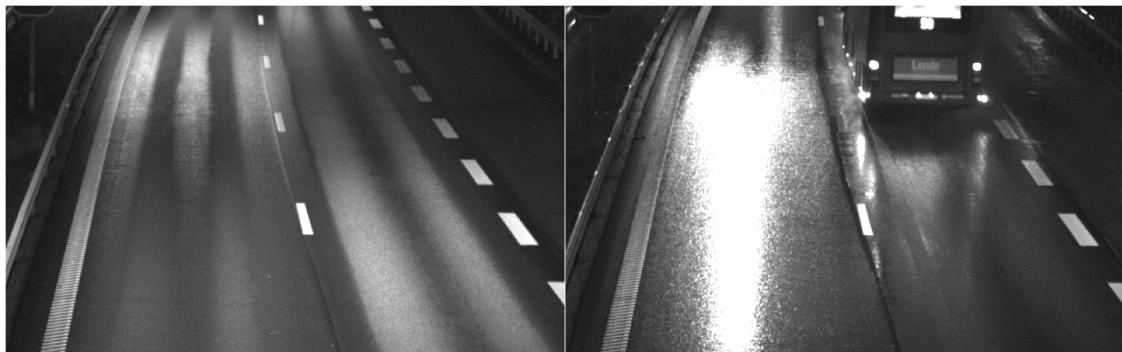


Figure 20. Images taken at 9.00pm (left) and 9.20pm (right) on 2015-11-16. One out of two exposure times only.

In Figure 21 and Figure 22, we show an example of a mixed night involving several rain showers. The night starts dry, the street lights are turned on at around 8.30pm and a first rain

shower appears at around 10.30pm. Then, the road surface slowly dries up and rain appears again at around 2am. In Figure 22, we show images just before and after some of the dramatic changes in the luminance values.

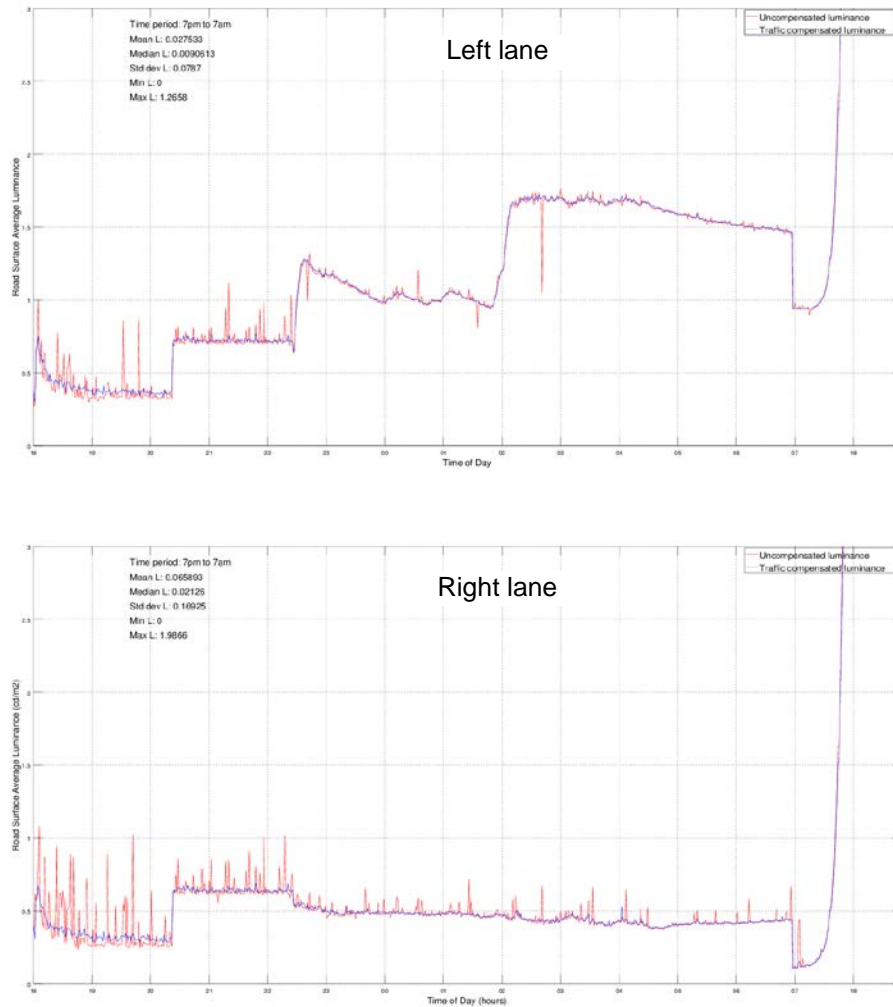


Figure 21. EN 13201 average surface luminance: October 24, 6pm, to October 25, 8am. Top row is left lane and bottom row is right lane. Uncompensated L_u in red, compensated L_t in blue.



Figure 22. Images taken at 8.43pm (top left) and 10.43pm (top right) on 2015-10-24, and 01.43am (bottom left) and 02.23am (bottom right) on 2015-10-25. One out of two exposure times only.

In Figure 23 and Figure 24, we show a night involving several events of interest. The first event occurs between 8pm and 10pm on 2016-01-20 as can be seen in Figure 23. The sharp rise in luminance values is due to road works and is not related to any change in weather condition. The second event, however, is due to fog slowly building up in the field of view. In Figure 24, we show four images taken from the start of the fog until it has cleared from the field of view of the camera. The average road surface luminance increases from around 0.7 cd/m² to 1.1 cd/m² in the left lane – an increase of around 50 percent.

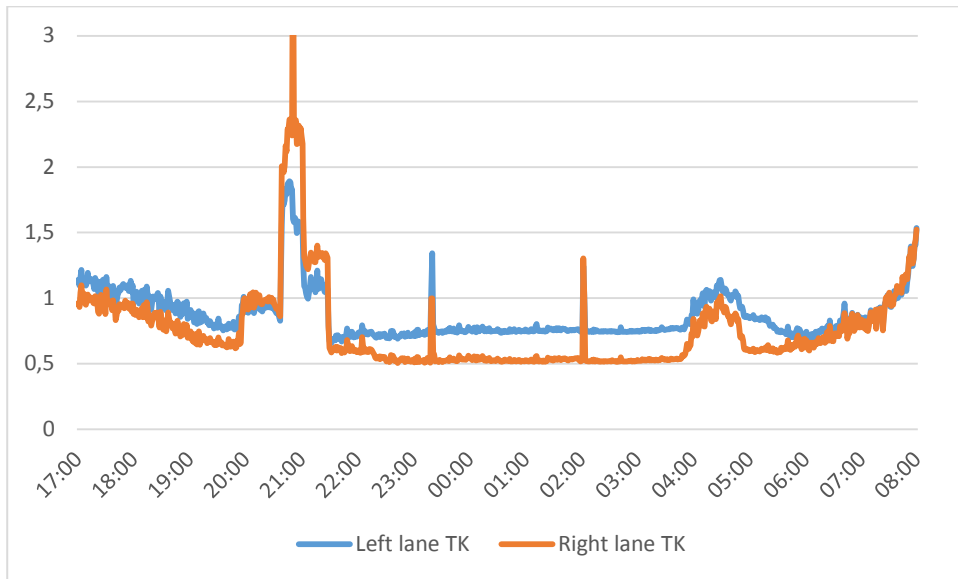


Figure 23. EN 13201 average surface luminance: January 20, 5pm, to January 21, 8am. Left lane (blue) and right lane (red), with traffic compensation.



Figure 24. Images taken at 4.00am (top left), 4.20am (top right), 4.40am (bottom left) and 5.00am (bottom right) on 2016-01-21. One out of two exposure times only.

Another night involving both fog and snowy conditions is the night between 2016-01-23 and 2016-01-24 where the luminance values are consistently high. The average road surface luminance as a function of time is shown in Figure 25 and a selection of images distributed through the night is shown in Figure 26. The fog is particularly dense at around midnight. In the left lane, the average luminance is around 1.5 cd/m² all night which is around twice the average value a typical dry-surface night.

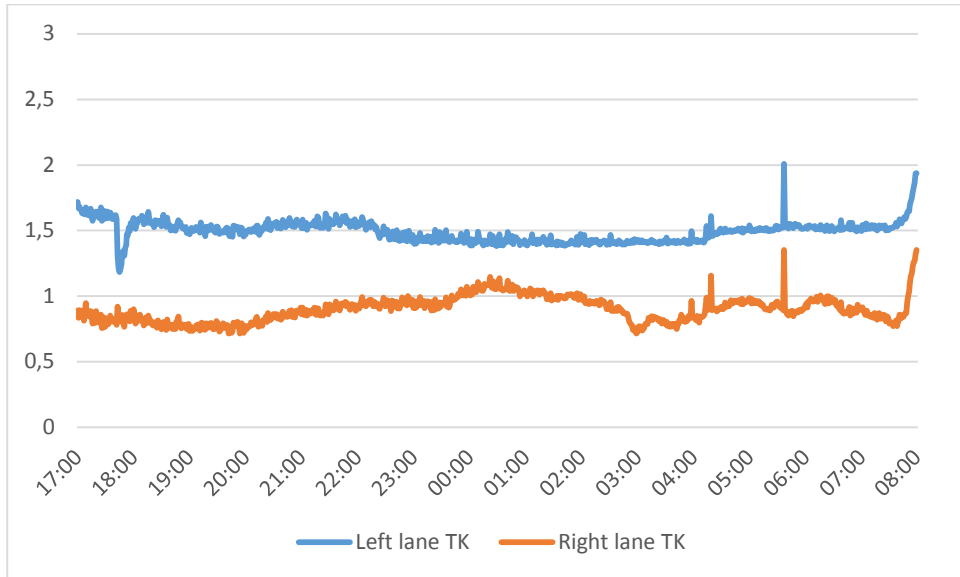


Figure 25. EN 13201 average surface luminance: January 23, 5pm, to January 24, 8am. Left lane (blue) and right lane (red), with traffic compensation.



Figure 26. Images taken at 9.00pm (top left) on 2016-01-23, 0.00am (top right), 3.00am (bottom left) and 6.00am (bottom right) on 2016-01-24. One out of two exposure times only.

4.6. Extreme event analysis

Spikes in the luminance signal may occur from time to time due to a number of reasons. One example is shown in Figure 27 where the uncompensated signal (shown in red colour) deviates strongly from the compensated one at approximately 9.40pm on the night between 2015-10-09 and 2015-10-10. The reason can be found in the images shown in Figure 28 taken just before, during and after the high-luminance event. The increase in luminance is caused by two or more vehicles illuminating the road surface. One is present within the field of view and one or two are just about to enter the measurement zone.

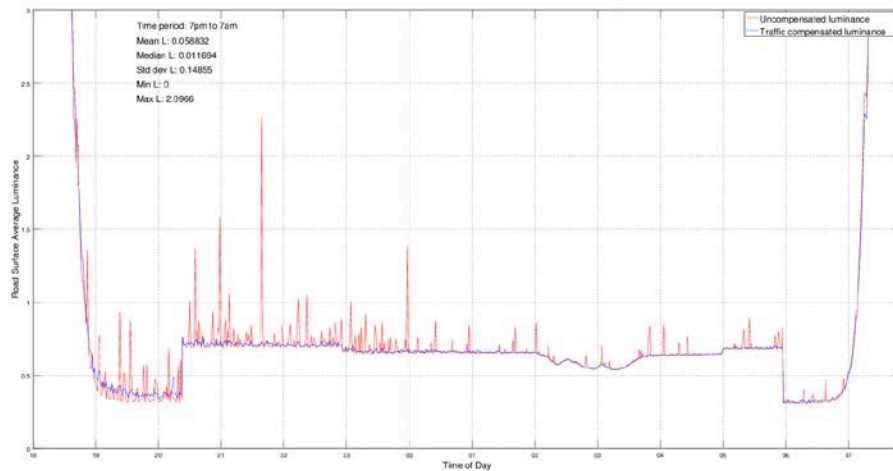


Figure 27. Luminance spike at around 9.40pm on the night between 2015-10-09 and 2015-10-10. Uncompensated L_u in red, compensated L_t in blue.

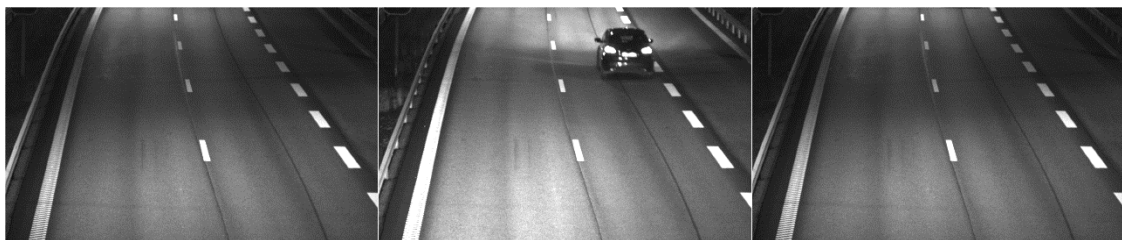


Figure 28. Images taken on 2015-10-09 at 9.23pm (left), 9.43pm (middle) and 10.03pm (right). One out of two exposure times only.

5. Future work

- A thorough analysis of the measurement error because of saturated pixels of the L_{seq} camera and how it will influence the levels of L_{th} .
- Investigate the quality of vision and visibility of road markings under wet conditions. The road surface might appear brighter when wet, but the visibility of white lines may be poorer, so it is important that the road illumination system compensates for that.
- Investigate the influence of perspective error and specular reflexes that the L_{seq} camera may register when mounted significantly higher than the driver's position.
- Analysis of the quality of vision in the tunnel opening during the day when the day light illumination changes. A comparison between tunnels with different design of the tunnel entrance portal would be interesting.
- A study of the sensitivity of the L_{seq} measure (as opposed to L_{20}) to the camera rotation angle.
- A more thorough investigation into the angular dependence of road surface luminance estimation according to EN 13201⁵.
- Explicit handling of specular surfaces such as pools of water through e.g. detection and masking.
- A field study looking at required sensor density (number of sensors per kilometre) to accurately model local conditions, with the objective of reaching a compromise allowing high-enough energy savings while maintaining traffic safety.
- A study of active lighting control in extreme conditions aiming to provide guidelines on how to control street lighting in e.g. foggy conditions and heavy rain/snow.

6. References

1. MTk4P06467-2 *Final report – Traffic compensated luminance estimation*, 2015-06-24
2. ML150916-1rev1, *Projektförslag Trafikkompenserad luminansmätning komplettering*
3. R.V. Karandikar, J. Opt. Soc. Am. 45, (6), p483-8, (1955)
4. CIE 88:2004. "Guide for The Lighting of Road Tunnels and Underpasses", International Commission on Illumination, ISBN 3 901 906 31 2, 2nd edition
5. EN 13201:2003 *Road lighting*

SP Technical Research Institute of Sweden Measurement Technology - Communication

Performed by

Mikael Lindgren

Appendices

Appendix 1: Road Surface Luminance Data – October 2015

Appendix 2: Road Surface Luminance Data – November 2015

Appendix 1

Appendix 1: Road Surface Luminance Data – October 2015

In this section, we report the average road surface luminance as a function of time at TKLM Test Site 2 where EN 13201 measurements have been performed. The measurements listed below are for October only. In each of the figures shown below, the unit on the y-axis is candela per square meter (cd/m^2) and, on the x-axis, we show the time of day in hours from 6pm to 8am. Each figure shows measurements taken from one full night.

The sun set during October was between 4.28pm and 6.46pm. The sun rise, on the other hand, was between 7.16am to 7.23am.

In the figures below, the red line shows the uncompensated raw luminance measurements. The blue line, on the other hand, shows the traffic compensated luminance measurements.

In each of the figures, the summary statistics for the period is shown in the upper left corner. This includes the mean and median luminance values, the standard deviation of the luminance and the minimum/maximum luminance values during the time period. Note that the summary statistics have been provided for a shorter time period – 7pm to 7am.

In each of the figures, the upper plot is for the left lane and the lower plot for the right lane.

Appendix 1

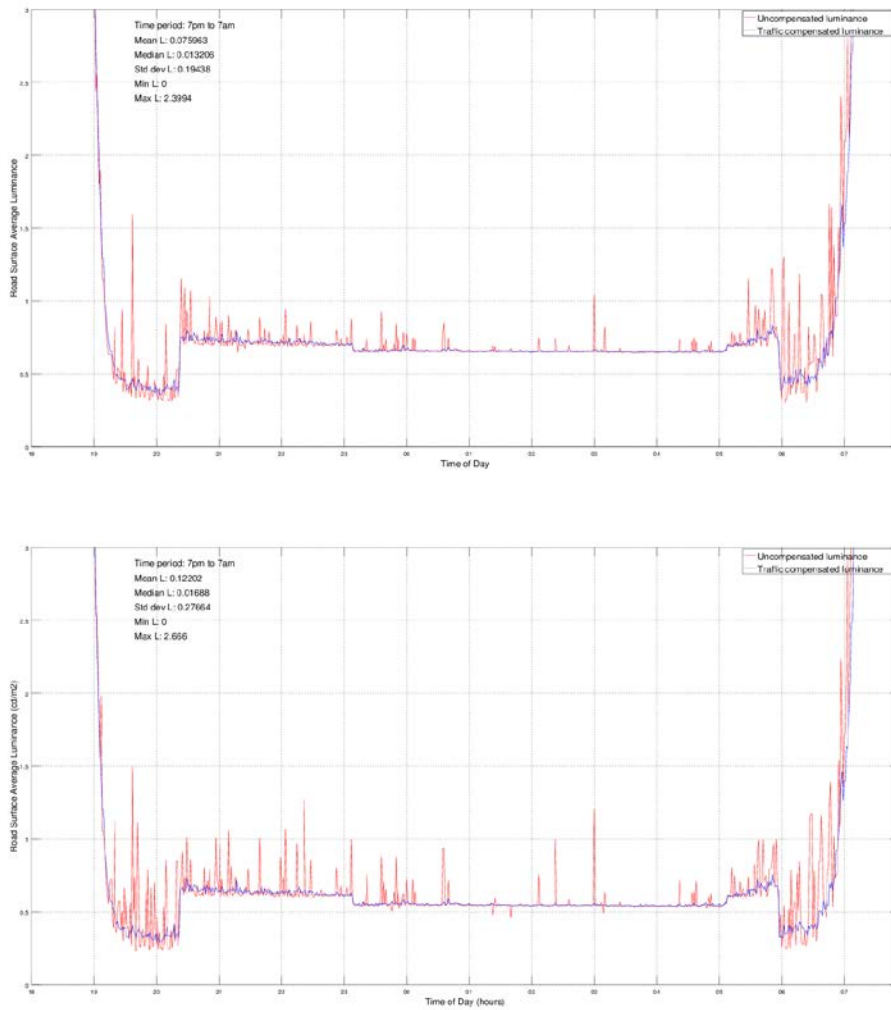


Figure A1- 1. EN 13201 average surface luminance: October 1, 6pm, to October 2, 8am.

Appendix 1

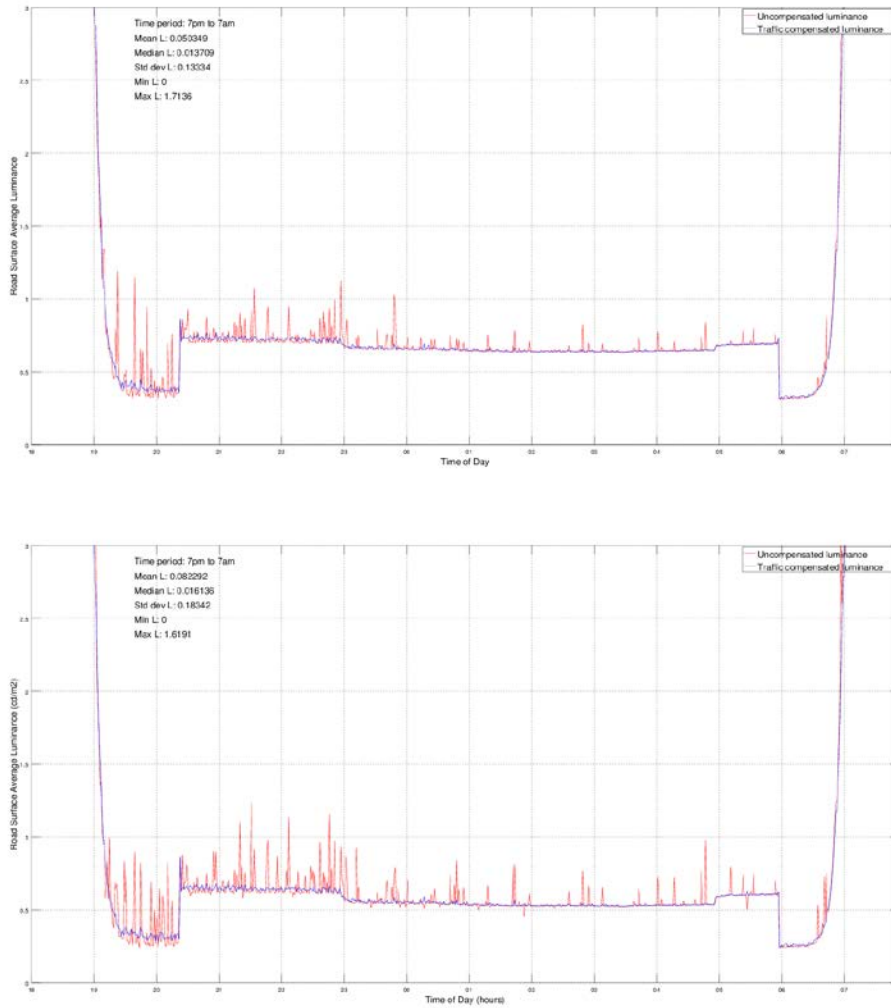


Figure A1- 2. EN 13201 average surface luminance: October 2, 6pm, to October 3, 8am.

Appendix 1

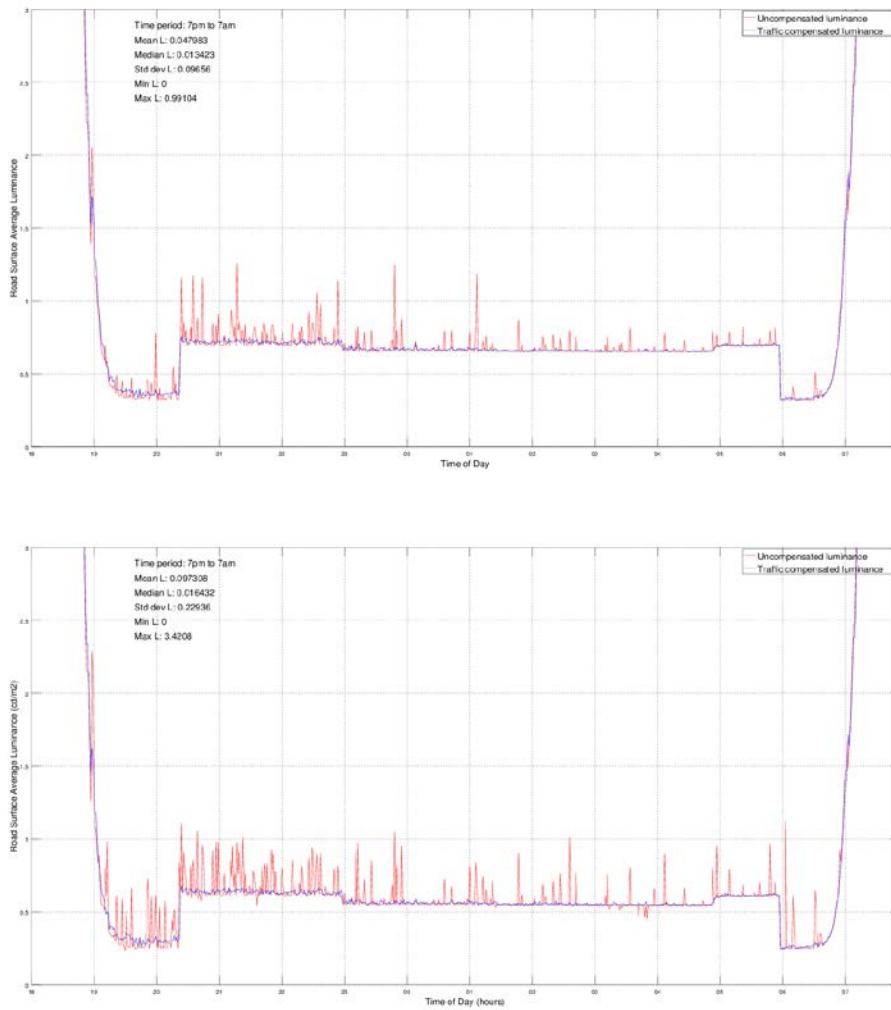


Figure A1- 3. EN 13201 average surface luminance: October 3, 6pm, to October 4, 8am.

Appendix 1

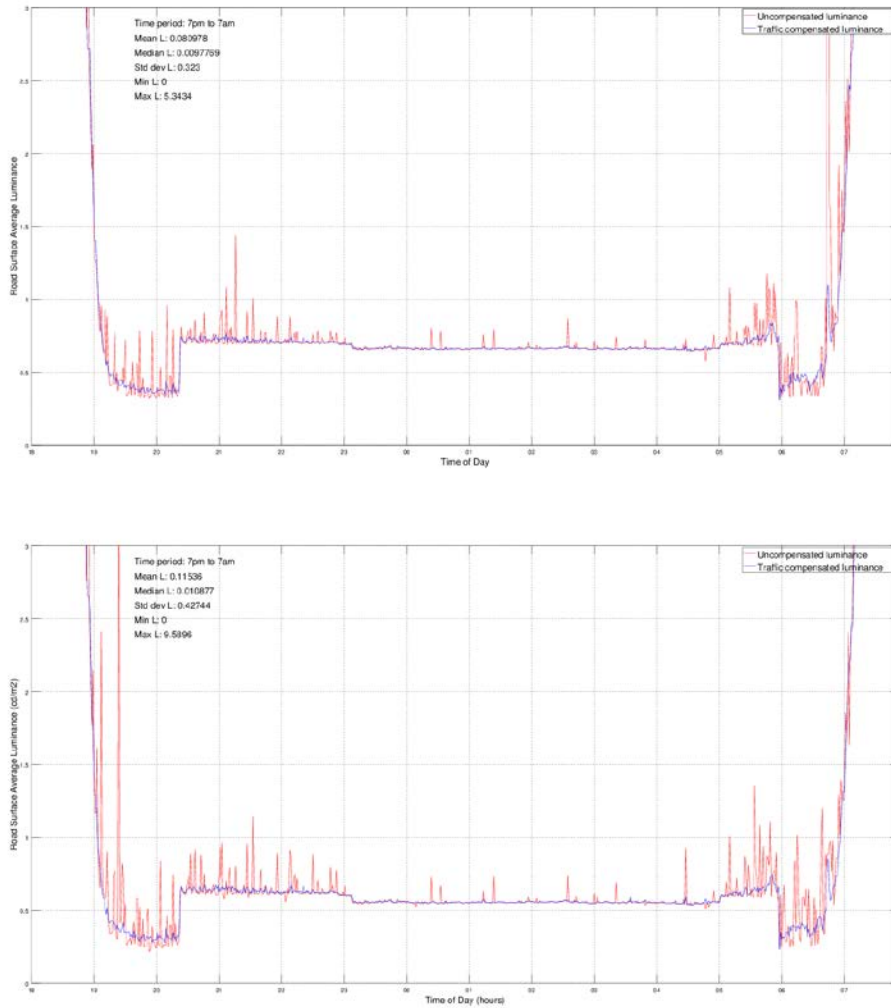


Figure A1- 4. EN 13201 average surface luminance: October 4, 6pm, to October 5, 8am.

Appendix 1

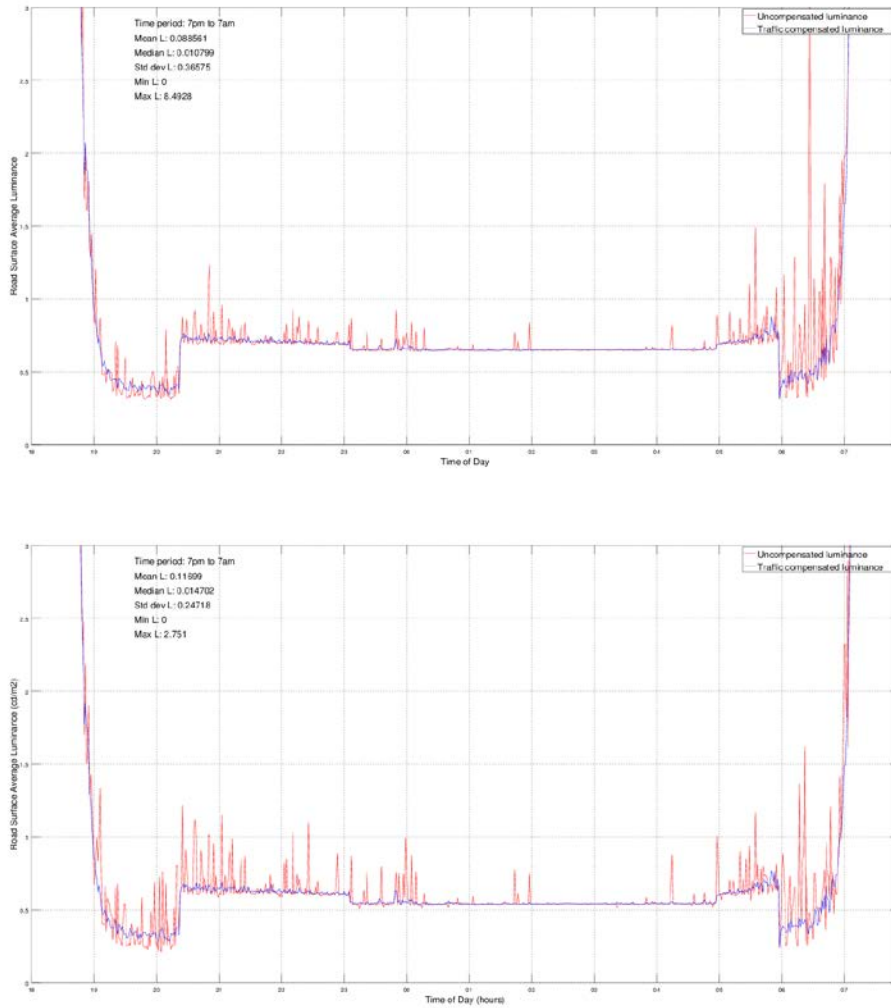


Figure A1- 5. EN 13201 average surface luminance: October 5, 6pm, to October 6, 8am.

Appendix 1

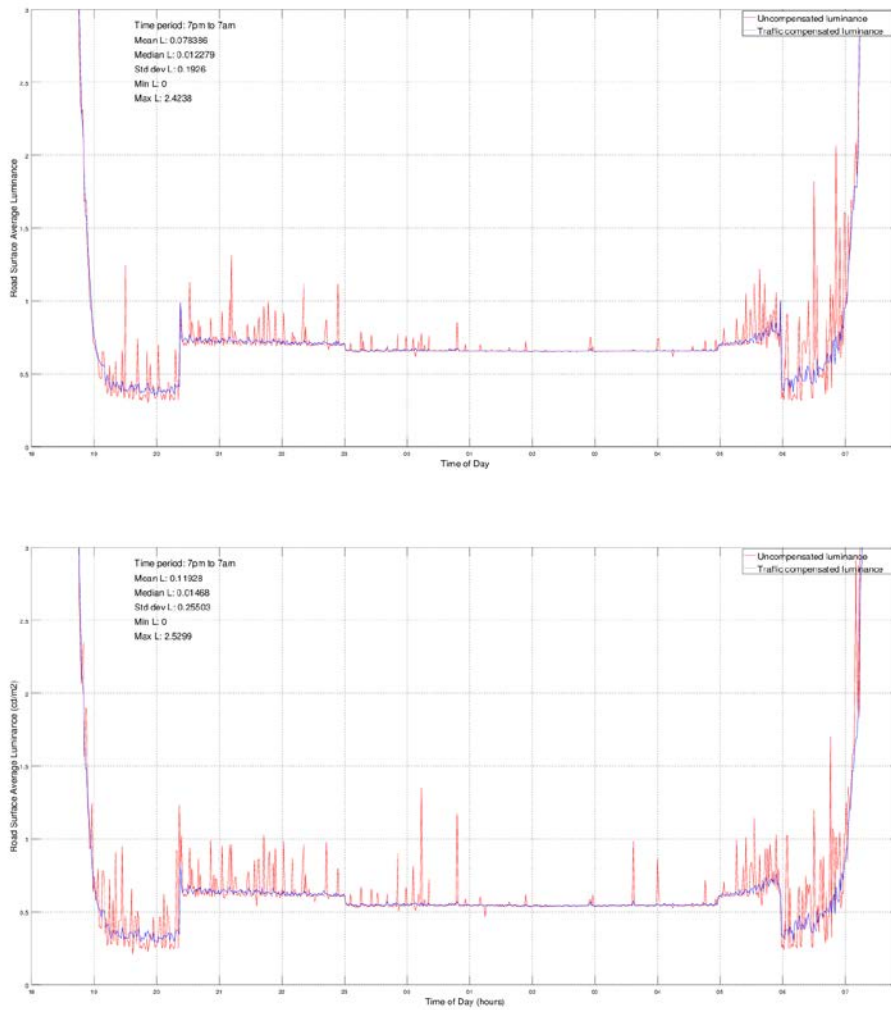


Figure A1- 6. EN 13201 average surface luminance: October 6, 6pm, to October 7, 8am.

Appendix 1

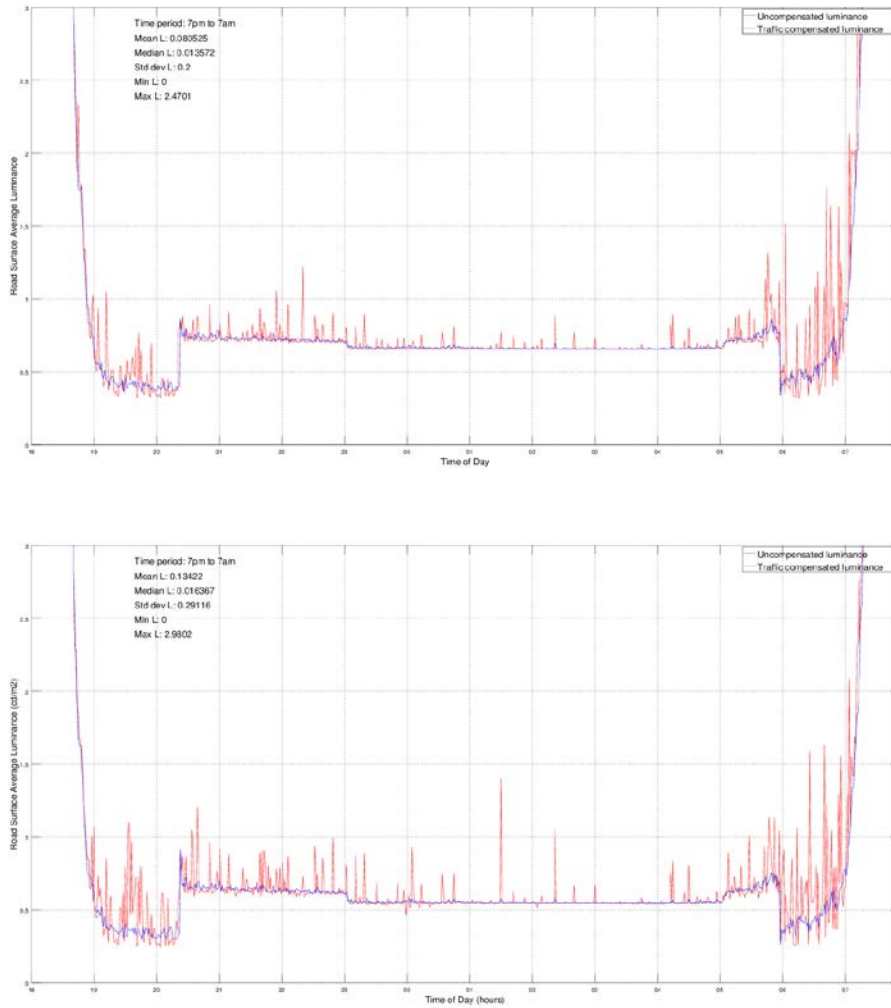


Figure A1- 7. EN 13201 average surface luminance: October 7, 6pm, to October 8, 8am.

Appendix 1

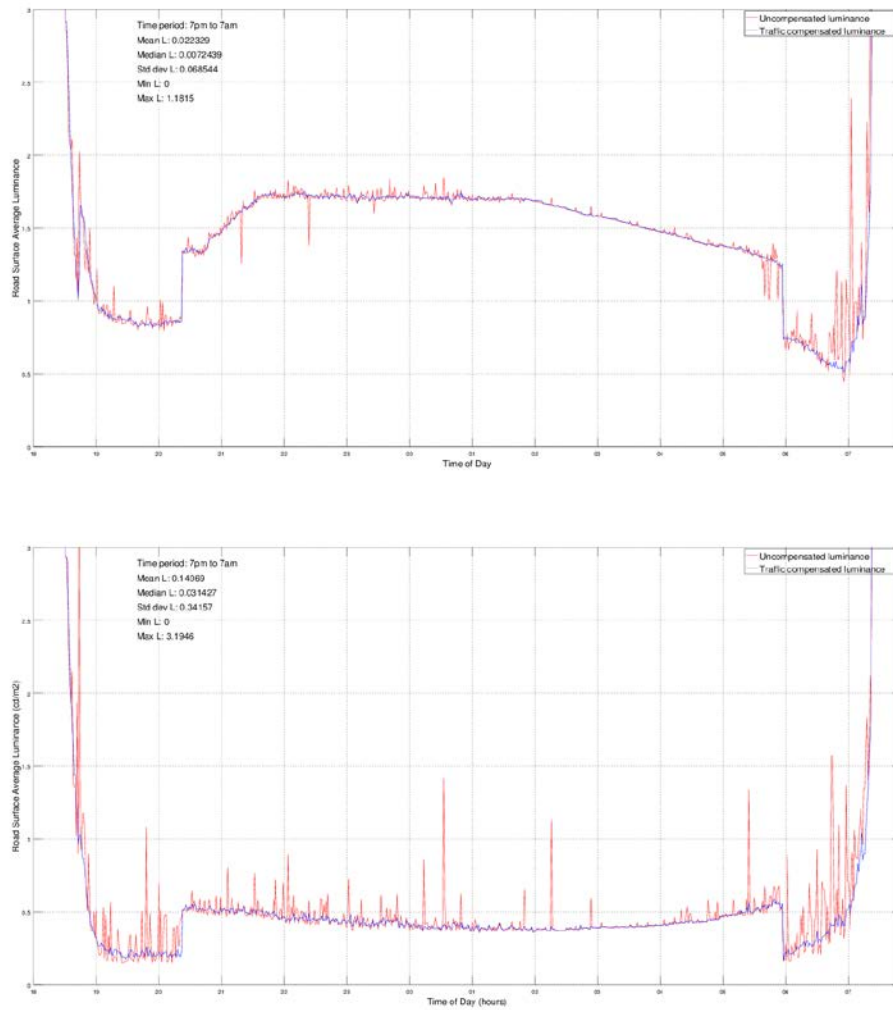


Figure A1- 8. EN 13201 average surface luminance: October 8, 6pm, to October 9, 8am.

Appendix 1

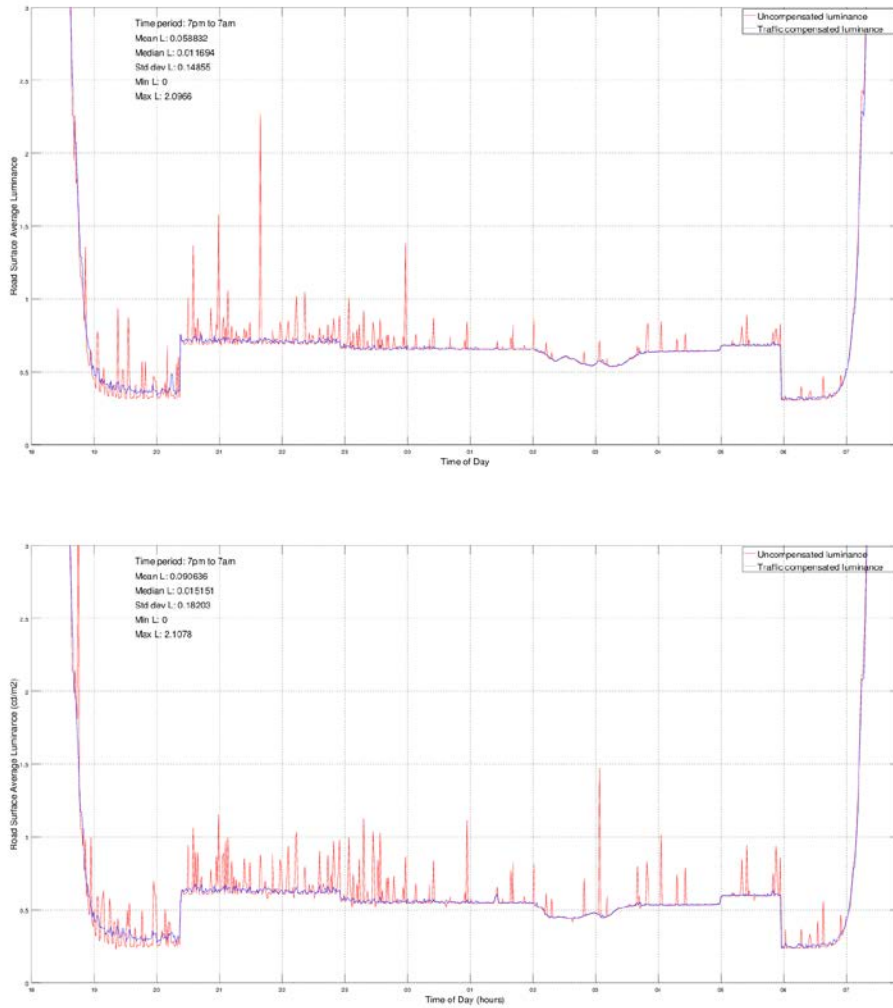


Figure A1- 9. EN 13201 average surface luminance: October 9, 6pm, to October 10, 8am.

Appendix 1

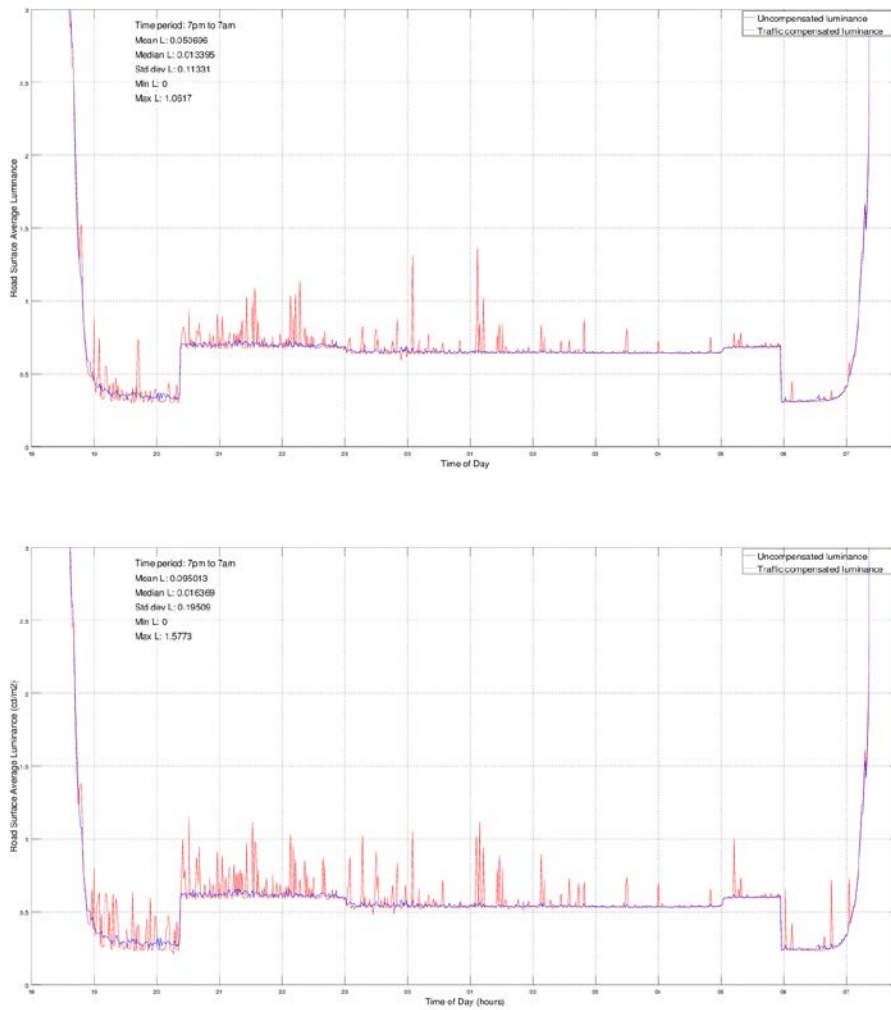


Figure A1- 10. EN 13201 average surface luminance: October 10, 6pm, to October 11, 8am.

Appendix 1

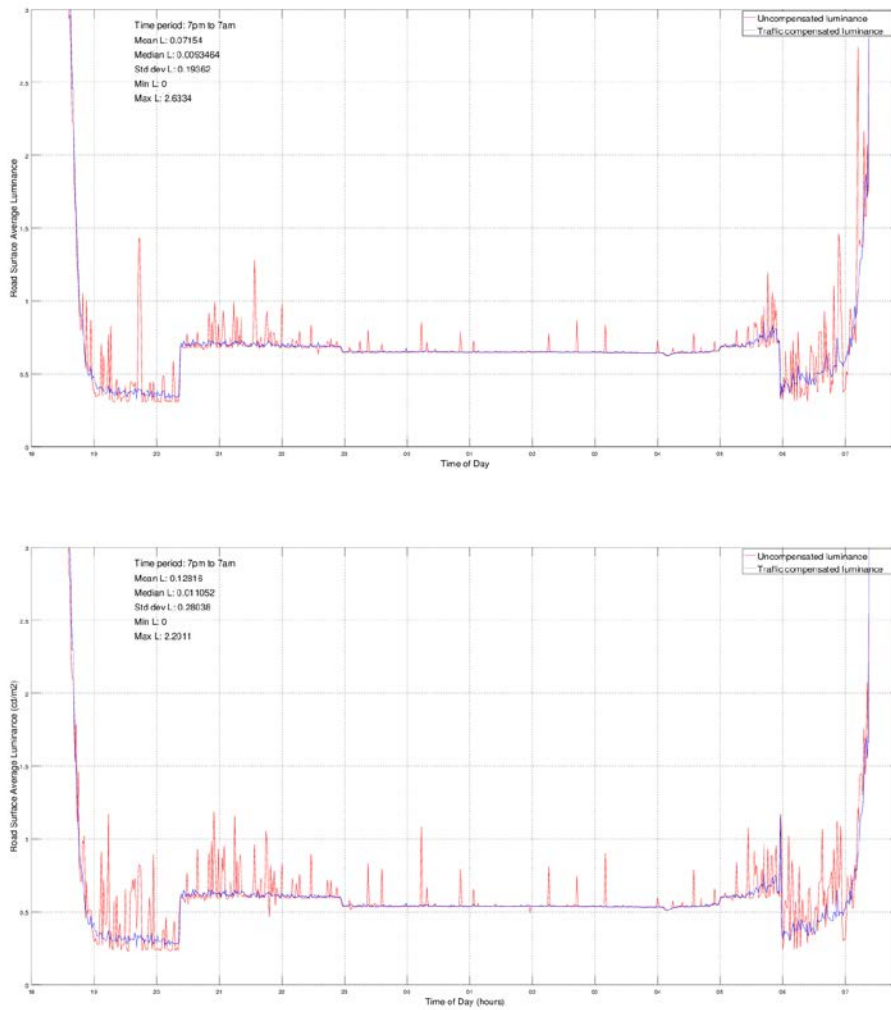


Figure A1- 11. EN 13201 average surface luminance: October 11, 6pm, to October 12, 8am.

Appendix 1

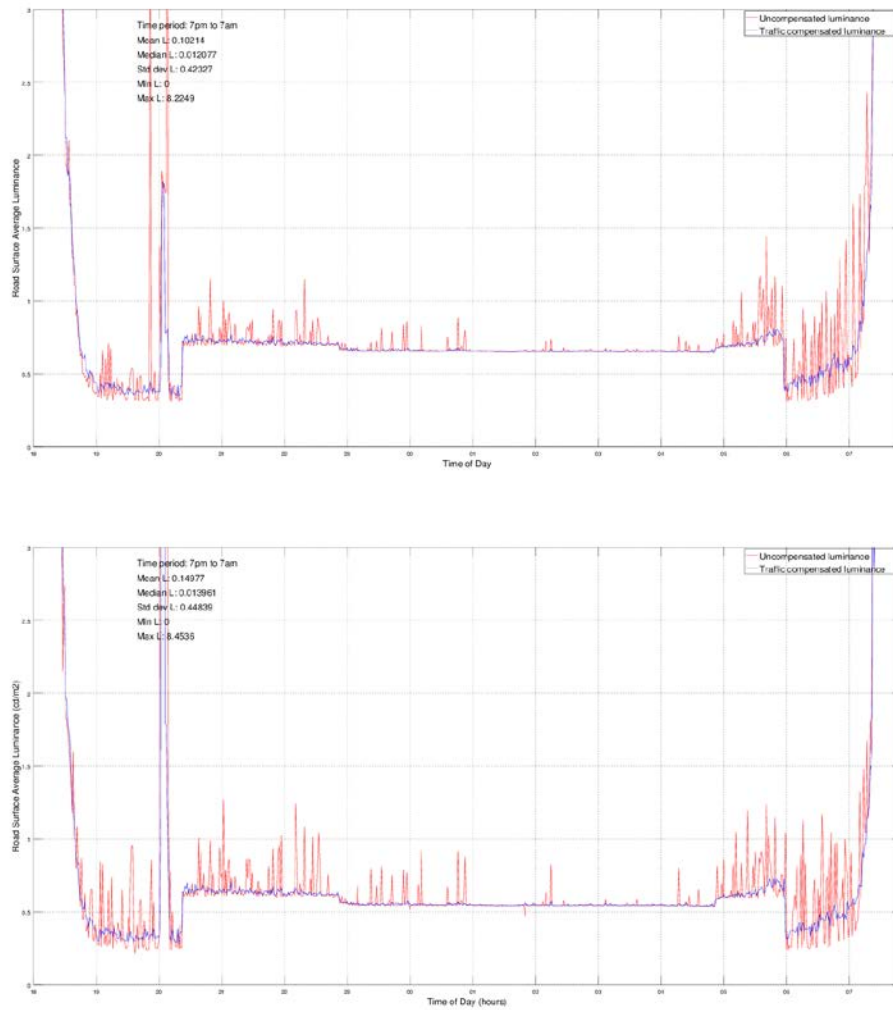


Figure A1- 12. EN 13201 average surface luminance: October 12, 6pm, to October 13, 8am.

Appendix 1

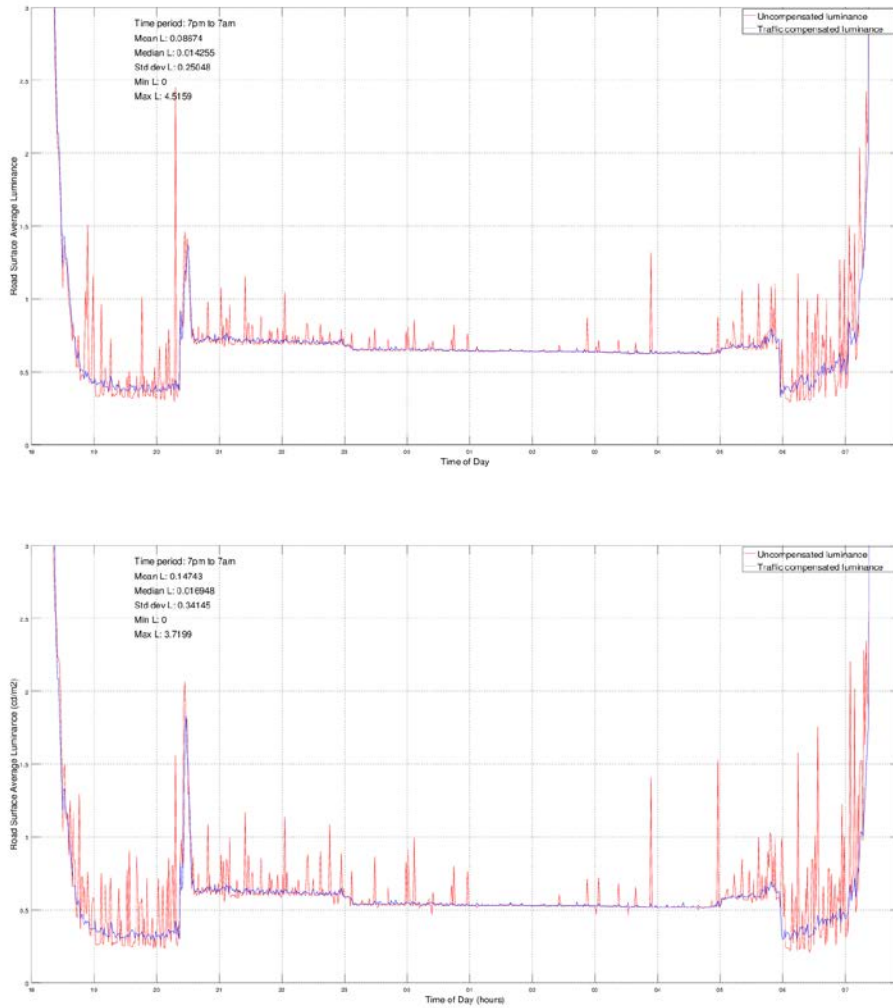


Figure A1- 13. EN 13201 average surface luminance: October 13, 6pm, to October 14, 8am.

Appendix 1

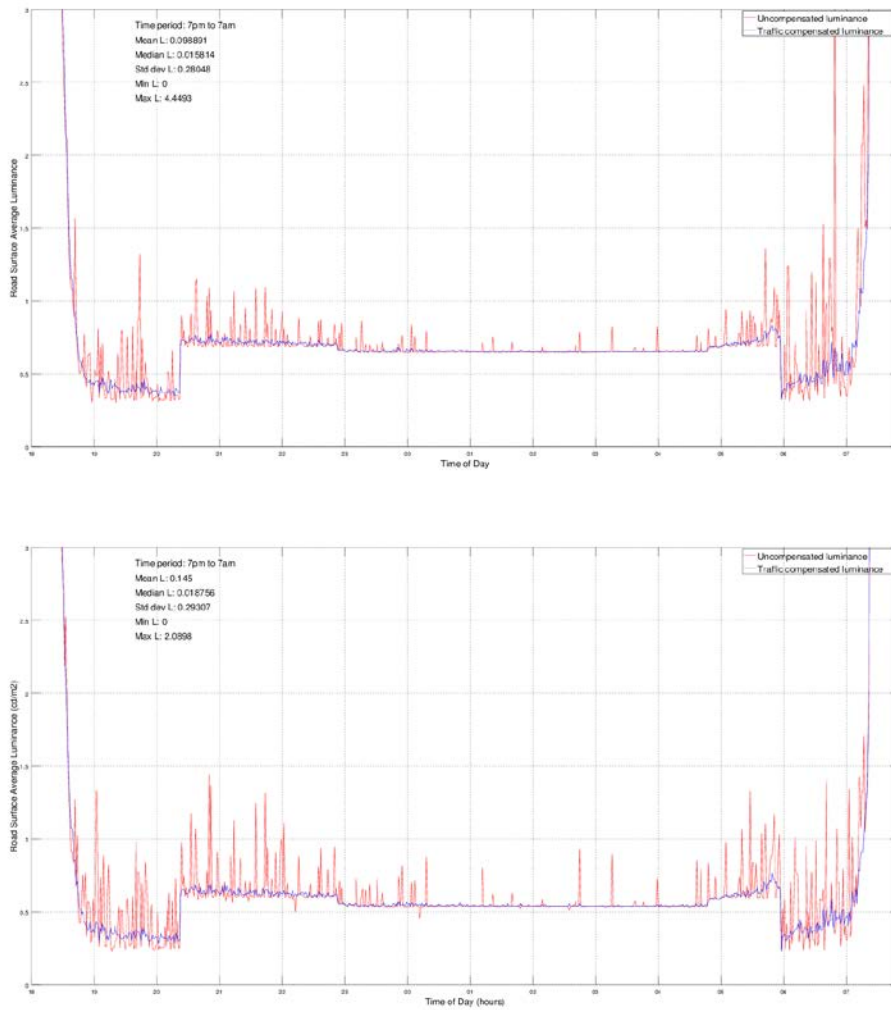


Figure A1- 14. EN 13201 average surface luminance: October 14, 6pm, to October 15, 8am.

Appendix 1

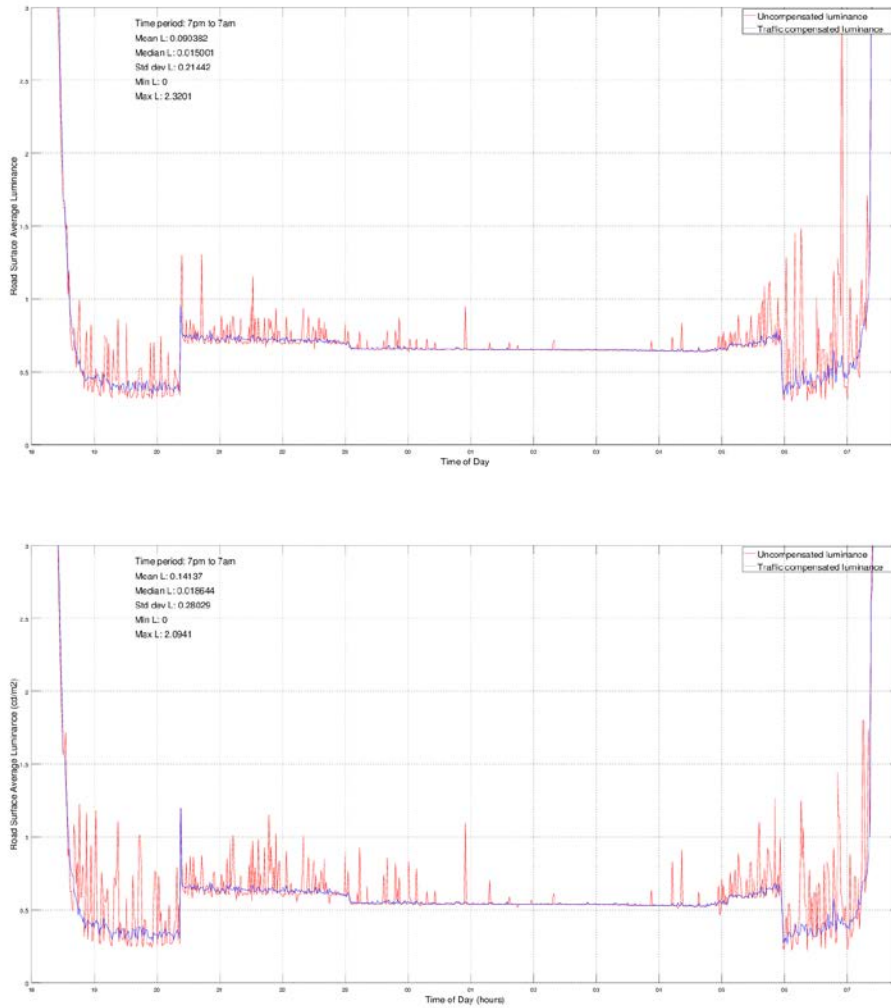


Figure A1- 15. EN 13201 average surface luminance: October 15, 6pm, to October 16, 8am.

Appendix 1

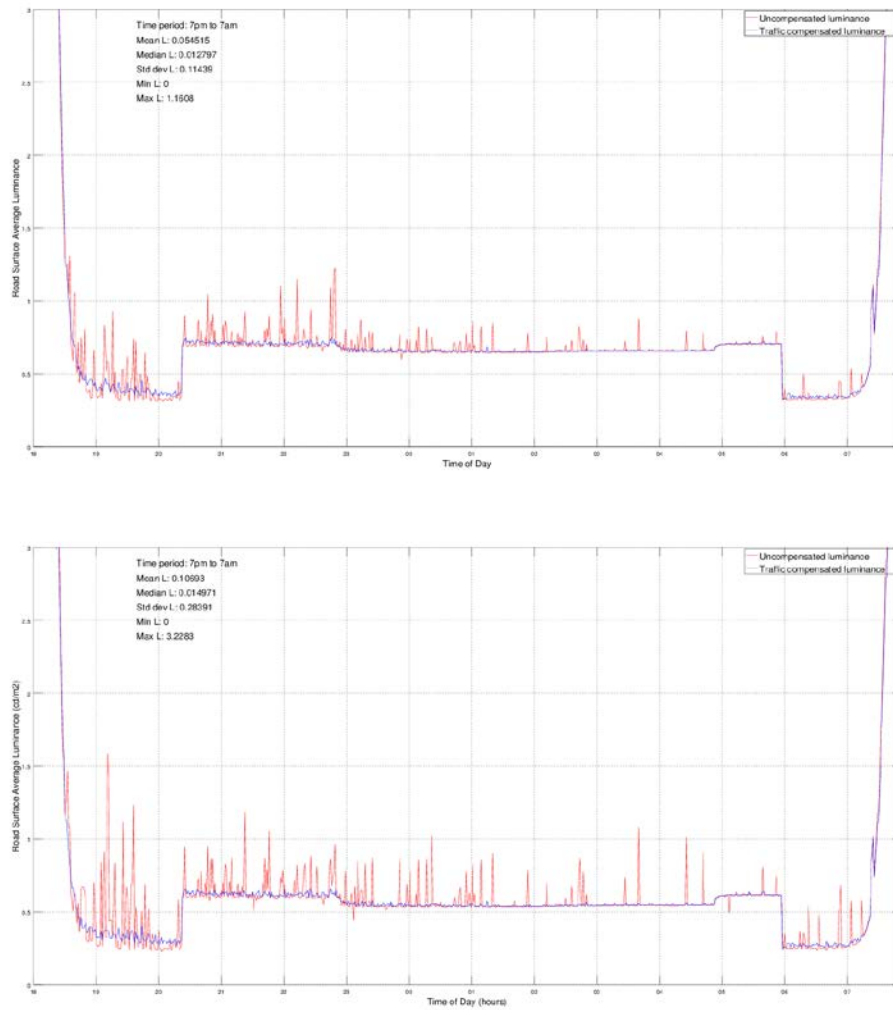


Figure A1- 16. EN 13201 average surface luminance: October 16, 6pm, to October 17, 8am.

Appendix 1

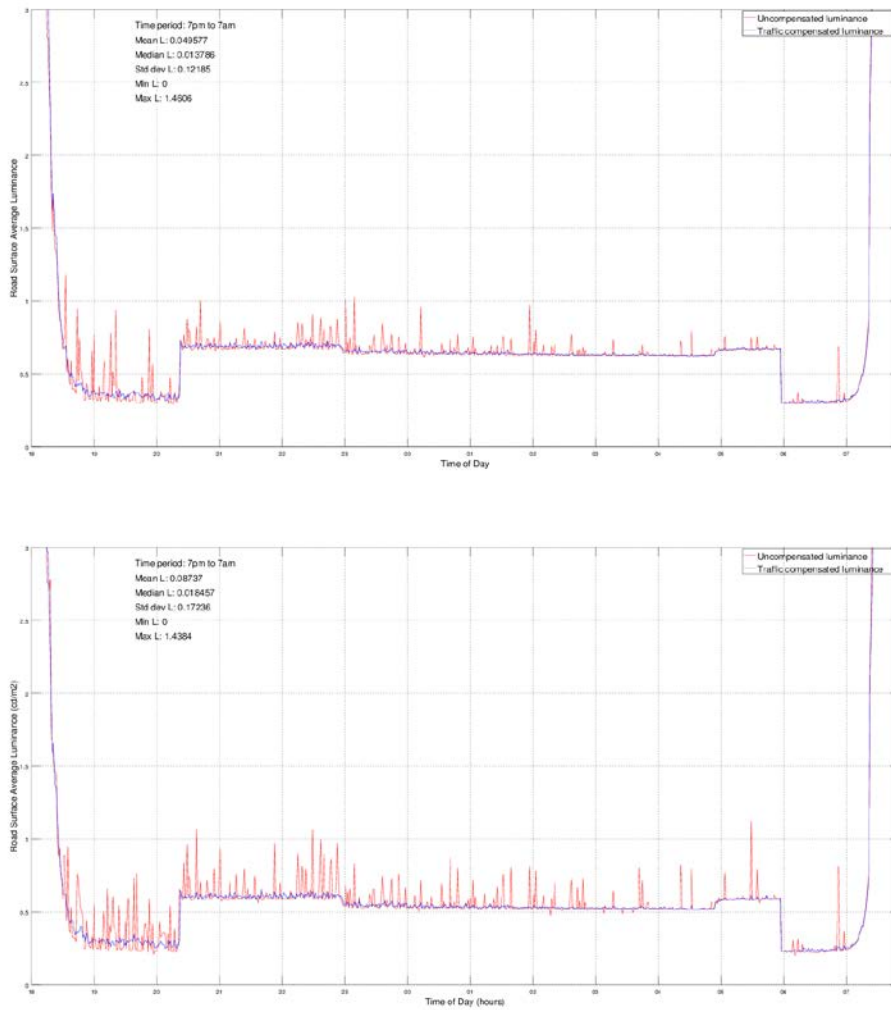


Figure A1- 17. EN 13201 average surface luminance: October 17, 6pm, to October 18, 8am.

Appendix 1

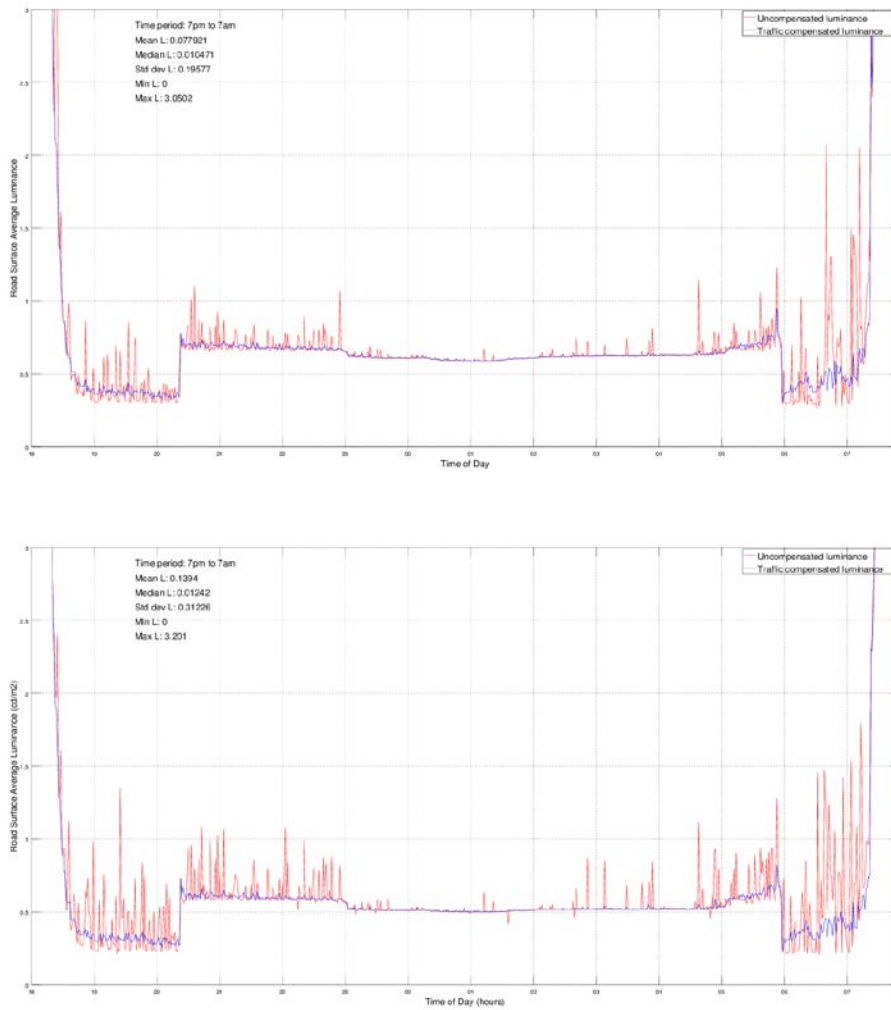


Figure A1- 18. EN 13201 average surface luminance: October 18, 6pm, to October 19, 8am.

Appendix 1

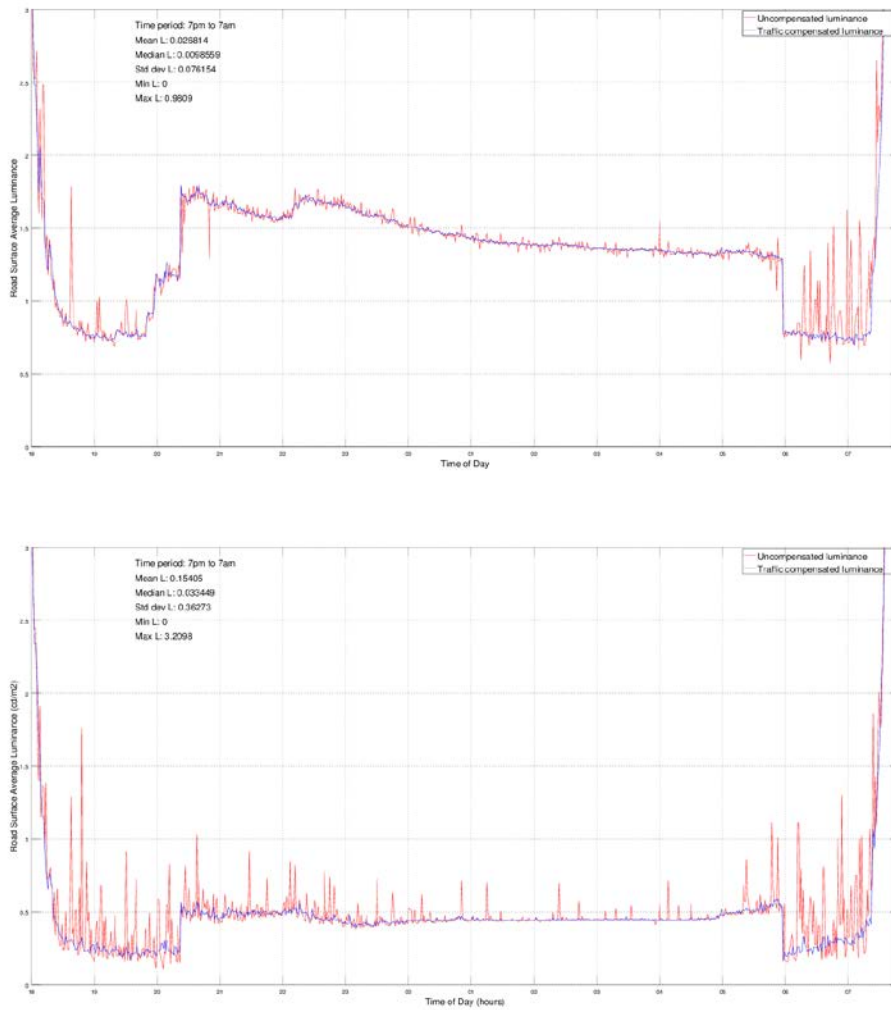


Figure A1- 19. EN 13201 average surface luminance: October 22, 6pm, to October 23, 8am.

Appendix 1

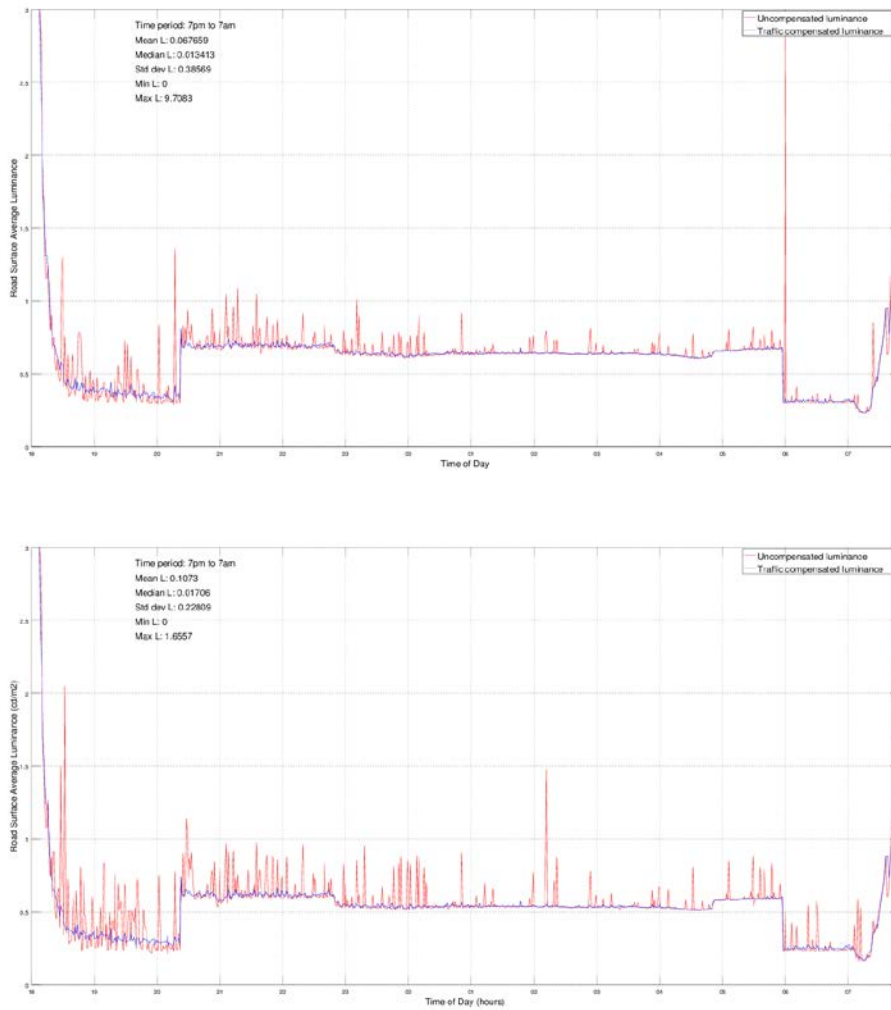


Figure A1- 20. EN 13201 average surface luminance: October 23, 6pm, to October 24, 8am.

Appendix 1

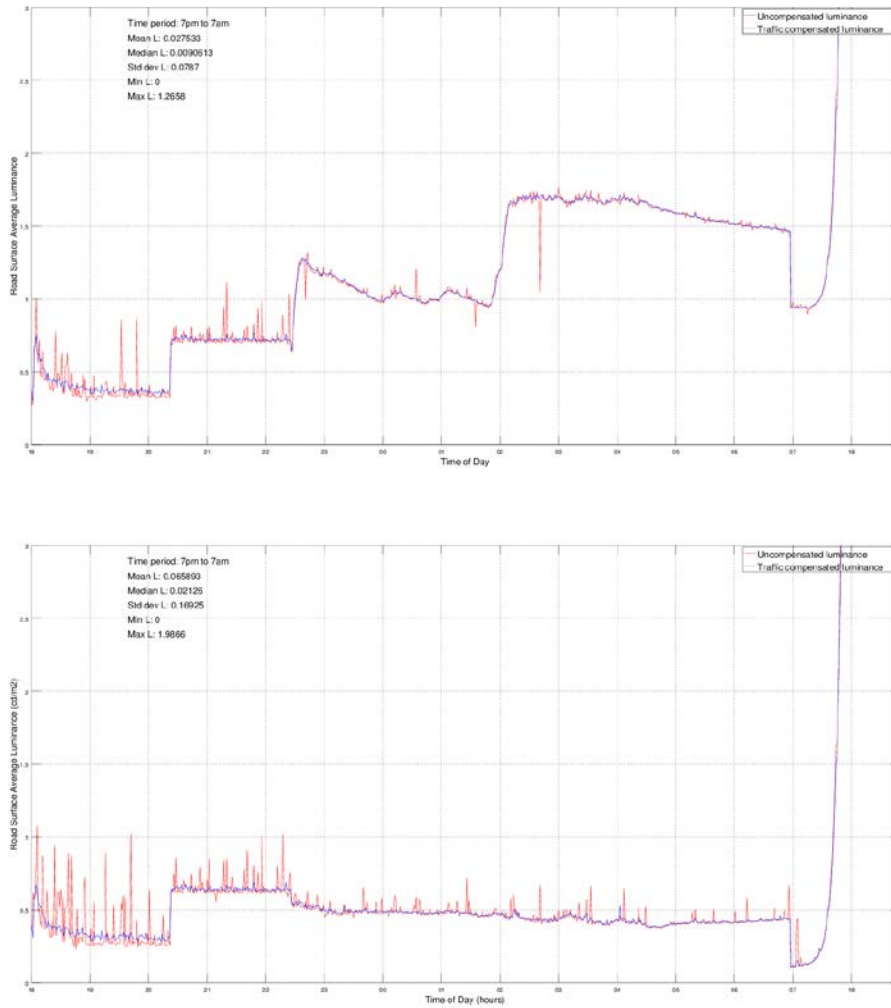


Figure A1- 21. EN 13201 average surface luminance: October 24, 6pm, to October 25, 8am.

Appendix 1

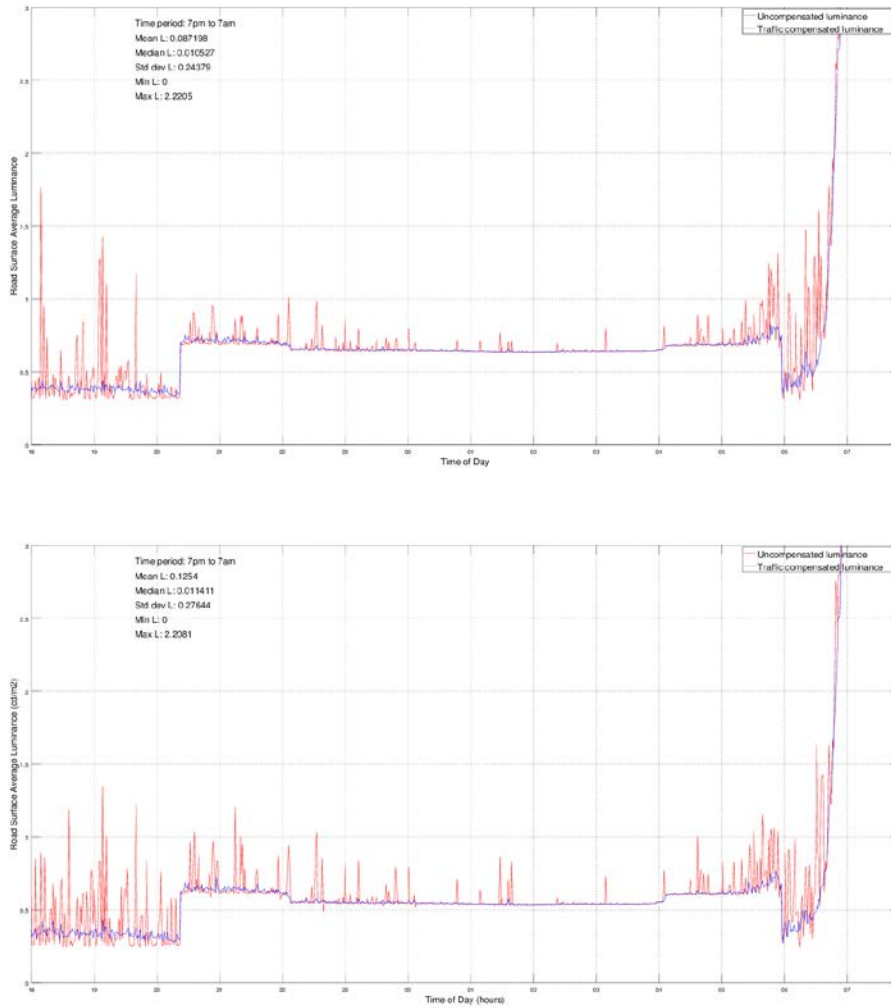


Figure A1- 22. EN 13201 average surface luminance: October 25, 6pm, to October 26, 8am.

Appendix 1

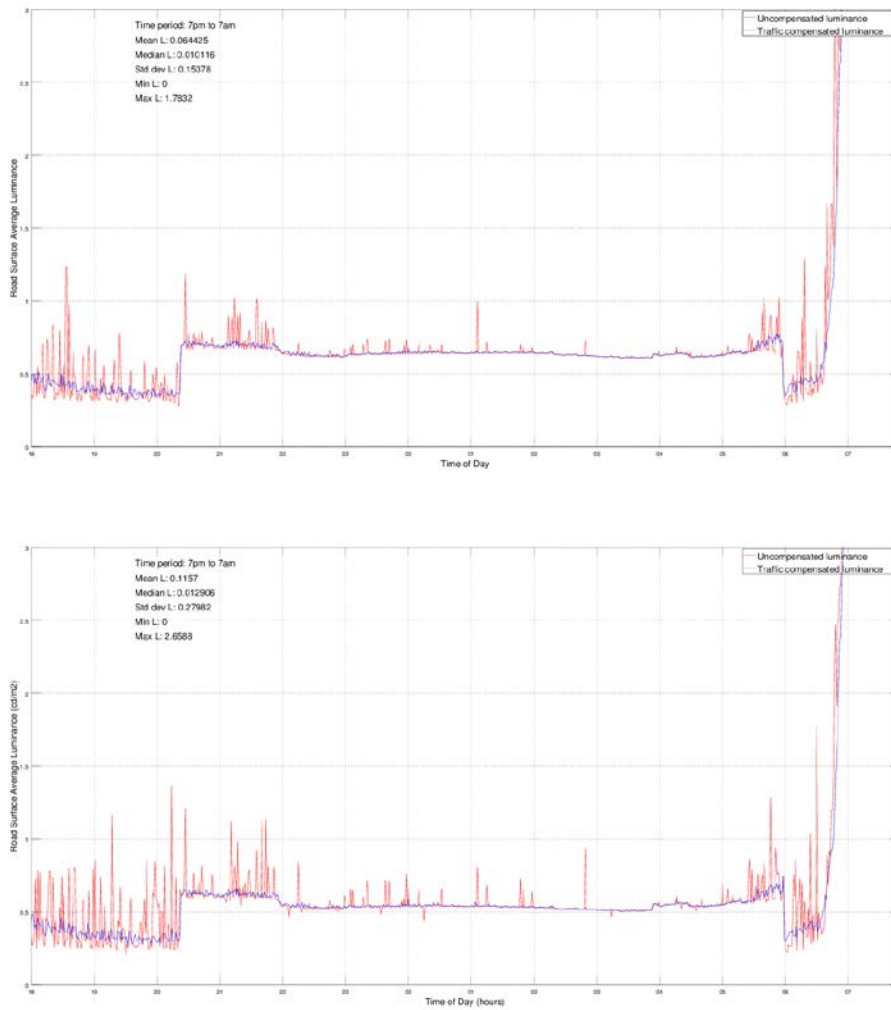


Figure A1- 23. EN 13201 average surface luminance: October 26, 6pm, to October 27, 8am.

Appendix 1

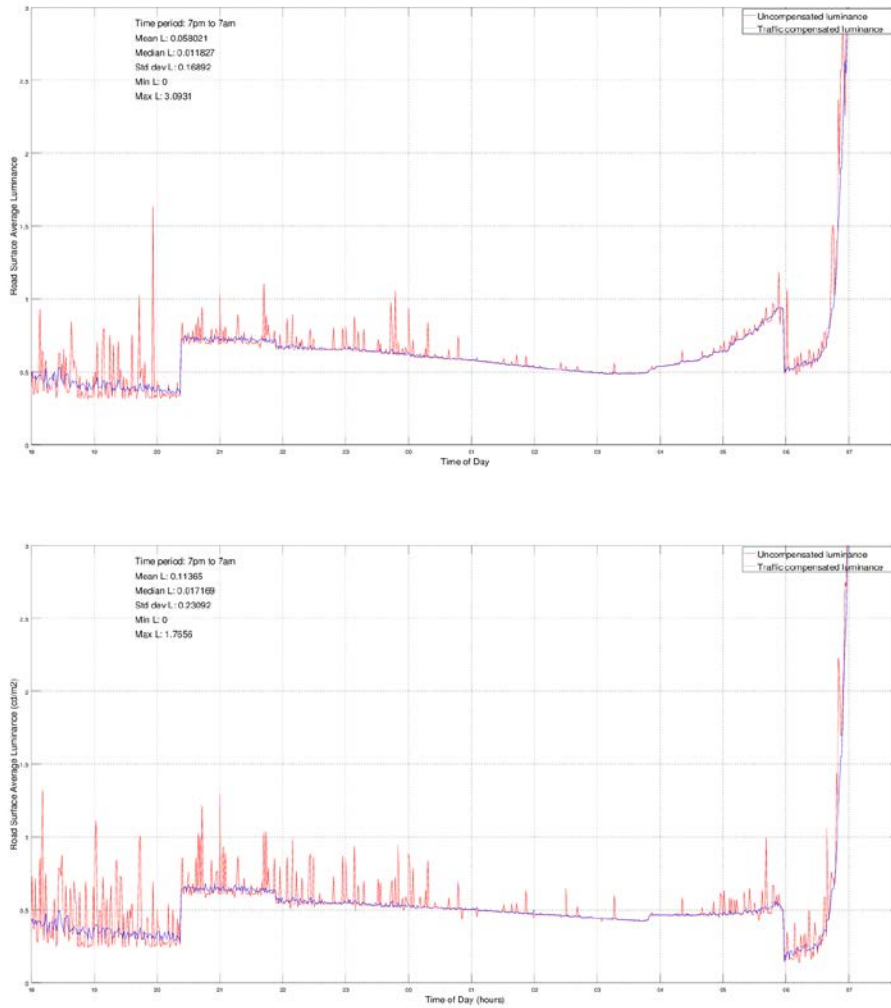


Figure A1- 24. EN 13201 average surface luminance: October 27, 6pm, to October 28, 8am.

Appendix 1

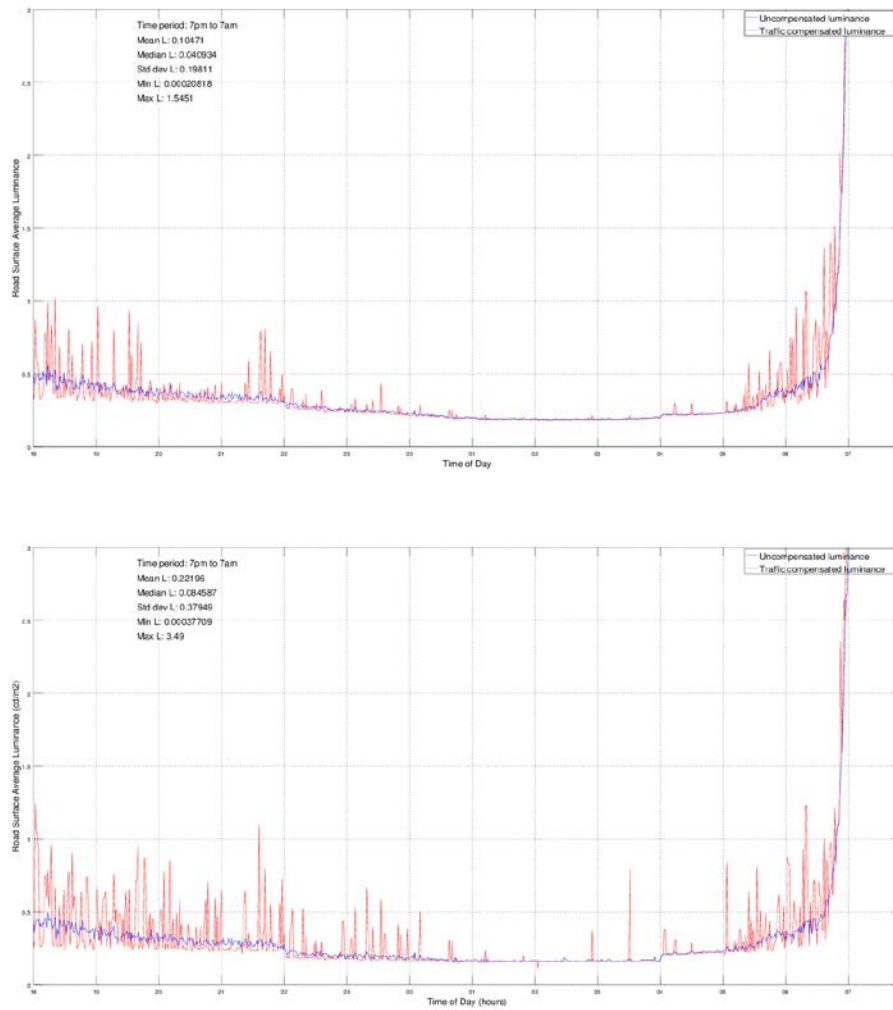


Figure A1- 25. EN 13201 average surface luminance: October 28, 6pm, to October 29, 8am.

Appendix 1

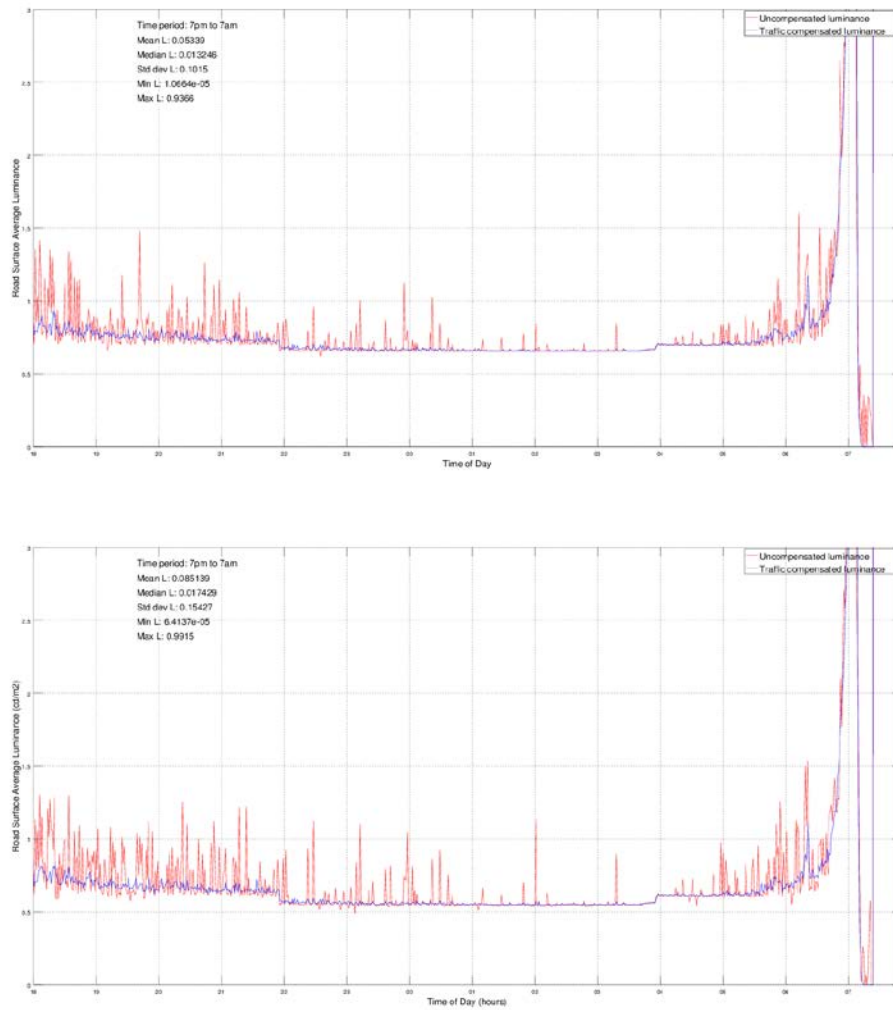


Figure A1- 26. EN 13201 average surface luminance: October 29, 6pm, to October 30, 8am.

Appendix 2

Appendix 2: Road Surface Luminance Data – November 2015

In this section, we report the average road surface luminance as a function of time at Test Site 2 where EN 13201 measurements have been performed. The measurements listed below are for November only. In each of the figures shown below, the unit on the y-axis is candela per square meter (cd/m^2) and, on the x-axis, we show the time of day in hours from 4pm to 8 am. Each figure shows measurements taken from one full night.

The sun set during November was between 3.33pm and 4.25pm. The sun rise, on the other hand, was between 7.25am to 8.28am.

In the figures below, the red line shows the uncompensated raw luminance measurements. The blue line, on the other hand, shows the traffic compensated luminance measurements.

In each of the figures, the summary statistics for the period is shown in the upper left corner. This includes the mean and median luminance values, the standard deviation of the luminance and the minimum/maximum luminance values during the time period. Note that the summary statistics have been provided for a shorter time period – 5pm to 7am.

In each of the figures, the upper plot is for the left lane and the lower plot for the right lane.

Appendix 2

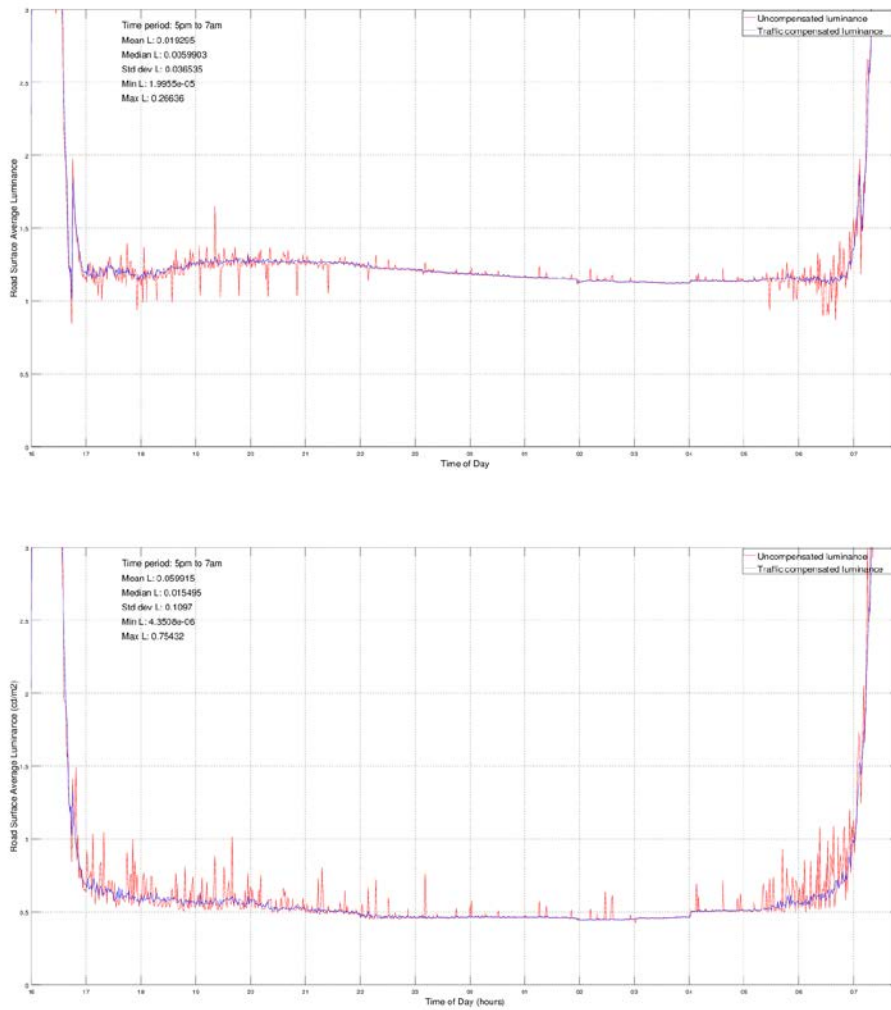


Figure A2- 1. EN 13201 average surface luminance: November 1, 4pm, to November 2, 8am.

Appendix 2

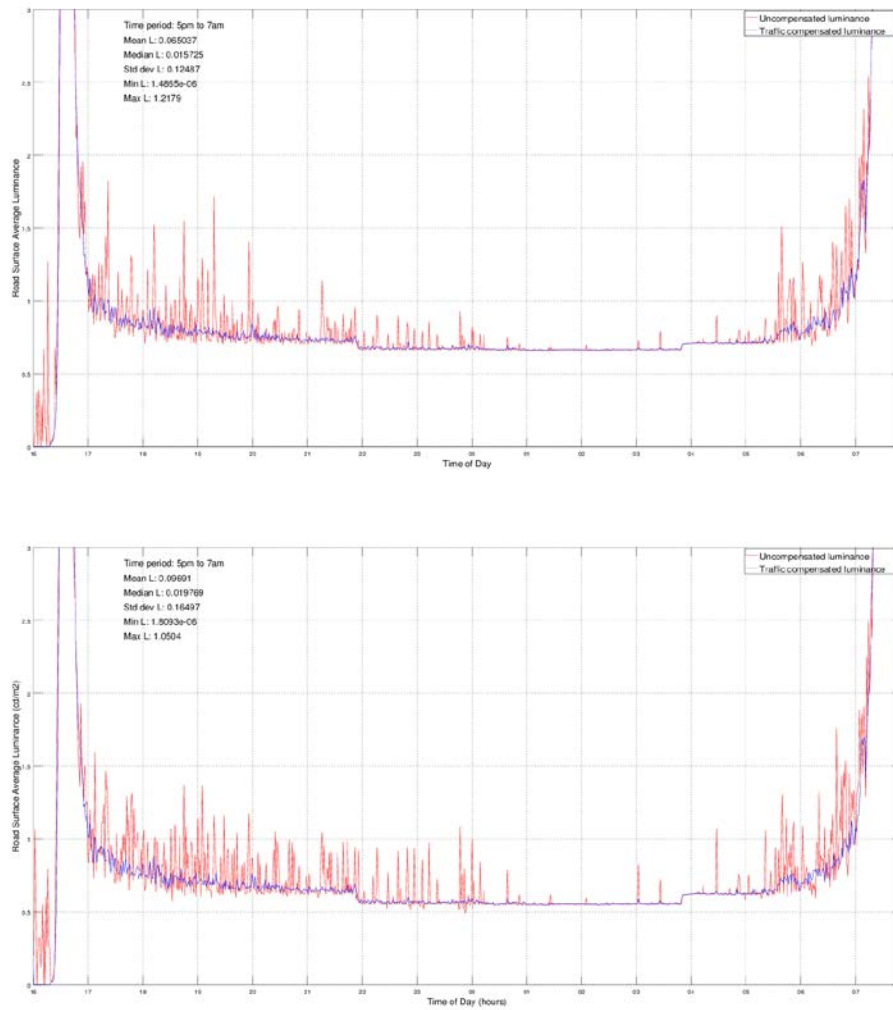


Figure A2- 2. EN 13201 average surface luminance: November 2, 4pm, to November 3, 8am.

Appendix 2

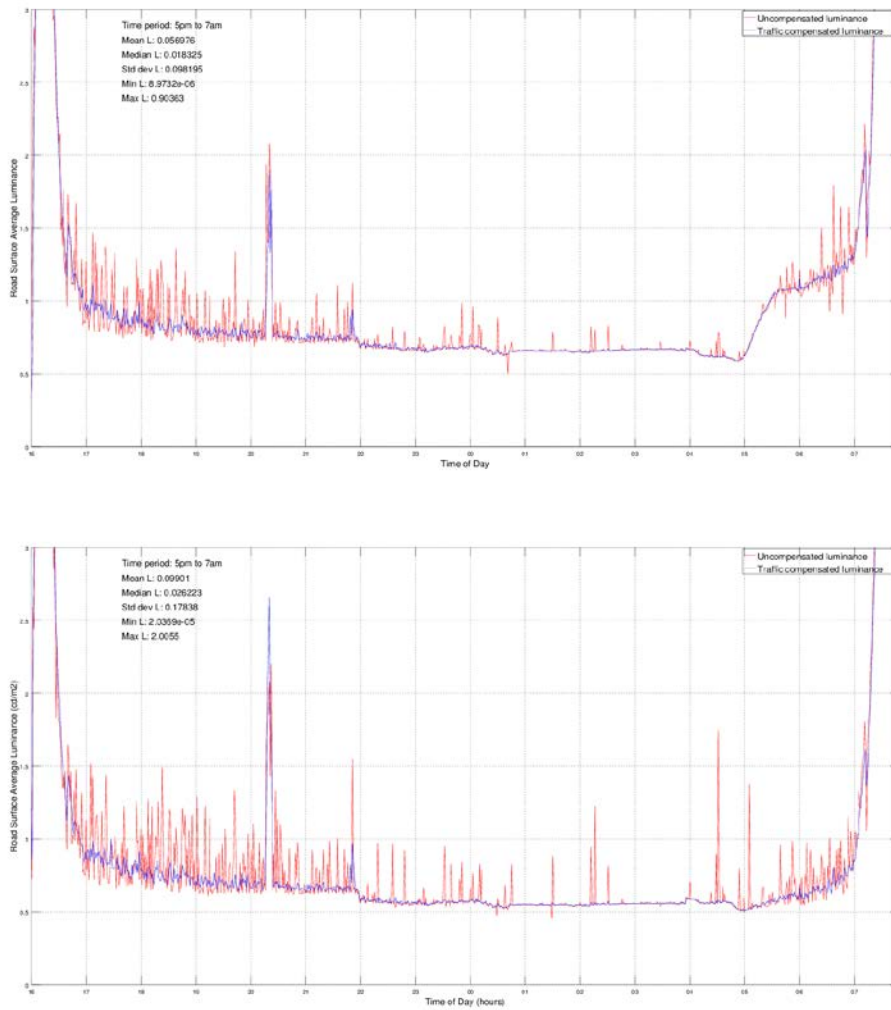


Figure A2- 3. EN 13201 average surface luminance: November 3, 4pm, to November 4, 8am.

Appendix 2

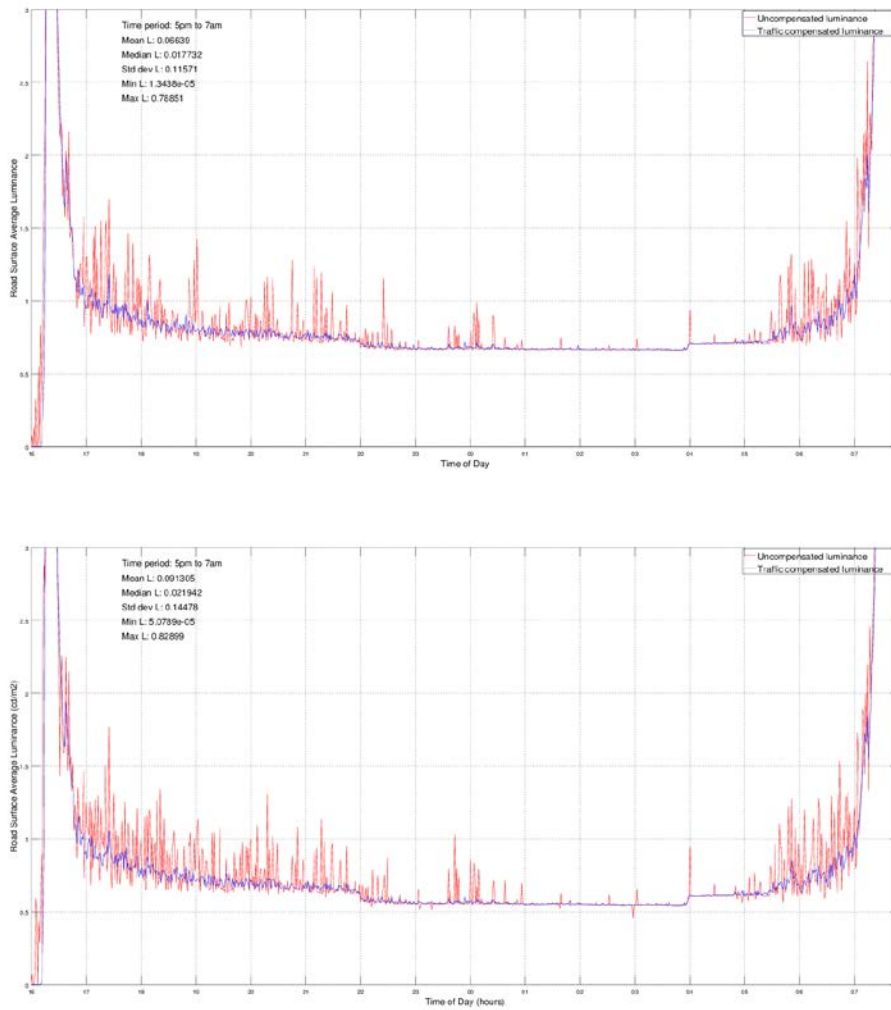


Figure A2- 4. EN 13201 average surface luminance: November 4, 4pm, to November 5, 8am.

Appendix 2

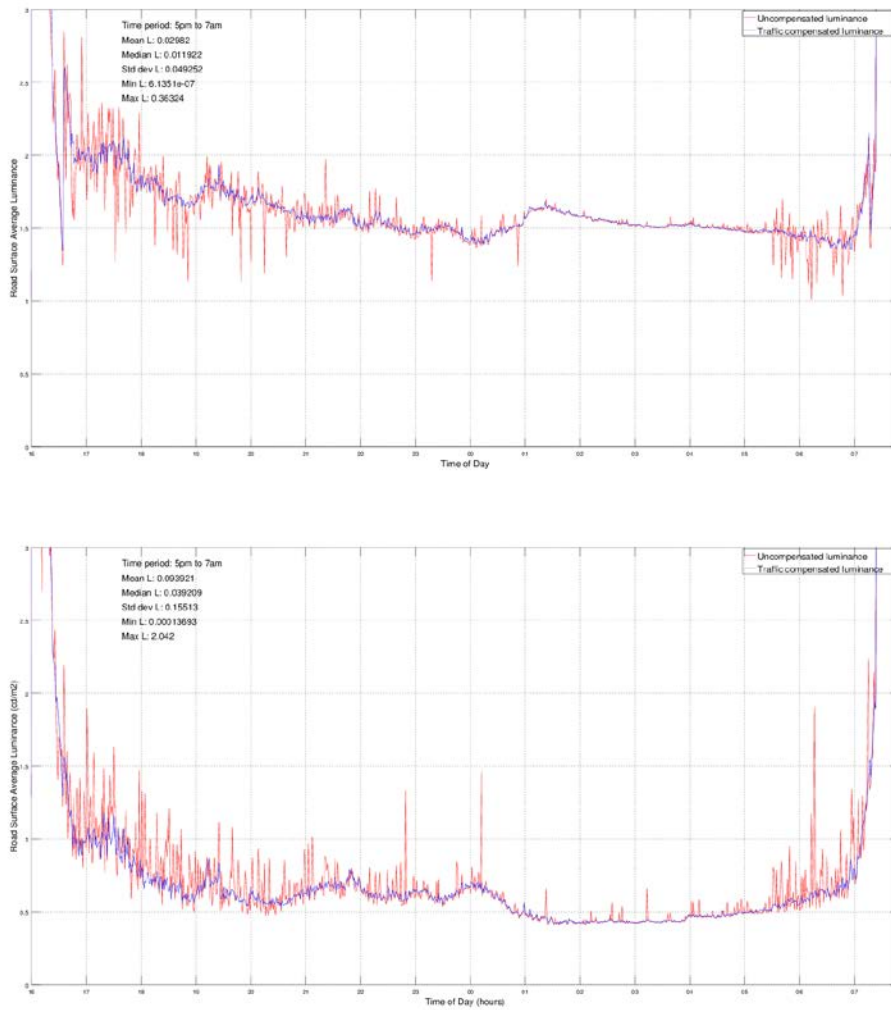


Figure A2- 5. EN 13201 average surface luminance: November 5, 4pm, to November 6, 8am.

Appendix 2

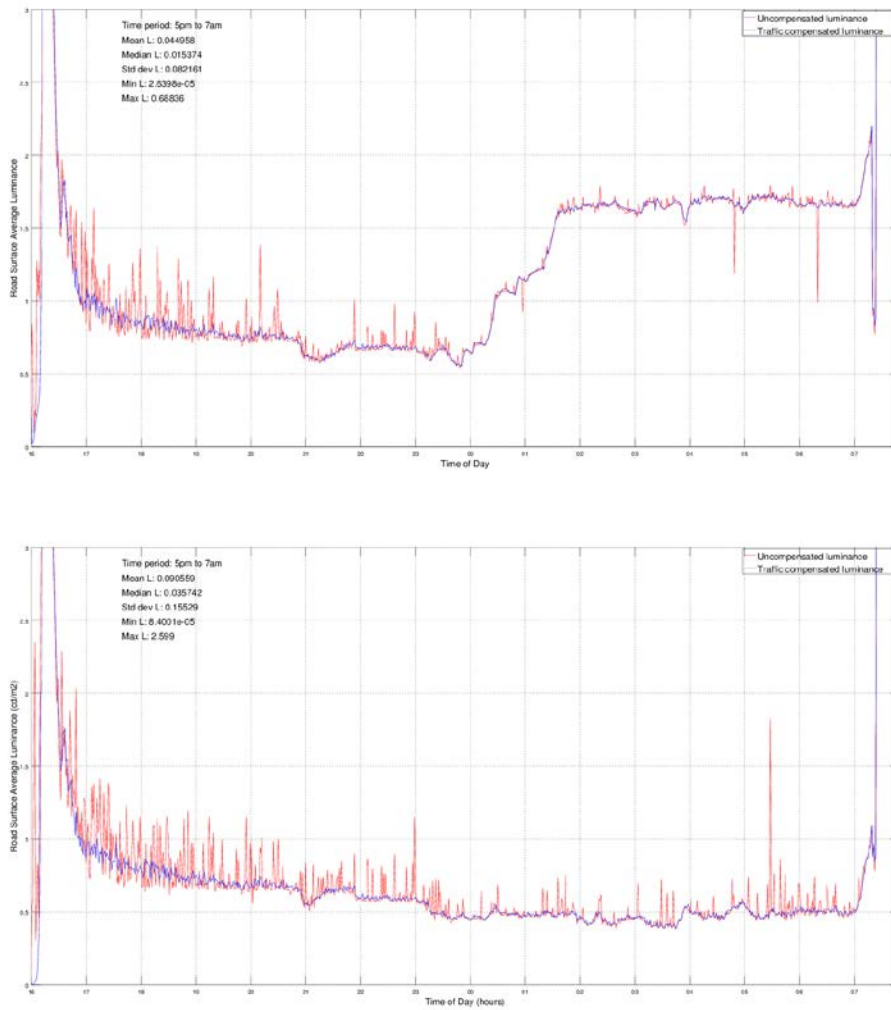


Figure A2- 6. EN 13201 average surface luminance: November 6, 4pm, to November 7, 8am.

Appendix 2

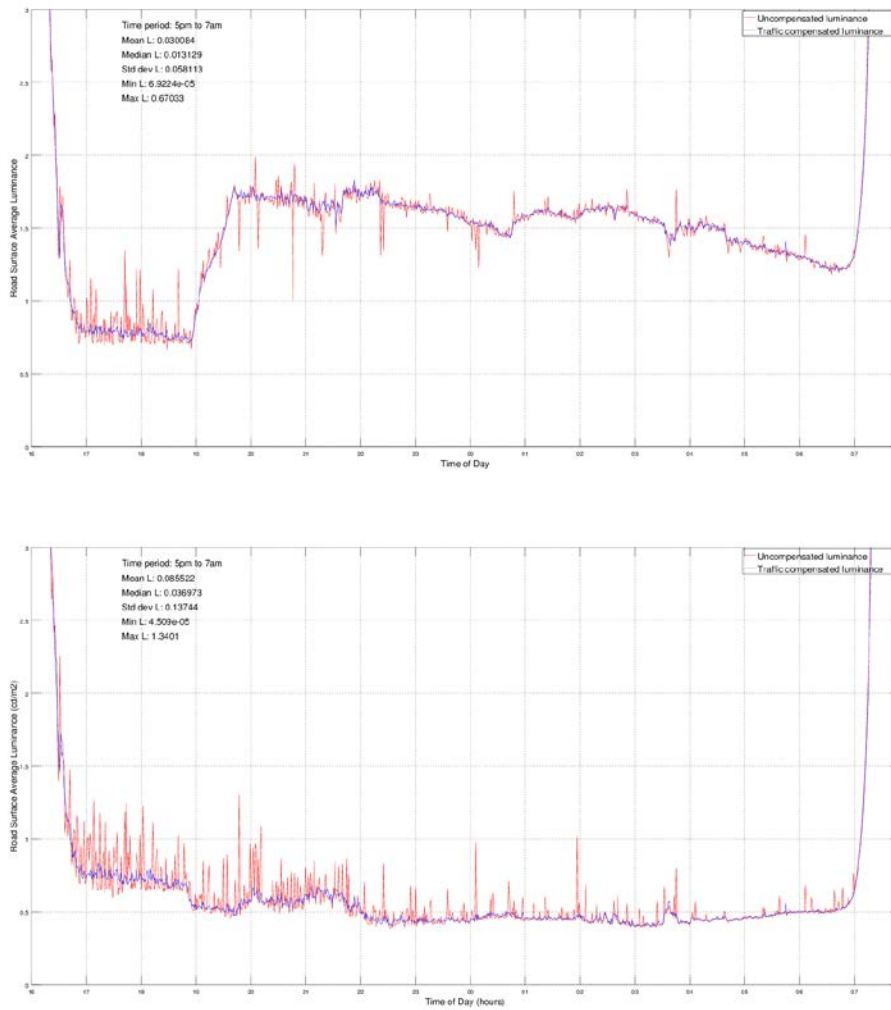


Figure A2- 7. EN 13201 average surface luminance: November 7, 4pm, to November 8, 8am.

Appendix 2

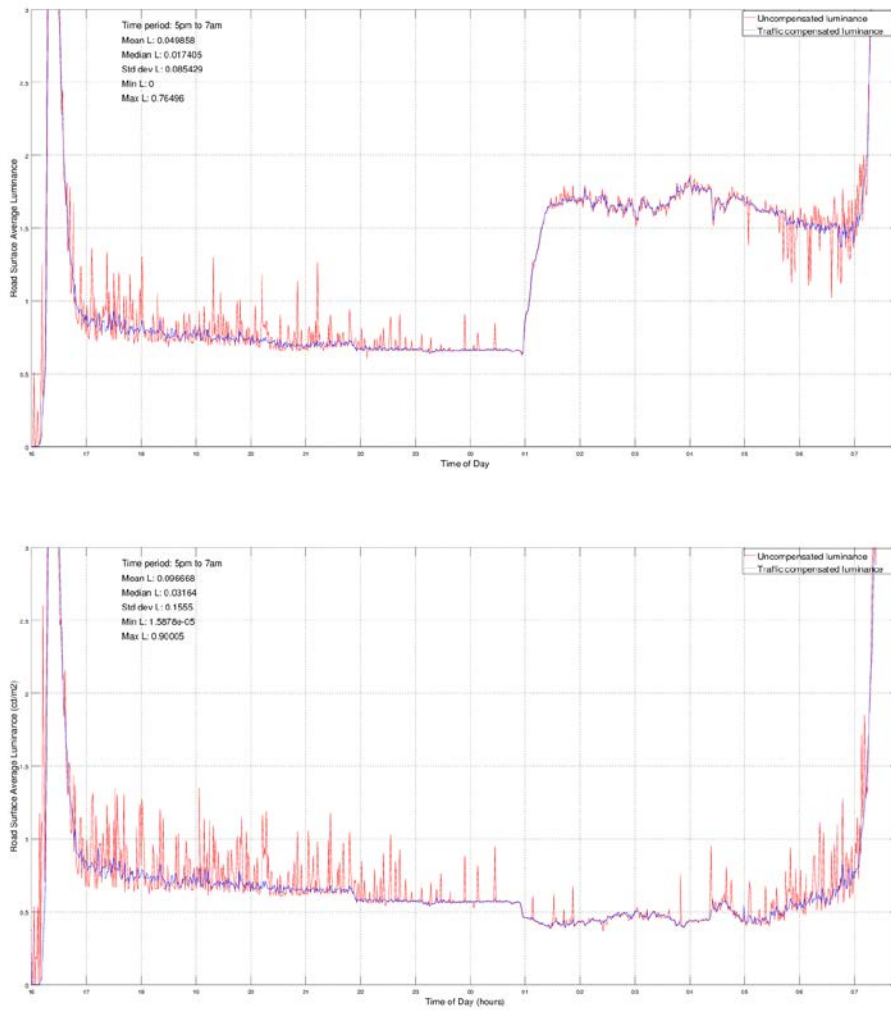


Figure A2- 8. EN 13201 average surface luminance: November 8, 4pm, to November 9, 8am.

Appendix 2

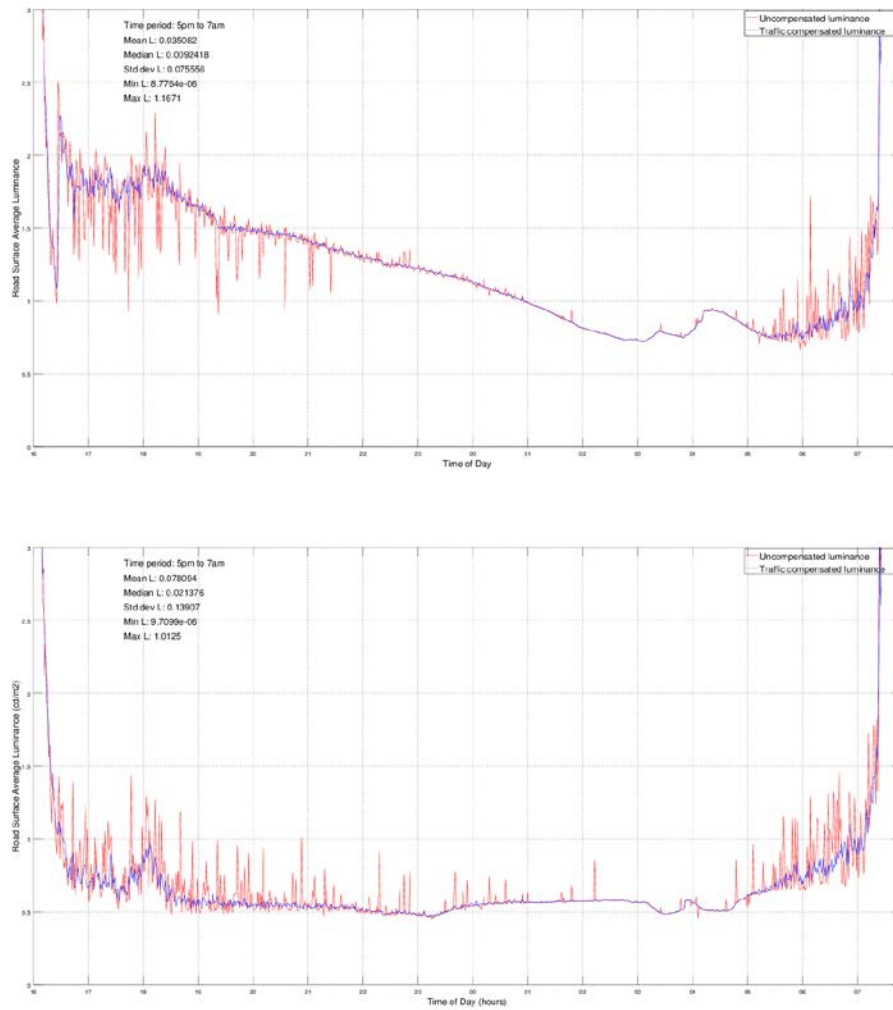


Figure A2- 9. EN 13201 average surface luminance: November 9, 4pm, to November 10, 8am.

Appendix 2

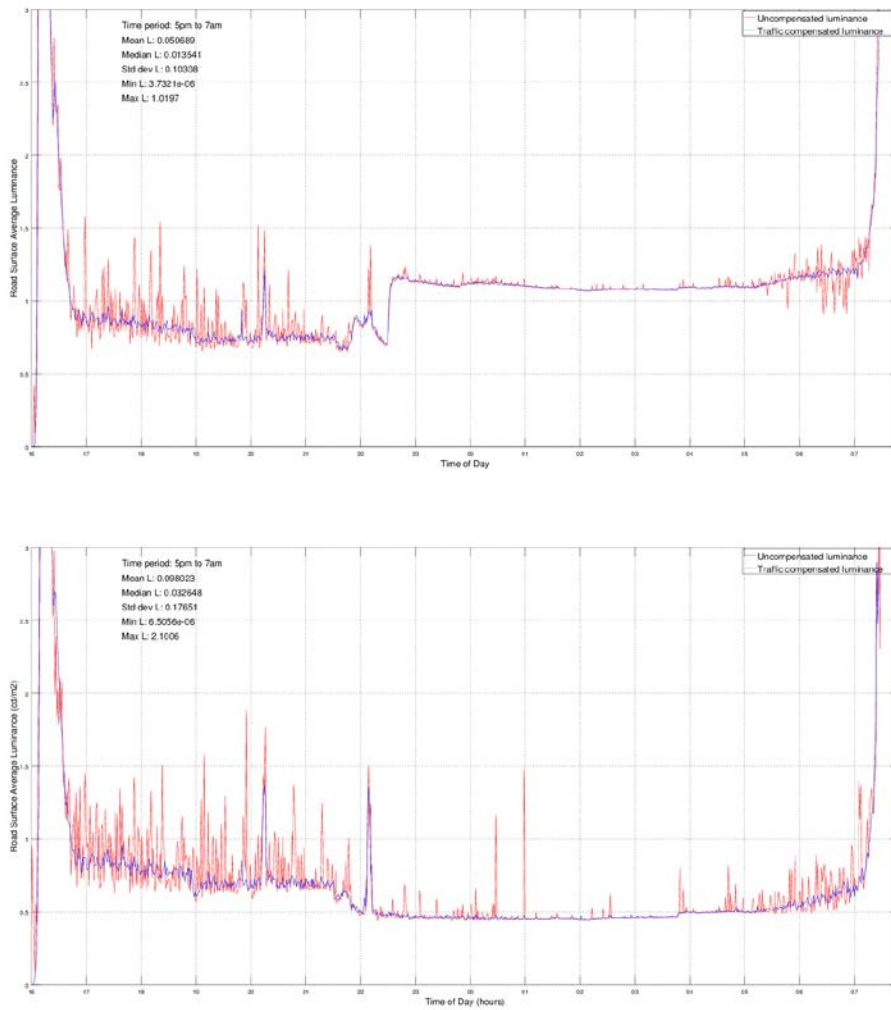


Figure A2- 10. EN 13201 average surface luminance: November 10, 4pm, to November 11, 8am.

Appendix 2

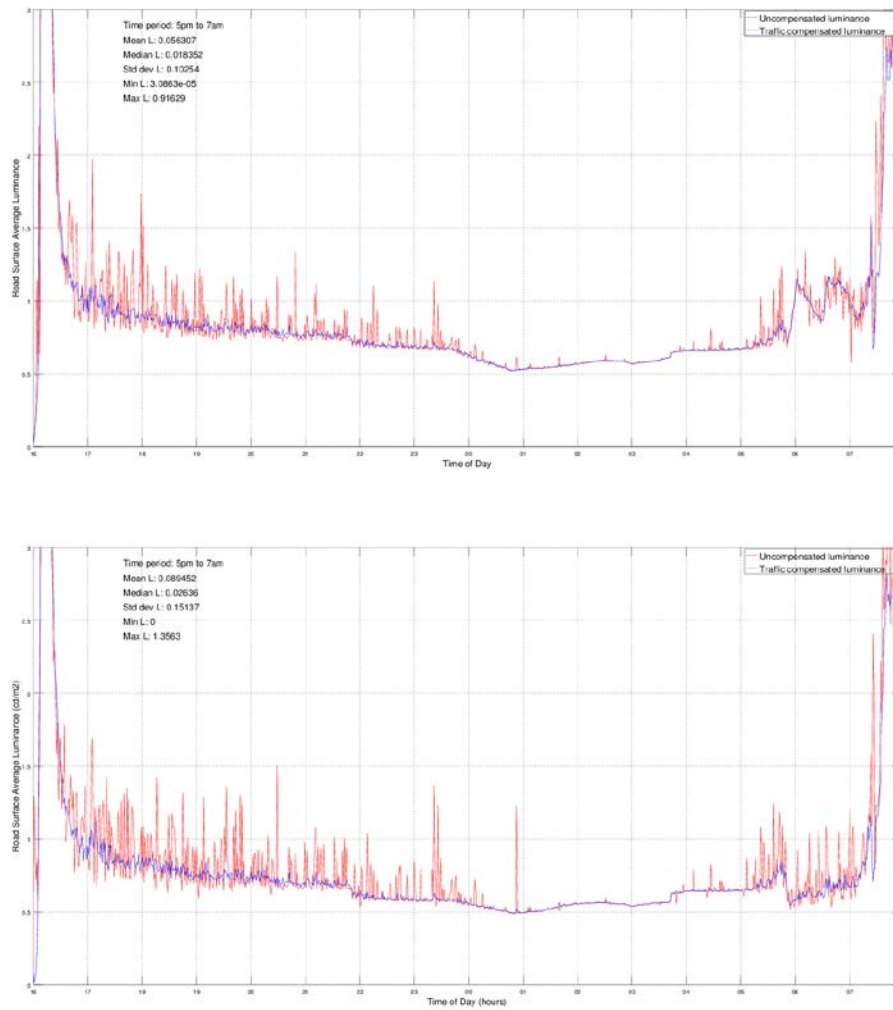


Figure A2- 11. EN 13201 average surface luminance: November 12, 4pm, to November 13, 8am.

Appendix 2

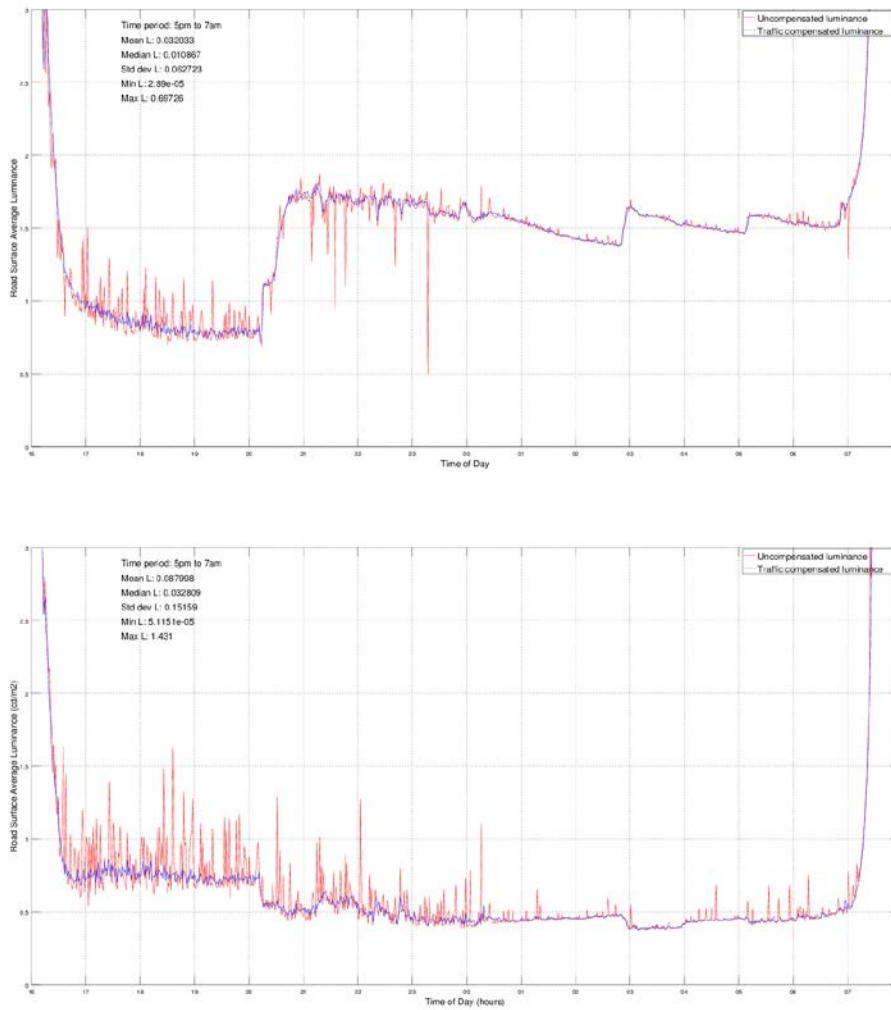


Figure A2- 12. EN 13201 average surface luminance: November 13, 4pm, to November 14, 8am.

Appendix 2

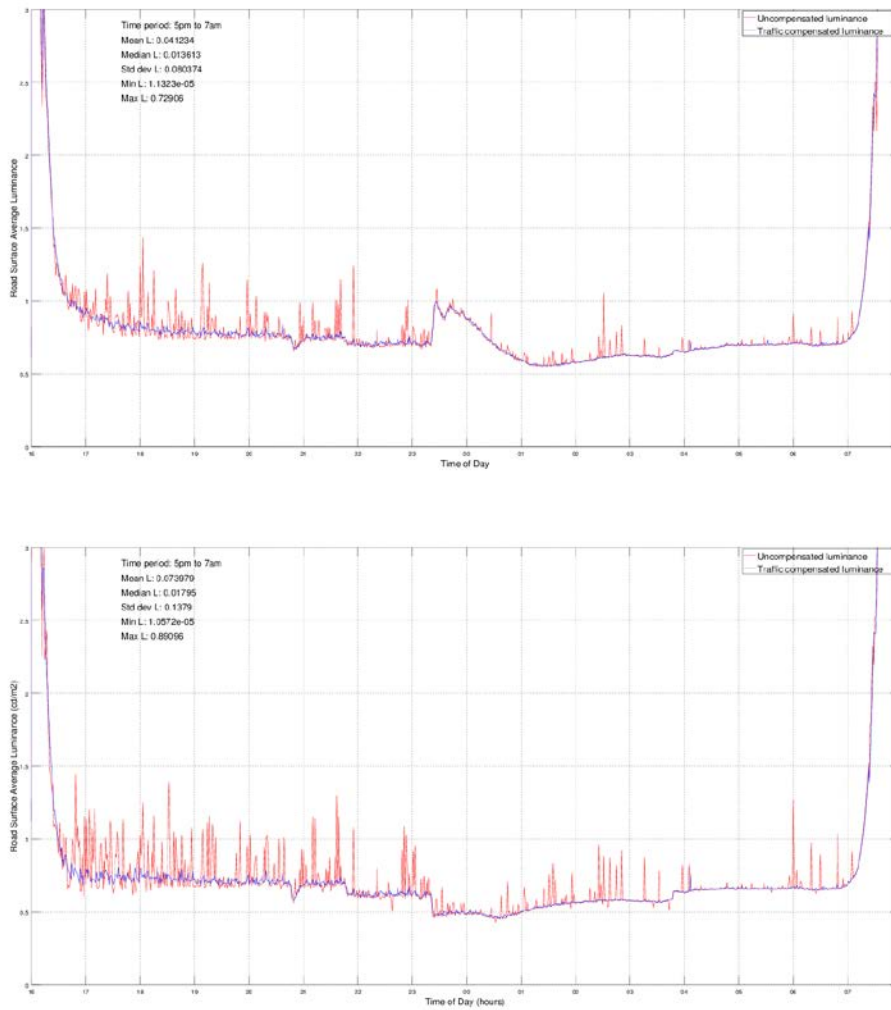


Figure A2- 13. EN 13201 average surface luminance: November 14, 4pm, to November 15, 8am.

Appendix 2

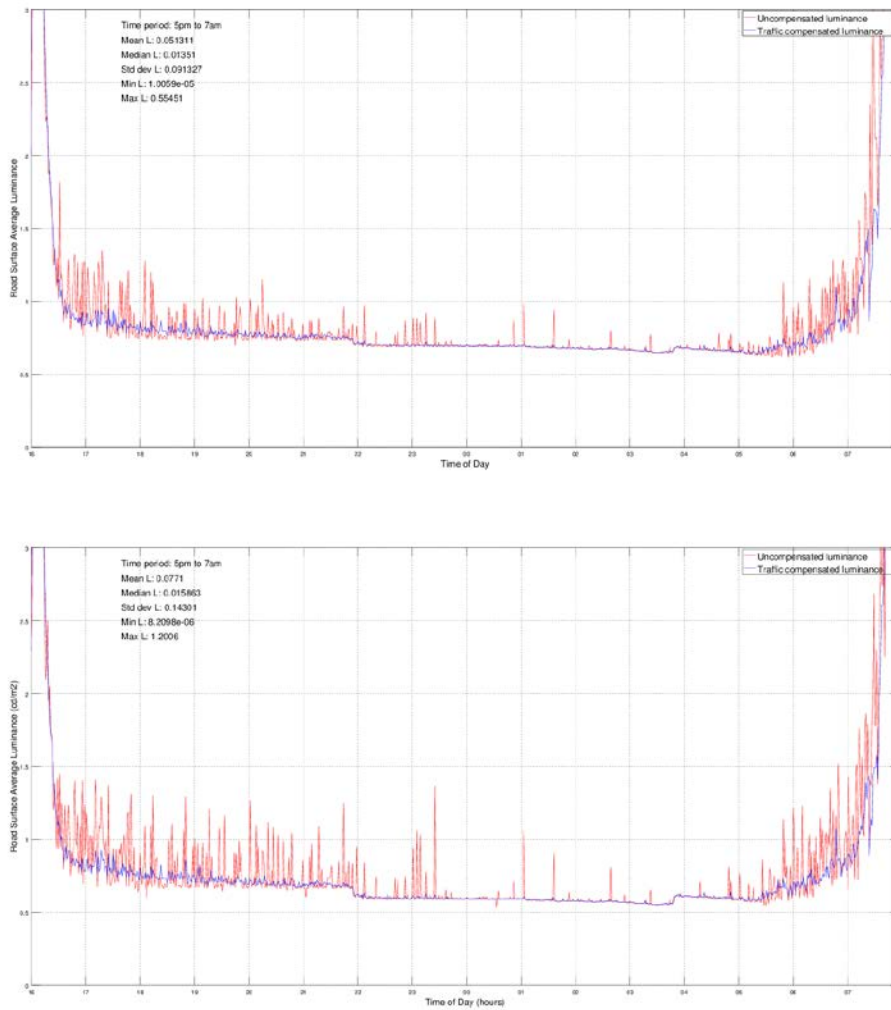


Figure A2- 14. EN 13201 average surface luminance: November 15, 4pm, to November 16, 8am.

Appendix 2

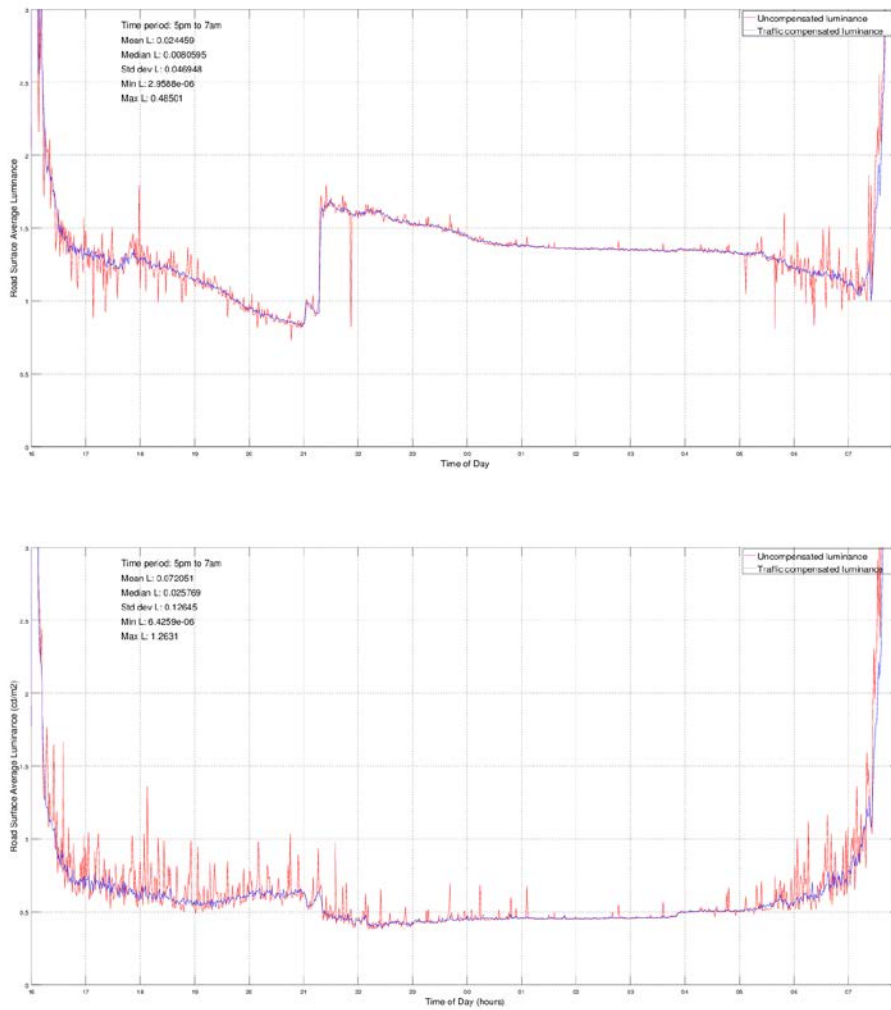


Figure A2- 15. EN 13201 average surface luminance: November 16, 4pm, to November 17, 8am.

Appendix 2

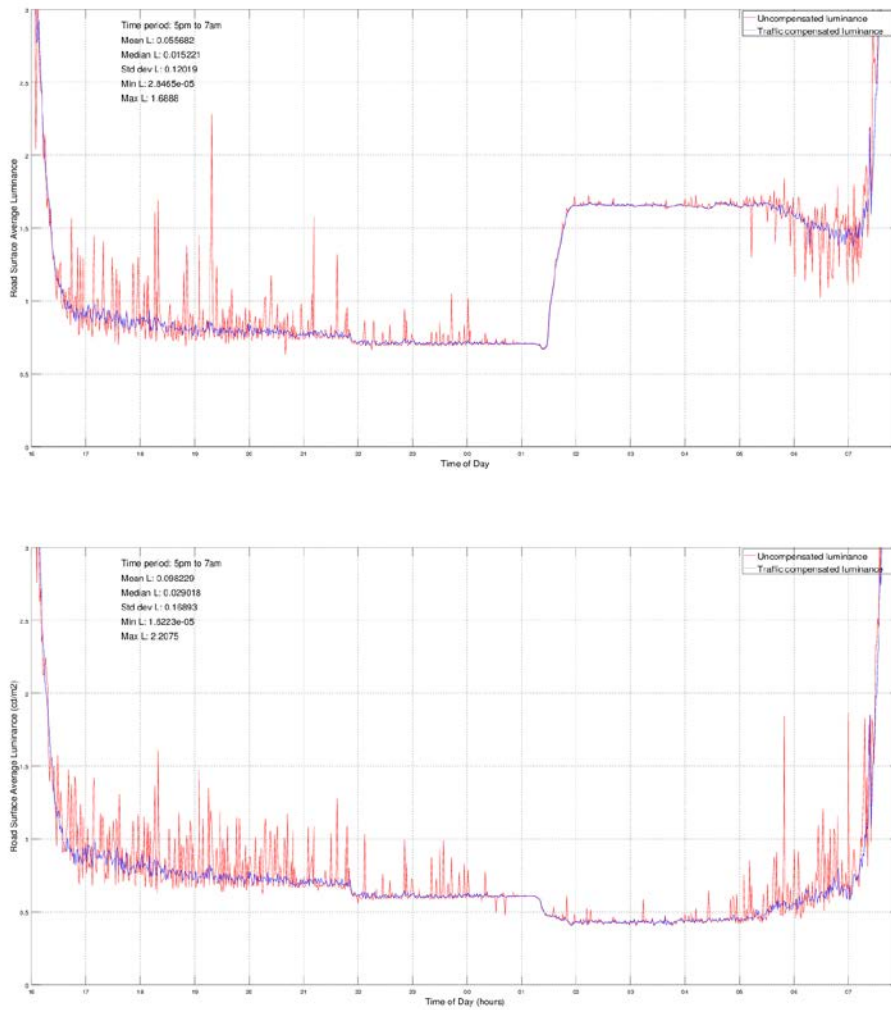


Figure A2- 16. EN 13201 average surface luminance: November 17, 4pm, to November 18, 8am.

Appendix 2

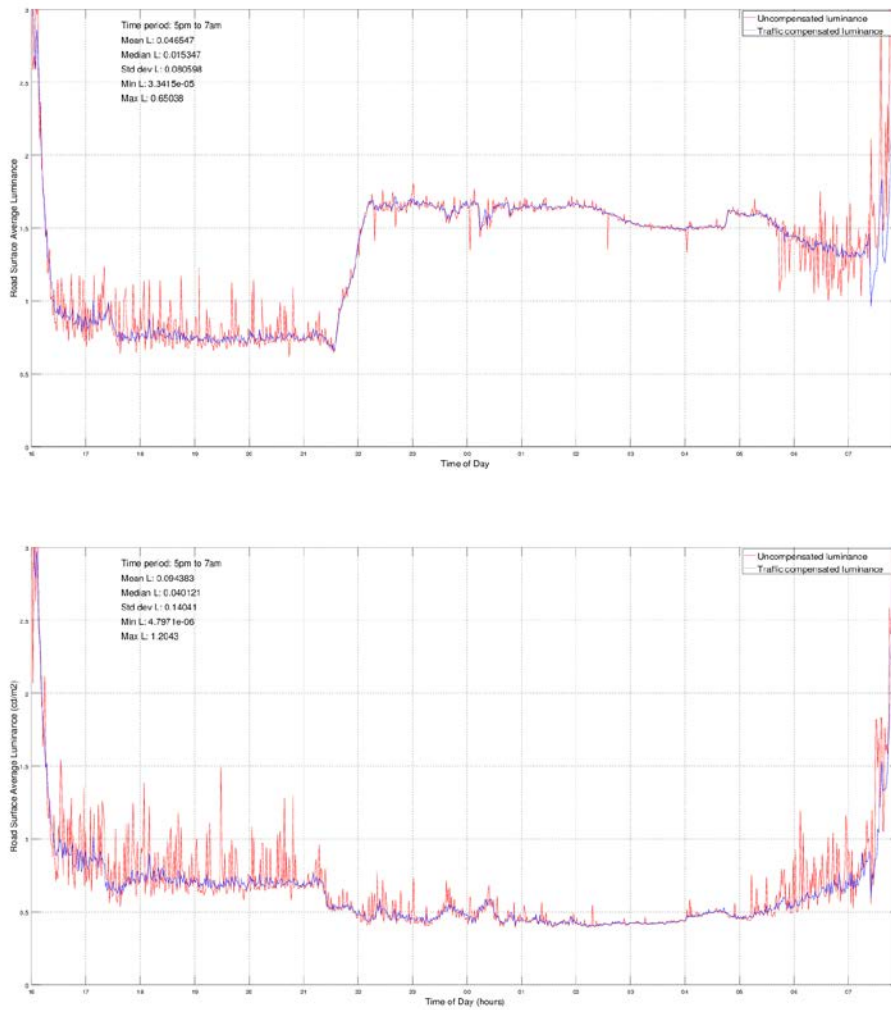


Figure A2- 17. EN 13201 average surface luminance: November 18, 4pm, to November 19, 8am.

Appendix 2

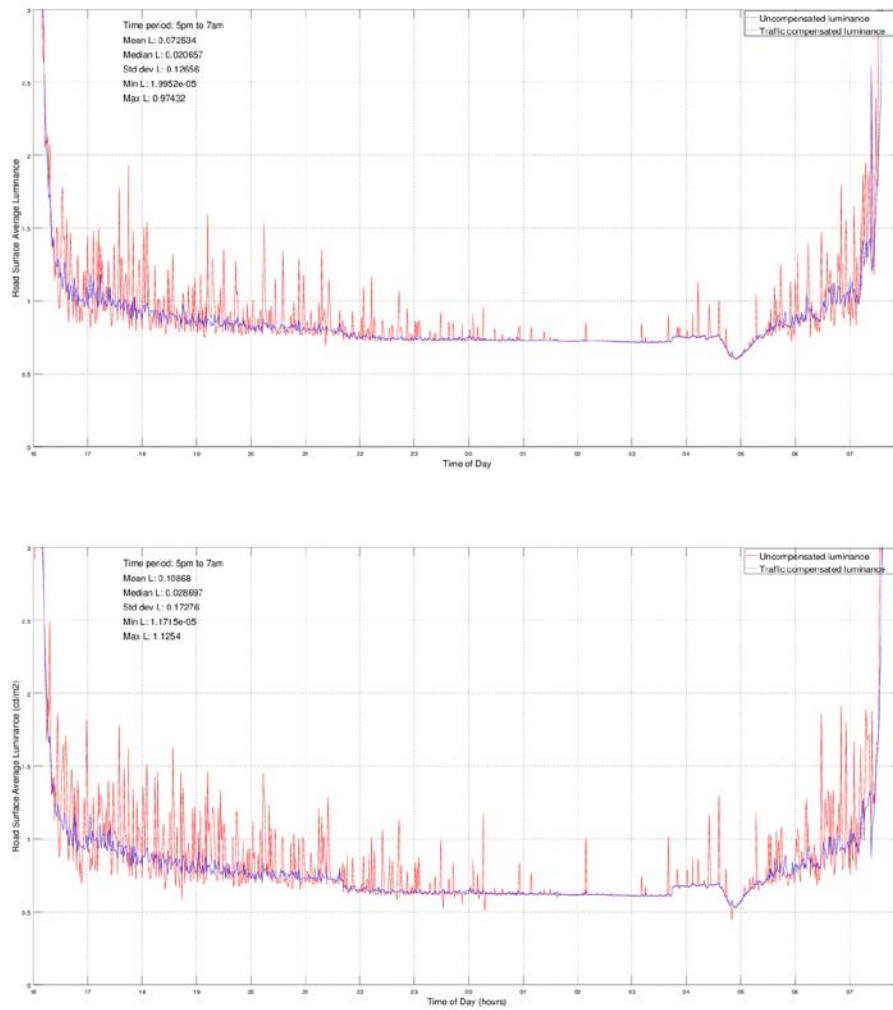


Figure A2- 18. EN 13201 average surface luminance: November 19, 4pm, to November 20, 8am.

Appendix 2

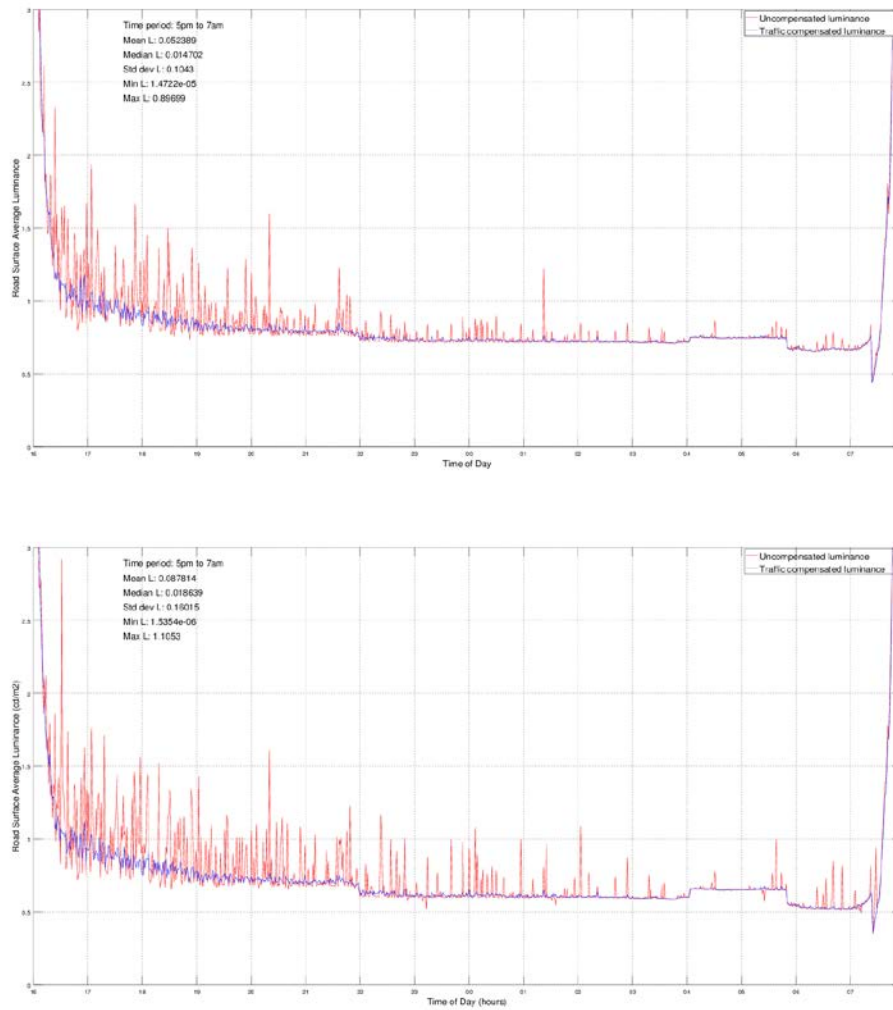


Figure A2- 19. EN 13201 average surface luminance: November 20, 4pm, to November 21, 8am.

Appendix 2

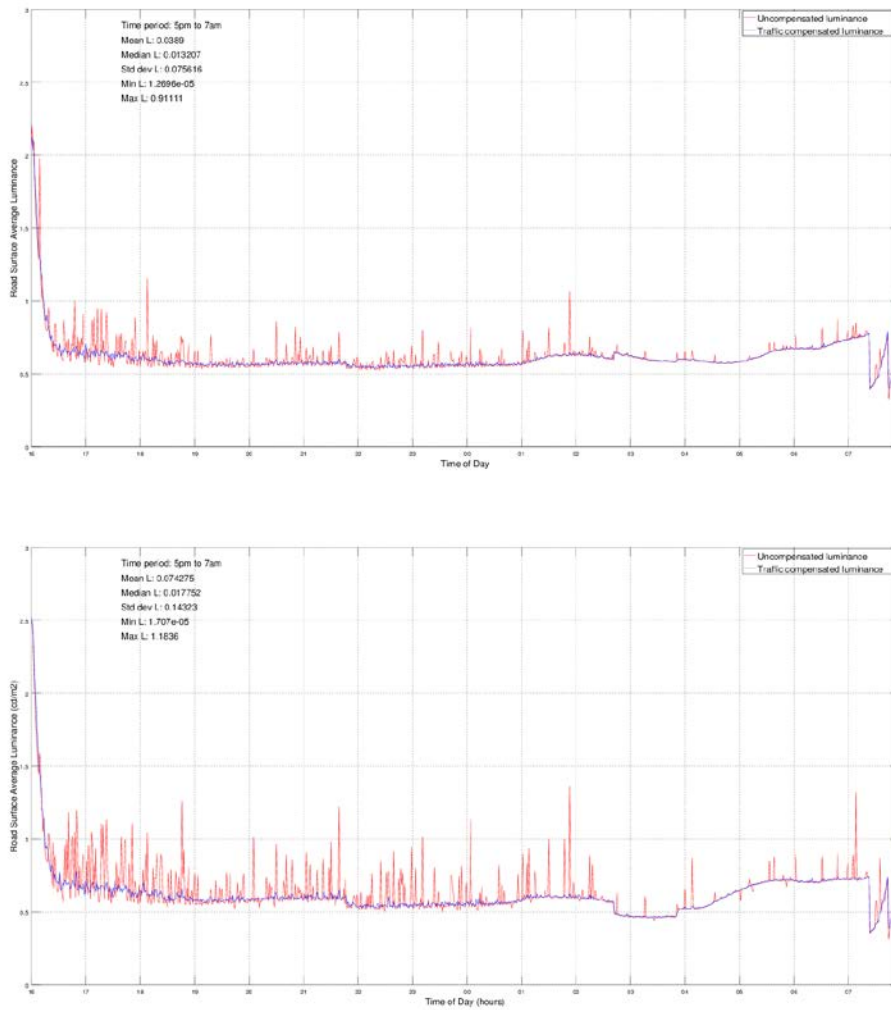


Figure A2- 20. EN 13201 average surface luminance: November 21, 4pm, to November 22, 8am.

Appendix 2

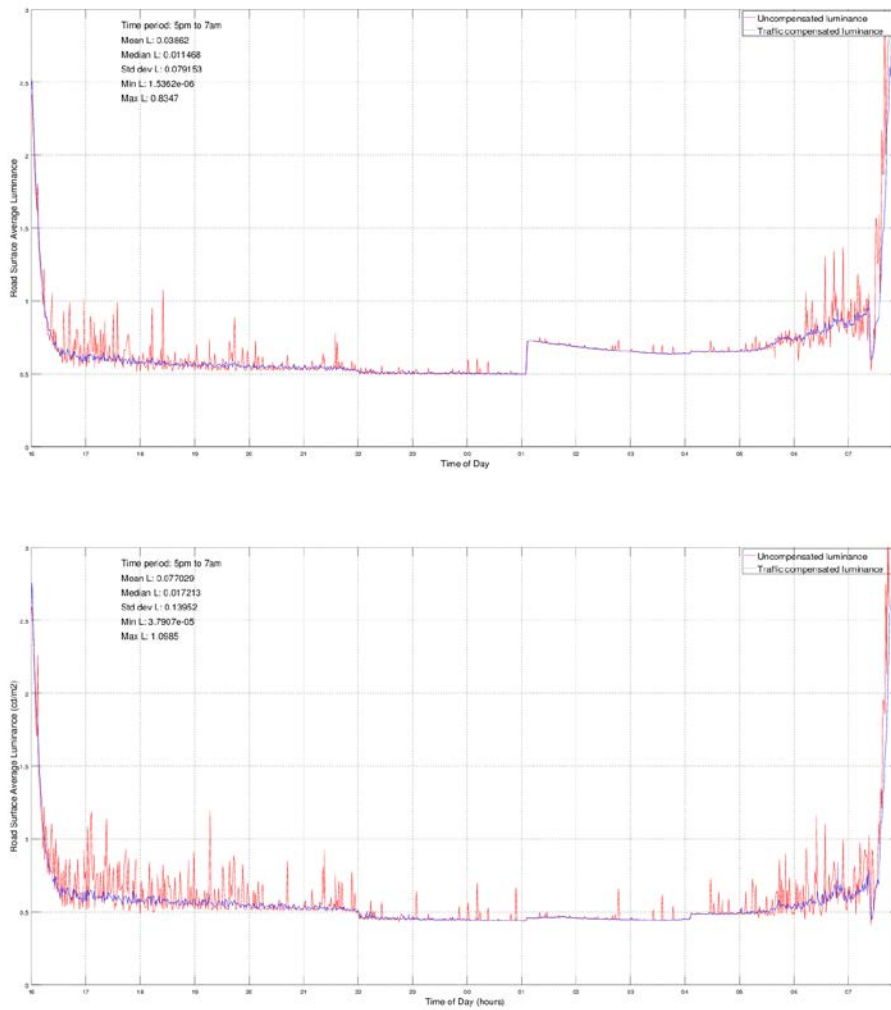


Figure A2- 21. EN 13201 average surface luminance: November 22, 4pm, to November 23, 8am.

Appendix 2

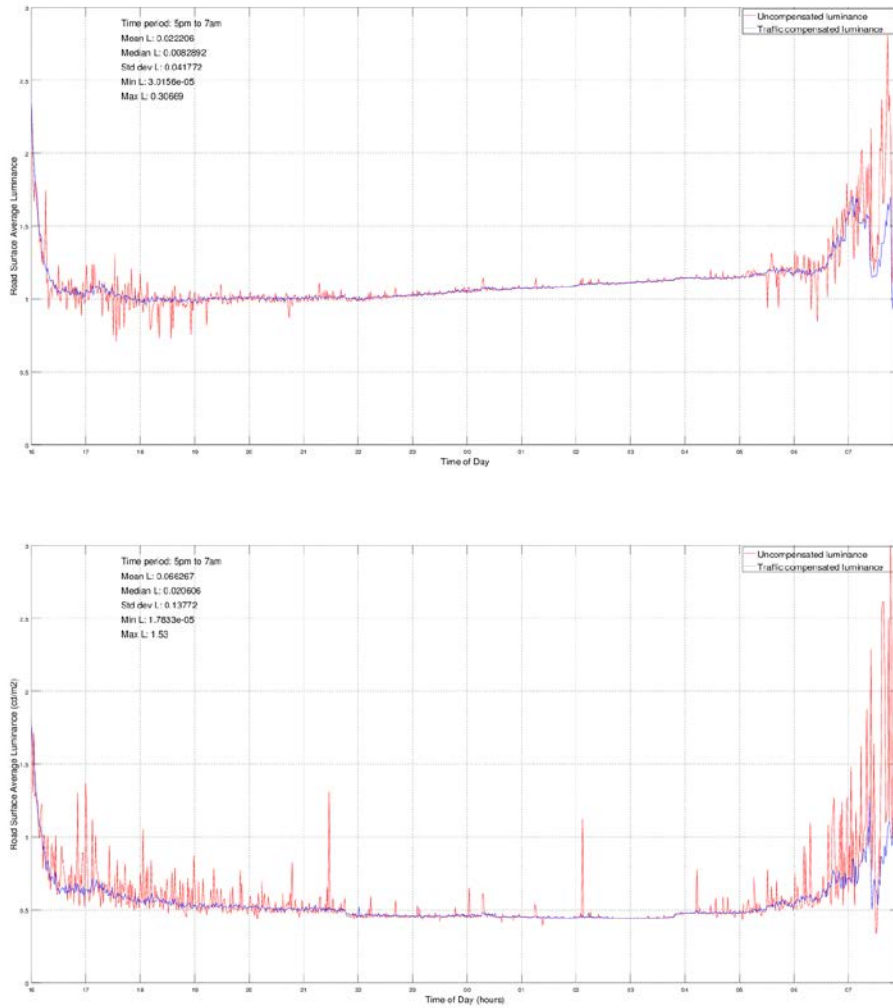


Figure A2- 22. EN 13201 average surface luminance: November 23, 4pm, to November 24, 8am.

Appendix 2

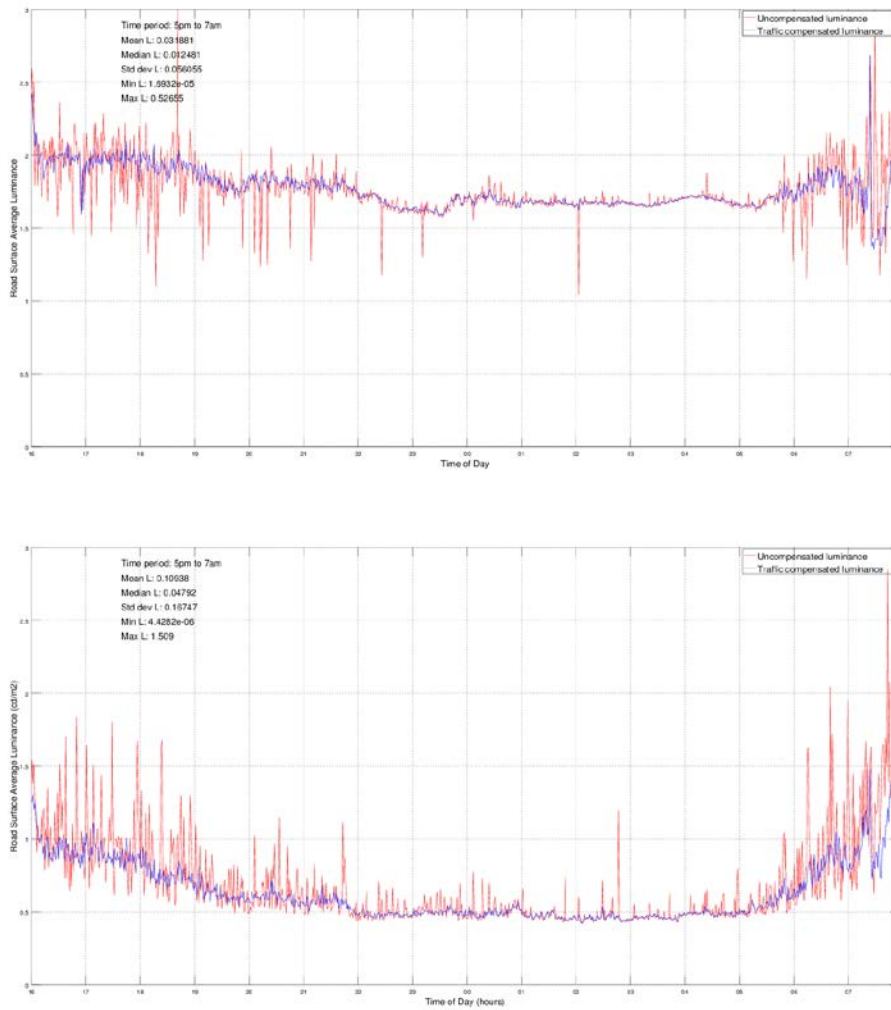


Figure A2- 23. EN 13201 average surface luminance: November 24, 4pm, to November 25, 8am.

Appendix 2

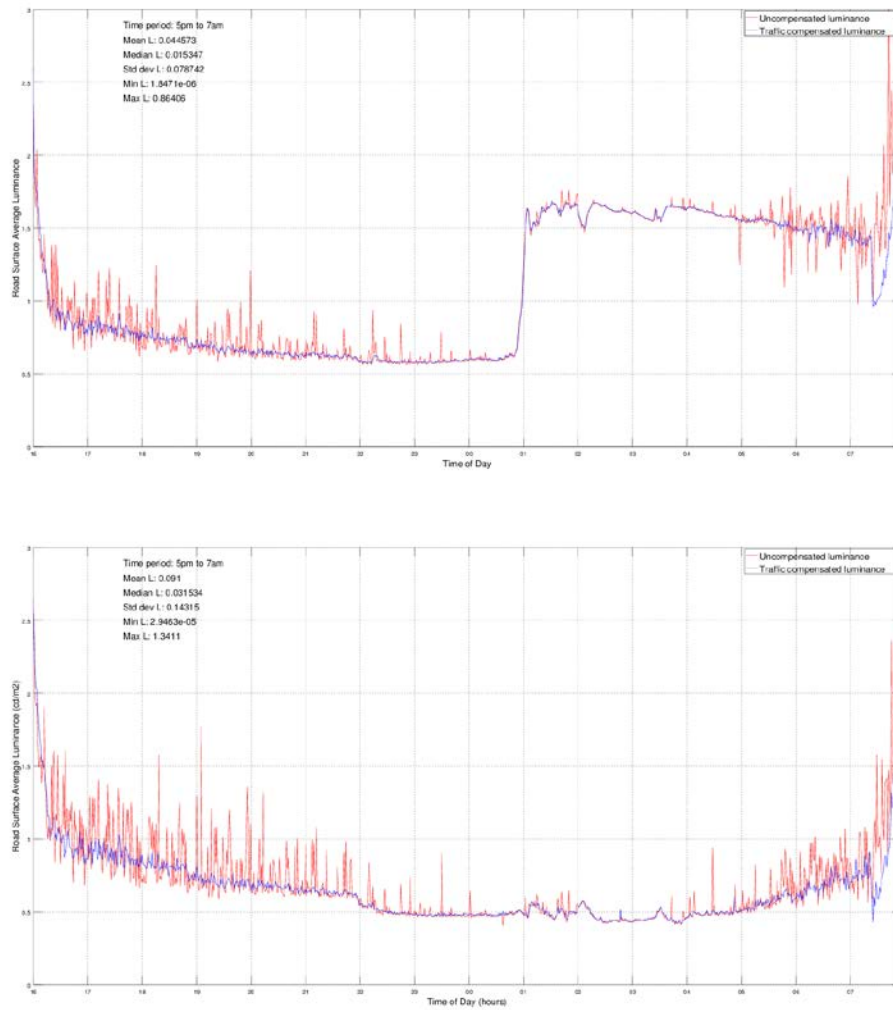


Figure A2- 24. EN 13201 average surface luminance: November 25, 4pm, to November 26, 8am.

Appendix 2

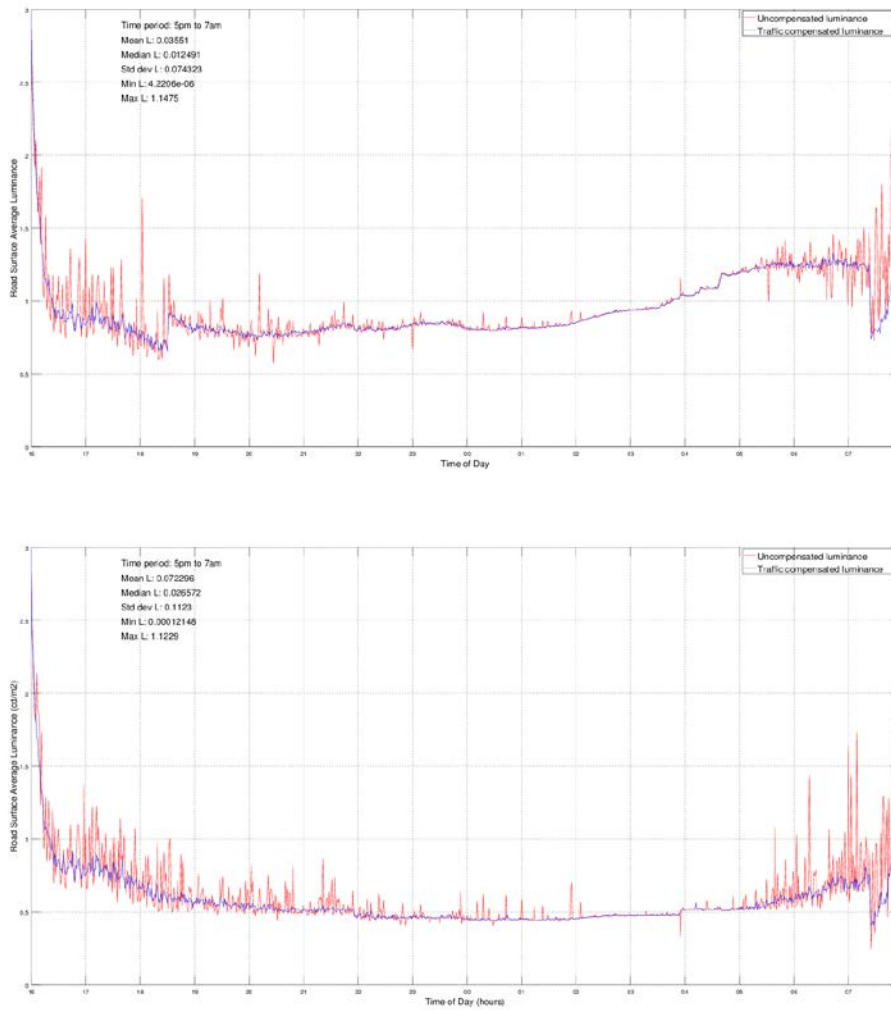


Figure A2- 25. EN 13201 average surface luminance: November 26, 4pm, to November 27, 8am.

Appendix 2

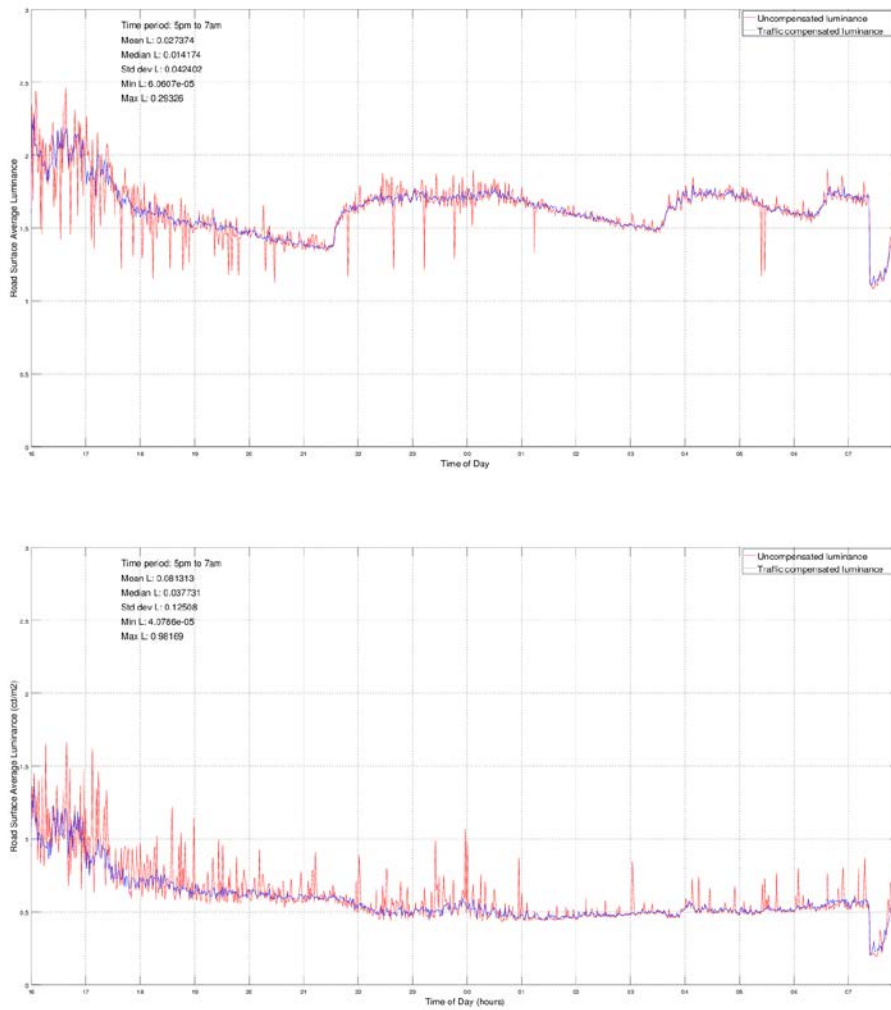


Figure A2- 26. EN 13201 average surface luminance: November 27, 4pm, to November 28, 8am.

Appendix 2

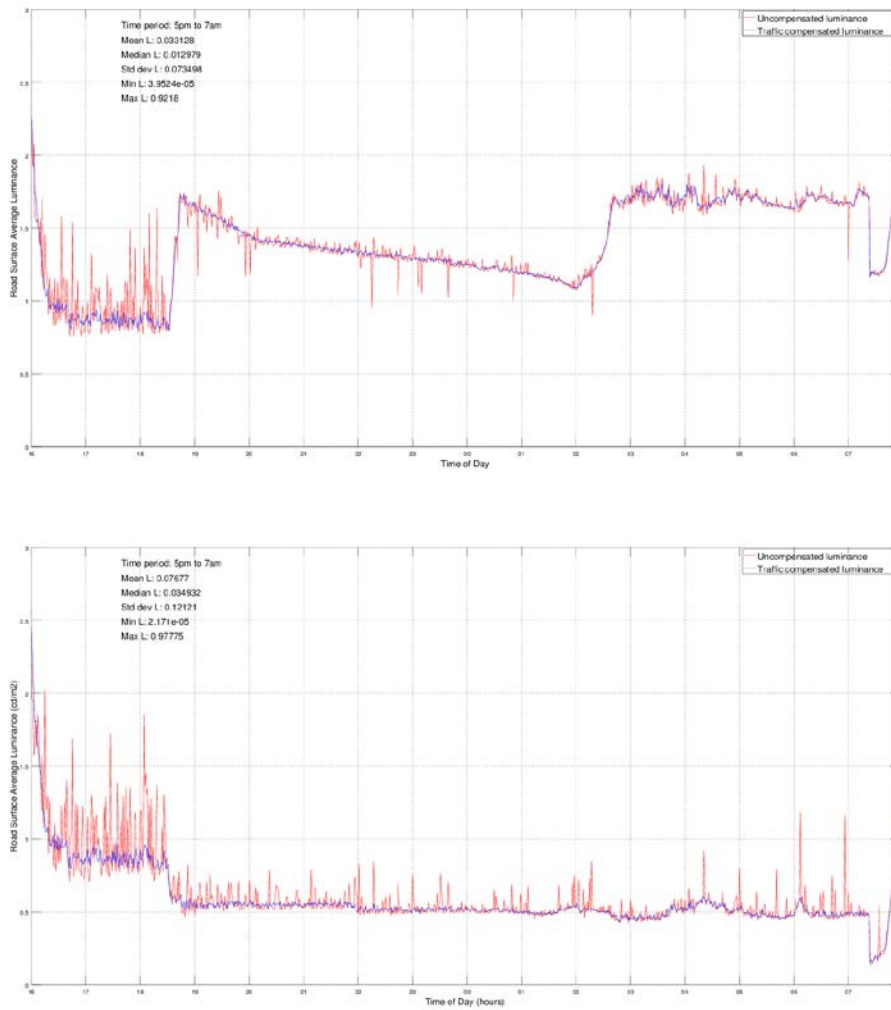


Figure A2- 27. EN 13201 average surface luminance: November 28, 4pm, to November 29, 8am.

Appendix 2

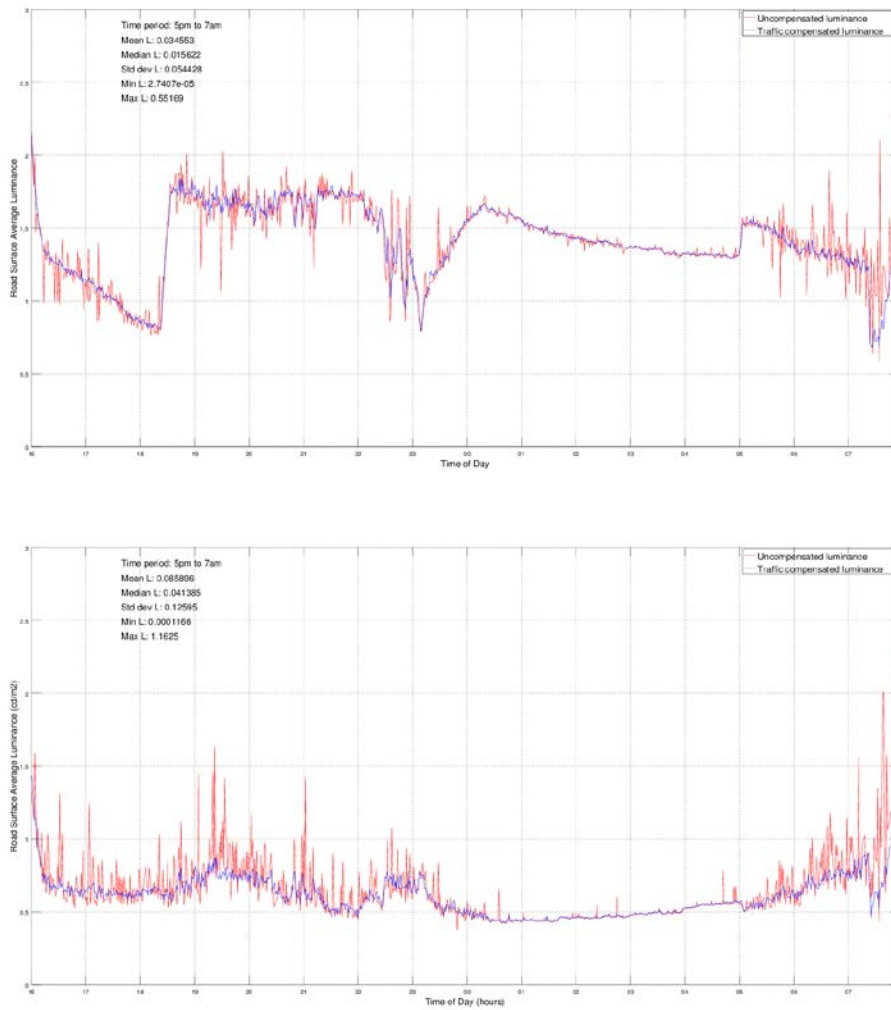


Figure A2- 28. EN 13201 average surface luminance: November 29, 4pm, to November 30, 8am.