Variable Lighting Levels for Highways - A Different Approach

Sofia Tolia[1], AECOM

[1]Lighting Engineer, MSc, MEng
tolia.a.sofia@gmail.com

Abstract:
The purpose of this paper is to examine the accuracy of the calculation method for the variable lighting classes that is briefly described in BS5489-1:2013 Code of Practice for the design of Road and further analysed in TR27 Code of practice for Variable Lighting Levels for highways. Furthermore, it proposes a new calculation procedure for the accurate diming profile during night time that is depending on each road's traffic flow and provides more safety to the road users. Finally, it introduces a method to calculate the exact dimming regimes in two different control strategies, a time-scheduled control strategy and a real-time data control strategy.

Keywords: Variable lighting levels, dimming, road safety.

Paper Length: 3172 words

1. Introduction

Nowadays we expect from outdoor lighting much more than the possibility to see at night. Road lighting has become a necessary tool for reducing the number of night-time road traffic accidents, improving the visual comfort of drivers, the potential to increase the night-time traffic capacity of a given road and the reduction of the criminality [1]. However, the lighting schemes that were applied until recently wouldn't provide those benefits to the users, either because of the lack of a proper lighting design or because of the selection of the wrong luminaires.

At the same time, the global climate shift, the rising energy costs and the reduction of CO2 emissions policy are major issues that the world faces today. Lighting accounts for 19% of the global electricity consumption and 14% in the European Union (EU). Outdoor lighting uses around 8% of the total electricity consumption globally [2]. According to Paul Waide, a senior policy analyst of the International Energy Agency (IEA)

> *"Lighting is a major source of electricity consumption. Nineteen percent of global electricity generation is taken for lighting - that's more than is produced by hydro or nuclear stations and about the same that's produced from natural gas."*[3]

Therefore, it is obvious that there are two major issues that the lighting designer faces regarding the design of the road lighting. Firstly, the proposed lighting scheme should be so developed in order to satisfy the user's needs and secondly, it should be energy efficient. The current principles of road lighting design, measurements, and calculations are based to a great extent on knowledge, research, experience, and consensus among experts in international lighting communities. These principles are well established and have been adopted in a number of lighting design standards, reports, and recommendations. However, there are new trends and directions in road lighting research and practice, which offer new opportunities to develop and optimise road lighting principles. Recent developments of light sources,

new equipment for road lighting measurements and road lighting control systems are affecting the further development of road lighting [4].
The lighting design standards that are being applied nowadays for the design of road lighting along Europe are EN 13201:2004 1-4 and EN 5489-1:2013. All of them provide guidelines that are essential for the development of an appropriate road lighting scheme. Specifically, in the United Kingdom there are further Technical Reports that support the abovementioned design standards and provide detailed guidelines to the lighting designers.
In this work the use of the abovementioned lighting standards are examined, when these are being applied during night time, when the traffic flow of the vehicles and the pedestrians is significantly reduced. In order to maintain safety for the road users and energy savings at the same time, a new, more detailed calculation method is proposed. The accuracy of the proposed method is applied in a case study of roads of Greece, where the UK and European standards and technical reports are used for lighting designs. Finally, a model created in Visual Basic is proposed in order to calculate the dimming regimes in two different lighting control strategies.

2. Theoretical Background

Designing the lighting scheme of a road in accordance to the European Standard can lead to some energy savings because in many cases the existing luminaires provide excessive lighting levels. However, the use of different control strategies could ensure further energy savings.
Traditionally, in road lighting the luminaires are switched on/off manually or automatically by photocells and/or timers which are programmed according to the sunset and sunrise hours. Therefore, lamps are burning at full power during the whole night and lighting intensity is often excessive when traffic flow is low or under extreme weather conditions (e.g. snow) [7].
In some cases, in order to consume less energy, every second luminaire is switched off after a specific time during night. However, this results into poor luminance uniformity and therefore poor driving conditions [8]. These disadvantages can be avoided with the appropriate use of the dimming technology.

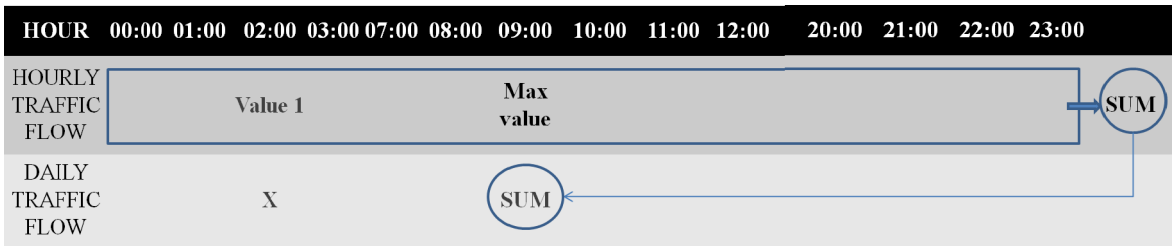
2.1 Current state-of-the-art

The initial motivation to develop road lighting control systems is to decrease the light level when traffic flow is low so that energy saving is achieved. Dimming technologies range from rather simple control systems to very complex ones, and the choice depends on the circumstances of the road and mainly on the budget.
A time-schedule-based step dimming is a commonly used control strategy. When the pattern of variation in traffic volumes is well known or can be reasonably assumed, a simple time-schedule-based control system may be appropriate. This control system is based on the experiences and analysis of previous traffic flows. The lamp light output is controlled centrally and can be adjusted to different dimming levels according to a pre-set time schedule. This solution is feasible and inexpensive and can provide significant energy savings. The only drawback is that the system does not adapt to the real-time needs of the light levels [7].
In order to withdraw this drawback, the use of another, more complicated control system is proposed which utilises traffic cameras to get real-time information about traffic flow in the roads and therefore the dimming levels are adjusted to the traffic flow that is measured.

The calculation of the dimming profile in both control strategies can currently be achieved by applying a variable lighting level approach in the road classification. According to the BS5489-1:2013 Code of Practice for the design of Road, the significant reductions of the traffic flow during night time could result in the reduction of the applied lighting levels, given that all the other parameters that define the road classification remain the same (i.e. type of road, crime risk, weather conditions, present of conflict areas, parked vehicles, etc.). However, the lighting classification for the traffic routes is based on average daily traffic flow (ADT) with the transition values between the lighting classes being 7000, 15000 and 40000 vehicles. In order to examine the application of the variable road classification, the actual hourly traffic flow should be examined [5]. As further detailed in TR27 Code of practice for Variable Lighting Levels for highways, the ADT transition levels should be scaled down to hourly transition levels and therefore the maximum hourly value (peak) is related to the daily sum.
The rationale behind this decision is that using the maximum values for the derivation of the scheme would serve even the most traffic-demanding days and therefore would take into consideration any possible variation in the traffic flow. At this stage of the calculation procedure, TR27 and BS5489-1:2013 recommends that the peak traffic flow is typically 10% of ADT for rural areas and 12% of ADT for urban areas [6].

2.2 A novel calculation approach

In this study instead of considering a fixed percentage of the ADT being the hourly peak traffic flow, a further data analysis is recommended. Given the hourly traffic data for each month, the whole range of the maximum traffic flow within the month can be obtained by applying simple statistical methods. The first step is to analyse the daily traffic flow, by calculating the average value and the standard deviation using data from all the months. Following this calculation, the range of the traffic flow within these months can be obtained and at this stage, the accurate maximum hourly value (peak) can be related to the daily sum and not the percentage recommended by TR27. The recommended calculation procedure and the formulas used are illustrated in figure 1 below.



$$MAX\ value = SUM$$

$$X = \frac{Value\ 1 \times SUM}{MAX\ value}$$

IN DAILY BASIS	1st Threshold	Value 2
	2nd Threshold	Value 3
IN HOURLY BASIS	1st Threshold	Y
	2nd Threshold	Z

Figure 1: Recommended calculation procedure for the two thresholds and formulas.

2.3 Case Study

This calculation method was examined in a case study on several roads around the Port of Piraeus in Greece. For more accurate results, the traffic flow data shall be analysed throughout 3 representative months of the year, which are March or September being closer to the equinox, December which is close to the winter solstice and July for the summer solstice.

However, to account for the high cost of these data (approx. 200euros for one-month data to be paid to the ministry of transportation of Greece), a single month needed to be chosen. This posed an additional challenge, as the choice of the month had to be taken after thorough consideration to avoid the generation of biased results. Therefore, March was considered to be the most representative month of the year. Firstly, it doesn't belong to the summer months (June-August), when the traffic is increased due to summer holidays. Moreover, it contains a balanced number of national holidays that could result into increased traffic levels. Last but not least, the fact that this month is close to the summer equinox indicates that the daylight availability abstains equal distance from the summer and the winter.

It should be noted that the difference of the data between weekdays and weekends is remarkable. Therefore, all the calculations were performed separately for the weekdays and the weekends.

Figure 2 illustrates a representative example of this difference, showing the actual traffic flow values of each day for one week within 24 hours.

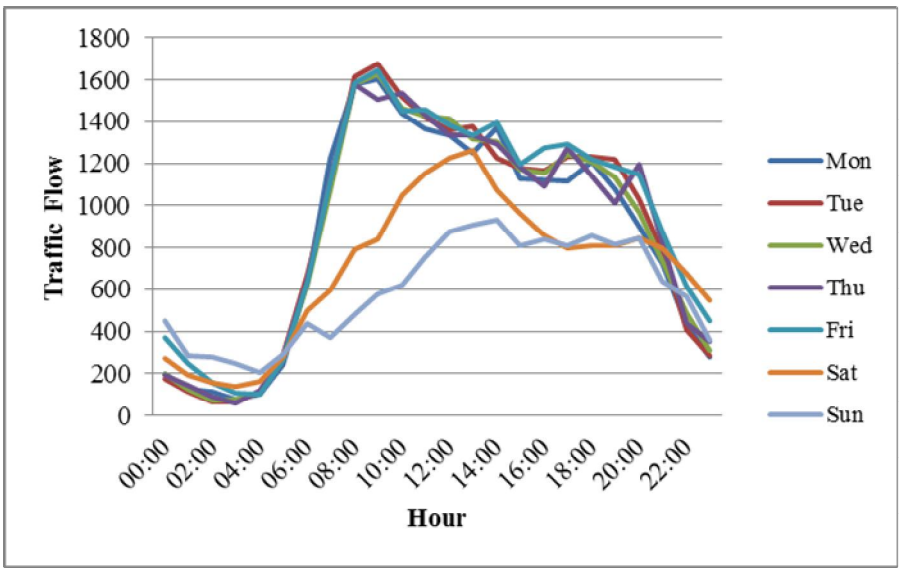


Figure 0: Graphical representation of the traffic flow during the week 4-10 March for road 699

Moreover, one of the weekdays (18/03) of March was a bank holiday. As shown in Figure 3, the traffic flow during this day was noticeably lower from the other weekdays; hence it was considered a statistical error and was excluded from the calculations.

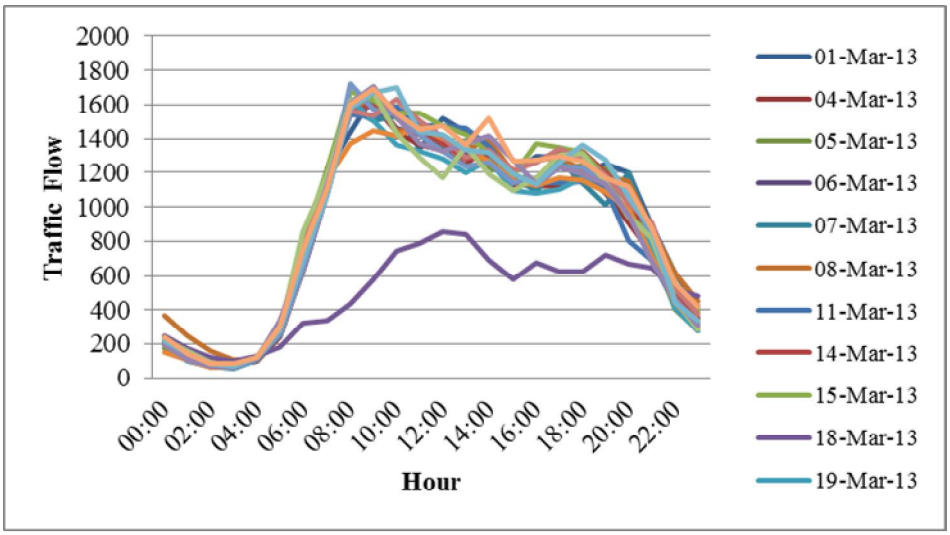


Figure 3: Traffic flow during all the weekdays of March for road 699

The traffic flow and the speed were monitored in 12 different positions along the port of Piraeus as illustrated in figure 4 below.

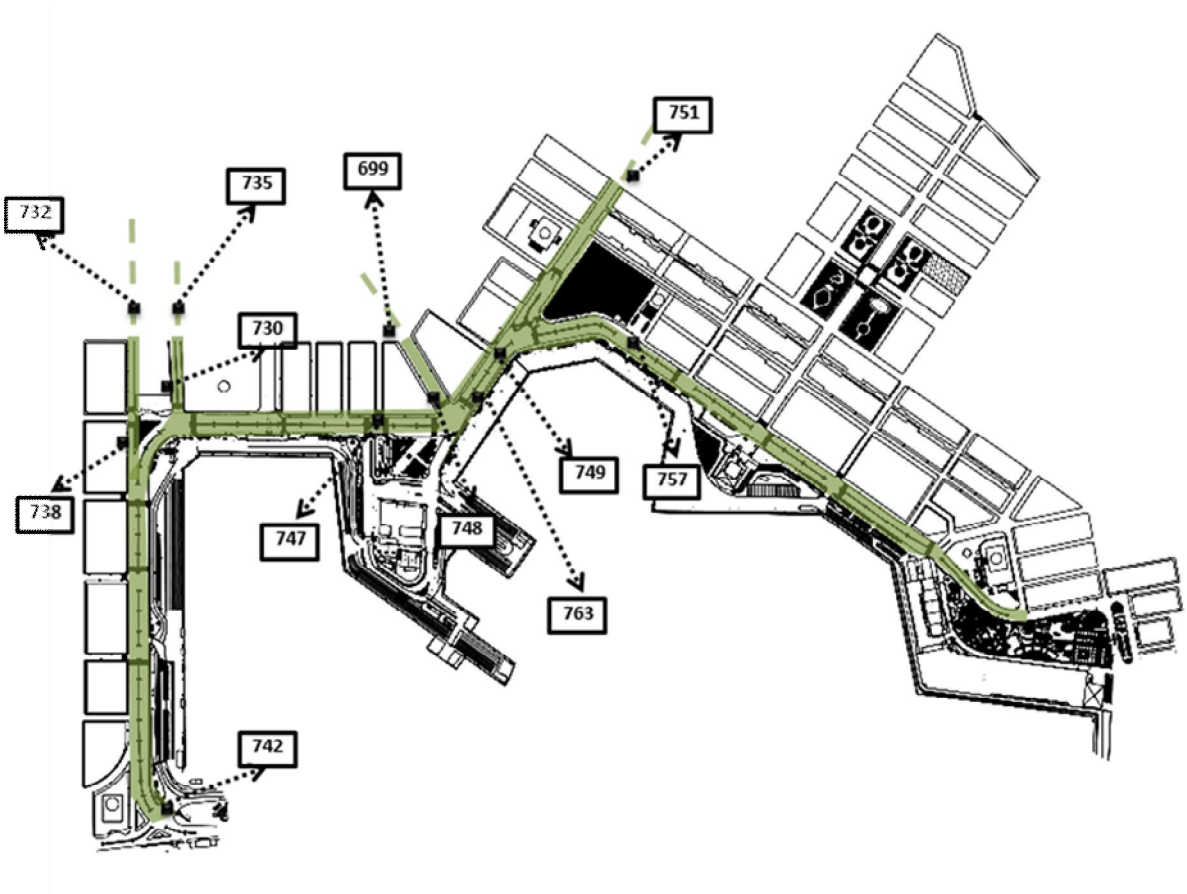


Figure 4: Measuring positions of the roads around the port of Piraeus.

The lighting classification as it derived by analysing all the relevant parameters (i.e. Speed, Users of the road, Geometrical characteristics , Traffic flow of vehicles, cyclists and pedestrians, Difficulty of navigation task, Parked vehicles, Facial recognition, Crime risk, Environmental and external conditions) is shown in table 1

and figure 5 below. It is noted that during the transaction from one road to another through the intersections, the lighting class alters only one level. Therefore, the increase and/or reduction of the luminance is not noticeable by the drivers and does not cause any inconvenience and/or distraction during driving.

Table 1: Lighting Classification of the roads around the port of Piraeus

Measuring position	Lighting Class
699	ME4a
730	ME4a
732	ME3b
735	ME4a
738	ME4b
742	ME4a
747	ME4a
748	ME4a
749	ME3b
751	ME4b
757	ME3b
763	ME3b

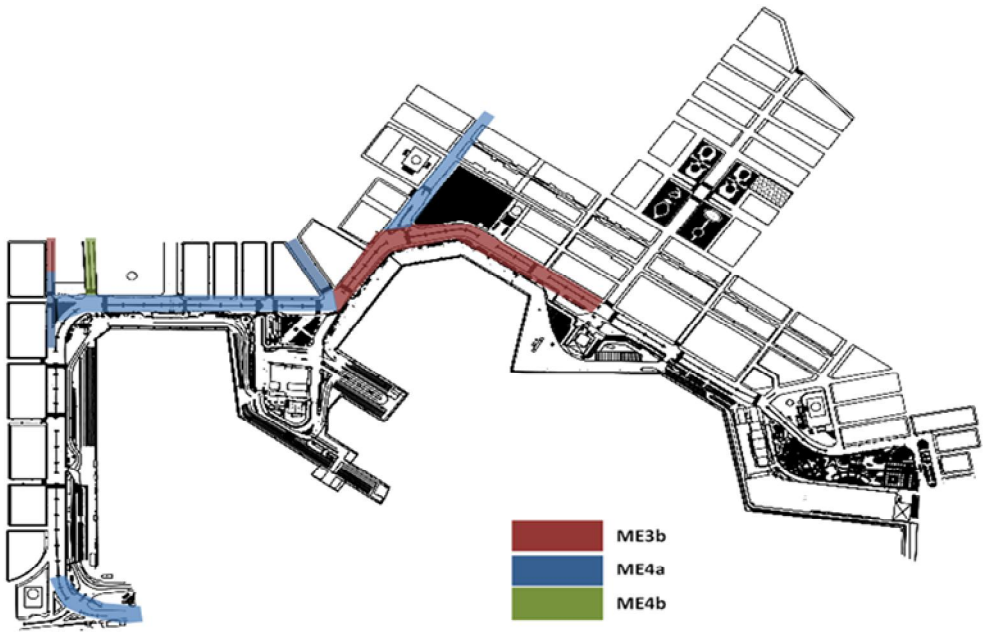


Figure 5: Lighting Classification of the roads around the port of Piraeus

The abovementioned calculation procedure can now be applied on all these roads in order to determine the variable lighting classes during the times of low traffic flow.

2.3 Further Analysis and Calculations

Following the lighting classification of all the roads and the determination of the new variable lighting classes, the next step is to calculate the possible dimming levels for every hour of the day. For that calculation a module in Visual Basic was created, which can be found in Appendix A. Subsequently, the hours for each level of dimming were counted both for the time-schedule-based dimming and for the real-time/dynamic dimming. It should be noted that the ministry provided data for 18 days of March and one of them was a Bank holiday (18 March) that was not considered in the calculations; therefore the hours that were counted refer to 17 days. In the first case, the data used to determine the dimming levels were the maximum traffic flow values for which the calculation was described above. In the second case, the dimming levels were calculated separately for each day of the month. In both cases, for more accurate results, it was taken into consideration that the fittings are turned on half an hour after the sunset and off half an hour before the sunrise. This consideration resulted in the calculation of the exact hours of dimming and not in an inaccurate estimation. The hours of sunrise and sunset during March that were taken into consideration in the calculations are listed in Appendix B

The final stage is to identify the luminance levels for each lighting class as per EN BS 13201/2004:2. This identification resulted in the calculation of the exact dimming percentages. It was estimated that the reduction percentage of the Watts consumed is approximately equal to the reduction percentage of the luminance because the installed luminaires in these roads are using LED technology.

3. Results and Discussion

The procedure described above was applied in all the 12 measuring positions of the roads along the port of Piraeus. After detailed analysis of all the data of the traffic flow it was identified that the calculation procedure proposed in TR27 does not provide accurate lighting classification at times with reduced traffic flow. A representative example is the road with the measuring position 735. According to TR27 and considering that this is a rural area, the thresholds where the lighting class should change are 1500 vehicles and 700 vehicles. With the proposed calculated method the thresholds are 1000.3 and 472 vehicles accordingly (table 2).

Table 2: Calculated thresholds of road lighting in daily and hourly basis for road 735

IN DAILY BASIS	1ST THRESHOLD	15000
	2ND THRESHOLD	7000
IN HOURLY BASIS (TR 27)	1ST THRESHOLD	1500
	2ND THRESHOLD	700
IN HOURLY BASIS (PROPOSED METHOD)	1ST THRESHOLD	1000.3
	2ND THRESHOLD	472

As illustrated in figure 6 below, with the TR27 method the first dimming value should be applied to the luminaires 4 hours earlier compared to the proposed method. This would result in roads being underlit for a significant amount of hours in relation to the hourly traffic flow proposed method.

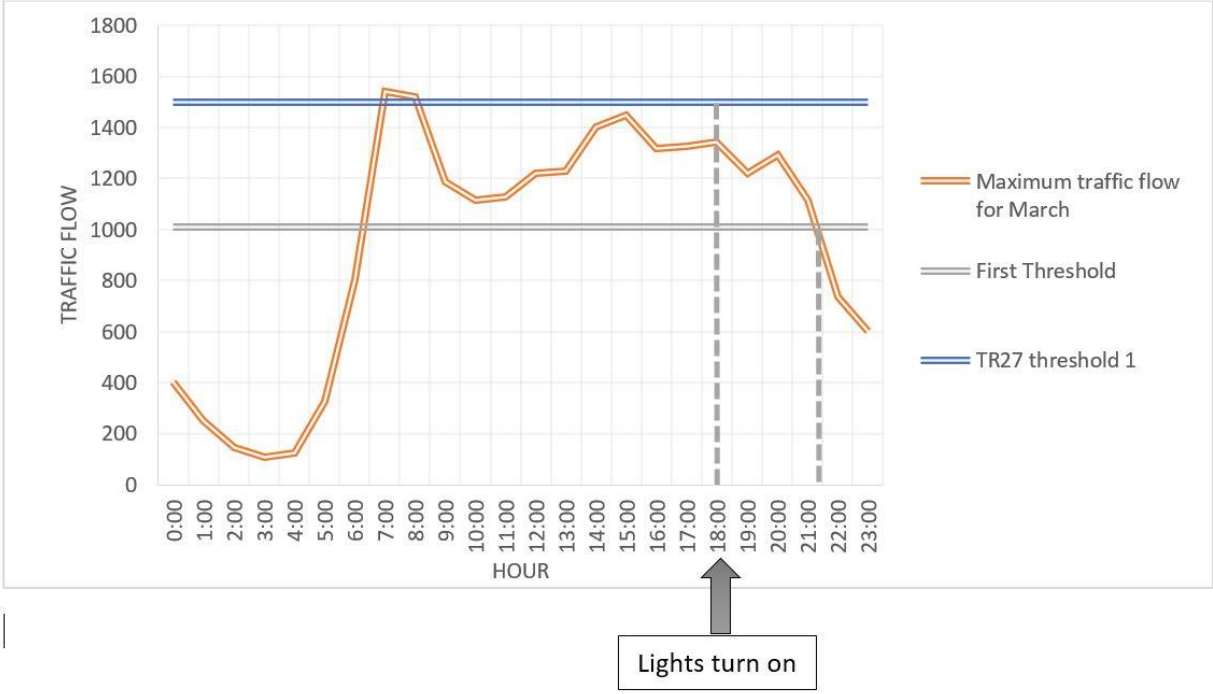


Figure 6: Comparison between the proposed calculation method and the TR27 calculation method

Moving forward with the traffic flow analysis on all the measuring positions, table 3 below summarises the calculated variable lighting classes on all the roads around the port of Piraeus based on the actual value of the traffic flow. It is remarkable that in several occasion the lighting class throughout the times with reduced traffic flow drops two levels.

Table 3: Variable lighting classes for the roads around the port of Piraeus

Measuring position	Lighting Class	Variable lighting classes	
699	ME4a	ME5	
730	ME4a	ME5	
732	ME3b	ME4a	ME5
735	ME4a	ME5	
738	ME4b	ME5	
742	ME4a	ME5	
747	ME4a	ME5	
748	ME4a	ME5	
749	ME3b	ME4a	ME5
751	ME4b	ME5	
757	ME3b	ME4a	ME5
763	ME3b	ME4a	ME5

Based on these lighting classes and the luminance levels that are applied to each of them according to EN BS 13201/2004:2, the exact dimming regimes for each road were calculated (table 4).

Table 4: Dimming Regime for all the roads around the port of Piraeus

Measuring position	First Dim	Second Dim
699	33.33%	-
730	33.33%	-
732	25.00%	50.00%
735	33.33%	-
738	33.33%	-
742	33.33%	-
747	33.33%	-
748	33.33%	-
749	25.00%	50.00%
751	33.33%	-
757	25.00%	50.00%
763	25.00%	50.00%

With the figures of table 4, a time-scheduled control strategy can be applied with a pre-set dimming profile for all these roads which has been calculated based on accurate data of the month.
A representative example (measuring point 763) of such a dimming profile in shown in figure 7 below

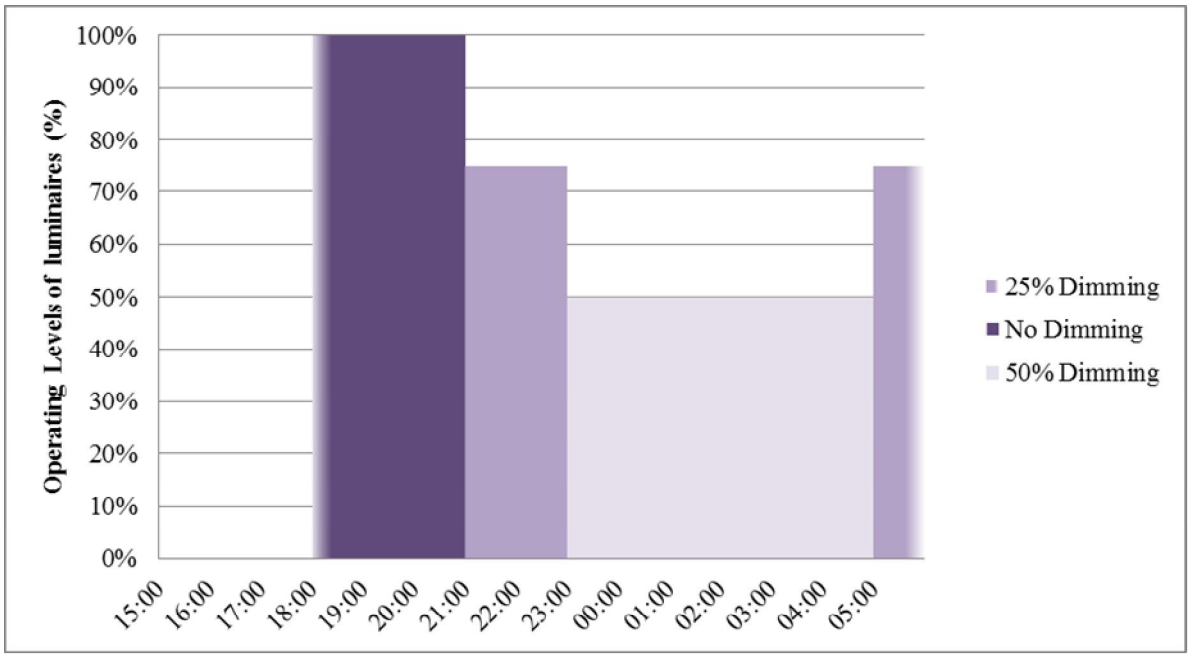


Figure 7: Dimming profile for the luminaires of road 763 during the weekdays with the time-scheduled control strategy

It is remarkable that the hours that the luminaires can operate in a dimmed level are more than the hours that they operate in 100% of their performance. Through the analysis of these roads, based on the time-scheduled control strategy, it is estimated that on average the luminaires could be operating in a dimmed level for 70% of the total operating hours.

Moving forward, the installation of some additional equipment that could connect the control system with the real-time counts of the traffic flow of each road, can offer an even more accurate dimming profile that reflects the exact traffic flow at all times. Figure 8 below illustrates such a dimming profile for the same road.

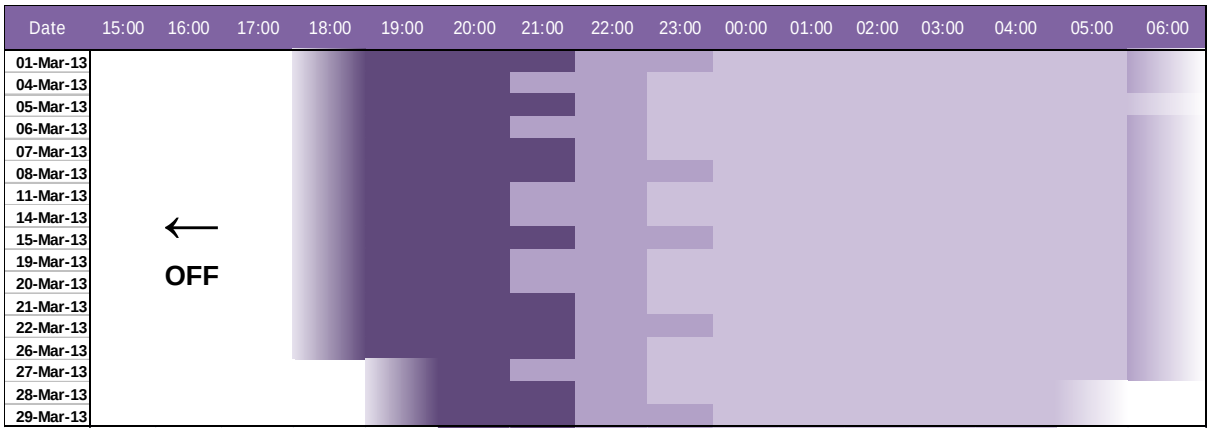


Figure 8: Dimming profile for the luminaires of road 763 during the weekdays with the real-time-data control strategy.

The hours of operation in each dimming level for both lighting control strategies can now be counted and they are summarised in table 5 below.

Table 5: Hours of operation in each dimming level for both lighting control strategies.

LEVELS OF DIMMING	HOURS	
	Time-scheduled	Real-time
No Dimming	69h 16min	57h 16min
25% of Dimming	38h 26min	37h 26min
50% of Dimming	84h 46min	97h 46min

Comparing the two strategies, the additional energy savings when applying the second strategy amount to 3%.

4. Conclusion

The preceded results and analysis provide a clear understanding of the benefits of the application of a dimming strategy on the lighting scheme of a road. As expected, the outcome of the study in relation to the switching transition levels for the variable classification was that the calculated percentage of the ADT for the maximum hourly value (peak) is significantly lower compared to the 10% or 12% recommended by TR27.

Even though this reduction in the switching transition levels would result in less energy savings, it provides greater accuracy in the calculation of the dimming values and therefore more safety for the road users, as the road classification is in absolute accordance with the lighting classes of the British and the European Standards.

On the roads along the port of Piraeus, it is observed that the levels of the traffic flow are reduced significantly and the application of a lighting control strategy could save significant amount of energy. A time-scheduled dimming strategy based on the real traffic flow data throughout the year could provide 29% overall energy savings.

Moreover, the application of a control strategy that could make use of the real-time information of the traffic flow at all times can offer 32% overall energy savings

However, prior to considering the application of the second diming strategy, an extensive study of the cost of installation of the required equipment should be conducted, in order to find out the payback period in comparison to the further energy savings that have been calculated within the framework of this paper.

References

[1] Peter Raynham, An examination of the fundamentals of road lighting for pedestrians and drivers. London: Lighting Research and Technology, 2004, Vol. 36, pp. 307-316.
[2] International Energy Agency, Light's labours lost - Policies for Energy efficient lighting, Paris: IEA Publications, 2006.
[3] Richard Black, Lighting the key to energy saving. BBC News. [Online] [Cited: 16 August 2013] http://news.bbc.co.uk/1/hi/sci/tech/5128478.stm
[4] Aleksanteri Ekrias, Development and enhancement of road lighting principles, Aalto University of science and technology, 2010
[5] BS5489-1:2013, European Standard. Code of Practice for the design of Road
[6] TR27, Technical Report, Code of practice for variable lighting levels for highways, Institution of Lighting Professionals
[7] LIping Guo, Intelligent road lighting control systems- Experiences, measurements and lighting control strategies. Espoo, Finland: Helsinki University of Technology, Department of electronics, Lighting unit, 2008.
[8] N. v. Tien, Y. Unhavaithaya, N. n. Dinh. Lighting control in street lighting- an overview of the state of art in technology and application.s.l. 6th Right Light International conference on energy-efficient lighting, 2005.

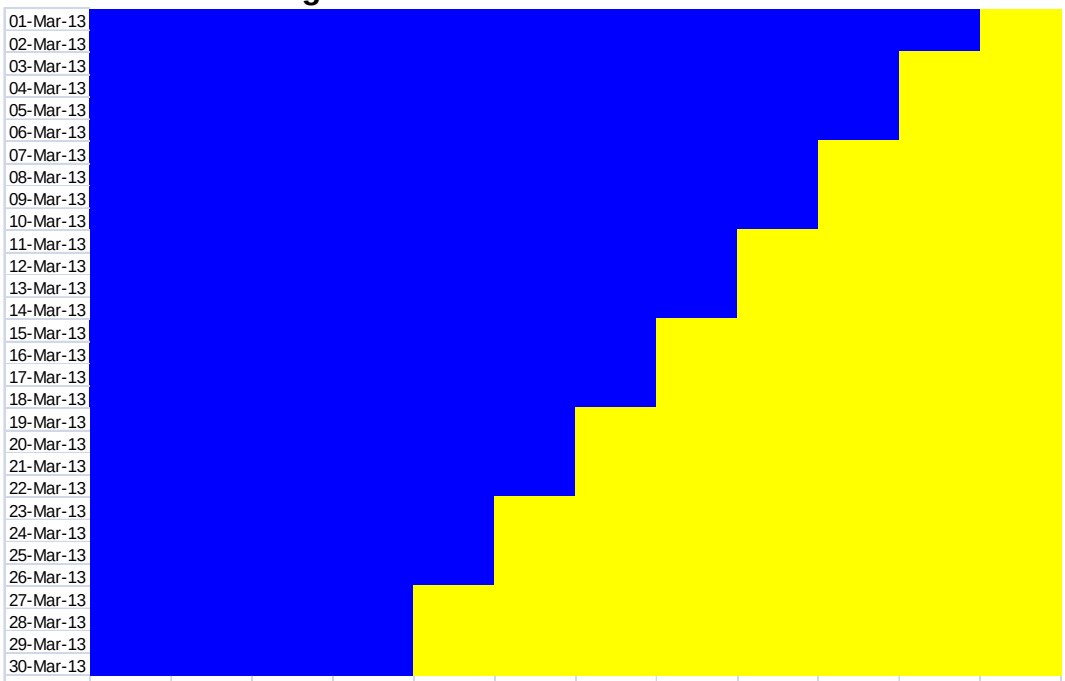
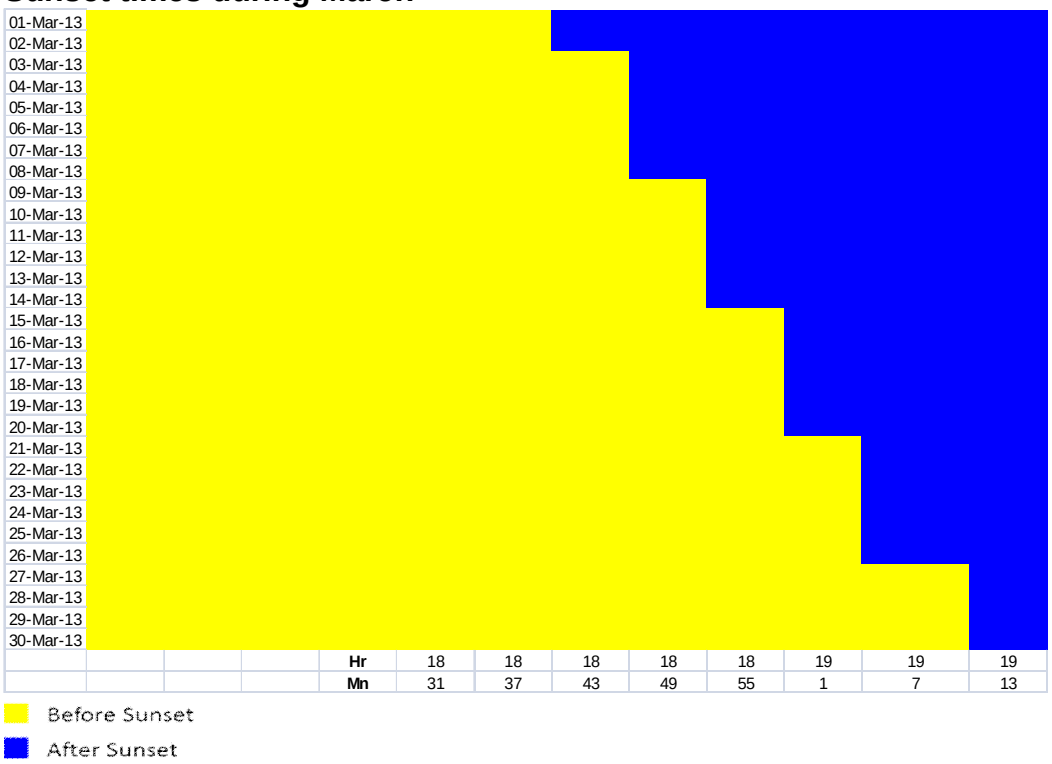
APPENDIX A

Module used in Visual Basic for the calculation of the dimming levels for all the roads.

```
Function Dim_Level(TCount, Thresh1, Threh2) As Double

    Dim result As Double

    Select Case TCount
        Case Is > Thresh1
          result = 0
        Case Threh2 To Thresh1
         result = -1
         Case Is < Threh2
          result = -2
    End Select

     Dim_Level = result

End Function
```

APPENDIX B

Sunrise times during March



Sunset times during March