
HELPING TO EXPLAIN LIGHTING QUALITY & ENERGY EFFICIENCY TO NON-EXPERTS

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Abstract: It is easy to understand why customers and end users often are disappointed when they do not see the well-publicised advances in the performance of light sources reflected in the energy efficiency of lighting installations. The authors have therefore undertaken a review of numerous measures of efficiency including: light source efficacy; gear efficiency; lamp lumen maintenance factor; luminaire light output ratio; luminaire maintenance factor, to establish a series of examples that may be used to illustrate how the output from a light source can be converted into the predicted illuminance in an installation, i.e. from lumens generated to lux delivered. The principles are illustrated by reference to T5 fluorescent lamps showing the influence of gear, luminaire and maintenance factors on the cost of generating lighting in an installation. Case studies show the importance of close cooperation and information exchange between the end user and the lighting designer.

Keywords: Energy efficiency; Lighting design; Lighting quality

1. Introduction

Although lighting professionals are familiar with all of the terms used to describe both lighting quality and energy efficiency there are still plenty of opportunities for confusion. The customers and end users are often in an even more disadvantageous position as they are frequently not familiar with all of the rather esoteric parameters and units. Thus, it is easy to understand why customers are disappointed when they do not see the well publicised advances in the performance of light sources reflected in the energy efficiency of lighting installations. Conveying quantitative measures of lighting quality to end users is even more difficult.

The authors have therefore undertaken a review of numerous measures of efficiency including: light source efficacy; gear efficiency; lamp lumen maintenance factor (LLMF); luminaire maintenance factor (LMF); light output ratio (LOR); room surface maintenance factor (RSMF), to establish a series of examples that may be used to illustrate how the output from a light source can be converted into the predicted illuminance in an installation. As this study is primarily concerned with illustrating the energy balance for a lighting system, lamp survival factors (LSF) have been omitted from the calculations. Another approach is to regard this study as the progression from lumens generated to lux delivered. This review is intended to guide the non-expert through this process.

However, this is not the complete story as this approach has to be complemented by the appropriate measures of lighting quality to ensure the visual comfort of the end users.

2. The functional unit

In this work the authors follow the practice of life cycle assessment by using a functional unit as the basis for comparing the energy efficiency of lighting systems and sub-systems. By defining a functional unit, the energy used to provide the functional unit can be tracked at each stage of the calculation thus giving an overall energy balance for the lighting design.

The functional unit used here is one million lumen hours (1.0×10^6 lm.h) and the comparisons are made by considering the energy required to generate one functional unit. To illustrate this concept a 150 W metal halide lamp with an output of 10,000 lm (a typical value for such a lamp part-way through its rated life with initial output 14,000 lm and LLMF 0.72 at 4,000 h) would generate 1.0×10^6

lm.h in 100 h. With the exception of the first few hundred hours of operation, the properties of such a light source can be considered constant throughout this period.

A 35 W T5 fluorescent lamp (CCT 3,500 K; R_a 85) with an initial output of 3,650 lm (assuming ambient temperature of 35°C) would generate one functional unit in 274 h while an 80 W version (CCT 4,000 K; R_a 85) with an initial output of 7,000 lm would generate a functional unit in 143 h. In both cases, the characteristics of the light sources can be regarded as unchanged during these periods.

When considering the energy consumed in generating one functional unit, the first of many avenues for confusion becomes apparent. The value of 35 W in the above example is a nominal value, on a high frequency electronic ballast the T5 lamp is designed to operate at 34.7 W. At 35 W the energy consumption would be 9.589 kW.h but at 34.7 W the consumption is 9.507 kW.h. Although the difference is small in this example, it does highlight the need to convey details to the end user.

The 80 W T5 lamp described above operating at 80 W will consume 11.4 kW.h in generating one functional unit.

Considering the light source as a stand alone entity is useful only for illustrating parameters and quantities, the other factors governing energy efficiency must now be taken into account.

3. Light source efficacy

Light source efficacy is often viewed as the traditional way to compare efficiency and cost effectiveness of lighting but the conversion of light generated into illumination delivered to the working plane is the factor that determines the energy efficiency of a lighting installation. In recent years, customers and end users have become more interested in energy consumption, and hence operating costs, rather than the efficiency of individual components and sub-assemblies. The efficacies of the T5 lamps described above are 105.2 lm/W and 87.5 lm/W for the 35 W and 80 W versions respectively. The system efficacy, however, will be determined by the lamp efficacy in combination with several other factors.

4. Ballast efficiency

The efficiencies of ballasts, especially those for fluorescent lamps, are rarely reported in manufacturer's datasheets but reference is given to Energy Efficiency Index (EEI). Minimum requirements for ballast efficiency are defined for each class within the EEI [1], [2] but this makes the translation into everyday language rather difficult, especially for the non-expert. Interrogation of table 17 (Energy Efficiency Index requirements for non-dimmable ballasts for fluorescent lamps) of Commission Regulation 245/2009 of 18 March 2009 [1] shows that the minimum ballast efficiencies for EEI A2 BAT, A2 and A3 are 0.915, 0.890 and 0.826 respectively.

A value of 0.90 (EEI A2) is used here to illustrate the system efficacy and the energy consumption for the (light source + ballast) combination to generate one function unit. Thus, the energy required to generate one functional unit from the T5 35 W lamp in its initial state when operated on an A2 ballast is 10.563 kW.h, corresponding to a system efficacy of 94.7 lm/W.

The minimum efficiency for an EEI A2 ballast for an 80 W T5 lamp is 0.909. Thus, for the example above the energy required to generate one functional unit is 12.573 kW.h, corresponding to a system efficacy of 79.5 lm/W.

5. Light output ratio (LOR)

The light output ratio (LOR) of a luminaire is defined in the SLL code for lighting [3] as the ratio of the total flux leaving the luminaire under standard conditions compared with the total flux of lamps used in the luminaire operated under standard conditions. In this example LOR 0.85 is used which for the 35 W T5 example above results in 12.427 kW.h being needed to generate one functional unit, corresponding to 80.5 lm/W.

6. Lamp lumen maintenance factor (LLMF)

Allowance in a lighting design has to be made for the through life reduction in lamp output, if the product technical datasheet does not provide the design output for the light source a useful approximation is to take the LLMF at 40% of rated life. In this example LLMF 0.925 is used. For the

35 W T5 example this equates to 13.435 kW.h to generate one functional unit, corresponding to 74.4 lm/W.

7. Luminaire maintenance factor (LMF)

While several factors affecting lighting efficiency are beyond the control of the end user once the system has been selected and installed, the luminaire maintenance factor is under the control of the end user. The rate at which the LMF decays is a function of the luminaire design and its surrounding environment in an installation. Reference [4] lists typical LMFs for a range of luminaires in clean, normal and dirty environments under various cleaning intervals (0.5 to 3 years). A bare lamp batten type luminaire in a normal environment with cleaning interval of one year is assigned LMF 0.89. For the 35 W T5 example used here, a LMF of 0.89 equates to 15.095 kW.h to generate one functional unit, corresponding to 66.2 lm/W.

8. Room surface maintenance factor (RSMF)

As with luminaire maintenance factors, the room surface maintenance factors are under the control of the end user. RSMFs are a combination of the effect of dirt deposition on the walls, ceiling & floors, the luminaire design and the contribution of reflections to the illuminance produced. Thus, RSMFs are dependent on the environment, the room surface cleaning interval, the luminaire design and the room index. Reference [4] lists RSMFs for several luminaire types in clean, normal and dirty environments for room indices ranging from 0.7 to 5.0 under various cleaning intervals.

For the 35 W T5 example used here, a RSMF of 0.96 (based on room index 2.5, direct type luminaire, normal environment with a cleaning interval of one year) equates to 15.724 kW.h to generate one functional unit, corresponding to 63.6 lm/W.

Figure 1 shows the energy needed to generate one functional unit from a 35 W T5 lamp taking into account the lamp efficacy, ballast efficiency, LOR, LLMF, LMR and RSMF.

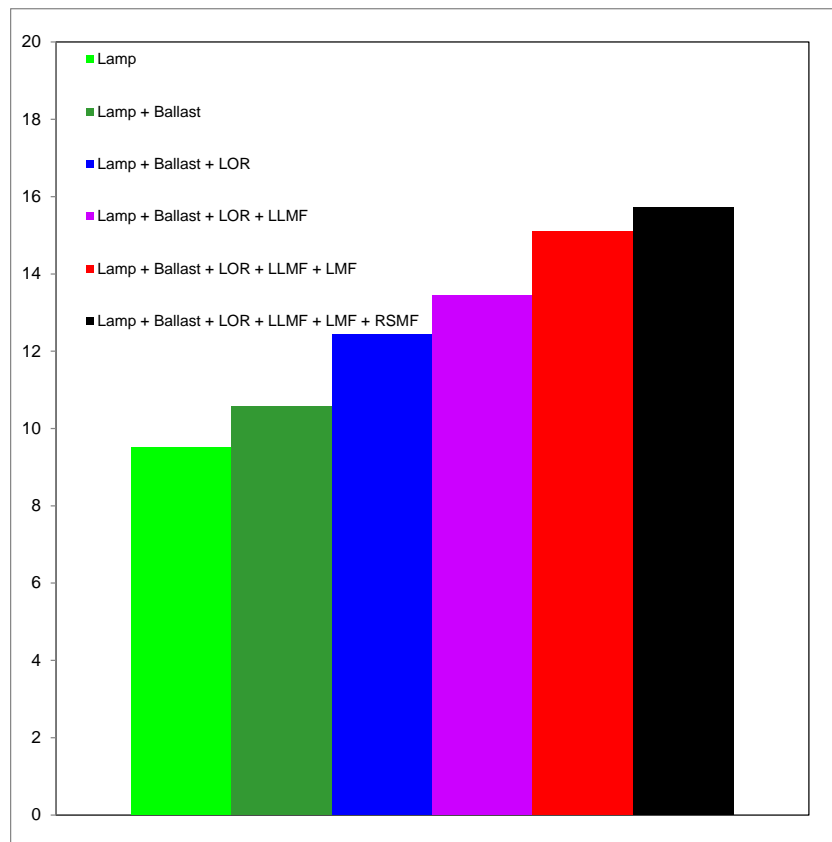


Figure 1: Energy required (kW.h) to generate 1.0×10^6 lm.h from a typical 35 W T5 fluorescent lamp

9. Cost-benefit analyses

It is important for end users to appreciate that to derive the full benefits from a lighting design not only must the cleaning cycles used for the design be adhered to but also that the correct information regarding, for example, the condition of existing room surfaces, likely changes to the reflectance of these surfaces and possible changes of use. As there are financial and environmental costs associated with maintaining cleaning cycles for the room surfaces and the luminaires, when provided with the relevant information end users are in a position to carry out cost-benefit analyses to determine the most appropriate maintenance regime. These points are further illustrated in the case studies discussed below. The impact of not adhering to cleaning intervals are particularly important where lighting systems are under constant illuminance control where deviation from the planned maintenance will result in additional running costs.

10. Case studies

The worked example shown is a warehouse which is used for dispatch, packing and handling goods. The building is 740 m² (38.5 m x 19.2 m) with a pitched roof (apex height 12 m, wall height 11 m) having no windows or skylights. The lighting scheme has been designed to meet 300 lux as per BS EN 12464-1:2011 with 0.6 uniformity (U_o) for the task area and 0.4 uniformity for the surrounding areas. Industry standard reflectances have been used for the building: 0.70 for the ceiling and roof structure; 0.50 for the grey breeze block walls and 0.20 for the unpolished concrete floor. All luminaires are mounted at 10 m (height measured from the bottom of the fitting) and are suspended from the roof structure. The working plane is calculated at floor level (0 m) to represent the type of activities taking place in the warehouse. The conditions inside the building are assumed to be a normal environment as described in reference [3]. A schematic image of the structure is shown in Figure 2. All lighting design and illuminance calculations were carried out using AGi32 [5].

The luminaires are fitted with 4 x 80 W T5 lamps, each lamp with output of 7,000 lm at 100 h. The power consumption for each luminaire is assumed to be 350 W which implies ballast efficiency 0.914 and corresponds to EEI A2. The luminaires are assumed to be B class, direct fittings (i.e. ULOR <10%) with LOR 0.89, a value typical for T5 high bay luminaires.

The overall maintenance factor is taken to be 0.70 which is a combination of LLMF (0.90), LMF based on a one year cleaning cycle (0.86) [3] and RSMF (0.91) also based on a one year cleaning cycle [3].



Figure 2: Exterior view of warehouse used in the case studies

The calculations and results are summarised in Table 1 with images of the illumination shown in Figures 3 to 8. With all four walls having reflectance 0.50, the target of 300 lux with 0.4 and 0.6

uniformity for the surrounding areas and task areas respectively is satisfied with 18 luminaires (6 x 3). If a maintenance factor of 0.60 is used instead of 0.70, the calculated illuminance in the surrounding areas drops below the target. To restore the illuminance of the surrounding areas to 300 lux, 21 luminaires (7 x 3) would be required with a corresponding increase in power loading from 8.52 W/m² to 9.94 W/m². However, the second configuration would mean that without constant illuminance control, the interior of the building would be over lit when the lighting is initially installed. These changes may also be represented by the increase from 2.66 to 3.11 W/m²/100 lx. The results from these calculations are shown in Figures 3, 4 & 5.

Figures 6, 7 and 8 show the effect of different wall colours or coverings. The north facing wall has been changed to represent a low reflective colour, for example blue breeze block, with 0.10 reflectance. Although the targets for illuminance (300 lux) and uniformity are still satisfied with 18 luminaires, Figure 6, the illuminance distribution is substantially different from that seen in Figure 3. Similar differences are apparent when comparing Figures 7 and 4 (both calculated with MF 0.60) when the illuminances fall below the 300 lux target. Employing 21 luminaires, Figure 8, again restores the illuminance to >300 lux but now the power demand has increased from 3.11 to 3.28 W/m²/100 lx compared to Figure 5.

The lower wall reflectance also serves to illustrate the impact of a build-up of dirt on a surface and hence the importance of having an effective cleaning program in maintaining the desired lighting levels.

11. Conclusions

The energy balance for a light source in an installation is shown by considering the energy required to generate one functional unit (1.0 x 10⁶ lm.h). The progression from light generated to lux delivered can then be related to the energy consumption as each of the relevant factors are considered.

To ensure the lighting design performs as intended, careful attention must be paid to all aspects of the input parameters including accurate values for the properties of walls, floors & ceilings and realistic cleaning cycles. Not providing the lighting designer with the correct properties of the surrounding surfaces will almost certainly result in the actual lighting system not meeting the end users' expectations as reflectances change not only the illuminance but also the uniformity.

Lighting controls will reduce the energy consumption of a lighting installation but careful attention must be paid to the selection of the light source and ballast to ensure they are suited to dimming. The efficacy of discharge light sources is inevitably lowered when they are operated at powers below the design power. The efficacy of dimming T5 fluorescent lamps can be estimated from the values in given in reference [1] but this is beyond the scope of this review.

The case studies in this review are intended to illustrate the importance of close collaboration between the end user and the lighting designer. Therefore the examples concentrate on the derivation of the energy balance for a light source in an installation and on the impact of numerous factors on the illuminance distribution rather than the actual annual energy consumption for a lighting installation. The authors advocate the use of LENI (Lighting Energy Numeric Indicator) [6] for demonstrating the energy efficiency of lighting installations.

Acknowledgements

The authors thank Mary Harding-Scott for help with calculations and Stewart Langdown & John Stocks for their valuable comments and advice.

References

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- [6] Energy performance of buildings - Energy requirements for lighting, BS EN 15193:2007

Table 1: Calculated illuminances for case studies

Ceiling	Reflectances					LOR	MF	Fittings	Total power	Surrounding		Task		Whole area		Image
	Wall 1	Wall 2	Wall 3	Wall 4	Floor					Lux	U _o	Lux	U _o	W/m ²	W/m ² /100 lux	
70	50	50	50	50	20	0.89	0.70	18 (6 x 3)	6300 W	321	0.54	349	0.74	8.52	2.66	Figure 3
70	50	50	50	50	20	0.89	0.60	18 (6 x 3)	6300 W	275	0.54	299	0.74	8.52	3.10	Figure 4
70	50	50	50	50	20	0.89	0.60	21 (7 x 3)	7350 W	320	0.54	348	0.74	9.94	3.11	Figure 5
70	50	50	10	50	20	0.89	0.70	18 (6 x 3)	6300 W	304	0.51	332	0.70	8.52	2.80	Figure 6
70	50	50	10	50	20	0.89	0.60	18 (6 x 3)	6300 W	261	0.51	285	0.70	8.52	3.27	Figure 7
70	50	50	10	50	20	0.89	0.60	21 (7 x 3)	7350 W	303	0.51	331	0.71	9.94	3.28	Figure 8

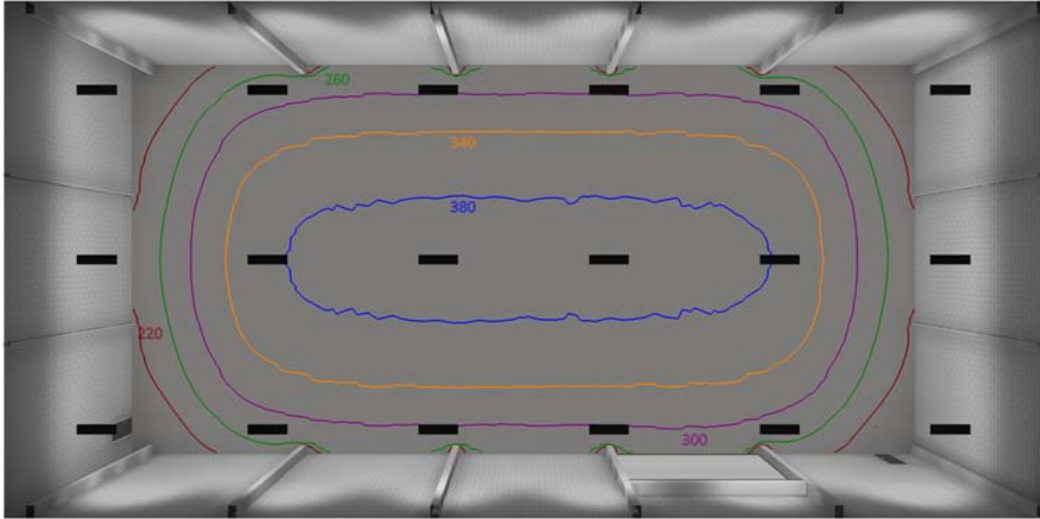


Figure 3: Case study 1 - Details listed in Table 1

Figure 4: Case study 2 - Details listed in Table 1

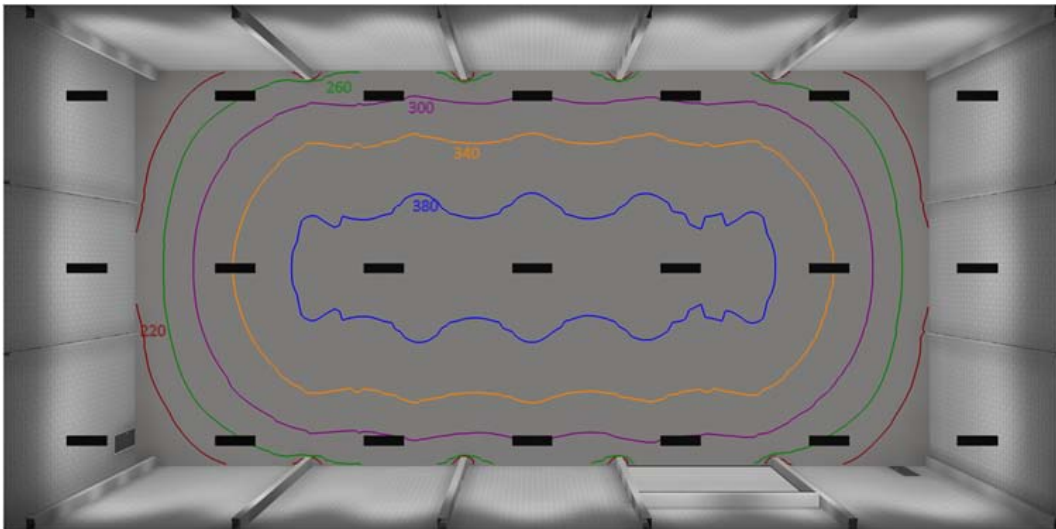


Figure 5: Case study 3 - Details listed in Table 1

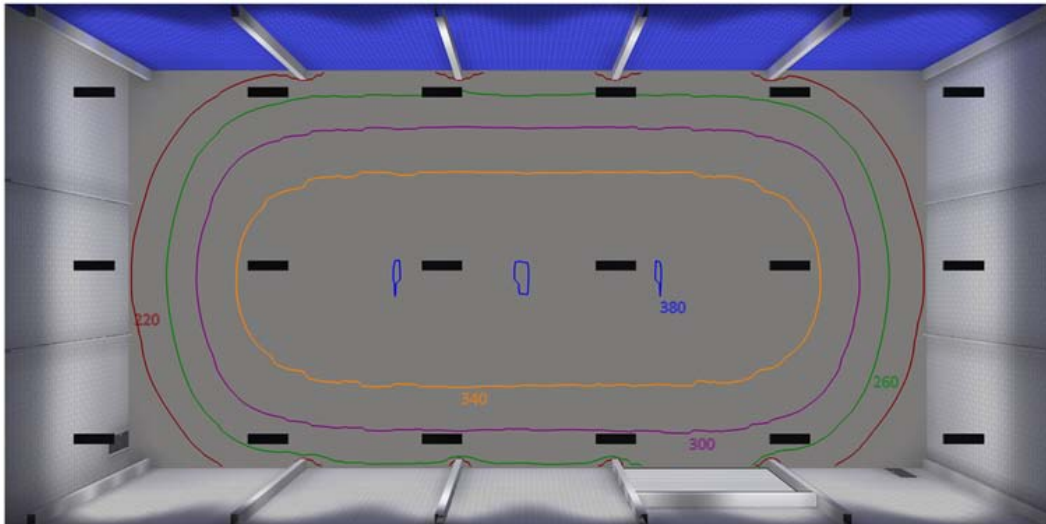


Figure 6: Case study 4 - Details listed in Table 1

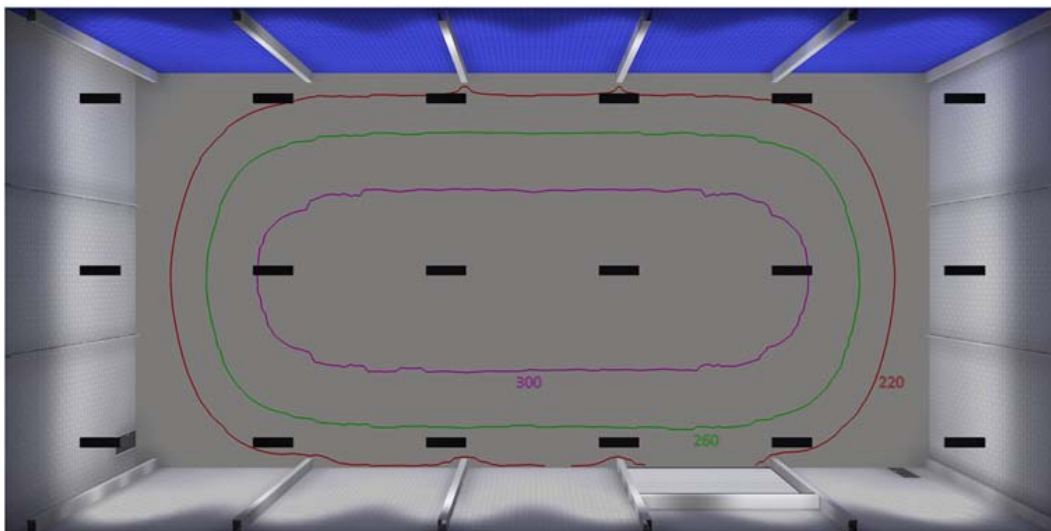


Figure 7: Case study 5 - Details listed in Table 1

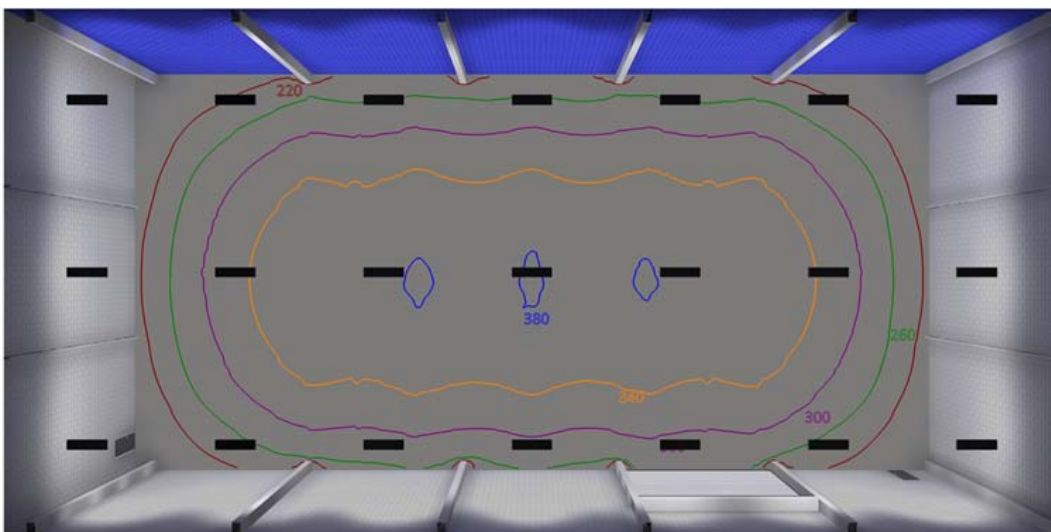


Figure 8: Case study 6 - Details listed in Table 1