Musco Sports Lighting Responses to the information and questions shared by WFWG member John Seymour

The WFWG (Via workgroup member John Seymour) provided the following technical questions that raise significant concerns for workgroup members which in their view have not been fully or satisfactorily resolved. These questions were forwarded to Musco for their response. The following answers in blue were provided by Mr. Bradley D. Schlesselman, LC, Application Engineering Manager/Lighting Specialist, Musco Lighting and Technical Committee Member, International Dark-Sky Association.

1. Glare: The fundamental question about glare is simply whether the County can demonstrate convincingly that glare will not be present at levels that generate serious discomfort to nearby residents, occupants of the school, and users of the fields. This is a difficult question to answer, I realize. As Fairfax County concluded in its recent study of sports field lighting, glare is simply light that hinders or bothers the human eye and “no generally established methods for calculating acceptable levels of glare have been established in the sports lighting industry.” Fairfax County Park Authority, Athletic Field Lighting: Technical Report (2005) at 2-10. Similarly, a recent report issued by Carnegie-Mellon commented that “the substantial glare caused by LEDs is not typically included as a measurement criteria in evaluation processes and when it is, the tools of measurement are inadequate. As a result glare persists as an issue.” Carnegie-Mellon, LED Street Light Research Project (2011) at 43.

As I understand it from the technical literature, there are several ways to estimate glare. One of the simplest is to measure the light emitted from the “worst case” luminaire. This “shorthand” measure has been adopted by Fairfax County, which recommends that, for rectangular fields with an edge of the playing field within 200’ from a residential property line, the maximum permitted glare is 7,000 candela. (Fairfax County Park Authority, Athletic Field Lighting Systems Performance Outline Specifications (July 28, 2010) at 5). Similarly, the British Institute of Lighting Engineers, in its “Guidance Notes for the Reduction of Light Pollution,” has established a maximum standard of 7,500 candela for residential neighborhoods. From the data in Musco’s photometrics, it is not entirely clear whether — even with 80’ poles — these limits will be met. For example, the photometrics provided in the draft Environmental Assessment indicate that light levels immediately north of the fields (where additional trailers will be installed) range up to more than 30,000 candela. Levels east of the site (toward the school) range up to 70,000 candela. Levels just short of the property line on the west (residential side of the fields) range up to 80,000 candela. It is unclear, from the data given, whether levels at the property line west of the site exceed the 7,000 to 7,500 candela benchmarks at some locations — although some data points appear to approach those thresholds. In any event, the high levels of glare arising from the LED lights appears to be a real concern at this site, unresolved by the data generated to date.

The glare (candela) values at the west residential property line will not exceed 7000 candela at any point along the property line, utilizing the 80’ pole option. Shorter poles would mean more glare impact at property line.

It is also not entirely clear to us how the glare computations were made. As one researcher familiar with LED lights warned recently: “a common mistake in measuring luminaire luminance is measuring
the entire fixture. Luminance must be measured at the luminous opening, in other words at the smallest point (without any breaks) that emits light out of the fixture. If one were to measure the entire LED luminaire, it would not account for the ‘shards’ of light emitted from each individual LED. The light emitted from individual LED luminaire designs is more akin to a series of laser beams in contrast to the homogeneous output of a traditional luminaire.” Nate Heiking, “Avoiding LED Glare Bombs,” LED Journal (Jan. 9, 2013). Thus, when Musco reports its glare measures (per light bank) or (per fixture), it is unclear to us whether predicted glare is being accurately modeled.

The author of this article speaks in theory and not in practical terms. It is theoretically possible to isolate every source, take a measurement of the radiant energy being produced and predict a result. However, LED luminaires consist of arrays of LED sources which creates a composite beam. This beam exits the luminaire housing and is captured as one complete beam via a photometric report done typically using a gonio-photometer. It is not possible for the gonio-photometer to differentiate between sources contributing to each of the solid angles present exiting the luminaire, when an array is present. The guidelines produced by the IES also indicate that LED luminaires be tested as one complete unit, not as individual sources. For this reason, the practical nature of what the author is describing is not realistic. Furthermore, due to the small source size of the LED and the array layout that exists, along with the distance from observation point to luminaire location, the observer will most likely only see the composite of the entire beam, not just an individual source. As for the question, “Does Musco report glare measurements per light bank or per fixture?”, Musco can do either, but for most cases, including this one, we have shown per fixture.

Finally, working group members have raised a concern about reflected glare. As noted in the IESNA Recommended Practice for Sports and Recreation Lighting (RP-6-1) “glare can be caused by the luminaires or indirectly from the reflection of surrounding structures within the field of view.” Similarly, the International Commission on Illumination, in its “Technical Report: Guide on the Effects of Obtrusive Light From Outdoor Lighting Installations” (2003) has emphasized that lighting designers should consider the influence of reflected light on predicted glare levels. Sections 2.7.3 and 3.3.5. At the Williamsburg site, residents living west of the site have expressed concern about reflected glare onto their properties from intensely illuminated school structures and the field itself. Musco’s response to this concern, in part, is that reflected glare is not within Musco’s control and thus is not reflected in the design. Musco has also indicated that reflected glare can be difficult to measure and, with respect to the school structures, would be affected by the color and location of the structures. Although acknowledging these concerns, we continue to believe that reflected light may contribute significantly to glare and that the absence of such data represents a real gap in our understanding of potential lighting effects.

Musco could show the illuminance (amount of light) incident on the façade of the building structure. However, due to many unknowns about the material makeup of the building and the inability for the lighting design software to calculate, the information the Workgroup is asking for, cannot be presented. I can say the impact to the community from light bouncing off the building due to the proposed LED solution, will be negligible.

We note that, in addition to the “worst case luminaire” measure of glare, lighting authorities have recommended other measures as well. Fairfax County, in its White Paper: Athletic Field Lighting and
Control of Obtrusive Light Pollution (2010) acknowledged that glare is difficult to measure and is “a result of source to background contrast ratio.”

There are 4 main criteria to understanding the implications of glare. These are: 1. Luminance of the Source, 2. Background Luminance, 3. Adaptive State of the Eye, 4. Size of the Source. Until recent research conducted out of the University of Nebraska at Omaha by Dr. Yulia Tyukhova, there was not a metric that could be applied with respect to glare for off-site sports lighting applications. A research scholar could cite the CIE UGR metric as a possible metric for evaluating glare in sports lighting applications. However, it is known that this metric fails to compute credible values when source sizes are small and background luminances are near zero. When observing sports lighting venues, both of these characteristics are present while viewing the scene during nighttime events. Dr. Tyukhova, at the request of Musco, conducted her research to close the gap between the small source size and background luminances near zero. She has written a couple of papers on the research, which simply creates an extension to the existing UGR metric, however, these papers have not yet been published for the use of the lighting community. Furthermore, even if her metric was available for use, glare is a very subjective response by those who experience it. What may be glare to one individual may not be to another.

Accordingly, Working Group members had suggested that, as another rough measure of glare, Musco compute a source to ambient ratio. Musco’s written response to that question was simply that such testing could not be conducted and that it would need to “use a developmental program to check glare.”

Based on the research done by Dr. Tyukhova, Musco has developed a High Dynamic Range Imaging (HDRI) system which utilizes her research to better predict and evaluate off-site glare for neighboring communities. However, the papers need to be published and metrics need to be established before Musco can use this tool in commercial applications.

Because of the significance of the glare issue to residents and the difficulty of measuring or estimating glare generally, some Working Group members continue to believe that the County should devote additional resources to generate reliable predictors of glare — both direct and reflected. **No need to do this as Dr. Tyukhova’s research will do this for you.** (Other commonly used measures of glare are the Glare Rating *(This is an on field metric and cannot be used off-site effectively)*, developed by the International Commission on Illumination for outdoor lighting applications and the BUG (Backlight, Uplight and Glare rating).

The BUG rating system is intended for fixed photometry only, meaning that the luminaires are always positioned in the same manner in every instance. Sports lighting applications, such as soccer fields, require aimable photometry. Because of this, it is not possible for an aimable sports lighting luminaire to gain the designation of the BUG rating system. I have had many conversations with the authors of the BUG system and I continue to fight them on this technicality. They repeatedly agree that the BUG system does not work with sports lighting applications.

2. Light Pole Locations: During Working Group discussions, members have raised questions about the locations of the poles. One threshold question is whether the design is fixed, or is still subject to revision. For example, concerns have been expressed that the current models likely do not accurately
predict light spill and glare because the pole locations may need to be adjusted to accommodate additional school structures to be erected adjacent to the fields. Thus, absent a final decision on pole locations, the predictions of lighting effects likely have some inherent measure of uncertainty.

*With the amount of work that Musco has placed into this project, I would hope that all of the foreseen pole placement issues have been resolved. Until foundations are in the ground, poles could always move. With that said, if pole locations need to move at this point, Musco would need to start this evaluation process again, which would be costly for the county and time consuming.*

Second, concerns have been raised about the proposed location of light poles S-3 and S-4. Both the IESNA and FIFA have developed standards for pole locations at the perimeter of soccer fields. The aim of these standards is to protect users from disabling glare by prohibiting the placement of light poles near the mouth of goals or where corner kicks take place. In particular, the U.S. Soccer Foundation recommends that poles be located between the penalty line and the goal line. Poles S-3 and S-4 are located at the extreme corner of the two fields, behind the goal lines. From the design diagrams provided, it appears that the poles also may be located close to or within prohibited glare zones. IESNA, Recommended Practice for Sports and Recreational Lighting at 61, figure 81; U.S. Soccer Federation, Lighting Standards of the U.S. Soccer Federation (2007) at 13.

*Musco assisted with the development of the USSF Lighting Guidelines, which is also the same parameters for IES and FIFA. The placement of poles S3 and S4, meet the Guidelines in question.*

Finally, concerns have also been expressed whether the current design has properly factored in the needed set-back for poles, in light of the Zoning Ordinance requirements. Generally speaking, the higher the structure the greater the set-back. Zoning Ordinance section 3.2.6.A.2.e. Members are seeking assurance that the County’s drawings and plans properly respect minimum County set-back requirements for high structures.

*Based on the current lighting plan, it appears that the proposed solution does indeed meet Ordinance Section 3.2.6.A.2.e. By our calculations the closest a pole can be to the property line, based on an 80' pole, is 32’. The S3 pole is 60’ from the closest property line.*

3. **Aiming Angle:** Because luminaire aiming angles are critical to minimizing glare, we had asked whether the proposed poles would conform to generally recommended pole design specifications—that is, whether the upper level of the defined beam would be no more than 80 degrees above nadir. IESNA, Recommended Practice for Sports and Recreational Area Lighting, RP-6-01 (2001) at 18. In Musco’s written response to this concern, it stated that the poles could comply with this standard provided that it “can still achieve a minimum aiming angle of 24 degrees down from horizontal.” We don’t understand the response and ask whether, with pole heights at the County maximum, such compliance can be achieved. We also ask whether, if pole heights could be raised to 80’, such compliance could be achieved.

*The current design is for 80’ poles. The answer to the question is YES, this design does meet the 80 degree criteria. The 80 degree criteria could also be met with shorter poles, however, the candela*
values at the property lines would go above the 7,000 cd value as discussed in question #1. Therefore, the 80’ pole option is still required, unless drastic on-field modifications are desired.

4. Pole Height: We have struggled, as you know, to understand the County’s requirements for pole height in S-3A zones. We had been advised, during Working Group deliberations, that the maximum height of poles in this zone is 68 feet. Zoning Ordinance section 4.2.3.A&B, section 3.1.6.B. But vertical distance must be measured from a calculated average elevation of the grade of the site at its perimeter — to ensure that builders do not bypass mandatory height limits by placing the structures at the highest point of a site. Zoning Ordinance section 3.1.6.A.2. As Robert Duffy indicated at our Scoping meeting (as I understood him), the average elevation of the overall Discovery site is 326’. My very quick review of the elevation of the 2 soccer fields themselves (using Google Earth) indicates that they average 334’. Based on the zoning ordinance, then, the maximum height of the structures (the light poles) should be in the neighborhood of 60’ — well below the heights at which most of the Musco modeling was performed. I do understand, of course, that Musco has conceded that pole heights less than 70’ would produce objectionable levels of glare and thus has modeled lighting effects at 80’ — a height one-third higher than legally permissible in this S-3A zone. Nevertheless, we believe that the County should clearly state the permissible height limitation in this zone for light poles and also carefully consider, as part of its review, the visual impact (aesthetics, architectural harmony, visual clutter) of six 80’ light poles carrying a dozen luminaires each producing 63,600 lumens, on a historically dark and quiet residential neighborhood.

In that regard, we note the care with which Arlington County has historically approached this issue. In granting site plans and use permits in the past, Arlington has followed modern principles of urban design to protect neighborhood character and architectural harmony. In a rare approval of a waiver of height limitations for sports lighting, the County made specific findings at Long Bridge that a height increase is permissible because it is a “major recreational center, is bounded by major roads and intense development and additional height will not adversely affect neighboring properties.” Site Plan Amendment for North Tract Special Planning District (Nov. 15, 2006). At this site, of course, waiver of the height limitation would represent a marked change in the life-long expectations of residents about peace, quiet, and visual harmony in their R-10 residential setting. I don’t see a question here, just a statement.

5. Light Levels On The Field: When many of us visited the Vienna Little League baseball field lit with Musco LED lights, we were struck at the extraordinarily high levels of lighting on the field. The glare — particularly to those of us with aging eyes — was disabling. Musco’s January 2016 data for 80’ poles has indicated that light intensity (per light bank) will average more than 40,000 candelas with a maximum of 1.56 million candelas. Musco’s April 2016 data estimated even higher levels — a high of 1.9 million maintained candela (per light bank) with an average of 55,000 candela. Because these levels are extraordinarily high, we are seeking a better understanding of the propriety of these levels for field users, the likely effects on children using the field, and how those levels compare to those typically provided on soccer fields in residential neighborhoods where no or very few spectators are expected. I am guessing that the visit to Vienna was for the purposes of an off-site demonstration. I gather there weren’t any issues from the Working Group for off-site control at this facility. For the sake of on-field evaluation, simply put, you picked a site that is completely different than what this project is about. The little league field you visited had light levels at least twice as high as what is being proposed for this site. The references to the maximum candela values are on field variables that are
not pertinent to the discussion about protecting the neighboring properties. However, since it was brought up, I will say that these values are well within the range of every, I mean every, recreational baseball, softball, and soccer field that exists in the nation today, where light levels are similar to the proposed.

6. Dark Sky Compliance: To its credit, Arlington has consistently insisted that County lighting be Dark Sky compliant. Arlington County has stated that, because “[it] is committed to creating and maintaining a higher standard and quality of life for its residents, the Division of Transportation shall comply with Dark Sky regulations that attempt to reduce light spill pollution.” Arlington County, Street Light Policy and Planning Guide (updated June 2006) at 9. In a recent site plan approval memorandum, Arlington County approved the applicant’s lighting plan only after finding that it “incorporates the dark sky lighting principles in accordance with the standards of the International Dark Sky Association.” Site Plan Amendment for 1100 Wilson Boulevard (March 9, 2015). In the Environmental Assessment for the Discovery School itself, Arlington County noted that on-site lights “will be Dark Sky compliant to reduce light pollution and glare.” Discovery Environmental Assessment (Revised June 22, 2014) at 6.

The International Dark Sky Association (IDA) provides objective, third party certification for “Dark Sky” luminaires to minimize glare, reduce light trespass, and protect the nighttime sky. According to the IDA, however, lights of the temperature and color proposed by Musco would not be eligible to receive Dark Sky certification. The lights proposed by Musco are 5700 Kelvin, well above the 3,000 Kelvin temperature necessary to receive Dark Sky approval. As the IDA has repeatedly emphasized, outdoor lighting of the type proposed by Musco “is more likely to contribute to light pollution because it has a significantly larger geographic reach than lighting with less blue light. Blue-rich white light sources are also known to increase glare and compromise human vision, especially in the aging eye.” IDA, LED Practical Guide (2016). The lights at issue, then, appear to violate long-established and sound policy to promote Dark Sky compliance in Arlington’s lighting initiatives.

In response to this concern, Musco indicated that warmer LED lights will result in higher initial and operating costs and might require an increase in luminaries and associated light spill. Given the very low levels of spill light predicted with 80’ poles, however, it’s unclear to me whether light spill should be a concern. Moreover, at least some investigators have concluded that high temperature units “contribute more to light pollution on a per lumen basis” than low temperature units. Ian Ashdown, Color Temperature and Outdoor Lighting (July 2015).

Because blue light is preferentially scattered, resulting in higher levels of light pollution, it could be speculated that warmer luminaries (even if greater numbers are needed) would result in less light pollution. Moreover, as discussed earlier, the most significant issue with LED lights is glare. According to the IDA, outdoor lighting with blue-rich white light is more likely to contribute to light pollution because it has a significantly larger geographic reach than lighting with less blue light. Blue-rich white light sources are also known to increase glare and compromise human vision, especially in the aging eye.” IDA, Practical Guide (2015). For all of these reasons, members of the Working Group would find it helpful to review photometrics reflecting lighting of the fields with LED lights of 3,000 Kelvin or less.

As a member of the IDA Technical Committee as well as the Musco Engineer responding to this inquiry, I am going to defer question #6 to Chris Monrad, Electrical Engineer, Monrad Engineering, Tucson, AZ, who is also a member of the IDA Technical Committee. He will tell you how the IDA feels
about the proposed Musco solution. Also see the Oct. 12, 2015 update to Ian Ashdown’s blog (as cited above) for the rest of the story regarding color temperature for sports lighting applications.

"Below is the link to Ian Ashdown’s blog that was referenced in the May 10, 2016 inquiry. Please see the update posted on Oct. 12, 2015, regarding the blue content and the effect on field turf/grass.

http://agi32.com/blog/category/correlated-color-temperature-cct/

I have also attached a couple Spectral Power Distributions (SPD) for various LED CCT sources and also for the legacy metal halide (MH) sources that have been utilized in sports lighting applications for the better part of 40 years. The percentage of lumens in the "Blue" range, for each, is listed on each of the documents. Note, due to the applied inefficiency of the MH compared to either of the LED sources, there will be a 92% greater total impact in the blue content for the legacy source than the 5000K CCT LED source. I took the existing MH design and LED design information, along with the attached SPD information to derive the 92% value. (see attached "Blue Content Hand Calcs")

7. Health and Environmental Effects: During Working Group deliberations, some members have requested from Musco all studies and reports in its possession bearing on the potential health and environmental effects from blue-white LED lighting. In its written response to this question, Musco denied having possession of any such studies and reports and stated further that, “no impact [will occur] due to the duration of the lighted venue and the color of the surface being lit will filter out the blue light. Additionally, control of light eliminates light on adjacent properties.”

Some Working Group members view this response skeptically, in light of the recent and robust scientific debate about potential health and environmental effects associated with intense LED lighting. I will not discuss this issue in depth here, because you have received more thorough discussions from other Working Group members. With respect Dark Sky compliance, however, the IDA has repeatedly cautioned that blue-white lights of the color temperature proposed for the Williamsburg site have been implicated in a host of adverse environmental and human health effects, including sleep deprivation. Other organizations, including the American Medication Association’s Council on Science and Public Health, the International Commission on Illumination, and the European Commission’s Scientific Committee on Emerging and Newly Identified Health Risks have issued similar warnings. In particular, the AMA has stated that even low levels of blue-spectrum light can disrupt melatonin production. If Musco has data confirming a dose-response relationship, or threshold and filtering effects relevant to sports lighting, it should provide such data to the Working Group.

Musco does not have the data the Working Group is looking for, because the data simply does not exist. Even within the medical community, if you look at all the papers going against “Blue Light” the conclusions are that more research is needed to confirm or deny the claims. I recommend the Working Group contact Brian Leibel, Technical Director of Standards, IESNA for his comments on the actual research conducted in this area and ask him for the documentation (he doesn’t have it because it doesn’t exist.) Lots of hype being made about something that MIGHT exist. The Working Group could also contact Bruce Kinzey, Pacific Northwest National Laboratory (PNNL), about the hype. A memo from him dated July 2016 has been attached.
8. Inability to Check Musco’s Data: Throughout this effort, the Working Group has relied exclusively on data provided by Musco. That data is, in turn, generated through the use of proprietary logarithms involving complex calculations and numerous assumptions and tradeoffs. *This is why the county is asking someone (me) who is Lighting Certified through the National Council on Qualifications for the Lighting Professions (NCQLP) for assistance on the matter.*

The Working Group has no way of testing those logarithms, confirming the accuracy of the calculations, validating assumptions made, or evaluating the tradeoffs. *This happens every day in the lighting profession. In the end, it is up to the lighting professional to make sure specifications are met.*

Rather, we must take the data as valid and replicable. Nor does it have any way to test the accuracy of Musco’s predictions of glare and light spill after-the-fact. Rather, they must be lived with.

*Musco will make sure that the end result is brought to within project specifications. It is guaranteed in writing.*

The Working Group has acknowledged that, with respect to some issues, absolute certainty will not be attainable. Nevertheless, scientific uncertainty should be an occasion for caution. Indeed, the special use permit process itself properly incorporates a precautionary principle when it requires the County — before it may grant a permit — to make three separate showings. Arlington County may approve a permit or permit amendment only if it (1) will not affect adversely the health or safety of persons residing or working in the neighborhood of the proposed use; (2) be detrimental to the public welfare or injurious to property or improvements in the neighborhood; and (3) be in conflict with the master plans of the County.” Arlington Zoning Ordinance section 15.4.3.

Given the extraordinary levels of scientific, human health, and technical uncertainty surrounding the erection of numerous LED light poles in the Williamsburg neighborhood, both modern scientific precautionary principles and Arlington’s own laws mandate a very careful and deliberate review. It bears repeating here that, irrespective of the charge to the Working Group, the ultimate burden of demonstrating compliance with special use permit requirements lies with the County, not the Working Group. At least in the minds of some Working Group members, the record to date is very poorly developed and provides no basis for such a permit.

*As a lighting professional, my job is lighting something the very best way possible. With that said, if the Working Group is looking for the very best sports lighting solution at recreational lighting levels for the betterment of the community, you will not find a better solution than what has been provided. As a long time (18 years) Lighting Designer, member of both the IES and International Dark-Sky Association, and scientific researcher of lighting for both sports and general lighting, I appreciate the diligent effort taken by the Working Group to make sure that this is the very best solution for the community.*

*Lastly, the legacy sources (metal halide) utilized in sports lighting applications over the past 40 years have likely contributed more to the potential “Blue Light to Human Health” hazard than the highest*
CCT LED sources being promoted today. This is based on information gathered from the Kinzey article. If a reduction in “Blue Light” is truly the mission, then a large and focused effort should be placed on retrofitting all legacy (metal halide) sports lighting projects to LED sports lighting products where extreme light control is possible.
4000K LED
405nm and 530nm = 30.46%
5000K LED
405nm and 530nm = 36.15%
Metal Halide
405nm and 530nm = 30.64%
Hello MSSLC Members:

I imagine most everyone is familiar with the recent position statement issued by the American Medical Association (AMA) on "high-intensity street lighting," due to the extensive media coverage following its release. We continue to field inquiries that include many passed along from our member municipalities and utilities, originating from their citizens and customers. The messages contained in the release have caused a stir.

DOE's Solid-State Lighting Program issued an SSL Postings within a few days of the AMA's release. This notes the importance of matching the characteristics of the product with the specific application, underscoring the AMA's call for the use of appropriate products. Since then a number of other organizations have also weighed in with very useful perspectives. You might want to check these out if you haven't already:

- Glenn Heinmiller of LAM Partners in Cambridge, MA, responded to a number of the AMA points and subsequent misinterpretations in the media coverage that immediately followed the release; Glenn was directly involved with the street lighting conversion in Cambridge that was referenced in the AMA's statement.
- The Lighting Research Center at RPI responded with a mix of technical discussion and concise topic-by-topic summaries to clarify some central points. They note that two key contributors to the influence of blue wavelengths on health include intensity and the amount of exposure time of the retina, both of which were left out of the AMA statement.
- The National Electrical Manufacturer's Association has also weighed in, reiterating the potential for controlling light distribution from LED products and noting that one color temperature (3000K) will not be appropriate for all applications.

In addition to the above I thought I might also provide some numbers for your use should you continue to get inquiries from your respective agencies and citizens. Probably most people do not have access to the actual spectral contents of the different types of lighting in common use or know how they compare with one another, even if they understand that
virtually all lighting sources produce some amount of melanopic content. Melanopic content is of interest here because it is regarded as a primary indicator of the relative potential for the listed light sources to stimulate the human biological responses that are the subject of much of the AMA's statement. Note, however, that influences from other photoreceptors like the rods and cones are also known to contribute to biological responses such as circadian and neurophysiological regulation, but in ways that are not fully clear to the medical research community.

Table 1 lists various sources used in street and area lighting and selected performance characteristics related to their spectral content. Data for each source includes a measured Correlated Color Temperature (CCT), the calculated percentage of radiant power contained in "blue wavelengths" (defined here from the literature related to sky glow as wavelengths between 405 and 530 nanometers [nm]), and the corresponding scotopic and melanopic multipliers relative to a high-pressure sodium (HPS) baseline, normalized for equivalent lumen output. Note that research on the contributions of different types of photoreceptors to visual and non-visual responses continues (e.g., see Amundadottir, 2016; Schlangen, 2016; Lucas et al., 2014) and may warrant updates to this table in the future.

Table 1. Selected blue light characteristics of various outdoor lighting sources at equivalent lumen output.

<table>
<thead>
<tr>
<th>Row</th>
<th>Light source</th>
<th>CCT (K)</th>
<th>% Blue*</th>
<th>Luminous Flux (lm)</th>
<th>Scotopic content relative to HPS</th>
<th>Melanopic content relative to HPS**</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PC white LED</td>
<td>2700</td>
<td>17% - 20%</td>
<td>1000</td>
<td>1.77 - 1.82</td>
<td>1.90 - 2.06</td>
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<tr>
<td>B</td>
<td>PC white LED</td>
<td>3000</td>
<td>16% - 25%</td>
<td>1000</td>
<td>1.89 - 2.13</td>
<td>2.10 - 2.51</td>
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<tr>
<td>C</td>
<td>PC white LED</td>
<td>3500</td>
<td>22% - 27%</td>
<td>1000</td>
<td>2.04 - 2.37</td>
<td>2.34 - 2.97</td>
</tr>
<tr>
<td>D</td>
<td>PC white LED</td>
<td>4000</td>
<td>27% - 32%</td>
<td>1000</td>
<td>2.10 - 2.65</td>
<td>2.35 - 3.40</td>
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<tr>
<td>E</td>
<td>PC white LED</td>
<td>4500</td>
<td>31% - 35%</td>
<td>1000</td>
<td>2.35 - 2.85</td>
<td>2.75 - 3.81</td>
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<td>F</td>
<td>PC white LED</td>
<td>5000</td>
<td>34% - 39%</td>
<td>1000</td>
<td>2.60 - 2.89</td>
<td>3.18 - 3.74</td>
</tr>
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<td>G</td>
<td>PC white LED</td>
<td>5700</td>
<td>39% - 43%</td>
<td>1000</td>
<td>2.77 - 3.11</td>
<td>3.44 - 4.52</td>
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<tr>
<td>H</td>
<td>PC white LED</td>
<td>6500</td>
<td>43% - 48%</td>
<td>1000</td>
<td>3.27 - 3.90</td>
<td>4.38 - 5.84</td>
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<tr>
<td>I</td>
<td>Narrowband amber LED</td>
<td>1606</td>
<td>0%</td>
<td>1000</td>
<td>0.36</td>
<td>0.12</td>
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<tr>
<td>J</td>
<td>Low pressure sodium</td>
<td>1719</td>
<td>0%</td>
<td>1000</td>
<td>0.35</td>
<td>0.10</td>
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<tr>
<td>K</td>
<td>PC amber LED</td>
<td>1872</td>
<td>1%</td>
<td>1000</td>
<td>0.70</td>
<td>0.42</td>
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<td>L</td>
<td>High pressure sodium</td>
<td>1959</td>
<td>9%</td>
<td>1000</td>
<td>0.89</td>
<td>0.86</td>
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<tr>
<td>M</td>
<td>High pressure sodium</td>
<td>2041</td>
<td>10%</td>
<td>1000</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>N</td>
<td>Incandescent</td>
<td>2851</td>
<td>12%</td>
<td>1000</td>
<td>2.26</td>
<td>2.79</td>
</tr>
<tr>
<td>O</td>
<td>Halogen</td>
<td>2934</td>
<td>13%</td>
<td>1000</td>
<td>2.28</td>
<td>2.81</td>
</tr>
<tr>
<td>P</td>
<td>F32T8/830 fluorescent</td>
<td>2940</td>
<td>20%</td>
<td>1000</td>
<td>2.02</td>
<td>2.29</td>
</tr>
<tr>
<td>Q</td>
<td>Metal halide</td>
<td>3145</td>
<td>24%</td>
<td>1000</td>
<td>2.16</td>
<td>2.56</td>
</tr>
<tr>
<td>R</td>
<td>F32T8/835 fluorescent</td>
<td>3480</td>
<td>28%</td>
<td>1000</td>
<td>2.37</td>
<td>2.87</td>
</tr>
<tr>
<td>S</td>
<td>F32T8/841 fluorescent</td>
<td>3965</td>
<td>30%</td>
<td>1000</td>
<td>2.58</td>
<td>3.18</td>
</tr>
<tr>
<td>T</td>
<td>Metal halide</td>
<td>4002</td>
<td>33%</td>
<td>1000</td>
<td>2.53</td>
<td>3.16</td>
</tr>
<tr>
<td>U</td>
<td>Metal halide</td>
<td>4041</td>
<td>35%</td>
<td>1000</td>
<td>2.84</td>
<td>3.75</td>
</tr>
</tbody>
</table>

* Percent blue calculated according to LSPDD: Light Spectral Power Distribution Database, http://galileo.graphics.cegepsherbrooke.qc.CA/app/en/home. The specific calculation, developed for evaluating the potential for affecting sky glow, divides the radiant power contained in the wavelengths between 405 and 530 nm by the total radiant power contained from 380 to 780 nm, for each light source.

** Melanopic content calculated according to CIE Irradiance Toolbox, http://files.cie.co.at/784_TN003_Toolbox.xls, 2015 as derived from Lucas et al., 2014.

Key: PC -- Phosphor Converted; LED -- Light Emitting Diode
As most products differ slightly from one another, the scotopic and melanopic values presented should be taken as being typical for the associated light source type, rather than exact. We have included ranges, for which we have data, to indicate the upper and lower limits that might be found in a representative set of LED product samples. The number of product samples underlying each CCT ranges from 2 (for 2700 K) to 19 (for 3000 K), with others falling in between (76 samples in all). Conventional light sources are all listed with single values rather than a range because DOE has performed less testing on those, but they would likewise be most accurately characterized by a range (albeit narrower than LED).

It is important to understand that performing a calculation with these values only provides an idea of the relative potential to cause human health impacts, rather than the actual (if any) impact of the melanopic content. These values do not yet take into account several critically-contributing factors noted in the LRC paper linked above, such as the intensity one might expect to find inside a bedroom from a streetlight outside. Furthermore, the melanopic content itself directly scales with light output for a given source, so reducing output by dimming dynamically reduces the corresponding content.

Finally, note that the scotopic and melanopic contents reported are listed relative to HPS, which was selected as the baseline for comparison due to its predominance in the existing outdoor lighting market.

The influence of blue wavelengths is immediately evident in all "white light" sources containing them. In addition, as demonstrated by the relative melanopic contents of conventional lighting sources in the table, the blue light issues being raised by the AMA are clearly nothing new to our lighted environment. What is new is our increased understanding of their potential influence regarding human and environmental health issues, as the related research progresses.

**Estimating the potential impacts**

A commonly cited advantage of LED lighting is the superior control available over its light distribution. This advantage arises because a luminaire needs to fit its output to a target area, for example a rectangular stretch of roadway extending 100+ feet out from under each side of a streetlight. To satisfy the application, fixtures employing omni-directional emitters like glass lamps require significant reshaping of the lamp’s output through reflectors and lenses, and despite great skill in this regard, the results remain far from perfect with large components of the light continuing to exit the fixture in unwanted directions. The latter often results in light trespass, glare, uplight (in older installations especially) and non-uniform illumination on the ground, all of which amount to wasted light and energy. In contrast, because LEDs emit in only one hemispherical direction, the optics’ job of shaping their light output into the pattern wanted is much easier from the start, and thereby enables the elimination of much of this waste.

One direct benefit resulting from the improved distribution is that lamp-based fixtures are now routinely being replaced with LED products that emit only half (or less) of the light output of the replaced conventional light source. This is a key concept for estimating the potential for impact from a lighting conversion program. For example, if product X has a melanopic content twice that of product Y, but can be run at one-third the output, then converting to product X might actually reduce melanopic output. As previously noted, dimming a given product similarly reduces its emitted melanopic content, in direct proportion to the reduced light output.
Numerous real-world examples exist of such reductions being achieved in actual street lighting conversion programs around the U.S. As a salient example, the city where I live, Portland, OR, has replaced its previous 100 W HPS fixtures emitting about 9,000 lumens (initial) with 4000 K LED products that are set to an initial output of 3,000 lumens, achieving a two-thirds reduction. As a result, in absolute terms, the LED products in Portland have likely had little impact on the melanopic output compared to the previous (and notably non-white) HPS fixtures they replaced, because the reduced light output offsets the LED's higher melanopic multiplier.

A second example is Cambridge, MA, which installed a dimming control system when it converted its street lighting to LED in 2013. According to a complete inventory of its lighting system at the time, the city replaced a total of about 54 million lumens (initial) of HPS lighting with about 32 million lumens (initial) of 4000 K LED lighting. The city's "maintained" setting of the controls system is at 70% output, meaning it actually only uses about 22.4 million lumens to light its streets at dusk when the lights first come on. Moreover, at midnight the dimmer setting is further reduced by another 50% (i.e., to 35% of full output), where it remains until early morning. Assuming even a high melanopic content factor relative to the original HPS of 3.4, during the initial evening hours its relative melanopic content emissions would amount to 3.4 x (22.4/54) = \(1.41\times\) those of the original HPS system. From midnight to the early morning hours, this value is reduced again by 0.5, yielding a factor of about \(0.71\times\). In other words, the Cambridge system has offset the increase in melanopic content of converting to 4000 K lights, at least during the middle of the night, by reducing their output while still gaining the benefits of improved visibility, reduced energy and maintenance, and increased lifetime and reliability.

To summarize a few key takeaways:

- The spectral content of a light source determines its melanopic content and can thereby be used to help in selecting the associated level of melanopic content of a system. In contrast, while CCT is acceptable as a first approximation of spectral content, it is a less accurate measure of relative melanopic content than SPD. The significant overlap between melanopic contents of PC White LEDs at 3000 K and 4000 K in the table, for example, shows that simply substituting a 3000 K product for a 4000 K product may not necessarily accomplish the intended result.
- The "raw" melanopic content produced by a light source is only one contributor to any ensuing environmental or health impacts actually realized. Focusing exclusively on that measure (or any single measure, such as CCT) ignores the various means of controlling or offsetting the increased melanopic content of white light sources, and particularly those noted (e.g., greatly improved distribution, dimming capability) that are enabled by LED technology.
- The ranges in melanopic content available among LED products suggest that LEDs offer substantial flexibility towards tailoring them to the specific application.
- For a given light source, output from the luminaire is directly related to its emitted level of melanopic content, so reducing initial output (as in the Portland example) or dimming the system (as Cambridge does after midnight) offer direct, easily realized reductions in this regard.

The real value in LEDs, as has been stressed all along, comes from the combination of these elements. The wide-ranging capabilities and characteristics of LEDs are greater than any other lighting source that has come before them, and thus they offer unparalleled potential for addressing the issues raised by the AMA. As noted in the SSL Postings, LEDs are a critical part of the solution provided that these functionalities are applied. This is the message that should be shared.
I hope this information is helpful in planning and understanding the potential impacts of your own conversion efforts. I would like to extend my sincere thanks to George Brainard, Ph.D., and Robert Lucas, Ph.D., who reviewed and commented on this issue of The Light Post for accuracy. Their assistance is greatly appreciated.

Bruce Kinzey, MSSLC Director
Pacific Northwest National Laboratory
MSSLC@pnnl.gov
48% Lens "Blue"
IN LED 5000K.
(Compared to MH)

MH:
  Cu - 501 - .58
  Cu - 502 - .55

LED:
  Cu - 501 - .77
  Cu - 502 - .72

 Holy

LED #1: 330' x 198' = 77 grid points x 90 = 6,930
LED #2: 400' x 180' = 60 grid points x 90 = 54,000

LED #1: 1,386,000 lumens needed
  MH: 134,000 lumens
  1,239,000 lumens generated
  1,008,600 lumens not on target

LED #2: 1,080,000 lumens needed.
  MH: 134,000 lumens
  195,636 lumens generated
  883,036 lumens not on target

Total: 1,887,291 lumens not on target

MH: 39.68% Lumens not on target
  LED: 36.6% Lumens not on target

505 - 530nm - 457,824.6 lumens
301,491 lumens
# Lighting System

## Pole / Fixture Summary

<table>
<thead>
<tr>
<th>Pole ID</th>
<th>Pole Height</th>
<th>Mtg Height</th>
<th>Fixture Qty</th>
<th>Luminaire Type</th>
<th>Load</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1-S2</td>
<td>80'</td>
<td>80'</td>
<td>10</td>
<td>216 LED</td>
<td>5.97 kW</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>80'</td>
<td></td>
<td>1</td>
<td>228 LED</td>
<td>0.63 kW</td>
<td>A</td>
</tr>
<tr>
<td>S3</td>
<td>80'</td>
<td>80'</td>
<td>6</td>
<td>216 LED</td>
<td>3.58 kW</td>
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<td></td>
<td>80'</td>
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<td>3</td>
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<td></td>
<td>80'</td>
<td></td>
<td>6</td>
<td>228 LED</td>
<td>3.78 kW</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>80'</td>
<td></td>
<td>6</td>
<td>228 LED</td>
<td>3.78 kW</td>
<td>B</td>
</tr>
<tr>
<td>S4</td>
<td>80'</td>
<td>80'</td>
<td>3</td>
<td>216 LED</td>
<td>1.79 kW</td>
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<td></td>
<td>80'</td>
<td></td>
<td>5</td>
<td>216 LED</td>
<td>2.99 kW</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>80'</td>
<td></td>
<td>6</td>
<td>228 LED</td>
<td>3.78 kW</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>80'</td>
<td></td>
<td>7</td>
<td>228 LED</td>
<td>4.41 kW</td>
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<td>S5-S6</td>
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<td>80'</td>
<td>10</td>
<td>216 LED</td>
<td>5.97 kW</td>
<td>A</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>84</td>
<td></td>
<td>51.04 kW</td>
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## Group Summary

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
<th>Load</th>
<th>Fixture Qty</th>
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<tbody>
<tr>
<td>A</td>
<td>Soccer 1</td>
<td>27.96 kW</td>
<td>46</td>
</tr>
<tr>
<td>B</td>
<td>Soccer 2</td>
<td>23.08 kW</td>
<td>38</td>
</tr>
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</table>

## Fixture Type Summary

<table>
<thead>
<tr>
<th>Type</th>
<th>Source</th>
<th>Wattage</th>
<th>Lumens</th>
<th>L90</th>
<th>L80</th>
<th>L70</th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>228 LED</td>
<td>LED 5700K - 75 CRI</td>
<td>630W</td>
<td>63,600</td>
<td>33,000</td>
<td>&gt;42,000</td>
<td>&gt;42,000</td>
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<tr>
<td>216 LED</td>
<td>LED 5700K - 75 CRI</td>
<td>597W</td>
<td>63,600</td>
<td>33,000</td>
<td>&gt;42,000</td>
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## Light Level Summary

### Calculation Grid Summary

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<th>Ave</th>
<th>Min</th>
<th>Max</th>
<th>Max/Min</th>
<th>Groups</th>
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<td>0.00</td>
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<td>100' Spill</td>
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<td>84</td>
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<td>200' Spill</td>
<td>Horizontal</td>
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<td>0</td>
<td>0</td>
<td>0.00</td>
<td>A,B</td>
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<td>Max Candela (by Fixture)</td>
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<td>200' Spill</td>
<td>Max Vertical Illuminance</td>
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<td>0</td>
<td>0.01</td>
<td>0.00</td>
<td>A,B</td>
<td>84</td>
</tr>
<tr>
<td>Blanket Grid</td>
<td>Horizontal Illuminance</td>
<td>1.21</td>
<td>0</td>
<td>42</td>
<td>0.00</td>
<td>A</td>
<td>46</td>
</tr>
<tr>
<td>Blanket Grid</td>
<td>Max Candela (by Light Bank)</td>
<td>28933</td>
<td>0</td>
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<td>Soccer 1</td>
<td>Horizontal Illuminance</td>
<td>30.9</td>
<td>22</td>
<td>43</td>
<td>1.96</td>
<td>A</td>
<td>46</td>
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<tr>
<td>Soccer 2</td>
<td>Horizontal Illuminance</td>
<td>30.4</td>
<td>22</td>
<td>41</td>
<td>1.93</td>
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<td>38</td>
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<tr>
<td>Soccer 3</td>
<td>Horizontal Illuminance</td>
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<td>18</td>
<td>46</td>
<td>2.61</td>
<td>A</td>
<td>46</td>
</tr>
<tr>
<td>Soccer 4</td>
<td>Horizontal Illuminance</td>
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<td>Horizontal</td>
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<td>A,B</td>
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<td>Spill @ Pl</td>
<td>Max Candela (by Fixture)</td>
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<td>Spill @ Pl</td>
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<td>0.00</td>
<td>A,B</td>
<td>84</td>
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### EQUIPMENT LIST FOR AREAS SHOWN

<table>
<thead>
<tr>
<th>Pole</th>
<th>Location</th>
<th>Size</th>
<th>Elevation</th>
<th>Mounting Height</th>
<th>Luminaire Type</th>
<th>QTY</th>
<th>Pole</th>
<th>Grid</th>
<th>Other Grids</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1</td>
<td>80'</td>
<td>2'</td>
<td>78'</td>
<td>228 / 216 LED</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>S2</td>
<td>80'</td>
<td>2'</td>
<td>82'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td>12</td>
<td>9</td>
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</tr>
<tr>
<td>1</td>
<td>S3</td>
<td>80'</td>
<td>3'</td>
<td>77'</td>
<td>228 / 216 LED</td>
<td>23</td>
<td>12</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

**TOTALS:** 64

### ILLUMINATION SUMMARY

**MAINTAINED HORIZONTAL FOOTCANDLES**

- **Guaranteed Average:** 30
- **Scan Average:** 30.88
- **Maximum:** 43
- **Minimum:** 22
- **Avg / Min:** 1.41
- **Guaranteed Max / Min:** 3
- **Max / Min:** 1.96
- **UG (adjacent pts):** 1.82
- **No. of Points:** 77

### LUMINAIRE INFORMATION

- **Color / CRI:** 5700K - 75 CRI
- **Luminaire Output:** 63,600 / 63,600 lumens
- **Total LLF:** 1.000
- **No. of Luminaires:** 46
- **Total Load:** 27.96 kW

**Lumen Maintenance**

<table>
<thead>
<tr>
<th>Luminaire Type</th>
<th>L90 hrs</th>
<th>L80 hrs</th>
<th>L70 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>228 LED</td>
<td>33,000</td>
<td>&gt;42,000</td>
<td>&gt;42,000</td>
</tr>
<tr>
<td>216 LED</td>
<td>33,000</td>
<td>&gt;42,000</td>
<td>&gt;42,000</td>
</tr>
</tbody>
</table>

*Reported per TM-21-11. See cutsheets for details.*

**Guaranteed Performance:** The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

**Field Measurements:** Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

**Electrical System Requirements:** Refer to Amperage Draw Chart and/or the "Musco Control System Summary" for electrical sizing.

**Installation Requirements:** Results assume +/- 5% nominal voltage at line side of the driver and structures located within 3 feet (1m) of design locations.
Arlington County Williamsburg Middle Soccer Fields
Arlington, VA

GRID SUMMARY
Name: Soccer 2
Size: 300' x 180'
Spacing: 30.0' x 30.0'
Height: 3.0' above grade

ILLUMINATION SUMMARY
MAINTAINED HORIZONTAL FOOTCANDLES
Entire Grid
Guaranteed Average: 30
Scan Average: 30.41
Maximum: 41
Minimum: 22
Avg / Min: 1.41
Guaranteed Max / Min: 3
Max / Min: 1.93
UG (adjacent pts): 1.73
No. of Points: 60

LUMINAIRE INFORMATION
Color / CRI: 5700K - 75 CRI
Luminaire Output: 63,600 / 63,600 lumens
Total LLF: 1.000
No. of Luminaires: 38
Total Load: 23.08 kW

Lumen Maintenance
Luminaire Type L90 hrs L80 hrs L70 hrs
228 LED 33,000 >42,000 >42,000
216 LED 33,000 >42,000 >42,000
Reported per TM-21-11. See cutsheets for details.

Guaranteed Performance: The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

Field Measurements: Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

Electrical System Requirements: Refer to Amperage Draw Chart and/or the "Musco Control System Summary" for electrical sizing.

Installation Requirements: Results assume +/- 5% nominal voltage at line side of the driver and structures located within 3 feet (1m) of design locations.

ENGINEERED DESIGN By: W.VICE • File #166262B • 19-Jan-16

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Arlington County Williamsburg Middle Soccer Fields

GRID SUMMARY

<table>
<thead>
<tr>
<th>No. of Luminaires: 46</th>
</tr>
</thead>
<tbody>
<tr>
<td>UG (adjacent pts): 1580.37</td>
</tr>
<tr>
<td>No. of Points: 900</td>
</tr>
<tr>
<td>TCC: 0.90</td>
</tr>
<tr>
<td>CU: 0.60</td>
</tr>
</tbody>
</table>

ILLUMINATION SUMMARY

| Field
| Cutsheet 
Max | Min |
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
</tr>
<tr>
<td>Avg</td>
</tr>
</tbody>
</table>

Electrical System Requirements:

- Rated by Manufacturer
- Refer to Amperage Chart and the "Musco Control System Summary"
- Includes lighting, fire, and security systems.

Installation Requirements:

- Results assume +/- 5% normal voltage at line side of the driver and structures located within 3 feet (1m) of design locations.
- Guaranteed Performance: The ILLUMINATION described above is guaranteed per year for the warranty time period.
- Warranty determined per annual maintenance schedule.
- Dimensions accurate to ±0.5%.
**ILLUMINATION SUMMARY**

**LUMINAIRE INFORMATION**

- **Luminaire Output:** 63,600 / 63,600 lumens
- **Scan Average:** 216 LED 33,000
- **No. of Points:** 900
- **Color / CRI:** 5700K - 75 CRI
- **Total Load:** 27.96 kW
- **Guaranteed Performance:** The ILLUMINATION described above is guaranteed per year. Warranty document includes 0.09% overall ILEX output failure.
- **Field Measurements:** Individual field measurements may vary from construction calculations and should be taken for accuracy.
- **Electrical System Requirements:** Refer to Appendix for direct and indirect light for electrical sizing.
- **Installation Requirements:** Results assume ±10% nominal voltage at line side of the phases and fixtures located within a foot (30 cm) of their locations.

---

**GRID SUMMARY**

- **Dimensions:** Scale in feet 1:150
- **Total Loads:** 27 kW max
- **Period:** 0.09%
- **Location:** Arlington County Williamsburg Middle Soccer Fields

---

**EQUIPMENT LIST FOR AREAS SHOWN**

<table>
<thead>
<tr>
<th>ANCHOR</th>
<th>POLE</th>
<th>GRIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

---

**ILLUMINATION SUMMARY**

- **Scan Average:** 216 LED 33,000
- **Color / CRI:** 5700K - 75 CRI
- **Total Load:** 27.96 kW
- **Guaranteed Performance:** The ILLUMINATION described above is guaranteed per year. Warranty document includes 0.09% overall ILEX output failure.

---

**GRID SUMMARY**

- **Dimensions:** Scale in feet 1:150
- **Total Loads:** 27 kW max
- **Period:** 0.09%
- **Location:** Arlington County Williamsburg Middle Soccer Fields

---

**EQUIPMENT LIST FOR AREAS SHOWN**

<table>
<thead>
<tr>
<th>ANCHOR</th>
<th>POLE</th>
<th>GRIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
EQUIPMENT LIST FOR AREAS SHOWN

<table>
<thead>
<tr>
<th>QTY</th>
<th>LOCATION</th>
<th>SIZE</th>
<th>GRADE</th>
<th>ELEVATION</th>
<th>MOUNTING</th>
<th>HEIGHT</th>
<th>LUMINAIRE TYPE</th>
<th>QTY / POLE</th>
<th>THIS GRID</th>
<th>OTHER GRIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1</td>
<td>80'</td>
<td>-80'</td>
<td>228 / 216 LED</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>S2</td>
<td>80'</td>
<td>-2'</td>
<td>78'</td>
<td>228 / 216 LED</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>S3</td>
<td>80'</td>
<td>2'</td>
<td>82'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>S4</td>
<td>80'</td>
<td>-3'</td>
<td>77'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>S5-S6</td>
<td>80'</td>
<td>1'</td>
<td>81'</td>
<td>216 LED</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>TOTALS</td>
<td></td>
<td></td>
<td>84</td>
<td>84</td>
<td>0</td>
<td>0</td>
<td>84</td>
<td>84</td>
<td>0</td>
</tr>
</tbody>
</table>

Guaranteed Performance: The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

Field Measurements: Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

Electrical System Requirements: Refer to Amperage Chart and/or the "Musco Control System Summary" for electrical sizing.

Installation Requirements: Results assume ±5% nominal voltage at line side of the driver and structures located within 3 feet (1m) of design locations.
EQUIPMENT LIST FOR AREAS SHOWN

<table>
<thead>
<tr>
<th>QTY</th>
<th>LOCATION</th>
<th>SIZE</th>
<th>GRADE</th>
<th>ELEVATION</th>
<th>MOUNTING HEIGHT</th>
<th>LUMINAIRE TYPE</th>
<th>QTY / POLE</th>
<th>THIS GRID</th>
<th>OTHER GRIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1</td>
<td>80'</td>
<td>-2'</td>
<td>228'-216'</td>
<td>228 / 216 LED</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>80'</td>
<td>-3'</td>
<td>78'-77'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>80'</td>
<td>2'</td>
<td>82'-80'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S4</td>
<td>80'</td>
<td>-4'</td>
<td>77'-76'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S5-S6</td>
<td>80'</td>
<td>2'</td>
<td>81'-80'</td>
<td>216 LED</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TOTALS

<table>
<thead>
<tr>
<th>QTY</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tr>
<td>84</td>
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<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GRID SUMMARY

Name: Spill @ PL
Spacing: 30.0'
Height: 8.0' above grade

MAINTAINED MAX VERTICAL FOOTCANDLES

Scan Average: 0.0048
Maximum: 0.12
Minimum: 0.00
No. of Points: 142

LUMINAIRE INFORMATION

Color / CRI: 5700K - 75 CRI
Luminaire Output: 63,600 / 63,600 lumens
Total LLF: 1.000
No. of Luminaires: 84
Total Load: 51.04 kW

Lumen Maintenance

Luminaire Type L90 hrs L80 hrs L70 hrs
228 LED 33,000 >42,000 >42,000
216 LED 33,000 >42,000 >42,000

Reported per TM-21-11. See cutsheets for details.

Guaranteed Performance: The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

Field Measurements: Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

Electrical System Requirements: Refer to Amperage Chart and/or the "Musco Control System Summary" for electrical sizing.

Installation Requirements: Results assume +/- 5% normal voltage at line side of the drivers and structures located within 3 feet (1m) of design locations.
ELEVATION

GRADE

MOUNTING

LUMINAIRE

GRID

OTHER

Guaranteed Performance: The ILLUMINATION shown above is guaranteed per our Terms and Conditions. Actual performance may vary due to site conditions. Initial performance may vary due to site conditions. Initial performance may vary due to site conditions.

Field Measurements: Individual fixture measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-66-04.

Electrical System Requirements: Refer to the "Musco Electrical System Summary" for electrical sizing.

Installation Requirements: Results assume +/- 5% normal voltage at line side of the driver and structures located within 3 feet (1m) of design locations.

Arlington County Williamsburg Middle Soccer Fields
Arlington, VA
Arlington County Williamsburg Middle Soccer Fields
Arlington, VA
ILLUMINATION SUMMARY

EQUIPMENT LIST FOR AREAS SHOWN

Pole Luminaires

<table>
<thead>
<tr>
<th>QTY</th>
<th>LOCATION</th>
<th>SIZE</th>
<th>GRADE</th>
<th>ELEVATION</th>
<th>MOUNTING HEIGHT</th>
<th>LUMINAIRE TYPE</th>
<th>QTY / POLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1</td>
<td>80'</td>
<td>-</td>
<td>80'</td>
<td>228 / 216 LED</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>1</td>
<td>S2</td>
<td>80'</td>
<td>-2'</td>
<td>78'</td>
<td>228 / 216 LED</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>1</td>
<td>S3</td>
<td>80'</td>
<td>2'</td>
<td>82'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>1</td>
<td>S4</td>
<td>80'</td>
<td>-3'</td>
<td>77'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>S5-S6</td>
<td>80'</td>
<td>1'</td>
<td>81'</td>
<td>216 LED</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

TOTALS: 84

Guaranteed Performance: The ILLUMINATION described above is guaranteed per your Musco Warranty Document and includes a 0.95 dirt depreciation factor.

Field Measurements: Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

Electrical System Requirements: Refer to Amperage Chart and/or the "Musco Control System Summary" for electrical sizing.

Installation Requirements: Results assume +/- 5% nominal voltage at line side of the driver and structures located within 5 feet (1m) of design locations.

We Make It Happen.

Always start with a solid foundation.

Musco Lighting
EQUIPMENT LIST FOR AREAS SHOWN

<table>
<thead>
<tr>
<th>ART</th>
<th>QTY</th>
<th>QTP</th>
<th>SIZE</th>
<th>ELEV.</th>
<th>LOC</th>
<th>MOUNTING</th>
<th>HEIGHT</th>
<th>LUMINAIRE</th>
<th>QTY / POLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1</td>
<td>80'</td>
<td>80' - 80'</td>
<td>228 / 216 LED</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>S2</td>
<td>1</td>
<td>80'</td>
<td>80' - 8'</td>
<td>228 / 216 LED</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>S3</td>
<td>1</td>
<td>80'</td>
<td>80' - 2'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>S4</td>
<td>1</td>
<td>80'</td>
<td>80' - 3'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>S5-S6</td>
<td>2</td>
<td>80'</td>
<td>80' - 1'</td>
<td>216 LED</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

TOTALS: 84

Guaranteed Performance: The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

Field Measurements: Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

Electrical System Requirements: Refer to Amperage Draw Chart and/or the "Musco Control System Summary" for electrical sizing.

Installation Requirements: Results assume +/- 5% nominal voltage at line side of the driver and structures located within 3 feet (1m) of design locations.
cosystem Lighting

**ILLUMINATION SUMMARY**

Not to be reproduced in whole or part without the written consent of Musco Sports Lighting, LLC. ©1981, 2016 Musco Sports Lighting, LLC.

**ENGINEERED DESIGN**
By: W.VICE  File #166262B  19-Jan-16

---

**GRID SUMMARY**

**Name:** 200' Spill  
**Spacing:** 30.0'  
**Height:** 3.0' above grade

---

**ILLUMINATION SUMMARY**

**MAINTAINED CANDELA (PER FIXTURE)**

<table>
<thead>
<tr>
<th>Overall Grid</th>
<th>Scan Average</th>
<th>Maximum</th>
<th>Minimum</th>
<th>No. of Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>179.7022</td>
<td>1746.95</td>
<td>0.00</td>
<td>104</td>
</tr>
</tbody>
</table>

---

**LUMINAIRE INFORMATION**

<table>
<thead>
<tr>
<th>Color / CRI</th>
<th>Luminaire Output</th>
<th>Total LLF</th>
<th>No. of Luminaires</th>
<th>Total Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>5700K - 75 CRI</td>
<td>63,600 / 63,600 lumens</td>
<td>1.000</td>
<td>84</td>
<td>51.04 kW</td>
</tr>
</tbody>
</table>

---

**Lumen Maintenance**

<table>
<thead>
<tr>
<th>Luminaire Type</th>
<th>L90 hrs</th>
<th>L80 hrs</th>
<th>L70 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>228 LED</td>
<td>&gt;42,000</td>
<td>&gt;42,000</td>
<td></td>
</tr>
<tr>
<td>216 LED</td>
<td>&gt;42,000</td>
<td>&gt;42,000</td>
<td></td>
</tr>
</tbody>
</table>

---

Reported per TM-21-11. See cutsheets for details.

---

**Guaranteed Performance:** The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

---

**Field Measurements:** Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

---

**Electrical System Requirements:** Refer to Amperage Draw Chart and/or the "Musco Control System Summary" for electrical sizing.

---

**Installation Requirements:** Results assume +/- 5% nominal voltage at line side of the above and structures located within 3 feet (1m) of design locations.
**EQUIPMENT LIST FOR AREAS SHOWN**

<table>
<thead>
<tr>
<th>Pole Location</th>
<th>QTY</th>
<th>LOCATION</th>
<th>SIZE</th>
<th>GRADE</th>
<th>ELEVATION</th>
<th>MOUNTING</th>
<th>HEIGHT</th>
<th>LUMINAIRE TYPE</th>
<th>QTY / POLE</th>
<th>THIS GRID</th>
<th>OTHER GRIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1</td>
<td></td>
<td>80'</td>
<td>-</td>
<td>79'</td>
<td></td>
<td></td>
<td>228 / 216 LED</td>
<td>11</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>S2</td>
<td>1</td>
<td></td>
<td>80'</td>
<td>-2'</td>
<td>78'</td>
<td></td>
<td></td>
<td>228 / 216 LED</td>
<td>21</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>S3</td>
<td>1</td>
<td></td>
<td>80'</td>
<td>2'</td>
<td>82'</td>
<td></td>
<td></td>
<td>228 / 216 LED</td>
<td>21</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>S4</td>
<td>1</td>
<td></td>
<td>80'</td>
<td>-3'</td>
<td>77'</td>
<td></td>
<td></td>
<td>228 / 216 LED</td>
<td>21</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>S5-S6</td>
<td>2</td>
<td></td>
<td>80'</td>
<td>1'</td>
<td>81'</td>
<td></td>
<td></td>
<td>216 LED</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

**TOTALS**

| QTY | 84  |

**GRID SUMMARY**

- **Name:** 100' Spill
- **Spacing:** 30.0’
- **Height:** 3.0’ above grade

**ILLUMINATION SUMMARY**

- **MAINTAINED HORIZONTAL FOOTCANDLES**
  - **Scan Average:** 0.0200
  - **Maximum:** 0.13
  - **Minimum:** 0.00
  - **No. of Points:** 77

- **LUMINAIRE INFORMATION**
  - **Color / CRI:** 5700K - 75 CRI
  - **Luminaire Output:** 63,600 / 63,600 lumens
  - **Total LLF:** 1.000
  - **No. of Luminaires:** 84
  - **Total Load:** 51.04 kW

- **Lumen Maintenance**
  - **Luminaire Type**
  - **L90 hrs**
  - **L80 hrs**
  - **L70 hrs**
    - 228 LED: 33,000 > 42,000 > 42,000
    - 216 LED: 33,000 > 42,000 > 42,000

Reported per TM-21-11. See cutsheets for details.

**Guaranteed Performance:** The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

**Field Measurements:** Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

**Electrical System Requirements:** Refer to Amperage Chart and/or the "Musco Control System Summary" for electrical sizing.

**Installation Requirements:** Results assume +/- 5% normal voltage at line side of the driver and structures located within 5 feet (1.5m) of design locations.
EQUIPMENT LIST FOR AREAS SHOWN

<table>
<thead>
<tr>
<th>QTY</th>
<th>LOCATION</th>
<th>SIZE</th>
<th>GRADE</th>
<th>ELEVATION</th>
<th>MOUNTING HEIGHT</th>
<th>LUMINAIRE TYPE</th>
<th>QTY / POLE</th>
<th>THIS GRID</th>
<th>OTHER GRIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1</td>
<td>80'</td>
<td>-</td>
<td>80'</td>
<td>228 / 216 LED</td>
<td>11</td>
<td>1</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>S2</td>
<td>80'</td>
<td>-</td>
<td>2'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>S3</td>
<td>80'</td>
<td>-</td>
<td>2'</td>
<td>228 / 216 LED</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>S4-S6</td>
<td>80'</td>
<td>-</td>
<td>3'</td>
<td>216 LED</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>84</td>
<td>84</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Guaranteed Performance: The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

Field Measurements: Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

Electrical System Requirements: Refer to Amperage Draw Chart and/or the "Musco Control System Summary" for electrical sizing.

At time of design, each pole location(s) dimensions are relative to 0,0 reference point(s).

Arlington County Williamsburg Middle Soccer Fields
Arlington, VA

GRID SUMMARY

Name: 100' Spill
Spacing: 30.0'
Height: 3.0' above grade

ILLUMINATION SUMMARY

MAINTAINED CANDELA (PER FIXTURE)
Ensemble Scan Average: 4388.8174
Maximum: 20571.80
Minimum: 0.00
No. of Points: 77

LUMINAIRE INFORMATION

Color / CRI: 5700K - 75 CRI
Luminaire Output: 63,600 / 63,600 lumens
Total LLF: 1.000
No. of Luminaires: 84
Total Load: 51.04 kW

Lumen Maintenance

<table>
<thead>
<tr>
<th>Luminaire Type</th>
<th>L90 hrs</th>
<th>L80 hrs</th>
<th>L70 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>228 LED</td>
<td>&gt;42,000</td>
<td>&gt;42,000</td>
<td></td>
</tr>
<tr>
<td>216 LED</td>
<td>&gt;42,000</td>
<td>&gt;42,000</td>
<td></td>
</tr>
</tbody>
</table>

Reported per TM-21-11. See cutsheets for details.

Guaranteed Performance: The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

Field Measurements: Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

Electrical System Requirements: Refer to Amperage Draw Chart and/or the "Musco Control System Summary" for electrical sizing.

Installation Requirements: Results assume +/- 5% nominal voltage at line side of the driver and structures located within 3 feet (1m) of design locations.

Arlington County Williamsburg Middle Soccer Fields
Arlington, VA

GRID SUMMARY

Name: 100' Spill
Spacing: 30.0'
Height: 3.0' above grade

ILLUMINATION SUMMARY

MAINTAINED CANDELA (PER FIXTURE)
Ensemble Scan Average: 4388.8174
Maximum: 20571.80
Minimum: 0.00
No. of Points: 77

LUMINAIRE INFORMATION

Color / CRI: 5700K - 75 CRI
Luminaire Output: 63,600 / 63,600 lumens
Total LLF: 1.000
No. of Luminaires: 84
Total Load: 51.04 kW

Lumen Maintenance

<table>
<thead>
<tr>
<th>Luminaire Type</th>
<th>L90 hrs</th>
<th>L80 hrs</th>
<th>L70 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>228 LED</td>
<td>&gt;42,000</td>
<td>&gt;42,000</td>
<td></td>
</tr>
<tr>
<td>216 LED</td>
<td>&gt;42,000</td>
<td>&gt;42,000</td>
<td></td>
</tr>
</tbody>
</table>

Reported per TM-21-11. See cutsheets for details.

Guaranteed Performance: The ILLUMINATION described above is guaranteed per your Musco Warranty document and includes a 0.95 dirt depreciation factor.

Field Measurements: Individual field measurements may vary from computer-calculated predictions and should be taken in accordance with IESNA LM-5-04.

Electrical System Requirements: Refer to Amperage Draw Chart and/or the "Musco Control System Summary" for electrical sizing.

Installation Requirements: Results assume +/- 5% nominal voltage at line side of the driver and structures located within 3 feet (1m) of design locations.
GLARE IMPACT

Map indicates the maximum candela an observer would see when facing the brightest light source from any direction.

A well-designed lighting system controls light to create visual comfort in a field of operation with minimal destructive off-site glare.
Ambient Light Levels taken at the Property Line February 29, 2016

Ambient Light Levels Taken on February 29th, 2016 by Joe Forche, Stephen Baker, and members of WFWG using a Gossen Mavolux Light Meter 5032C (Serial #3C15706) Calibrated November 6th, 2015.

The .02 fc down the property line were due to a neighboring property with existing LED lights attached to the back fence. In addition, the .02 fc and 1.5 fc respectively along the street and the southernmost border of this illustration were due to existing street lighting.
Existing Ambient light levels with the addition of Property line Spill from Photometric plan

The following represents the addition of the property line spill light levels from the Photometric Plan using 80’ poles at 30fc horizontal average on the playing surface combined with the existing Ambient Light Levels Taken on February 29th, 2016 by Joe Forche, Stephen Baker, and members of WFWG using a Gossen Mavolux Light Meter 5032C (Serial #3C15706) Calibrated November 6th, 2015. The figures illustrate combined maximum horizontal spill light at the property line.