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RCHITECTURAL INFORMATION

BLUE LIGHT HAZARDS AND TELEVISION

Ian Ashdown, P. Eng., FIES, Senior Scientist, SunTracker Technologies Ltd. Published: 2017/05/19

If you have grandchildren, you may be old enough to remember “black and white” (that is, monochrome) televisions sets with rabbit ear antennae and some of the worst children’s television programming that has ever been produced. Iconic programs such as Captain Kangaroo, Mighty Mouse, Howdy Doody … “Hey kids! What time is it? It’s Howdy Doody Time!”

”

FIG. 1 – Howdy Doody, NBC television star (1947 – 1960).

Having grown up in the 1950s, I will not – no, I refuse to – explain the premise of the Howdy Doody show or any of its ilk. Suffice it to say that North American parents of that time were savvy enough to understand that children enraptured by moving images on a television screen were slightly more manageable than when we were charging around the house playing ethnically-insensitive “cowboys and Indians” with our cap guns and tomahawks.

If we were admonished at all, it was with the common refrain, “Don’t sit so close to the TV, you’ll hurt your eyes!” It was, however, of no use; we would have willingly glued our noses to the cathode ray tube (CRT) glass screens for hours on end if Krazy Glue® had been invented then (FIG. 2).

FIG. 2 – Television in the 1950s.

To our parents’ everlasting surprise, we somehow managed to survive into adulthood and appreciate better television programming. If they were around today, they would have smiled at the thought of our children and grandchildren gluing their noses to tablet computer and smartphone displays for hours on end … some things never change.
Truly, some things do not change. Today, parents and grandparents alike fret over the “blue light hazard” inherent in computer displays. We panic when we are shown spectral power distributions for tablet computers, such as those for the Apple iPad® shown in Figure 3.

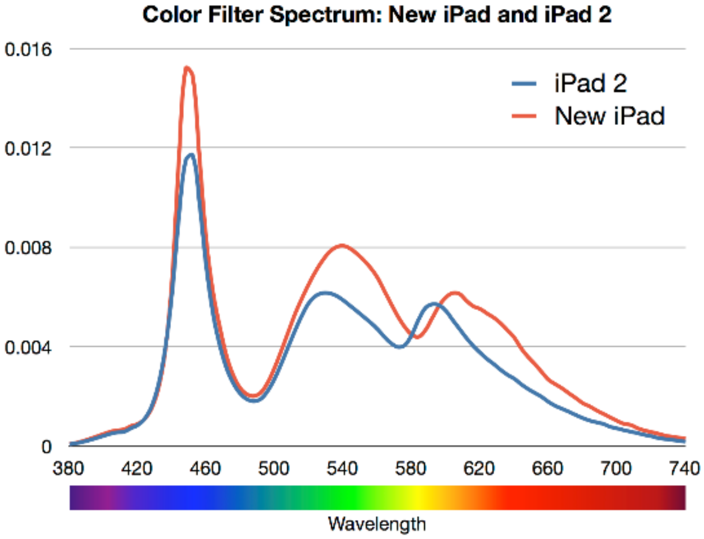


FIG. 3 – Typical tablet spectral power distribution.

“Look at that blue peak! Compared to incandescent lighting or even the spectral power distribution of daylight, it is horrific! Surely it will damage our children’s eyes!”
Well … no. Having survived the 1950s, I can all but assure you that this will not happen. I recall endless hours staring at the television screen at point-blank range, no different than what most children (and adults) do today. Television in the 1950s was a technology in its infancy, something that was only possible with the development of a phosphor called JEDEC Phosphor P4-Sulphide1. You could always tell if your neighbors were watching television by the blue flickering light emanating from their living room windows.

Blue? Yes, the “white point” color temperature of P4-sulphide phosphors was an eye-searing 11,000 kelvins. If you think daylight LED lamps with their 5000K CCTs are “too cold,” just think of what we children suffered through before our parents finally bought color televisions in the mid-1960s.
But wait, it gets worse! Remember what I said about “some things never change?” Well then, have a look at Figure 4.

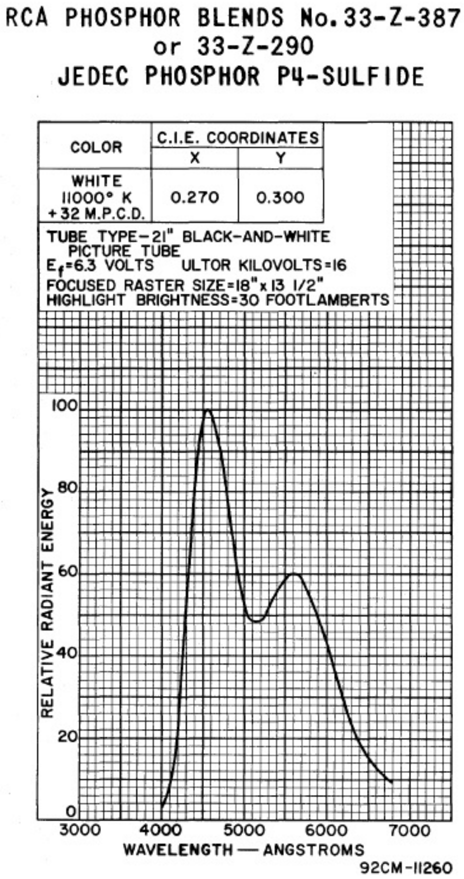


FIG. 4 – JEDEC P4-sulphide phosphor spectral power distribution.

“Look at that blue peak! Surely it will damage our children’s eyes!” If only our parents knew the hazards they were exposing us to (in addition to the cancer-causing cocktail of chemicals in our TV dinners and desserts).

There is, of course, no relation between the technologies of monochrome CRT phosphors and phosphor-based white light LEDs. White-light LEDs consist of blue “pump” LEDs and yttrium-aluminum-garnet (YAG) or similar phosphors, while P4 was a blend of blue-emitting and yellow-emitting phosphors that were excited by an electron beam. Still, you could easily mistake Figure 4 for the spectral power distribution of a 11,000K white light LED.

Now to be fair, this is entirely anecdotal information. I do not have information on the number of hours per day we “baby boomers” spent as kids watching television compared to how many hours a day we spend in front of our computer displays. All I am willing to say is that we (mostly) survived, and we smile when we see you and your kids emulating our television viewing habits of sixty years ago.

References

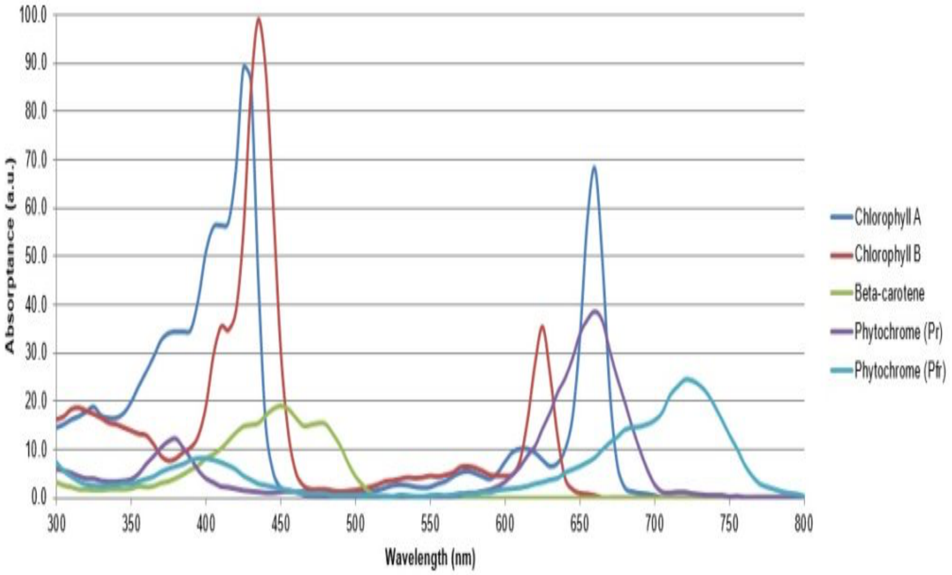
RCA. 1961. RCA Phosphors for Cathode-Ray Tubes, Black-and-White and Color Picture Tubes, and Other Applications. Harrison, NJ: Radio Corporation of America.

1 JEDEC is the Joint Electron Device Engineering Council. Formed in 1958 as a standards organization, it remains today the “technical voice of the semiconductor industry.”

H ORTICULTURAL INFORMATION

HORTICULTURAL LIGHTING METRICS

Ian Ashdown, P. Eng., FIES, Senior Scientist, SunTracker Technologies Ltd. Published: 08/04/2017



UPDATE 17/08/26 – This article was first published on August 25th, 2017 in Urban Ag News.

It was all so easy until recently. Plants require light in order to grow, and so we provided them with daylight and/or electric lighting. Given the singular choice of high-pressure sodium (HPS) lamps, we only needed to be concerned about measuring Photosynthetically Active Radiation (PAR) and Daily Light Integrals (DLI).

The introduction of light-emitting diodes (LEDs) and solid-state lighting (SSL) has changed everything. With the ability to independently control the light source spectrum from ultraviolet through visible light to far-red, researchers and growers are discovering that plant species and even cultivars respond differently to different spectral power distributions. From these discoveries are coming ìlight recipesî for optimal plant growth and health.

Light recipes require more than a pinch of salt and a dash of cayenne, however. We need to measure and quantify the light received by plants, much as professional lighting designers have long measured and quantified light for building interiors and outdoor areas. These designers have numerous of metrics to call upon, all of them based on the human perception of visible light. Unfortunately, plants do not respond to light as we do, and so units of measurements such as lumens, lux, and candela are all but meaningless for horticultural lighting.

Given this, the American Society of Agricultural and Biological Engineers has just announced the publication of ANSI/ASABE S640 JUL 2017, *QUANTITIES AND UNITS OF ELECTROMAGNETIC RADIATION FOR PLANTS (PHOTOSYNTHETIC ORGANISMS)*. Developed over two years by an international team of experts from industry and academia, this standard brings some much-needed order to the metrics of horticultural lighting.

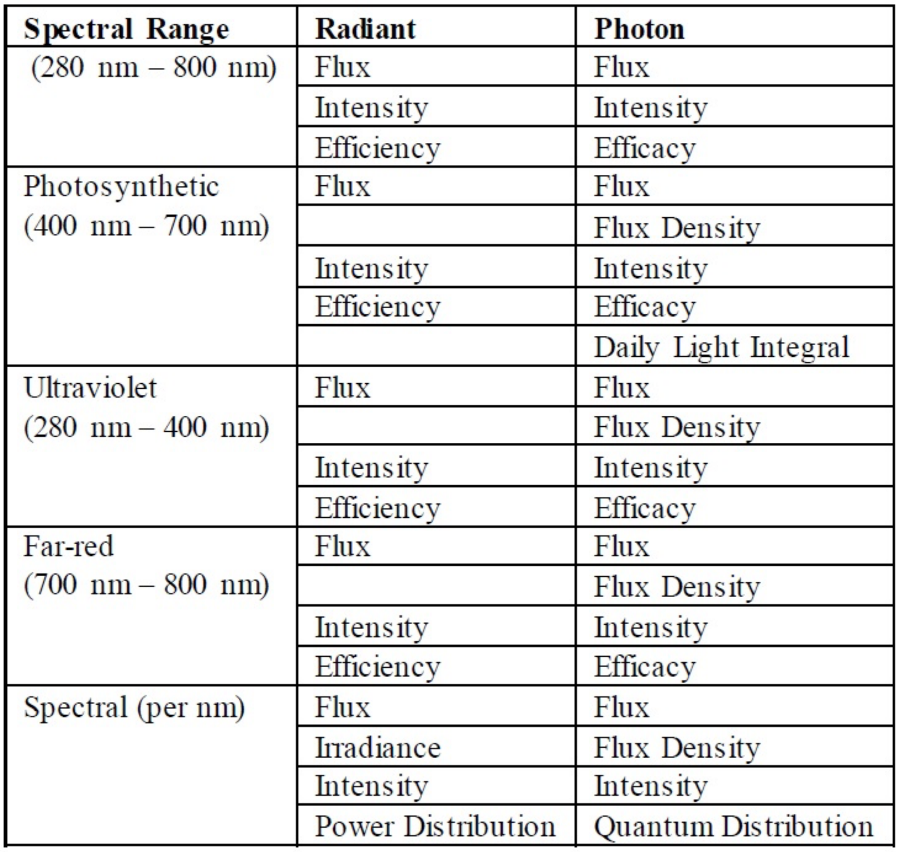
The document formally defines 33 electromagnetic radiation metrics for horticultural lighting. They are fully compatible with metrics previously defined by standards from the American Society of Agricultural Engineers (precursor of the ASABE), the Illuminating Engineering Society (IES), the Commission Internationale díEclairage (CIE), and the International Organization for Standards (ISO). They are, however, specific to the needs of horticulture and plant biology.

What we perceive as visible light spans the electromagnetic spectrum with wavelengths from 400 nm (deep blue) to 700 nm (deep red). Coincidentally, this is the same range over which plant photosynthesis occurs. Outside of this range, plants respond to ultraviolet and far-red radiation. The P_{fr} isoform of phytochrome, for example, has a peak spectral absorptance of 735 nm, and is responsible for initiating many photomorphogenetic functions. Similarly, the photopigment UVR8 is responsible for sensing excess UV-B radiation (280 nm – 315 nm) and initiating plant stress responses to prevent DNA damage. With this, the metrics are therefore divided into three spectral ranges: ultraviolet (280 nm – 400 m), photosynthetic (400 nm – 700 nm), and far-red (700 nm – 800 nm).

The other division of the metrics is based on radiant versus photon flux. Every photon has a specific wavelength (e.g., 555 nm), and its energy (stated in watt-seconds, or joules) is inversely proportional to its wavelength. Plant photosynthesis does not care about photon energy, however ñ the chlorophyll molecule absorbs the photon for its chemical action and releases any excess energy as heat. Thus, horticulturalists and plant biologists are interested in the flow (or “photon flux”) of photons per second, with no regard for wavelength. This flux is measured in micromoles (6.23×10^{17}) of photons per second with a broadband “quantum sensor,” typically a silicon photodiode with an optical filter.

Forest ecologists, on the other hand, are often interested in the energy of sunlight incident on the forest canopy, and so they measure electromagnetic radiation in terms of “radiant flux,” stated in watts. Here, wavelength matters, with blue light photons having more energy than red light photons. A broadband sensor, again typically a silicon photodiode with an optical filter, is used to measure radiant flux over the spectral range of interest.

It is also important to be able to measure and quantify the spectral power distribution of light sources with a spectroradiometer. In one recent study, for example, a difference of 10 nm in the peak wavelength of green LEDs (520 nm versus 530 nm) had a pronounced effect on the growth and development of red leaf lettuce (Johkan et al. 2012). We therefore have both spectral radiant flux and spectral photon flux, measured in watts per nanometer and micromoles per second per nanometer respectively.
With these divisions, we have the following horticultural lighting metrics defined by ANSI/ASABE S640:



Spectral Range	Radiant	Photon
(280 nm – 800 nm)	Flux	Flux
	Intensity	Intensity
	Efficiency	Efficacy
Photosynthetic (400 nm – 700 nm)	Flux	Flux
		Flux Density
	Intensity	Intensity
	Efficiency	Efficacy
		Daily Light Integral
Ultraviolet (280 nm – 400 nm)	Flux	Flux
		Flux Density
	Intensity	Intensity
	Efficiency	Efficacy
Far-red (700 nm – 800 nm)	Flux	Flux
		Flux Density
	Intensity	Intensity
	Efficiency	Efficacy
Spectral (per nm)	Flux	Flux
	Irradiance	Flux Density
	Intensity	Intensity
	Power Distribution	Quantum Distribution

For now, horticulturalists will continue to measure PAR as photosynthetic photon flux density (PPFD) with a quantum sensor, and measure or calculate daily light integrals (integrated daily PPFD). However, ANSI/ASABE S640 is important in that it provides a framework with which to quantify forthcoming light recipes for optimal growth and health of urban agriculture crops.

Looking beyond light recipes, horticultural luminaire manufacturers will be able to quantify the optical performance characteristics of their products, and lighting design software developers will be able to develop products specifically for horticultural lighting design in greenhouses and vertical farms. It all begins, however, with horticultural lighting metrics.

ANSI/ASABE S640 is available for purchase from the ASABE Technical Library (https://elibrary.asabe.org).

References

Jokhan, M, et al. 2012. “Effect of Green Light Wavelength and Intensity on Photomorphogenesis and Photosynthesis in *LACTUCA SATIVA*,” Environmental and Experimental Botany 75:128-133.

GENERAL

INFORMATION

RETHINKING THE PHOTOMETRIC DATA FILE FORMAT

Ian Ashdown, P. Eng., FIES, Senior Scientist, SunTracker Technologies Ltd. Published: 2017/03/01

If you perform lighting design calculations today, you can thank the efforts of the IES Computer Committee (IESCC) some thirty years ago. Its members recognized an industry need, and so developed and published IES LM-63-86, IES Recommended Standard File Format for Electronic Transfer of Photometric Data. With the growing popularity of the IBM Personal Computer for business applications, it was an idea whose time had come.

The need was clear: Lighting Technologies (Boulder, CO) had released its *LUMEN MICRO* lighting design and analysis software product in 1982, and luminaire manufacturers needed to provide photometric data for their products. For them, IES LM-63 was a god-send in that it established an industry-standard file format[7].

In keeping with the technology of the time, the file format was human-readable ASCII text, something that could be printed with a dot-matrix printer. It also resulted in files of only a few kilobytes, a definite advantage when data files were transferred by mail on 5-1/4 inch floppy diskettes capable of holding 360 kilobytes of data. The file format itself revealed something of its origins by limiting line lengths to 80 characters — the width of an IBM Hollerith punch card in the 1960s (FIG. 1).

FIG. 1 – IBM Hollerith 80-character punch cards

Thirty years later, our personal computers are one thousand times faster, with one million times the memory capacity and ten million times more data storage capacity. Data is transferred by fiber optic cable and satellite links at gigahertz rates … and we are still using IES LM-63 photometric data files!

The "we," of course refers mostly to North America. In Europe, the equivalent file format is EULUMDAT, which was introduced in 1990 for use with Microsoft's MS-DOS 3.0 operating system[14]. Again, in keeping with the technology of the time, it was also human-readable ASCII text.

It is a testament to something … exactly what is unclear … that these two file formats have met the lighting industry's needs for so long. Coming from an era of floppy diskettes and dial-up modems with acoustic couplers (FIG. 2), they should have become extinct decades ago. (The Chartered Institute of Building Services Engineers in the United Kingdom introduced its CIBSE TM14 file format specification in 1988, but it has since slipped into obscurity[2].)

FIG. 2 – Modern communications technology circa 1986.

To be fair, LM-63 was revised in 1991, 1995, and 2002. These revisions, however, at best tweaked the file format specification to resolve various ambiguities and add a few minor features. What we have today is basically what was published in 1986, a time when the pinnacle of lamp technology was the compact fluorescent lamp with an electronic ballast.

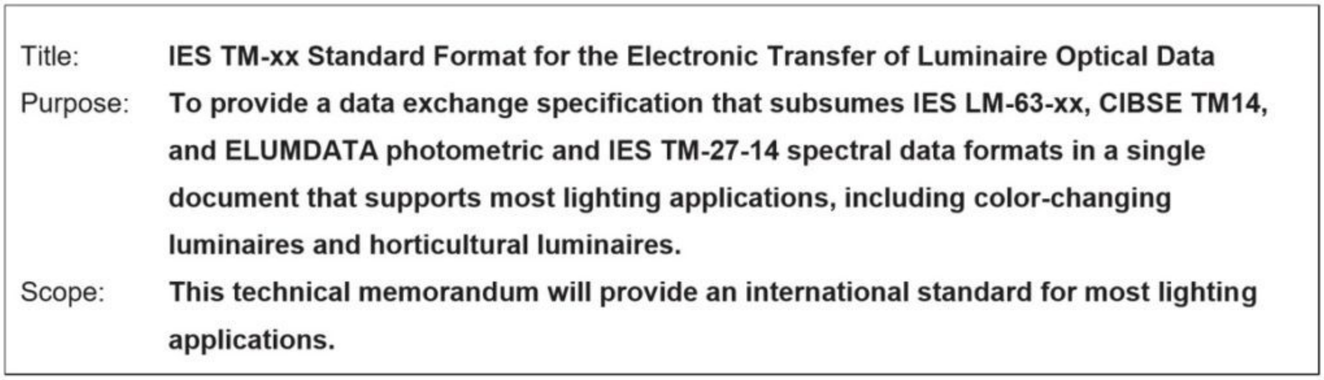
If the LM-63 file format has an advantage, it is that it is an ANSI/IES standard that is maintained by an internationally recognized standards organization. EULUMDAT, on the other hand, is a *DE FACTO* standard that has been essentially frozen in time since its publication in 1990[á]. Without the authority of a standards organization such as ANSI/IES or CEN (European Committee for Standardization) to maintain the file format, it can never be revised.

The problem is that while LM-63 and EULUMDAT are still useful in terms of characterizing architectural and roadway luminaires, the lighting industry has moved beyond luminous intensity distributions. As professional lighting designers, we now have to consider color-changing luminaires, theatrical lighting, human-centric lighting, horticultural lighting, ultraviolet sterilization units, radiant heating devices, and more. We need to consider spectral power distributions, radiant intensity, photon intensity, S/P ratios, melanopic lumens, color rendition metrics … the list goes on and on.

The LM-63 and EULUMDAT file formats are clearly incapable of characterizing light sources and luminaires for these applications. It is therefore time, indeed well past time, to rethink the photometric data file format.

Standards Development

In September 2016, the IESCC initiated a project to develop a new photometric data format from first principles. As is often the case with such projects, one or two members write an initial draft based on their expertise and knowledge. This draft document is reviewed, edited numerous times, and voted upon by the committee members. If approved as a project, the proposed project is again reviewed and voted upon by the IES Board of Directors. In January 2017, technical committee project IES TM-xx, Standard Format for the Electronic Transfer of Luminaire Optical Data, was officially approved (FIG. 3).



Title:	**IES TM-xx Standard Format for the Electronic Transfer of Luminaire Optical Data**
Purpose:	**To provide a data exchange specification that subsumes IES LM-63-xx, CIBSE TM14, and ELUMDATA photometric and IES TM-27-14 spectral data formats in a single document that supports most lighting applications, including color-changing luminaires and horticultural luminaires.**
Scope:	**This technical memorandum will provide an international standard for most lighting applications.**

FIG. 3 – IESCC project summary

Luminaire Component Data

Some readers may recognize this proposed standard from a previous incarnation known as IESNA LM-74-05, Standard File Format for the Electronic Transfer of Luminaire Component Data[8]. The IESCC worked on the development of this document for nearly a decade prior to its publication in 2005. It was ambitious effort to combine all aspects of luminaires into a single file, including far-field photometry, lamp and ballast information, physical geometry, construction materials and finishes, CAD drawings and photographs, and more.

Unfortunately, it was too ambitious. Despite the first release being focused on lamp data, the standard was never adopted by its intended audience of luminaire manufacturers, architects and engineers, lighting product specifiers, photometric testing laboratories, and lighting software developers. To the frustration of the IESCC members, the lighting industry at the time did not see a need for such a standard.

Today, we might look upon LM-74-05 as being an early example of a specialized building information management (BIM) schema, one that focused on a small subset of typically much larger datasets. (A document schema is conceptually equivalent to a file format.) The Green Building XML Schema (gbXML) for BIM applications provides an excellent example. Quoting from the gbXML Web site:

"The Green Building XML schema, or 'gbXML,' was developed to facilitate the transfer of building information stored in CAD-based building information models, enabling interoperability between disparate building design and engineering analysis software tools. This is all in the name of helping architects, engineers, and energy modelers to design more energy efficient buildings."

Unfortunately for lighting design professionals, the gbXML schema has an XML "element" (see below) called "Photometry," whose description reads:

> "This element has been left open for use with other photometry definitions. Photometric data is required for various forms of lighting analysis. This tag provides a way for the photometric data to be passed. Since this can be done in a variety of ways (iesna LM-63, cibse TM14, ELUMDAT, etc.) a specific format is not being specified."

Defining a new luminaire optical data format that is compatible with the gbXML schema therefore serves a clear and present need.

Understanding XML

The advantage of gbXML is that it is based on the international data exchange standard XML (eXtensible Markup Language)[15]. The details of this standard are complex and exhausting, but basically every XML document consists of text strings called "elements" such as:

```
<name>Alfred E. Neuman</name>
```

where the data is surrounded by begin and end "tags."

These elements can be arranged in a hierarchy, such as:

```
<person>
  <name>Alfred E. Neuman</name>
  <employer>MAD Magazine</employer>
</person>
```

In this example, the <person> element is the "parent," and any elements within it are its "children."

Building on this simplest of representations, virtually any type of data can be unambiguously represented within an XML document. If a person or computer program reading an XML document encounters an unknown element tag, the element and its children (if any) can simply be ignored.

This, of course, is the problem with including LM-63 or EULUMDAT text files verbatim (i.e., as a multiline text string) within gbXML or similar BIM documents. Yes, it can be done, but the computer program reading the document needs to be able to somehow identify and read these files. Designing IES TM-xx as an XML document resolves this problem.

Having chosen a suitable representation for TM-xx, we can now consider what it needs to represent.

Luminaire Optical Data

IES TM-xx represents the luminaire optical data in four sections:

1. Header
2. Luminaire
3. Equipment
4. Light source

Header

The header section includes information that is currently available in LM-63 and EULUMDAT files:

- Manufacturer
- Catalog number
- Description
- Test laboratory
- Report number
- Report date
- Document creator
- Document creation date
- Unique identifier
- Comments

Most of these elements are self-explanatory, with the exception of the "unique identifier" element. One of the problems with current photometric data files is that there is no version control. If a company reissues photometric data for a product, there is no way of distinguishing between files other than their file creation dates. If the files are copied for any reason, these dates can change.

The unique identifier element is a "Universally Unique IDentifier" (UUID) that uniquely identifies the TM-xx document, regardless of whether it has been copied as a file. While it does not prevent someone from intentionally modifying the document data, it at least solves the problem of multiple files with the same name.

The IESCC is currently considering the addition of search terms and possibly CAD symbols to the header section. These and other details may therefore result in changes to the draft release of TM-xx, but the basic structure discussed here will remain.

Luminaire

TM-xx represents the luminaire as a rectangular box or cylinder. The luminaire section therefore lists the dimensions of these geometric objects as length, width, and height. In addition, each face may include an emission area. These areas are useful for calculating visual glare metrics such as the CIE Unified Glare Rating (UGR)[5], and also for modeling the luminaire as one or more area sources or arrays of point sources for lighting calculations and visualization.

The luminaire section also includes the light center position with respect to the geometric center of the luminaire. (The light center represents the fixed position about which the goniometer rotates while performing intensity distribution measurements.)

Equipment

The equipment section describes the laboratory equipment used to perform the luminaire optical data measurements. These can include:

- Goniometer (intensity measurements)
- Integrating sphere (flux measurements)
- Spectroradiometer (spectral power distribution measurements)

and detailed information specific to these instruments.

Light Source

Photometric data files assume that the luminaire includes one or more removable lamps, but this concept does not apply to solid state lighting, which may have removable LED modules or non-removable LED arrays. For the purposes of TM-xx, these are collectively referred to as “light sources.” Following LM-63 and EULUMDAT, the information pertaining to them may include (as applicable):

- Quantity
- Description
- Catalog number
- Rated lumens
- Input wattage
- Tilt angle

In addition, the information may include correlated color temperature (CCT) values, color rendering metric values (Ra and R9 for CIE Colour Rendering[3] and Rf and Rg for IES Color Rendition[11]), and scotopic-to-photopic lumens (S/P) ratios[9]. (Note that these values may need to be expressed as ranges for variable color temperature light sources.) There are actually 14 CIE Colour Rendering Special Indices (R1 to R14), which may be required for special purposes. These can either be calculated by the user from the measured spectroradiometric data for the light source (see below), or represented by custom XML elements.

Spectroradiometric Data

A key requirement of the light source section is to represent the spectral power distribution (SPD) of the light source. Following IES TM-27-14, IES Standard Format for the Electronic Transfer of Spectral Data[10], the measured spectral radiant flux is reported for each wavelength.

Most SPDs are reported with constant wavelength intervals (e.g., 5 nm), but TM-xx does not impose such a restriction. Consequently, both continuous and line emission spectral features can be represented with arbitrary wavelength precision.

Intensity Data

With photometric data files, most of the data represents the luminous intensity measurements for vertical and horizontal angles. The same is true for TM-xx documents in the light source section except that, depending on the application, the intensity measurements may be based on luminous flux, radiant flux, photon flux[ß], or spectral radiant flux.

Luminous intensity distributions are expressed in lumens per steradian (i.e., candela), and are most useful for architectural and roadway lighting applications.
Radiant intensity distributions are expressed in watts per steradian, and are most useful in characterizing ultraviolet and infrared radiation sources for applications such as UV sterilization and radiant heating.

Photon intensity distributions are expressed in micromoles per steradian per second, and are most useful for horticultural lighting applications[1].
Both radiant and photon intensity are measured over a specified range of wavelengths. When photon intensity is measured over the range of 400 nm to 700 nm, it is equivalent to photosynthetically active radiation (PAR)[1].

Spectral radiant intensity distributions assign an SPD to each measurement for vertical and horizontal angles. Expressed in watts per steradian per nanometer, they are useful for representing the variation in color over viewing angle, such as occurs with phosphor-coated white light LEDs.

Finally, each intensity measurement is expressed as (for example):

```
<IntensityData horz="0.0" vert="0.0">109</IntensityData>
```

By explicitly expressing the vertical and horizontal angles for each measurement, there is no requirement for the data to be organized as a two-dimensional array of vertical angles and horizontal planes. This is important because some robotic goniometers are capable of measuring angular positions on a geodesic sphere and other complex angular patterns.

Exclusions

IES TM-xx differs from its predecessor LM-74-05 in that it focuses exclusively on luminaire optical data. This necessarily excludes other luminaire components and characteristics, including:

- Detailed physical dimensions
- Mechanical and structural data
- Materials and finishes
- Building code certifications
- CAD drawings
- Photographs and renderings
- Electronic ballasts and drivers
- Lighting controls and sensors

It would certainly be possible to include this information, but it comes at a price. Every time a component option is added to a product, it increases the number of product variations exponentially. If, for example, a lighting control has four ordering options, this potentially results in 16 different TM-xx documents.

With this, the design philosophy for TM-xx follows what Albert Einstein purportedly once said: “Everything should be made as simple as possible, but no simpler.” Given the purposeful extensibility of XML, it is always possible to add elements with custom tags for specific purposes. To avoid conflicts with identical tag names being used by other companies, an XML namespace can be used to uniquely identify the custom tags. With this, TM-xx is being designed to be “as simple as possible but no simpler.”

This design philosophy also extends to the intensity data. TM-xx optionally reports luminous, radiant, photon, and spectral radiant intensity, but not, for example, *MELANOPIC* intensity that is useful in human centric lighting applications[13].

The reason is that if you report melanopic intensity, you should arguably also report *CYANOPIC*, *CHLOROPIC*, *ERYTHROPIC*, and *RHODOPIC* intensity to represent to the responsivity of short-wavelength, (blue), medium-wavelength (green), and long-wavelength (red) cones and rods respectively in the human retina. (Melanopic intensity represents the responsivity of intrinsic retinal ganglion cells, or ipRGCs, to retinal irradiance.) This is, of course, an extreme example, but it illustrates the complexities that can arise in trying to satisfy every requirement.

Luminous, radiant, photon, and spectral radiant intensity are optionally reported because they are the most commonly used metrics in architectural, roadway, and horticultural lighting applications. All other intensity metrics can be calculated, if necessary, by appropriately weighting the spectral radiant intensity data.

Files versus Documents

Thirty years ago, almost all data was stored on magnetic media — floppy disks, hard disks, and magnetic tape. Data, whatever its form, was organized in the form of files. It therefore made sense to refer to photometric data files and file formats.

Today, data is stored on a variety of media, including magnetic, optical, solid state, and holographic devices. Long-term storage of data still requires data files and file formats, such as the default NTFS file system used by Microsoft Windows operating systems.

However, the data itself has become somewhat more amorphous. How it is organized better described as a document, a symbolic representation of the data.

Using gbXML as an example, an architect or engineer may assemble a temporary BIM document by linking together information from various manufacturers. The BIM program sends requests to the manufacturers’ servers, which may in turn assemble BIM documents to be returned as XML documents. The documents are compressed for transmission, so that the document format is converted into a more compact representation. More to the point, the document may never exist as a physical file. With this, TM-xx defines a standard format for XML *DOCUMENTS*. The term “file” is properly relegated to the era of floppy disks and acoustic modems.

Why Not JSON?

Computer-savvy readers may well ask, “Why XML and not JSON?” After all, JSON is an alternative computer markup language that is widely used to exchange data between browsers and servers[12]. Compared to XML, it is a much simpler and less verbose language that typically results in smaller documents. It also natively supports two-dimensional data (i.e., matrices) such as luminous intensity distributions, which are more difficult to represent in XML.

The answer is that the electronic exchange of data between computer systems typically involves compressed documents, often with the ZIP file format. In the compression process, the element tags are represented by single symbols, which typically results in document compression ratios of 10:1. More to the point, compressed XML and JSON documents representing the same data are typically the same size. With this, the ability to embed TM-xx documents in XML-based BIM documents outweighs any advantages of JSON.

International Standards

Referring once again to FIG. 3, note the phrase "international standard." There have been several attempts in the past to develop an international standard for photometric data formats, including CIE 102-1993, Recommended File Format for the Electronic Transfer of Luminaire Photometric Data[4] and EN 13032-1:2004+A1:2012, Light and Lighting — Measurement and Presentation of Photometric Data of Lamps and Luminaires — Part 1[6]. Despite being an explicitly international file format developed by representatives of eleven countries, CIE 102 was never adopted for commercial use.

Sadly, the same fate seems to have befallen EN 13032-1.

This is, unfortunately, the fate of many standards. Companies and individuals volunteer their time and expertise to develop standards that meet perceived industry needs, but the industry in question is the final arbiter of what its needs are. If existing standards are sufficient, it is often difficult to convince manufacturers to abandon them in favor of a new and untried standard. Good examples of this are CIE 102-1993, EN 13032-1, and IES LM-74-05, but there are many others.

Recognizing this problem, the IES Computer Committee has chosen to work directly with its international colleagues, including lighting software companies, luminaire manufacturers, testing laboratories, lighting professionals, and academia with expertise in both architectural and horticultural lighting. It is further using social media to communicate its activities and invite feedback from several thousand lighting professionals. More than any other standard, TM-xx is being designed by those who will most benefit from its adoption and use.

Finally — and this is perhaps a key point — IES TM-xx has been explicitly designed to be forward compatible with IES LM-63, EULUMDAT, and CIBSE TM14. That is, it will be possible to automatically batch convert previous photometric data files into TM-xx documents with insignificant loss of information. Lighting software companies, luminaire manufacturers, and testing laboratories will therefore be encouraged but not required to transition their workflow and photometric data to TM-xx. In the meantime, lighting design software will be able to seamlessly support both photometric data files and TM-xx documents.

Summary

The intent of this article has been to: 1) review the history of photometric data file formats; 2) describe the ongoing efforts of the IES Computer Committee and its partners to develop an international standard for architectural, roadway, and horticultural lighting; and 3) describe both the design philosophy and the international effort behind the development of IES Technical Memorandum TM-xx, Standard Format of the Electronic Transfer of Luminaire Optical Data.

Simply put, the lighting industry currently relies on photometric data file formats that were developed three decades ago. IES TM-xx is being designed for today and the future.

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W3C Extensible Markup Language (XML) 1.0, Fifth Edition (http://www.w3.org/TR/REC-xml).

[á] The EULUMDAT file format specification is available from http://www.helios32.com/Eulumdat.htm.

[ß] Photon flux, also commonly referred to as quantum flux, is the rate of flow of photons. Radiant flux, by comparison, is the rate of flow of energy. The energy of a photon is inversely proportional to its wavelength, so quantum flux is not directly comparable to radiant flux.

D

AYLIGHTING INFORMATION

CERISE365 AND DAYSIM

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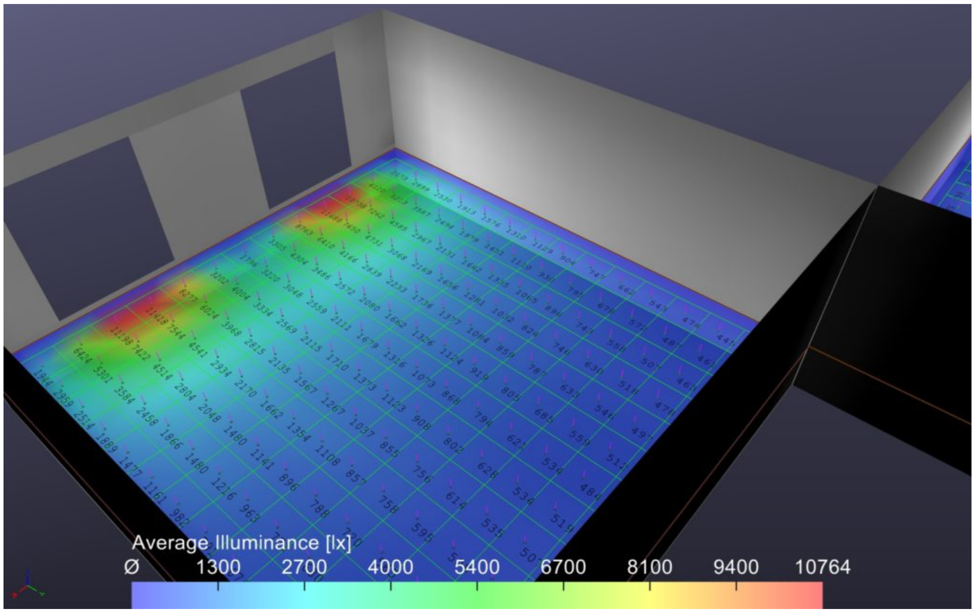


CERISS365 and *DAYSIM* are daylighting analysis software programs that perform climate-based annual daylight simulations, including the calculation of annual daylight metrics. This white paper compares their performance in terms of accuracy and calculation times. Average illuminance and spatial daylight autonomy values agree to within 8 percent, while *CERISE365* is approximately **250 times** faster than *DAYSIM* for a benchmark model.

> *NOTE: THE CLIMATE-BASED ANNUAL DAYLIGHTING SOFTWARE DESCRIBED IN THIS WHITE PAPER WAS PREVIOUSLY IMPLEMENTED IN LIGHTING ANALYSTS' LICASO DAYLIGHTING DESIGN PRODUCT. THIS PRODUCT WAS NOT A COMMERCIAL SUCCESS, AND HAS SINCE BEEN REMOVED FROM THE MARKET.*

Climate-Based Daylight Metrics

Quoting from the *IES LIGHTING HANDBOOK*, Tenth Edition,[5] the definition of *DAYLIGHT AUTONOMY* seems simple enough: "… the measure of the percentage of the operating period (or number of hours) that a particular daylight level is exceeded throughout the year." It includes *SPATIAL DAYLIGHT AUTONOMY* (sDA)[6], which "… reports the percentage of sensors (or building area) that achieves a minimum daylight illuminance level (typically 300 lux) for a minimum percent of the analysis year (time)." Other dynamic daylight metrics include *CONTINUOUS DAYLIGHT AUTONOMY* (cDA)[6], *MAXIMUM DAYLIGHT AUTONOMY* (mDA)[6], *USEFUL DAYLIGHT ILLUMINANCE* (UDI)[9] and more, all with seemingly simple definitions.

Simple to say, yes, but calculating these metrics is another matter entirely. Behind the scene are devilishly complex algorithms that require massive amounts of computation. Until recently, the only options for professional lighting designers and architects have been based on the justly acclaimed *RADIANCE* suite of lighting simulation tools. A typical example is *DAYSIM*, which is described as "… validated, *RADIANCE*-based daylighting analysis software that models the annual amount of daylight in and around buildings."

Cerise365 is the first climate-based annual daylight simulation software program that is not based on *RADIANCE*. More than this, it is not even based on the *RADIANCE* computational model of ray tracing. Rather, it relies on proven radiosity methods[1], and in particular the algorithms that have been driving Lighting Analysts' *AGI32* and *ELUMTOOLS* lighting design and analysis software products for nearly two decades. (See *ALLTHINGLIGHTING*'s blog article Climate-Based Daylight Modeling for further details.)

… but enough gratuitous advertising. The intent of this white paper is to compare the performance of *CERISE365* and *DAYSIM* in terms of accuracy and calculation times. This is not a case of which program is better suited for any given application, but simply to see whether the two programs are indeed comparable.

Benchmark Model

The spatial daylight autonomy metric has been adopted for use with green building certification by the US Green Building Council[10] and the International WELL Building Institute.[3] However, the United Kingdom Education Funding Agency mandates the use of both spatial daylight autonomy and useful daylight illuminance daylight metrics for its Priority School Building Programme.[4] The benchmark model used in this white paper is therefore based on a typical 55-m^2 classroom in accordance with the PSBP baseline design.

The benchmark model consists of four identical rooms facing north, south, east, and west, with each room having two glazed windows (FIG. 1). Each room measures 7.5 meters long by 7.0 meters wide by 3.2 meters high.

Each window measures 1.68 meters wide by 2.0 meters high, is positioned 0.85 meters above the floor and 0.5 meters from the closest wall, and has a transmittance of 70 percent.

The floor reflectance is 20 percent, the wall reflectance is 60 percent, and the ceiling reflectance is 80 percent.

A virtual ground plane with 18 percent reflectance is assumed for *CERISE365*. The equivalent for *RADIANCE* (and hence *DAYSIM*) is a 180-degree glow source (essentially an upside-down sky) with uniform luminance that is the horizontal illuminance due to the diffuse skylight and direct sunlight multiplied by the ground plane reflectance.[8] *DAYSIM* allows the user to specify the ground plane reflectance, with a default value of 20 percent.

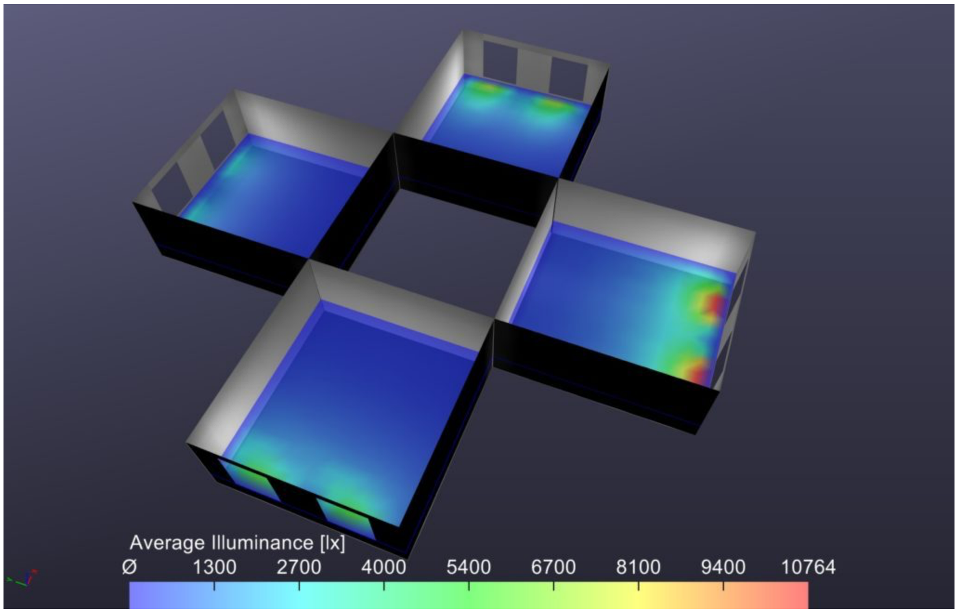


Figure 1 – Benchmark model.

A grid of 15 by 15 virtual photometers, spaced at 0.5-meter intervals, is centered in each room, with a mounting height of 0.75 meters (FIG. 2).

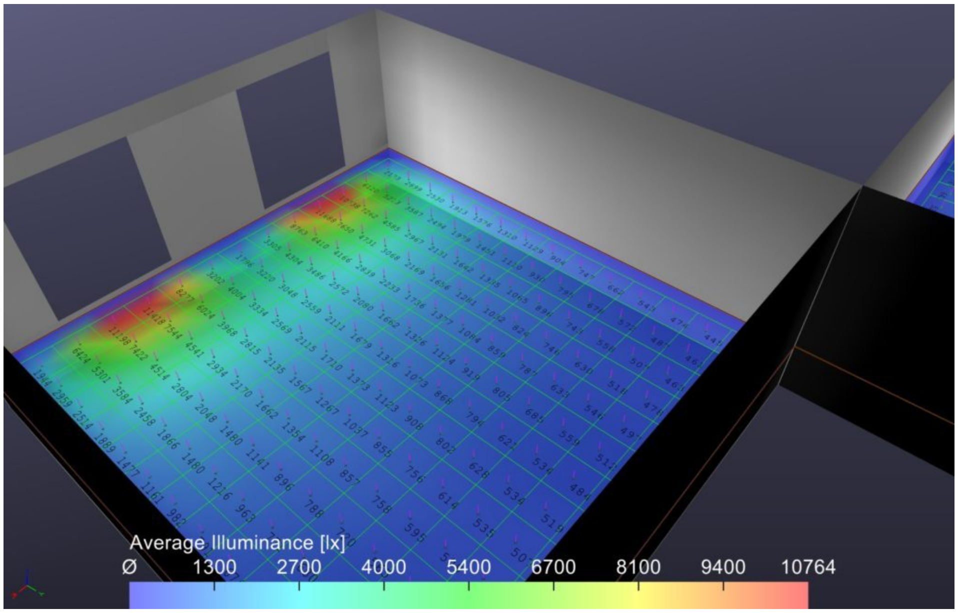


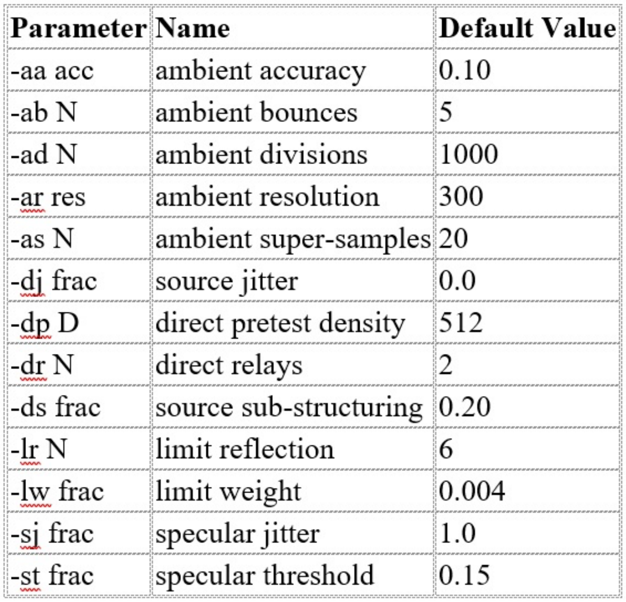
Figure 2 – Virtual photometer layout.

Simulation Parameters

The TMY3 weather file is LONDON/GATWICK-GBR (37760), with a site location of 51.15 degrees north and 0.18 degrees west. All simulations were run in one-hour increments for the entire year, with occupied hours of 8:00 AM to 4:00 PM for a total of 2,920 hours, and Daylight Saving Time from March 29th to October 25th.

DAYSIM

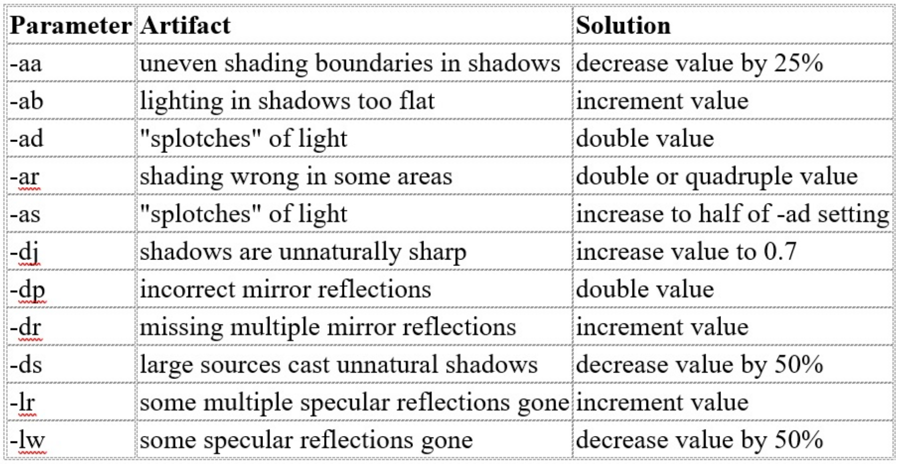
DAYSIM uses a modified version of the *RADIANCE* utility program *RTRACE* called *RTRACE_DC*., where the ìdcî suffix represents “daylight coefficients.” Of the 46 user-specified parameters available for *RTRACE*, *RTRACE_DC* provides user access to 13 of them with default values (Table 1).



Parameter	Name	Default Value
-aa acc	ambient accuracy	0.10
-ab N	ambient bounces	5
-ad N	ambient divisions	1000
-ar res	ambient resolution	300
-as N	ambient super-samples	20
-dj frac	source jitter	0.0
-dp D	direct pretest density	512
-dr N	direct relays	2
-ds frac	source sub-structuring	0.20
-lr N	limit reflection	6
-lw frac	limit weight	0.004
-sj frac	specular jitter	1.0
-st frac	specular threshold	0.15

Table 1 – *DAYSIM* User-Specified Parameters

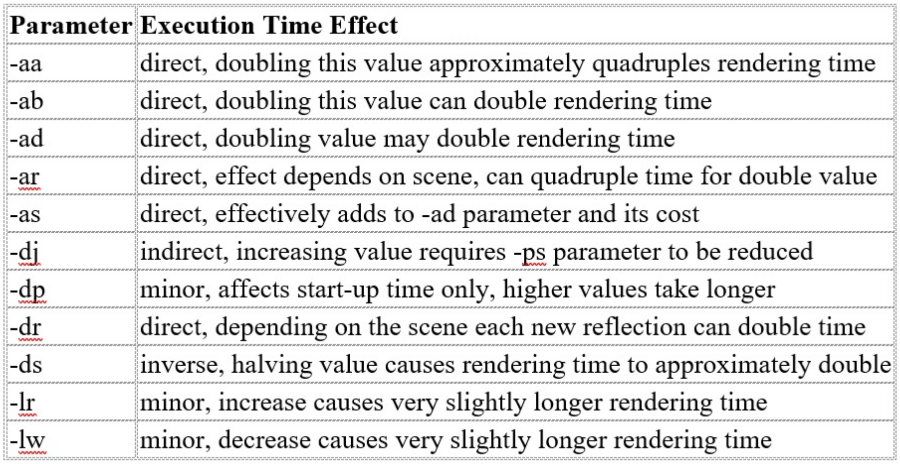
It is not obvious to *DAYSIM* users what effect these parameters will have on the calculations. However, the same parameters are available for the *RADIANCE* utility program *RPICT*, and so reference can be made to http://radsite.lbl.gov/radiance/refer/Notes/rpict_options.html, with rendering artifacts related to the relevant parameters enumerated in Table 2.



Parameter	Artifact	Solution
-aa	uneven shading boundaries in shadows	decrease value by 25%
-ab	lighting in shadows too flat	increment value
-ad	"splotches" of light	double value
-ar	shading wrong in some areas	double or quadruple value
-as	"splotches" of light	increase to half of -ad setting
-dj	shadows are unnaturally sharp	increase value to 0.7
-dp	incorrect mirror reflections	double value
-dr	missing multiple mirror reflections	increment value
-ds	large sources cast unnatural shadows	decrease value by 50%
-lr	some multiple specular reflections gone	increment value
-lw	some specular reflections gone	decrease value by 50%

Table 2 – Artifacts Associated with *DAYSIM* Parameters

Some of these parameters are problematic, of course, in that their effects can only be seen in the renderings generated by *RPICT*. Without access to these renderings, *DAYSIM* users have little choice but to accept its default values.
More obvious are the effects of the parameter values on the calculation times. These are (again from the *RPICT*documentation) enumerated in Table 3.



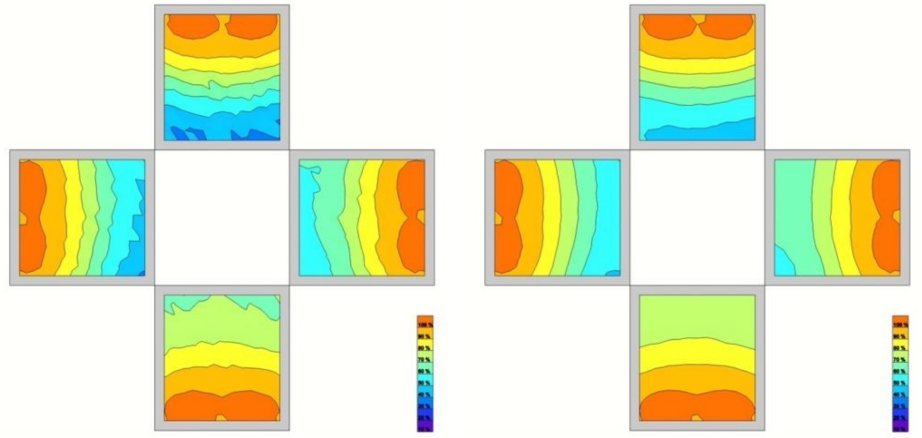
Parameter	Execution Time Effect
-aa	direct, doubling this value approximately quadruples rendering time
-ab	direct, doubling this value can double rendering time
-ad	direct, doubling value may double rendering time
-ar	direct, effect depends on scene, can quadruple time for double value
-as	direct, effectively adds to -ad parameter and its cost
-dj	indirect, increasing value requires -ps parameter to be reduced
-dp	minor, affects start-up time only, higher values take longer
-dr	direct, depending on the scene each new reflection can double time
-ds	inverse, halving value causes rendering time to approximately double
-lr	minor, increase causes very slightly longer rendering time
-lw	minor, decrease causes very slightly longer rendering time

Table 3 – Calculation Times Associated with *DAYSIM* Parameters

(The *-PS* parameter of *RTRACE* is not accessible to the user, so presumably *RTRACE_DC* modifies this parameter accordingly when the *-DJ* parameter is changed from its default value.)

What is clear is that the *-A** parameters can be very expensive in terms of calculation time, and should therefore be changed with considerable caution. In the absence of *RPICT* renderings, however, the only indication of the effect of these parameters is on the uniformity of the virtual photometer readings.

To illustrate this point, FIG. 3 shows the isolux distribution of photometer readings for two sets of *-A** parameter values, with all other parameters being set to their *DAYSIM* default values.



-aa	0.1	-aa	0.1
-ab	5	-ab	7
-ad	1000	-ad	5000
-ar	300	-ar	300
-as	20	-as	500

Figure 3 – Visualization of DAYSIM –a* parameter values effect on photometer uniformity.

Simply by looking at the isolux distributions, it is evident that setting *-AD* to 1000 and *-AS* to 20 results in "splotches" of light. Raising these parameter values to 5,000 and 500, respectively, appears to resolve this issue, but at the expense of increasing the calculation time. (In this particular example, the *DAYSIM* calculation time increased by a factor of 6.5 times.)

It should also be noted that the optimal *-A** parameter values are scene-dependent. Mastery of these parameters requires an in-depth understanding of how *RADIANCE* interpolates its cached irradiance values.

DAYSIM further offers three options for daylight coefficients:

- Original with 65 representative direct solar positions (e.g., FIG. 4)
- DDS (Dynamic Daylight Simulations) with 2,305 representative direct solar positions
- Shadow testing with hourly direct solar positions taken directly from TMY3 weather file records

In the third option, the actual solar position is bi-linearly interpolated from the representative direct solar positions for the first two options. (The third option is reportedly rarely used because it is very expensive in terms of calculation time.)

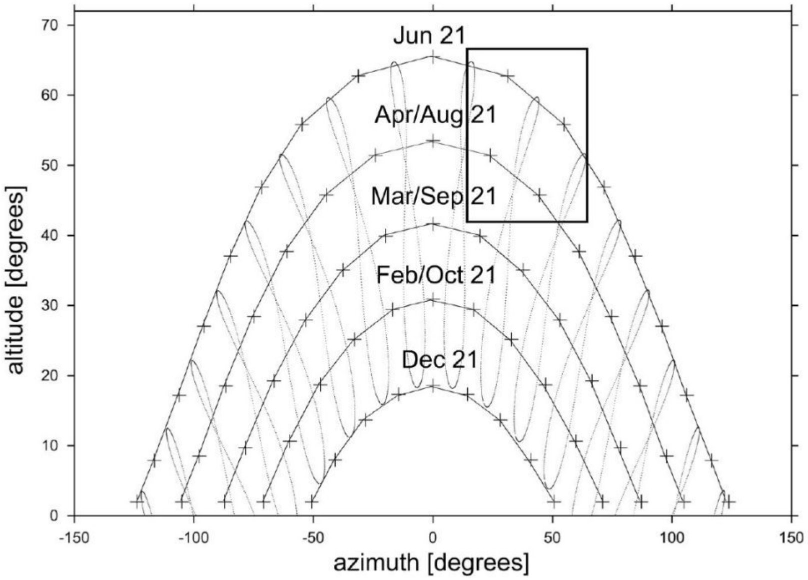


FIG. 4 –Annual solar path (65 positions) for Freiberg, Germany.

Cerise365

In accordance with radiosity methods, *CERISE365* subdivides each surface into a two-level hierarchy of patches and elements (Fig. 5). For each interreflection, light is received by the elements of a patch and then reflected (and transmitted for translucent surfaces) from the center of the patch.[1] The combined direct sunlight and diffuse daylight are interreflected (or ìbouncedî) between elements and patches in this way until mostly absorbed.

Compared to *DAYSIM*, *CERISE365* has only four user-specified parameters for climate-based annual daylight modeling:

- Maximum surface patch area
- Maximum window patch area
- Number of elements per surface patch
- Stopping criterion for absorbed light

For the benchmark model, the maximum patch area is 1.0 m^2, the number of elements per patch is four, and the stopping criterion is 99 percent. (That is, the bounces of light stop when 99 percent of the interreflected light is absorbed.)

Direct sunlight and diffuse skylight incident upon the windows are received by each window patch and transmitted into the room interior from the center of each patch. For the benchmark model, each window patch has an area of approximately 0.3 m^2.

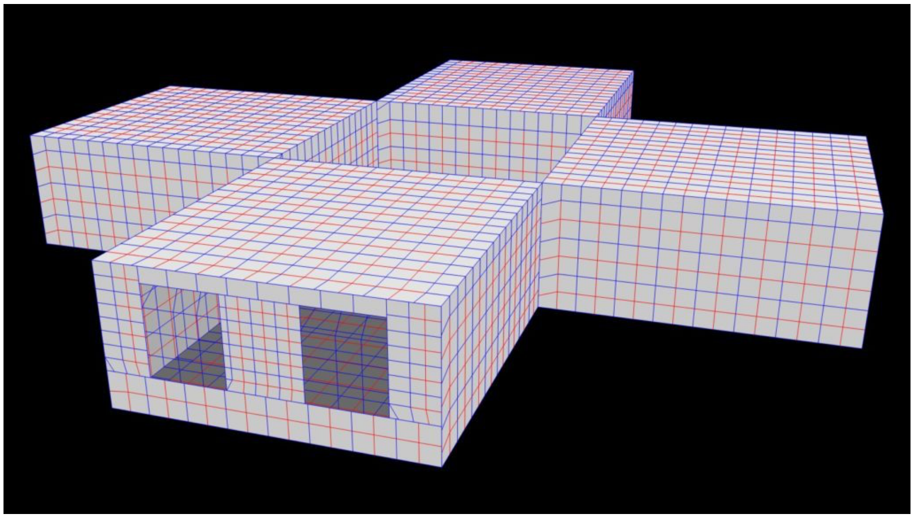


Figure 5 – *CERISE365* surface discretization into patches (blue lines) and elements (red lines).

CERISE365 defines 120 representative direct solar positions, as shown in FIG. 6, where the representative positions are calculated for each hour on the specified dates. The actual solar position for any given hour and date is then linearly interpolated from the representative direct solar positions for the same hour. (See the blog article *CLIMATE-BASED DAYLIGHT MODELING* for further details.)

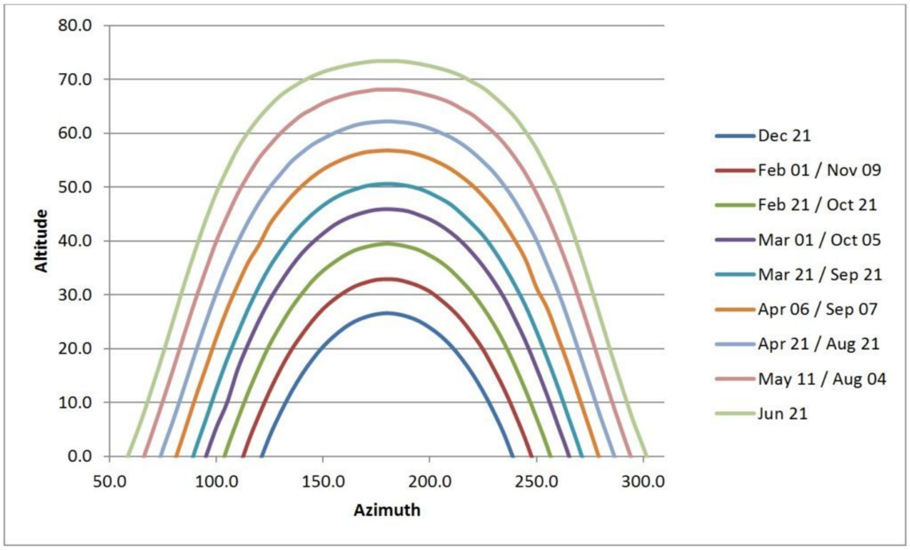


Figure 6 – *CERISE365* representative direct solar positions.

CERISE365 generates a variety of daylight metrics:

- Illuminance
- Basic Daylight Autonomy (DA)
- Continuous Daylight Autonomy (cDA)
- Maximum Daylight Autonomy (mDA / maxDA)
- Minimum Daylight Autonomy (minDA)

- Spatial Daylight Autonomy (sDA)
- Useful Daylight Illuminance (UDI)
- Annual Daylight Exposure (ADE)
- Annual Sunlight Exposure (ASE)
- Spatial Annual Sunlight Exposure (sASE)

It also provides three-dimensional rendered views (e.g., FIG. 7) and animations of single days and the entire year. This enables the user to both analyze and visualize the distribution of daylight throughout the year.

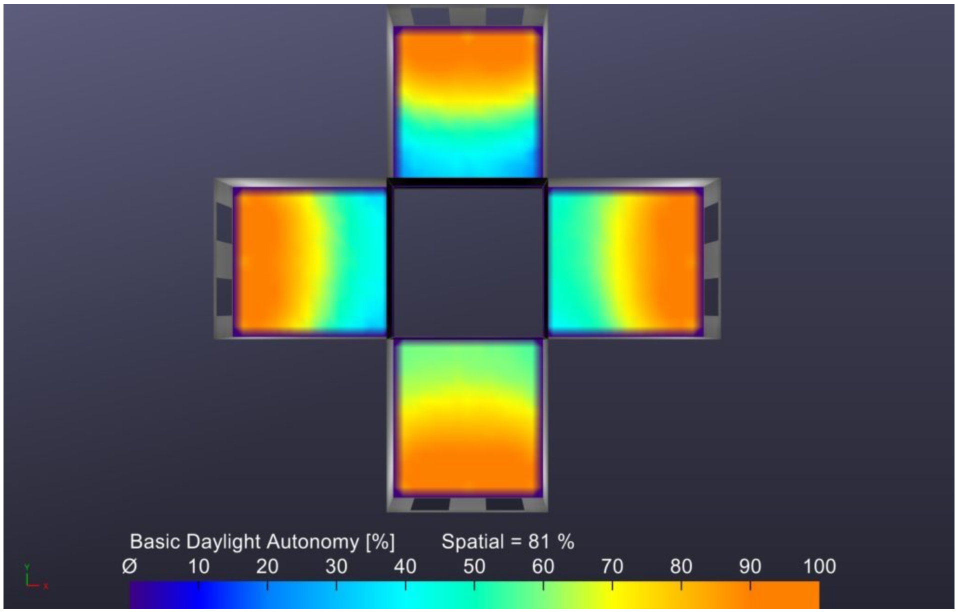


Figure 7 – *CERISE365* Daylight Autonomy.

Results

All tests were performed on a Windows 10 desktop computer with an Intel Core i7-4770K quad core CPU (3.5 GHz overclocked at 4.1 GHz) and 32 GB of random access memory

As previously noted, both the accuracy and execution time of *DAYSIM* is strongly dependent on the user-specified parameter values, as is evident from FIG. 3. Consequently, eight separate simulations were performed with different parameter settings for *-AB*, *-AD*, *-AR*, and *-AS*, with each simulation being compared with the *CERISE365*results. (Default values were used for all other *DAYSIM* parameters.) Two metrics were chosen for comparison purposes: average illuminance as measured by the virtual photometers, and spatial daylight autonomy for 300 lux and 50 percent minimum time (designated as $\text{sDA}_{300/50\%}$ by IES LM-83-12).[6] The benchmark results are presented in Appendix A.

The *DAYSIM* versus *CERISE365* average illuminance differences are plotted in Figure 8. Assuming that the *DAYSIM*simulations represent increasing accuracy with each simulation, it is evident that *CERISE365* underestimates the average illuminance of the south room by 5 percent and the west room by 3 percent, and overestimates the average illuminance of the north room by 2 percent and the east room by 1 percent. Considering that *DAYSIM* and *CERISE365* use completely different computational models, these differences are remarkably small.

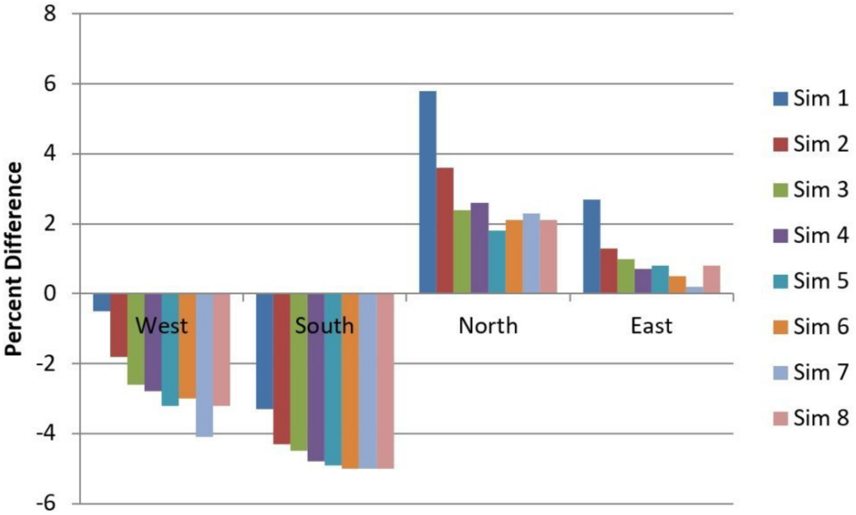


Figure 8 – *DAYSIM* versus *CERISE365* average illuminance differences.

The *DAYSIM* versus *CERISE365* sDA$_{300/50\%}$ differences are plotted in Figure 9. Again assuming that the *DAYSIM*simulations represent increasing accuracy with each simulation, it is evident that *CERISE365* underestimates the sDA of the west room by 8 percent, the north room by 4 percent, and the east room by 8 percent.

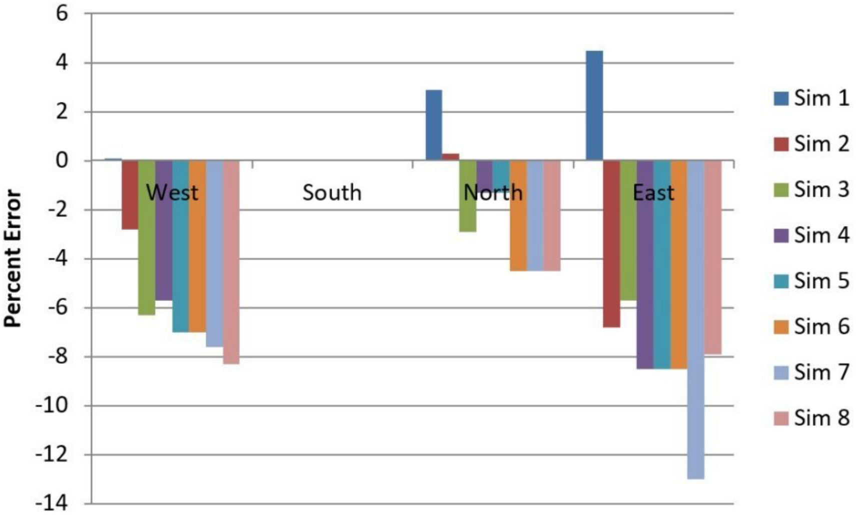


Figure 9 – *DAYSIM* versus *CERISE365* sDA300/50% differences.

The *DAYSIM* sDA value for the east room appears to be a calculation anomaly, possibly due to a remaining “splotch” of light. Ray tracing in *RADIANCE* is a stochastic (i.e., random) process, and so this anomaly may not occur if the benchmark is executed on a different machine.
The execution times for the different simulations are summarized in Table 13.

Simulation	*DAYSIM* Execution Time(minutes)	*CERISE365* Comparison (45 seconds)
1	28	37 times
2	69	92 times
3	103	137 times
4	143	190 times
5	176	234 times
6	182	242 times
7	221	294 times
8	261	348 times

Table 13 – *DAYSIM* / *CERISE365* execution times

The differences in execution time between *CERISE365* and *DAYSIM* are perhaps surprising, but they are typical due to differences between the ray tracing and radiosity calculation models. Simply put, radiosity methods are better able to take advantage of scene redundancy between hourly calculations.

Conclusions

For both the average illuminance and spatial daylight autonomy metrics used in this benchmark comparison, it must be implicitly assumed that *DAYSIM* generates correct values. *DAYSIM* is described as “validated, *RADIANCE*-based daylighting analysis software,” but the simulations show that the two metrics converge to constant values only for Simulations 6 through 8. It is true that *RADIANCE* has been validated by a number of studies, but the accuracy of its photometric predictions is highly dependent on the parameters chosen for *RTRACE* and, by extension, *RTRACE_DC*.

Simulation 1 generates average illuminance results that differ by up to 6 percent from the converged values of Simulations 6 through 8. Similarly, the sDA results differ by up to 13 percent. Given this, the differences in results between *DAYSIM* and *CERISE365* for Simulations 6 through 8 are arguably acceptable. (As an aside, differences of ±10 percent between predicted and measured illuminances are considered quite acceptable in electric lighting calculations.)

Regarding the difference in calculation times — *CERISE365* is hundreds of times faster than *DAYSIM* — this must be put into perspective. For the past three decades, *RADIANCE* has been the gold standard for electric lighting and daylighting research, and *DAYSIM* has built upon this foundation by offering lighting researchers open-source software for dynamic daylight metrics, annual visual glare analysis, and electric lighting control. The innumerable user-specified parameters of rtrace and other *RADIANCE* tools (including *DAYSIM*) may make them difficult to master, but they are essential for lighting research.

SunTracker Technologies' *CERISE365* , by comparison, is a commercial product that is powered by SunTracker's patented and patent-pending algorithms. It is intended for use as a climate-based daylighting simulation and analysis tool for professional lighting designers and architects.

In summary then, this benchmark analysis has shown that *DAYSIM* and *CERISE365* generate comparable results in terms of dynamic daylight metrics such as spatial daylight autonomy. *CERISE365* is clearly faster, but this comes at a cost for daylighting research, as there are fewer parameters to experiment with. Which software to choose depends, as always, on the user's requirements.

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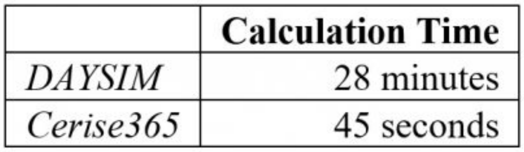
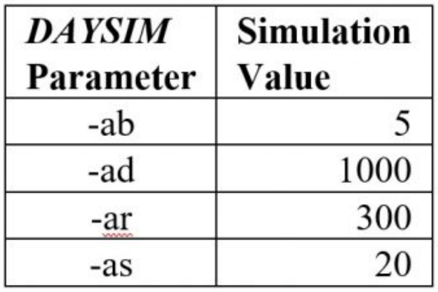
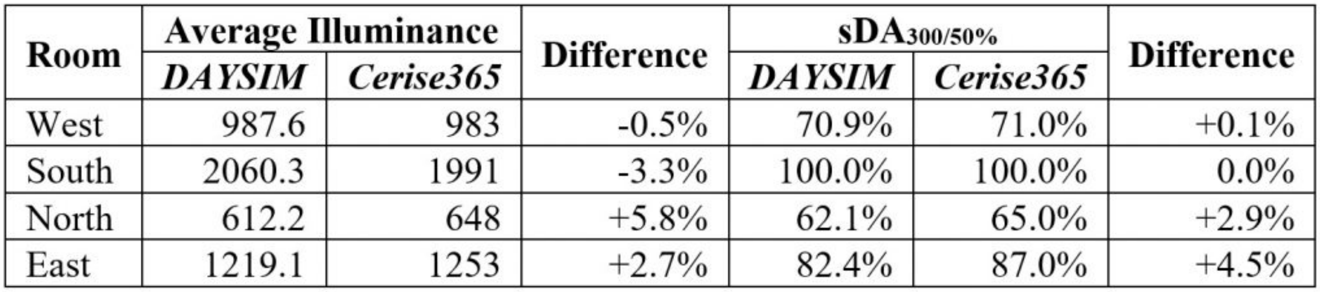
Appendix A – Benchmark Results



	Calculation Time
DAYSIM	28 minutes
Cerise365	45 seconds

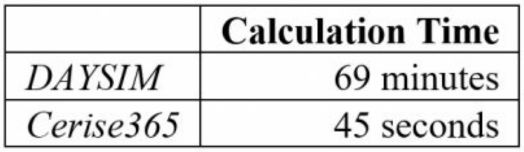


***DAYSIM* Parameter**	**Simulation Value**
-ab	5
-ad	1000
-ar	300
-as	20

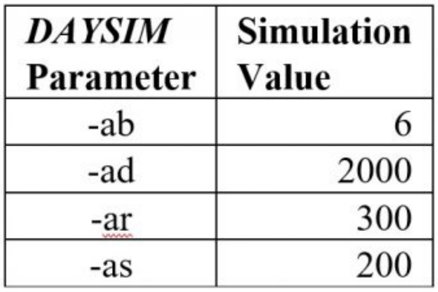


Room	**Average Illuminance**		**Difference**	**$sDA_{300/50\%}$**		**Difference**
	DAYSIM	***Cerise365***		***DAYSIM***	***Cerise365***	
West	987.6	983	-0.5%	70.9%	71.0%	+0.1%
South	2060.3	1991	-3.3%	100.0%	100.0%	0.0%
North	612.2	648	+5.8%	62.1%	65.0%	+2.9%
East	1219.1	1253	+2.7%	82.4%	87.0%	+4.5%

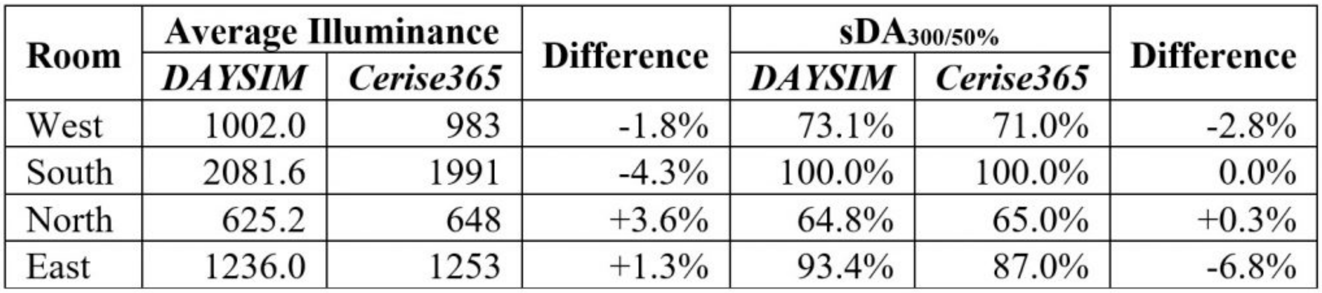
Table A1 – *DAYSIM* / *CERISE365* Simulation
1



	Calculation Time
DAYSIM	69 minutes
Cerise365	45 seconds

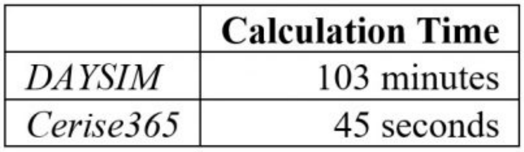


***DAYSIM* Parameter**	**Simulation Value**
-ab	6
-ad	2000
-ar	300
-as	200

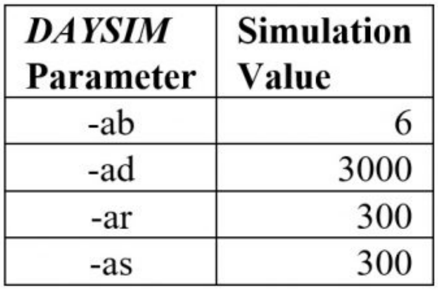


Room	**Average Illuminance**		**Difference**	**$sDA_{300/50\%}$**		**Difference**
	DAYSIM	***Cerise365***		***DAYSIM***	***Cerise365***	
West	1002.0	983	-1.8%	73.1%	71.0%	-2.8%
South	2081.6	1991	-4.3%	100.0%	100.0%	0.0%
North	625.2	648	+3.6%	64.8%	65.0%	+0.3%
East	1236.0	1253	+1.3%	93.4%	87.0%	-6.8%

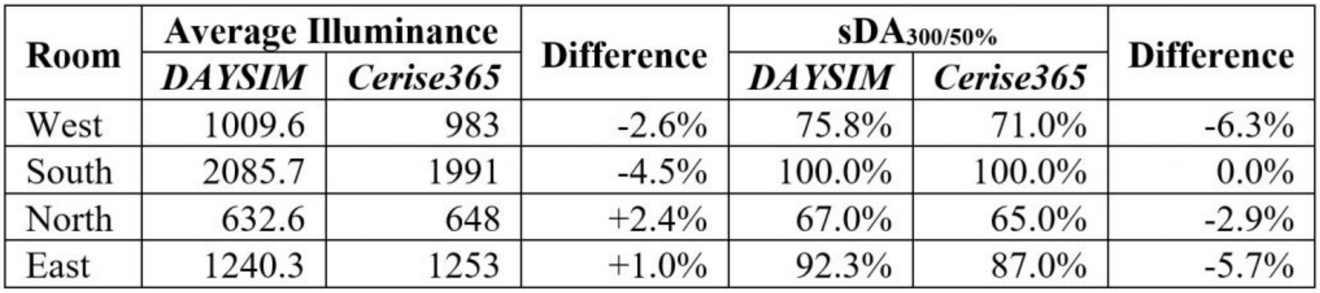
Table A2 – *DAYSIM* / *CERISE365* Simulation 2



	Calculation Time
DAYSIM	103 minutes
Cerise365	45 seconds



***DAYSIM* Parameter**	**Simulation Value**
-ab	6
-ad	3000
-ar	300
-as	300



Room	**Average Illuminance**		**Difference**	**$sDA_{300/50\%}$**		**Difference**
	DAYSIM	***Cerise365***		***DAYSIM***	***Cerise365***	
West	1009.6	983	-2.6%	75.8%	71.0%	-6.3%
South	2085.7	1991	-4.5%	100.0%	100.0%	0.0%
North	632.6	648	+2.4%	67.0%	65.0%	-2.9%
East	1240.3	1253	+1.0%	92.3%	87.0%	-5.7%

Table A3 – *DAYSIM* / *CERISE365* Simulation 3

	Calculation Time
DAYSIM	143 minutes
Cerise365	45 seconds

***DAYSIM* Parameter**	**Simulation Value**
-ab	6
-ad	4000
-ar	300
-as	400

Room	**Average Illuminance**		**Difference**	**$sDA_{300/50\%}$**		**Difference**
	DAYSIM	***Cerise365***		***DAYSIM***	***Cerise365***	
West	1011.4	983	-2.8%	75.3%	71.0%	-5.7%
South	2092.0	1991	-4.8%	100.0%	100.0%	0.0%
North	631.3	648	+2.6%	65.9%	65.0%	-1.3%
East	1243.2	1253	+0.7%	95.1%	87.0%	-8.5%

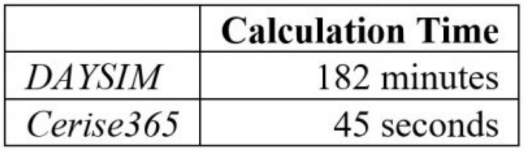
Table A4 – *DAYSIM* / *CERISE365* Simulation
4

	Calculation Time
DAYSIM	176 minutes
Cerise365	45 seconds

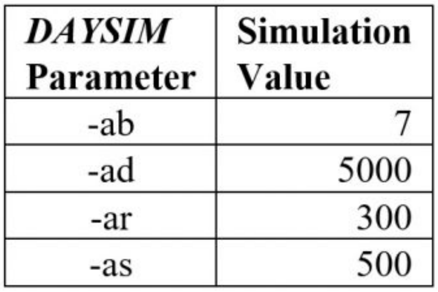
***DAYSIM* Parameter**	**Simulation Value**
-ab	6
-ad	5000
-ar	300
-as	500

Room	**Average Illuminance**		**Difference**	**$sDA_{300/50\%}$**		**Difference**
	DAYSIM	***Cerise365***		***DAYSIM***	***Cerise365***	
West	1015.8	983	-3.2%	76.4%	71.0%	-7.0%
South	2093.9	1991	-4.9%	100.0%	100.0%	0.0%
North	636.4	648	+1.8%	65.9%	65.0%	-1.3%
East	1243.0	1253	+0.8%	95.1%	87.0%	-8.5%

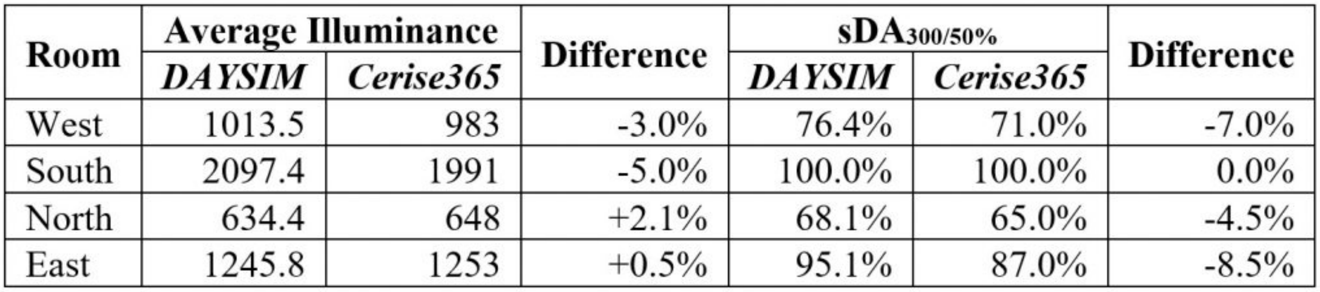
Table A5 – *DAYSIM* / *CERISE365* Simulation
5



	Calculation Time
DAYSIM	182 minutes
Cerise365	45 seconds

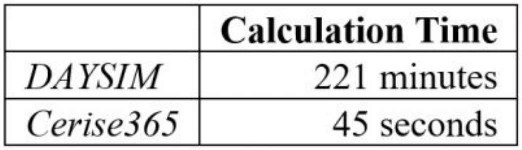


***DAYSIM* Parameter**	**Simulation Value**
-ab	7
-ad	5000
-ar	300
-as	500

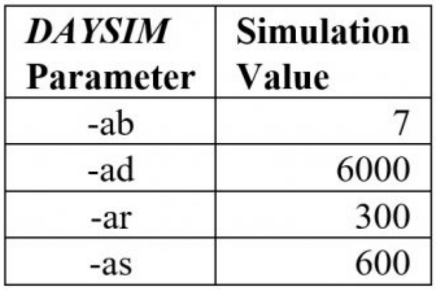


Room	**Average Illuminance**		**Difference**	**$sDA_{300/50\%}$**		**Difference**
	DAYSIM	***Cerise365***		***DAYSIM***	***Cerise365***	
West	1013.5	983	-3.0%	76.4%	71.0%	-7.0%
South	2097.4	1991	-5.0%	100.0%	100.0%	0.0%
North	634.4	648	+2.1%	68.1%	65.0%	-4.5%
East	1245.8	1253	+0.5%	95.1%	87.0%	-8.5%

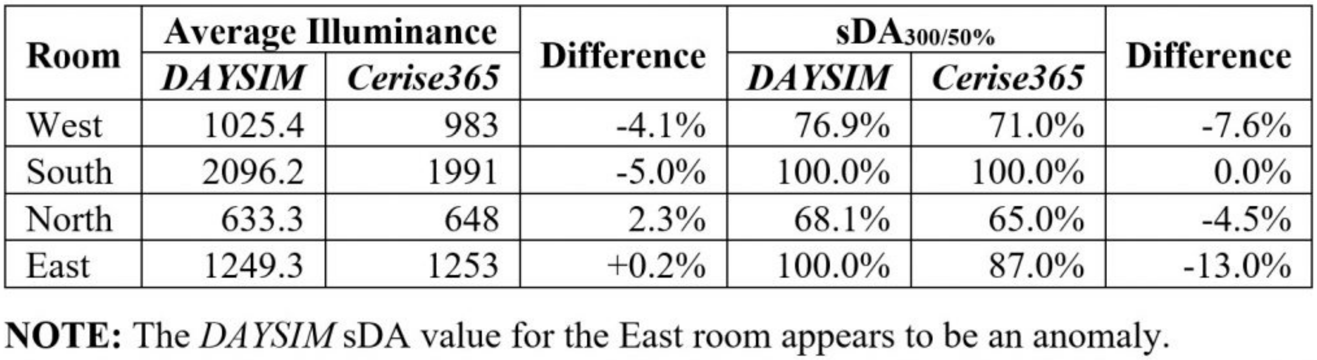
Table A6 – *DAYSIM* / *CERISE365* Simulation 6



	Calculation Time
DAYSIM	221 minutes
Cerise365	45 seconds



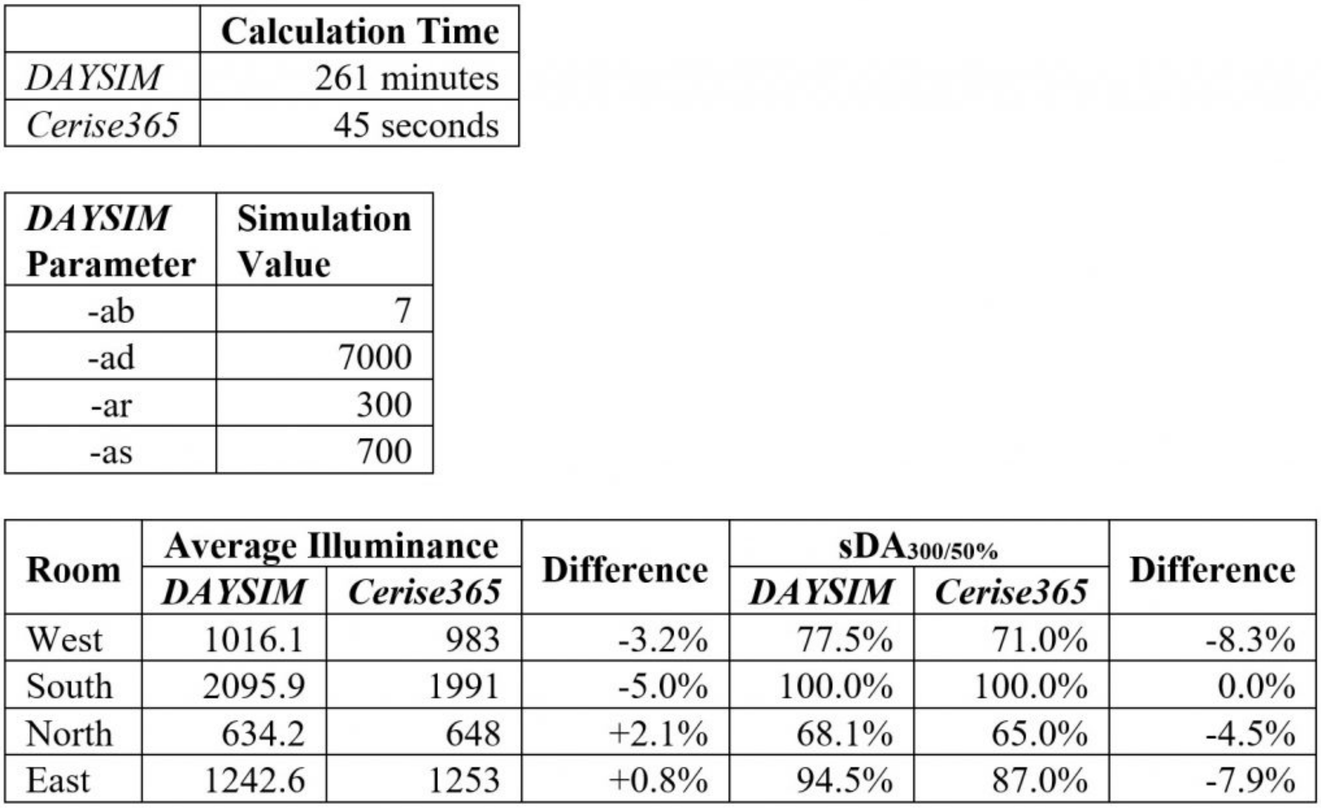
***DAYSIM* Parameter**	**Simulation Value**
-ab	7
-ad	6000
-ar	300
-as	600



Room	**Average Illuminance**		**Difference**	**$sDA_{300/50\%}$**		**Difference**
	DAYSIM	***Cerise365***		***DAYSIM***	***Cerise365***	
West	1025.4	983	-4.1%	76.9%	71.0%	-7.6%
South	2096.2	1991	-5.0%	100.0%	100.0%	0.0%
North	633.3	648	2.3%	68.1%	65.0%	-4.5%
East	1249.3	1253	+0.2%	100.0%	87.0%	-13.0%

NOTE: The *DAYSIM* sDA value for the East room appears to be an anomaly.

Table A7 – *DAYSIM*/*CERISE365* Simulation 7



	Calculation Time
DAYSIM	261 minutes
Cerise365	45 seconds

***DAYSIM* Parameter**	**Simulation Value**
-ab	7
-ad	7000
-ar	300
-as	700

Room	**Average Illuminance**		**Difference**	**$sDA_{300/50\%}$**		**Difference**
	DAYSIM	***Cerise365***		***DAYSIM***	***Cerise365***	
West	1016.1	983	-3.2%	77.5%	71.0%	-8.3%
South	2095.9	1991	-5.0%	100.0%	100.0%	0.0%
North	634.2	648	+2.1%	68.1%	65.0%	-4.5%
East	1242.6	1253	+0.8%	94.5%	87.0%	-7.9%

Table A8 – *DAYSIM/CERISE365* Simulation 8

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