VIRTUAL SKY DOMES
MAKING THE CIE/ISO STANDARD GENERAL SKY AVAILABLE FOR CAD-BASED LIGHT SIMULATION SOFTWARE

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ABSTRACT

The objective of this paper is to establish the VSD as a generic method to set up daylight for different light simulation software. The validation against measured data is published in a prior paper (Wittkopf., 2005). A Virtual Sky Dome (VSD) is a hemisphere comprising of 145 light sources with distinct intensity that resemble the sky luminance distribution for any location, time and sky type. The light properties are calculated by a spreadsheet tool and used to write scene files for the software Lightscape, Radiance and Photopia. Eventually diffuse illuminance under a selected sky type is compared, indicating that the VSD is a generic method to set up daylight.

INTRODUCTION

Daylight conscious architects or consultants nowadays use simulation software to predict their design. It is mostly modeled in 3D and subsequently imported into daylight simulation software, which generates outputs to assists in the design development. But most of the existing standard light simulation software over-simplify the daylight settings, in which they normally do not comply with the new CIE/ISO Standard General Sky. The new standard comprises of fifteen Standard Sky Luminance Distributions (SSLD) with sky types that better represent the daylight settings for various daylight climate regions.

The Virtual Sky Dome (VSD) approach aims to make these sky types available for use in standard light simulation software. Basically, a VSD is a substitution of the complex equations, where all the fifteen SSLD are incorporated. A spreadsheet tool takes in solar position and sky type and calculates the luminous flux for 145 point light sources at their respective positions in the sky dome. The entire dome is then representing the luminous distribution of a particular sky type (Wittkopf., 2004). Direct sunlight can be considered as well, by inserting an additional light source for the sun, which leads to the Virtual Sky and Sun Dome (VSSD). After that, this pre-processing data is converted into scene file format for the light simulation software and added into a 3D model, such as a building, façade or other object, where the daylight performance is to be evaluated. The light propagation simulation process would generate the illuminance values for planes of any orientation and location. As a result, performance indicator such as Daylight Factor, Daylight Glare Index and Daylight Autonomy can be determined.

The paper elaborates how software tools can be used to set up VSD for use in the lighting simulation software Lightscape, Photopia and Radiance. Furthermore it compares the resulting diffuse illuminance on various planes and eventually introduces the application of VSD for complex daylight re-directing devices.

DAYLIGHT CONDITIONS

The presence of daylight will mostly result in diffuse horizontal illuminance Dv, regardless of the sky condition (overcast, cloudy, partly cloudy or clear sky).

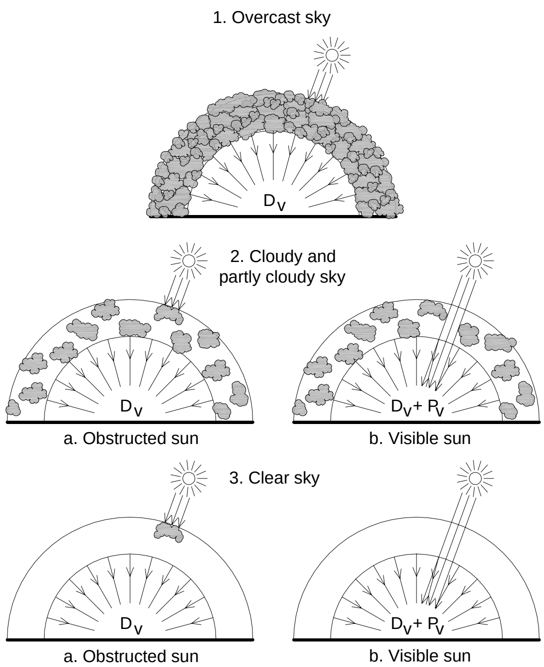


Figure 1. Daylight Illuminance conditions

However, merely the cloudy and clear skies will generate an additional direct horizontal solar illuminance Pv, where the sun is unobstructed. The total or global horizontal solar illuminance Gv is basically the sum of Dv and Pv. But when the sun is shaded and Pv = 0, then Gv = Dv. These conditions are illustrated in Figure 1.

VSD GEOMETRY

The Virtual Sky Dome structure follows the International Daylight Measurement Programme where sky scanner seperate the sky vault into 145 patches and arranges them chronologically into in eight vertical rings with different numbers of patches. Figure 2 shows the elevation of the different rings and figure 3 is the common key to the sky patch numbering.

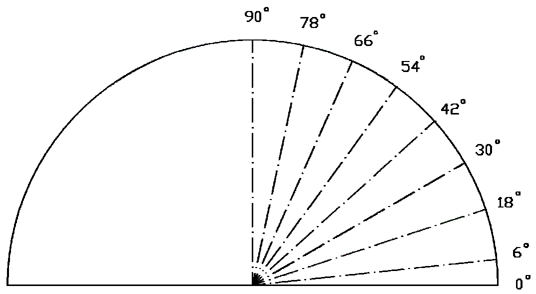


Figure 2. Vertical structure of the sky dome

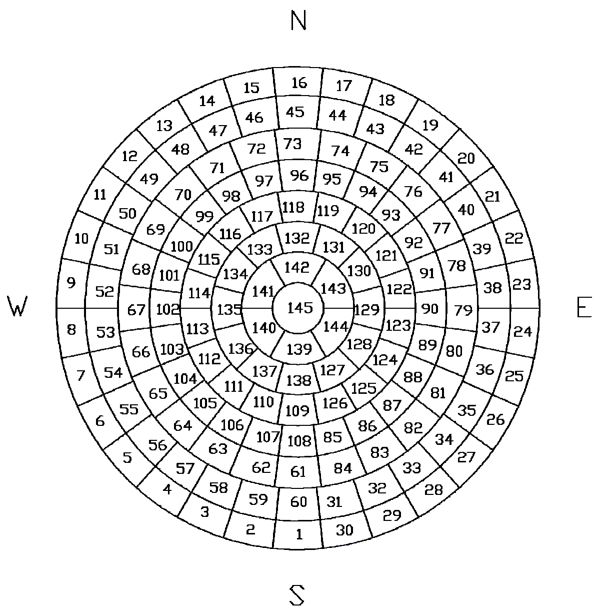


Figure 3. Key to sky patch numbering

The individual patches is originally of circular shape but simplified into planar surfaces in the VSD geometry. This results in a CAD model with slight gaps between the patches or areas of overlapping, shown in figure 4.

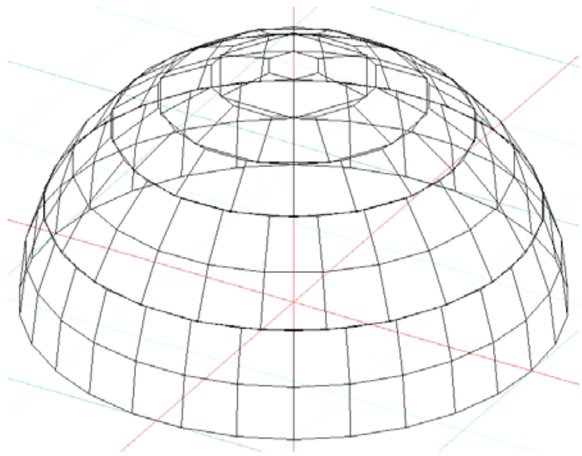


Figure 4. Geometry of VSD

VSD LIGHT PROPERTIES

The calcluation of luminance for all sky patches or their representation as a point or spotlight is according to the ISO/CIE standard. The following section documents the calculation if patch 85 is to be represented by a point light..

The position (x, y, z) can be calculated for a given elevation γ, azimuth α, and radius r of the hemisphere with the following equations:

$$X_{\text{Sky patch}} = r \cdot \sin\alpha \cdot \cos\gamma \quad \text{(eq. 1)}$$

$$Y_{\text{Sky patch}} = r \cdot \cos\alpha \cdot \cos\gamma \quad \text{(eq. 2)}$$

$$Z_{\text{Sky patch}} = r \cdot \sin\gamma \quad \text{(eq. 3)}$$

For example, for a given radius r=100 of the hemisphere the center of sky patch 85 will be located at:

$$X_{85} = 100 \cdot \sin(165\,\pi/180) \cdot \cos(42\,\pi/180) = 19.23$$

$$Y_{85} = 100 \cdot \cos(165\,\pi/180) \cdot \cos(42\,\pi/180) = -71.78$$

$$Z\ 85 = 100 \cdot \sin(165\,\pi/180) = 66.91$$

The North-axis of the hemisphere equals the positive Y-axis and the East-axis corresponds to the positive X-axis and the projection of the zenith coincides with the origin at (x,y) = (0,0). As such the center of the sky patch 85 in the XY-plane can be located at 19.23 m along the positive X-axis and 71.78 along the negative Y-axis.

The position of an arbitrary sky element is defined by its zenith angle, Z, and by the azimuth difference between the element and the sun, $|\alpha-\alpha_s|$. If Z_s is the zenith angle of the sun, the angular distance between the element and the sun is:

$$\chi = \arccos(\cos Z_s \cdot \cos Z + \sin Z_s \cdot \sin Z \cdot \cos|\alpha-\alpha_s|)$$
(eq. 4)

Alternatively, the angle elevation, γ, is used to define the position of an element. Hence:

$$Z = \pi/2 - \gamma \quad \text{(eq. 5)}$$

Similarly, the zenith angle of the sun may be obtained from the solar elevation by

$$Z_s = \pi/2 - \gamma_s \quad \text{(eq. 6)}$$

The ratio of the luminance, L_v, of an arbitrary sky element to the zenith luminance, L_z, is:

$$\frac{L_v}{L_z} = \frac{f(\chi) \cdot \varphi(Z)}{f(Z_s) \cdot \varphi(0^0)} \quad \text{(eq. 7)}$$

The luminance gradation function φ relates the luminance of a sky element to its zenith angle:

$$\varphi(Z) = 1 + a \exp(b/\cos Z) \quad \text{(eq. 8)}$$

when $0 \leq Z \leq \pi/2$ and at horizon is $\varphi(\pi/2) = 1$

Equation 7 requires the value at the zenith. This is:

$$\varphi(0^0) = 1 + a \exp(b) \quad \text{(eq. 9)}$$

The function f is a scattering indicatrix which relates the relative luminance of a sky element to its angular distance from the sun:

$$f(\chi) = 1 + c \cdot [\exp(d\chi) - \exp(d\pi/2)] + e \cdot \cos^2\chi \quad \text{(eq. 10)}$$

Its value at the zenith is:

$$f(Z_s) = 1 + c \cdot [\exp(dZ_s) - \exp(d\pi/2)] + e \cdot \cos^2 Z_s \quad \text{(eq. 11)}$$

The parameters a, b, c, d and e are given in (Kittler et al., 2006) for standard sky types.

The absolute zenith luminance for Tv > 12 can be calculated in kcd/m^2:

$$L_z = \frac{D_v}{E_v}\left[\frac{B(\sin \gamma_s)^C}{(\cos \gamma_s)^D} + E \sin\gamma_s\right] \quad \text{(eq. 12)}$$

For sunny periods when the sun filter is given by $T_v \leq 12$, then L_z in kcd/m^2 can be determined after:

$$L_z = A\sin \gamma_s + 0.7(T_v+1)\frac{(\sin \gamma_s)^C}{(\cos \gamma_s)^D} + 0.04T_v \quad \text{(eq. 13)}$$

where $A = (A1 \cdot T_v + A2)$

Eventually, the luminance flux is determined by:

$$F = 4\pi \cdot L_v \cdot A \quad \text{(eq. 14)}$$

The area of the each sky element is:

$$A = 2\pi \cdot r \cdot h \quad \text{(eq. 15)}$$

VSD SPREADSHEET

This calculation is automated in a spreadsheet. Input variables are sun azimuth, elevation and sky dome radius. Output are the luminance and luminous flux values for all 145 patches or their point light representations across all 15 different sky types. Those values can be saved as comma separated values to be parsed by subsequent tools. Table 1 and 2 list the luminance and lumonius flux values for sky type 11, assuming a sun position at 66 degree elevation due South (sky patch 109) for a sky dome radius of 100m. These settings are used to write the respective file formats for the different software.

Table 1
Luminance in cd/m2 for sky type 11 (sun altitude 66 degree, azimuth 180 degree, sky dome radius 100m)

Patch	0	1	2	3	4	5	6	7	8	9
0		12,355	12,212	11,812	11,239	10,591	9,958	9,402	8,957	8,636
10	8,431	8,327	8,297	8,313	8,349	8,380	8,392	8,380	8,349	8,313
20	8,297	8,327	8,431	8,636	8,957	9,402	9,958	10,591	11,239	11,812
30	12,212	13,411	12,786	11,909	10,939	10,004	9,180	8,501	7,973	7,585
40	7,318	7,145	7,044	6,991	6,967	6,960	6,967	6,991	7,044	7,145
50	7,318	7,585	7,973	8,501	9,180	10,004	10,939	11,909	12,786	13,411
60	13,638	15,509	14,952	13,548	11,830	10,208	8,867	7,842	7,099	6,587
70	6,253	6,051	5,945	5,912	5,945	6,051	6,253	6,587	7,099	7,842
80	8,867	10,208	11,830	13,548	14,952	18,758	16,375	13,715	11,399	9,591
90	8,250	7,288	6,615	6,160	5,872	5,714	5,663	5,714	5,872	6,160
100	6,615	7,288	8,250	9,591	11,399	13,715	16,375	18,758	19,769	28,113
110	24,319	18,243	13,608	10,543	8,589	7,368	6,636	6,248	6,127	6,248
120	6,636	7,368	8,589	10,543	13,608	18,243	24,319	25,684	16,277	11,433
130	8,951	7,770	7,420	7,770	8,951	11,433	16,277	25,684	43,867	24,511
140	17,255	11,542	9,998	11,542	17,255	14,923				

Table 2

Luminous flux in klm for sky type 11 (sun altitude 66 degree, azimuth 180 degree, sky dome radius 100m)

Patch	0	1	2	3	4	5	6	7	8	9
0		67,609	66,822	64,636	61,499	57,957	54,492	51,448	49,015	47,255
10	46,137	45,565	45,401	45,491	45,684	45,855	45,922	45,855	45,684	45,491
20	45,401	45,565	46,137	47,255	49,015	51,448	54,492	57,957	61,499	64,636
30	66,822	70,176	66,908	62,316	57,242	52,348	48,036	44,485	41,723	39,693
40	38,292	37,391	36,861	36,582	36,456	36,422	36,456	36,582	36,861	37,391
50	38,292	39,693	41,723	44,485	48,036	52,348	57,242	62,316	66,908	70,176
60	71,368	92,374	89,060	80,698	70,462	60,801	52,816	46,707	42,282	39,232
70	37,243	36,039	35,409	35,215	35,409	36,039	37,243	39,232	42,282	46,707
80	52,816	60,801	70,462	80,698	89,060	95,874	83,696	70,100	58,263	49,019
90	42,169	37,249	33,808	31,486	30,013	29,203	28,946	29,203	30,013	31,486
100	33,808	37,249	42,169	49,019	58,263	70,100	83,696	95,874	101,039	151,535
110	131,083	98,331	73,351	56,830	46,297	39,716	35,771	33,678	33,024	33,678
120	35,771	39,716	46,297	56,830	73,351	98,331	131,083	143,699	91,067	63,963
130	50,078	43,471	41,516	43,471	50,078	63,963	91,067	143,699	245,425	140,200
140	98,695	66,016	57,189	66,016	98,695	64,545				

VSD SIMULATION IN LIGHTSCAPE

Lightscape used to be a standalone light simulation software before it became embedded in 3D Studio MAX and 3D VIZ. It uses the Radiosity technique whereby any surface that receives light reflects it in an ideal diffuse manner. Effects such as reflection and transparency can be added by using an additional ray tracing technique, but these results are view dependent and can only be captured in a 2D image file. Using Lightscape standalone instead of MAX/VIZ allows better control over the complex meshing and process parameters. One main drawback is the limitation of the light reflection model to ideal diffuse which totally neglects specular reflection.

The main file in Lightscape is the so-called Preparation file, which contains all information of the scene. It is usually created through the GUI but can be manually edited because of its ASCII file format. Subsequent scripts or controls in the main GUI are used to calculate the Radiosity simulation, to perform light analysis and to render image files for presentations or animations

A VSD for Lightscape is generated by a program that parses the luminance flux values from the VSD spreadsheet and overwrites the default light properties in a master VSD file that already exists in Lightscape preparation format. During this process the luminous flux values are reduced for spotlights with 60deg spread following equation 16.

F (Point light with isotropic distribution) * 0.0487215 = F (Spotlight 60deg) (eq. 16)

Figure 5 is a cutout of the preparation file where the properties of the spotlight representing patch 109 is defined.

```
Source:  Spot_109_E_54
         Type: Point
         Flags: 0x0
         Filter: 1 1 1
         Color: 1 1 1
         lid(spotlight) {
         flux = 7382999.3;
         field = 30.0 deg;
         beam = 30.0 deg;
```

Figure 5. Properties of a light source in the Lightscape preparation file

Figure 6 depicts the complete VSD with spotlights located at the center of each patches and oriented towards the center of the dome at 0,0,0.

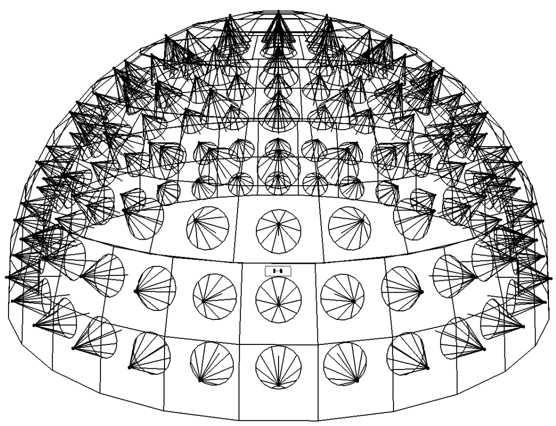


Figure 6. VSD with spotlights

VSD SIMULATION IN RADIANCE

Radiance is considered the standard light simulation software for architects and daylight consultants worldwide. As typical for applications developed in *Unix* environments, it consists of a collection of more than 100 tools, that are all specialized to perform a specific task, but can be connected like the elements of a chain to adopt to actual requirements. Most users control radiance simulations by the command line and use scripting to automate tasks or do calculations, but there are also graphical interfaces available that allow the integration into CAD and modeling software i.e. Rayfront, an advanced front-end that can be integrated into AutoCAD, but also be used as a standalone application.

Radiance comes with a number of sky models. Included in the distribution is the *gensky* program, which generates uniform CIE overcast, intermediate and clear skies. The program *gendaylit* generates Perez All Weather Model Skies. Finally, Phillip Greenup developed and documented a routine to use SSLD skies with Radiance.

Radiance uses description languages to describe geometry, materials, lights and formulas. Usually, a simulation workflow starts by converting geometry from CAD-formats to the scene description language, and either describing the material properties or linking to an existing material library. The mapping between material and surface is usually done by the converters using layer or group names, but more complex mapping patterns can be used with some CAD-formats. Radiance scenes consist of primitives (that can be materials, geometry and lights), commands (which allows to include the output of external programs or scripts directly into the scene by writing the command after a leading exclamation mark) and comments (lines starting with #). The definition of a new primitive generates an id, that can be used as modifiers for other primitives. That way, suitable primitives can be chained. This introduces the first line of a primitive's definition in a Radiance scene:

```
(modifier) (type of primitive) (id of
primitive)
```

This first line is followed by three groups of values, all three beginning with the number of values for that group. The first group takes all string values, the second integer and the third real number values. A complete example will read like this:

```
void light 10
0
0
3 20.0 20.0 20.0
```

The reserved modifier name void makes the primitive not being modified by others. So we define a primitive of type light with the id 10, passing no string and integer values but three real numbers to express the light's intensity. The light intensity in Radiance is defined as general radiance in Watt per Steradian per area whereas the VSD outputs luminance or luminous flux. Equation 17 converts the luminance L to radiance R.

$$R = L/179 \qquad \text{(eq. 17)}$$

So the above example of our light modifier describes a source with a luminous flux of 20 W/sr / m^2. The sky patches for our VSD are represented as planar faces modified with Radiance's light modifier. With the modifier being named after the sky patch it represents, the example given shows the definition of patch 10 as a planar polygon, modified by the previously defined primitive named “10” (our light material for the patch) and given the id Skypatch_10:

```
10 polygon Skypatch_10
0
0
12
     -95.6773   20.3368   20.7912
     -97.8148   20.7912   0
     -91.3545   40.6737   0
     -89.3582   39.7848   20.7912
```

As we see, the polygon takes 12 real number values, which are the coordinates of the polygons vertices. The format of the value groups all beginning with the number of values following allows us to use so-called whitespaces to achieve some basic formatting, rendering the definition more readable. All the spaces and line-breaks on the third value line will be ignored, as the Radiance parser knows that the next 12 field belong to one group and are to be interpreted as real numbers.

We generate our VSD geometry from a CAD model, that has been exported in the well-supported obj-format and translated into a Radiance scene by the translator *obj2rad*. Another possible approach would be to use a script generating the polygons from their solid angles and position, which might even be called from the scene file itself.

To verify our VSD, we will first render a panoramic view from the origin (0;0;0), direction up (0;0;1), showing the illuminance distribution over the dome. Rendering is done in two steps, first the scene is compiled into an *octree*, than *rpict*, the raytracer used to generate pictures from Radiance scene, writes the image. Finally, *falsecolor* generates an image showing the illuminance values in lux.

```
oconv vsd.rad > vsd.oct
```

```
rpict -i+ -vth -vu 0 1 0 -vp 0 0 0 -vd 0 0
1 -ab 1 -vh 180 -vv 180 vsd.oct
irradiance.hdr

falsecolor -log 2 -s 20000 -l Lux
irradiance.hdr | ximage
```

Oconv simply takes the scene's filename as an argument. To control *rpict*, we set the -i-flag (-i+) to switch to irradiance, set the view type (-vth), the direction that will point up in the image (-vu 0 1 0, setting positive y to be up), set up the camera by defining position (-vp 0 0 0) and direction (-vd 0 0 1), set the number of ambient bounces to zero (-ab 0) and the horizontal and vertical view angles both to 180. *Rpict* will write its output to the image file irradiance.hdr, the input for the Radiance script falsecolor, that will generate an image showing the illuminance on a logarithmic scale from zero to 20000 lux, writing the result not to a file but to ximage. The result is shown in figure 7.

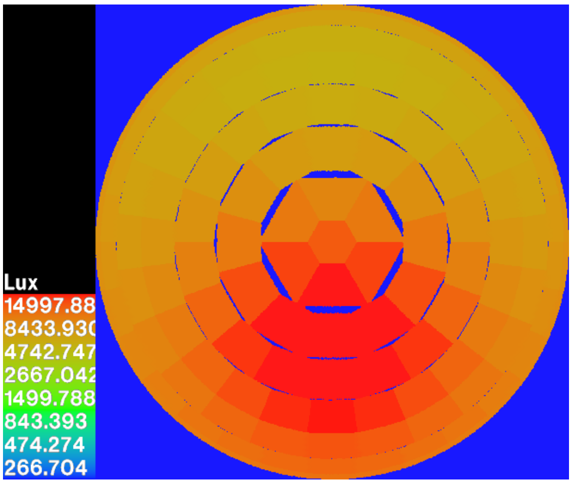


Figure 7. Falsecolor rendering viewing straight up into the VSD

The image clearly shows the illuminance distribution of the sky with the brighter areas around the sun due South. As we used a very basic approximation to the dome, there are rather large gaps (with zero illuminance) mainly between the more central patches of the vsd. This may lead to considerable errors especially for vertical illuminance. One way to reduce these errors is to improve the geometry of planar surfaces in the VSD, by refining those especially in the upper part of the dome and closing the gaps. This allows us to keep the generic representation of the VSD as geometry and material while reducing the error caused by the approximation of the dome.

Another approach, that certainly fits best to Radiance's capability of including scripts and mathematical expressions, would be to define the VSD without the use of the geometric model. This would define the sky patches as sources, a Radiance primitive not giving an actual geometry, but the position and solid angle of a (infinitely) distant light source. While giving up the generic representation of the VSD (the source primitive can be hardly describes in CAD software and renders the VSD application-specific to Radiance), this kind of VSD could be used with models of all sizes and could eliminate the errors introduced by the approximation of the dome with planar faces.

To measure the exact values of illumination at a certain point, Radiance provides the program *rtrace*. Given the option -I, it will calculate the irradiance measured from points and directions taken from its input. The output can be used to determine the illuminance using the general equitation 18:

$$I = Ir*179 \text{ lm/W} \qquad \text{(eq. 18)}$$

With I being Illuminance (lux) and Ir Irradiance (W/m^2) as calculated by *rtrace*, 179 lm/W being an average luminous efficacy. To allow coloured skys with different Irradiance values for the three rgb-channles, we multiply the luminous efficacy with the photometric average of the red, green and blue irradiance values obtained from *rcalc* instead as in equation 19:

$$I = (0.265* Ir\ red + 0.670* Ir\ green + 0.065* Ir\ blue) * 179 \text{ lm/W} \qquad \text{(eq. 19)}$$

The command line to calculate vertical illuminance in lux reaching point (0;0;0) from the octree VSD.oct we compiled before reads:

```
echo 0 0 0 0 0 1 | rtrace -I+ -h -ab 3 -x 1
vsd.oct  | rcalc -e
'$1=179*(0.265*$1+0.67*$2+0.065*$3)'
```

The output of *rtrace* (three irradiance values for red, green and blue) is sent to the Radiance tool *rcalc*, which translates the irradiance to illuminance values. As it would be a tedious task to define all 145 modifiers and the geometry for every VSD, we developed a tool that reads the radiance of the 145 sky patches as comma separated values from a file (which can be written from the spreadsheet), translates these to modifier definitions and combines the 145 modifiers with the VSD geometry, which eventually produces a complete Radiance scene that can be used in conjunction with the geometry we want to put into our environment.

VSD SIMULATION IN PHOTOPIA

Photopia is a commercial optical design and analysis tool. It uses ray tracing algorithms to calculate the interaction of light with materials. The main reason of selecting Photopia is the fact that it comes with a sophisticated material library comprising of BRDF/BTDF data for over 150 common materials from all major manufacturers. Advanced daylighting relies on reflectors and refractors and therefore only if their material data is properly set up, we can expect usable results in computational simulation.

Daylight in Photopia can be set up in a very similar way to the VSD approach. It also uses a half dome, whose surfaces emit light of distinct magnitude to represent daylight. However there are two main differences to the VSD. First the geometric segmentation in photopia equally divides the half dome into 6 horizontal rings (15deg step) of each 24 segments, resulting in 144 segments. This results in bigger surfaces at the horizon and smaller surfaces at the zenith. The VSD approach aims at having all patches of same size. Another difference is the definition of light intensity in the patches. Those patches in VSD have a luminance value that is absolute i.e. 4kcd/m2. The luminance assigned to a patch in Photopia is a relative value. The simulation first refers to another file that contains the total luminous flux (sum of all patches) and then determines a real luminance for each patch according to the share of the initial value.

Setting up a VSD in Photopia is easy. The generic geometry of the VSD has to be imported (via DXF) in order to replace the initial half dome. Each light source has to be in a separate layer starting with the prefix ‘Lamp’ i.e. ‘Lamp109’. ‘Sails’ are added at one vertex of each patch to indicate the surface normal.

The layer names are referred to in the ‘Lamp Definition File’ (*.LDF). The initial rated luminous flux is also stated there as the sum of all 145 spotlights:

```
Name: Singapore VSD11 66Altitude
180Azimuth
Library Name: VSD
Manufacturer: N/A
Code: 0830SING
Lamp Watts: 0
Typical Ballast Watts: 0
Initial Rated Lumens: 210494960
Theory
Lumen Ratio: 1.0
Layer: LAMP-VSD11-001
Material: CLEAR001
Luminance Filename: LAMP-VSD11-001.LUM
Shading Ability: SHADOW
Layer: LAMP-VSD11-002
Material: CLEAR001
Luminance Filename: LAMP-VSD11-002.LUM
```

All sky patches or rather layer are associated with external *.LUM files. This ‘Lamp Luminance File’ describes how the luminance spreads from a plane it is associated with (the ‘sail’ just tells which half room is to be considered). The first line defines the angular increment between the luminance values. The second line defines the luminance perpendicular to a surface. The third line defines the luminance at the first angular increment away from perpendicular, axially symmetric, etc. However there can only be 10 luminance values. In our case a 60 degree spotlight could be set up through the same luminance for perpendicular, 5, 10, 15, 20, 25, 30 angles (7 values):

```
5
2935
2935
2935
2935
2935
2935
2935
0
0
0
```

Alternatively we could use 4 values with an increment of 10 degrees or just 2 values with 30 degree. However smaller increments ensure a better distribution of the luminance values. Whereas Lightscape and Radiance define all light sources in one file, Photopia requires 145 individual LUM files.

All files are automatically generated in a fashion similar to the other software.

Figure 8 depicts a VSD in Photopia with some of the processed light rays visualized as 3d rays. We can note that the light defined in the lum file is emitted from the whole patch and not just the centre, making some rays from the lower ring actually beam upwards.

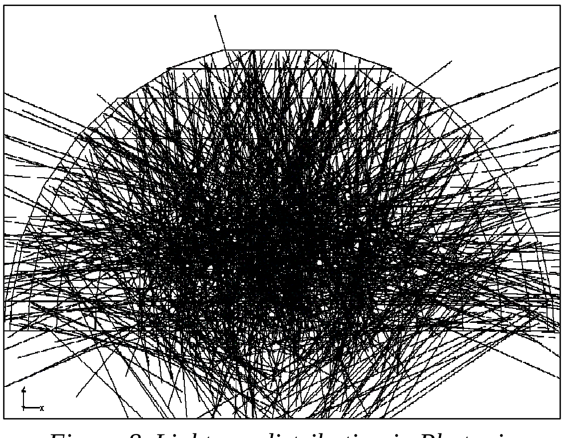
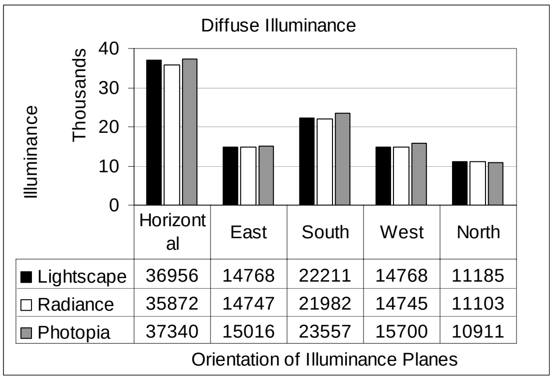


Figure 8. Light ray distribution in Photopia

ILLUMINANCE READINGS

Each of the software provides features or scripts to perform lighting analysis. One horizontal and four vertical illuminance planes have been defined and readings at position 0.0.0 are taken after processing the simulation. The results are very close with

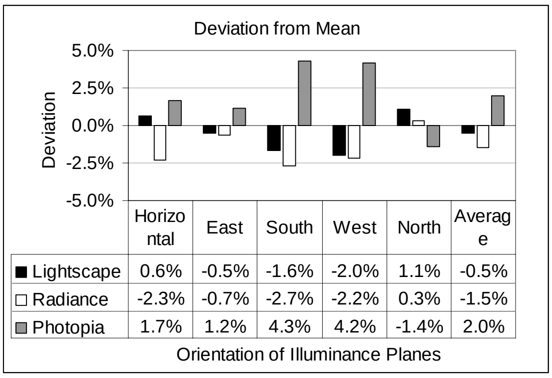
Radiance achieving slightly lower illuminance level compared to Photopia as shown in figure 9.



	Horizontal	East	South	West	North
Lightscape	36956	14768	22211	14768	11185
Radiance	35872	14747	21982	14745	11103
Photopia	37340	15016	23557	15700	10911

Figure 9. Diffuse Illuminance

Figure 10 relates the individual illuminance values to the average, expressed as deviation in percent. The maximum positive devition is caused by Photopia with around 4% on the South and West facing vertical planes. Similarly for those planes Radiance scores the highest negative deviation with values around -2-3%. The deviation is on average around 2%.



	Horizontal	East	South	West	North	Average
Lightscape	0.6%	-0.5%	-1.6%	-2.0%	1.1%	-0.5%
Radiance	-2.3%	-0.7%	-2.7%	-2.2%	0.3%	-1.5%
Photopia	1.7%	1.2%	4.3%	4.2%	-1.4%	2.0%

Figure 10. Illuminance deviation

DISCUSSION

The deviations are probably due to the simplification of the VSD geometry. However the impact is insignificant from the low deviations. The daylight setting using the VSD approach generates very similar values for diffuse illuminace across this range of software and thus the VSD could be seen as a generic method to set up daylight.

APPLICATION FOR DAYLIGHT DESIGN STUDIES

The VSD was subsequently used to assess the increase of Daylight Autonomy through the use of anidolic integrated ceilings (AIC) in office spaces (Wittkopf et al., 2006) AIC comprises of external collectors of non-imaging optics and internal reflective funnels and exit apertures to re-direct ddiffuse daylight deep into the building interior. The software Photopia was used because it provides material libraries of the particular material used in anidolic devices. A VSD was built by taking into account a mix of frequent sky types in Singapore, analysed from real measurements (Tregenza, 1999). With this we could simulate the Daylight Automomy of a reference room with and without an AIC. Our findings reveal that AIC increases the Daylight Autonomy by 20-30%, which is directly proportional to savings in electrical lighting.

CONCLUSION

VSD represents a new method by which daylight settings can be defined in a generic way for use in a range of light simulation software. VSD can be used to generate a sky pattern or a mix of sky types representing the daylight climate of a particular location. It replaces or extends the daylight definitions and makes sure that they comply with the current CIE/ISO Standard General Sky.

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