Calculating spatial efficiency of indoor lighting using lighting application efficacy framework

Parisa Mahmoudzadeh; Pennsylvania State University
Dr. Wenye Hu; University of Sydney
Dr. Wendy Davis; University of Sydney
Dr. Alp Durmus; Pennsylvania State University

20th International Radiance Workshop
Toronto, Canada
August 4, 2022
Outline

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  • Spatial efficiency basics
  • Procedure map

• Methods
  • Variables
  • Radiance functions
  • Room, material, luminaire setup
  • Calculation settings

• Results
• Future study
• Documentation
• Lighting application efficacy (LAE): light that contributes to visual perception
• Spatial efficiency: the proportion of light emitted by the luminaires that reflect off surfaces and ultimately reach the eyes of occupants.

Figure 1. The light that contributes to visual perception.
Procedure map for the spatial efficiency calculations

Part I: Definition

Section I: defining specific independent variables such as the calculation points and luminaire coordinates

Python

Section II: Establishing an automated process to execute simulations with Radiance Lighting for different sets of variables consecutively

Python

Part II: Development

Part III: Simulation

Section I: Acquire irradiance RGB values in calculation points for each simulation condition defined in Part I

Radiance

Section I: Calculating spatial efficiency values for task surfaces in each simulation condition

Excel

Part IV: Calculation

Part V: Analysis

Section I: Analyzing the effect of each independent variable on spatial efficiency

Excel/Python

Section II: Sub-analyzing the effect of each independent variable on spatial efficiency in categories

Excel/Python
Spatial efficiency basics

Spatial efficiency (unitless) = \( \frac{\text{Radiant flux (watts) at the work plane level}}{\text{Input power of the luminaires (watts)}} \)

\( = \frac{(R+G+B \text{ values for Irradiance (watts/m}^2) \text{) } \times \text{(Area of the work plane (m}^2))}{\text{Input power of the luminaires}} \)
Variables

- Room dimensions
- Reflectance levels of surfaces inside the room
- Luminaire types, numbers, and placement
- Work plane size and calculation points
1. Creating a room: ‘genbox’ (feasible through different programs)
2. Converting any number of luminaire IES data files to a readable files by Radiance: ‘ies2rad’
3. Placing the luminaires in the desired position: ‘xform’
4. Creating an octree from the Radiance scene descriptions: ‘oconv’
5. Tracing rays in the Radiance scene: ‘rtrace’
   • rtrace with the “I” option which will compute irradiance rather than radiance, with the input origin and direction interpreted instead as measurement point and orientation
Room setup

1. genbox plastic room 10 10 3 > room10.rad

2. plastic polygon room.2310
   0
   0
   12
   10 10 0 10
   10 10 0 0
   10 0 0 0
   0 0 0 0

3. plastic polygon room.3267
   0
   0
   12
   10 10 0 0
   10 10 0 3
   10 10 0 3
   10 10 0 3

4. plastic polygon room.5137
   0
   0
   12
   10 0 0 0
   10 0 0 3
   10 0 0 3
   10 0 0 3

5. plastic polygon room.6457
   0
   0
   12
   0 10 0 0
   0 10 0 3
   0 10 0 3
   0 10 0 3
Material setup (reflectance levels)

<table>
<thead>
<tr>
<th>Material</th>
<th>Reflectance Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>void plastic floor</td>
<td>0.2 0.2 0.2 0 0</td>
</tr>
<tr>
<td>void plastic wall</td>
<td>0.5 0.5 0.5 0 0</td>
</tr>
<tr>
<td>void plastic ceiling</td>
<td>0.8 0.8 0.8 0 0</td>
</tr>
</tbody>
</table>

Reflectance levels (gray scale):

- 20%
- 50%
- 80%
Luminaire setup

[INPUTWATTAGE] 8.2
Luminaire set up

ies2rad 6-inch-downlight.ies

xform -t 2.5 2.5 3 6-inch-downlight.rad > luminaire_transformed.rad

xform -t 7.5 7.5 3 6-inch-downlight.rad >> luminaire_transformed.rad
Calculation settings

• Octree file:

  1. `Oconv luminaire_transformed.rad room10.rad > room10.oct`

• Calculating irradiance:

  2. `rtrace -I -as 4096 -ar 100 -aa 0.1 -ab 50 room10.oct < in.dat > out.dat`

• Rendering the scene (optional):

  3. `rvu -as 1024 -ar 100 -aa 0.1 -ab 50 room10.oct`
Calculation settings

• Calculating irradiance:

```
rtrace -I -as 4096 -ar 100 -aa 0.1 -ab 50 room10.oct < in.dat > out.dat
```

• Calculation points’ coordinates:

<table>
<thead>
<tr>
<th>Point coordinates</th>
<th>Vector direction</th>
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<tbody>
<tr>
<td>1 1 0.76</td>
<td>0 0 1</td>
</tr>
<tr>
<td>1 2 0.76</td>
<td>0 0 1</td>
</tr>
<tr>
<td>1 3 0.76</td>
<td>0 0 1</td>
</tr>
<tr>
<td>1 4 0.76</td>
<td>0 0 1</td>
</tr>
<tr>
<td>4 1 0.76</td>
<td>0 0 1</td>
</tr>
<tr>
<td>3 1 0.76</td>
<td>0 0 1</td>
</tr>
<tr>
<td>2 1 0.76</td>
<td>0 0 1</td>
</tr>
</tbody>
</table>
Automating the process

Figure 2. Python code for automating the simulation process.

Figure 3. Rendering process for a simulation condition.
Results

R  
1.863722e+00 + 1.863722e+00 + 1.863722e+00 = 5.59 watts/m^2
1.132321e+00 + 1.132321e+00 + 1.132321e+00 = 3.40 watts/m^2
5.018600e-01 + 5.018600e-01 + 5.018600e-01 = 1.51 watts/m^2
2.037378e+00 + 2.037378e+00 + 2.037378e+00 = 6.11 watts/m^2

G

B

Irradiance
Results

Spatial efficiency = \frac{(R+G+B \text{ values for Irradiance } (\text{watts/m}^2)) \times (\text{Area of the work plane } (\text{m}^2))}{\text{Input power of the luminaires}}

Spatial efficiency = \frac{(5.59 \text{ (watts/m}^2)) \times (1 \text{ (m}^2))}{8.2 \text{ watts}} = 68\%

- Optimizing design features so that spatial efficiency values are closer to 1 or 100%
Future study

• Implementing the effect of the human eye field of view sensitivity to brightness to spatial efficiency values using ‘rsensor’ program

• ‘rsensor’ traces rays outward from sensors into the Radiance scene given by octree, sending the computed sensor value to the standard output

Figure 4. Human field of view and brightness perception.

<table>
<thead>
<tr>
<th>Azimuthal angles</th>
<th>Sensitivity values</th>
</tr>
</thead>
<tbody>
<tr>
<td>degrees</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>.02</td>
</tr>
<tr>
<td>45</td>
<td>.01</td>
</tr>
<tr>
<td>90</td>
<td>.001</td>
</tr>
</tbody>
</table>
Thank you!

- [Access link to input files]

- The LAE project has been funded by the U.S. Department of Energy.

- Contact: parissa@psu.edu