Calculating spatial efficiency of indoor lighting using lighting application efficacy framework

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- Methods
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  - Radiance functions
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Introduction

- 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.

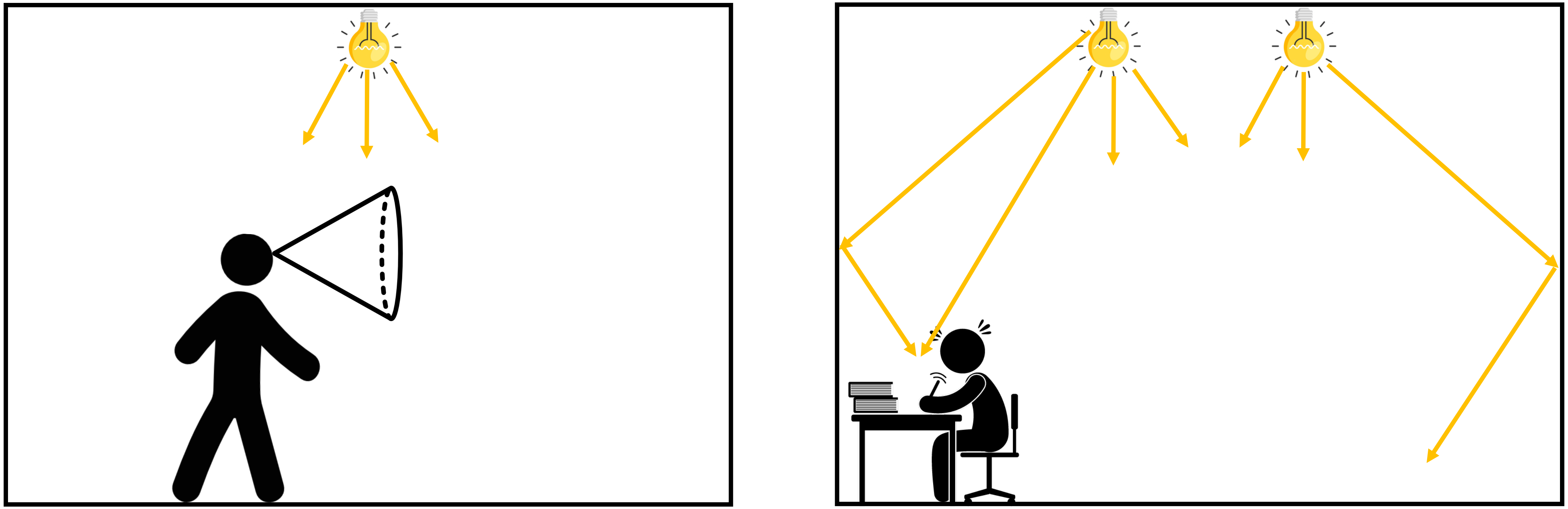


Figure 1. The light that contributes to visual perception.

Procedure map for the spatial efficiency calculations

Part I: Definition

Section I: independent variables

Part II: Development

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 III: Simulation

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

Radiance

Part IV: Calculation

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

Excel

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

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

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

Variables

- Room dimensions
- Reflectance levels of surfaces inside the room
- Luminaire types, numbers, and placement
- Work plane size and calculation points

Fundamental Radiance programs

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

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

1

```
# genbox plastic room 10 10 3

plastic polygon room.1540
0
0
12
        10      0       0
        10      0       3
         0      0       3
         0      0       0

plastic polygon room.4620
0
0
12
         0      0       3
         0     10       3
         0     10       0
         0      0       0

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

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

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

plastic polygon room.6457
0
0
12
         0     10       3
         0      0       3
        10      0       3
        10     10       3
```

2

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

3

Material setup (reflectance levels)

```
void plastic floor
0
0
5 0.2 0.2 0.2 0 0

void plastic wall
0
0
5 0.5 0.5 0.5 0 0

void plastic ceiling
0
0
5 0.8 0.8 0.8 0 0
```

Reflectance levels (gray scale):

- 20%
- 50%
- 80%

Luminaire setup

[_INPUTWATTAGE] 8.2

6-inch-downlight.ies - Notepad

File Edit Format View Help

```
IESNA:LM-63-2002
[TEST] LTL27779P2282
[ISSUEDATE] 2/12/2022
[TESTLAB] SCALED PHOTOMETRY
[MANUFAC] Gotham Architectural Lighting
[LUMCAT] EVO6 27/07 AR MD LD
[LUMINAIRE] EVO 6IN ROUND, 80 CRI, 2700K, 750LM, MED DIST, CLEAR, MATTE DIFFUSE
[DISTRIBUTION] DIRECT, SC-0=0.89, SC-90=0.88
[_TOTALLUMINAIRELUMENS] 653.9
[_INPUTWATTAGE] 8.2
[_LAMPTYPE] LED
[_MOUNTING] Recessed
[_PHYSICALDIMENSIONS] -0.52, -0.52, 0
[_FAMILY] EVO? 6" Round Downlight
[_PRODUCTID] e8f55b95-fce7-4d5e-bbec-693d2799f850
[_APERTURE] 6
TILT=NONE
1  -1  0.206395369482618  37  5  1  1  -0.52  -0.52  0
1  1  8.2
0  2.5  5  7.5  10  12.5  15  17.5  20  22.5  25  27.5  30
32.5  35  37.5  40  42.5  45  47.5  50  52.5  55  57.5  60
62.5  65  67.5  70  72.5  75  77.5  80  82.5  85  87.5  90
0  22.5  45  67.5  90
4059  4066  4026  3952  3945  3962  3935  3790  3469  2985
2439  1941  1519  1138  831  573  340  182  99  50  23  9
5  3  3  0  1  0  2  1  1  1  0  0  0  0  0
4059  4038  3980  3906  3903  3922  3892  3746  3428  2941
2399  1911  1493  1124  823  576  345  185  101  51  22
9  5  3  3  2  2  1  1  1  1  0  0  0  0  0  0
4059  4039  3982  3914  3905  3930  3902  3752  3422  2940
2392  1898  1485  1118  820  569  340  179  97  48  21  8
4  3  2  2  2  0  1  1  1  0  0  0  0  0  0
4059  4044  3992  3929  3918  3943  3910  3747  3418  2916
2376  1891  1480  1119  816  562  333  174  93  48  20  9
4  3  2  2  1  0  1  1  0  0  0  0  0  0  0
4059  4050  3999  3938  3923  3940  3903  3740  3410  2912
2362  1891  1476  1112  811  556  326  172  92  45  20  9
3  3  2  2  2  0  1  1  0  0  0  0  0  0  0
```

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

Switching to irradiance (-I) — **Calculation points' coordinates** (in.dat)

```
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:

2

Switching to irradiance (-I)

Calculation points' coordinates (in.dat)

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

- Calculation points' coordinates:

Point coordinates ← (columns 1–3) | (columns 4–6) → Vector direction

1	1	0.76	0	0	1
1	2	0.76	0	0	1
1	3	0.76	0	0	1
1	4	0.76	0	0	1
4	1	0.76	0	0	1
3	1	0.76	0	0	1
2	1	0.76	0	0	1

Automating the process

```python
import ...


j = 0


room_sizes = ['3.5 3.5 3', '5 5 3', '9.5 9.5 3', '20 20 3']
for u in range (4):

    with open('pyroom.bat', 'w') as f:
        f.write('genbox plastic pyroom '+room_sizes[u]+' > pygenroom.rad')

    print('u='+str(u))
    try:
        os.remove("pygenroom.rad.rad")
    except:
        print("No pygenroom.rad detected")
    os.startfile("pyroom.bat")


    floor_ref = ['5 0.1 0.1 0.1 0 0', '5 0.2 0.2 0.2 0 0', '5 0.3 0.3 0.3 0 0']
    Wall_ref = ['5 0.3 0.3 0.3 0 0', '5 0.5 0.5 0.5 0 0', '5 0.6 0.6 0.6 0 0']
    ceiling_ref = ['5 0.4 0.4 0.4 0 0', '5 0.64 0.64 0.64 0 0', '5 0.8 0.8 0.8 0 0.3']
    reflines = ['void plastic floor', '0', '0', 'ref_f', '', 'void plastic wall', '0', '0', 're
```

Figure 2. Python code for automating the simulation process.

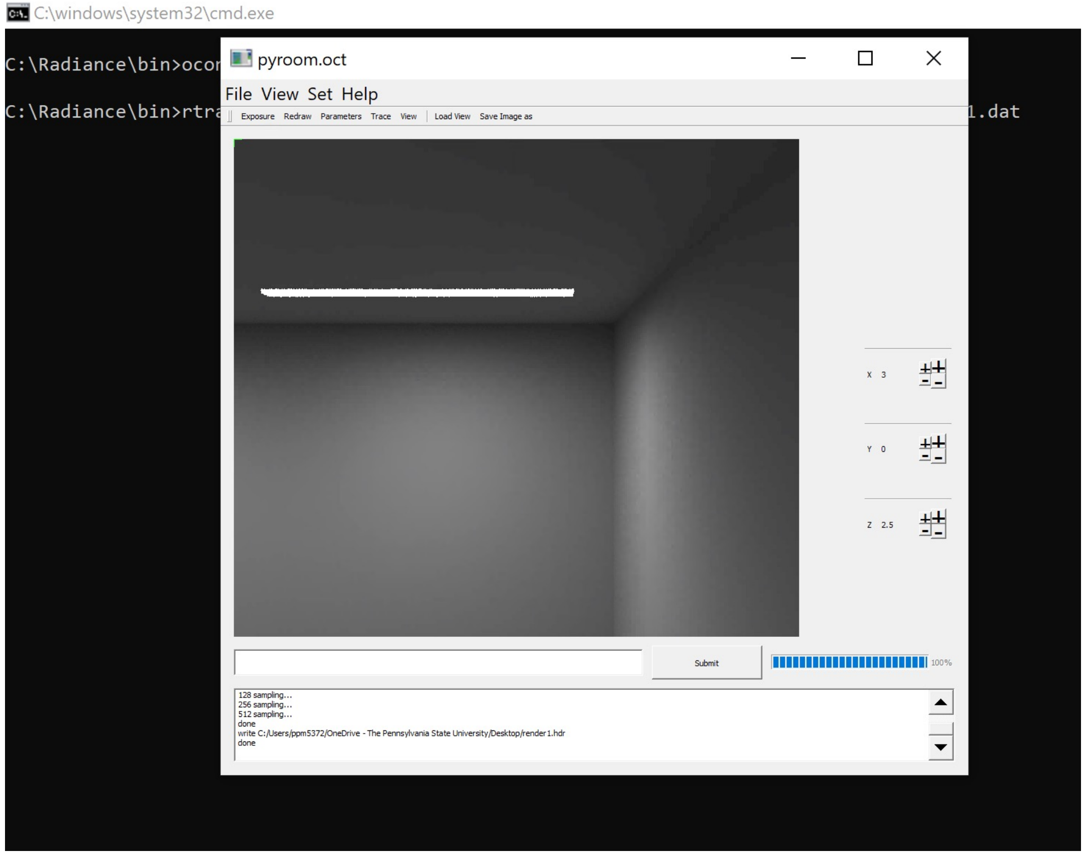


Figure 3. Rendering process for a simulation condition.

Results

R		G		B		Irradiance
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

Results

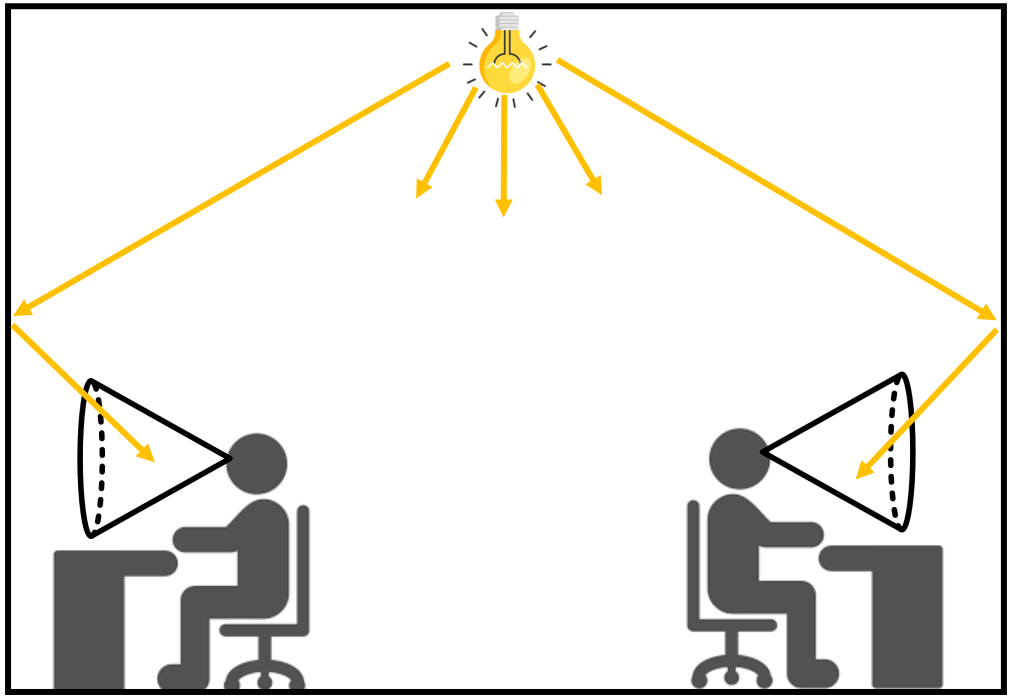
$$\text{Spatial efficiency} = \frac{\text{(R+G+B values for Irradiance (watts/m^2)) x (Area of the work plane (m^2))}}{\text{Input power of the luminaires}}$$

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

- 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



Azimuthal angles

Polar angles

degrees	0	90	180	270
0	.02	.04	.02	.04
45	.01	.02	.01	.02
90	.001	.002	.001	.002

Sensitivity values

Figure 4. Human field of view and brightness perception.

Thank you!

- [Access link to input files]

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