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Modified climate-based daylight modeling methods for buildings

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Outline

1. Introduction
2. Research problem
3. Methods
4. Results
5. Discussions
6. Conclusion and onging work

1 Introduction

Introduction

Previous work at Hunan University


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Analysis of dynamic louver control with prism redirecting fenestrations for office daylighting optimization

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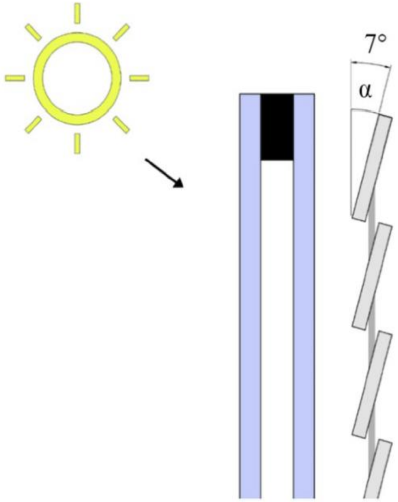

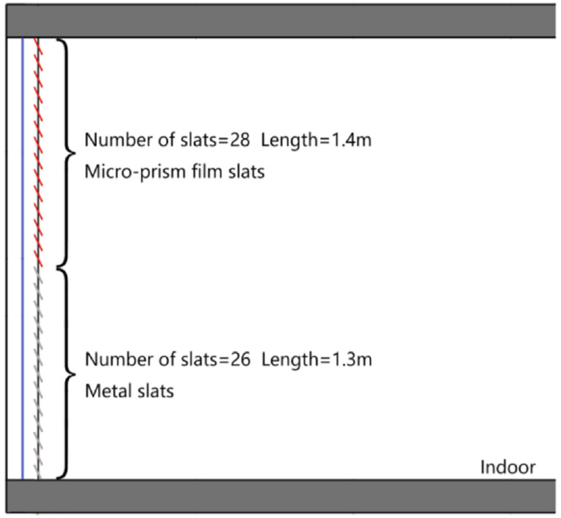

- A dynamic micro-prism film louvers combined with the proposed control strategy provided a better daylighting luminous environment, with improved useful daylight illuminance (UDI) at inner space, and yielded less glare occurrence rates at space close to windows, compared with dynamic metal louvers and double glazing.
- The combined dynamic louvers are consisted of micro-prism film slats and metal slats to reduce the possible glare on the premise and improve the indoor illuminance at the inner space.
- The simulation results showed that the combined dynamic louvers could reduce the discomfort glare occurrence rate by 68.9%, compared to the discomfort rate with double glazing at the front zone; $UDI_{300\text{-}2000\ lx}$ of the combined louvers could be improved by 23%, compared with that of double glazing at the front zone. Compared with the metal louvers with similar low glare occurrence rate, the combined louvers could improve $UDI_{100\text{-}300\ lx}$ at front/middle/back zones by 7.9%, 29.1%, and 2.9%, respectively, and $UDI_{300\text{-}2000\ lx}$ by 40.0%, 11.7%, and 5.7% at these zones, respectively.

Introduction

Previous work at Hunan University


Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

A study of daylight glare evaluation with prism daylighting redirecting fenestrations

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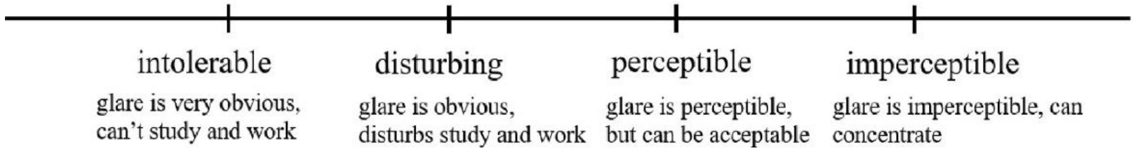
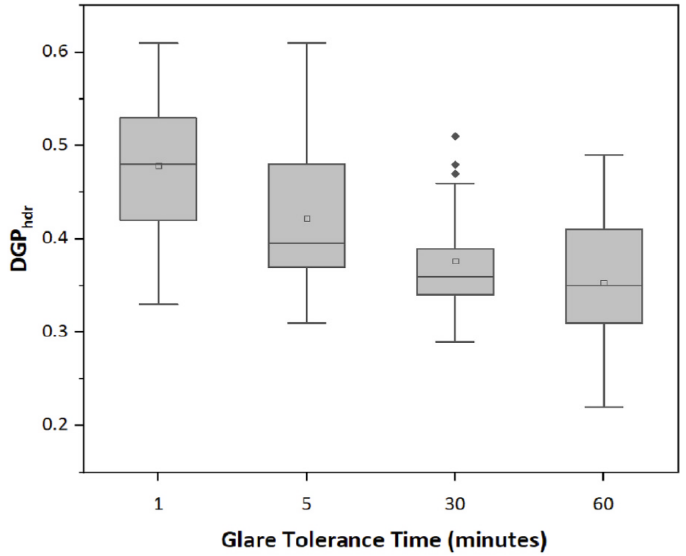
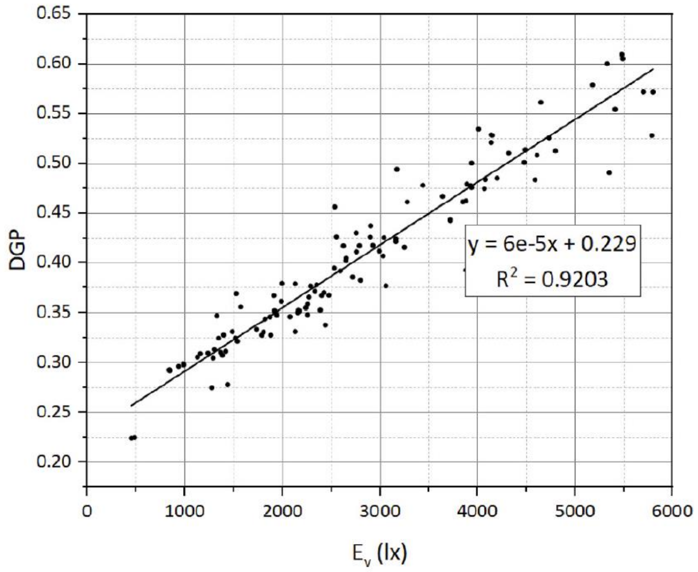
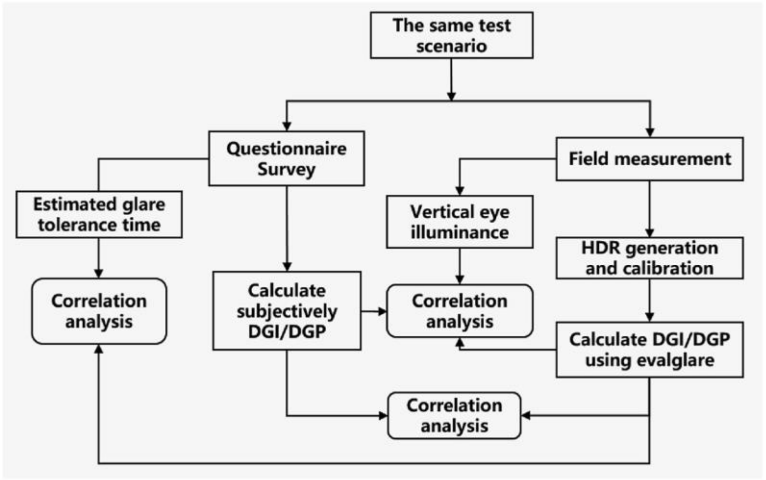








Introduction

Previous work at Hunan University

Threshold for different glare levels from various countries' investigations.

Threshold values of E_v (lx)	Results in this study	Bian and Luo's study in China [23]	Wienold et al.'s cross-validation study [28]
Imperceptible-perceptible	2300	2000	2484
Perceptible-disturbing	3000	3000	3359
Disturbing-intolerable	4300	5000	4384

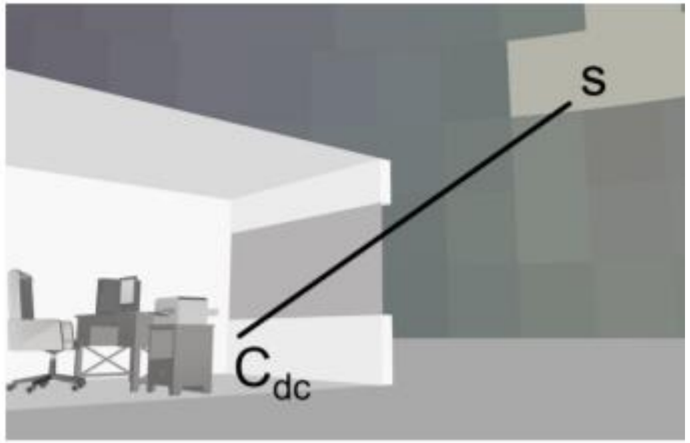
The first-hand literature review found that some research [6,27] over-interpreted Iwata *et al.*'s findings [16,17] and incorrectly stated Japanese people were found to be more tolerant of glare than Americans and Europeans.

HDR photography was used to calculate daylight glare indices, and subjective response was measured by continuous and discrete scales. The statistical results showed that Daylight Glare Probability (DGP) correlated strongly with subjective glare perception and was more robust than Daylight Glare Index (DGI) with PDRF systems. In addition, subjectively estimated glare tolerance time was proposed, and the research results revealed that subjectively estimated glare tolerance time strongly correlated with subjective responses.

Vertical eye illuminance as a daylight glare index for PDRF was also investigated. Three Ev thresholds of different glare perception levels were determined. Three Ev values on four categories of perceived glare levels with PDRF for young adults in classrooms under subtropical skies were identified as 2300 lx, 3000 lx, and 4300 lx, corresponding to the thresholds of imperceptible-perceptible, perceptible–disturbing, and disturbing-intolerable, respectively.

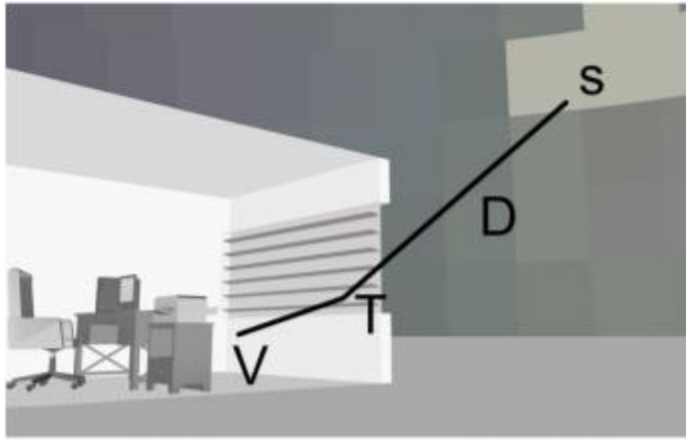
Introduction

Climate-Based daylight modeling research progress



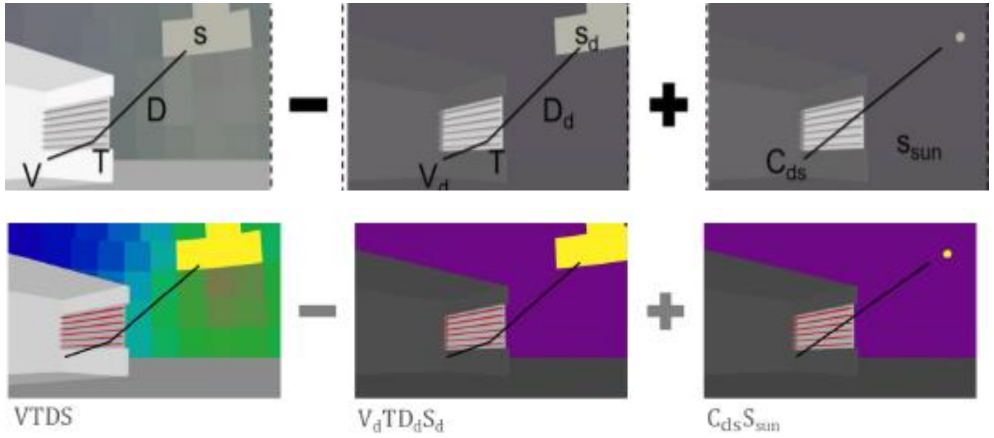
Two-phase Method

1983, Tregenza



Three-phase Method

2011, Greg Ward



Five-phase Method

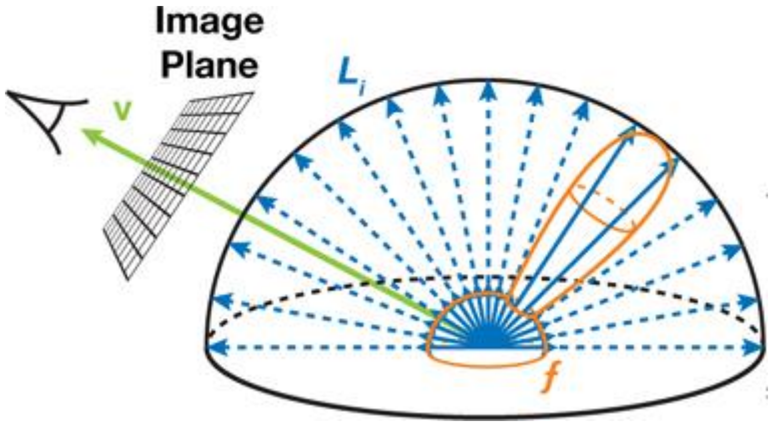
2013, Andy Mcneil;
2017, David Geisler-Moroder

P.R. Tregenza, I.M. Waters, Daylight coefficients, Lighting Research & Technology. 1983,15 65–71.
A. Mcneil, The Five-Phase method for simulating complex fenestration with Radiance, Lawrence Berkeley National Laboratory, 2013.
D. Geisler-Moroder, E.S. Lee, G.J. Ward, Validation of the five-phase method for simulating complex fenestration systems with radiance against field measurements, in: Building Simulation Conference Proceedings, International Building Performance Simulation Association, 2017: pp. 927–935.

2 Research problem

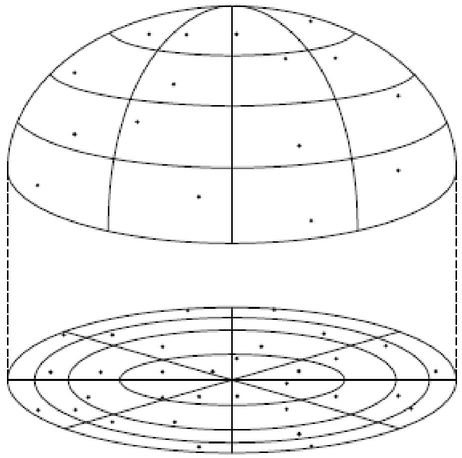
Research Problem

Ambient cache disabled



Standard Monte Carlo methods need to sample random directions over the hemisphere at each pixel for diffuse reflection calculation, this result in the huge computation cost [1]

Without ambient cache



Only several points over the hemisphere are sampled and cached, and interpolation is done between these values [2]

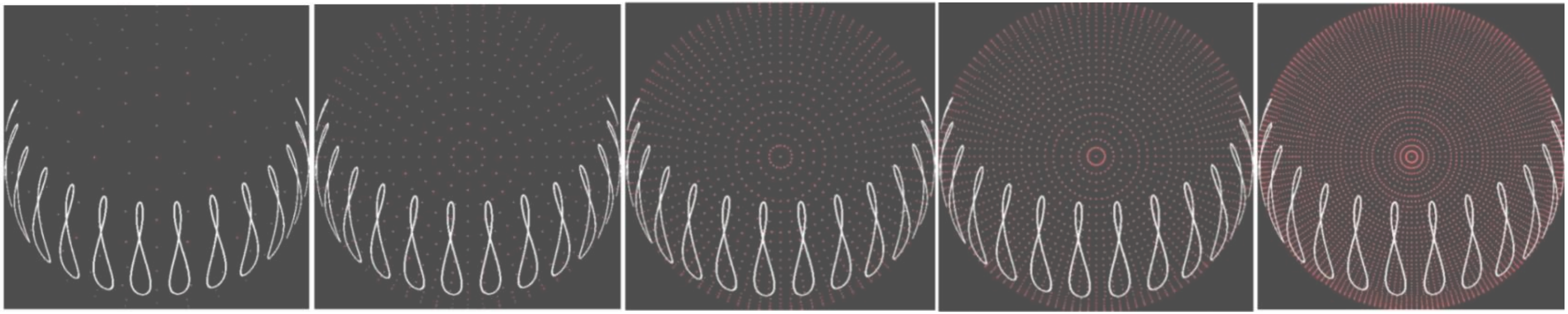
With ambient cache

However, in *rcontrib*, the core of climate-based daylight modeling, the ambient cache was disabled.

[1] https://discourse.radiance-online.org/t/why-the-irradiance-cache-is-disabled-in-rcontrib-rfluxmtx/6220
[2] Greg Ward and Rob Shakespeare. 2021. Rendering with Radiance.

Research Problem

Inexact sun positions were used to calculate the direct sunlight



MF:1(145) MF:2(577) MF:2(1297) MF:2(3601) MF:6(5185) [1]

Source:

Accuracy

Time efficient

No matter how many sun patches are used, it was impossible to model the exact sun positions.

[1] Subramaniam, S. 2017. Daylighting Simulations with Radiance using Matrix-based Methods. https://www.researchgate.net/publication/325248488

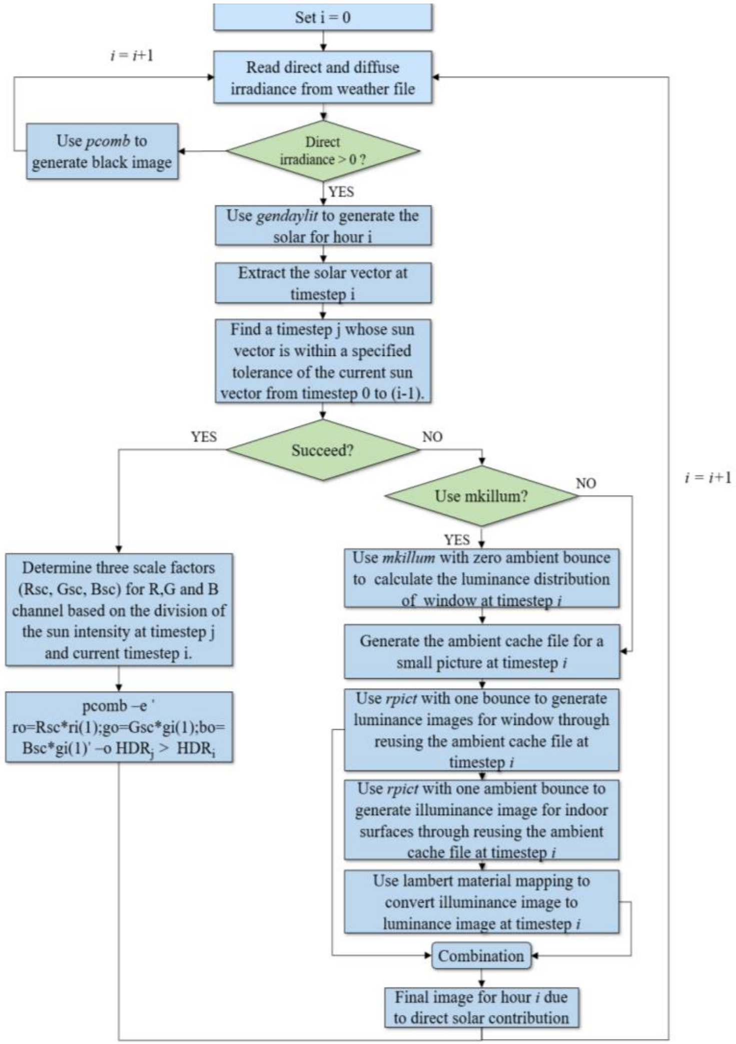
3

Methods

Zhao, Y. and Tian, Z. 2023. Modified climate-based daylight modeling methods for buildings. *Building and Environment*, 242: 110598. https://doi.org/10.1016/j.buildenv.2023.110598

Method M5-PM(A)

Direct sunlight calculation that can use the exact sun positions



Direct sunlight calculation that can use the exact sun positions

Main optimization measures:

1. It uses ***rpict*** to calculate the direct sunlight at each timestep, with ambient cache enabled.
2. It can use exact sun position at each timestep, also a sun position deviation tolerance was employed to accelerate the calculation in the scene that is insensitivity to the sun position. The sun position deviation was calculated using formula (1)

$$\theta = \arccos \frac{\vec{S_i} \cdot \vec{S_j}}{|\vec{s_i}||\vec{s_j}|} \qquad (1)$$

where:

$\vec{S_i}$ are the sun vector at timestep i;

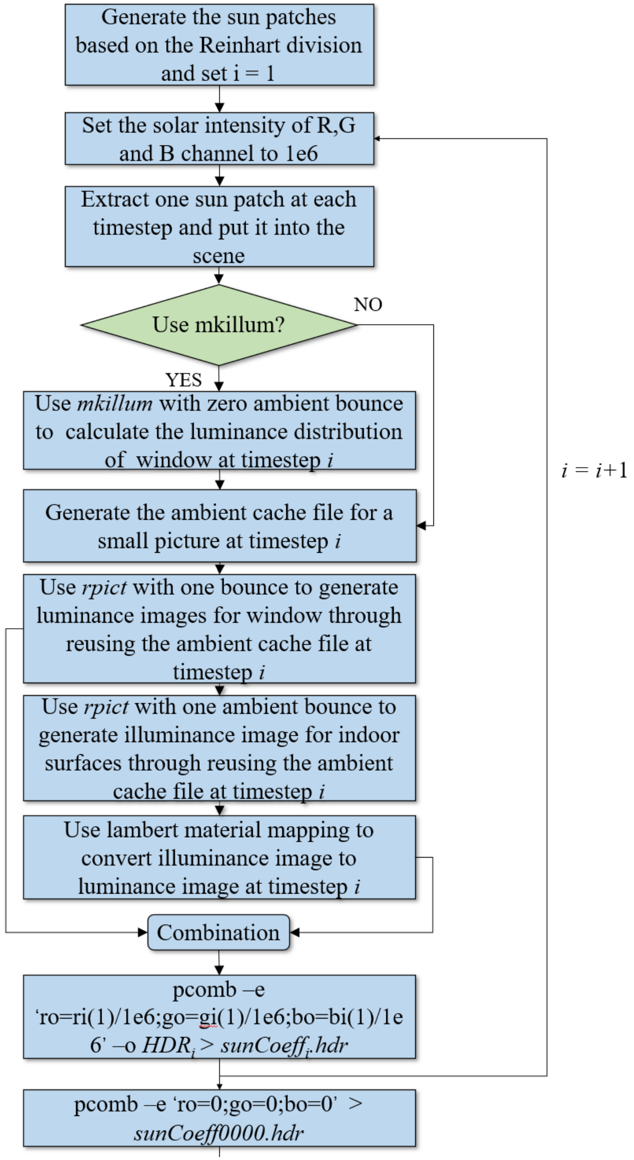
$\vec{S_j}$ are the sun vector at timestep j;

θ are the angle between $\vec{S_i}$ and $\vec{S_j}$.

3. It uses overture calculation to make the rendered image more smoothly.
4. It uses ***mkillum*** to improve the image quality when needed.
5. It uses multithreading to conduct the process parallelly.

Method M5-PM(B)

Using rpict to calculate the sun coefficients for accelerating calculation process

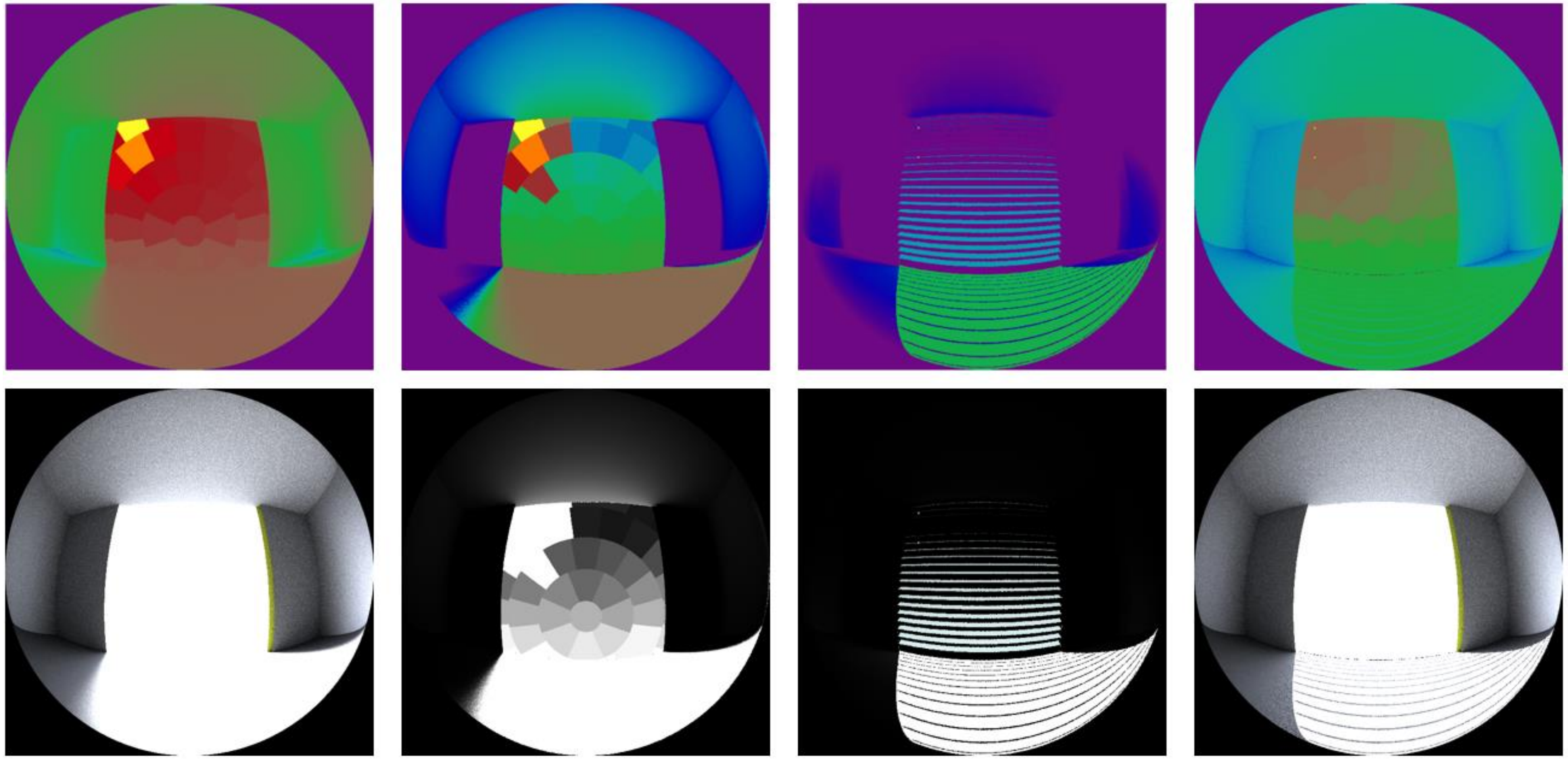


Main optimization measures:

1. It uses ***rpict*** with ambient cache to calculate the sun coefficients
2. It uses overture calculation to take fully advantage of the ambient cache to accelerate the run.
3. It uses ***mkillum*** to improve the image quality when needed.

Methods

Use *rpict* to calculate the direct sunlight

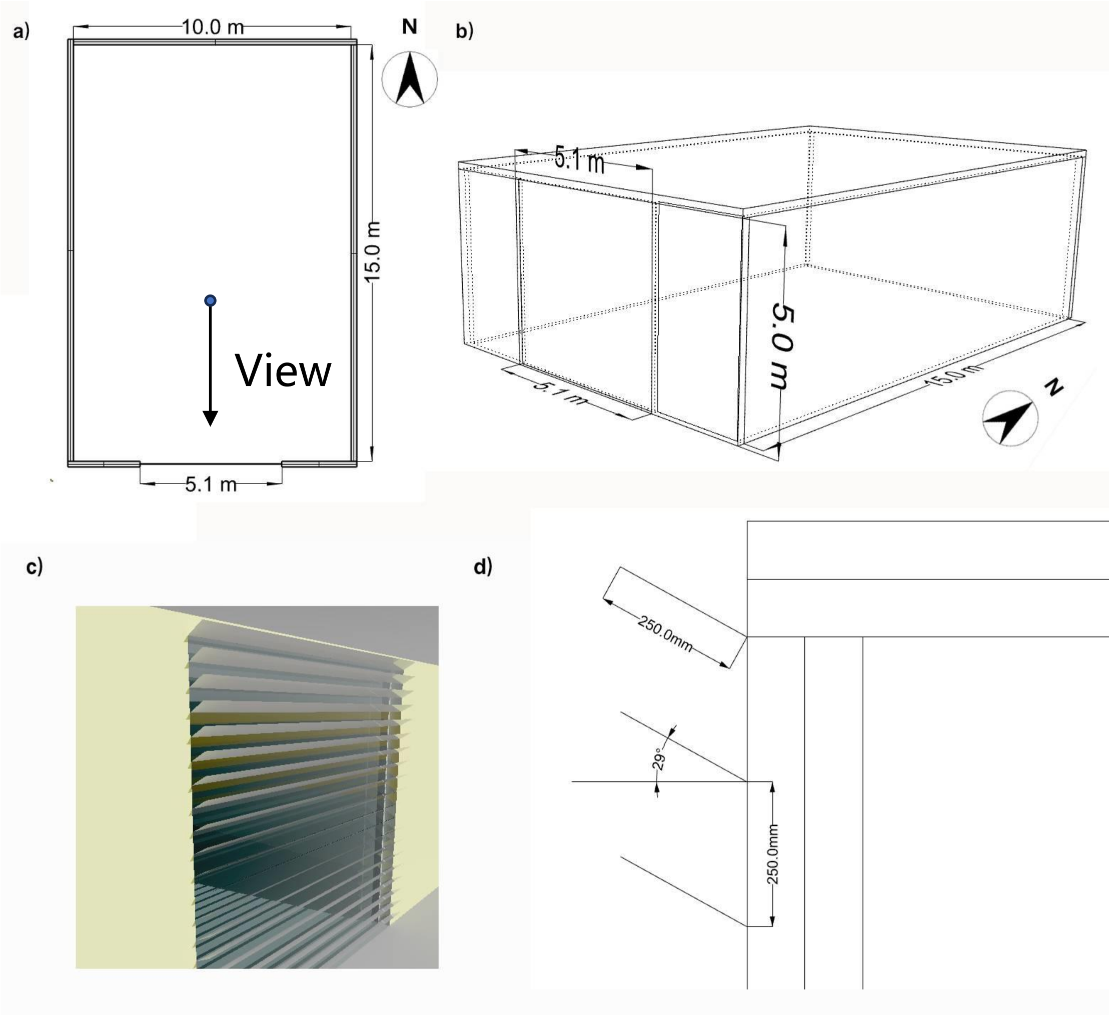


$L_{3\text{-}PM}$ $- L_{ds\text{-}3\text{-}PM}$ $+ L_{ds}\ (mkillum + rpict)$ $= L_{M5\text{-}PM}$

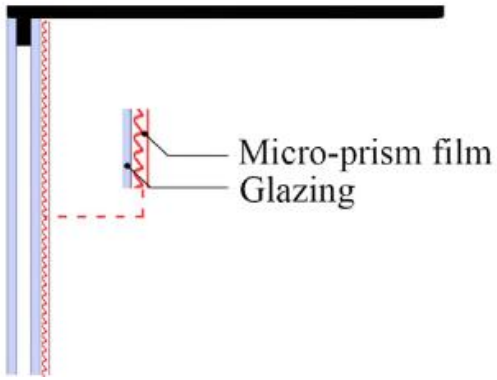
The proposed direct sunlight calculation methods was employed to replace the sun-coefficient method to obtain two modified five-phase method, named as M5-PM(A) and M5-PM(B).

Methods

Test Cases: prismatic redirecting fenestration and specular blinds



Specular blinds



Prismatic Daylight Redirecting Fenestration (PDRF)

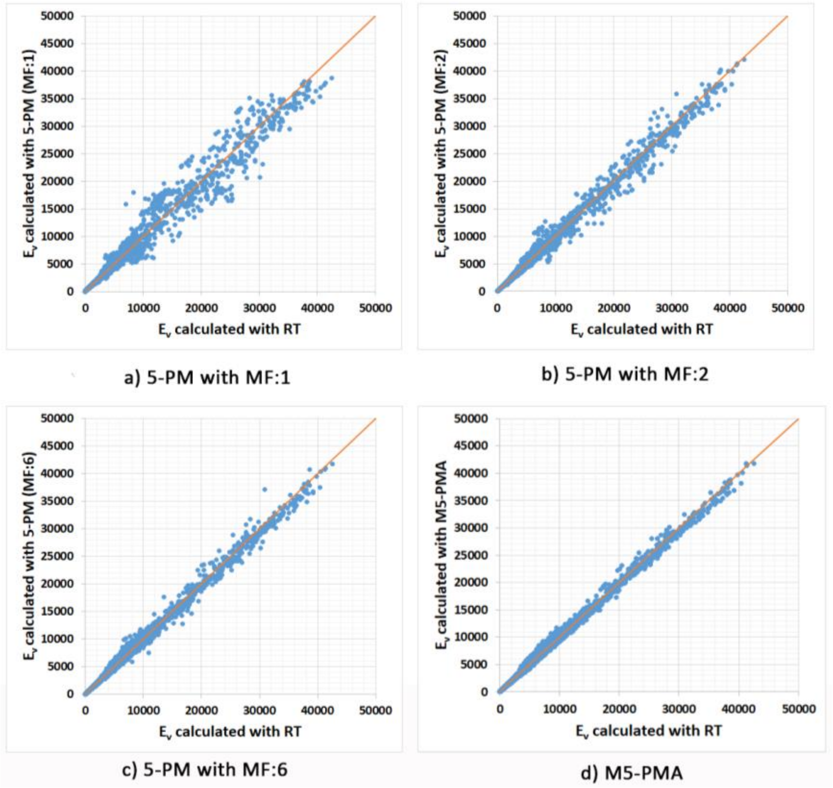
Surfaces	Reflectance
Wall	0.55
Ceiling	0.75
Floor	0.20
Ground Plane	0.20

Note：The accurate geometry was developed for the specular blinds, and BSDF for PDRF

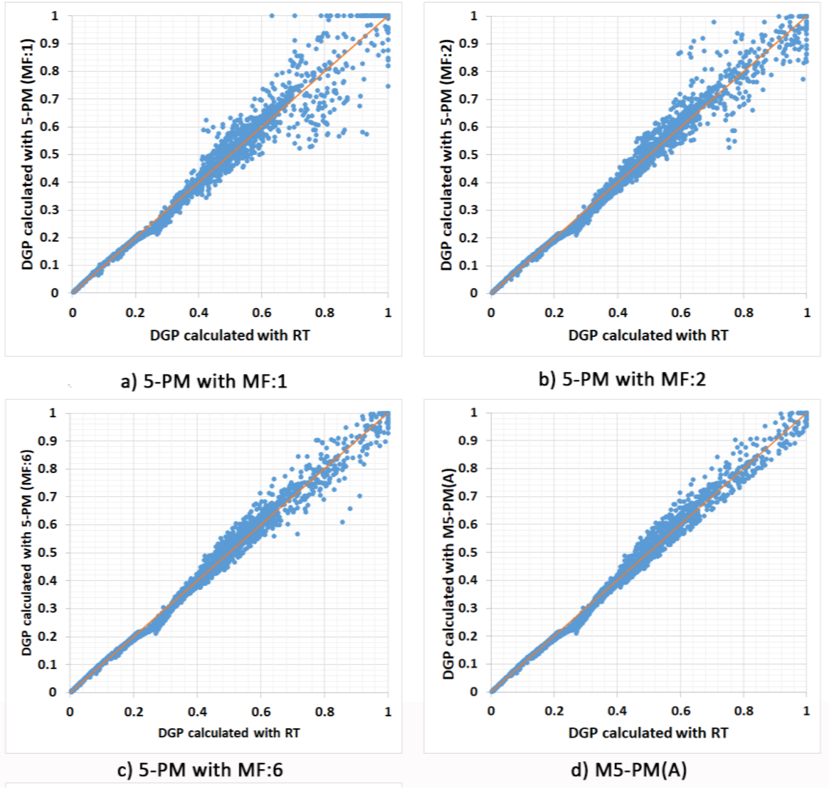
4 Results

Results

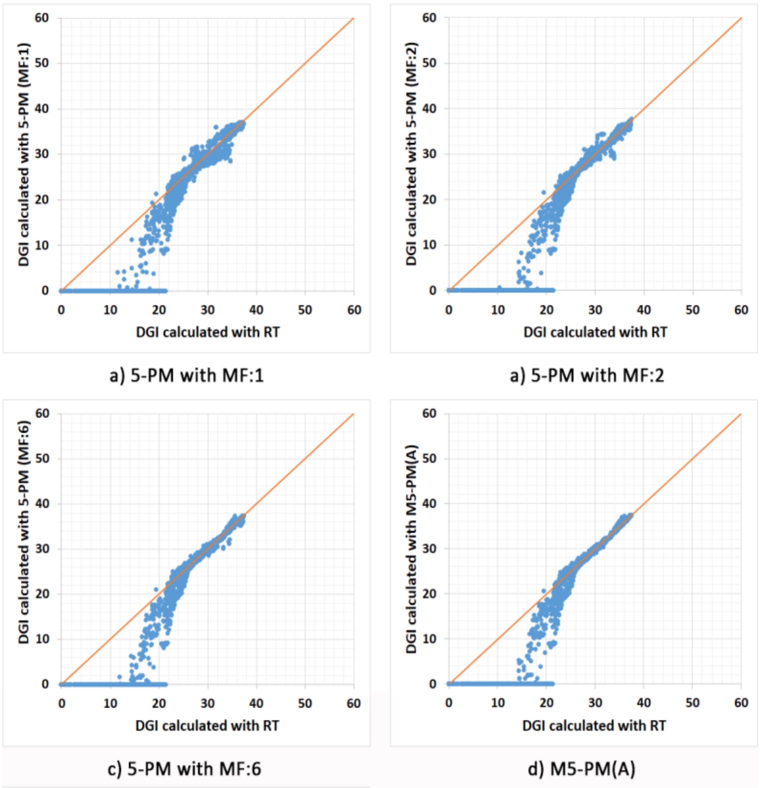
Results for Prismatic Redirecting Daylighting Fenestration using M5-PM(A)



Vertical eye illuminance



DGP



DGI

The glare metrics values calculated with M5-PM(A) and 5-PM have very good agreement with refence case (RT)

Note: The reference case is the conventional ray-tracing method

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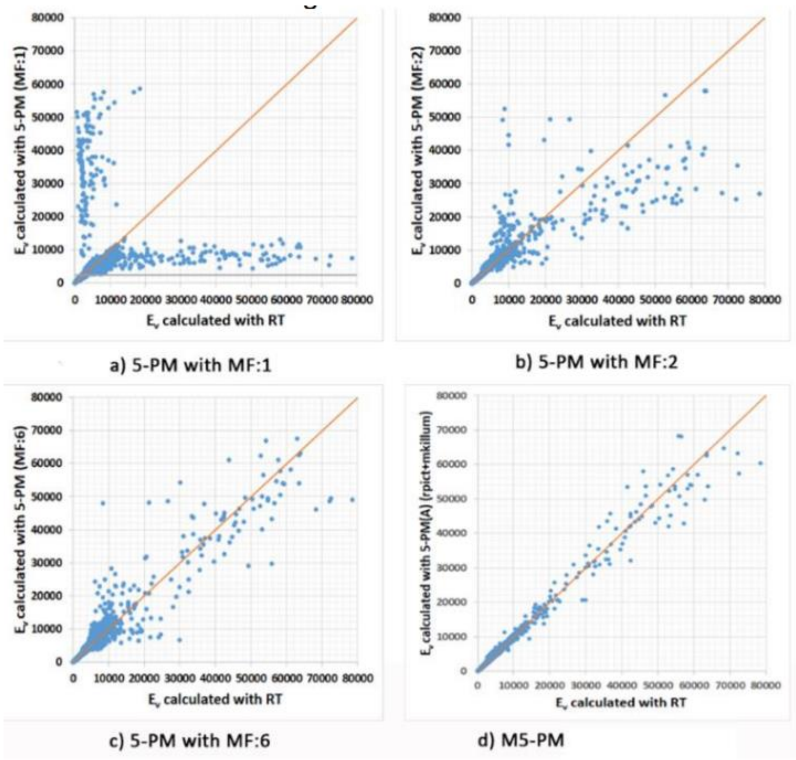
Results

Error analysis for PDRF using the 5-PM(A)

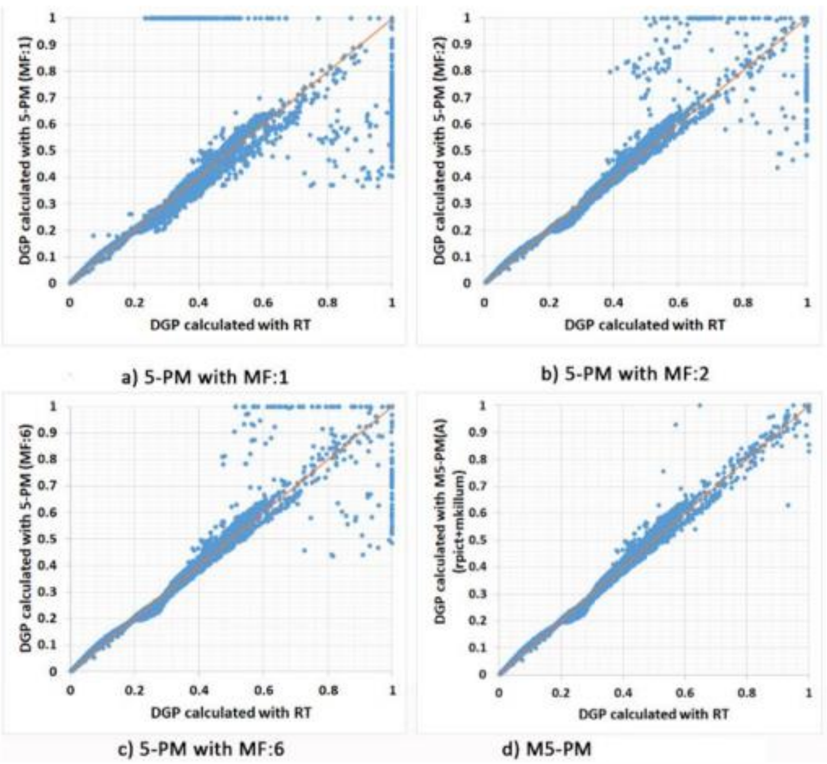
Glare Metrics			5-PM MF:1	5-PM MF:2	5-PM MF:3	5-PM MF:4	5-PM MF:5	5-PM MF:6	M5-PM(A)
DGP	<0.35	RMSE	0.016	0.016	0.016	0.016	0.016	0.016	0.016
		MBE	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	0.35-0.40	RMSE	0.010	0.009	0.008	0.008	0.008	0.008	0.008
		MBE	0.002	0.001	0.000	0.000	-0.000	-0.000	0.000
	0.40-0.45	RMSE	0.029	0.015	0.014	0.015	0.014	0.014	0.014
		MBE	-0.004	0.000	0.000	0.000	-0.000	-0.000	0.000
	⩾0.45	RMSE	**0.053**	**0.041**	**0.035**	**0.030**	**0.030**	**0.029**	**0.03**
		MBE	-0.003	-0.005	-0.006	-0.005	-0.004	-0.004	-0.005
	Overall	RMSE	0.035	0.028	0.024	0.022	0.022	0.021	0.019
		MBE	0.003	0.003	0.002	0.003	0.003	0.003	0.003
Percentage of discomfort glare (DGP >0.40)			44.6%	44.7%	44.7%	44.6%	44.5%	44.5%	44.7%
E_v	Overall	RMSE	1172.4	714.6	578.4	533.0	514.7	503.5	417.2
		MBE	-29.0	-16.1	-16.3	-16.3	-14.4	-14.7	-23.2
DGI	<18	RMSE	8.8	8.6	8.6	8.6	8.5	8.6	8.7
		MBE	5.0	5.0	5.0	4.9	4.9	5.0	5.0
	18-24	RMSE	10.8	10.8	10.7	10.7	10.7	10.7	10.6
		MBE	8.2	1.1	1.1	1.1	1.1	1.1	1.1
	24-31	RMSE	1.0	0.9	0.9	0.9	0.9	0.8	0.8
		MBE	0.8	0.14	0.14	0.14	0.15	0.16	0.18
	>31	RMSE	**1.4**	**0.80**	**0.50**	**0.40**	**0.40**	**0.50**	**0.30**
		MBE	0.2	0.06	-0.007	-0.006	-0.02	0.004	0.04
	Overall	RMSE	5.94	5.82	5.82	5.80	5.79	5.80	5.84
		MBE	2.33	2.30	2.29	2.29	2.28	2.29	2.33
Percentage of discomfort glare (DGI > 24)			57.2%	57.2%	57.3%	57.3%	57.3%	57.3%	57.4%

Results

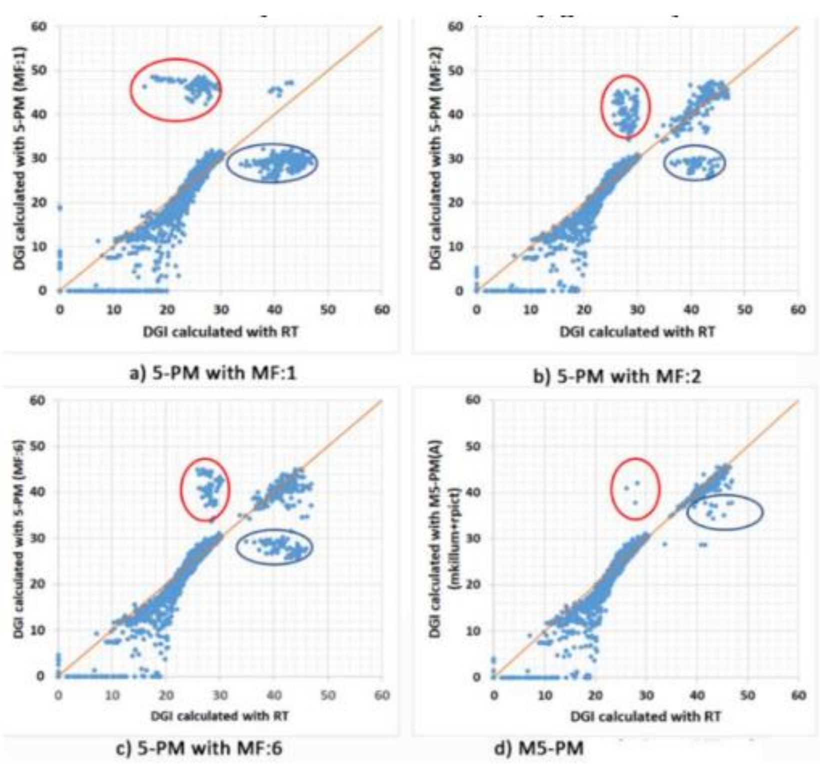
Results for the specular blinds using M5-PM(A)



Ev



DGP



DGI

The glare metrics values calculated with M5-PM(A) have very good agreement with refence case (RT), but and the ones with 5-PM have many outliers. For the DGI calculation, 5-PM may produce reliable results.

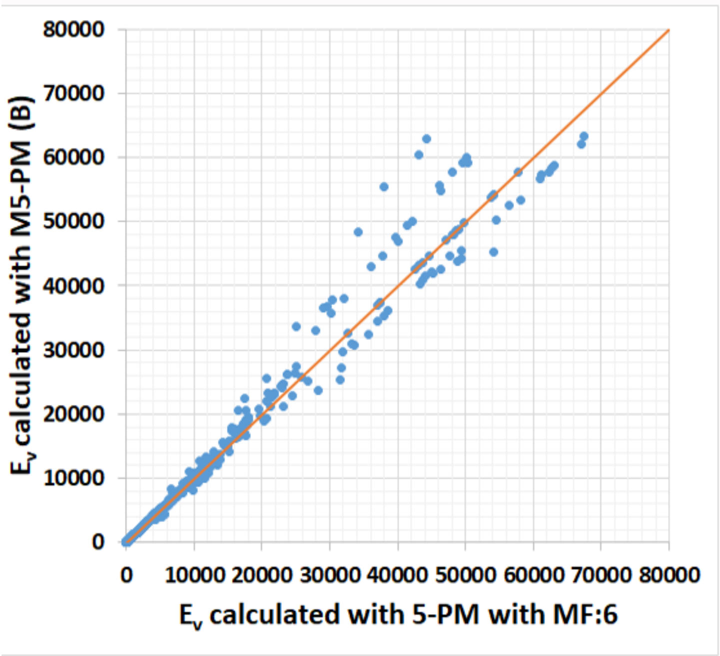
Results

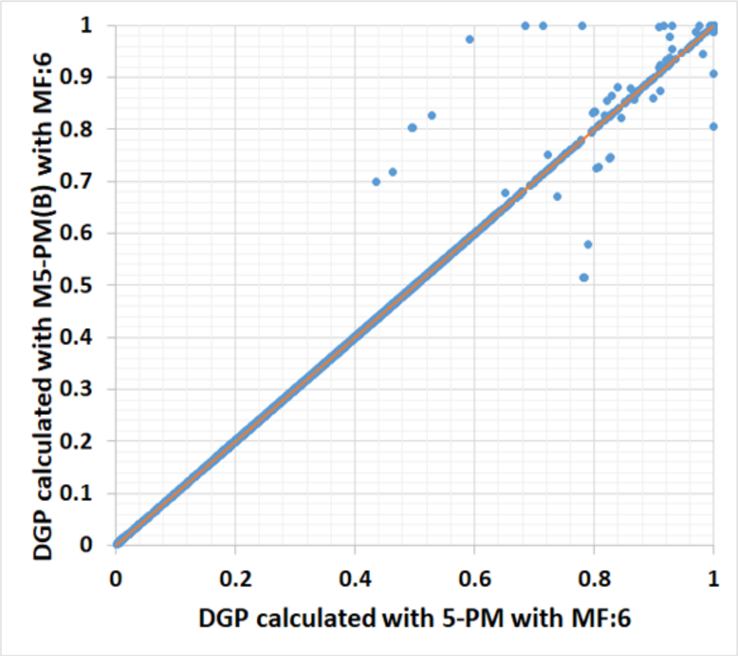
Error analysis for the specular using M5-PM(A)

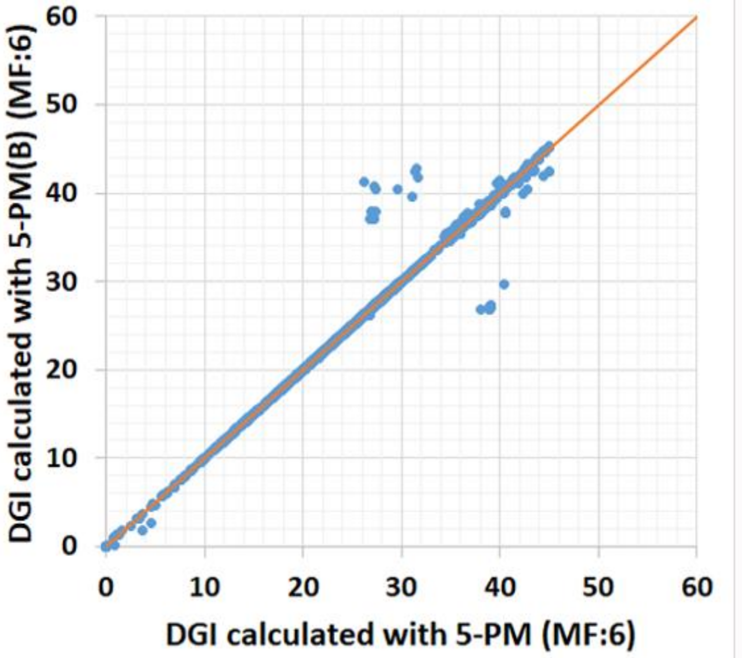
Glare Metrics			5-PM MF:1	5-PM MF:2	5-PM MF:3	5-PM MF:4	5-PM MF:5	5-PM MF:6	M5-PM(A)
DGP	<0.35	RMSE	0.100	0.013	0.013	0.013	0.013	0.012	0.012
		MBE	-0.015	0.001	0.001	0.001	0.001	0.001	0.001
	0.35-0.40	RMSE	0.135	0.026	0.018	0.018	0.018	0.018	0.018
		MBE	-0.008	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
	0.40-0.45	RMSE	0.123	0.045	0.024	0.024	0.024	0.024	0.024
		MBE	-0.009	-0.005	-0.004	-0.004	-0.004	-0.004	-0.004
	⩾0.45	RMSE	0.193	0.12	0.140	0.134	0.120	0.120	0.03
		MBE	0.068	-0.017	-0.010	0.002	-0.011	-0.002	-0.007
	Overall	RMSE	0.138	0.123	0.070	0.068	0.060	0.059	0.021
		MBE	0.002	-0.006	-0.003	-0.001	-0.004	-0.002	-0.003
Percentage of discomfort glare (DGP > 0.40)			36.4%	36.3%	36.4%	36.4%	36.4%	36.5%	36.4%
E_v	Overall	RMSE	8079	3202	3023.0	3275	2223	2071	928
		MBE	-161.6	95.8	-221.5	168.3	17.4	19.8	-65.8
DGI	<18	RMSE	6.3	4.5	4.7	4.5	4.5	4.3	4.8
		MBE	1.80	1.49	1.55	1.50	1.50	1.52	1.56
	18-24	RMSE	7.1	4.9	5.0	5.0	5.1	5.2	5.1
		MBE	0.45	0.68	0.69	0.68	0.68	0.69	0.68
	24-31	RMSE	4.6	3.0	2.9	2.4	2.7	2.5	1.1
		MBE	-1.38	-1.06	-1.01	-0.88	-0.94	-0.86	-0.55
	>31	RMSE	12.3	6.4	8.1	5.47	7.0	6.3	2.3
		MBE	11.55	2.40	5.08	4.47	3.56	5.9	0.90
	Overall	RMSE	6.26	4.11	4.18	4.18	4.10	4.46	3.48
		MBE	0.79	0.50	0.77	0.77	0.63	0.74	0.70
Percentage of discomfort glare (DGI > 24)			52.2%	52.1%	52.1%	52.2%	52.2%	52.1%	52.2%

Results

Results for the specular blinds using M5-PM(B)



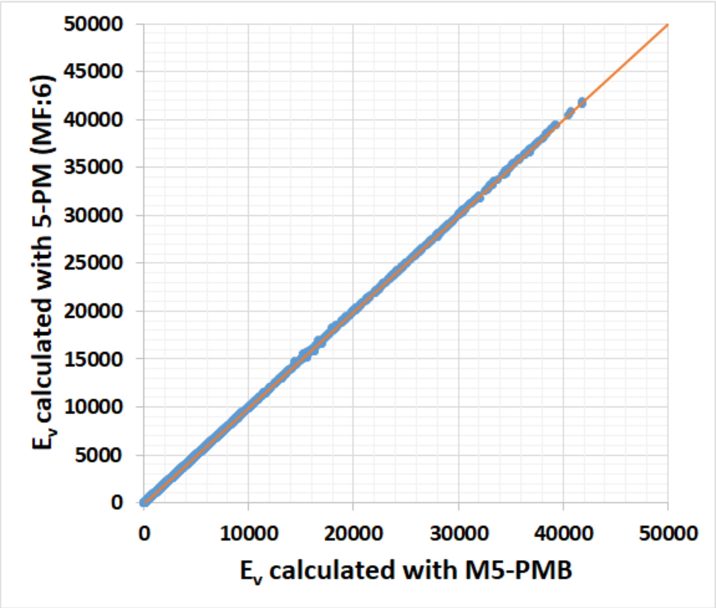


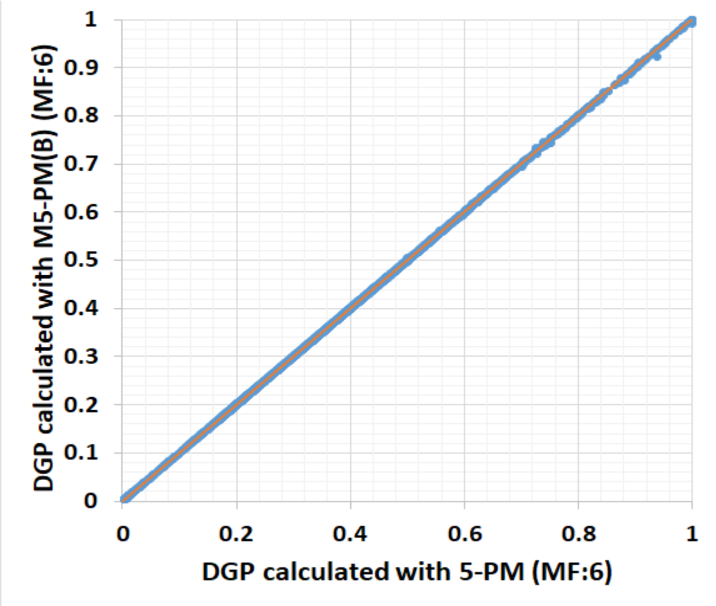


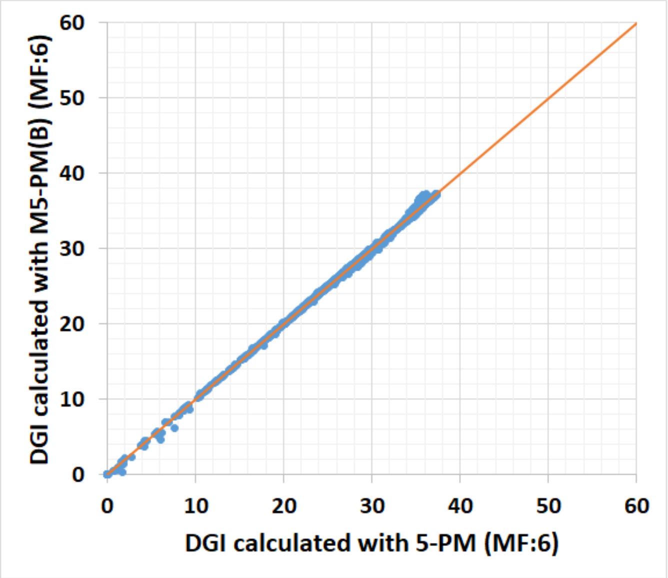
The glare metrics values derived with the M5-PM(B) are very close to the values computed with 5-PM.

Results

Results for the PDRF using M5-PM(B)







The glare metrics values derived with the M5-PM(B) are very close to the values computed with 5-PM.

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Results

Computation Time

Computation Time for the PDRF

Procedure	Computation time (Hours)							
	5-PM						M5-PM(A)	M5-PM(B)
MF	1	2	3	4	5	6	/	6
3-PM	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
Direct 3-PM	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Direct sunlight	0.72	2.17	5.20	9.90	25.90	41.45	1.40	3.97
Combine	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Total	4.9	6.35	9.38	14.08	30.08	45.63	**5.58**	**8.15**

Computation Time for the specular blinds

Procedure	Computation time (Hours)							
	5-PM						M5-PM	M5-PM(B)
MF	1	2	3	4	5	6	/	6
3-PM	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
Direct 3-PM	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Direct sunlight	0.43	1.54	3.92	7.03	11.7	19.8	**1.1**	**3.73**
Combine	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Total	4.61	5.72	8.1	11.2	15.9	24	**5.3**	**7.91**

Note: CPU: 16 virtual cores, 3.2 GHz, Memory: 24G, Hard Disk: 1T SSD

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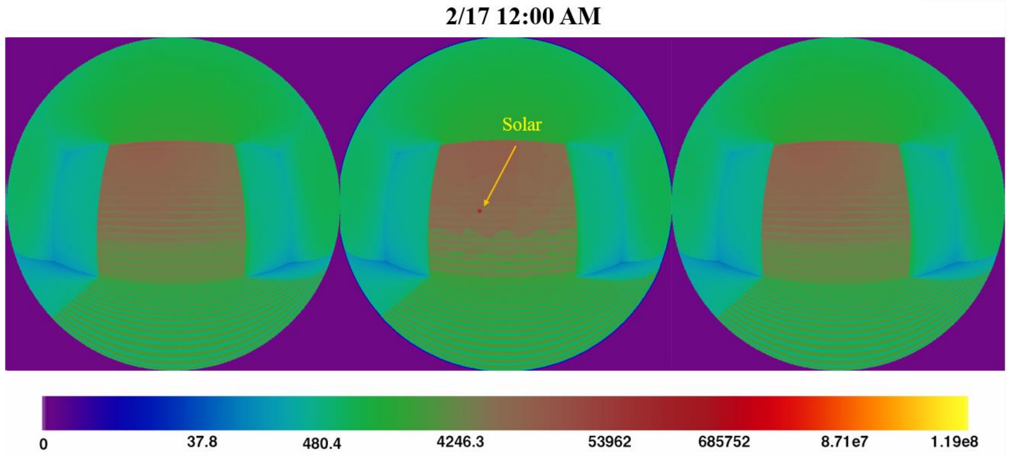
5 Discussions

Discussions

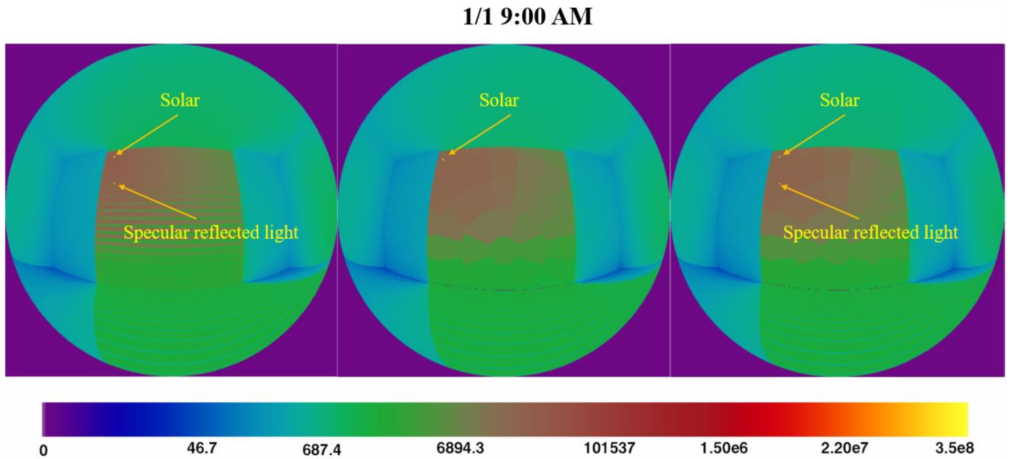
Reason for the outliers presenting the results of the 5-PM when modeling the specular blinds

a) Falecolor image at 2/17 12:00 am rendered with the RT, 5-PM and M5-PM(A)

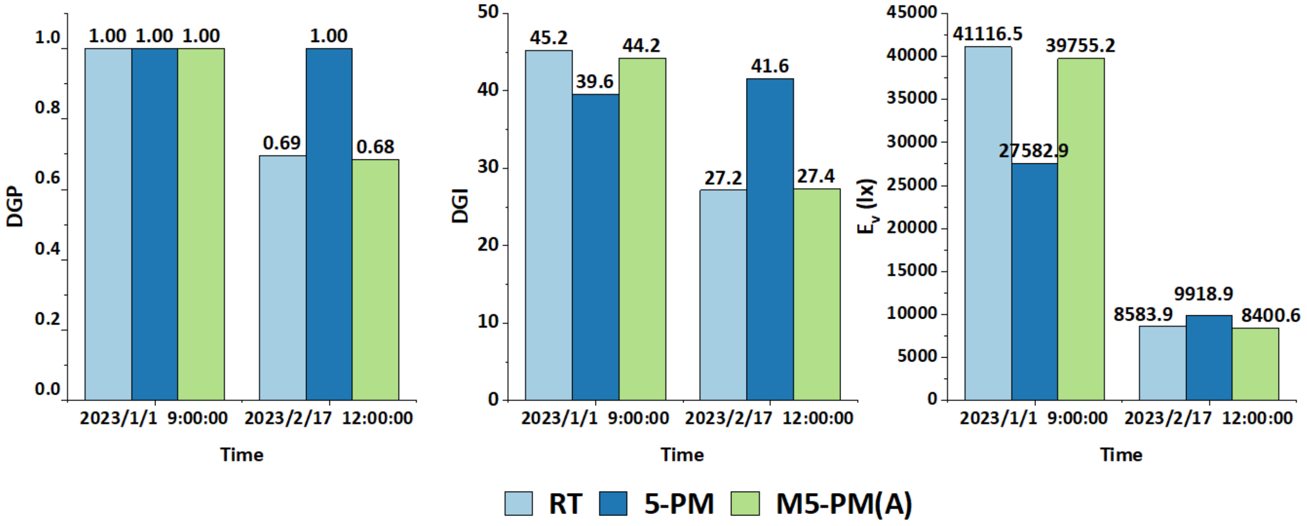


Rendered with the RT | Rendered with the 5-PM | Rendered with the M5-PM(A)

b) Falecolor image at 1/1 9:00 am rendered with the RT, 5-PM and M5-PM(A)



Rendered with the RT | Rendered with the 5-PM | Rendered with the M5-PM(A)



The sun position deviation leads to the error of glare metrics calculation in the 5-PM.

Discussions

mkillum may not work for some situations

Glare Metrics			M5-PM(A)*	M5-PM(A)**	M5-PM(B)*	M5-PM(B)**
DGP	<0.35	RMSE	0.012	0.012	0.013	0.013
		MBE	0.001	0.001	0.001	0.001
	0.35-0.40	RMSE	0.018	0.018	0.020	0.020
		MBE	-0.002	-0.002	-0.002	-0.002
	0.40-0.45	RMSE	0.024	0.024	0.026	0.026
		MBE	-0.004	-0.004	-0.004	-0.004
	≥0.45	RMSE	0.03	0.045	0.122	0.123
		MBE	-0.007	-0.004	-0.017	-0.014
	Overall	RMSE	0.021	0.026	0.062	0.062
		MBE	-0.003	-0.03	-0.006	-0.005
E_v	Overall	RMSE	928	989	1930.5	2053.1
		MBE	-65.8	-42.0	-144.2	-165.9
DGI	<18	RMSE	4.8	4.8	4.7	4.6
		MBE	1.56	1.59	1.52	1.54
	18-24	RMSE	5.1	5.2	5.2	5.1
		MBE	0.68	0.69	0.69	0.69
	24-31	RMSE	1.1	1.1	2.5	2.5
		MBE	-0.55	-0.55	-0.97	-0.95
	>31	RMSE	2.3	3.2	7.4	7.7
		MBE	0.90	1.27	5.3	5.5
	Overall	RMSE	3.48	3.57	4.1	4.2
		MBE	0.70	0.73	0.7	0.76

mkillum may not work for some situations, but not using mkillum will not reduce the accuracy.

* With *mkillum*
** Without *mkillum*

6 Conclusion and ongoing work

Conclusion

1. This study proposed two optimized direct solar computation methods and they were used to replace the sun-coefficient method in the 5-PM simulation, thus obtaining two modified Five-phase methods.

2. Results derived by the 5-PM and the modified Five-phase methods are compared, and the key findings are that for fenestration systems that are sensitive to solar position or specular reflect sunlight, the M5-PM(A) can obtain more reliable values for contrast-based glare metrics compared with the 5-PM, even if the maximum sun patches (5185 sun patches) are applied in the sun coefficient method.

3. For the calculation of saturation-based glare metrics or glare metrics based on both contrast and saturation, the M5-PM can reduce outliers and obtain more accurate glare metric values. This is essential for some application scenarios such as model-based control blinds.

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Ongoing work 1

Optimization of the three-phase method

Methods

$$I = VTDs$$

Use ***rpict*** to calculate the V matrix

Use NumPy to speed up the matrix multiplication

Results

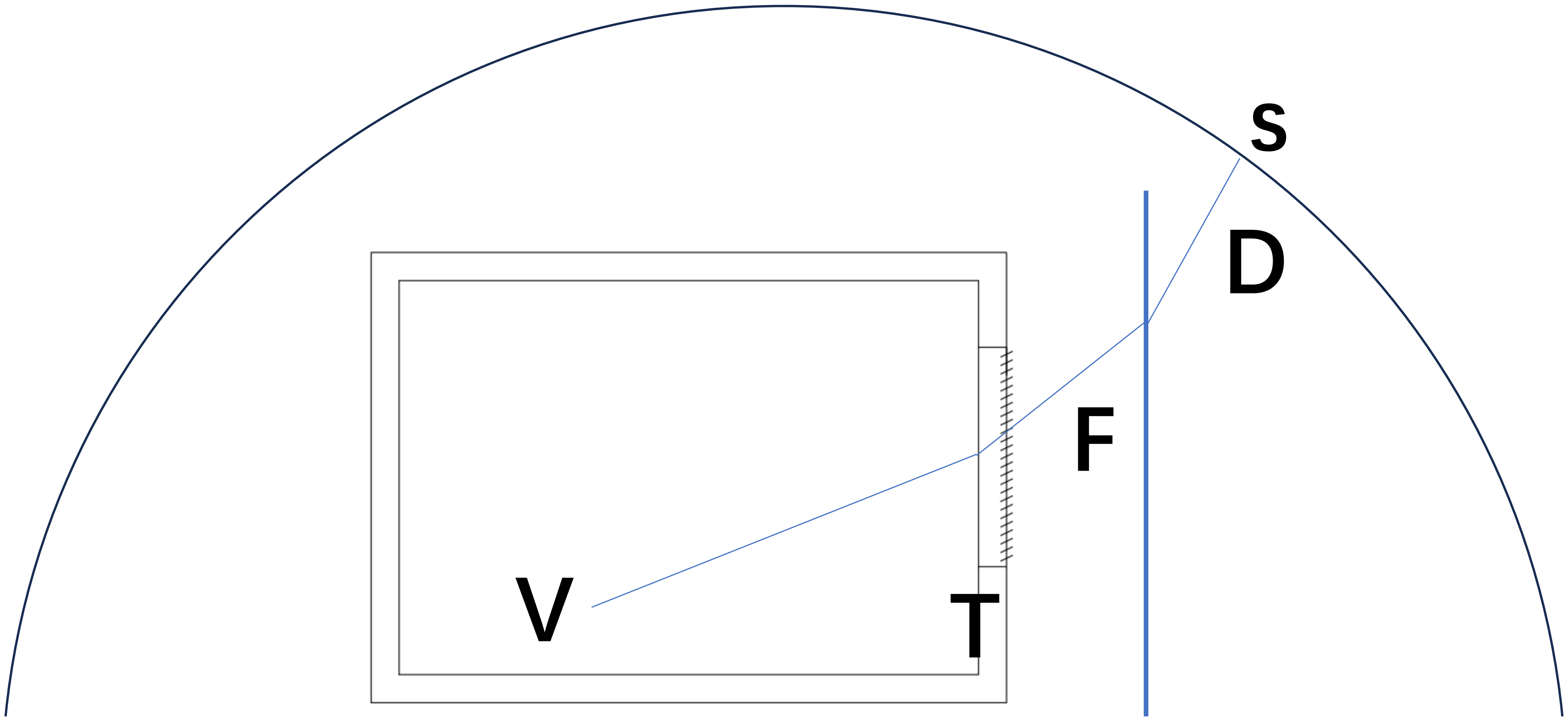
Methods	Computing Time (minutes)	
	The optimized three-phase method	The original three-phase method
Sky patches	2305	2305
V matrix	12	26
D matrix	0.04	0.04
Multiplication	8	130.56
Total	**20.04**	**156.6**

Note: CPU: 16 virtual cores,3.2 GHz; Memory: 24G; Hard Disk:1T SSD
The optimized three-phase method and the original three-phase take **6 minutes** and **85 minutes,** respectively, running on a desktop computer with following configuration:
CPU: 24 virtual cores, 3.2 GHz; Memory: 128 G; Hard Disk: 2T SSD

Ongoing work 2

Climate-based daylight simulation for BSDF dynamic blinds

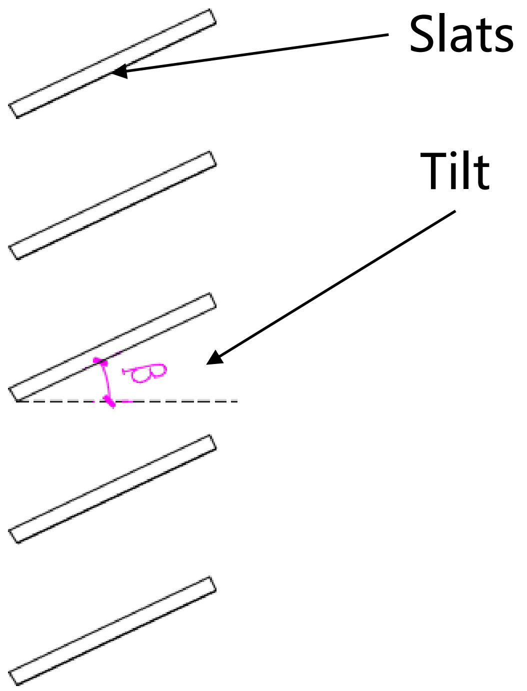
The Modified 4-phase method with varied F matrix



F matrix is used to denote the reflux transfer of blinds, the F matrix varies with the time

Further work 2

Climate-based daylight simulation for dynamic blinds



The tilts of the slats range from -90° to 90°

Calculate Method
Pseudocode:

```
Tilts = [-89.5, -88.5, -87.5, ... 89.5] // tilt range was divided into
//180 sections, and the center tilt for each section was used.
Fs = [ ] // F matrix set
for tilt in Tilts:
    calculate the F matrix for each tilt
    Fs.append(F)
for i = 0 to 8760:
    Read the actual tilt from the control schedule
    Find the tilt is closest to the actual tilt from Tilts
    Find the F according to the tilt
    dctimestep  V T F_i D s
```

Multi-threading was employed to accelerate the run.

This method provide a parametric run for different blinds control.

Thank You!
&
Questions?

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