DAYLIGHT REFLECTANCE DESIGN GUIDE

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BCA

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National University of Singapore

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Preamble

The 'Daylight Reflectance Design Guide' has been jointly prepared by the Building and Construction Authority (BCA) and National University of Singapore (NUS) to provide information and a better understanding on daylight reflectance of buildings.

Copyright

The information in this guide is derived from a joint research project between BCA and NUS titled "Study on Acceptable Reflectance Level of Building Façade Materials in Singapore". The project team comprises Prof. Wong Nyuk Hien, Dr. Marcel Ignatius, and Wen Jianxiu from the Department of Building, College of Design and Engineering, NUS; Ar.Tan Jwu Yih, Wilson Qiu, Tan Shu Ping, Adrian Lee from BCA.

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01
INTRODUCTION

1.1 PURPOSE OF THIS GUIDE

Recommendations to help industry understand the key design factors that contribute to solar reflectance in buildings

To achieve attractive architectural effects, the design of buildings has become more diverse with prevalent use of reflective materials such as glass and metal cladding. Glare from reflected sunlight from a building façade can be a significant issue in Singapore with its strong solar radiation characteristic and highly built-up urban environment. Appropriate planning and design can help to improve the visual performance of a building façade and minimise incidences of reflected glare.

While the industry is familiar with the regulatory requirement of limiting the total reflectance value of the building envelope, designers should also take into consideration other parameters that contribute to solar reflectance at the onset of design. The Daylight Reflectance Design Guide highlights the key design factors related to solar reflectance from the urban planning and building design's perspective based on local research findings. It recommends a set of considerations for assessing the site and building parameters as well as mitigating measures to minimise the occurrences of reflected glare. In addition, an example of using computer simulation method for solar glare evaluation is also included in the Guide to assess a building's potential to cause significant glare to neighbouring buildings.

The Daylight Reflectance Design Guide is primarily targeted at building designers, but will be of interest to building developers, facility managers and other stakeholders who are involved in the design decision process. However, this Guide is not meant to be a substitute for compliance with the Building Control Regulations and the maximum allowable reflectance value for façade material prescribed in the Approved Document.

Figure 1-1 Building with reflective façade materials

Figure 1-2 Building with top hung window increases probability of reflected glare

02 BUILDING DESIGN GUIDELINES

2.1 SITE ANALYSIS

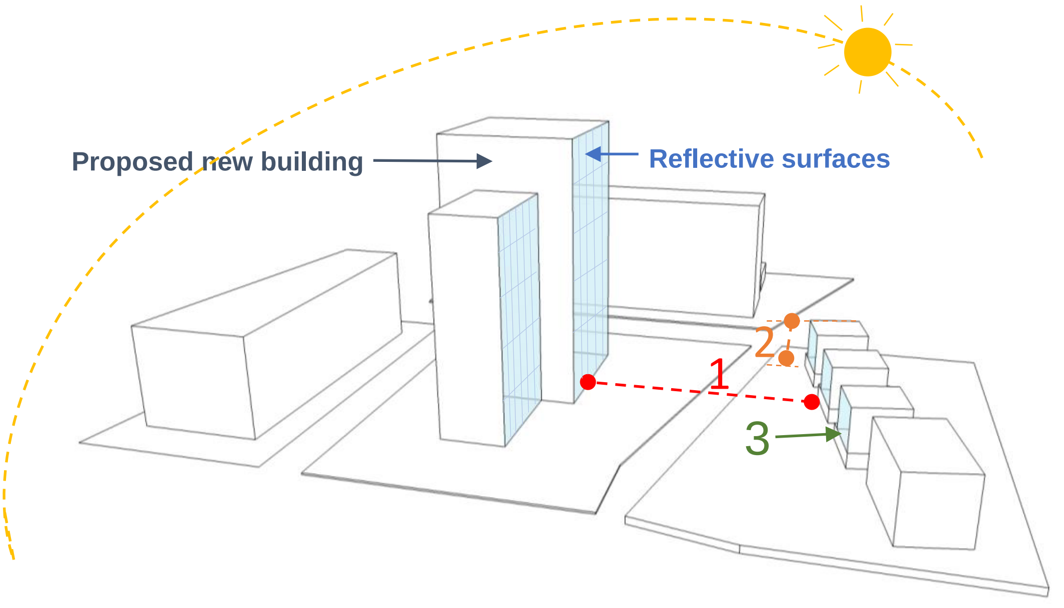


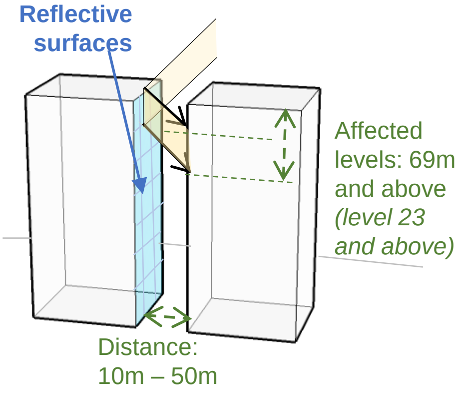
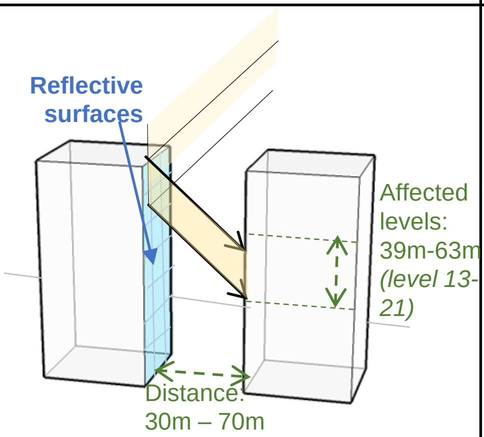
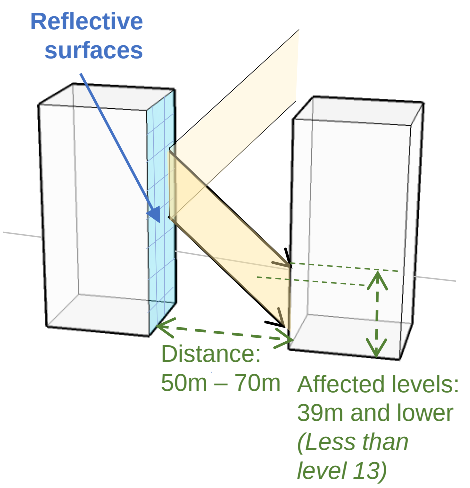
Figure 2-1 Site parameters

A new building with reflective facade materials such as glass and metal should consider the parameters below during the planning and design stages:

1. Distance from the existing surrounding buildings
2. Height of the existing surrounding buildings
3. Windows of surrounding buildings

2.1.1 Distance between reflective facade and surrounding buildings

When a reflective facade is facing the sun, reflected glare will likely occur. The space between two buildings needs to be considered carefully during the planning and design stages to minimise the incidences of reflected glare.

<table>
<tr><th colspan="3">Table 2.1 – Gaps between buildings</th></tr>
<tr><th>Distance</th><th colspan="2">Affected areas</th></tr>
<tr><td>10m-50m</td><td>
</td><td>• Less building surface exposed to the sun with more overshadowing; reduces the chances of reflected glare occurrences from the reflective façade.
• Higher possibility of reflected glare incidents on higher levels of adjacent buildings.
• When the distance is facing 30m or lesser, avoid facing East, West, Southeast and Northwest.</td></tr>
<tr><td>30m-70m</td><td>
</td><td>• Higher possibility of reflected glare incidents on middle levels of adjacent buildings.
• Avoid facing East, West, Southeast, Northwest, Northeast and Southwest.</td></tr>
<tr><td>50m-70m</td><td>
</td><td>• More external building surface exposed to the sun; increases the chances of reflected glare occurrences from the reflective façade.
• Higher possibility of reflected glare incidents on lower levels of adjacent buildings.</td></tr>
</table>

2.1.2 Height ratio

The height ratio is derived by comparing the height of the new building with that of a surrounding building. A higher ratio means the new building is comparatively taller than its neighbouring building.

If the reflective façade of a new building with a high height ratio is oriented along the sun path, the duration of sunlight exposure will be longer. With this, it contributes to higher chances of reflected glare to the lower surrounding buildings.

Reflected glare from different parts of the length of the new building's façade can be observed by the lower surrounding buildings for a longer period of the day as the sun changes its position.

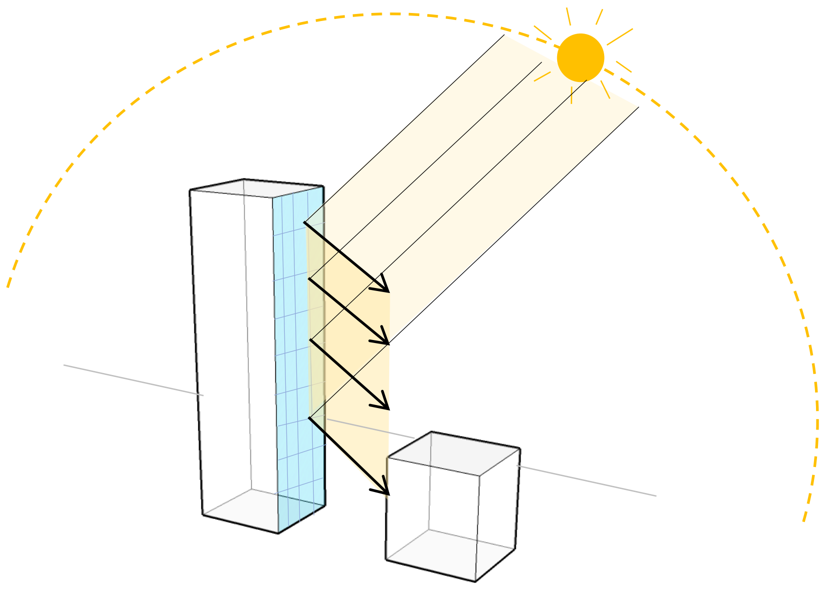


Figure 2-2 High height ratio creates higher chances of reflected glare

QUICK TIPS

When surrounded by low-rise developments, a new high-rise building should adopt mitigation measures to minimise reflected glare onto the surrounding.

Examples of the mitigation solutions include using less reflective façade materials or installing external shading devices on the high-rise building facades.

2.1.3 Windows of surrounding buildings

Studies have shown that the window-to-wall ratio (WWR) of a building can affect the visual comfort of its occupants. A building with high WWR will have more extensive fenestration, through which, more solar radiation will enter the interior spaces and subsequently increase the chances of experiencing reflected glare from the surroundings.

During the planning and design process of a new building, designers should take into account the window locations of existing surrounding buildings and their WWR as part of the assessment of the probability of reflected glare. Research shows that buildings with WWR above 0.5 have higher tendency to be affected by reflected glare.

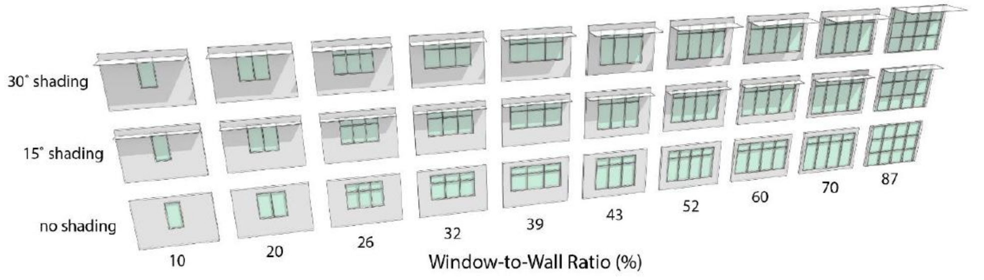


Figure 2-3 –Window-to-wall ratio (WWR) is the percentage of glazing areas relative to its exterior wall envelope areas.
(Code of Environmental Sustainability of Buildings)

QUICK TIPS

Window-to-wall ratio (WWR) has the highest influence on the probability of reflected glare as compared to other building parameters. The new building could consider adopting mitigation measures such as the application of anti-glare window films or the use of non-reflective facade materials. For the affected surrounding buildings, installing shading devices at the fenestrations could be an option.

2.2 BUILDING PARAMETERS

2.2.1 Reflective materials & orientation

Reflective materials such as glass and metallic cladding panels are commonly used in modern high-rise buildings. To minimise the reflection of sunlight to the surrounding developments, the building façade with reflective materials should be oriented towards the north and south directions.

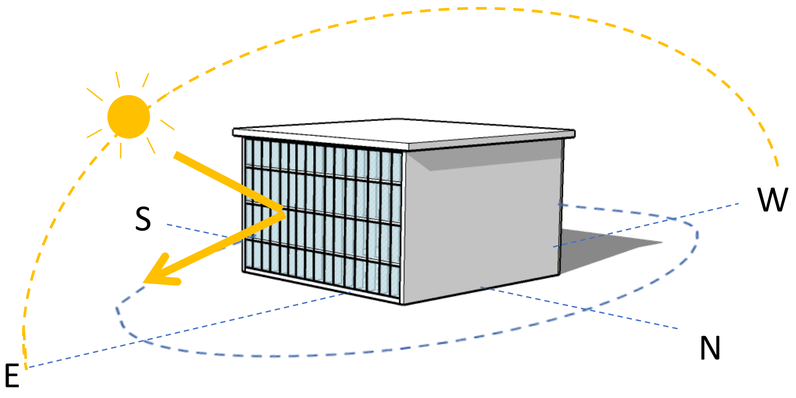


Figure 2-4 Reflective surfaces should not face W-E

Table 2.2 – Recommended orientation for building facade with reflective materials		
Orientation		**Recommendation**
West & East	Higher probability of reflected glare • *More and longer solar exposure*	Avoid to face: • Northwest (45°) • West (90°) • Southeast (225°) • East (270°)
North & South	Lower probability of reflected glare	Should face: • North (0°) • South (180°)

Related information

Effective Daylight - Under the Code of Environmental Sustainability of Buildings, design that optimises the use of natural lighting to improve visual comfort and reduce the need for artificial lighting during daylight hours is encouraged.

QUICK TIPS

Highly reflective materials such as glass windows or metal claddings should avoid facing northwest, west, southeast and east directions to reduce the probability of reflected glare to the surroundings.

2.2.2 Reflective building materials

Visual discomfort arising from reflected glare is closely related to the texture and colours of the reflective building facade. Research shows that the selection of façade materials of appropriate reflectance properties is the key factor in minimising incidences of reflectance glare. Designers should carefully select suitable materials for the external surfaces (including roof) of a building such that any reflection of sunlight off the external surface of the building does not result in loss of amenity to occupants of other buildings in the vicinity of that building.

Baseline requirements

Under the Approved Document, Section P, the materials used on the external envelope of the building are acceptable if:

a) the glass for the building work has a daylight reflectance not exceeding 20%
b) any material, other than glass, for the building work on –
   (i) the façade of the building has a specular reflectance not exceeding 10%
   (ii) the roof of the building, inclined at an angle not exceeding 20 degrees from the horizontal plane, has a specular reflectance not exceeding 10%
   (iii) the roof of the building, inclined at an angle more than 20 degrees from the horizontal plane, has a daylight reflectance not exceeding 20% and a specular reflectance not exceeding 10%
c) emulsion paint on plastered or concrete surfaces has a specular reflectance not exceeding 10%

Daylight reflectance of a material is the sum of its specular reflectance and diffuse reflectance values.

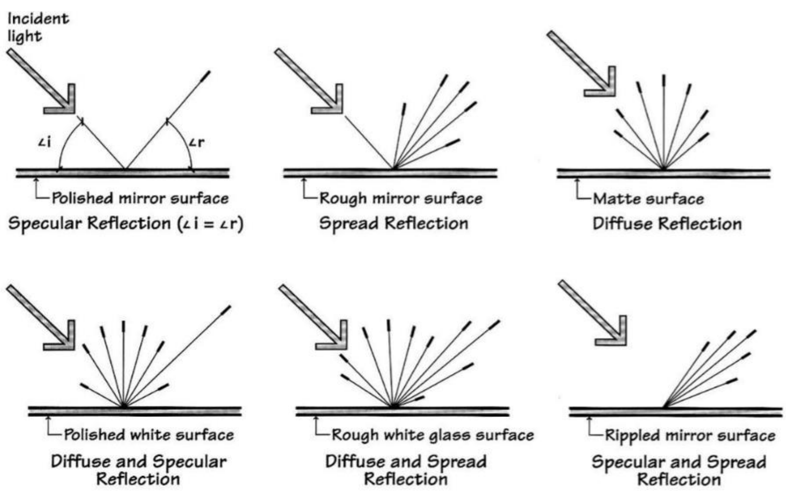


Figure 2-5. Specular, spread, and diffuse reflections

Egan, M. D., & Olgyay, V. W. (2002). Architectural lighting (2nd ed.). Boston: McGraw-Hill

QUICK TIPS

By changing the angle of the reflective surface, discomfort glare issues can be effectively avoided.

Curved façade such as concave or convex may concentrate light and cause discomfort glare. Designers should study the probability of reflected glare through glare evaluation simulation.

2.2.3 Reflective building materials surface areas

Apart from using materials of low reflectance for the building external surfaces, an alternative strategy is to reduce the external surfaces that are affected by direct sunlight through artificial shading.

The use of sun shading devices can help to block or reduce the amount of direct sunlight on the surfaces and reduce reflected glare onto other buildings.

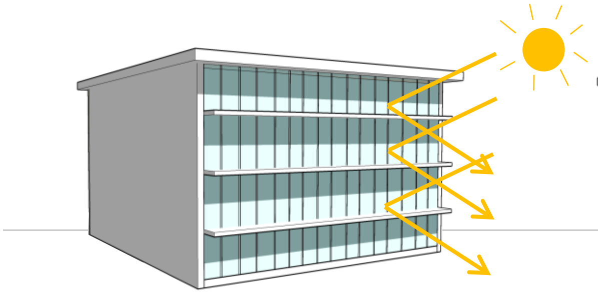


Figure 2-6 Façade with sun shading

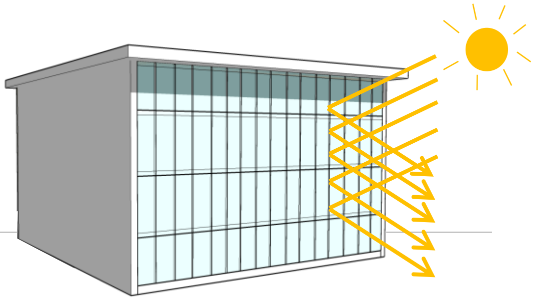


Figure 2-7 Façade without sun shading

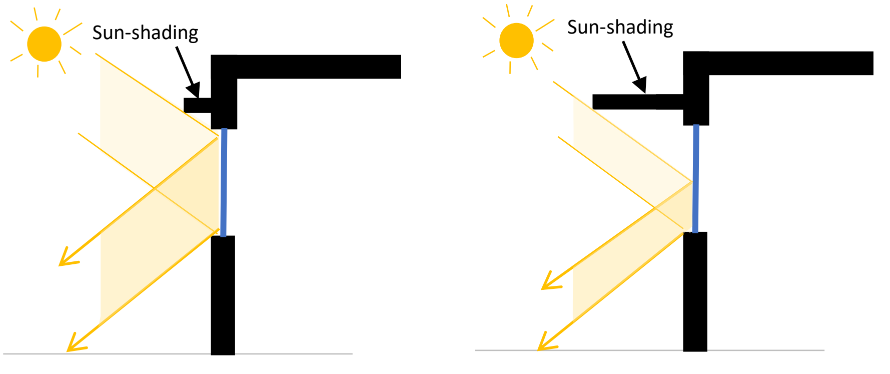


Figure 2-8 Sun-shading as mitigation measures at affected buildings. When the depth of sun shading increases, it will result in lesser reflected glare to the surrounding.

Designers should note that the use of sun shading devices will also affect daylight admittance, building energy performances and façade maintenance.

Related information

Lighting – BCA Approved Document, Section F states that (natural) lighting shall be adequately provided in a building for its intended purpose. Under the BCA Code of Environmental Sustainability of Buildings, designs that optimise the use of natural lighting to improve visual comfort and reduce the need for artificial lighting during daylight hours are encouraged.

Maintenance – Under the BCA Design for Maintainability Façade Access Design Guide, designers should provide safe and easy access to every part of a building's façade including sunshades for efficient maintenance and inspection.

2.2.4 Reflective building elements

When an external reflective building element is tilted at an angle and facing the sun, it could become a source of reflected glare and cause visual discomfort to the surroundings. Top-hung windows and poorly placed metallic sun shades are common façade elements that cause reflected glare.

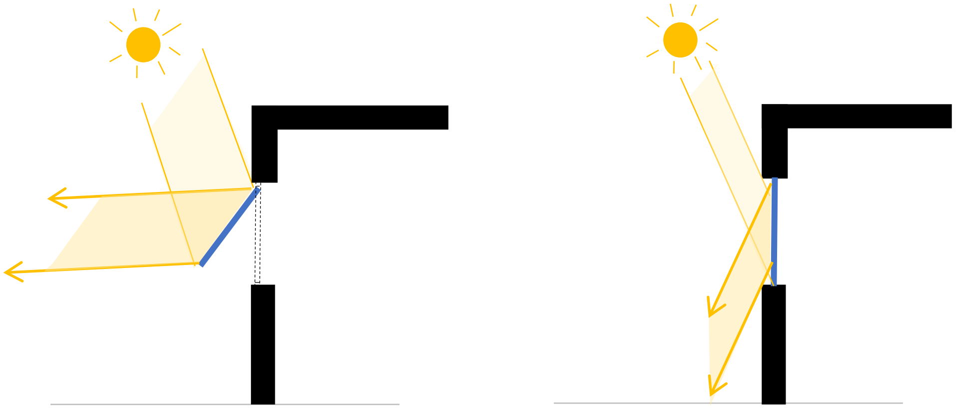


Figure 2-9 Sunlight reflected from a top-hung window

Designers may carry out computer simulations (see Chapter 3: Glare Evaluation Simulation) to identify potential reflectors and predetermine the solar glare impact.

Designers should consider minimising the use of inclined reflective building elements, for instance, use sliding windows instead of top-hung windows or swing casement windows. The reflectance of a window can also be reduced by applying anti-reflective films.

2.2.5 Photovoltaics as/on building envelope

While solar photovoltaics are encouraged as part of the drive towards environmental sustainability, photovoltaic surfaces are reflective and they should be installed in a manner that minimises reflected glare to neighbouring buildings.

Figure 2-10 Sunlight reflected from photovoltaics

Orientation - Photovoltaic surfaces are typically placed to face the East and West directions. However, they should be sloped horizontally to the sky for maximum solar exposure. If photovoltaic are placed vertically, there will be very high probability of reflected glare. In such instance, designers must provide mitigations to reduce reflected glare.

Angle of photovoltaics on rooftops – The tilt of the photovoltaic panels should not exceed more than 15 degrees from the horizontal plane to reduce the probability of reflected glare.

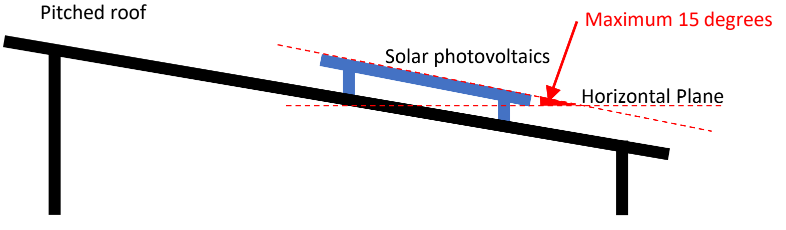


Figure 2-11 Photovoltaics should be installed in a way that minimises reflected glare to surroundings

Colour - Darker colour photovoltaics have a lower reflectance value and hence glare. Various photovoltaics available on the market also have different degrees of opacity, which also influences reflectance values.

Anti-reflective coating - Application of anti-reflective coating on photovoltaics can reduce reflected glare as well.

QUICK TIPS

Where photovoltaics are designed as part of the building envelope, such as Building Integrated Photovoltaics (BIPV), they shall be assessed as an integral part of the façade which must comply with the maximum allowable daylight reflectance value for façade material.

Designers should balance between energy efficiency, glare impact, maintainability and architectural aesthetics.

03 GLARE EVALUATION SIMULATION

Purpose of this section

Glare Evaluation Simulation (GES) is a useful and scientific method to study the probability of reflected glare and its impact on neighbouring buildings. However, GES should not be a substitute for compliance with the prescribed maximum allowable reflectance value for façade materials, but rather, a means for validating the effectiveness of design strategies/ solutions to address potential/ post-construction reflected glare issues.

This section provides an example of GES method.

3.1 METHODOLOGY

3.1.1 Glare evaluation

Flow-chart below gives an overview of the process of Glare Evaluation Simulation. Subsequent sections would provide step-by-step guidance for each of the evaluation process.

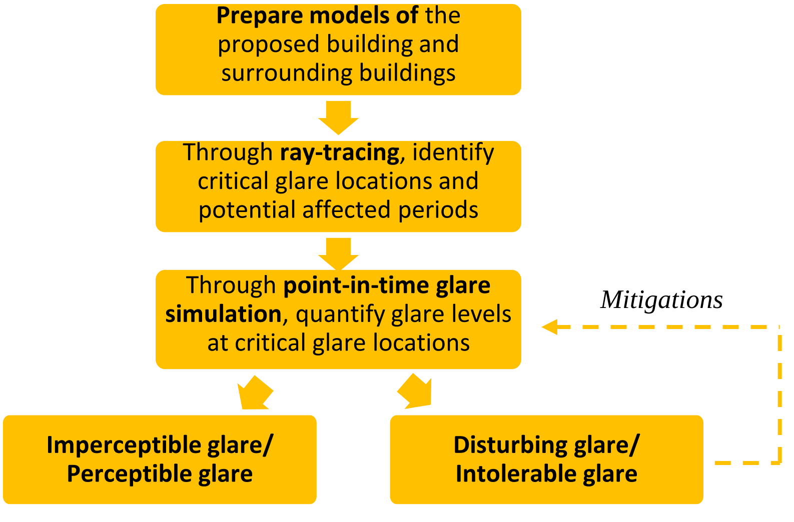


Figure 3-1 Flowchart for Glare Evaluation Simulation (GES)

3.1.2 Simulation Software

Glare simulation needs daylight simulation software such as Radiance to render wide-angle images, and a glare evaluation tool such as Evalglare to calculate the Daylight Glare Probability (DGP) of a resulting image. The following list of software is recommended:

1. Rhinoceros with the plug-in of Grasshopper, Ladybug, Honeybee & Radiance
2. or Rhinoceros with the plug-in of Grasshopper, ClimateStudio
3. or IES with Radiance
4. or OpenStudio with Radiance

3.2 PARAMETERS

3.2.1 Simulation requirement

The simulation should be based on the building models and the site massing models with terrains from the project architect with accurate relevant parameters as listed below.

3.2.2 Model of site information

The proposed building, along with its surrounding buildings, should be developed for simulations with accurate information as listed below:

a. [Affecting building] Proposed building with reflective surfaces modelled
b. [Affected buildings] Surrounding potentially affected buildings with windows and estimated interior layout modelled
c. Accurate distance between buildings
d. Accurate building height and orientation

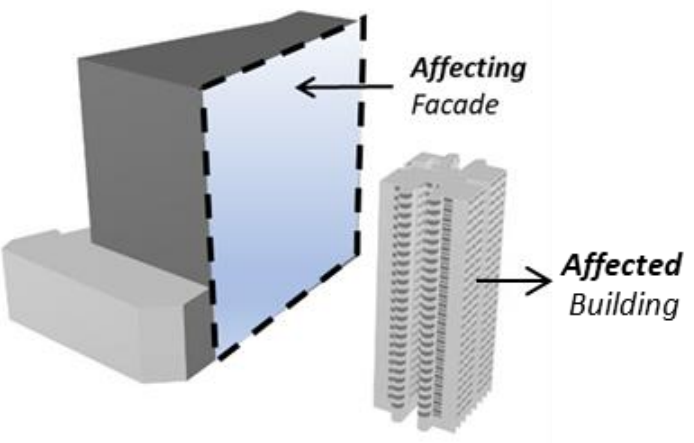


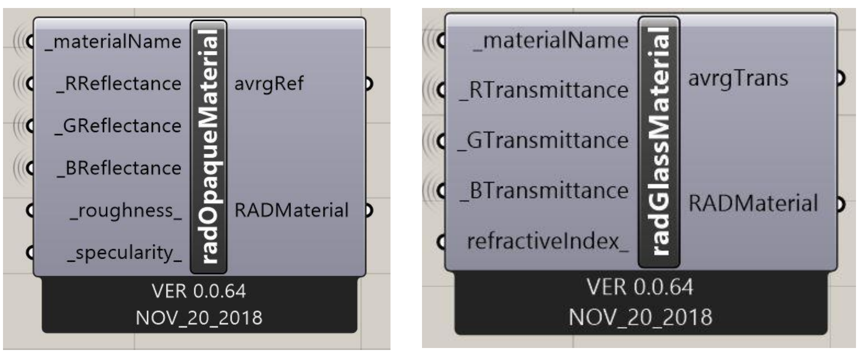
Figure 3-2 Example of a model of affecting building (proposed) and affected building (surrounding affected buildings)

3.2.3 Façade profile

Façade material properties for the proposed building need to be assigned to the model accordingly.

a. Façade materials' composition
b. Façade reflectance/transmittance values
c. Façade roughness
d. Façade specularity

The settings of façade materials should be based on the actual properties provided by the manufacturer. It is not acceptable to conduct this simulation using properties of common materials for the façade of the proposed building.



(a) Opaque Material (b) Glass Material

Figure 3-3 Examples for settings from Rhinoceros with the plug-in of Grasshopper, Ladybug, Honeybee & Radiance for façade profile

3.2.4 Sun path and weather condition/s

With accurate sun path and weather information, critical areas that might be affected by reflected glare can be identified accurately.

The accurate sun path and weather information could be obtained from the relevant weather data file (.epw format) from online database:

a. http://climate.onebuilding.org/WMO_Region_5_Southwest_Pacific/SGP_Singapore/SGP_SG_Changi.Intl.AP.486980_TMYx.zip
b. or https://www.ladybug.tools/epwmap/
c. or other weather stations

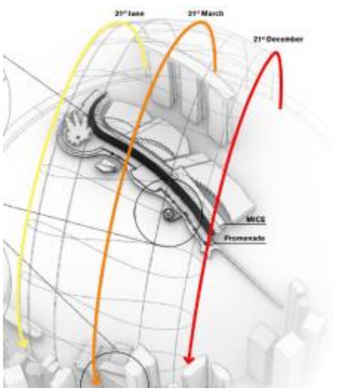


Figure 3-4 Examples for Sun path simulation

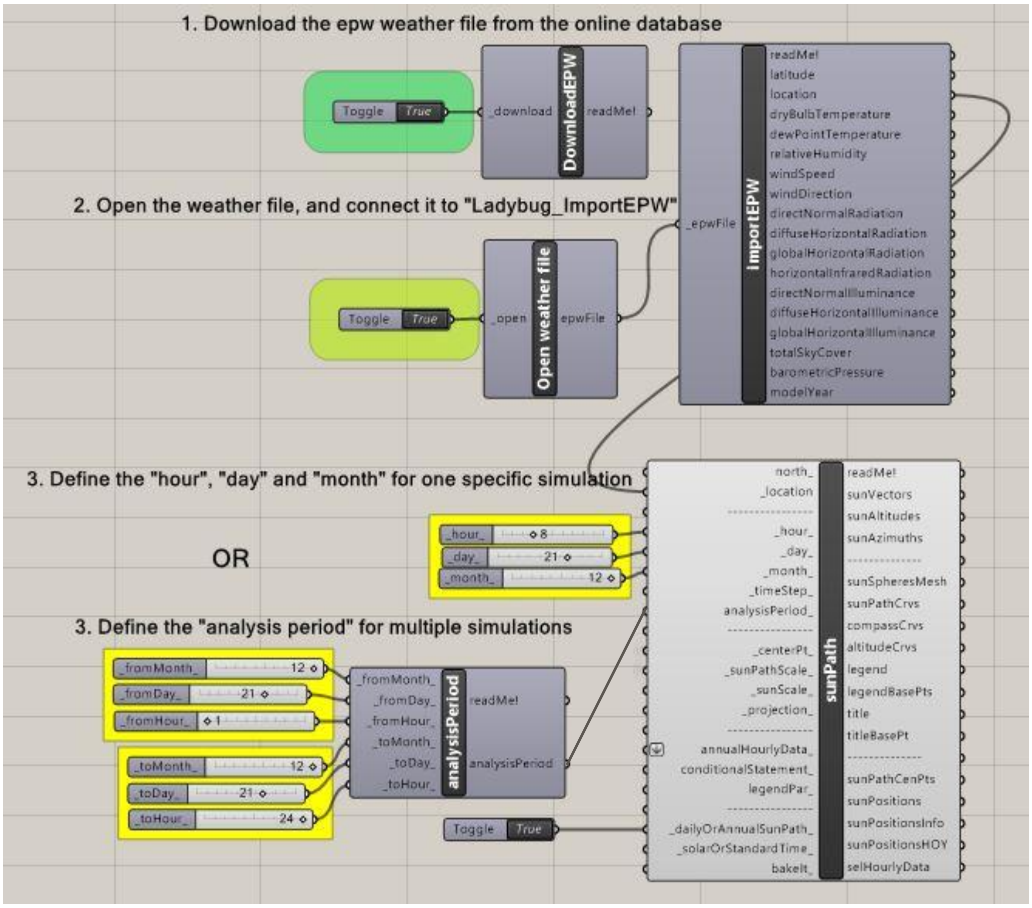


Figure 3-5 Step-by-step for sun path and weather

An example of the simulation file can be checked here:
http://hydrashare.github.io/hydra/viewer?owner=mostaphaRoudsari&fork=hydra_1&id=Sun_path&slide=0&scale=1&offset=0,0

3.3 SIMULATION PROCESS

3.3.1 Ray-tracing simulation

Ray-tracing simulation is used to determine the affected period of the possible reflected glare incident on surrounding buildings.

It is defined as an affected period when
a. reflective surface of the proposed building is exposed to the sun and,
b. affected surrounding buildings' façade is not directly exposed to the sun

A conservative scenario of sunny and clear skies should be used to illustrate the risk of glare. The sun crosses the celestial equator on 21st March; the sun is positioned at the Tropic of Cancer and Tropic of Capricorn on 21st June and 21st December respectively. In order to take into account the critical sun's positions, designers should minimally include these 3 dates (21st March, 21st June and 21st December) in the simulation. Hourly data is required for each date.

After the ray-tracing simulation, a point-in-time glare simulation is required to measure the impact of reflected glare. Point-in-time glare simulation will be explained in the next section.

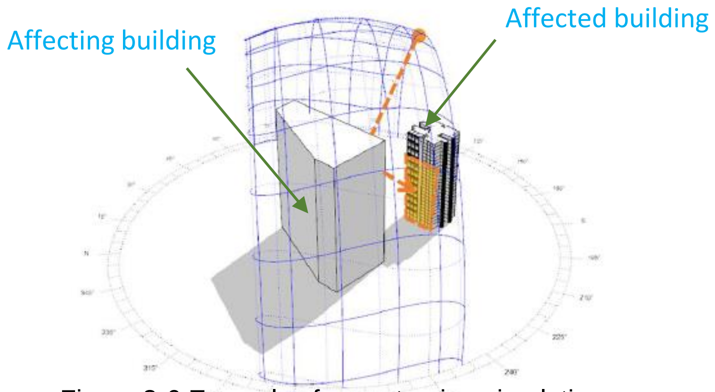


Figure 3-6 Examples for ray-tracing simulation

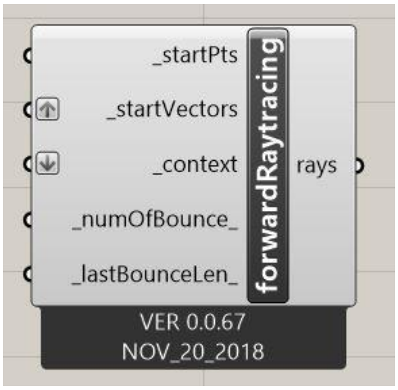


Figure 3-7 The component for ray-tracing simulation in Grasshopper

An example of the simulation file can be checked here:
http://hydrashare.github.io/hydra/viewer?owner=mostaphaRoudsari&fork=hydra_1&id=Ray_tracing&slide=0&scale=3.1751025846159937&offset=-2057.3105415082928,-463.00479723796764

3.3.2 Point-in-time glare simulation

After the affected periods are identified by ray-tracing simulation, point-in-time glare simulation is required to quantify glare levels at the affected buildings.

For the camera angle, it is crucial that designers consider the views of occupants affected by the possible source of glare. It is suggested to use angular fisheye with horizontal view to mimic the occupants' eye.

For the camera point, it should be located based on the activities of the spaces. For example, in office buildings, the camera point should be the exact sitting position of the nearest person to the façade. For residential buildings, the distance between the camera and the window cannot be more than half of the room depth of the affected areas.

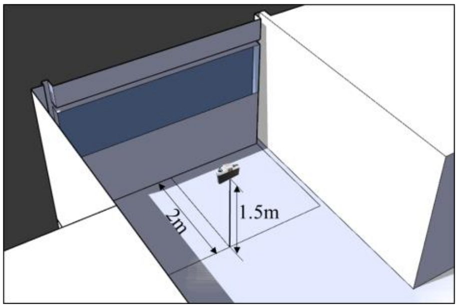


Figure 3-8 An example of a camera point at an affected area for residential buildings

As with ray-tracing simulation, a conservative scenario of sunny and clear skies should be used to illustrate the risk of glare. The sun crosses the celestial equator on 21st March; the sun is positioned at the Tropic of Cancer and Tropic of Capricorn on 21st June and 21st December respectively. In order to take into account the critical sun's positions, designers should minimally include these 3 dates (21st March, 21st June and 21st December) in the simulation. Hourly data is required for each date.

The quality of export should be of <u>high quality</u>. An example of the settings for point-in-time glare simulation should refer to table 3-1 below.

Table 3-1. An example of settings for point-in-time glare simulation

Ambient bounce (-ab)	Ambient division (-ad)	Ambient sampling (-as)	Ambient resolution (-ar)	Ambient accuracy (-aa)
6	2048	1024	256	0.2

Simulation examples can be checked here:

(1) Rhinoceros with the plug-in of Grasshopper, Ladybug, Honeybee & Radiance:
http://hydrashare.github.io/hydra/viewer?owner=mostaphaRoudsari&fork=hydra_1&id=Glare_Analysis&slide=0&scale=1&offset=36.57300409621291,8.836795537274412
(2) Rhinoceros with the plug-in of Grasshopper, ClimateStudio:
https://www.solemma.com/learn

3.4 EXPECTED RESULT

3.4.1 Glare perceptible value

The result of the simulation should contain a glare perceptible value. It should be Daylight Glare Probability (DGP) or other equivalent standards. Based on study done by A.Jakubiec and Reinhart (2010), DGP is the most robust metric that generates the most reliable results under daylighting conditions. The glare criterion for DGP is shown in Table 3-2. To meet the requirement, the DGP value during the affected period should be lower than 0.40.

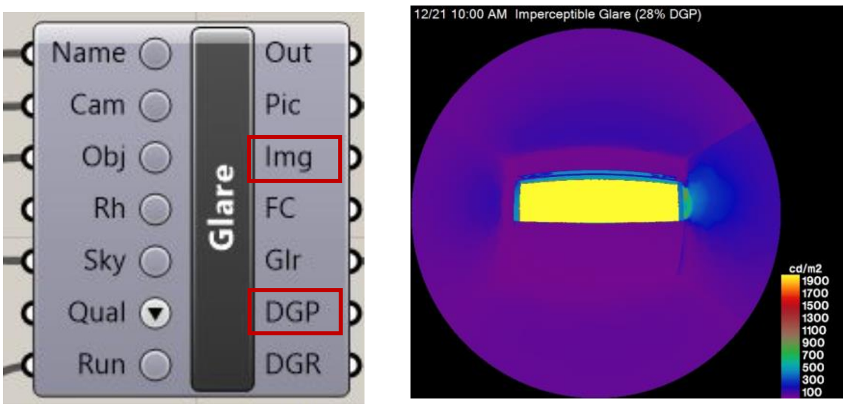


Figure 3-9 Assessment should consist of both DGP values and images to highlight the affected areas

Table 3-2. Glare criterion for Daylight Glare Probability

Degree of Perceived Glare	Daylight Glare Probability (DGP)
Imperceptible	<0.35
Perceptible	0.35-0.40
Disturbing	0.40-0.45
Intolerable	>0.45

04
CHECKLISTS

- BUILDING DESIGN
- GLARE EVALUATION SIMULATION

4 CHECKLISTS

No.	Checklist for building design	
Site analysis		
1	Examine the distance between reflective façade and adjacent building/s and assess potential reflected glare.	☐
2	Examine the height ratio of the proposed building and surrounding buildings. Higher probability of reflected glare if the proposed building is higher than surrounding buildings.	☐
3	Examine the location of windows and the window-to-wall ratio (WWR) of surrounding buildings. Surrounding building/s that have higher WWR and facing the reflective façade of the proposed building are more susceptible to reflected glare.	☐
Building parameters		
4	Ensure that the building façade with reflective materials are not facing the northwest, west, southeast and east directions.	☐
5	Ensure that the external building materials comply with max allowable reflectance value prescribed in Approved Document.	☐
6	Identify any large area/s of reflective façade, assess potential reflected glare and provide mitigations.	☐
7	Examine the placement of photovoltaic panels - If integrated with building envelope, mandatory to comply with max allowable reflectance value prescribed in Approved Document. - Assess potential reflected glare and provide mitigations through orientation, angle of installation, colour, application of anti-reflective coating, etc.	☐
8	Identify external reflective building elements installed with an angle (e.g. top-hung windows), assess potential reflected glare and provide mitigations.	☐

No.	Checklist for Glare Evaluation Simulation (GES)	
Simulation software		
1	Prepare the acceptable simulation software for GES	☐
Model parameters		
2	Prepare the site massing model and the proposed building model with the information below:- • [Affecting building] Proposed building with reflective surfaces modelled • [Affected buildings] Surrounding potentially affected buildings with windows and estimated interior layout modelled • Accurate distance between buildings • Accurate building height and orientation	☐
3	Include façade material properties from manufacturer:- • Façade materials' composition • Façade reflectance/transmittance values • Façade roughness • Façade specularity	☐
4	Include accurate sun path and weather information	☐
Simulation process		
5	Ray-tracing simulation settings:- • Sunny and clear skies • Includes minimally 21st March, 21st June and 21st December • Includes minimally hourly data for these 3 dates	☐
6	Point-in-time glare simulation settings:- • Camera angle to follow the view of occupants. Use angular fisheye with horizontal view to mimic the occupants' eye • Camera point based on activities of spaces • Export quality set to high • Sunny and clear skies • Includes minimally 21st March, 21st June and 21st December • Includes minimally hourly data for these 3 dates	☐
Expected result		
7	DGP value to be lower than 0.4	☐