A Generalized Radiosity Simulation Model and Full-Scale Experimental Verification of a Corner Office having Three Section Façade with Motorized Shading

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Abstract

A Generalized Radiosity Simulation Model and Full-Scale Experimental Verification of a Corner Office having Three Section Façade with Motorized Shading

Shahriar Hossain

Daylight distribution models are essential for daylighting design and present information in a visual manner that facilitates decision making. With an accurate model, daylight in a space can be distributed in an efficient and comfortable way, so that the need for electric lighting in daytime is reduced. On the other hand, motorized shades can be controlled automatically to better distribute daylight on the work plane and reduce or avoid glare.

Most of modern buildings, both commercial and high-rise residential, have windows in more than one orientation and have the provision for daylight penetration into space. In this study, a radiosity model for simulating the daylight distribution of a corner office having two windows in various orientations with motorized shades has been developed. The model calculates the illuminance at different locations on the work plane.

The simulation model based on radiosity theory is verified with measured data under overcast and clear sky conditions with direct and diffuse lighting, and a parametric analysis is carried out for various room shapes and shading devices and façade orientations. The model is implemented in Mathcad and used to predict the illuminance distribution in the room for developing improved control strategies for shade positions and also for design guidelines to select the properties of the shades. Three section façade is considered with the bottom section being opaque (spandrel), the middle viewing section and a top daylighting section. Variable shade transmittance in the middle

and top section of the facades is studied, and it is shown that having a higher transmittance in the top section results in improved daylight utilization and a middle section with lower transmittance provide privacy to the building occupants. Specific recommendations are made for shade transmittances for upper and middle part of the façade to maintain occupant privacy with acceptable illuminance in the work-plane.

Acknowledgments

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I am forever grateful to my parents and my lovely wife. Without their sacrifice and support, I couldn't be able to make this real. I'm all about, only because of them.

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Nomenclature

W_1	Room length (m)
$W2$	Room width (m)
H	Room Height (m)
Y_1	Spandrel height (m)
Y_2	Height of the clear glass section (m)
Y_3	Height of the fritted glass section (m)
M	Luminous exitance (lx)
F_{ij}	View factor from surface i to j
τ	Visible transmittance
ρ	Visible reflectance
L_z	Sky luminance at zenith.
E_{ho}	Horizontal illuminance (lx)
E_{vo}	Vertical Illuminance (lx)
E_{xt}	Extraterritorial solar radiation (W/m^2)
E_{sc}	Solar illuminance constant (lx)
E_{dn}	Solar illuminance at sea level (lx)
J	Julian day number
α	Solar altitude
δ	Solar Declination Angle
φ	Solar azimuth
γ	Surface solar azimuth

d	Profile angle
θ	Angle of incidence
V	Spectral Luminous Efficiency
λ	Wevelength
k	Maximum luminous efficacy
E	Illuminance (lx)
N	Total number of surfaces
C	Configuration factor
z, y, w	Distance of enclosed surfaces from point of interest

Subscripts

i, j	Index
0	Initial value
point	Point of interest

Chapter 1: Introduction

1.1 Background

The use of energy is increasing with continuously as it is an essential element in our lives. Saving energy and the environmental impacts of energy production and use are a major concern worldwide. According to Energy use data handbook, 1990-2013 (Natural Resource Canada) , lighting energy is 12% of the total energy used in commercial buildings in Canada.

As commercial buildings have larger facades with transparent or colored glass, study of daylight has become a primary choice for researchers. Daylighting plays a major role in occupant comfort and behavior and as has a direct impact on energy use. Daylight, that is visible solar radiation, which is about 42% of total solar radiation, has an immediate impact on human health and performance. Research shows that students, having a classroom with more window area score 7% to 18% higher on a standardized than others (Heschong et al. 2002). However, daylighting system should be designed carefully, as they can be a cause for overheating of the space or discomfort due to glare.

In order to control the penetration of sunlight into the space, an optimized and accepted daylight model should be developed. There are different types of models and simulation software are present, which simulates the daylight distribution through windows on a certain orientation. Windows in more than one façade is a different scenario than in one. Almost every building has such location at corner perimeter of the building. A better design of that type of corner office or zone of the building can increase occupant performance and reduces the energy consumption for lighting and HVAC system. In addition, motorized shading systems can be optimally operated and positioned based on daylight levels, occupancy of the space and the need to prevent glare.

1.2 Motivation

Modeling of a corner room with façade on near-south and near-east side utilizing the three-section façade design concept is a new field of research to study the corner perimeter zone of a building. The three section façade (Kapsis et al. 2015) consists of a lower part of the opaque (spandrel) panel, a middle section of clear glazing and an upper section of fritted glass. The top can be used to distribute daylight to the deeper parts of the room without the need of full view to the outdoors; architects often use fritted glass to reduce solar gains while allowing much daylight through but a better option would be to use semitransparent photovoltaic glazing in place of fritted glass to allow daylight transmission but also generate solar electricity.

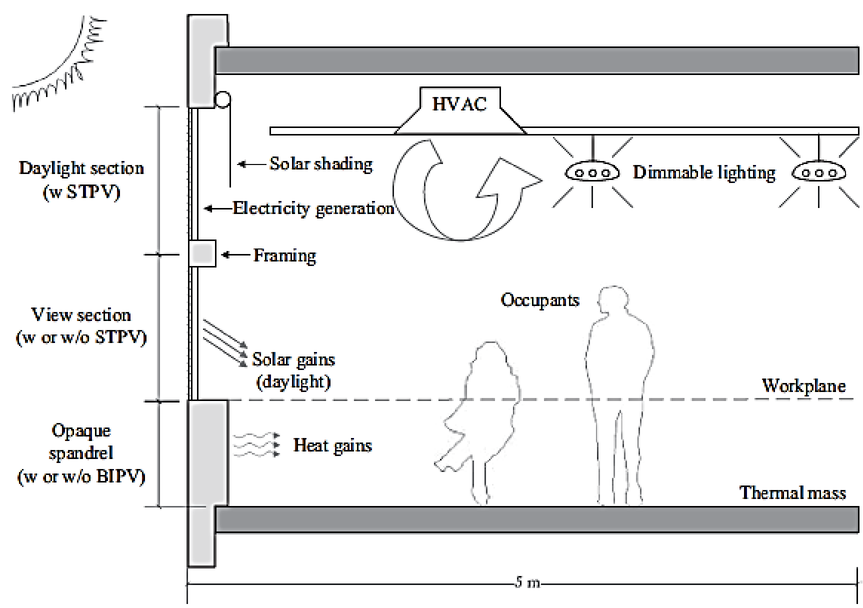


Figure 1: A three Section facade concept (Kapsis and Athienitis 2015)

Daylight mathematical models calculate interior light levels in space and on the work plane which is generally assumed to be a virtual horizontal surface about 0.8 m above the floor. Models use different sky scenarios, such as clear sky or overcast, or real world weather data files for a particular location. A building can be tested early in the design phase by simulating with the model or existing buildings can be studied as part of a retrofit strategy to select new shading devices, new lighting systems or a new control system that can dim the lights in order to save energy by using more daylight. There are many software packages available for general simulation, but the primary purpose of the model described in this thesis to be used to develop a shade control strategy with a bottom-up approach to prevent glare and maintain acceptable light levels on the workplane.

For that purpose, the radiosity method (Athienitis and Tzempelikos 2002) is used to simulate the office and compare with measured data to validate the model and simulate different configurations of shade and interior surfaces. The model is general so that it can be used with fenestration on just one façade by changing the properties of the interior surfaces.

1.3 Objectives

The primary objectives of this thesis are as below

- To develop a radiosity model to analyze the daylight distribution of a corner office with windows on two sides.
- To see the effect of the different position of motorized shades on a three section façade.
- To validate the developed model through an experimental result in a full scale office.

- To investigate different design options by varying properties of the interior surface and glazing properties and to develop design guidelines.

1.4 Corner room with 3 section façade on each side

Most commercial buildings nowadays have larger façade with glass all around it. Those perimeter zone of the buildings have the provision for daylight penetration through windows made of glass. Almost all of those buildings have corner portion with a window in more than one orientation.

In this thesis, a similar kind of room is studied, which has windows on near south and near west direction. Each of those three section façades is formed with the bottom section being opaque (spandrel), the middle viewing section with clear glass and a top daylighting section with fritted glass. Figure 2 shows a typical three section façade having windows in two directions

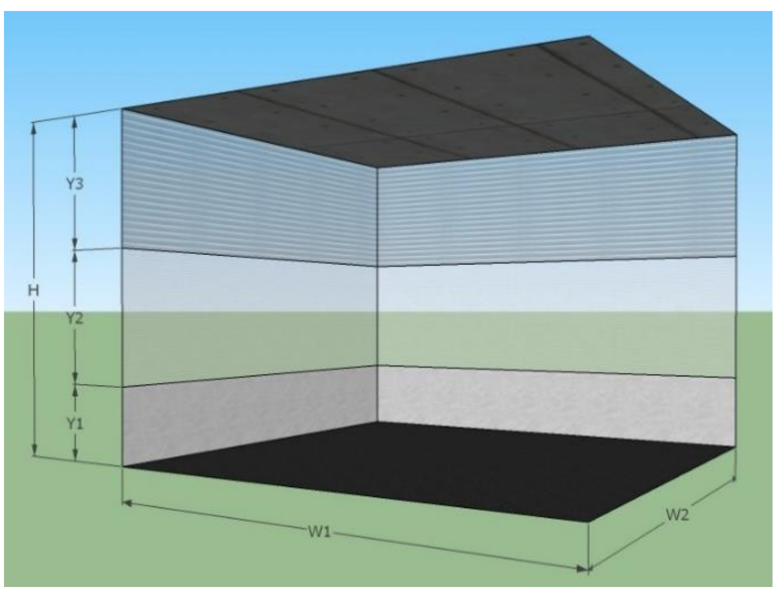


Figure 2: A typical three section façade having windows in two orientations

1.5 Thesis Overview

Chapter 2 presents a literature review of recent and past work done by researchers in this field. These reviews consist of daylight and studies various modeling approaches, different types of shading devices, shade control strategies, glare prevention techniques, and occupant behavior, comfort, and privacy.

Chapter 3 describes the detailed radiosity model of a corner office room with windows on two adjacent façades. A fourteen-surface room enclosure model was considered (Two vertical walls, floor, ceiling, and three sections of each façade divided into two part for shading position calculation) for the calculations of view factors needed in the radiosity model. Initial luminous exitance was calculated using CIE overcast sky model. Then the configuration factor for any point on the workplane with respect to each interior surface was calculated and multiplied with the final luminous exitance to get the workplane illuminance.

Chapter 4 validates the model with experimental data. The detail explanation of the experiment and the equipment used are discussed in this section. A parametric analysis for various shade transmittances and floor reflectance were performed.

Chapter 5 presents the conclusions of the thesis and recommendations for future possibilities of this work.

Chapter 2: Literature Review

2.1 Introduction

Modern buildings are becoming more stylish and their peremeter zones are becoming more transparent. This approach of newly built building reduces the thermal mass and thus increase the energy uses. To improve the performace of the building in terms of energy uses façade design approaches has been the primary concern for the engineers. This chapter of the thesis focuses on some important works done previously by other researchers. This literature review includes daylight performance analysis of commercial buildings, shading of the fenestration, occupancy privacy in the work area and some glare prevention strategies. This thesis describes the daylight model for a corner office with façade on two sides. There aren't many previous works on this type of case.

This chapter will also include some important reviews on daylight performance indicators and effects of different types of shading devices for offices.

2.2 Sunlight on Earth

Life exists on earth only because of the sun. The sun is the main source of light and heat on the earth and most importantly it is free. Many researchers have done and are still doing an extensive investigation of different ways of utilizing the power of the sun. The power of the sun can either be used as a light source or as a heat source. These lights in heat sources are now converted to renewable energy.

The diameter of the sun is approximately $1.39*10^6$ KM and it is nearly 149.6 million Km away from the earth. it mostly consists of hydrogen gas. Sunlight is only the part of the electromagnetic radiation emitted my sun. Before sunlight falls on the earth surface, it crosses the atmosphere where most of the radiation is absorbed. The earth only receives only a part of 10^9 of the total energy of the sun. Before hitting the atmosphere, the solar radiation is close to a black body and the temperature is about 5800K. From the total range of the solar spectrum, our interest is in the visible part of that. The human eye can be responsive to the only 380nm to 780nm wavelength of the spectrum (Murdoch 2003).

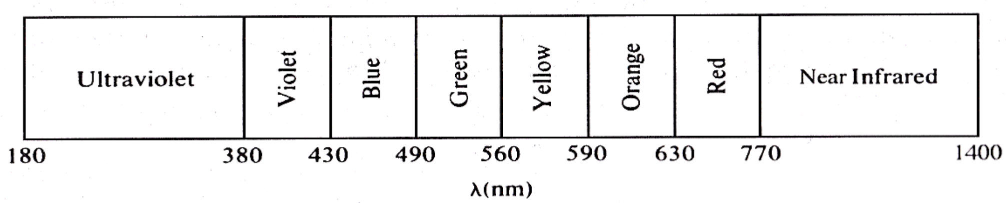


Figure 3: Visible Spectrum (Murdoch 2003)

The total extraterritorial solar radiation (Murdoch, 2003) can be expressed as

$$E_{xt} = E_{sc}\left[1 + 0.034\,cos\frac{360}{365}(j-2)\right] \quad (1)$$

2.3 Daylight modeling approaches

Sunlight has been the primary source of lighting for many years. Quantification and different quality measures of daylight make it easy for researchers to utilize daylight more efficiently and effectively in buildings.

For effective and efficient utilization, a model needs to be developed to characterize the fenestration systems, including shading. There are three types of modeling techniques.

- Radiosity (Applied for diffuse light)
- Ray Tracing (Applied for direct light)
- Hybrid (combination of both)

Radiosity method (Athienitis and Tzempelikos 2002) is one of them commonly used and the illuminance at any point in a space can be predicted and the shades can be controlled according to that prediction. Previously this method was only used to calculate the heat transfer between surfaces. But now a day it is widely used for lighting rendering.

(Lehar and Glicksman 2007) shows this radiosity method as a rapid algorithm for lighting analysis. The main part of the calculation is to determine the view factor. If the view factor is calculated once the lighting calculation can be done easily by varying other parameters. They used the radiosity method for the diffuse light calculation and then added the direct sunlight contribution through the window with it. They found approximately 10% error compared to the verified lighting simulation software to their calculation and accepted that variation.

On the other hand, (Athienitis and Boxer 2011) showed a comparison between simple radiosity method (3 surfaces and 7 surfaces) and a detailed 600 surface radiosity model and found that the 7 surface model gives very close result as of the 600 surface.

Typical case of an office with a carpet, false ceiling and light colored walls

Reflectance %		MODEL	POINT 1	POINT 2	POINT 3	POINT 4
CEILING	70	3-SURFACE	2370	1262	802	602
FLOOR	30	7-SURFACE	2448	1341	876	668
WALLS	50	600-SURFACE	2383	1363	897	678

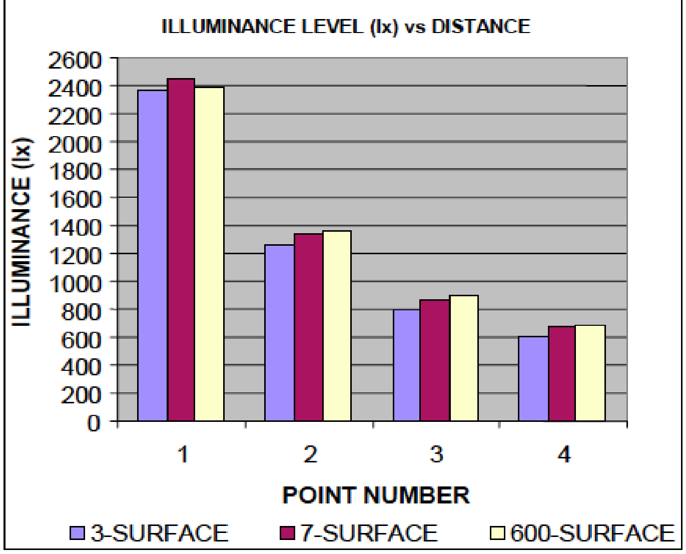


Figure 4: Comparison of illuminance level between 3-surface, 7-surface and complex 600-surface model (Athienitis and Boxer 2011)

The direct sunlight that enters the room through the unshaded part of the window can be calculated by the ray-tracing method (Kuhn et al. 2001). This method traces the path of sun rays and shows the sun patch on the room (Glassner 1989). This method is ideal for analyzing daylight distribution where direct light is important and glare prevention is a must. It indicates the pattern of the beam and direct glare so that the shade can be controlled accordingly (Kapsis et al. 2010). This method is also important to the designer of venetian blinds (Tzempelikos et al. 2007).

(Chan and Tzempelikos 2012) also presented a hybrid ray tracing and radiosity method to calculate the daylight distribution more accurately.

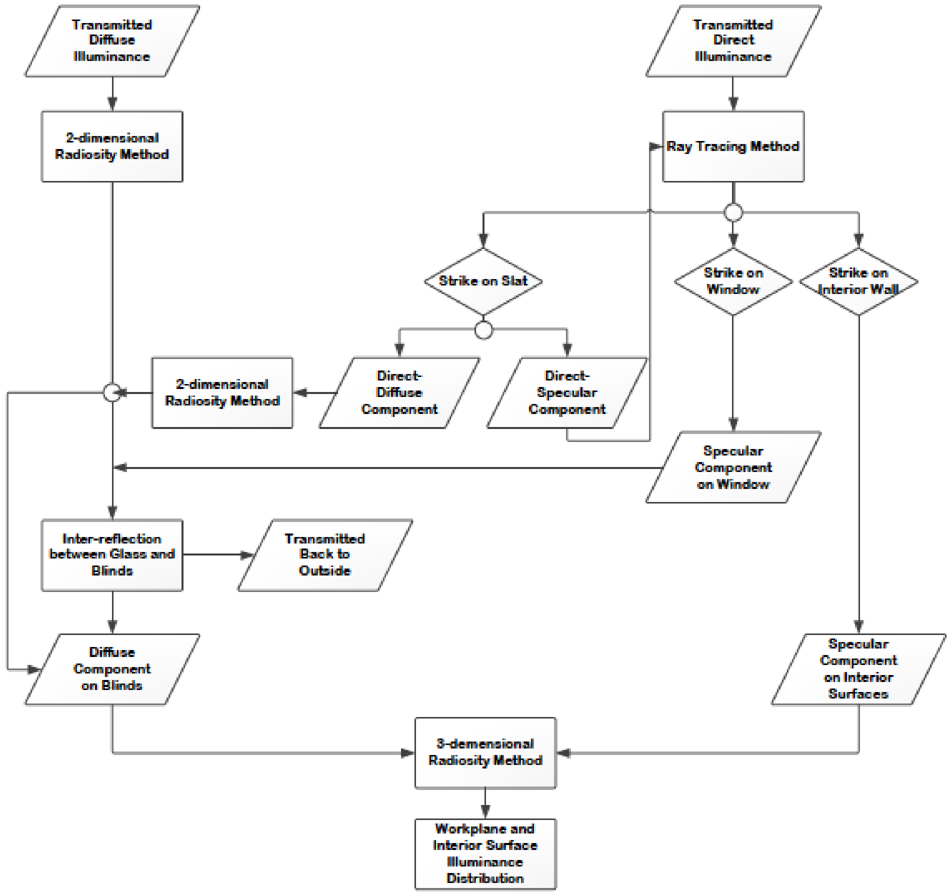


Figure 5: Hybrid ray tracing and radiosity method flowchart (Chan and Tzempelikos 2012)

Direct glare prevention was also partly done with bottom-up roller shades (Kapsis et al. 2010) and analyzed using the ray-tracing method. They described a glare free zone (GFZ) and traced the sun ray path to determine that zone.

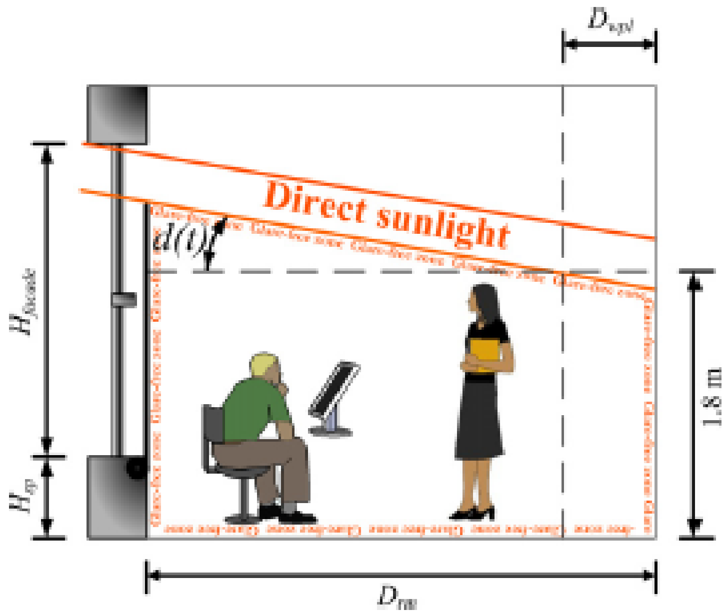


Figure 6: Glare free zone concept (Kapsis et al. 2010)

2.4 Different types of Shading

With the increased use of fenestration in façades, it is essential to design shading and daylighting systems together with appropriate strategies for their control so that daylight is used effectively while preventing glare.

Research into different types of shades and blinds such as venetian blinds, (Tzempelikos et al. 2007), (Mettanant and Chaiwiwatworakul 2014), (Lee et al. 1998), bottom up shades (Kapsis et al. 2010) is also ongoing. Dynamic window technologies have been studied recently, where shades can be located internally, externally or in-between the window panel as a possible classification of shading proposed by (Bellia et al. 2014).

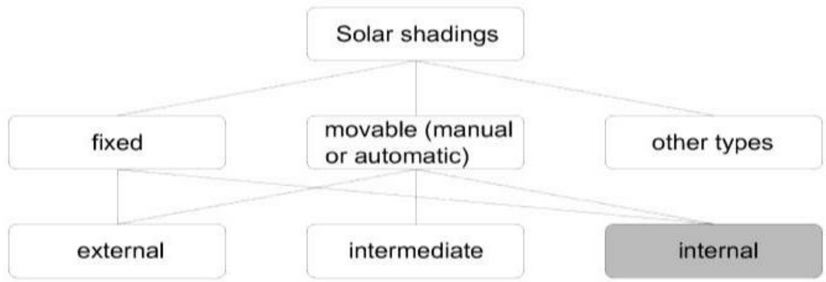


Figure 7: Possible classification of shading (Bellia et al. 2014)

External shades have stronger effect on the heating and daylight than internal shading (Morini et al. 2014). But interior shades are most common in commercial buildings in Canada as they can be installed after the initial design stage without affecting the exterior appearance of the building and they have low maintenance and are easy to install. In addition they are not affected by exterior snow and freezing rain. With the bottom-up shades it is reported that 8-58% higher daylight autonomy can be obtained compared to conventional roller shades which operate from top to bottom. This type of shade contributes to saving energy for the artificial lighting of 21-41% (Kapsis et al. 2010).

2.5 Shade control strategies

Roller shades are one of the most common, efficient and easiest ways to control the amount of light entering a space. Using shades on windows, the direct sunlight and the solar heat gain can be controlled and the energy consumption can be reduced (Mills and McCluney 1993); (Athienitis and Santamouris 2002). Shades can be positioned manually, but controlling the position of motorized shades automatically can be more efficient and cost-effective in terms of energy consumption (Kapsis et al. 2010) and glare minimization.

Shade control strategies can be open-loop or closed-loop. Open loop control system of blinds involves a model and the pre-calculated solar angles to determine the position of the shades accordingly (Skelly and Wilkinson 2001), (Vine et al. 1998), (Shen and Tzempelikos 2014).

On the other hand closed-loop control strategies need the sensor value to be fed backed to the system (Reinhart and Voss 2003), (Mukherjee et al. 2010).

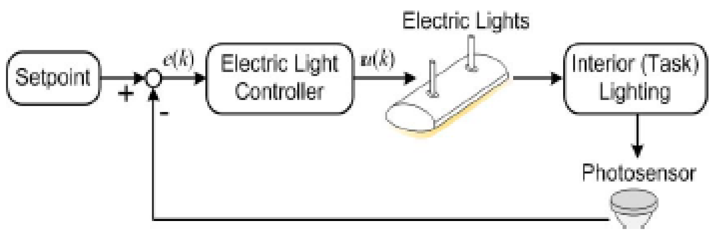


Figure 8: Closed-loop control strategies for lighting (Mukherjee et al. 2010)

(Shen et al. 2014) examined and compared three types of control with seven different strategies (Table-1). In the manual control strategy (1), the lights are controlled by on (with or without dimming) or off position as per occupant's presence. The first five independent control strategies daylight and lighting control work independently, whereas in the last two integrated strategies daylight and lighting are being controlled by sharing the control information with HVAC system.

Table: 1: Types of control with different strategies.

Control type	Control strategy
Manual control	Strategy 1: Manual control of lights and no blinds
Independent control	Strategy 2: Independent open-loop blind, closed-loop dimming control Strategy 3: Independent open-loop blind, closed-loop dimming control, occupancy and HVAC mode shared with blind system Strategy 4: Independent closed-loop blind, closed-loop dimming control Strategy 5: Independent closed-loop blind, closed-loop dimming, occupancy and HVAC mode shared with blind system
Integrated control	Strategy 6: Fully integrated lighting and daylighting control with blind tilt angle control without blind height control Strategy 7: Fully integrated lighting and daylight control with blind tilt angle and height control

They showed a fully integrated open-loop and closed-loop lighting and daylighting control system in accordance with the sun angle, HVAC sensor, photo sensor and occupancy sensor.

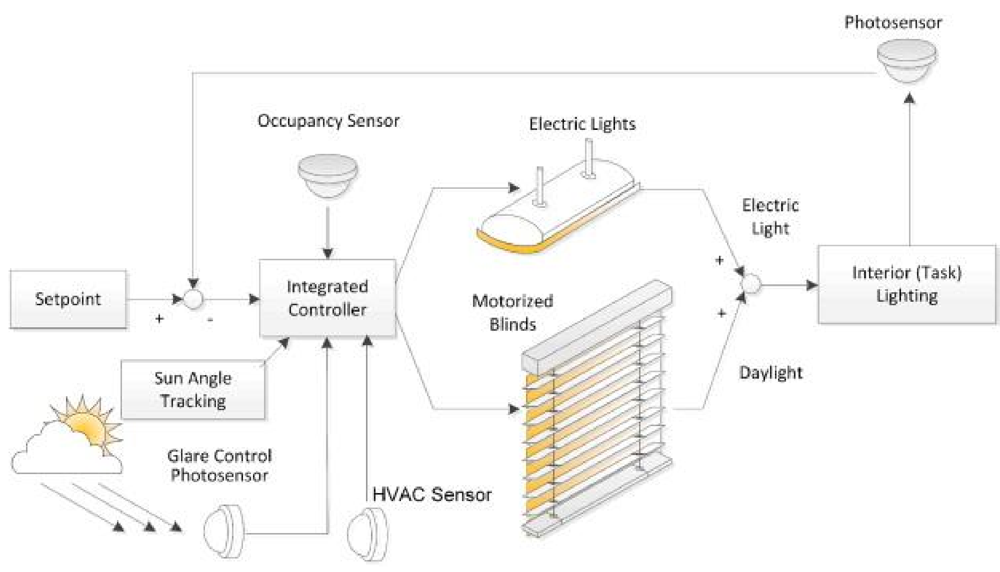


Figure 9: Shade control integrated with electric lighting (Shen et al. 2014)

2.6 Occupant comfort and privacy

Daylight utilization in perimeter zones of office buildings is particularly important as it reduces the need for electric lighting and it contributes to a higher quality indoor environment (Boyce et al. 2003); (Farley and Veitch 2001). Boyce has given a conceptual chart which shows the impact of lighting condition in a room on the occupant's visual performance.

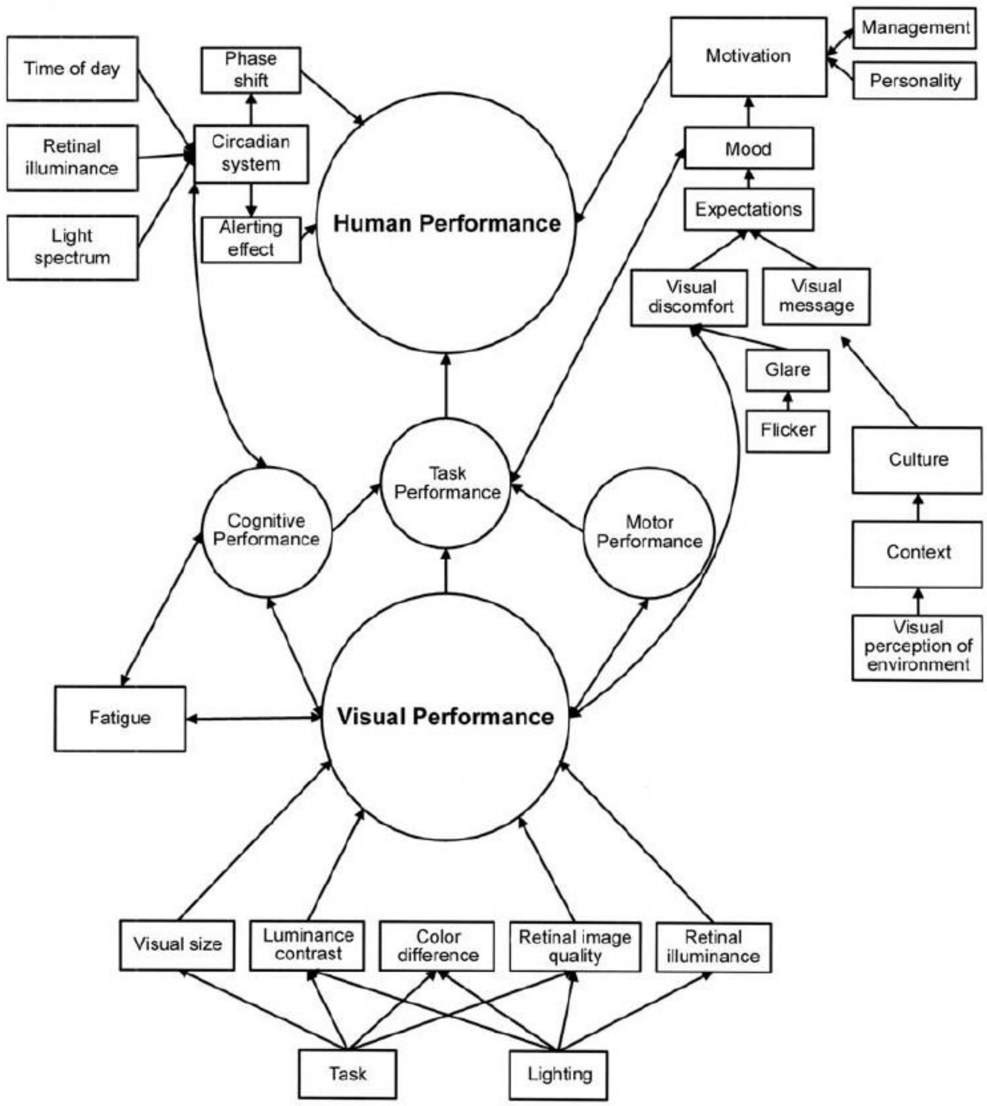


Figure 10: Influence of lighting on human performance (Boyce et al. 2003)

Presently, many researchers are working on modeling daylight in buildings and controlling it according to occupant needs (Muller et al. 1995); (Robinson and Stone 2006).

A real life study (Reinhart and Voss 2003) shows that people in the office close their shades when the direct sunlight is over 50 W/m^2 on the work plane.

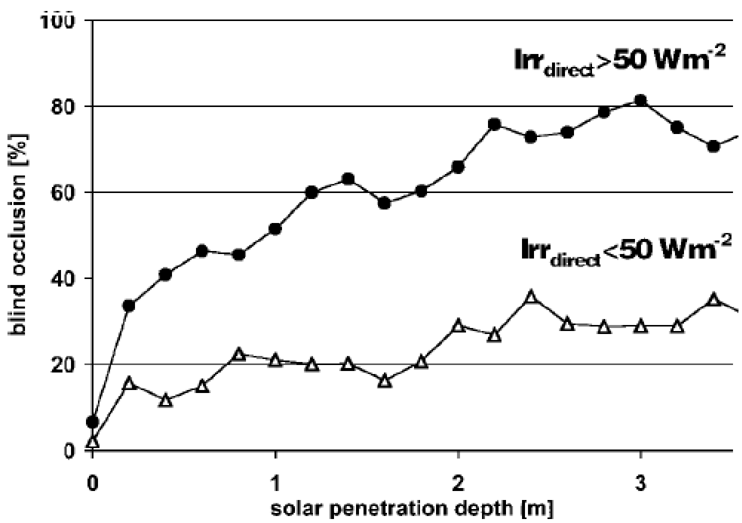


Figure 11: Blind position vs solar penetration depth for irradiance over and below 50 W/m^2 (Reinhart and Voss 2003)

When it comes to venetian blinds many people keep the blinds down with the slats in the horizontal position either for privacy or they like to use the artificial lights rather than moving the blinds manually (Escuyer and Fontoynont 2001).

2.7 Conclusion

A lot of effort has been made by researchers for modeling daylight penetration in space. Models consist of various aspect on energy saving, glare prevention and light levels control strategies. Some models are integrated with the building HVAC system to develop control strategies to reduce solar heat gain.

Based on the literature review, it can be concluded that continued research is needed to save energy by using more daylight rather than electric lighting while preventing glare. This needs to be done both the design stage of a building by selecting appropriate shading and daylighting systems and developing improved methods for their control.

This thesis works on both of the above needs for the specific configuration of a corner office that has windows on two orientations.

Chapter 3: Radiosity Model of the Corner Room

3.1 Introduction

A corner room in a commercial building is most demandable because it has windows on two adjacent façade compared to the most common case of having only one window or no window. Corner rooms have more exposure to the sunlight than other rooms in the buildings. Though the area ratio of the corner space to the other conventional spaces in the perimeter zone of a building is not significant, it is more important to analyze and design carefully. Because of having glass façade on two sides, these areas can be over heated or can face more glare from the sunlight.

This model describes the most common case of an office perimeter corner zone (figure-2). By varying the non-dimensionalized room dimensions (such as $\frac{W1}{W2}$, $\frac{W1}{H}$, $\frac{W2}{H}$), façade aspect ratio (such as $\frac{Y1}{H}, \frac{Y2}{H}, \frac{Y3}{H}$) or surface properties, the daylight distribution of any space with fenestration at any orientation can be simulated and analyzed. This model consists of a three section façade where the lower part is opaque (spandrel), the middle section is clear and the upper section is fritted glass.

To develop this model, the radiosity method was used to predict the daylight distribution at different points of interest in an office. The radiosity method is based on diffuse daylight transmitted through the windows/shades and the daylight reflected from the interior surfaces also assumed to be diffuse. This model was developed by using the Mathcad 15 program.

Some assumptions were made to develop the model. Those are:

- All internal surfaces of the room are diffuse.
- There are no external obstacles.
- The reflectance of the room surfaces is calculated as an area weighted average.

The input parameters of the model are as below:

- The geographic location,
- The room dimensions,
- The reflectance of the interior surfaces, glazing and shades,
- The visible transmittance of the glazing and shades, and
- The sky condition.

3.2 Solar Position and Angles

To analyze the daylight, it is very important to know the relationship of earth to the sun. To calculate the exact position of the sun some angles are used. The definitions and schematic of those solar angles are described below.

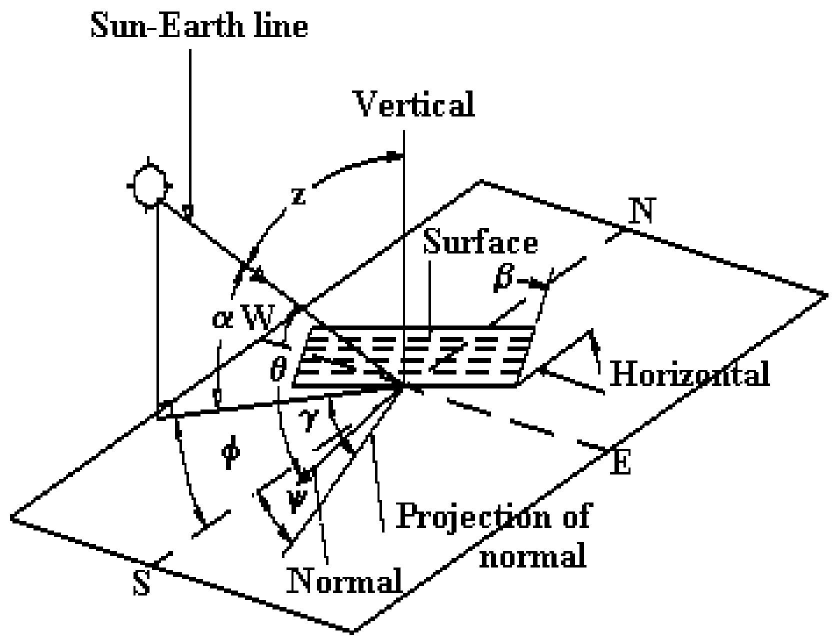


Figure 12: Solar geometry (Athienitis 1999)

Solar Declination Angle (δ)

Solar declination angle is the angle between the earth-sun line and the equatorial plane on a specific day.

$$\delta(n) = 23.45 \times \sin\left(360 \times \frac{284+n}{365}\right) \quad (2)$$

Where n is the number of the day of the year. i.e. n=1 for January 1.

Solar altitude (α_s)

The altitude angle is the angle between the sun rays and the horizontal plane on earth. This angle often describes how high the sun appears in the sky.

$$\sin \alpha_s = sinL.sin\delta + cosL.cos\delta.cosH \quad (3)$$

Where L= latitude of the location and H=Hour Angle

The altitude angle is negative when the sun drops below the horizon.

Solar azimuth (φ)

Solar azimuth is the angle between the projected sun rays on a horizontal plane from the due south. The angle is measured positive eastward.

$$sin\varphi = cos\delta.\frac{sinH}{cos\alpha_s} \qquad (4)$$

Surface solar azimuth (γ)

This is the angle between the projection of the sun rays to the horizontal plane and the line normal to the surface.

Angle of incidence (θ)

This is the angle between the sun rays and normal to the surface.

Profile angle (d)

Profile angle is the vertical angle from the horizon of the sun projected onto the horizontal plane.

3.3 Sky model

The international commission on illumination (CIE) published a standard sky model for the overcast and clear sky in 1996, and this model is accepted worldwide for luminance distribution and daylighting analysis. This model defines the luminance of the sky at any point and calculates the illuminance at any surface on earth.

A more detail mathematical sky model developed by (Perez et al. 1990) is also known as Perez All-Weather sky Model. Real weather data are used as an input of this model.

3.3.1 CIE Overcast Sky

The overcast sky is described where clouds completely cover the sky, and the sun is not visible. This is the condition where the sunlight is completely diffused by the clouds.

Based on the CIE overcast sky model, the horizontal illuminance at any point (Murdoch, 2003) is defined by

$$E_{ho} = 300 + 21000 sin\alpha_s \text{ (lx)} \quad (5)$$

The vertical illuminance due to the diffused light is 40% of the horizontal illuminance.

$$E_{vo} = 0.4E_{ho} \text{ (lx)} \quad (6)$$

3.3.2 CIE Clear Sky

For clear sky modeling, the sky luminance depends on various angles. Under this condition, beam (direct solar radiation) is excluded and again light from the clear sky is diffuse. Firstly the average illuminance on a surface perpendicular to the sun rays and just at the outer atmosphere can be calculated by

$$E_{sc} = k \int_{0.38}^{0.78} E_{s\lambda} V(\lambda) d\lambda = 127.5\ Klx \quad (7)$$

Where, V(λ) is the spectral luminous efficiency of the eyes, k is the maximum luminous efficacy (683lm/W). This E_{sc} is called the solar illuminance constant.

The actual illuminance on any day of the year outside the earth atmosphere on a surface perpendicular to the sun rays is as follow

$$E_{xt} = E_{sc} \left[1 + 0.034 \cos \frac{360}{365}(n-2)\right] \quad (8)$$

Where, n is the number of the day in a year.

The solar illuminance to the sea level (E_{dn}) can be expressed as

$$E_{dn} = E_{xt}.e^{-cm} \quad (9)$$

Where c is the optical atmospheric extinction coefficient with a value for clear sky of 0.21 and m is the relative optical mass. m can be expressed in terms of solar altitude as

$$m = \frac{1}{sin\alpha_s}$$

Now the horizontal illuminance on a given surface is given by

$$E_{hd} = E_{dn}.sin\alpha_s \quad (10)$$

3.3.3 Perez all-weather sky model

This model is used to explain the relative luminance distribution of the sky depending on two key parameters, the sky brightness and the sky clearness. These two parameters can be calculated from the diffuse horizontal and direct normal irradiance data for specific location and time.

This model gives a realistic sky illuminance data calculated from the different atmospheric condition, which are used for daylight calculations.

3.4 Radiosity Method

The radiosity method is based on diffuse daylight transmitted through the windows/shades and the daylight reflected from the interior surfaces. Initially, this method was only used to solve the radiation heat transfer equations. The amount of light radiated from a surface is the summation of the initial luminous exitance of that surface and the amount of reflected light from that surface.

$$M_i = M_{0i} + \rho_i \sum_j M_j F_{i,j} \quad (11)$$

where,

M_i = Final luminous exitance of surface i (lx)

$M_{0,i}$ = Initial luminous exitance of surface i (lx)

ρ_i = Reflectance of surface i

M_j = Final luminous exitance of surface j (lx)

$F_{i,j}$ = View factor between surfaces i and j

Radiosity is a method to compute the amount of light between different diffused surfaces in an enclosure. There are some steps to follow for solving a radiosity problem

- Calculate the initial luminous exitance of each surface enclosure, if any.
- Calculate the effective reflectance of each enclosure surface.
- Calculate the view factors between enclosure surfaces.
- Calculate the total luminous exitance of each enclosure surface, using the radiosity matrix.

  $$M_i = M_{0i} + \rho_i \sum_j M_j F_{i,j} \quad (12)$$

- Calculate the total illuminance on a point of interest, using the configuration factors between the enclosure surfaces and the point of interest.

  $$E_{point} = \sum_{i=1}^{7} c_{i,point} \cdot M_i \quad (13)$$

3.5 Model Description

Generally, we can develop a detailed model by subdividing room surfaces into smaller discrete regions. A fourteen-surface room enclosure (Figure 13) was considered (Two vertical walls, floor, ceiling, and three sections of each façade divided into two parts for shading position calculation) for the calculations. The main input parameters for this model are i) the geographic location, ii) the room dimension, iii) the reflectance of the interior surfaces, glazing and shades, iv) the visible transmittance of the glazing and shades, and v) the sky condition.

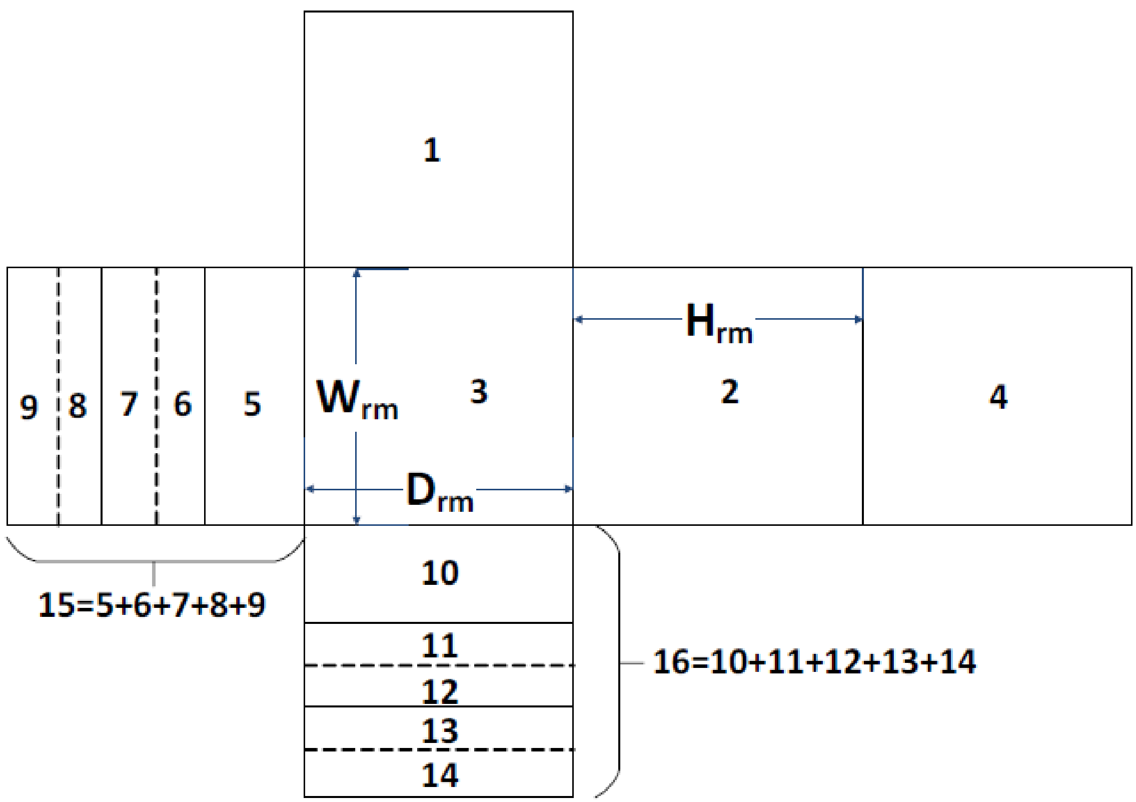


Figure 13: A 14-Surface Room Enclosure for view factor calculation

To find the final luminous exitance, the initial luminous exitance of each surface and the view factors between room surfaces were calculated. The CIE overcast sky model was used to calculate the initial luminous exitance. The model input is hourly diffuse irradiance, and it is better suited for overcast weather conditions. Using this sky model we can estimate the illuminance value to use in the model (Murdoch, B. 2003).

$$L_z = 123 + 8600 \sin\alpha_t \qquad (14)$$

Where, L_z is the sky luminance at zenith.

The horizontal illuminance due to overcast sky is given by (Murdoch, B. 2003),

$$E_{ho_t} = \frac{7\pi}{9} L_z = 0.30 + 21 sin\alpha_t \qquad (15)$$

For a day (June 9, 2015) with an overcast sky, the incident illuminance on the façade is shown in figure 14.

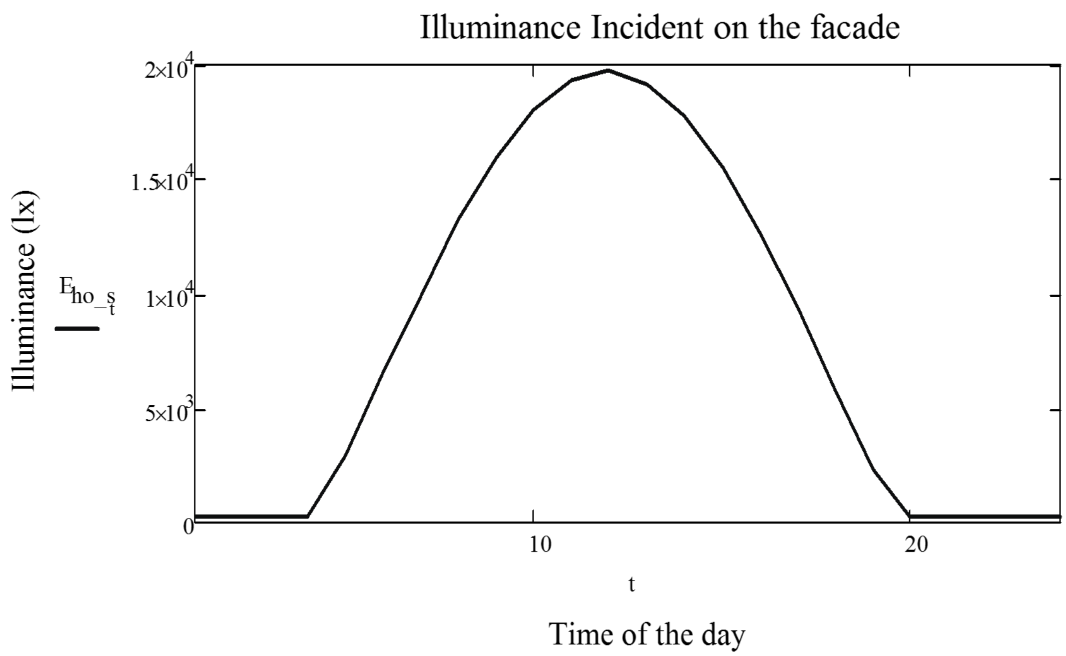


Figure 14: Illuminance on an overcast day (June 9, 2015)

After calculating the total luminous exitance (M_i) of surface *i*, the illuminance on the point of interest was calculated by multiplying the total luminous exitance with the configuration factor between surface *i* and the point of interest

$$E_{point} = \sum_i^N C_{i,point} M_i \quad (16)$$

Where N is the number of surfaces. For calculating the configuration factor C, twenty-five measurement points were used at the work plane level (Figure 15) and from each of these points, the configuration factor is determined using the following equations.

$$C_{parallel}(z, y, w) = \frac{1}{2\pi}\left[\frac{z}{\sqrt{z^2+y^2}}.atan\left(\frac{w}{\sqrt{z^2+y^2}}\right) + \frac{w}{\sqrt{w^2+y^2}}.atan\left(\frac{z}{\sqrt{w^2+y^2}}\right)\right] \quad (17)$$

$$C_{perpendicular}(z,y,w) = \frac{1}{2\pi}\left[atan\left(\frac{w}{y}\right) - \frac{y}{\sqrt{z^2+y^2}}.atan\left(\frac{w}{\sqrt{z^2+y^2}}\right)\right] \quad (18)$$

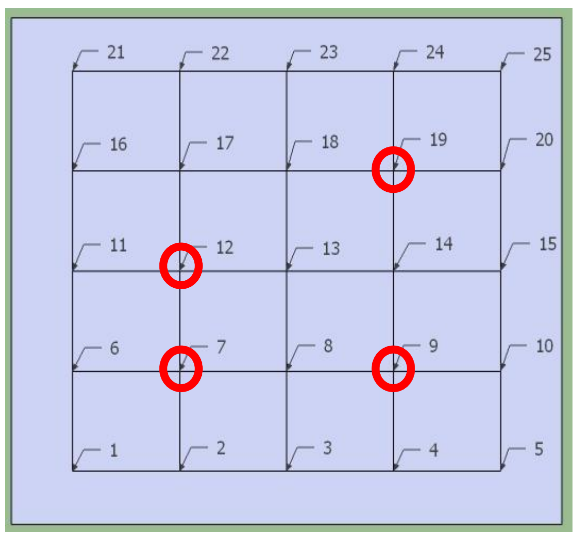
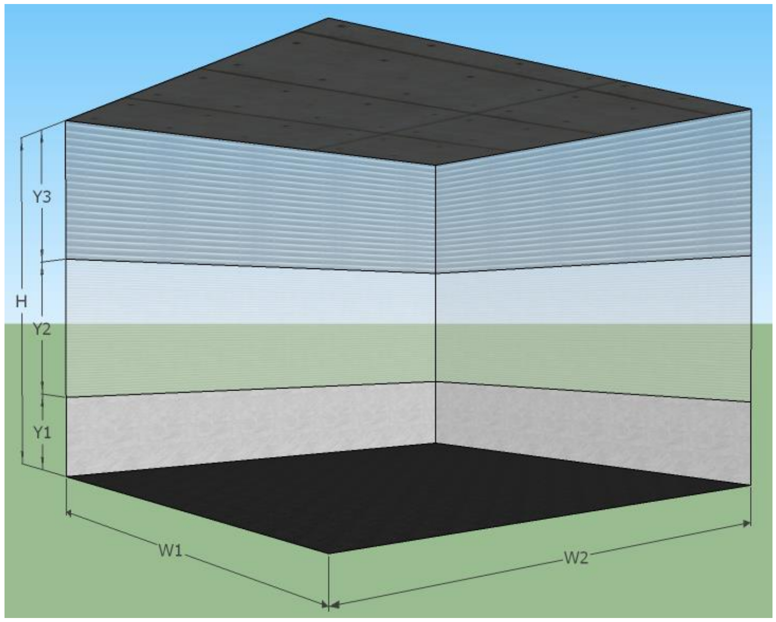
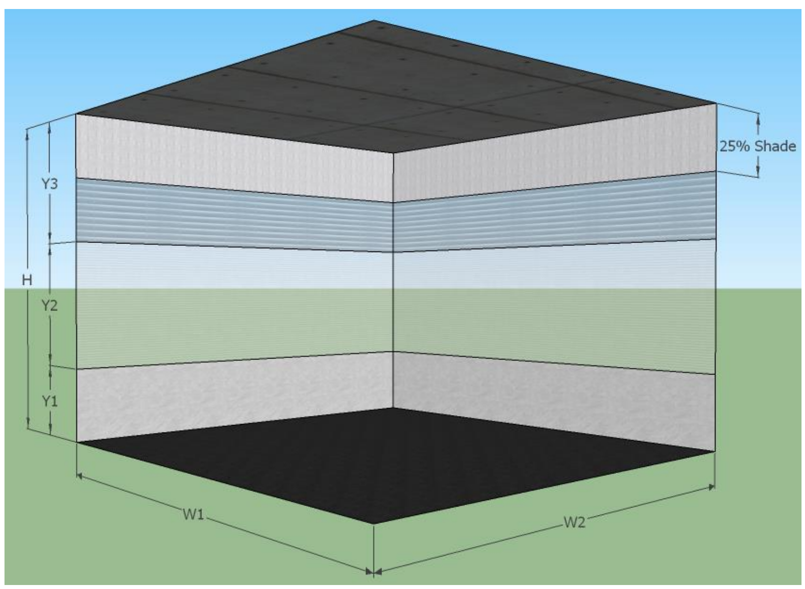


Figure 15: Top view of the workplane showing the five by five array simulation points (measurement points are circled)

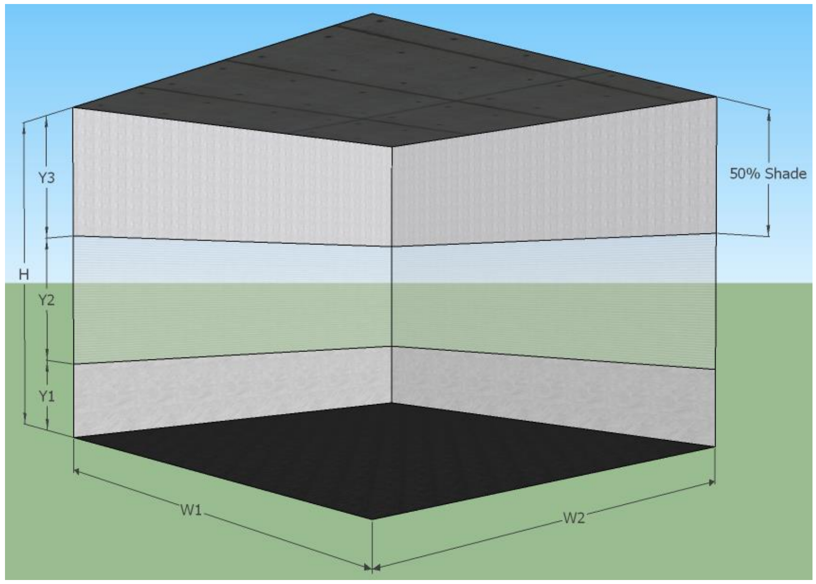
To simulate the daylight distribution, five different configurations of shading position (Figure: 16) were implied. Cases considered included no shade (0% shade i.e. fully open), 25% shade, 50% shade, 75% shade and fully closed means 100% shade.



(1)



(2)



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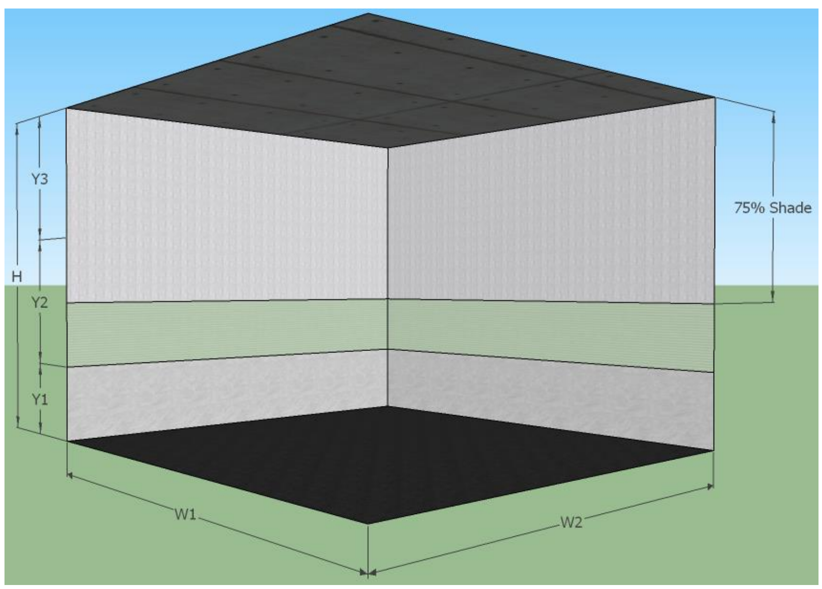
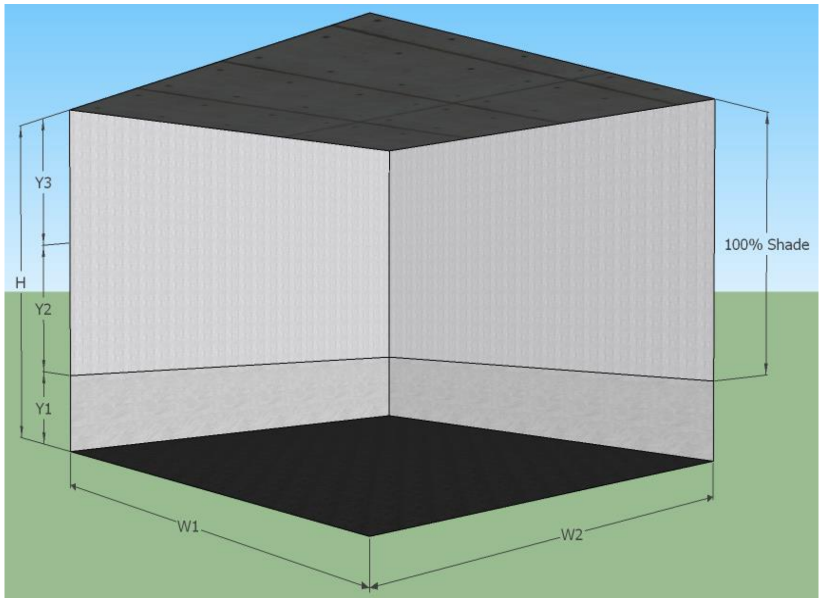


(4)



(5)

Figure 16: Shading position configurations

3.6 Daylight Glare Probability (DGP)

Daylight glare probability (DGP) (Wienold and Christoffersen 2006) is a matrix commonly used for classify the glare produced by sunlight. DGP is calculated by the position, size and luminance of the source and the vertical eye illuminance. DGP under 0.3 is considered barely perceptible, from 0.3 to 0.45 is disturbing and over 0.45 is intolerable (Athienitis and O'Brien 2015). The DGP can be calculated by the following equation:

$$DGP = 5.87 \times 10^{-5}\, E_v + 9.18 \times 10^{-2} log\left(1 + \sum_i \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} P_i^2}\right) + 0.16 \quad (19)$$

where, E_v is the vertical eye illuminance, L_s is the source luminance, ω_s is the solid angle of the source from the observer, P is the position index of the observer.

When the position index (P) is located above the line of vision, that can be calculated as follows:

$$\ln P = \left[35.2 - 0.31889\tau - 1.22e^{-\frac{2\pi}{9}}\right] \times 10^{-3}\sigma + [21 + 0.26667\tau - 0.002963\tau^2] \times 10^{-5}\sigma^2 \qquad (20)$$

where τ is the angle from the vertical of plane containing source and line of sight, σ is the angle between line of sight and line from eye to source.

If the position index (P) is located below the line of vision, that be calculated as follows:

$$P = 1 + 0.8\,\frac{R}{D}\ if\ R > 0.6D \qquad (21)$$

$$P = 1 + 1.2\,\frac{R}{D}\ if\ R < 0.6D \qquad (22)$$

$$R = \sqrt{H^2 + Y^2} \qquad (23)$$

where D is the distance between eye and plane of source in the direction of view, H is the vertical distance between source and the view direction and Y is the horizontal distance between the source and view direction.

Chapter 4: Experiment and model verification

4.1 Introduction

In order to verify the model, an experiment was conducted in a typical office room located on the 15th floor of Concordia University, Montreal (45.50 N, 740 W). During experimentation, an acceptable work plane illuminance for the office was maintained. The surface azimuth of the two façades are 20^0 west of south and 110^0 west of south. On both sides of the façade, there are no external visual obstacles.

Figure 17: Engineering and visual Arts (EV) building, Concordia University, Montreal, QC (www.concordia.ca).

The primary objectives of the experiment were:

- Compare the simulated data with the real data (Overcast and sunny sky conditions) and validate the radiosity model and its assumptions
- Analyzing the daylight distribution on the typical room
- Parametric analysis with different properties of the room and the shading devices

4.2 Properties of the room components

Each façade consists of three sections, the opaque spandrel (0.8m from the floor), the lower clear glass section (double-glazed with a low emissivity coating) and the upper fritted glass section (50% gray ceramic frit). Each glazing is 1.25 m high. A motorized roller shade was installed above the glazing. The reflectance of the walls, floor, and ceiling, are 70%, 5% and 80% respectively. The clear and fritted glazing have a normal visible transmittance of 68% and 48% respectively.

4.3 Experimental set-up

A corner office in the Concordia EV building was used for model verification. The building has façades with complete measurement setups of exterior solar radiation and daylight. Several equipment were installed for the experiment. For measuring the illuminance, a number of Li-Cor Photometric sensors (Model LI-2100R, by LI-COR) were installed at work plane height (0.8 m). For data acquisition, an Agilent DAS unit was used. The roller shades were already installed at that office room.

Some photometric sensors were mounted on the work plane, and two of them were installed on both the windows to measure the incoming light. Installed shades can be adjusted manually by a switch placed in the room or automatically through BAC-net.

Figure 18: Experiment Set-ups in a full-scale office room

All the data were collected by an Agilent Data Acquisition System and stored on PC. A short description of all the equipments are given below which were used in this experiment.

4.3.1 Li-Cor Photometer

The illuminance was measured using Li-cor LI-210 Photometric sensor. The sensor consists of a silicon photodiode that provides a spectral response ± 5%. It is cosine corrected up to 80° angle of incidence, with a linear response up to 100 klx, for operating temperatures of -20°C to 65°C. Its response time is 10 μs (specifications are from the official website: www.licor.com)

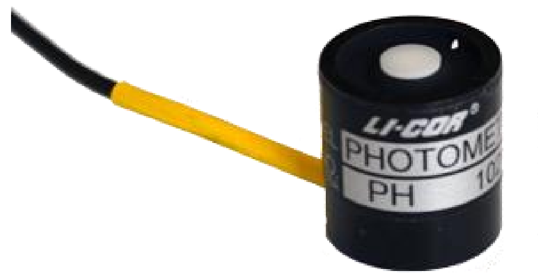


Figure 19: Li-cor LI-210 Photometric sensor

4.3.2 Data Acquisition System

Agilent Data Acquisition system was used in this experiment. It is generally used for data acquisition with a variety of plug-in modules known as thermocouple multiplexer.

The data were collected through a Lab View program to a computer connected to the data acquisition system.

4.3.3 Façade

The three sections of the façade consist of an opaque spandrel, one clear glass section, and one fritted glass section. Both the glass sections are made of double glazing, low e-coated and argon gas filled. The clear and fritted glazing have a normal visible transmittance of 68% and 48% respectively for the diffused light (Kapsis 2009).

For the direct sunlight, the transmittance of both the glasses depends on the angle of incidence of the solar radiation on the glazing.

4.3.4 Shades

A set of pre-installed roller shades were used for the experiment. This roller shade is connected to a BAC-net system and automatic and manually operated. The shades are installed just in front of the windows and is made of fabric. The optical properties of the fabric are as follows:

- Transmittance = 5%
- Reflectance = 55%

4.4 Sensor positioning

To take the measurement two sensors (sensor 1 and sensor 2) were placed on the meeting table (Table: B). Two sensors (sensor 3 and sensor 4) were placed on the working desk (Table: A). One sensor (sensor 5) was set on just top of the monitor and attached to the north wall. Two sensors (sensor 6 and sensor 8) were placed close to the south and east façade. One sensor (sensor 7) was set on the south façade to measure the illuminance at the window.

The schematics of the position of the sensors are given below (Figure 20 and 21):

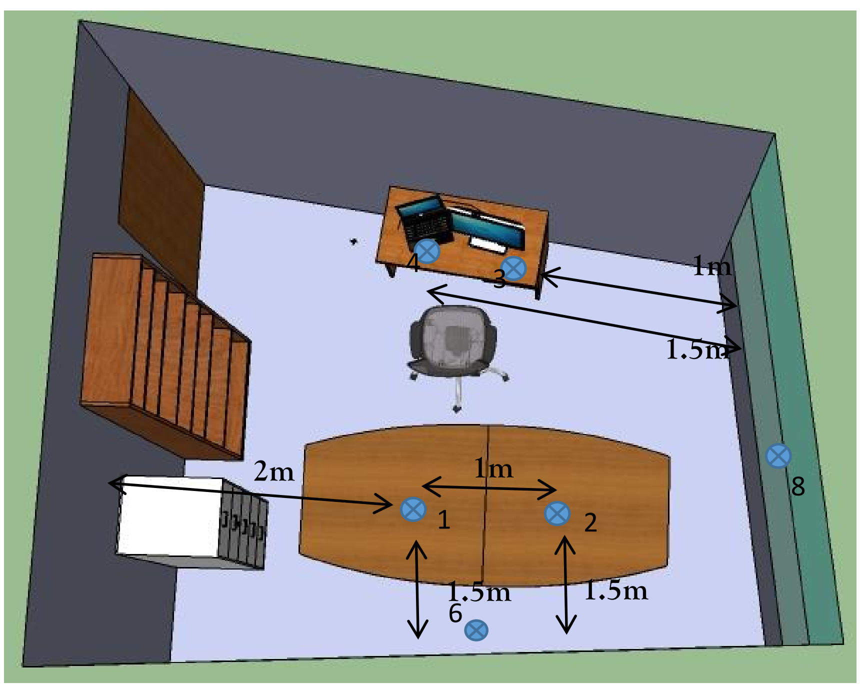


Figure 20: Schematic of the sensor position on the work plane.

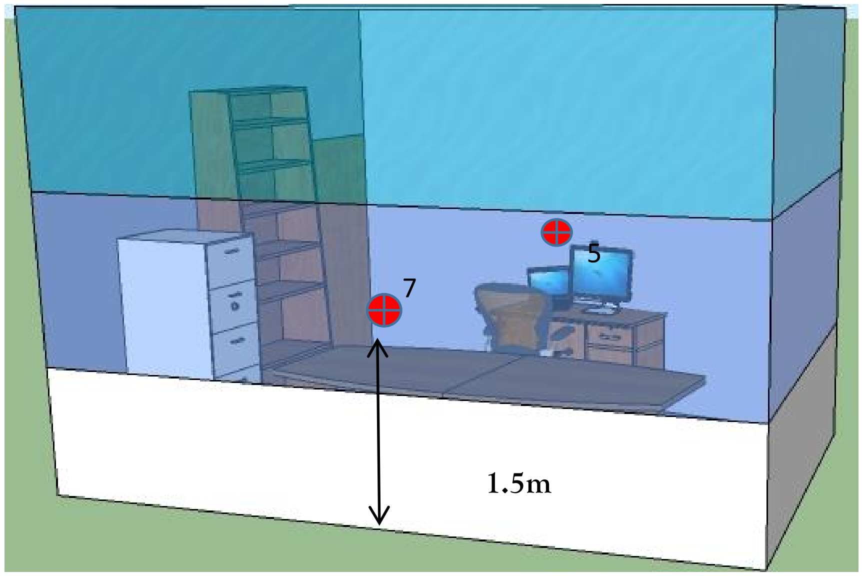


Figure 21: Schematic of the sensor position on the windows

4.5 Experimental verification on overcast day

Measurements were taken at different points on the work plane on many days with varying shade position configurations. The area-weighted properties (e.g. to account for furniture) of the room surfaces, glazing and shades were used in this model. The work plane illuminance values were measured using LI-COR light sensors installed on the work plane (0.8 m from the floor)

This experiment was conducted to consider overcast days. This verification has been carried out on four selected points on the work plane.

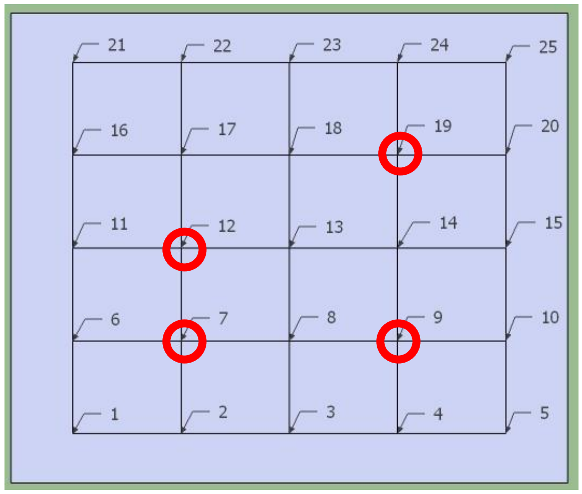


Figure 22: Selected points of measurement on the work plane

After taking data for several overcast and sunny days, some data had been chosen for the verification. Table 2 shows the simulated and measured illuminance for different shading position at different places on the work plane.

Table: 2: Simulated and measured illuminance for different shading position at different places on the work plane.

Shade Position	Point 9		Point 7		Point 12		Point 19	
	S (lx)	M (lx)	S (lx)	M (lx)	S (lx)	M (lx)	S (lx)	M (lx)
0% (open)	6873	6677	8442	8516	7615	7945	5330	5240
25%	6030	5943	7648	8190	6708	6806	4371	4024
50%	4990	3822	6532	5988	5513	5165	3323	2488
75%	4147	3712	5825	5831	4709	5120	2303	2854
100% (closed)	204	203	225	242	249	251	226	223

When a linear regression was plotted (Figure 22) for the measured and simulated illuminance data, it is seen that the coefficient of determination (R^2) for the curve is 0.97, which is very much acceptable.

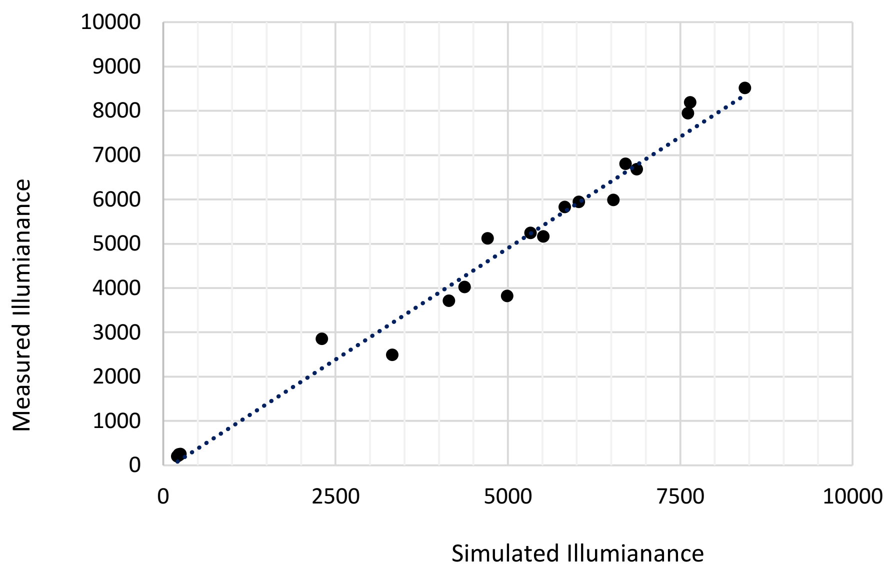


Figure 23: Measured vs simulated data of illuminance on work-plane (lux)

Figures 24-28 show the simulated and measured illuminance on the work plane for five different shade positions (all open, 25%, 50%, 75% and all shades closed) individually. The comparison of simulation results and measured data show that for an overcast day, the simulation results on average differ 1-10% from the measured data which is an acceptable agreement. Because of the shape, the interior surfaces, furniture inside the room and occupant's presence, this accuracy level is being considered as acceptable. Moreover, sometimes real sky condition is quite different from the simulation due to a different circumstance, such as cloud cover. For this reason, in some cases, the simulated result appears higher than the measured value (such as the 50% shade condition).

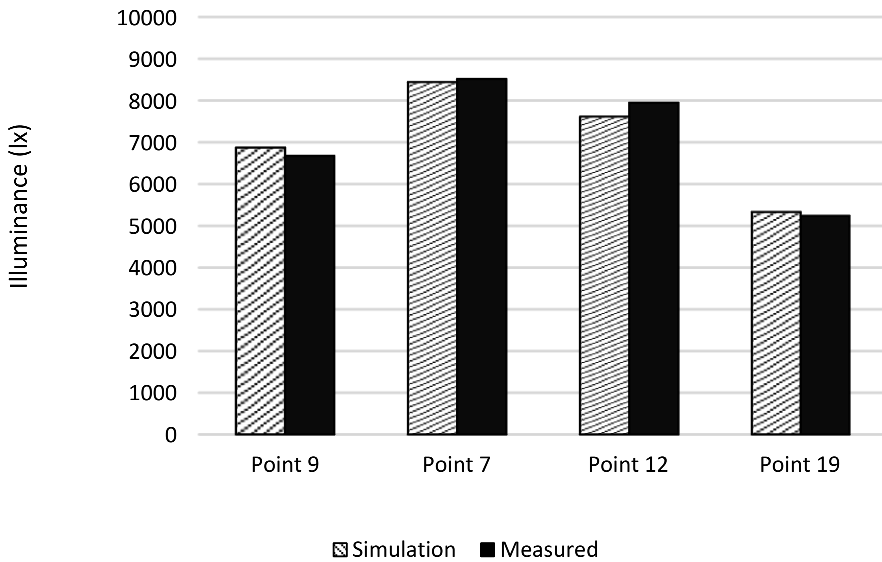


Figure 24: Illuminance comparison for all open shade configuration

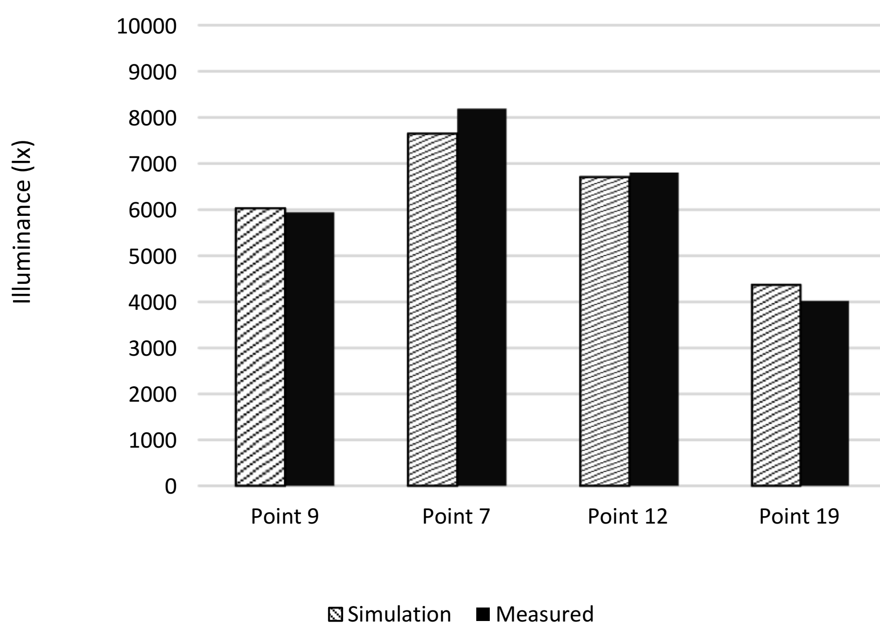


Figure 25: Illuminance comparison for 25% shade configuration

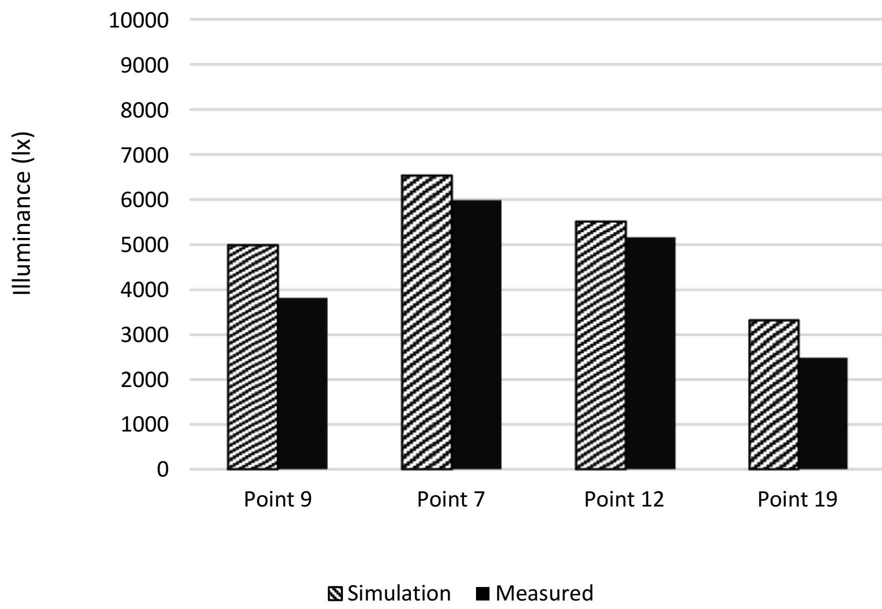


Figure 26: Illuminance comparison for 50% shade configuration

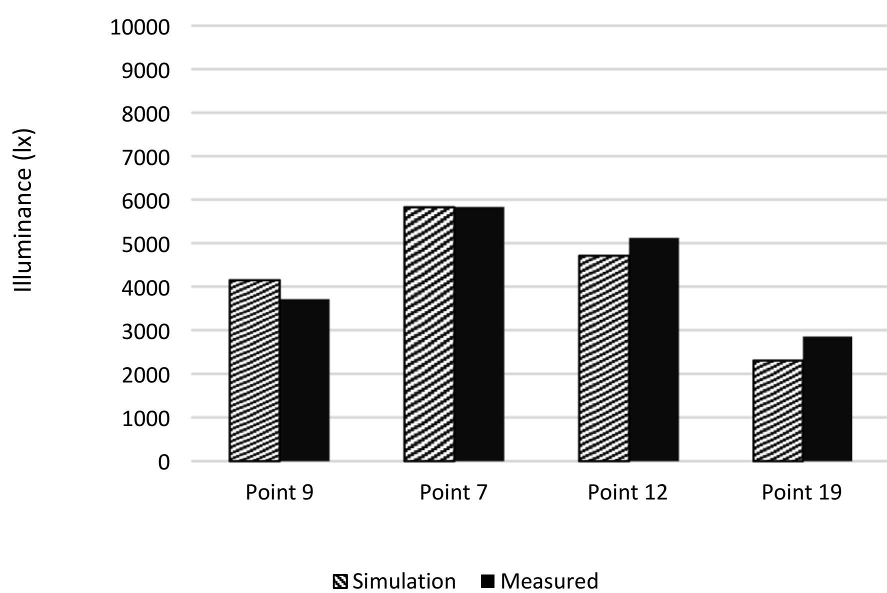


Figure 27: Illuminance comparison for 75% shade configuration

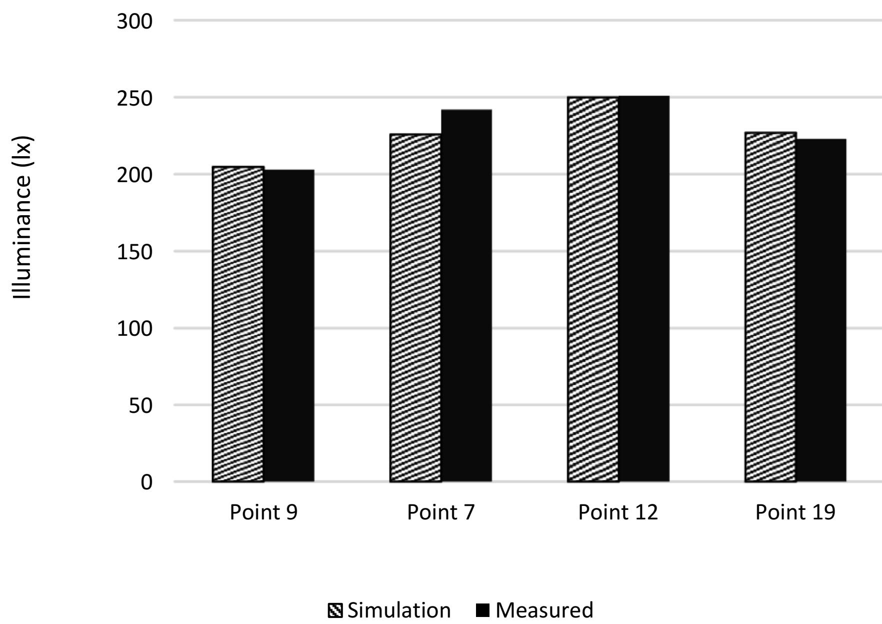


Figure 28: Illuminance comparison for all closed shade configuration

4.6 Parametric Analysis

Changing the optical properties of the glazing, shades and room surfaces, we can predict the daylight distribution for any enclosed spaces. Having façade on two sides makes the model more generalized, as one façade on either orientation can also be analyzed.

After verifying the model, parametric simulations were performed for varying floor reflectance to investigate the effect on work plane illuminance level. The effect of transmittance of the shades was also analyzed for various configurations and the effect of two different shades in two sections of each façade. The configuration with higher transmittance on the upper section and lower transmittance on the lower section of the façade show a significant effect on illuminance. This is acceptable because in the middle viewing section of the facade we cannot have a high transmittance for privacy reasons; however, in the top third of the facade, we have more flexibility in using a higher transmittance so as to have more daylight penetrate deep into the room. This is a particularly important aspect of the model and this study.

The floor of the corner office where the experiments took place, has a low optical reflectance of 5%. Many offices have lighter colored floors with higher reflectance. A sensitivity analysis on floor reflectance was performed with reflectance varying from 5% to 50% in 5% increments (normally a floor reflectance above 30% is not advisable in offices). The results suggest an 8-12% increase in work plane illuminance due to the variation of the floor reflectance from 5% to 50%. The analysis was performed for all shades open (Figure 29) and all shades closed (Figure 30).

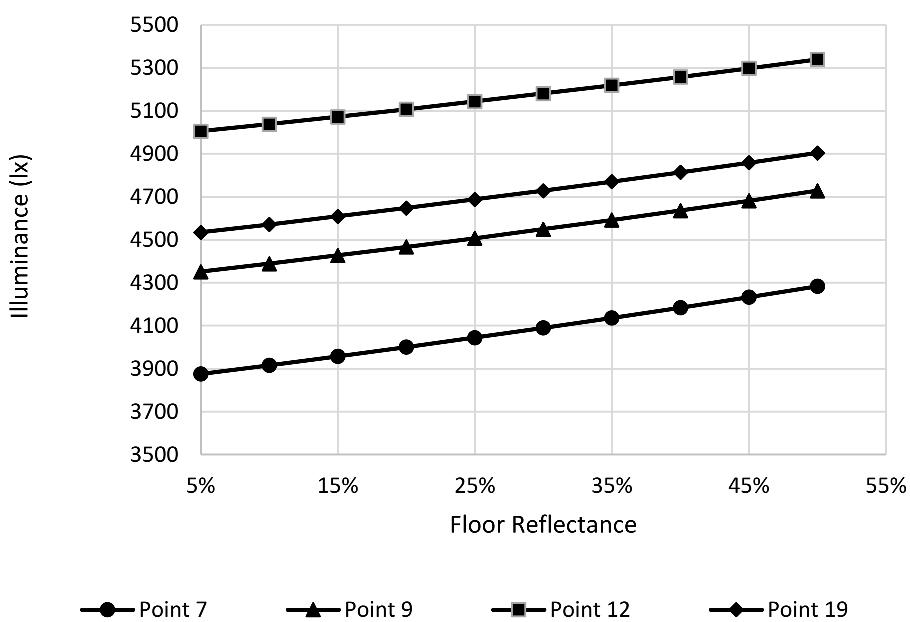


Figure 29: Work plane illuminance vs floor reflectance (for all shades open)

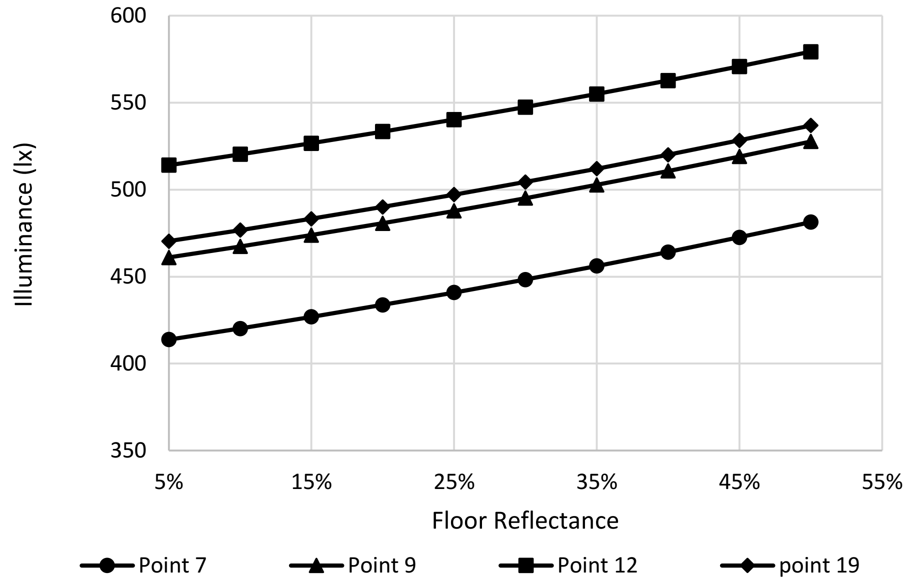


Figure 30: Work plane illuminance vs floor reflectance (for all shades closed)

The analysis was also done to see the effect of transmittance of the roller shades (Figure 31). It is apparent that if more daylight passes through the shade, the work plane illuminance will be higher.

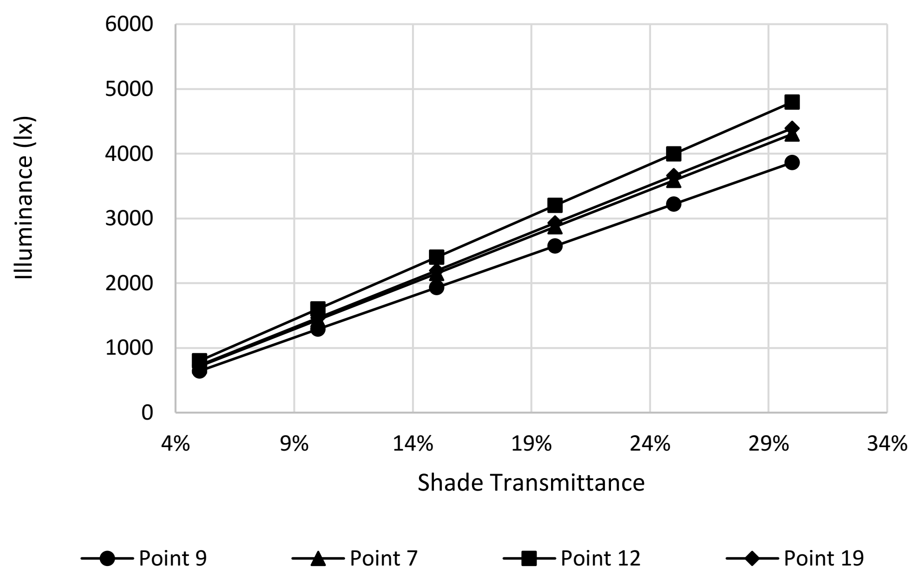


Figure 31: Work plane illuminance vs shade transmittance

The primary purpose of windows on perimeter façade are to provide daylight in to the space and for outdoor view. But privacy of the occupants working close to the façade is also an important issue now a days. There are different ideas of privacy. Some people wants to block the full view from outside and for some people the view of shadows from outside is preferable. To block the complete view from outside, a blackout shade is preferable. But for other option shades with lower transmittance can be used. However when blackout shades are closed, the outdoor view and also natural light is being sacrificed.

To see the various options of shading, balancing the daylighting through upper part of the façade and maintaining privacy by middle part of the façade, another parametric simulation was done varying the transmittance of the shades on different sections of façade. This simulation was performed with the top part of the façade transmittance varying from 1% to 25% and middle part of the façade transmittance varying from 1% to 10%. A fabric with 1% transmittance provides more privacy and less light than a fabric with 10% transmittance. This simulation was done for three types of room geometry.

- Windows on near-south and near-east facades (Figure 32).
- Window on near-east façade only (Figure 33).
- Window on near-south façade only (Figure 34).

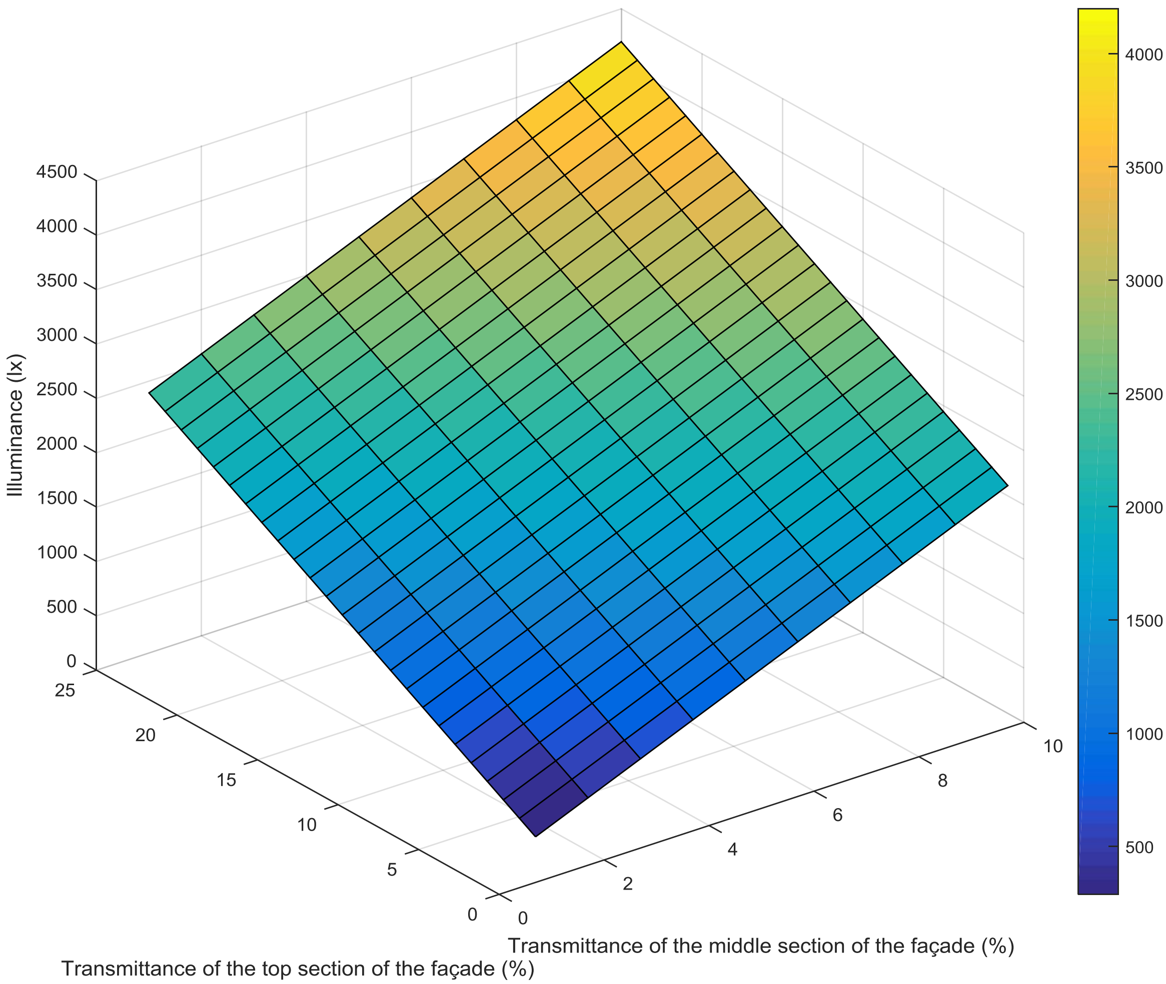


Figure 32: Work-plane illuminance due to different shade transmittance on different sections of near-south and near-east facades.

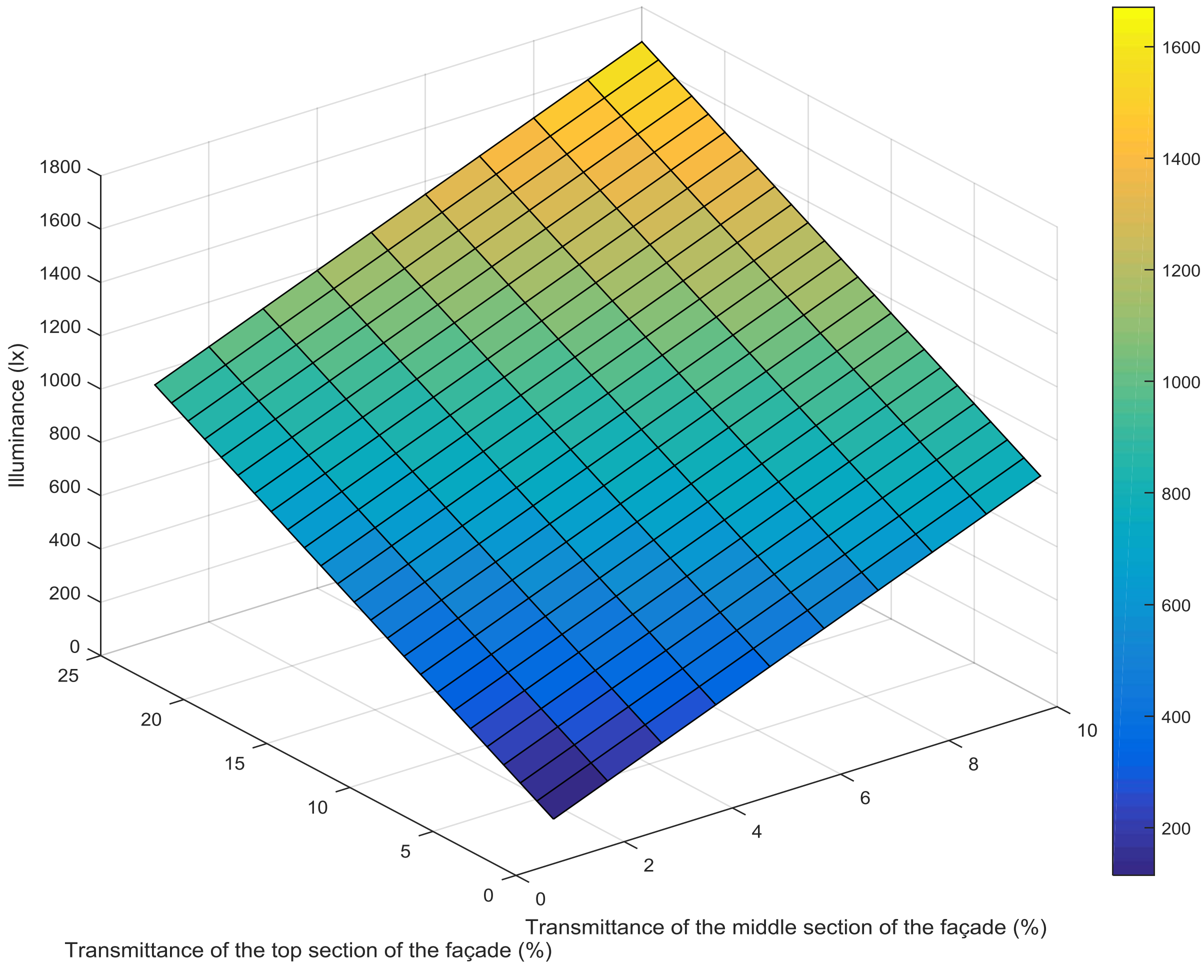


Figure 33: Work-plane illuminance due to different shade transmittance on different sections of near-east façade (Considering near-south facade is opaque).

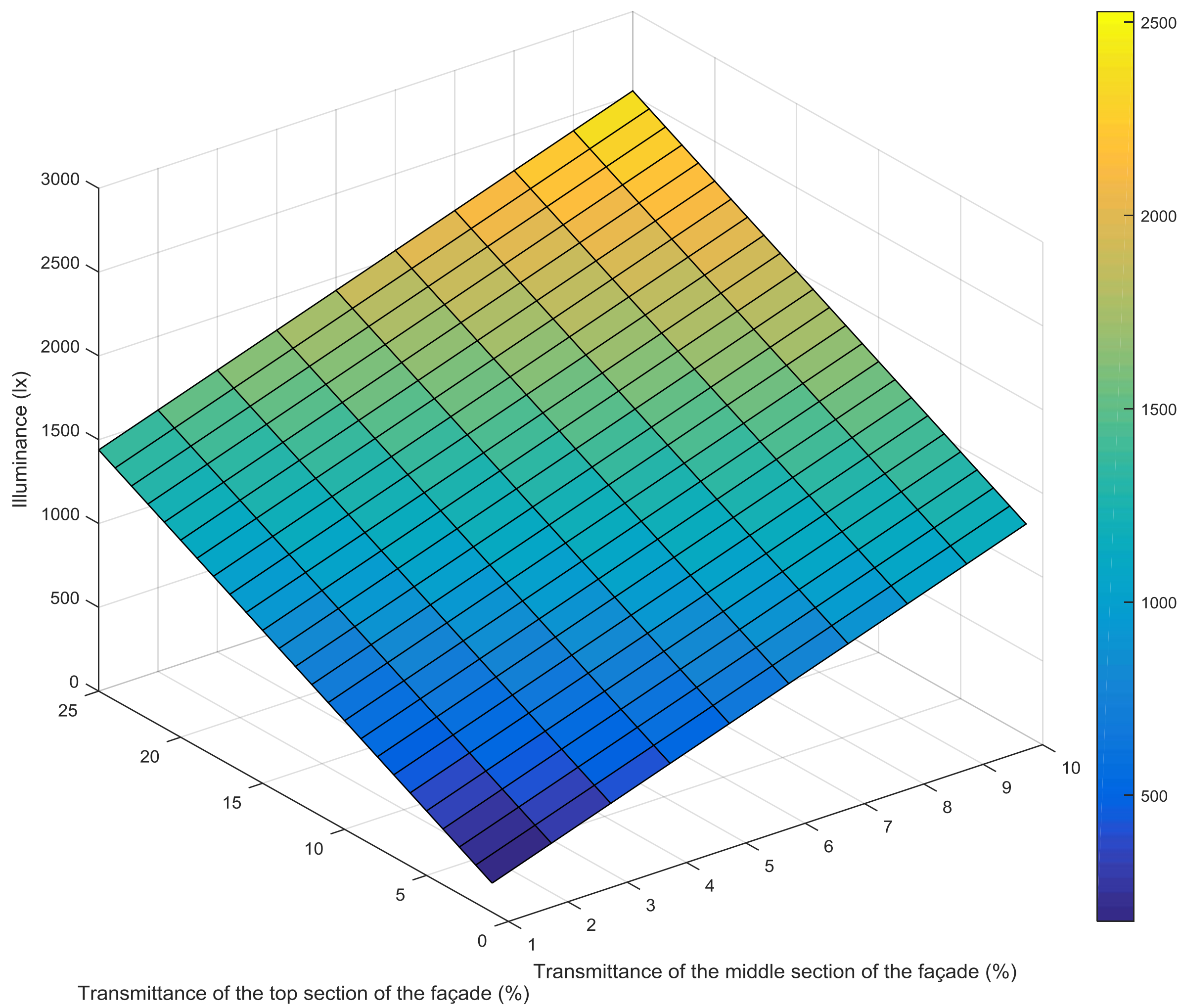


Figure 34: Work-plane illuminance due to different shade transmittance on different sections of near-south façade (Considering near-east facade is opaque).

Figures 32 - 34 show the results in the morning (10 AM) on a clear sky day for a range of transmittance values of the shade in the top and middle facade sections. As can be seen, acceptable work-plane illuminance levels (>2000 lx) can be maintained by using different shades on upper and middle portion of the façade. From the graphs, the right combination of shade transmittance can be determined depending the needs of the occupants, whether they need the privacy or the daylight or both. This types of configuration of shading can also reduce the glare caused by the direct sunrays.

A daylight glare probability (DGP) analysis has been done on the work-plane (Table-B of figure 18) level for three types of room geometry mentioned above with different shade transmittances on different sections of the façade to determine the limit of the maximum transmittance for the shades so as to avoid glare. DGP is determined from the luminance of the diffuse source (windows with all shades closed) and the vertical illuminance on the work-plane. DGP is used to classify the glare range. DGP under 0.3 is considered barely perceptible (i.e. it is acceptable), from 0.3 to 0.45 it is disturbing and over 0.45 is intolerable (Athienitis and O'Brien 2015).

Figures 35-37 show the results for calculated DGP on a typical clear sky day (9 June, 10 AM) on the work-plane. From the figures, the maximum limit can be determined for both shade transmittances on top and middle section of each façade. Depending on the occupant's need, whether the privacy or the daylight is needed, the transmittance of the shades can be set accordingly. To calculate the DGP no veiling glare was taken into account assuming there are no internal reflections from the computer monitor or from any other surfaces.

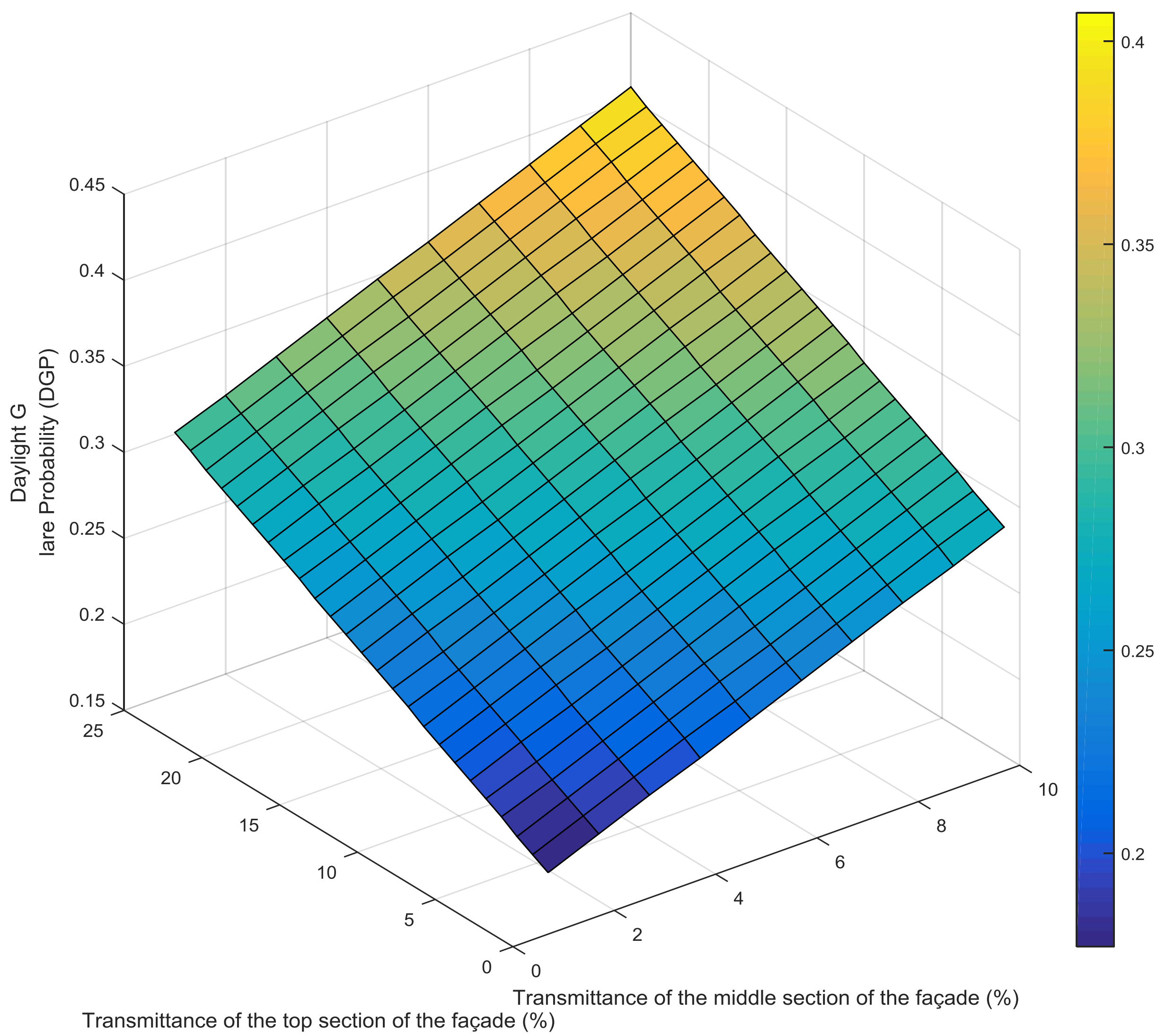


Figure 35: Calculated Daylight Glare Probability (DGP) for different shade transmittances on different sections of both façades.

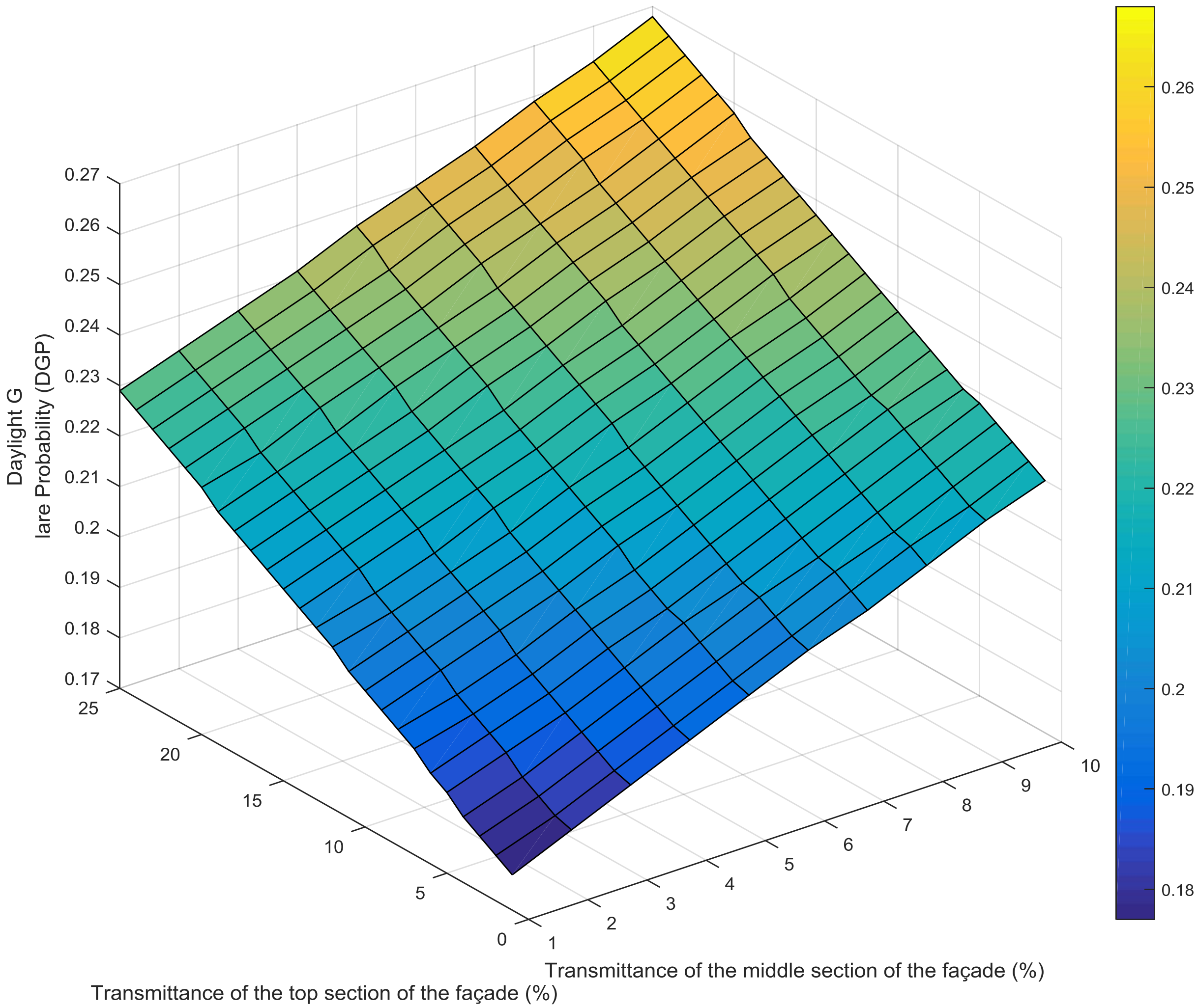


Figure 36: Calculated Daylight Glare Probability (DGP) for different shade transmittances on different sections of near-east façade (Considering near-south facade is opaque).

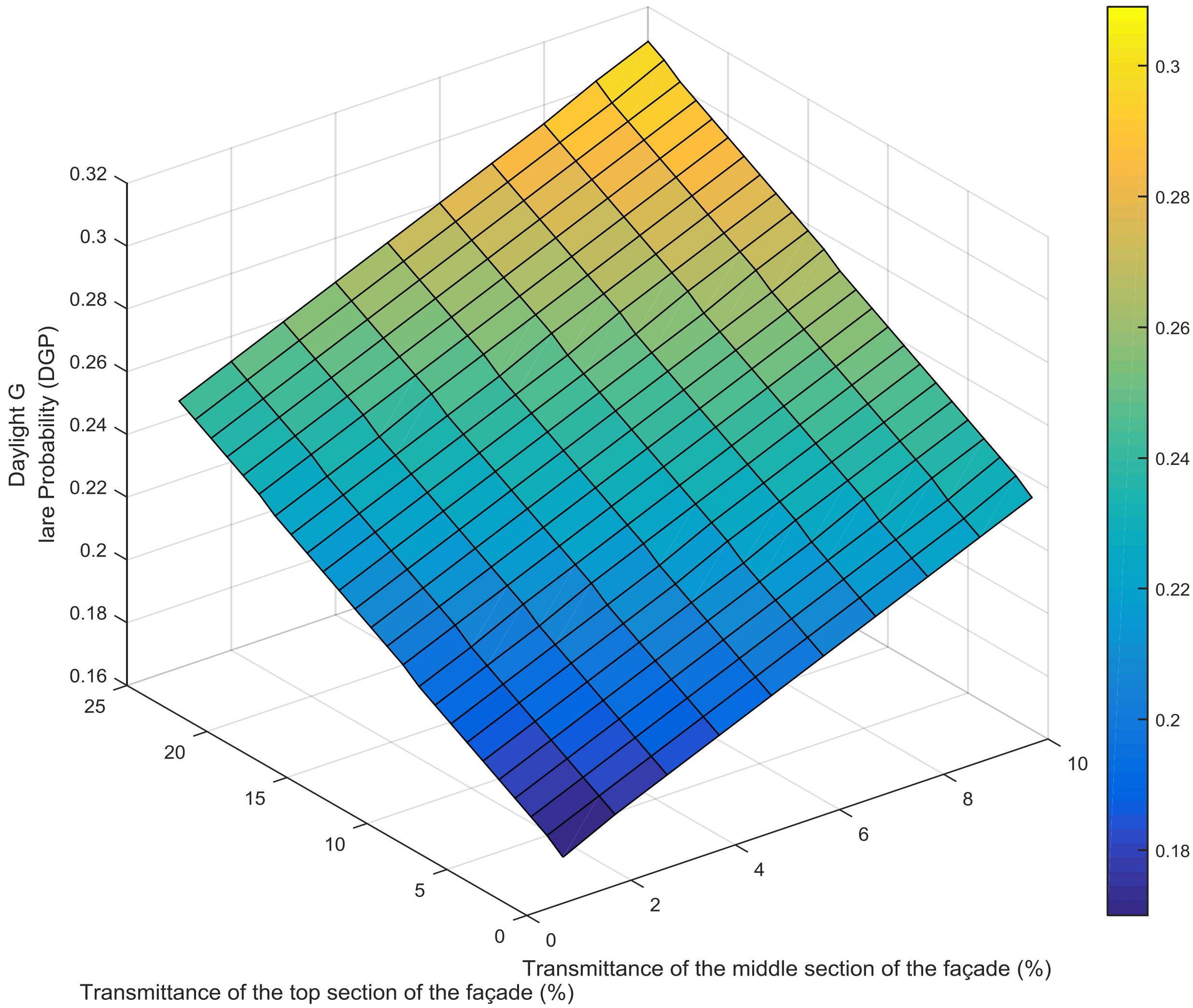


Figure 37: Calculated Daylight Glare Probability (DGP) for different shade transmittances on different sections of near-south façade (Considering near-east facade is opaque).

From the figures it can be clearly seen that, maintaining the privacy of the occupant with lower transmittance on the middle section of the façade, we can use the shade on the upper part with higher transmittance. Considering the shade transmittance of the middle section as 5%, the maximum limit for the shade transmittance of the top part of the façade can be 15% (Figure 35) to avoid glare.

For two other types of room geometry where only one façade is considered, it can be seen from the simulation that, the maximum limit of shade transmittance for the top section can be over 20%.

The DGP values for combination of shades with different transmittances are listed on appendix A, B and C.

Chapter 5: Conclusion

5.1 Conclusions

In this thesis, a generalized radiosity model is presented for a corner office having three section façade. The three section façade (Kapsis et al. 2015) consists of a lower part of the opaque (spandrel) panel, a middle section of clear glazing and an upper section of fritted glass. The model is verified with experimental measurements for a zone with up to two glazed 3-section facades with the possibility of two types of shades. The model was then extended to simulate various scenarios of interest. This model was designed specifically for a corner office, but can be easily adjusted to model any room in a perimeter zone of a building having its façade in any orientation.

A fourteen-surface room enclosure was considered to calculate the view factor of the room. The main input parameters for this model are i) the geographic location, ii) the room dimension, iii) the reflectance of the interior surfaces, glazing and shades, iv) the visible transmittance of the glazing and shades, and v) the sky condition.

To simulate the daylight distribution, five different configurations of shading position were implied. Those includes, no shade (0% shade i.e. fully open), 25% shade, 50% shade, 75% shade and fully closed means 100% shade.

The model was then verified by conducting a full scale experiment. For the experiment, a full-scale office room with windows on two adjacent façades was used. The experiment validates the model with all shading position for an overcast sky condition.

Comparing the simulated results and measured data for an overcast day, it is found that the simulation results on average differ 1-10% from the measured data which is an acceptable agreement, because of the shape, the interior surfaces, furniture inside the room and occupant's presence.

A model parametric study and the simulation results of the effect of floor reflectance, shade transmittance was also performed. The results suggest an 8-12% increase in work plane illuminance due to the variation of the floor reflectance from 5% to 50%.

Using low transmittance shades for privacy reasons in the middle section of a 3-section facade and a higher transmittance in the top section for deep daylight penetration allows for more flexibility in daylight design; some of the low sunlight can be blocked while providing overall increased daylight utilization and occupant privacy. The daylight glare probability (DGP) shows that, on a clear sky assuming all transmitted sunlight is diffused and with all shades are closed, high transmittance for the top section with maximum limit of 15% is ideal to avoid glare while keeping the privacy at the same time by installing a shade with 5% transmittance at the middle section.

DGP analysis also shows that, having windows on one façade can maximize the limit for shade transmittances on both sections of the façade.

5.2 Future Work

As the modern architectural building uses perimeter zones of the building for as the main path to allow daylights in the buildings, it has become more important to study the distribution of daylight in every corner of the buildings. It helps to reduce the electric energy for artificial lighting as well as contributes to design the HVAC system.

As this radiosity model is only validated for overcast sky condition, a further study can be done for the sunny day with diffuse and direct sunlight.

The top fritted part of the windows can be installed with semi-transparent photovoltaics to generate electricity while allowing some sunlight to the room, leaving the middle section for outdoor views or shaded as occupants need. The experiment can further be extended to various dimensionless design parameter ranges such as $\frac{W1}{W2}$, $\frac{W1}{H}$, $\frac{W2}{H}$, façade aspect ratio (such as $\frac{Y1}{H}$, $\frac{Y2}{H}$, $\frac{Y3}{H}$).

Finally, an improved control strategy can be development to reduce glare and excessive lighting and heat gain by controlling the shades to desired positions.

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Appendix A

Calculated Daylight Glare Probability (DGP) for different shade transmittances on different sections of both façade.

Upper	Lower (1%)	Lower (2%)	Lower (3%)	Lower (4%)	Lower (5%)	Lower (6%)	Lower (7%)	Lower (8%)	Lower (9%)	Lower (10%)
1%	0.177	0.189	0.201	0.212	0.224	0.236	0.248	0.26	0.271	0.283
2%	0.182	0.194	0.206	0.218	0.229	0.241	0.253	0.265	0.277	0.288
3%	0.187	0.199	0.211	0.223	0.235	0.246	0.258	0.27	0.282	0.293
4%	0.193	0.204	0.216	0.228	0.24	0.251	0.263	0.275	0.287	0.299
5%	0.198	0.209	0.221	0.233	0.245	0.257	0.268	0.28	0.292	0.304
6%	0.203	0.215	0.226	0.238	0.25	0.262	0.274	0.285	0.297	0.309
7%	0.208	0.22	0.232	0.243	0.255	0.267	0.279	0.29	0.302	0.314
8%	0.213	0.225	0.237	0.248	0.26	0.272	0.284	0.296	0.307	0.319
9%	0.218	0.23	0.242	0.254	0.265	0.277	0.289	0.301	0.312	0.324
10%	0.224	0.235	0.247	0.259	0.271	0.282	0.294	0.306	0.318	0.329
11%	0.229	0.24	0.252	0.264	0.276	0.287	0.299	0.311	0.323	0.335
12%	0.234	0.246	0.257	0.269	0.281	0.293	0.304	0.316	0.328	0.34
13%	0.239	0.251	0.262	0.274	0.286	0.298	0.31	0.321	0.333	0.345
14%	0.244	0.256	0.268	0.279	0.291	0.303	0.315	0.326	0.338	0.35
15%	0.249	0.261	0.273	0.284	0.296	0.308	0.32	0.332	0.343	0.355
16%	0.254	0.266	0.278	0.29	0.301	0.313	0.325	0.337	0.348	0.36
17%	0.26	0.271	0.283	0.295	0.307	0.318	0.33	0.342	0.354	0.365
18%	0.265	0.276	0.288	0.3	0.312	0.323	0.335	0.347	0.359	0.371
19%	0.27	0.282	0.293	0.305	0.317	0.329	0.34	0.352	0.364	0.376
20%	0.275	0.287	0.298	0.31	0.322	0.334	0.346	0.357	0.369	0.381
21%	0.28	0.292	0.304	0.315	0.327	0.339	0.351	0.362	0.374	0.386
22%	0.285	0.297	0.309	0.321	0.332	0.344	0.356	0.368	0.379	0.391
23%	0.29	0.302	0.314	0.326	0.337	0.349	0.361	0.373	0.385	0.396
24%	0.296	0.307	0.319	0.331	0.343	0.354	0.366	0.378	0.39	0.401
25%	0.301	0.312	0.324	0.336	0.348	0.359	0.371	0.383	0.395	0.407

Appendix B

Calculated Daylight Glare Probability (DGP) for different shade transmittances on different sections of east façade (Considering south facade is opaque).

Upper	Lower (1%)	Lower (2%)	Lower (3%)	Lower (4%)	Lower (5%)	Lower (6%)	Lower (7%)	Lower (8%)	Lower (9%)	Lower (10%)
1%	0.177	0.182	0.187	0.192	0.197	0.202	0.206	0.211	0.216	0.22
2%	0.179	0.183	0.188	0.193	0.198	0.203	0.208	0.213	0.217	0.222
3%	0.181	0.185	0.19	0.195	0.2	0.205	0.21	0.214	0.219	0.224
4%	0.183	0.187	0.192	0.197	0.202	0.207	0.211	0.216	0.221	0.226
5%	0.186	0.19	0.194	0.199	0.204	0.208	0.213	0.218	0.223	0.228
6%	0.188	0.192	0.196	0.201	0.205	0.21	0.215	0.22	0.225	0.229
7%	0.191	0.194	0.198	0.203	0.207	0.212	0.217	0.222	0.227	0.231
8%	0.193	0.196	0.2	0.205	0.209	0.214	0.219	0.224	0.228	0.233
9%	0.195	0.199	0.203	0.207	0.212	0.216	0.221	0.226	0.23	0.235
10%	0.197	0.201	0.205	0.209	0.214	0.218	0.223	0.228	0.232	0.237
11%	0.199	0.203	0.207	0.211	0.216	0.22	0.225	0.23	0.234	0.239
12%	0.202	0.205	0.209	0.213	0.218	0.222	0.227	0.232	0.236	0.241
13%	0.204	0.207	0.211	0.216	0.22	0.225	0.229	0.234	0.238	0.243
14%	0.206	0.21	0.214	0.218	0.222	0.227	0.231	0.236	0.241	0.245
15%	0.208	0.212	0.216	0.22	0.224	0.229	0.233	0.238	0.243	0.247
16%	0.21	0.214	0.218	0.222	0.226	0.231	0.235	0.24	0.245	0.249
17%	0.212	0.216	0.22	0.224	0.229	0.233	0.238	0.242	0.247	0.251
18%	0.214	0.218	0.222	0.226	0.231	0.235	0.24	0.244	0.249	0.253
19%	0.216	0.22	0.224	0.229	0.233	0.237	0.242	0.246	0.251	0.255
20%	0.219	0.222	0.227	0.231	0.235	0.239	0.244	0.248	0.253	0.258
21%	0.221	0.225	0.229	0.233	0.237	0.242	0.246	0.25	0.255	0.26
22%	0.223	0.227	0.231	0.235	0.239	0.244	0.248	0.253	0.257	0.262
23%	0.225	0.229	0.233	0.237	0.241	0.246	0.25	0.255	0.259	0.264
24%	0.227	0.231	0.235	0.239	0.244	0.248	0.252	0.257	0.261	0.266
25%	0.229	0.233	0.237	0.241	0.246	0.25	0.254	0.259	0.263	0.268

Appendix C

Calculated Daylight Glare Probability (DGP) for different shade transmittances on different sections of south façade (Considering east facade is opaque).

Upper	Lower (1%)	Lower (2%)	Lower (3%)	Lower (4%)	Lower (5%)	Lower (6%)	Lower (7%)	Lower (8%)	Lower (9%)	Lower (10%)
1%	0.17	0.178	0.185	0.192	0.199	0.206	0.213	0.22	0.227	0.234
2%	0.174	0.181	0.188	0.195	0.202	0.209	0.216	0.223	0.23	0.238
3%	0.177	0.184	0.191	0.198	0.205	0.212	0.219	0.226	0.233	0.241
4%	0.18	0.187	0.194	0.201	0.208	0.215	0.222	0.229	0.237	0.244
5%	0.183	0.19	0.197	0.204	0.211	0.218	0.225	0.233	0.24	0.247
6%	0.186	0.193	0.2	0.207	0.214	0.221	0.229	0.236	0.243	0.25
7%	0.189	0.196	0.203	0.21	0.217	0.225	0.232	0.239	0.246	0.253
8%	0.192	0.199	0.206	0.213	0.22	0.228	0.235	0.242	0.249	0.256
9%	0.195	0.202	0.209	0.217	0.224	0.231	0.238	0.245	0.252	0.259
10%	0.198	0.205	0.213	0.22	0.227	0.234	0.241	0.248	0.255	0.262
11%	0.202	0.209	0.216	0.223	0.23	0.237	0.244	0.251	0.258	0.265
12%	0.205	0.212	0.219	0.226	0.233	0.24	0.247	0.254	0.261	0.268
13%	0.208	0.215	0.222	0.229	0.236	0.243	0.25	0.257	0.264	0.271
14%	0.211	0.218	0.225	0.232	0.239	0.246	0.253	0.26	0.267	0.275
15%	0.214	0.221	0.228	0.235	0.242	0.249	0.256	0.263	0.271	0.278
16%	0.217	0.224	0.231	0.238	0.245	0.252	0.259	0.267	0.274	0.281
17%	0.22	0.227	0.234	0.241	0.248	0.255	0.263	0.27	0.277	0.284
18%	0.223	0.23	0.237	0.244	0.251	0.259	0.266	0.273	0.28	0.287
19%	0.226	0.233	0.24	0.248	0.255	0.262	0.269	0.276	0.283	0.29
20%	0.23	0.237	0.244	0.251	0.258	0.265	0.272	0.279	0.286	0.293
21%	0.233	0.24	0.247	0.254	0.261	0.268	0.275	0.282	0.289	0.296
22%	0.236	0.243	0.25	0.257	0.264	0.271	0.278	0.285	0.292	0.299
23%	0.239	0.246	0.253	0.26	0.267	0.274	0.281	0.288	0.295	0.302
24%	0.242	0.249	0.256	0.263	0.27	0.277	0.284	0.291	0.298	0.306
25%	0.245	0.252	0.259	0.266	0.273	0.28	0.287	0.294	0.302	0.309

Appendix D

Radiosity Simulation Model

A RADIOSITY MODEL OF A CORNER OFFICE ROOM

Parameters :

Location :

Latitude: $L := 45.5 \cdot deg$

Local standard time meridian: $STM := 75 \cdot deg$

Longitude: $LNG := 74 \cdot deg$

Window surface azimuth: $\psi_s := -20 \cdot deg$

The surface tilt angle of the window is: $\beta_w := 90deg$

$\psi_e := -110 \cdot deg$

Representative days

$$\begin{pmatrix} \text{Equinox} \\ \text{Summer\_Solstice} \\ \text{Winter\_Solstice} \\ \text{Winter\_Sunny} \\ \text{Winter\_Overcast} \\ \text{Summer\_Sunny} \\ \text{Summer\_Overcast} \end{pmatrix} := \begin{pmatrix} 79 \\ 172 \\ 355 \\ 13 \\ 39 \\ 243 \\ 170 \end{pmatrix}$$

Selected day

$n := 161$ ...... June 09, 2015

Solar geometry

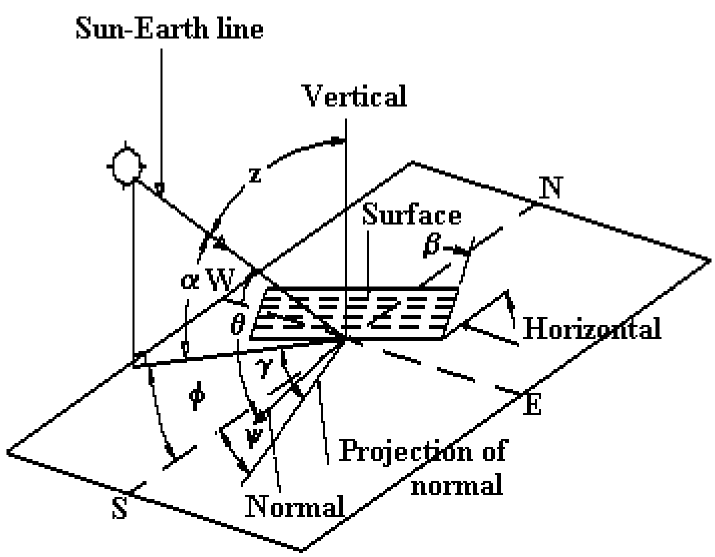


Fig.1 Solar geometry (Athienitis, 1998)

Equation of time (ET):

$$ET(n) := \left(9.87\cdot\sin\left(4\cdot\pi\cdot\frac{n-81}{364}\right) - 7.53\cdot\cos\left(2\cdot\pi\cdot\frac{n-81}{364}\right) - 1.5\cdot\sin\left(2\cdot\pi\cdot\frac{n-81}{364}\right)\right)\cdot min$$

Apparent Solar Time (AST):

$$AST(n,t) := t\cdot hr + ET(n) + \frac{(STM - LNG)\cdot hr}{15\cdot deg} \qquad s(n,t) := AST(n,t) - 12\cdot hr$$

Solar declination (δ):

$$\delta(n) := 23.45\cdot deg\cdot\sin\left(360\cdot\frac{284+n}{365}\cdot deg\right)$$

Hour angle (H):

$$H(n,t) := (AST(n,t) - 12\cdot hr)\cdot\left(15\cdot\frac{deg}{hr}\right)$$

Sunset hour angle (h_s):

$$h_s(n) := (\mathrm{acos}(-\tan(L)\cdot\tan(\delta(n))))$$

Sunset time (t_s):

$$t_s(n) := h_s(n)\cdot\frac{hr}{15\cdot deg}$$

Surface sunset time (t_{ss}):

$$t_{ss}(n) := \min\left(\left(h_s(n)\quad \mathrm{acos}\left(-\tan\left(L-\beta_w\right)\cdot\tan(\delta(n))\right)\right)\right)\cdot\frac{hr}{15\cdot deg}$$

Solar altitude (α_s):

$$\alpha_s(n,t) := \begin{cases} \mathrm{asin}\begin{bmatrix}(\cos(L))\cdot\cos(\delta(n))\cdot\cos(H(n,t)) \;\ldots \\ +(\sin(L))\cdot\sin(\delta(n))\end{bmatrix} & \text{if } \mathrm{asin}\begin{bmatrix}(\cos(L))\cdot\cos(\delta(n))\cdot\cos(H(n,t)) \;\ldots \\ +\sin(L)\cdot\sin(\delta(n))\end{bmatrix} > 0\cdot deg \\ 0\cdot deg & \text{otherwise}\end{cases}$$

Solar azimuth (ϕ):

$$\phi(n,t) := \mathrm{acos}\left(\frac{\sin\left(\alpha_s(n,t)\right)\cdot\sin(L) - \sin(\delta(n))}{\cos\left(\alpha_s(n,t)\right)\cdot\cos(L)}\right)\cdot\frac{H(n,t)}{|H(n,t)|}$$

Surface solar azimuth for south window (γ_s):

$$\gamma_s(n,t) := \phi(n,t) - \psi_s$$

Surface solar azimuth for east window (γ_e):

$$\gamma_e(n,t) := \phi(n,t) - \psi_e$$

Zenith angle (Z):

$$Z(n,t) := \mathrm{acos}((\cos(L)\cdot\cos(\delta(n))\cdot\cos(H(n,t)) + \sin(L)\cdot\sin(\delta(n))))$$

Angle of incidence for south window (θ_s):

$$\theta\theta_s(n,t) := \cos(\alpha_s(n,t))\cdot\cos(|\gamma_s(n,t)|)\cdot\sin(\beta_w) + \sin(\alpha_s(n,t))\cdot\cos(\beta_w)$$

$$\theta_s(n,t) := \operatorname{acos}\left(\frac{\theta\theta_s(n,t) + |\theta\theta_s(n,t)|}{2}\right)$$

Angle of incidence for east window (θ_s):

$$\theta\theta_e(n,t) := \cos(\alpha_s(n,t))\cdot\cos(|\gamma_e(n,t)|)\cdot\sin(\beta_w) + \sin(\alpha_s(n,t))\cdot\cos(\beta_w)$$

$$\theta_e(n,t) := \operatorname{acos}\left(\frac{\theta\theta_e(n,t) + |\theta\theta_e(n,t)|}{2}\right)$$

Profile angle for south window (d_s):

$$d_s(n,t) := \operatorname{atan}\left(\frac{\tan(\alpha_s(n,t))}{\cos(\gamma_s(n,t))}\right)$$

Profile angle for east window (d_e):

$$d_e(n,t) := \operatorname{atan}\left(\frac{\tan(\alpha_s(n,t))}{\cos(\gamma_e(n,t))}\right)$$

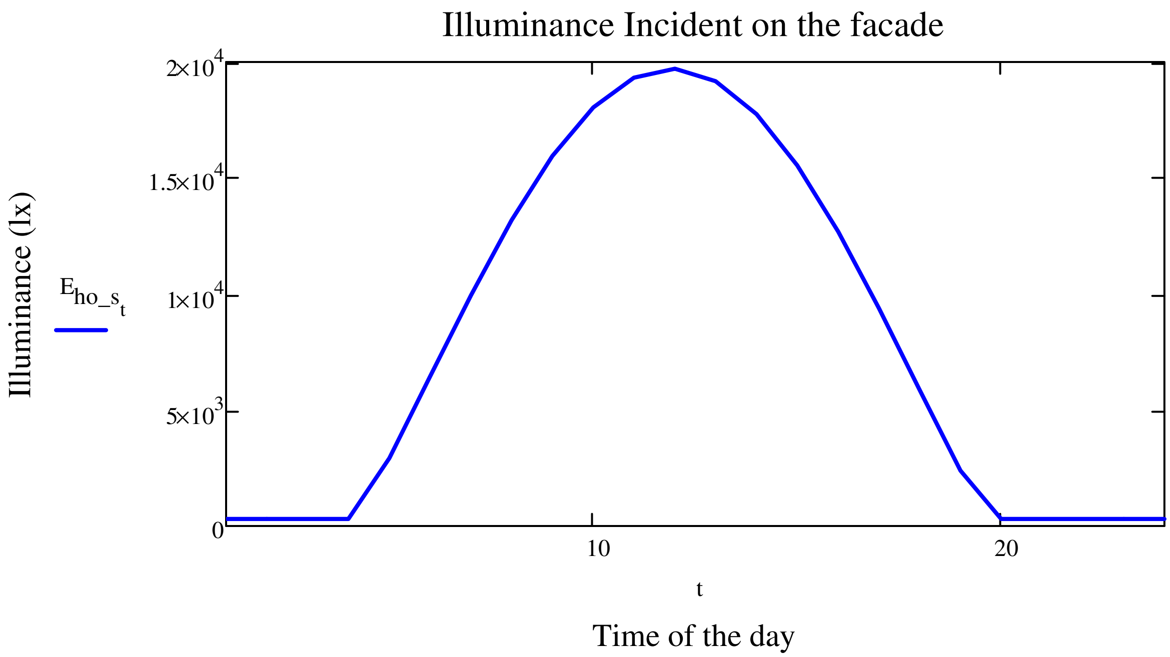
CIE Overcast Day

$t := 1, 2 .. 24$

$L_{zs_t} := 123 + 8600 \cdot \sin(\alpha_s(n, t))$

$L_{sky\_s_t} := \frac{L_{zs_t}}{3} \cdot (1 + 2 \cdot \cos(\theta_s(n, t)))$

$E_{ho\_s_t} := \frac{7 \cdot \pi}{9} \cdot L_{zs_t} \cdot lx$



$E_{d\_south_t} := E_{ho\_s_t}$

$E_{d\_east_t} := E_{ho\_s_t}$

Visible transmittance of a double glazing window (Lower Facade):

$Sd\_pos\_south := 0$ $\quad$ $Sd\_pos\_east := 25$ .... Select shade position (0%, 25%, 50%, 75%, 100%)

$\tau_{shade} := 0.05$

$$\tau_{s\_lower\_l_t} := \begin{cases} \tau_{shade} \cdot 0.69 & \text{if } Sd\_pos\_south = 100 \\ 0.69 & \text{otherwise} \end{cases}$$

$$\tau_{e\_lower\_l_t} := \begin{cases} \tau_{shade} \cdot 0.69 & \text{if } Sd\_pos\_east = 100 \\ 0.69 & \text{otherwise} \end{cases}$$

$$\tau_{s\_lower\_u_t} := \begin{cases} \tau_{shade} \cdot 0.69 & \text{if } Sd\_pos\_south = 100 \vee Sd\_pos\_south = 75 \\ 0.69 & \text{otherwise} \end{cases}$$

$$\tau_{e\_lower\_u_t} := \begin{cases} \tau_{shade} \cdot 0.69 & \text{if } Sd\_pos\_east = 100 \vee Sd\_pos\_east = 75 \\ 0.69 & \text{otherwise} \end{cases}$$

$$\tau_{s\_upper\_l_t} := \begin{cases} \tau_{shade} \cdot 0.48 & \text{if } Sd\_pos\_south = 100 \vee Sd\_pos\_south = 75 \vee Sd\_pos\_south = 50 \\ 0.48 & \text{otherwise} \end{cases}$$

$$\tau_{e\_upper\_l_t} := \begin{cases} \tau_{shade} \cdot 0.48 & \text{if } Sd\_pos\_east = 100 \vee Sd\_pos\_east = 75 \vee Sd\_pos\_east = 50 \\ 0.48 & \text{otherwise} \end{cases}$$

$$\tau_{s\_upper\_u_t} := \begin{cases} \tau_{shade} \cdot 0.48 & \text{if } Sd\_pos\_south = 100 \vee Sd\_pos\_south = 75 \vee Sd\_pos\_south = 50 \vee Sd\_pos\_south = 25 \\ 0.48 & \text{otherwise} \end{cases}$$

$$\tau_{e\_upper\_u_t} := \begin{cases} \tau_{shade} \cdot 0.48 & \text{if } Sd\_pos\_east = 100 \vee Sd\_pos\_east = 75 \vee Sd\_pos\_east = 50 \vee Sd\_pos\_east = 25 \\ 0.48 & \text{otherwise} \end{cases}$$

$$\tau_t := \begin{pmatrix} \tau_{s\_upper\_u_t} \\ \tau_{s\_upper\_l_t} \\ \tau_{s\_lower\_u_t} \\ \tau_{s\_lower\_l_t} \\ \tau_{e\_upper\_u_t} \\ \tau_{e\_upper\_l_t} \\ \tau_{e\_lower\_u_t} \\ \tau_{e\_lower\_l_t} \end{pmatrix}$$

Luminous exitance (For Diffused Daylighting)

$E_{facade\_s\_lower\_diff\_u_t} := \tau_{s\_lower\_u_t} \cdot E_{d\_south_t}$

$E_{facade\_e\_lower\_diff\_u_t} := \tau_{e\_lower\_u_t} \cdot E_{d\_east_t}$

$E_{facade\_s\_upper\_diff\_u_t} := \tau_{s\_upper\_u_t} \cdot E_{d\_south_t}$

$E_{facade\_e\_upper\_diff\_u_t} := \tau_{e\_upper\_u_t} \cdot E_{d\_east_t}$

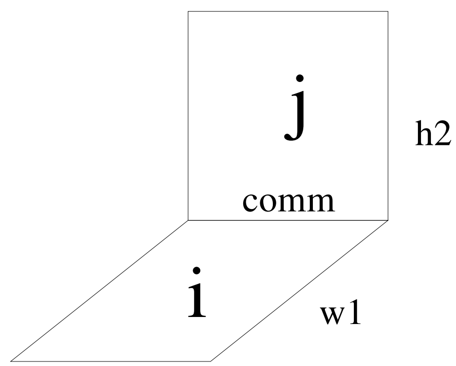
$E_{facade\_s\_lower\_diff\_l_t} := \tau_{s\_lower\_l_t} \cdot E_{d\_south_t}$

$E_{facade\_e\_lower\_diff\_l_t} := \tau_{e\_lower\_l_t} \cdot E_{d\_east_t}$

$E_{facade\_s\_upper\_diff\_l_t} := \tau_{s\_upper\_l_t} \cdot E_{d\_south_t}$

$E_{facade\_e\_upper\_diff\_l_t} := \tau_{e\_upper\_l_t} \cdot E_{d\_east_t}$

View Factors Between Internal Surfaces



Define the following intermediate variables for calculating view factor from surface i to surface j:

$w = \frac{w1}{comm}$ $\qquad$ $h = \frac{h2}{comm}$

$A(h,w) := h^2 + w^2$ $\qquad$ $B(w) := 1 + w^2$

$C(h) := 1 + h^2$ $\qquad$ $D(h,w) := 1 + (h^2 + w^2)$

$E(w) := w^2$ $\qquad$ $G(h) := h^2$

View factor Fij from i to j:

$$Fij(w,h) := \frac{\left(w \cdot atan\left(\frac{1.}{w}\right) + h \cdot atan\left(\frac{1}{h}\right)\right) - \sqrt{A(h,w)} \cdot atan\left(\frac{1}{\sqrt{A(h,w)}}\right) \ldots + 0.25 \cdot \ln\left[\left(\frac{E(w) \cdot D(h,w)}{B(w) \cdot A(h,w)}\right)^{E(w)} \cdot \left(\frac{G(h) \cdot D(h,w)}{C(h) \cdot A(h,w)}\right)^{G(h)} \cdot \frac{B(w) \cdot C(h)}{D(h,w)}\right]}{\pi \cdot w}$$

The other view factors between the room surfaces are calculated by applying the following principles:

1. Reciprocity: $A_i \cdot F_{i,j} = A_j \cdot F_{j,i}$

2. Symmetry, e.g.: $F_{7,5} = F_{7,8}$

3. Energy conservation: $\sum_j F_{i,j} = 1$ (for any surface i)

$W_{rm} := 4.5 \cdot m$ ...width of room (along facade)

$D_{rm} := 3.8 \cdot m$ ...depth of room

$H_{rm} := 3.5 \cdot m$ ...height of room

$H_{sp} := 1m$ ...height of spandrel (distance from window to floor)

$H_{facade\_s\_lower} := 1.25 \cdot m$

$H_{facade\_s\_upper} := 1.25 \cdot m$

$H_{facade\_e\_lower} := 1.25 \cdot m$

$H_{facade\_e\_upper} := 1.25 \cdot m$

$$H_{shade25} := \frac{H_{facade\_s\_upper}}{2}$$

$H_{shade50} := H_{facade\_s\_upper}$

$$H_{shade75} := H_{facade\_s\_upper} + \frac{H_{facade\_s\_lower}}{2}$$

$H_{shade100} := H_{facade\_s\_upper} + H_{facade\_s\_lower}$

<u>Area of room surfaces:</u>

$A_1 := D_{rm} \cdot H_{rm}$

$A_2 := W_{rm} \cdot H_{rm}$

$A_3 := W_{rm} \cdot D_{rm}$

$A_4 := A_3$

$A_5 := H_{sp} \cdot W_{rm}$

$$A_6 := W_{rm} \cdot \frac{H_{facade\_s\_lower}}{2}$$

$A_7 := A_6$

$$A_8 := W_{rm} \cdot \frac{H_{facade\_s\_upper}}{2}$$

$A_9 := A_8$

$A_{10} := H_{sp} \cdot D_{rm}$

$$A_{11} := D_{rm} \cdot \frac{H_{facade\_e\_lower}}{2}$$

$A_{12} := A_{11}$

$$A_{13} := D_{rm} \cdot \frac{H_{facade\_e\_upper}}{2}$$

$A_{14} := A_{13}$

$A_{15} := W_{rm} \cdot H_{rm}$

$A_{16} := D_{rm} \cdot H_{rm}$

$\rho_1 := 0.7$ $\rho_4 := 0.8$

$\rho_2 := 0.7$ $\rho_5 := 0.7$

$\rho_3 := 0.05$ $\rho_{10} := 0.7$

$$\rho_6 := \begin{cases} 0.55 & \text{if } Sd\_pos\_south = 100 \\ 0.1 & \text{otherwise} \end{cases}$$

$$\rho_7 := \begin{cases} 0.55 & \text{if } Sd\_pos\_south = 100 \lor Sd\_pos\_south = 75 \\ 0.1 & \text{otherwise} \end{cases}$$

$$\rho_8 := \begin{cases} 0.55 & \text{if } Sd\_pos\_south = 100 \lor Sd\_pos\_south = 75 \lor Sd\_pos\_south = 50 \\ 0.1 & \text{otherwise} \end{cases}$$

$$\rho_9 := \begin{cases} 0.55 & \text{if } Sd\_pos\_south = 100 \lor Sd\_pos\_south = 75 \lor Sd\_pos\_south = 50 \lor Sd\_pos\_south = 25 \\ 0.1 & \text{otherwise} \end{cases}$$

$$\rho_{11} := \begin{cases} 0.55 & \text{if } Sd\_pos\_east = 100 \\ 0.1 & \text{otherwise} \end{cases}$$

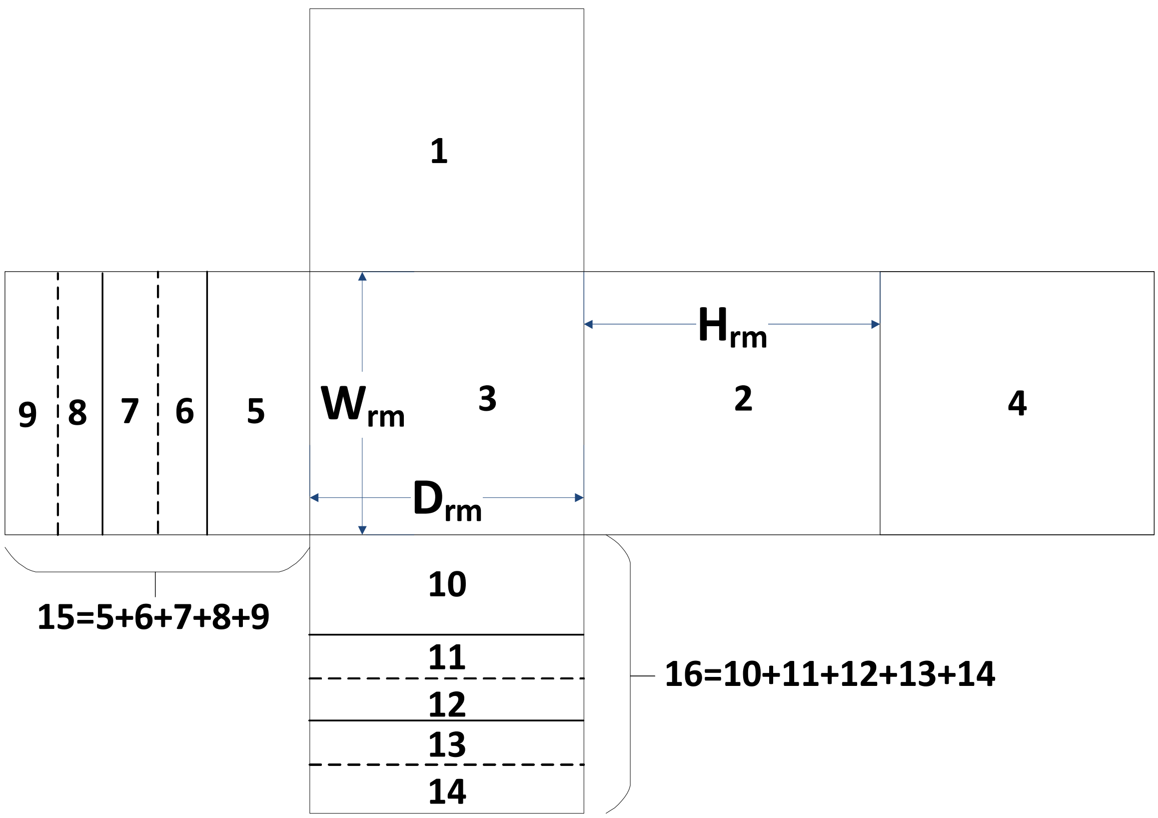
$$\rho_{12} := \begin{cases} 0.55 & \text{if } Sd\_pos\_east = 100 \lor Sd\_pos\_east = 75 \\ 0.1 & \text{otherwise} \end{cases}$$

$$\rho_{13} := \begin{cases} 0.55 & \text{if } Sd\_pos\_east = 100 \lor Sd\_pos\_east = 75 \lor Sd\_pos\_east = 50 \\ 0.1 & \text{otherwise} \end{cases}$$

$$\rho_{14} := \begin{cases} 0.55 & \text{if } Sd\_pos\_east = 100 \lor Sd\_pos\_east = 75 \lor Sd\_pos\_east = 50 \lor Sd\_pos\_east = 25 \\ 0.1 & \text{otherwise} \end{cases}$$

$$\rho := \begin{pmatrix} \rho_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \rho_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \rho_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \rho_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_8 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_9 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_{10} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_{12} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_{13} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_{14} \end{pmatrix}$$

Calculation of view factors:



$w1 := H_{rm}$ $\quad h2 := D_{rm}$ $\quad comm := W_{rm}$

$w := \frac{w1}{comm}$ $\quad h := \frac{h2}{comm}$

$F_{23} := Fij(w,h)$ $\quad F_{32} := A_2 \cdot \frac{F_{23}}{A_3}$

$F_{24} := F_{23}$ $\quad F_{42} := F_{32}$ $\quad F_{4\_15} := F_{42}$

$F_{15\_4} := F_{23}$ $\quad F_{15\_3} := F_{23}$ $\quad F_{3\_15} := F_{42}$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := H_{rm}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{2\_16} := Fij(w,h)$ $F_{16\_2} := A_2 \cdot \frac{F_{2\_16}}{A_{16}}$ $F_{21} := F_{2\_16}$

$F_{12} := F_{16\_2}$ $F_{15\_16} := F_{21}$ $F_{16\_15} := F_{12}$

$F_{15\_1} := F_{21}$ $F_{1\_15} := F_{12}$

$w1 := H_{rm}$ $h2 := W_{rm}$ $comm := D_{rm}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{13} := Fij(w,h)$ $F_{31} := A_1 \cdot \frac{F_{13}}{A_3}$ $F_{16\_3} := F_{13}$

$F_{3\_16} := F_{31}$ $F_{4\_16} := F_{31}$ $F_{16\_4} := F_{13}$

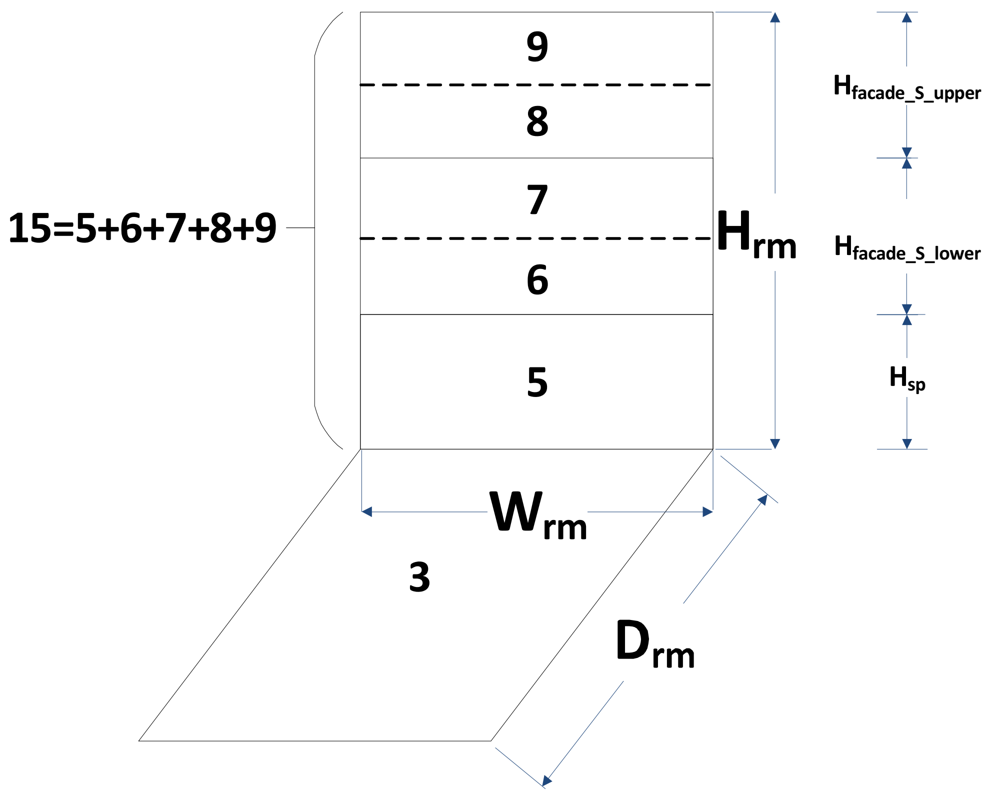
$F_{14} := F_{13}$ $F_{41} := F_{31}$

$F_{15\_2} := 1 - 2 \cdot F_{15\_1} - 2 \cdot F_{15\_4}$ $F_{2\_15} := F_{15\_2}$

$F_{16\_1} := 1 - 2 \cdot F_{16\_4} - 2 \cdot F_{16\_2}$ $F_{1\_16} := F_{16\_1}$

$F_{43} := 1 - 2 \cdot F_{42} - 2 \cdot F_{41}$ $F_{34} := F_{43}$

View factors between surfaces 5,6,7,8,9 and surface 3.



$A_{56} := W_{rm} \cdot \left(H_{sp} + H_{facade\_s\_lower}\right)$

$w1 := D_{rm}$ $h2 := H_{sp}$ $comm := W_{rm}$

$w := \dfrac{w1}{comm}$ $h := \dfrac{h2}{comm}$

$F_{35} := Fij(w, h)$ $F_{53} := A_3 \cdot \dfrac{F_{35}}{A_5}$

$w1 := D_{rm}$ $h2 := H_{sp} + \dfrac{H_{facade\_s\_lower}}{2}$ $comm := W_{rm}$

$w := \dfrac{w1}{comm}$ $h := \dfrac{h2}{comm}$

$F_{3\_56} := Fij(w, h)$

$F_{63} := \left(F_{3\_56} - F_{35}\right) \cdot \dfrac{A_3}{A_6}$ $F_{36} := A_6 \cdot \dfrac{F_{63}}{A_3}$

$w1 := D_{rm}$ $h2 := H_{sp} + H_{facade\_s\_lower}$ $comm := W_{rm}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{3\_567} := Fij(w,h)$

$F_{73} := (F_{3\_567} - F_{3\_56}) \cdot \frac{A_3}{A_7}$ $F_{37} := A_7 \cdot \frac{F_{73}}{A_3}$

$w1 := D_{rm}$ $h2 := H_{sp} + H_{facade\_s\_lower} + \frac{H_{facade\_s\_upper}}{2}$ $comm := W_{rm}$

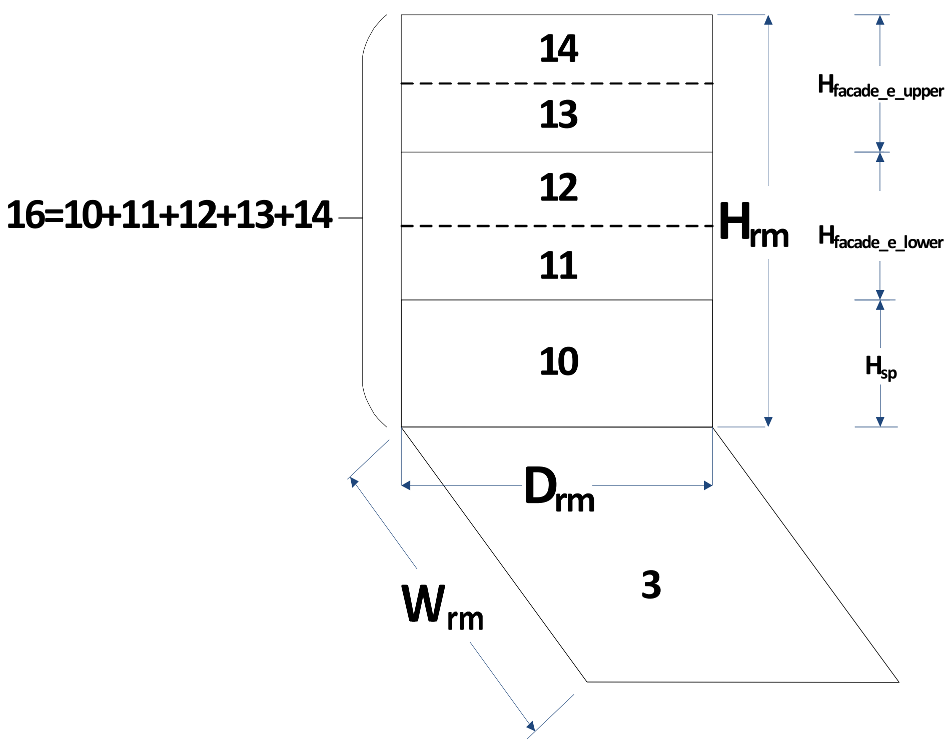
$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{3\_5678} := Fij(w,h)$

$F_{83} := (F_{3\_5678} - F_{3\_567}) \cdot \frac{A_3}{A_8}$ $F_{38} := A_8 \cdot \frac{F_{83}}{A_3}$

$F_{93} := (F_{3\_15} - F_{3\_5678}) \cdot \frac{A_3}{A_8}$ $F_{39} := A_9 \cdot \frac{F_{93}}{A_3}$

View factors between surfaces 10,11,12,13,14 and surface 3.



$$A_{9\_10} := D_{rm} \cdot \left(H_{sp} + H_{facade\_e\_lower}\right)$$

$w1 := W_{rm}$ $\quad h2 := H_{sp}$ $\quad comm := D_{rm}$

$w := \dfrac{w1}{comm}$ $\quad h := \dfrac{h2}{comm}$

$F_{3\_10} := Fij(w,h)$ $\quad F_{10\_3} := A_3 \cdot \dfrac{F_{3\_10}}{A_{10}}$

$w1 := W_{rm}$ $\quad h2 := H_{sp} + \dfrac{H_{facade\_e\_lower}}{2}$ $\quad comm := D_{rm}$

$w := \dfrac{w1}{comm}$ $\quad h := \dfrac{h2}{comm}$

$F_{3\_10\_11} := Fij(w,h)$

$F_{11\_3} := \left(F_{3\_10\_11} - F_{3\_10}\right) \cdot \dfrac{A_3}{A_{11}}$ $\quad F_{3\_11} := A_{11} \cdot \dfrac{F_{11\_3}}{A_3}$

$w1 := W_{rm}$ $\quad h2 := H_{sp} + H_{facade\_e\_lower}$ $\quad comm := D_{rm}$

$w := \dfrac{w1}{comm}$ $\quad h := \dfrac{h2}{comm}$

$F_{3\_10\_11\_12} := Fij(w,h)$

$F_{12\_3} := \left(F_{3\_10\_11\_12} - F_{3\_10\_11}\right) \cdot \dfrac{A_3}{A_{12}}$ $\quad F_{3\_12} := A_{12} \cdot \dfrac{F_{12\_3}}{A_3}$

$w1 := W_{rm}$ $\quad h2 := H_{sp} + H_{facade\_e\_lower} + \dfrac{H_{facade\_e\_upper}}{2}$ $\quad comm := D_{rm}$

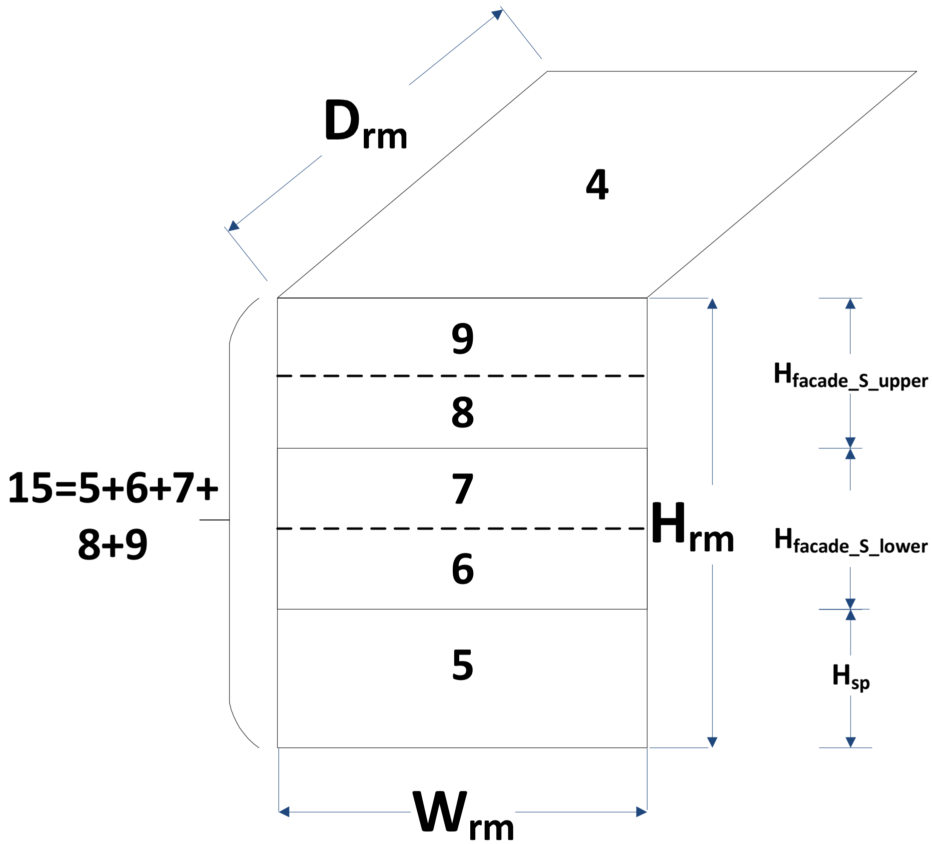
$w := \dfrac{w1}{comm}$ $\quad h := \dfrac{h2}{comm}$

$F_{3\_10\_11\_12\_13} := Fij(w,h)$

$F_{13\_3} := \left(F_{3\_10\_11\_12\_13} - F_{3\_10\_11\_12}\right) \cdot \dfrac{A_3}{A_{13}}$ $\quad F_{3\_13} := A_{13} \cdot \dfrac{F_{13\_3}}{A_3}$

$F_{14\_3} := (F_{3\_16} - F_{3\_10\_11\_12\_13}) \cdot \frac{A_3}{A_{14}}$ $\qquad$ $F_{3\_14} := A_{14} \cdot \frac{F_{14\_3}}{A_3}$

View factors between surfaces 5,6,7,8,9 and surface 4.



$A_{76} := W_{rm} \cdot (H_{facade\_s\_upper} + H_{facade\_s\_lower})$

$w1 := D_{rm}$ $\qquad$ $h2 := \frac{H_{facade\_s\_upper}}{2}$ $\qquad$ $comm := W_{rm}$

$w := \frac{w1}{comm}$ $\qquad$ $h := \frac{h2}{comm}$

$F_{49} := Fij(w, h)$ $\qquad$ $F_{94} := A_4 \cdot \frac{F_{49}}{A_9}$

$w1 := D_{rm}$ $\qquad$ $h2 := H_{facade\_s\_upper}$ $\qquad$ $comm := W_{rm}$

$w := \frac{w1}{comm}$ $\qquad$ $h := \frac{h2}{comm}$

$F_{4\_98} := Fij(w,h)$

$F_{84} := \left(F_{4\_98} - F_{49}\right)\cdot\frac{A_4}{A_8}$ $\quad$ $F_{48} := A_8\cdot\frac{F_{84}}{A_4}$

$w1 := D_{rm}$ $\quad$ $h2 := H_{facade\_s\_upper} + \frac{H_{facade\_s\_lower}}{2}$ $\quad$ $comm := W_{rm}$

$w := \frac{w1}{comm}$ $\quad$ $h := \frac{h2}{comm}$

$F_{4\_987} := Fij(w,h)$

$F_{74} := \left(F_{4\_987} - F_{4\_98}\right)\cdot\frac{A_4}{A_7}$ $\quad$ $F_{47} := A_7\cdot\frac{F_{74}}{A_4}$

$w1 := D_{rm}$ $\quad$ $h2 := H_{facade\_s\_upper} + H_{facade\_s\_lower}$ $\quad$ $comm := W_{rm}$

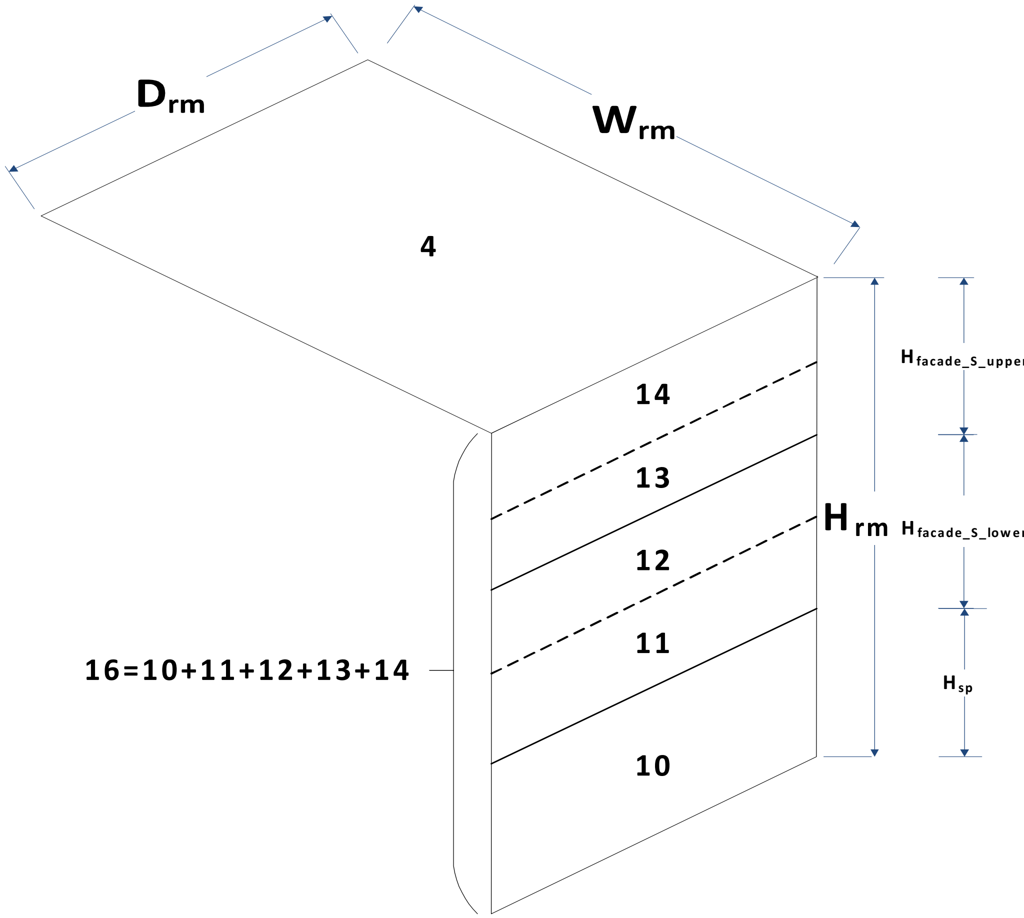
$w := \frac{w1}{comm}$ $\quad$ $h := \frac{h2}{comm}$

$F_{4\_9876} := Fij(w,h)$

$F_{64} := \left(F_{4\_9876} - F_{4\_987}\right)\cdot\frac{A_4}{A_6}$ $\quad$ $F_{46} := A_6\cdot\frac{F_{64}}{A_4}$

$F_{54} := \left(F_{4\_15} - F_{4\_9876}\right)\cdot\frac{A_4}{A_5}$ $\quad$ $F_{45} := A_5\cdot\frac{F_{54}}{A_4}$

View factors between surfaces 10,11,12,13,14 and surface 4.



$A_{10\_11} := D_{rm} \cdot \left(H_{facade\_e\_upper} + H_{facade\_e\_lower}\right)$

$w1 := W_{rm}$ $\qquad h2 := \dfrac{H_{facade\_e\_upper}}{2}$ $\qquad comm := D_{rm}$

$w := \dfrac{w1}{comm}$ $\qquad h := \dfrac{h2}{comm}$

$F_{4\_14} := Fij(w,h)$ $\qquad F_{14\_4} := A_4 \cdot \dfrac{F_{4\_14}}{A_{14}}$

$w1 := W_{rm}$ $\qquad h2 := H_{facade\_e\_upper}$ $\qquad comm := D_{rm}$

$w := \dfrac{w1}{comm}$ $\qquad h := \dfrac{h2}{comm}$

$F_{4\_14\_13} := Fij(w,h)$

$F_{13\_4} := \left(F_{4\_14\_13} - F_{4\_14}\right) \cdot \dfrac{A_4}{A_{13}}$ $\qquad F_{4\_13} := A_{13} \cdot \dfrac{F_{13\_4}}{A_4}$

$w1 := W_{rm}$ $h2 := H_{facade\_e\_upper} + \frac{H_{facade\_e\_lower}}{2}$ $comm := D_{rm}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{4\_14\_13\_12} := Fij(w,h)$

$F_{12\_4} := (F_{4\_14\_13\_12} - F_{4\_14\_13}) \cdot \frac{A_4}{A_{12}}$ $F_{4\_12} := A_{12} \cdot \frac{F_{12\_4}}{A_4}$

$w1 := W_{rm}$ $h2 := H_{facade\_e\_upper} + H_{facade\_e\_lower}$ $comm := D_{rm}$

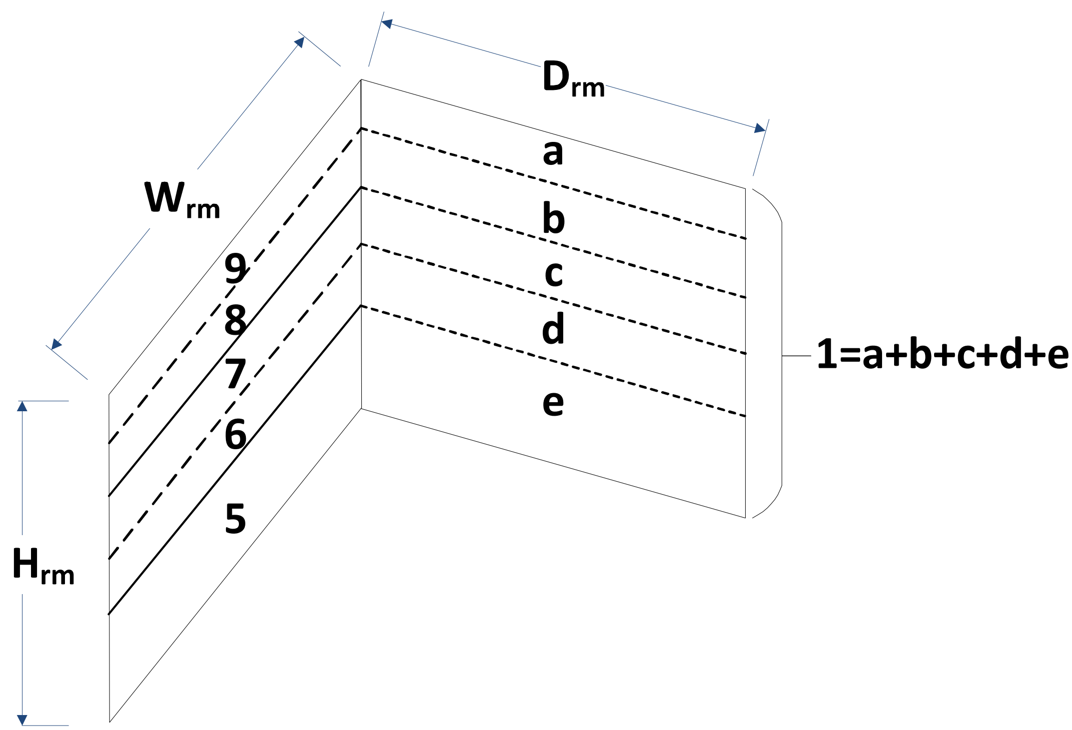
$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{4\_14\_13\_12\_11} := Fij(w,h)$

$F_{11\_4} := (F_{4\_14\_13\_12\_11} - F_{4\_14\_13\_12}) \cdot \frac{A_4}{A_{11}}$ $F_{4\_11} := A_{11} \cdot \frac{F_{11\_4}}{A_4}$

$F_{10\_4} := (F_{4\_16} - F_{4\_14\_13\_12\_11}) \cdot \frac{A_4}{A_{10}}$ $F_{4\_10} := A_{10} \cdot \frac{F_{10\_4}}{A_4}$

View factors between surfaces 5,6,7,8,9,10 and surface 1.



$A_a := D_{rm} \cdot H_{facade\_s\_upper}$ $A_b := D_{rm} \cdot H_{facade\_s\_lower}$ $A_c := D_{rm} \cdot H_{sp}$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := \frac{H_{facade\_s\_upper}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{9a} := Fij(w, h)$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := \frac{H_{facade\_s\_upper}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{8b} := Fij(w, h)$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := \frac{H_{facade\_s\_lower}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{7c} := Fij(w, h)$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := \frac{H_{facade\_s\_lower}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{6d} := Fij(w, h)$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := H_{sp}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{5e} := Fij(w, h)$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := \frac{H_{facade\_s\_upper}}{2} + H_{facade\_s\_lower} + H_{sp}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{8765\_bcde} := Fij(w, h)$

$$F_{9\_bcde} := \frac{\left[A_{15} \cdot F_{15\_1} - A_9 \cdot F_{9a} - \left(A_8 + A_7 + A_6 + A_5\right) \cdot F_{8765\_bcde}\right]}{2 \cdot A_9}$$

$F_{91} := F_{9a} + F_{9\_bcde}$ $\qquad$ $F_{19} := A_9 \cdot \frac{F_{91}}{A_1}$

$w1 := W_{rm}$ $\qquad$ $h2 := D_{rm}$ $\qquad$ $comm := H_{facade\_s\_upper}$

$w := \frac{w1}{comm}$ $\qquad$ $h := \frac{h2}{comm}$

$F_{98\_ab} := Fij(w,h)$

$$F_{8a} := \frac{\left[\left(A_9 + A_8\right) \cdot F_{98\_ab} - A_9 \cdot F_{9a} - A_8 \cdot F_{8b}\right]}{2 \cdot A_8}$$

$w1 := W_{rm}$ $\qquad$ $h2 := D_{rm}$ $\qquad$ $comm := H_{facade\_s\_lower} + H_{sp}$

$w := \frac{w1}{comm}$ $\qquad$ $h := \frac{h2}{comm}$

$F_{765\_cde} := Fij(w,h)$

$$F_{8\_cde} := \frac{\left[\left(A_8 + A_7 + A_6 + A_5\right) \cdot F_{8765\_bcde} - A_8 \cdot F_{8b} - \left(A_7 + A_6 + A_5\right) \cdot F_{765\_cde}\right]}{2 \cdot A_8}$$

$F_{81} := F_{8a} + F_{8b} + F_{8\_cde}$ $\qquad$ $F_{18} := A_8 \cdot \frac{F_{81}}{A_1}$

$w1 := W_{rm}$ $\qquad$ $h2 := D_{rm}$ $\qquad$ $comm := H_{facade\_s\_upper} + \frac{H_{facade\_s\_lower}}{2}$

$w := \frac{w1}{comm}$ $\qquad$ $h := \frac{h2}{comm}$

$F_{987\_abc} := Fij(w,h)$

$$F_{7\_ab} := \frac{\left[\left(A_9 + A_8 + A_7\right) \cdot F_{987\_abc} - \left(A_9 + A_8\right) \cdot F_{98\_ab} - A_7 \cdot F_{7c}\right]}{2 \cdot A_7}$$

$w1 := W_{rm}$ $\qquad$ $h2 := D_{rm}$ $\qquad$ $comm := \frac{H_{facade\_s\_lower}}{2} + H_{sp}$

$w := \frac{w1}{comm}$ $\qquad$ $h := \frac{h2}{comm}$

$F_{65\_de} := Fij(w,h)$

$$F_{7\_de} := \frac{\left[\left(A_7 + A_6 + A_5\right) \cdot F_{765\_cde} - \left(A_6 + A_5\right) \cdot F_{65\_de} - A_7 \cdot F_{7c}\right]}{2 \cdot A_7}$$

$$F_{71} := F_{7\_ab} + F_{7c} + F_{7\_de} \qquad F_{17} := A_7 \cdot \frac{F_{71}}{A_1}$$

$$w1 := W_{rm} \qquad h2 := D_{rm} \qquad comm := H_{facade\_s\_upper} + H_{facade\_s\_lower}$$

$$w := \frac{w1}{comm} \qquad h := \frac{h2}{comm}$$

$$F_{9876\_abcd} := Fij(w, h)$$

$$F_{6\_abc} := \frac{\left[\left(A_9 + A_8 + A_7 + A_6\right) \cdot F_{9876\_abcd} - \left(A_9 + A_8 + A_7\right) \cdot F_{987\_abc} - A_6 \cdot F_{6d}\right]}{2 \cdot A_6}$$

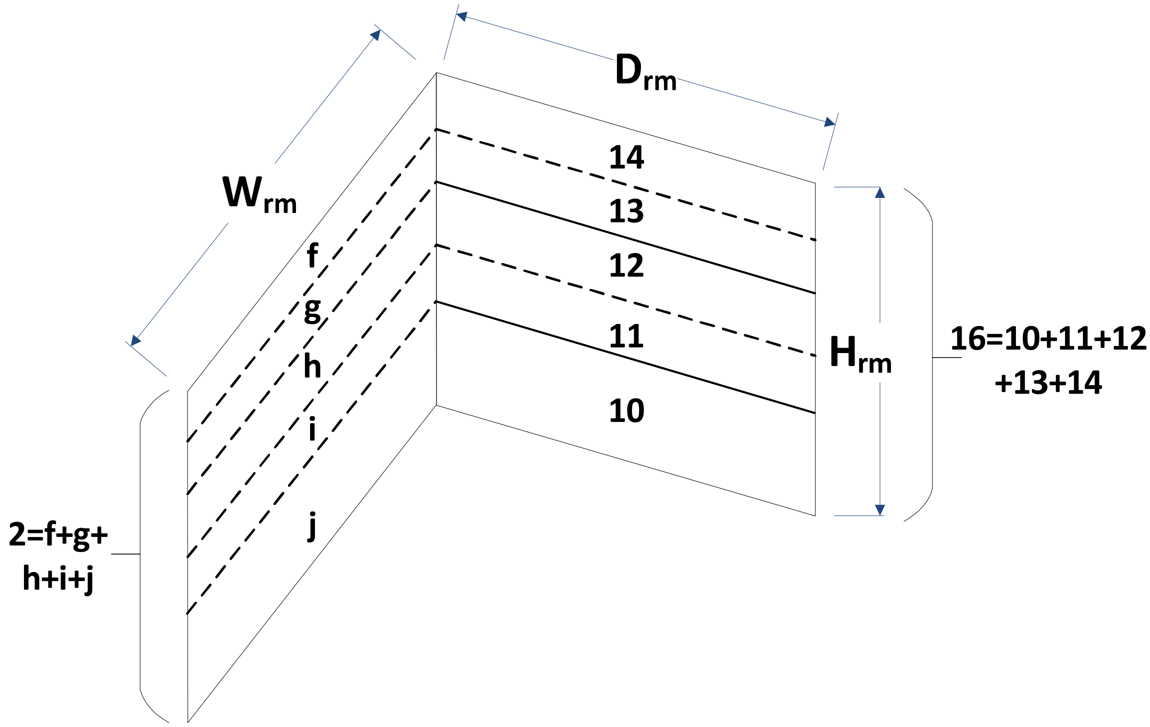
$$F_{6\_e} := \frac{\left[\left(A_6 + A_5\right) \cdot F_{65\_de} - A_6 \cdot F_{6d} - A_5 \cdot F_{5e}\right]}{2 \cdot A_6}$$

$$F_{61} := F_{6\_abc} + F_{6d} + F_{6\_e} \qquad F_{16} := A_6 \cdot \frac{F_{61}}{A_1}$$

$$F_{5\_abcd} := \frac{\left[A_1 \cdot F_{15\_1} - \left(A_9 + A_8 + A_7 + A_6\right) \cdot F_{9876\_abcd} - A_5 \cdot F_{5e}\right]}{2 \cdot A_5}$$

$$F_{51} := F_{5\_abcd} + F_{5e} \qquad F_{15} := A_5 \cdot \frac{F_{51}}{A_1}$$

View factors between surfaces 10,11,12,13,14 and surface 2.



$A_d := W_{rm} \cdot H_{facade\_e\_upper}$ $A_e := W_{rm} \cdot H_{facade\_e\_lower}$ $A_e := W_{rm} \cdot H_{sp}$

$w1 := D_{rm}$ $h2 := W_{rm}$ $comm := \frac{H_{facade\_e\_upper}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{14f} := Fij(w, h)$

$w1 := D_{rm}$ $h2 := W_{rm}$ $comm := \frac{H_{facade\_e\_upper}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{13g} := Fij(w, h)$

$w1 := D_{rm}$ $h2 := W_{rm}$ $comm := \frac{H_{facade\_e\_lower}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{12h} := Fij(w, h)$

$w1 := D_{rm}$ $\quad$ $h2 := W_{rm}$ $\quad$ $comm := \frac{H_{facade\_e\_lower}}{2}$

$w := \frac{w1}{comm}$ $\quad$ $h := \frac{h2}{comm}$

$F_{11i} := Fij(w,h)$

$w1 := D_{rm}$ $\quad$ $h2 := W_{rm}$ $\quad$ $comm := H_{sp}$

$w := \frac{w1}{comm}$ $\quad$ $h := \frac{h2}{comm}$

$F_{10j} := Fij(w,h)$

$w1 := D_{rm}$ $\quad$ $h2 := W_{rm}$ $\quad$ $comm := \frac{H_{facade\_e\_upper}}{2} + H_{facade\_e\_lower} + H_{sp}$

$w := \frac{w1}{comm}$ $\quad$ $h := \frac{h2}{comm}$

$F_{13121110\_ghij} := Fij(w,h)$

$$F_{14\_ghij} := \frac{\left[A_{16} \cdot F_{16\_2} - A_{14} \cdot F_{14f} - \left(A_{13} + A_{12} + A_{11} + A_{10}\right) \cdot F_{13121110\_ghij}\right]}{2 \cdot A_{14}}$$

$F_{14\_2} := F_{14f} + F_{14\_ghij}$ $\quad$ $F_{2\_14} := A_{14} \cdot \frac{F_{14\_2}}{A_2}$

$w1 := D_{rm}$ $\quad$ $h2 := W_{rm}$ $\quad$ $comm := H_{facade\_e\_upper}$

$w := \frac{w1}{comm}$ $\quad$ $h := \frac{h2}{comm}$

$F_{1413\_fg} := Fij(w,h)$

$$F_{13f} := \frac{\left[\left(A_{14} + A_{13}\right) \cdot F_{1413\_fg} - A_{14} \cdot F_{14f} - A_{13} \cdot F_{13g}\right]}{2 \cdot A_{13}}$$

$w1 := D_{rm}$ $\quad$ $h2 := W_{rm}$ $\quad$ $comm := H_{facade\_e\_lower} + H_{sp}$

$w := \frac{w1}{comm}$ $\quad$ $h := \frac{h2}{comm}$

$F_{121110\_hij} := Fij(w,h)$

$$F_{13\_hij} := \frac{\left[\left(A_{13} + A_{12} + A_{11} + A_{10}\right)\cdot F_{13121110\_ghij} - A_{13}\cdot F_{13g} - \left(A_{12} + A_{11} + A_{10}\right)\cdot F_{121110\_hij}\right]}{2\cdot A_{13}}$$

$$F_{13\_2} := F_{13f} + F_{13g} + F_{13\_hij} \qquad F_{2\_13} := A_{13}\cdot\frac{F_{13\_2}}{A_2}$$

$$w1 := D_{rm} \qquad h2 := W_{rm} \qquad comm := H_{facade\_e\_upper} + \frac{H_{facade\_e\_lower}}{2}$$

$$w := \frac{w1}{comm} \qquad h := \frac{h2}{comm}$$

$$F_{141312\_fgh} := Fij(w, h)$$

$$F_{12\_fg} := \frac{\left[\left(A_{14} + A_{13} + A_{12}\right)\cdot F_{141312\_fgh} - \left(A_{14} + A_{13}\right)\cdot F_{1413\_fg} - A_{12}\cdot F_{12h}\right]}{2\cdot A_{12}}$$

$$w1 := D_{rm} \qquad h2 := W_{rm} \qquad comm := \frac{H_{facade\_e\_lower}}{2} + H_{sp}$$

$$w := \frac{w1}{comm} \qquad h := \frac{h2}{comm}$$

$$F_{1110\_ij} := Fij(w, h)$$

$$F_{12\_ij} := \frac{\left[\left(A_{12} + A_{11} + A_{10}\right)\cdot F_{121110\_hij} - \left(A_{11} + A_{10}\right)\cdot F_{1110\_ij} - A_{12}\cdot F_{12h}\right]}{2\cdot A_{12}}$$

$$F_{12\_2} := F_{12\_fg} + F_{12h} + F_{12\_ij} \qquad F_{2\_12} := A_{12}\cdot\frac{F_{12\_2}}{A_2}$$

$$w1 := D_{rm} \qquad h2 := W_{rm} \qquad comm := H_{facade\_e\_upper} + H_{facade\_e\_lower}$$

$$w := \frac{w1}{comm} \qquad h := \frac{h2}{comm}$$

$$F_{14131211\_fghi} := Fij(w, h)$$

$$F_{11\_fgh} := \frac{\left[\left(A_{14} + A_{13} + A_{12} + A_{11}\right)\cdot F_{14131211\_fghi} - \left(A_{14} + A_{13} + A_{12}\right)\cdot F_{141312\_fgh} - A_{11}\cdot F_{11i}\right]}{2\cdot A_{11}}$$

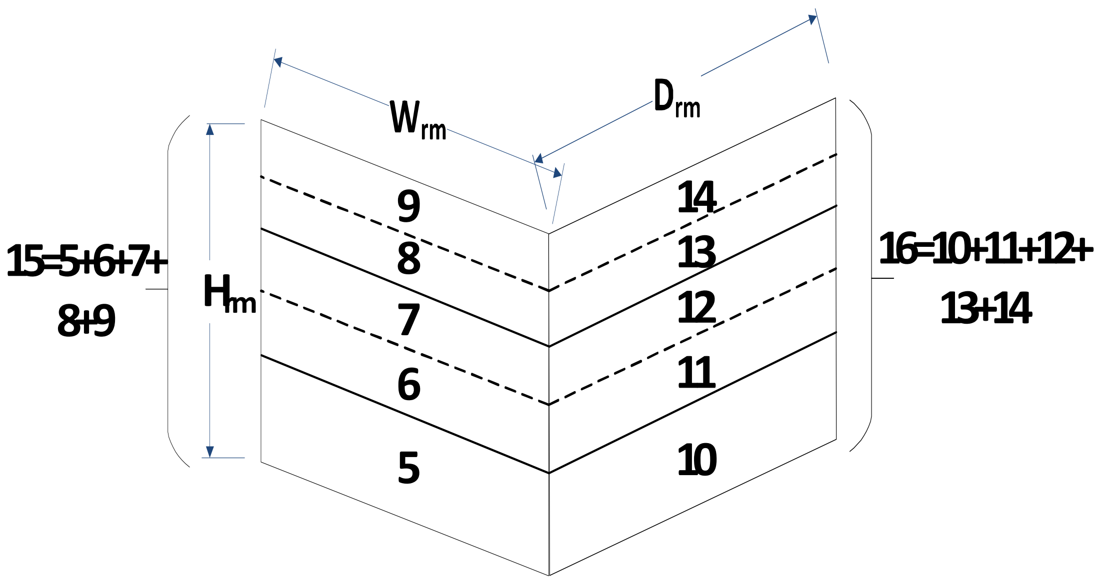
$$F_{11\_j} := \frac{\left[\left(A_{11} + A_{10}\right)\cdot F_{1110\_ij} - A_{11}\cdot F_{11i} - A_{10}\cdot F_{10j}\right]}{2\cdot A_{11}}$$

$F_{11\_2} := F_{11\_fgh} + F_{11i} + F_{11\_j}$ $\quad$ $F_{2\_11} := A_{11} \cdot \frac{F_{11\_2}}{A_2}$

$$F_{10\_fghi} := \frac{\left[A_{16} \cdot F_{16\_2} - \left(A_{14} + A_{13} + A_{12} + A_{11}\right) \cdot F_{14131211\_fghi} - A_{10} \cdot F_{10j}\right]}{2 \cdot A_{10}}$$

$F_{10\_2} := F_{10\_fghi} + F_{10j}$ $\quad$ $F_{2\_10} := A_{10} \cdot \frac{F_{10\_2}}{A_2}$

View factors between surfaces 5,6,7,8,9 and surface 10,11,12,13,14.



$w1 := W_{rm}$ $\quad$ $h2 := D_{rm}$ $\quad$ $comm := \frac{H_{facade\_e\_upper}}{2}$

$w := \frac{w1}{comm}$ $\quad$ $h := \frac{h2}{comm}$

$F_{9\_14} := Fij(w,h)$ $\quad$ $F_{14\_9} := A_9 \cdot \frac{F_{9\_14}}{A_{14}}$

$w1 := W_{rm}$ $\quad$ $h2 := D_{rm}$ $\quad$ $comm := \frac{H_{facade\_e\_upper}}{2}$

$w := \frac{w1}{comm}$ $\quad$ $h := \frac{h2}{comm}$

$F_{8\_13} := Fij(w,h)$ $F_{13\_8} := A_8 \cdot \frac{F_{8\_13}}{A_{13}}$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := \frac{H_{facade\_e\_lower}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{7\_12} := Fij(w,h)$ $F_{12\_7} := A_7 \cdot \frac{F_{7\_12}}{A_{12}}$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := \frac{H_{facade\_e\_lower}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{6\_11} := Fij(w,h)$ $F_{11\_6} := A_6 \cdot \frac{F_{6\_11}}{A_{11}}$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := H_{sp}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{5\_10} := Fij(w,h)$ $F_{10\_5} := A_5 \cdot \frac{F_{5\_10}}{A_{10}}$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := H_{facade\_s\_upper}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{98\_1413} := Fij(w,h)$

$$F_{8\_14} := \frac{\left[\left(A_9 + A_8\right) \cdot F_{98\_1413} - A_9 \cdot F_{9\_14} - A_8 \cdot F_{8\_13}\right]}{2 \cdot A_8} \qquad F_{14\_8} := A_8 \cdot \frac{F_{8\_14}}{A_{14}}$$

$$F_{9\_13} := \frac{\left[\left(A_9 + A_8\right) \cdot F_{98\_1413} - A_9 \cdot F_{9\_14} - A_8 \cdot F_{8\_13}\right]}{2 \cdot A_9} \qquad F_{13\_9} := A_9 \cdot \frac{F_{9\_13}}{A_{13}}$$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := H_{facade\_s\_upper} + \frac{H_{facade\_s\_lower}}{2}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{987\_141312} := Fij(w,h)$

$$F_{7\_1314} := \frac{\left[\left(A_9 + A_8 + A_7\right)\cdot F_{987\_141312} - \left(A_9 + A_8\right)\cdot F_{98\_1413} - A_7\cdot F_{7\_12}\right]}{2\cdot A_7}$$

$w1 := W_{rm}$ $\qquad h2 := D_{rm}$ $\qquad comm := \frac{H_{facade\_s\_upper}}{2} + \frac{H_{facade\_s\_lower}}{2}$

$w := \frac{w1}{comm}$ $\qquad h := \frac{h2}{comm}$

$F_{87\_1312} := Fij(w, h)$

$$F_{9\_1213} := \frac{\left[\left(A_9 + A_8 + A_7\right)\cdot F_{987\_141312} - \left(A_8 + A_7\right)\cdot F_{87\_1312} - A_9\cdot F_{9\_14}\right]}{2\cdot A_9}$$

$$F_{7\_13} := \frac{\left[\left(A_8 + A_7\right)\cdot F_{87\_1312} - \left(A_8\right)\cdot F_{8\_13} - A_7\cdot F_{7\_12}\right]}{2\cdot A_7} \qquad F_{13\_7} := A_7\cdot\frac{F_{7\_13}}{A_{13}}$$

$$F_{8\_12} := \frac{\left[\left(A_8 + A_7\right)\cdot F_{87\_1312} - \left(A_8\right)\cdot F_{8\_13} - A_7\cdot F_{7\_12}\right]}{2\cdot A_8} \qquad F_{12\_8} := A_8\cdot\frac{F_{8\_12}}{A_{12}}$$

$$F_{7\_14} := F_{7\_1314} - F_{7\_13} \qquad F_{14\_7} := A_7\cdot\frac{F_{7\_14}}{A_{14}}$$

$$F_{9\_12} := F_{9\_1213} - F_{9\_13} \qquad F_{12\_9} := A_9\cdot\frac{F_{9\_12}}{A_{12}}$$

$w1 := W_{rm}$ $\qquad h2 := D_{rm}$ $\qquad comm := H_{sp} + \frac{H_{facade\_s\_lower}}{2}$

$w := \frac{w1}{comm}$ $\qquad h := \frac{h2}{comm}$

$F_{65\_1110} := Fij(w, h)$

$$F_{6\_10} := \frac{\left[\left(A_6 + A_5\right)\cdot F_{65\_1110} - \left(A_6\right)\cdot F_{6\_11} - A_5\cdot F_{5\_10}\right]}{2\cdot A_6} \qquad F_{10\_6} := A_6\cdot\frac{F_{6\_10}}{A_{10}}$$

$$F_{5\_11} := \frac{\left[\left(A_6 + A_5\right)\cdot F_{65\_1110} - \left(A_6\right)\cdot F_{6\_11} - A_5\cdot F_{5\_10}\right]}{2\cdot A_5} \qquad F_{11\_5} := A_5\cdot\frac{F_{5\_11}}{A_{11}}$$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := H_{facade\_s\_upper} + H_{facade\_s\_lower}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{9876\_14131211} := Fij(w,h)$

$$F_{6\_121314} := \frac{\left[(A_9 + A_8 + A_7 + A_6) \cdot F_{9876\_14131211} - (A_9 + A_8 + A_7) \cdot F_{987\_141312} - A_6 \cdot F_{6\_11}\right]}{2 \cdot A_6}$$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := \frac{H_{facade\_s\_upper}}{2} + H_{facade\_s\_lower}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{876\_131211} := Fij(w,h)$

$$F_{9\_131211} := \frac{\left[(A_9 + A_8 + A_7 + A_6) \cdot F_{9876\_14131211} - (A_6 + A_8 + A_7) \cdot F_{876\_131211} - A_9 \cdot F_{9\_14}\right]}{2 \cdot A_9}$$

$$F_{6\_1213} := \frac{\left[(A_8 + A_7 + A_6) \cdot F_{876\_131211} - (A_8 + A_7) \cdot F_{87\_1312} - A_6 \cdot F_{6\_11}\right]}{2 \cdot A_6}$$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := H_{facade\_s\_lower}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{76\_1211} := Fij(w,h)$

$$F_{7\_11} := \frac{\left[(A_7 + A_6) \cdot F_{76\_1211} - (A_6) \cdot F_{6\_11} - A_7 \cdot F_{7\_12}\right]}{2 \cdot A_7} \qquad F_{11\_7} := A_7 \cdot \frac{F_{7\_11}}{A_{11}}$$

$$F_{6\_12} := \frac{\left[(A_7 + A_6) \cdot F_{76\_1211} - (A_6) \cdot F_{6\_11} - A_7 \cdot F_{7\_12}\right]}{2 \cdot A_6} \qquad F_{12\_6} := A_6 \cdot \frac{F_{6\_12}}{A_{12}}$$

$$F_{8\_1112} := \frac{\left[(A_8 + A_7 + A_6) \cdot F_{876\_131211} - (A_7 + A_6) \cdot F_{76\_1211} - A_8 \cdot F_{8\_13}\right]}{2 \cdot A_8}$$

$F_{9\_11} := F_{9\_131211} - F_{9\_1213}$ $\quad F_{11\_9} := A_9 \cdot \frac{F_{9\_11}}{A_{11}}$

$F_{6\_14} := F_{6\_121314} - F_{6\_1213}$ $\quad F_{14\_6} := A_6 \cdot \frac{F_{6\_14}}{A_{14}}$

$F_{8\_11} := F_{8\_1112} - F_{8\_12}$ $\quad F_{11\_8} := A_8 \cdot \frac{F_{8\_11}}{A_{11}}$

$F_{6\_13} := F_{6\_1213} - F_{6\_12}$ $\quad F_{13\_6} := A_6 \cdot \frac{F_{6\_13}}{A_{13}}$

$w1 := W_{rm}$ $\quad h2 := D_{rm}$ $\quad comm := \frac{H_{facade\_s\_upper}}{2} + H_{facade\_s\_lower} + H_{sp}$

$w := \frac{w1}{comm}$ $\quad h := \frac{h2}{comm}$

$F_{8765\_13121110} := Fij(w,h)$

$$F_{9\_13121110} := \frac{\left[\left(A_{15}\right) \cdot F_{15\_16} - \left(A_8 + A_7 + A_6 + A_5\right) \cdot F_{8765\_13121110} - A_9 \cdot F_{9\_14}\right]}{2 \cdot A_9}$$

$F_{9\_10} := F_{9\_13121110} - F_{9\_131211}$ $\quad F_{10\_9} := A_9 \cdot \frac{F_{9\_10}}{A_{10}}$

$$F_{5\_131211} := \frac{\left[\left(A_8 + A_7 + A_6 + A_5\right) \cdot F_{8765\_13121110} - \left(A_8 + A_7 + A_6\right) \cdot F_{876\_131211} - A_5 \cdot F_{5\_10}\right]}{2 \cdot A_5}$$

$$F_{5\_14131211} := \frac{\left[\left(A_{15}\right) \cdot F_{15\_16} - \left(A_9 + A_8 + A_7 + A_6\right) \cdot F_{9876\_14131211} - A_5 \cdot F_{5\_10}\right]}{2 \cdot A_5}$$

$F_{5\_14} := F_{5\_14131211} - F_{5\_131211}$ $\quad F_{14\_5} := A_5 \cdot \frac{F_{5\_14}}{A_{14}}$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := H_{facade\_s\_lower} + H_{sp}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{765\_121110} := Fij(w,h)$

$w1 := W_{rm}$ $h2 := D_{rm}$ $comm := \frac{H_{facade\_s\_lower}}{2} + H_{sp}$

$w := \frac{w1}{comm}$ $h := \frac{h2}{comm}$

$F_{65\_1110} := Fij(w,h)$

$$F_{5\_1211} := \frac{\left[\left(A_7 + A_6 + A_5\right)\cdot F_{765\_121110} - \left(A_7 + A_6\right)\cdot F_{76\_1211} - A_5\cdot F_{5\_10}\right]}{2\cdot A_5}$$

$F_{5\_13} := F_{5\_131211} - F_{5\_1211}$ $F_{13\_5} := A_5\cdot\frac{F_{5\_13}}{A_{13}}$

$F_{5\_12} := F_{5\_1211} - F_{5\_11}$ $F_{12\_5} := A_5\cdot\frac{F_{5\_12}}{A_{12}}$

$$F_{8\_121110} := \frac{\left[\left(A_8 + A_7 + A_6 + A_5\right)\cdot F_{8765\_13121110} - A_8\cdot F_{8\_13} - \left(A_7 + A_6 + A_5\right)\cdot F_{765\_121110}\right]}{2\cdot A_8}$$

$$F_{8\_1211} := \frac{\left[\left(A_8 + A_7 + A_6\right)\cdot F_{876\_131211} - A_8\cdot F_{8\_13} - \left(A_7 + A_6\right)\cdot F_{76\_1211}\right]}{2\cdot A_8}$$

$F_{8\_10} := F_{8\_121110} - F_{8\_1211}$ $F_{10\_8} := A_8\cdot\frac{F_{8\_10}}{A_{10}}$

$$F_{7\_1110} := \frac{\left[\left(A_7 + A_6 + A_5\right)\cdot F_{765\_121110} - \left(A_6 + A_5\right)\cdot F_{65\_1110} - A_7\cdot F_{7\_12}\right]}{2\cdot A_7}$$

$F_{7\_10} := F_{7\_1110} - F_{7\_11}$ $F_{10\_7} := A_7\cdot\frac{F_{7\_10}}{A_{10}}$

View factors between surfaces 5,6,7,8,9 and surface 2.

$F_{52} := 1 - F_{51} - F_{53} - F_{54} - F_{5\_10} - F_{5\_11} - F_{5\_12} + F_{5\_13} - F_{5\_14}$ $\quad F_{25} := A_5 \cdot \frac{F_{52}}{A_2}$

$F_{62} := 1 - F_{61} - F_{63} - F_{64} - F_{6\_10} - F_{6\_11} - F_{6\_12} + F_{6\_13} - F_{6\_14}$ $\quad F_{26} := A_6 \cdot \frac{F_{62}}{A_2}$

$F_{72} := 1 - F_{71} - F_{73} - F_{74} - F_{7\_10} - F_{7\_11} - F_{7\_12} + F_{7\_13} - F_{7\_14}$ $\quad F_{27} := A_7 \cdot \frac{F_{72}}{A_2}$

$F_{82} := 1 - F_{81} - F_{83} - F_{84} - F_{8\_10} - F_{8\_11} - F_{8\_12} + F_{8\_13} - F_{8\_14}$ $\quad F_{28} := A_8 \cdot \frac{F_{82}}{A_2}$

$F_{92} := 1 - F_{91} - F_{93} - F_{94} - F_{9\_10} - F_{9\_11} - F_{9\_12} + F_{9\_13} - F_{9\_14}$ $\quad F_{29} := A_8 \cdot \frac{F_{82}}{A_2}$

View factors between surfaces 10,11,12,13,14 and surface 1.

$F_{10\_1} := 1 - F_{10\_2} - F_{10\_3} - F_{10\_4} - F_{10\_5} - F_{10\_6} - F_{10\_7} - F_{10\_8} - F_{10\_9}$ $\quad F_{1\_10} := A_{10} \cdot \frac{F_{10\_1}}{A_1}$

$F_{11\_1} := 1 - F_{11\_2} - F_{11\_3} - F_{11\_4} - F_{11\_5} - F_{11\_6} - F_{11\_7} - F_{11\_8} - F_{11\_9}$ $\quad F_{1\_11} := A_{11} \cdot \frac{F_{11\_1}}{A_1}$

$F_{12\_1} := 1 - F_{12\_2} - F_{12\_3} - F_{12\_4} - F_{12\_5} - F_{12\_6} - F_{12\_7} - F_{12\_8} - F_{12\_9}$ $\quad F_{1\_12} := A_{12} \cdot \frac{F_{12\_1}}{A_1}$

$F_{13\_1} := 1 - F_{13\_2} - F_{13\_3} - F_{13\_4} - F_{13\_5} - F_{13\_6} - F_{13\_7} - F_{13\_8} - F_{13\_9}$ $\quad F_{1\_13} := A_{13} \cdot \frac{F_{13\_1}}{A_1}$

$F_{14\_1} := 1 - F_{14\_2} - F_{14\_3} - F_{14\_4} - F_{14\_5} - F_{14\_6} - F_{14\_7} - F_{14\_8} - F_{14\_9}$ $\quad F_{1\_14} := A_{14} \cdot \frac{F_{14\_1}}{A_1}$

View factors which are Zero

$F_{11} := 0$

$F_{22} := 0$

$F_{33} := 0$

$F_{44} := 0$

$F_{55} := 0$

$F_{66} := 0$

$F_{77} := 0$

$F_{88} := 0$

$F_{99} := 0$

$F_{10\_10} := 0$

$F_{11\_11} := 0$

$F_{12\_12} := 0$

$F_{13\_13} := 0$

$F_{14\_14} := 0$

$F_{56} := 0$

$F_{57} := 0$

$F_{58} := 0$

$F_{59} := 0$

$F_{65} := 0$

$F_{67} := 0$

$F_{68} := 0$

$F_{69} := 0$

$F_{75} := 0$

$F_{76} := 0$

$F_{78} := 0$

$F_{79} := 0$

$F_{85} := 0$

$F_{86} := 0$

$F_{87} := 0$

$F_{89} := 0$

$F_{95} := 0$

$F_{96} := 0$

$F_{97} := 0$

$F_{98} := 0$

$F_{10\_11} := 0$

$F_{10\_12} := 0$

$F_{10\_13} := 0$

$F_{10\_14} := 0$

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$F_{13\_10} := 0$

$F_{13\_11} := 0$

$F_{13\_12} := 0$

$F_{13\_14} := 0$

$F_{14\_10} := 0$

$F_{14\_11} := 0$

$F_{14\_12} := 0$

$F_{14\_13} := 0$

$$F_t := \begin{pmatrix} F_{11} & F_{12} & F_{13} & F_{14} & F_{15} & F_{16} & F_{17} & F_{18} & F_{19} & F_{1\_10} & F_{1\_11} & F_{1\_12} & F_{1\_13} & F_{1\_14} \\ F_{21} & F_{22} & F_{23} & F_{24} & F_{25} & F_{26} & F_{27} & F_{28} & F_{29} & F_{2\_10} & F_{2\_11} & F_{2\_12} & F_{2\_13} & F_{2\_14} \\ F_{31} & F_{32} & F_{33} & F_{34} & F_{35} & F_{36} & F_{37} & F_{38} & F_{39} & F_{3\_10} & F_{3\_11} & F_{3\_12} & F_{3\_13} & F_{3\_14} \\ F_{41} & F_{42} & F_{43} & F_{44} & F_{45} & F_{46} & F_{47} & F_{48} & F_{49} & F_{4\_10} & F_{4\_11} & F_{4\_12} & F_{4\_13} & F_{4\_14} \\ F_{51} & F_{52} & F_{53} & F_{54} & F_{55} & F_{56} & F_{57} & F_{58} & F_{59} & F_{5\_10} & F_{5\_11} & F_{5\_12} & F_{5\_13} & F_{5\_14} \\ F_{61} & F_{62} & F_{63} & F_{64} & F_{65} & F_{66} & F_{67} & F_{68} & F_{69} & F_{6\_10} & F_{6\_11} & F_{6\_12} & F_{6\_13} & F_{6\_14} \\ F_{71} & F_{72} & F_{73} & F_{74} & F_{75} & F_{76} & F_{77} & F_{78} & F_{79} & F_{7\_10} & F_{7\_11} & F_{7\_12} & F_{7\_13} & F_{7\_14} \\ F_{81} & F_{82} & F_{83} & F_{84} & F_{85} & F_{86} & F_{87} & F_{88} & F_{89} & F_{8\_10} & F_{8\_11} & F_{8\_12} & F_{8\_13} & F_{8\_14} \\ F_{91} & F_{92} & F_{93} & F_{94} & F_{95} & F_{96} & F_{97} & F_{98} & F_{99} & F_{9\_10} & F_{9\_11} & F_{9\_12} & F_{9\_13} & F_{9\_14} \\ F_{10\_1} & F_{10\_2} & F_{10\_3} & F_{10\_4} & F_{10\_5} & F_{10\_6} & F_{10\_7} & F_{10\_8} & F_{10\_9} & F_{10\_10} & F_{10\_10} & F_{10\_12} & F_{10\_13} & F_{10\_14} \\ F_{11\_1} & F_{11\_2} & F_{11\_3} & F_{11\_4} & F_{11\_5} & F_{11\_6} & F_{11\_7} & F_{11\_8} & F_{11\_9} & F_{11\_10} & F_{11\_11} & F_{11\_12} & F_{11\_13} & F_{11\_14} \\ F_{12\_1} & F_{12\_2} & F_{12\_3} & F_{12\_4} & F_{12\_5} & F_{12\_6} & F_{12\_7} & F_{12\_8} & F_{12\_9} & F_{12\_10} & F_{12\_11} & F_{12\_12} & F_{12\_13} & F_{12\_14} \\ F_{13\_1} & F_{13\_2} & F_{13\_3} & F_{13\_4} & F_{13\_5} & F_{13\_6} & F_{13\_7} & F_{13\_8} & F_{13\_9} & F_{13\_10} & F_{13\_11} & F_{13\_12} & F_{13\_13} & F_{13\_14} \\ F_{14\_1} & F_{14\_2} & F_{14\_3} & F_{14\_4} & F_{14\_5} & F_{14\_6} & F_{14\_7} & F_{14\_8} & F_{14\_9} & F_{14\_10} & F_{14\_11} & F_{14\_12} & F_{14\_13} & F_{14\_14} \end{pmatrix}$$

Illuminance Calculation:

Initial luminous exitance of each room surface:

$$M_{o_t} := \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ E_{facade\_s\_lower\_diff\_l_t} \\ E_{facade\_s\_lower\_diff\_u_t} \\ E_{facade\_s\_upper\_diff\_l_t} \\ E_{facade\_s\_upper\_diff\_u_t} \\ 0 \\ E_{facade\_e\_lower\_diff\_l_t} \\ E_{facade\_e\_lower\_diff\_u_t} \\ E_{facade\_e\_upper\_diff\_l_t} \\ E_{facade\_e\_upper\_diff\_u_t} \end{pmatrix}$$

"Final" luminous exitance of each room surface:

$$I := \text{identity}(14) = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$i := 14$

$$M_{1_t} := \left(I - \rho \cdot F_t\right)^{-1} \cdot M_{o_t}$$

Configuration factors between room surfaces and workplane

$H_{workplane} := 0.8m$ Note: The workplane is positioned 0.8m from the floor.

Configuration factors for points positioned to a plane parallel to the source plane:

$$C_{parallel}(z, y, w) := \frac{1}{2\pi}\left(\frac{z}{\sqrt{z^2 + y^2}} \cdot \text{atan}\left(\frac{w}{\sqrt{z^2 + y^2}}\right) + \frac{w}{\sqrt{w^2 + y^2}} \cdot \text{atan}\left(\frac{z}{\sqrt{w^2 + y^2}}\right)\right)$$

Configuration factors for points positioned to a plane perpendicular to the source plane:

$$C_{perpendicular}(z, y, w) := \frac{1}{2\cdot\pi}\left(\text{atan}\left(\frac{w}{y}\right) - \frac{y}{\sqrt{z^2 + y^2}} \cdot \text{atan}\left(\frac{w}{\sqrt{z^2 + y^2}}\right)\right)$$

$j := 1, 2 .. 25$ ...number of selected points

South wall (surface 5,6,7,8,9)

$$z_{j,t} := H_{rm} - H_{workplane}$$

$$y_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \frac{D_{rm} - 0.8m}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ \frac{2\cdot(D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \frac{3\cdot(D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \lor j = 6 \lor j = 11 \lor j = 16 \lor j = 21 \\ \frac{W_{rm} - 1m}{4} + 0.1\cdot m & \text{if } j = 2 \lor j = 7 \lor j = 12 \lor j = 17 \lor j = 22 \\ \frac{2\cdot(W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 3 \lor j = 8 \lor j = 13 \lor j = 18 \lor j = 23 \\ \frac{3\cdot(W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 4 \lor j = 9 \lor j = 14 \lor j = 19 \lor j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$C_{56789\_1_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 5 \vee j = 10 \vee j = 15 \vee j = 20 \vee j = 25 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ \dfrac{2\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$C_{56789\_2_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$C_{56789_{j,t}} := C_{56789\_1_{j,t}} + C_{56789\_2_{j,t}}$$

South wall (surface 5,6,7,8)

$$z_{j,t} := H_{rm} - H_{workplane} - \frac{H_{facade\_s\_upper}}{2}$$

$$y_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ \dfrac{2\cdot\left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3\cdot\left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \vee j = 6 \vee j = 11 \vee j = 16 \vee j = 21 \\ \dfrac{W_{rm} - 1m}{4} + 0.1\cdot m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ \dfrac{2\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$C_{5678\_1_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 5 \lor j = 10 \lor j = 15 \lor j = 20 \lor j = 25 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 4 \lor j = 9 \lor j = 14 \lor j = 19 \lor j = 24 \\ \dfrac{2\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \lor j = 8 \lor j = 13 \lor j = 18 \lor j = 23 \\ \dfrac{3\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 2 \lor j = 7 \lor j = 12 \lor j = 17 \lor j = 22 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$C_{5678\_2_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$C_{5678_{j,t}} := C_{5678\_1_{j,t}} + C_{5678\_2_{j,t}}$$

$$C_{9_{j,t}} := C_{56789_{j,t}} - C_{5678_{j,t}}$$

South wall (surface 5,6,7)

$$z_{j,t} := H_{rm} - H_{workplane} - H_{facade\_s\_upper}$$

$$y_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ \dfrac{2\cdot\left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3\cdot\left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \lor j = 6 \lor j = 11 \lor j = 16 \lor j = 21 \\ \dfrac{W_{rm} - 1m}{4} + 0.1\cdot m & \text{if } j = 2 \lor j = 7 \lor j = 12 \lor j = 17 \lor j = 22 \\ \dfrac{2\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \lor j = 8 \lor j = 13 \lor j = 18 \lor j = 23 \\ \dfrac{3\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 4 \lor j = 9 \lor j = 14 \lor j = 19 \lor j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$C_{567\_1_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 5 \vee j = 10 \vee j = 15 \vee j = 20 \vee j = 25 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ \dfrac{2\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$C_{567\_2_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$C_{567_{j,t}} := C_{567\_1_{j,t}} + C_{567\_2_{j,t}}$$

$$C_{8_{j,t}} := C_{5678_{j,t}} - C_{567_{j,t}}$$

South wall (surface 5,6)

$$z_{j,t} := H_{rm} - H_{workplane} - H_{facade\_s\_upper} - \frac{H_{facade\_s\_lower}}{2}$$

$$y_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ \dfrac{2\cdot\left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3\cdot\left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \vee j = 6 \vee j = 11 \vee j = 16 \vee j = 21 \\ \dfrac{W_{rm} - 1m}{4} + 0.1\cdot m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ \dfrac{2\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$C_{56\_1_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 5 \vee j = 10 \vee j = 15 \vee j = 20 \vee j = 25 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ \dfrac{2 \cdot \left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3 \cdot \left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$C_{56\_2_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$

$C_{56_{j,t}} := C_{567\_1_{j,t}} + C_{567\_2_{j,t}}$

$C_{7_{j,t}} := C_{567_{j,t}} - C_{56_{j,t}}$

Surface 5

$z_{j,t} := \text{if}\left[\left(H_{sp} - H_{workplane}\right) > 0m, H_{sp} - H_{workplane}, 0 \cdot m\right]$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \vee j = 6 \vee j = 11 \vee j = 16 \vee j = 21 \\ \dfrac{W_{rm} - 1m}{4} + 0.1 \cdot m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ \dfrac{2 \cdot \left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3 \cdot \left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$C_{5\_1_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 5 \vee j = 10 \vee j = 15 \vee j = 20 \vee j = 25 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ \dfrac{2\cdot(W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3\cdot(W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$C_{5\_2_{j,t}} := C_{perpendicular}(z_{j,t}, y_{j,t}, w_{j,t})$$

$$C_{5_{j,t}} := C_{5\_1_{j,t}} + C_{5\_2_{j,t}}$$

$$C_{6_{j,t}} := C_{56789_{j,t}} - C_{5_{j,t}} - C_{7_{j,t}} - C_{8_{j,t}} - C_{9_{j,t}}$$

North wall (surface 2)

$$z_{j,t} := H_{rm} - H_{workplane}$$

$$y_{j,t} := \begin{cases} 0.4m & \text{if } 21 \le j \le 25 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ \dfrac{2\cdot(D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3\cdot(D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \vee j = 6 \vee j = 11 \vee j = 16 \vee j = 21 \\ \dfrac{W_{rm} - 1m}{4} + 0.1\cdot m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ \dfrac{2\cdot(W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3\cdot(W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$C_{2\_1_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$

$$w_{j,t} := \begin{cases} 0.5m & \text{if } j = 5 \vee j = 10 \vee j = 15 \vee j = 20 \vee j = 25 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ \dfrac{2\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$C_{2\_2_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$

$C_{2_{j,t}} := C_{2\_1_{j,t}} + C_{2\_2_{j,t}}$

East wall (surface 10,11,12,13,14)

$z_{j,t} := H_{rm} - H_{workplane}$

$$y_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \vee j = 6 \vee j = 11 \vee j = 16 \vee j = 21 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ \dfrac{2\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3\cdot\left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1\cdot m & \text{if } 6 \le j \le 10 \\ \dfrac{2\cdot\left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3\cdot\left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$C_{1011121314\_1_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 21 \le j \le 25 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1 \cdot m & \text{if } 16 \le j \le 20 \\ \dfrac{2 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$C_{1011121314\_2_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$C_{1011121314_{j,t}} := C_{1011121314\_1_{j,t}} + C_{1011121314\_2_{j,t}}$$

East wall (surface 10,11,12,13)

$$z_{j,t} := H_{rm} - H_{workplane} - \frac{H_{facade\_e\_upper}}{2}$$

$$y_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \lor j = 6 \lor j = 11 \lor j = 16 \lor j = 21 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 2 \lor j = 7 \lor j = 12 \lor j = 17 \lor j = 22 \\ \dfrac{2 \cdot (W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 3 \lor j = 8 \lor j = 13 \lor j = 18 \lor j = 23 \\ \dfrac{3 \cdot (W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 4 \lor j = 9 \lor j = 14 \lor j = 19 \lor j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1 \cdot m & \text{if } 6 \le j \le 10 \\ \dfrac{2 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$C_{10111213\_1_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 21 \le j \le 25 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1 \cdot m & \text{if } 16 \le j \le 20 \\ \dfrac{2 \cdot \left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3 \cdot \left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$C_{10111213\_2_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$C_{10111213_{j,t}} := C_{10111213\_1_{j,t}} + C_{10111213\_2_{j,t}}$$

$$C_{14_{j,t}} := C_{1011121314_{j,t}} - C_{10111213_{j,t}}$$

East wall (surface 10,11,12)

$$z_{j,t} := H_{rm} - H_{workplane} - H_{facade\_e\_upper}$$

$$y_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \vee j = 6 \vee j = 11 \vee j = 16 \vee j = 21 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ \dfrac{2 \cdot \left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3 \cdot \left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1 \cdot m & \text{if } 6 \le j \le 10 \\ \dfrac{2 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$C_{101112\_1_{j,t}} := C_{perpendicular}(z_{j,t}, y_{j,t}, w_{j,t})$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 21 \le j \le 25 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1 \cdot m & \text{if } 16 \le j \le 20 \\ \dfrac{2 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$C_{101112\_2_{j,t}} := C_{perpendicular}(z_{j,t}, y_{j,t}, w_{j,t})$$

$$C_{101112_{j,t}} := C_{101112\_1_{j,t}} + C_{101112\_2_{j,t}}$$

$$C_{13_{j,t}} := C_{10111213_{j,t}} - C_{101112_{j,t}}$$

East wall (surface 10,11)

$$z_{j,t} := H_{rm} - H_{workplane} - H_{facade\_e\_upper}$$

$$y_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \vee j = 6 \vee j = 11 \vee j = 16 \vee j = 21 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ \dfrac{2\cdot(W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3\cdot(W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1\cdot m & \text{if } 6 \le j \le 10 \\ \dfrac{2\cdot(D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3\cdot(D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$C_{1011\_1_{j,t}} := C_{perpendicular}(z_{j,t}, y_{j,t}, w_{j,t})$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 21 \le j \le 25 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1\cdot m & \text{if } 16 \le j \le 20 \\ \dfrac{2\cdot(D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3\cdot(D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$C_{1011\_2_{j,t}} := C_{perpendicular}(z_{j,t}, y_{j,t}, w_{j,t})$$

$C_{1011_{j,t}} := C_{1011\_1_{j,t}} + C_{1011\_2_{j,t}}$

$C_{12_{j,t}} := C_{101112_{j,t}} - C_{1011_{j,t}}$

East wall (surface 10)

$z_{j,t} := \text{if}\left[\left(H_{sp} - H_{workplane}\right) > 0m, H_{sp} - H_{workplane}, 0 \cdot m\right]$

$$y_{j,t} := \begin{cases} 0.5m & \text{if } j = 1 \vee j = 6 \vee j = 11 \vee j = 16 \vee j = 21 \\ \frac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ \frac{2 \cdot \left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \frac{3 \cdot \left(W_{rm} - 1m\right)}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \frac{D_{rm} - 0.8m}{4} + 0.1 \cdot m & \text{if } 6 \le j \le 10 \\ \frac{2 \cdot \left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \frac{3 \cdot \left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$C_{10\_1_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 21 \le j \le 25 \\ \frac{D_{rm} - 0.8m}{4} + 0.1 \cdot m & \text{if } 16 \le j \le 20 \\ \frac{2 \cdot \left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \frac{3 \cdot \left(D_{rm} - 0.8m\right)}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$C_{10\_2_{j,t}} := C_{perpendicular}(z_{j,t}, y_{j,t}, w_{j,t})$

$C_{10_{j,t}} := C_{10\_1_{j,t}} + C_{10\_2_{j,t}}$

$C_{11_{j,t}} := C_{1011121314_{j,t}} - C_{10_{j,t}} - C_{12_{j,t}} - C_{13_{j,t}} - C_{14_{j,t}}$

West Wall (Surface 1)

$z_{j,t} := H_{rm} - H_{workplane}$

$$y_{j,t} := \begin{cases} 0.5m & \text{if } j = 5 \vee j = 10 \vee j = 15 \vee j = 20 \vee j = 25 \\ \dfrac{W_{rm} - 1m}{4} + 0.1m & \text{if } j = 4 \vee j = 9 \vee j = 14 \vee j = 19 \vee j = 24 \\ \dfrac{2 \cdot (W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 3 \vee j = 8 \vee j = 13 \vee j = 18 \vee j = 23 \\ \dfrac{3 \cdot (W_{rm} - 1m)}{4} + 0.1m & \text{if } j = 2 \vee j = 7 \vee j = 12 \vee j = 17 \vee j = 22 \\ W_{rm} - 0.5m & \text{otherwise} \end{cases}$$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 1 \le j \le 5 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1 \cdot m & \text{if } 6 \le j \le 10 \\ \dfrac{2 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 16 \le j \le 20 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$C_{1\_1_{j,t}} := C_{perpendicular}(z_{j,t}, y_{j,t}, w_{j,t})$

$$w_{j,t} := \begin{cases} 0.4m & \text{if } 21 \le j \le 25 \\ \dfrac{D_{rm} - 0.8m}{4} + 0.1 \cdot m & \text{if } 16 \le j \le 20 \\ \dfrac{2 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 11 \le j \le 15 \\ \dfrac{3 \cdot (D_{rm} - 0.8m)}{4} + 0.1m & \text{if } 6 \le j \le 10 \\ D_{rm} - 0.4m & \text{otherwise} \end{cases}$$

$$C_{1\_2_{j,t}} := C_{perpendicular}\left(z_{j,t}, y_{j,t}, w_{j,t}\right)$$

$$C_{1_{j,t}} := C_{1\_1_{j,t}} + C_{1\_2_{j,t}}$$

Ceiling (surface 4)

$$C_{4_{j,t}} := 1 - C_{1_{j,t}} - C_{2_{j,t}} - C_{56789_{j,t}} - C_{1011121314_{j,t}}$$

For Whole Room:

$$C_{room_{j,t}} := \left(C_{1_{j,t}} \ C_{2_{j,t}} \ 0 \ C_{4_{j,t}} \ C_{5_{j,t}} \ C_{6_{j,t}} \ C_{7_{j,t}} \ C_{8_{j,t}} \ C_{9_{j,t}} \ C_{10_{j,t}} \ C_{11_{j,t}} \ C_{12_{j,t}} \ C_{13_{j,t}} \ C_{14_{j,t}}\right)$$

Workplane Illuminance due to diffuse daylighting

$E_{workplane_{j,t}} := C_{room_{j,t}} \cdot M1_t$ ...workplane illuminace due to diffuse daylighting transmitted through the fenestration

$$E_{wpd_t} := \begin{pmatrix} E_{workplane_{1,t}} & E_{workplane_{2,t}} & E_{workplane_{3,t}} & E_{workplane_{4,t}} & E_{workplane_{5,t}} \\ E_{workplane_{6,t}} & E_{workplane_{7,t}} & E_{workplane_{8,t}} & E_{workplane_{9,t}} & E_{workplane_{10,t}} \\ E_{workplane_{11,t}} & E_{workplane_{12,t}} & E_{workplane_{13,t}} & E_{workplane_{14,t}} & E_{workplane_{15,t}} \\ E_{workplane_{16,t}} & E_{workplane_{17,t}} & E_{workplane_{18,t}} & E_{workplane_{19,t}} & E_{workplane_{20,t}} \\ E_{workplane_{21,t}} & E_{workplane_{22,t}} & E_{workplane_{23,t}} & E_{workplane_{24,t}} & E_{workplane_{25,t}} \end{pmatrix}$$