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Evaluating The Daylighting Potential In The Monetary Times Building

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Evaluating the daylighting potential in the Monetary Times Building At Ryerson University, Toronto

by

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Executive summary

Daylighting design is not just to install large windows and provide maximum daylighting. As a result, uncontrolled daylighting creates over brightness and glare near perimeter zones, increases cooling load in cooling season, increases energy consumption and outweighs the benefits of daylighting. The purpose of daylighting design strategies is to provide controlled daylight with uniform and adequate levels of illuminance in the space. In this paper, problems with daylighting in the Monetary Times Building at Ryerson University have been studied and daylighting design strategies have been evaluated.

The study results showed that the employed daylighting design strategies in the MON building could be saved up to 135038.4 KWh/year or 61.76 KWh/m^2 of energy in electrical lighting account. Furthermore, the above daylighting strategy is cost effective; it can be saved up to $14,872.09 per year and the cost for daylighting strategies can be paid-back in up to 15 years.

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1 Introduction

Today, the world is facing challenges of global warming and climatic changes because of excessive emissions of greenhouse gases. One of the main factors of greenhouse gases emissions is extensive use of fossil fuels for our energy generation. Fossil fuels resources are very limited and non-renewable. Now, the world population is growing very fast and cities are getting crowded at a much higher rate. Moreover, everyday new technologies are coming in the world and humans are getting more dependent on machines, leading to a rapidly growing energy demand and the fastest depletion of natural resources. Consequently, energy prices increase day by day. National Resource Canada’s 2009 statistics show that in Canada commercial /institutional buildings have consumed 1186 PJ energy and emitted 60.9 Mt of CO_2 in the environment (National Resource Canada, 2012).

The sun provides plenty of energy in the form of light and heat; environmental friendly and renewable. The Earth receives $173x10^{12}$ KWh energy from the sun in one hour (Kalogirou, 2009, p.49), and 40% of this energy is in the form of visible light (IESNA, 2000, ch.8). Sustainability can be achieved by introducing the daylight in buildings. As a result, some of this energy can be used in commercial/ institutional buildings by bringing in daylight inside of the buildings. This amount of daylight can save significant amount of energy in the account of electrical light. The amount of daylight is sufficient enough to fulfill lighting requirements in the building even in overcast sky conditions.

The objective of this research is to evaluate the daylight potential in the Monetary Times (MON) building (Civil Engineering at Ryerson University, Toronto) and design the appropriate daylighting strategies that can contribute significant energy savings, health benefits, improvement of indoor comfort and productivity.

1.1 Research Questions

The following questions will be answered through this research;

- How much daylighting is used in the existing building?
- What are the problems using daylighting in the building?
- What strategies should be implemented to improve the daylighting use?

- How much energy can be saved through the maximum use of daylighting in the building?
- What is the cost to implement the daylighting strategies?
- What are the cost benefits to implement the daylighting strategies?

1.2 Significance of the Study

Most of the population in cities like Toronto, work in an indoor environment and they also spend a large amount of time without sun exposure. So, it is very important to take the health benefits and other advantages of daylight. Commercial buildings are using extensive amounts of electrical lighting to illuminate the vast spaces which can be lowered if daylighting strategies are used. Daylight strategies are not only sustainable but are also cost effective. This daylight study shows that it will be useful for any type of commercial/institutional building, e.g. offices, schools, to implement this strategy. From this study it is expected that energy utilization, health benefits, ergonomics and cost effectiveness of lighting in the buildings will be improved.

1.3 Scope and Limitations

The following limitations were imposed on this study;

- Limited access to the building
- Major structural modifications were not considered
- Photo sensors and automated electrical lighting controls were also not considers
- Savings in cooling load/ HVAC energy in cooling season were not calculated
- Increases in heating energy in winter were also not calculated

All four floors of the MON building were studied for daylight illumination level and distribution through simulation and field measurements. Six rooms of different orientations and locations were used for field measurement to validate the simulation model. The study was done during the summer and the field measurement was done in the month of June. During the summer term the departments do not offer full courses and the building is not fully operational, so most of the rooms were closed during this time period and only some of the rooms were available for field measurements, and only for limited time.

Numerous limitations were imposed on this study. Major structural modifications including light pipes were not considered for daylighting design strategies. Due to time constrain photo sensor and automated electrical lighting control systems were also not included in the daylighting design strategies. For the energy savings calculation, savings in cooling/HVAC energy were not considered, only savings in electrical lighting energy were calculated. As well as heating energy will be increased in winter, it was not also calculated. Another limitation in this study is the dynamic nature of sky conditions and daylight illuminance level with limited access to field measurements.

1.4 Background of the Problem

In commercial/institutional buildings electrical lights are a significant source of energy consumption. Generally, commercial/institutional buildings use 35 to 65 percent of their total energy for electrical lighting (Hakkarainen, 2005). This situation gets worse when 100 percent outputs of electrical lights are used all day, while the daylight is available to compensate fully or partially electrical lights. Many studies showed that the daylight can offset the need of electrical lights in the institutional buildings during the day time (Ihm, Nemri & Krarti, 2009). Daylight can provide adequate level of illuminance by using the controller and sensor. Simulation analysis and field survey showed that daylighting can give extensive savings in energy, from 30 to 70 percent of electrical light consumption (Ihm, Nemri & Krarti, 2009). Efficient lighting control can provide better visual comfort, health benefit and energy savings, while, uncontrolled daylighting can produce negative impacts on occupant's visual comfort, create glare problem and increase cooling load during cooling season.

1.5 Approach to Solve the Problems

- Develop the simulation model for the existing building.
- Validate the simulation model through field measurements.
- Site survey has been conducted to identify the problems.
- Sun path study has been performed and used to develop the daylighting strategies.
- Daylighting strategies have been developed and incorporated in the simulation model.
- Daylighting strategies have been evaluated through simulation model.
- Energy savings and cost benefits have been calculated.

The MON building was simulated with the lighting software "AGi32" to evaluate the daylighting potential in the building (Lighting Analysts, 2012). For this purpose, the simulation model was developed for the existing building. The field measurements were carried out and used to validate the simulation model. Six rooms of different orientations and locations were used for the field measurements. Only these rooms were available for field measurements. For the field measurements, grid points 3 feet by 3 feet were made on drawings and 2.5 feet workplane height was used. Illuminating Engineering Society of North America (IESNA) recommended that the illuminance meter should be placed 30" above the ground level for measure illuminance on horizontal surface (IESNA, 2000). Only unobstructed grid points were used to take measurements. Hand light meter Extech HD450 was used to measure the illuminance levels on various points in rooms and outdoor as well. The light meter can measure up to 400 K.lux and it has accuracy of $\pm$ 5 percent for illuminance up to 4 K.lux. Above 4 K.lux it has accuracy of $\pm$10 percent. The daylight levels obtained from the field measurements were compared with the simulation's calculation results to validate with the simulation model.

The sun path study was performed for the windows on each of the floor's sides to evaluate the direct sunlight potential hours for each room. The sun path study's result was used to develop the daylighting design strategies. These daylighting strategies were incorporated into the simulation model to predict the indoor illuminance levels for the year round.

The illuminance prediction results were used to calculate the energy savings in electrical lighting energy consumption for each month and annually. For energy savings calculation it was assumed that the electrical lights were controlled according to room illuminance and sky conditions. Later on, the energy savings results were used to calculate the cost benefits and the simple payback period.

2 Literature Review

2.1 Human Comfort and Health Benefits from Daylight

Daylight is a comfortable source of light for occupants even though it has variation in luminous condition (Dubois 2007). A study regarding variation in luminous was conducted by Dubois in 2007. The study was carried out in a café in the School of Architecture at Laval University, Quebec, Canada. The researcher applied behavior mapping, photographs and external sky condition data for analysis. He found that the most preferable area for its occupants for all types of activities was close to the windows and were the brightest, and daylight zone in the Café.

The daylight is not only the bright light and source of heat but it also affects human health and psychology. A lack of daylight can cause several health and psychological problems, including cardiac disease (Boubekri 2008). Effects of daylight on human bodies take in two ways, one through the eyes to the Pineal gland in brain where Hypothalamus controls metabolism and endocrine system, and the other from skin through photosynthesis process (Boubekri 2008).

Human sleep-wake cycle, body temperature and daily activity are controlled by Suprachiasmatic Nucleus (SCN) in pineal, the SCN is also called as “the body clock or circadian rhythm” (Brainard & Glickman, 2003). Each morning when the human body receives the adequate level of daylight, it stimulates pineal gland and synchronizes the body clock to the Earth’s 24 hours rotational cycle (Hansen, 2006). Daylight stimulates the secretion of serotonin hormones and suppresses the production of melatonin hormones in pineal glands, while night or darkness acts as vice versa. Serotonin and melatonin hormones define the body activity level. The high level of serotonin hormone makes alertness while melatonin hormone causes drowsiness and sleep (Boubekri, 2008, Bommel, 2004). Those people who live and work without contact of daylight can experience problems with their body clock or circadian rhythms and it can cause sleeping disorder, anxiety, Seasonal Affective Disorder (SAD) and several other diseases (Boubekri, 2008). Besides this, Serotonin hormone also helps to produce insulin in the human body, regulate the kidney function, sex organs and body temperature, and also have influences on the mood (Hansen, 2006).

The human skin produces vitamin D through the process of Photosynthesis from the ultraviolet rays B, which are present in the sunlight. Ultraviolet rays are divided into three wavelength spectrums i.e. UV-A wavelength 320nm to 400nm, UV-B 290nm to 315nm and UV-C less than 280nm. UV-A is responsible for skin tanning/pigmentation while UV-C is absorbed in ozone (Boubekri, 2008). Excess exposure of UV rays can cause skin cancer, while lower exposure of UV can cause vitamin D deficiency (Lucas & Ponsonby, 2002). Vitamin D is also available in food but its contribution is very small. About 80% to 100% of Vitamin D is produced by the skin through sunlight (Boubekri 2008). A study was conducting in Massachusetts General Hospital and Harvard Medical School on 290 hospitalized patients. Researchers found that 57% of the patients had severe Vitamin D deficiency because of their limited access to the sunlight and not because of their dietary intake (Boubekri, 2008). High latitude locations have higher Vitamin D deficiency rate because have less sunlight exposure, especially in winter. In the USA, 41% of the male population and 53% of the female population have vitamin D deficiency (Patel, DeCaro & Mather, 2008). Deficiency of vitamin D can cause osteoporosis, rickets and osteomalacia. .

Deficiency of vitamin D in adult male can cause Osteomalacia. Deficiency of vitamin D has also multiple harmful effects on cardiovascular system in adults (Boubekri, 2008). A study found that patients of severe congestive Heart Failure (CHF) also have also vitamin D deficiency beside hyperparathyroidism. (Patel, DeCaro & Mather, 2008). Therefore, it is necessary to design commercial/ institutional buildings that can provide adequate level of daylight to the occupants.

2.2 Energy Savings

Many studies showed that the daylight can offset the need of electrical light in commercial/ institutional buildings during the day time (Ihm, Nemri & Krarti, 2009). Daylight can provide adequate level of illuminance by using the controller and sensor. Simulation analysis and field survey showed that the daylighting can give huge savings in energy, from 30 to 77 percent in electrical lights energy consumption (Ihm, Nemri & Krarti, 2009). A case study was done by the Lighting Research Center (LRC) and Daylight Dividends in 2004 on Harmony Library, Fort Collins, Colorado, USA, to investigate the integration of architectural elements and electrical lighting control in good daylighting design. Researchers found that the library's architectural elements like shadings and windows, and electrical lights elements like lighting fixtures and lighting control systems were designed according to daylight requirements. These strategies gave significant saving in electrical light consumption. Almost half of the main area lights were turned off by photo sensors. 78% of the time, those photo sensors would turn off the electrical lights and only 22% of the time turns on the lights during operating hours. This daylighting design strategies gave a 36% of energy saving (Daylighting Dividends, Case Study Harmony Library, 2004). Efficient daylighting control can provide better visual comfort, health benefit and energy savings. Whereas, uncontrolled daylighting can produce negative impacts on occupants' visual comforts, create glare problem and increase cooling loads during cooling season. Daylighting not only reduces the demand of electrical lights and peak load demand but it also reduces the building cooling load and air-conditioner size (Li DHW 2010).To lower the energy cost of the building it is required that the daylighting system should work constantly throughout the year. (Isoardi, Cowling & Coyne, 2006).

Energy Center Wisconsin performed an experiment in 2005 to evaluate the energy savings in lighting, cooling, heating and fan energy consumption by using daylighting strategies (Energy Center Wisconsin, 2005). The study was executed at the Energy Resource Station near Des Moines, Iowa in two set of identical rooms. Those rooms had separate lighting and HVAC system. One set had standard room configuration, clear glazing and ceiling mounted fluorescent lights with no dimming control. For the other set of rooms were used high performance glazing was used to block direct sunlight and glare, photo sensor and lights with dimming control. The study was conducted in three sessions: summer, fall and winter. The result of this study showed that there were significant savings in lighting and cooling energy. It showed that the energy savings in lighting was 32 percent, cooling 25 percent, fan 3 percent and demand charges 24 percent. This study further showed that the daylighting also reduced 26 percent peak cooling load demand as compared to a standard room. As a result, it can reduce the chiller size too (Energy Center Wisconsin, 2005).

2.3 Shading Device Control and Human Behavior

Uncontrolled daylight can cause several problems for its occupants. Excessive daylight can create glare on the perimeter zone, increase the cooling load and outweigh the benefit of daylight (S.Y.Koo 2010). Shading devices are the most important element of the daylight design. If shading devices are not designed according to sun path and requirement, it can fail the entire efforts of daylight design and cause extreme discomfort for its occupants, and significantly increased energy consumption for the building. There are two types of shading devices. External shading device like overhangs and internal shading devices include blinds and curtains. An internal shading device does not give the benefit in solar heat gain; moreover, the occupant pulls down the blind in unwanted situation that often will not be lifted up again for a longer time period. The survey showed that the frequency of blinds reopen is 0 – 1 times in a day, once they are pulled down (S.Y.Koo 2010).

2.4 Design Strategies

Daylight design strategies start from the planning phase then goes to the implementation phase. Daylight planning begins with the site selection, orientation of building and building shape. Then it continues with optimizing windows, interior finishes, electrical lights and control system (Tanteri, 2006). All daylighting strategies are moved around sunlight and sky's luminance distribution in the space. Daylighting strategies depend on the availability of natural lights and that is determined by the site location i.e. latitude, building orientation, depth of room and interior layout, building's surrounding obstructions season and climate (Daylighting in Building, 2000).

2.4.1 Site Location and Orientation

Site locations and orientations play an important role in daylighting design. The amount of daylight varies from locations to orientations. The geographical locations are defined by latitude and longitude (IESNA, 2000). Daylight can be divided into two components, direct sunlight and diffused lights. Direct sunlight comes directly from the sun to the Earth's surface in clear sky condition, while the diffused lights come from the sky, surroundings and ground reflectance (Gordon, 2003). Daylight availability can be calculated by determining the solar position at the site and the day and time of the year (IESNA, 2000). The Earth revolves around the sun on its axis and has a tilt or declination angle towards the sun. The declination angles change from $+23.45^o$ to -23.45^o from June 21 to December 21. Change in the declination angle changes the seasons and intensity of daylight at all geographical locations (Kalogirou, 2009).

The daylighting strategies for direct sunlight are quite different from diffuse light. The small amount of direct sunlight can provide adequate illuminance level to the interior space (Daylighting in Building, 2000). Sun path diagram can be used to predict the direct sunlight on the site.

2.4.2 Glazing

Glazing is an important part of daylighting design strategies. Solar radiation has 50 percent infrared radiation of its total radiation and it enters in the building through glazing. This infrared radiation is not contributed in visible light (Lechner, 2008). Some glazing can reflect the infrared radiation. Tinted glass can block the infrared radiation as well as visible light. Moreover, tinted glass destroys daylight colours and it also produces heat, ultimately increases the building cooling load. As a result, it is not a good choice for daylighting design. While the reflective glazing can reflect only infrared radiation, not visible light and does not destroy daylight colours or generate heat. Visible transmittance of glazing determines the ratio of visible light transmitted through glazing; it ranges from 0.9 for highly clear glazing to 0.1 for highly tinted glazing. Solar Heat Gain Coefficient (SHGC) determines the total solar radiation passed through the glazing. The ratio of visible transmittance to the solar heat gain coefficient is visible light to the solar gain. If the ratio is higher the daylight will be cooler. (Lechner, 2008).

2.4.3 Sidelighting (Windows)

Windows are commonly used as sidelighting in the buildings. They provide daylight, sight and ventilation simultaneously (Lam, 1986). Windows are the big source of daylighting. The direct sunlight depends on window’s orientations and sizes. South orientation has more direct sunlight than east and west windows, while north windows have least direct sunlight. For the diffused daylight, window orientation is not a matter and all orientations have the same daylight. Poorly designed windows can create uncomfortable glare, excessive daylighting and increased cooling load in cooling season. As the rule of thumb, the useful daylight depth is 1.5 times height of the window (Boubekri, 2008). Most windows are designed in three different positions in the walls i.e. upper, middle and lower part of the walls.

2.4.3.1 High windows

High windows or upper window can provide the deepest penetration of direct sunlight and diffused skylights on the working plane. Other than daylighting, these windows have some more advantages. They are good for security and privacy point of view, as well as space under the windows can be utilized to put some furniture like bookshelves, cabinets, picture frame etc; upper windows have some drawback as well. They have a high potential of uncomfortable glare and poor distribution of ground reflected daylights through ceiling (Lam, 1986).

2.4.3.2 Low windows

Advantages and disadvantages of low windows are opposite of high windows. Lower windows provide uniform light distribution of ground reflected sunlight but have the potential for glare at the tasks level, if they are close to the window. Other inconvenience of low windows includes unsatisfactory views and has privacy issues (Lam, 1986).

2.4.3.3 Middle windows

Middle windows do not provide deep penetration of diffuse skylight as high windows, nor provide uniform light distribution from ground reflected sunlight as low window (Lam, 1986). Middle windows have clear advantage over the views on the high and low windows. Middle windows provide better view and they have average performance as compared to high windows and low windows (Lam, 1986).

2.4.3.4 Light shelves

Light shelves are also a part of sidelighting and it can be placed just above the eye level. Light shelves are used to improve the indoor illuminance of daylighting and controls glare. It also works as a shading device to block direct sunlight. It has better performance in direct sunlight and on south orientation (O'Connor, Lee, Rubinstein & Selkowitz, 1997, Boubekri, 2008). Light shelves should be designed at the planning stages and integrated with windows. Their sizes depend on window's width and room's depth. Light shelves can be installed at the exteriorside, interior side or both sides of the windows (Boubekri, 2008).

2.4.4 Shading Devices Design

Shading devices are used to avoid direct solar radiation entering the building and spaces, especially in the cooling season. Most common external shadings are overhangs, canopies and awnings. While internal shadings are curtains, blinds and shades (Karlen & Benya, 2004). Shadings are very important for daylighting design because if the shading devices are not designed according to sun path and the requirement, will fail the entire efforts for daylighting integration. External Shadings are more efficient than internal shadings in terms of energy savings (Lecher, 2008), as internal shadings not only block direct sunlight but also block the view. Furthermore, internal shadings do not provide much benefit in solar heat gain, whereas efficient external shadings provide excellent daylight, views, heat gain in winter and minimize solar heat gain in summer. External shading devices can be categorized into movable and fixed. Moveable shading devices are more efficient than fixed shadings, but need to operate manually or automatically to adjust according to sun and sky conditions. Fixed shading devices are less expensive and less efficient than moveable shading devices (Karlen & Benya, 2004).

Most external shading devices can be divided into horizontal overhangs, vertical fins or combination of both. Horizontal louvers have some advantages over horizontal solid overhangs. Horizontal louvers put less structural load on the walls as snow can pass through the louvers in winter. In addition to that, in summer hot air passes through the louvers thus reducing heat effect on the window (Lechner, 2008).

Horizontal shadings are good for south orientation windows. They block high altitude direct sunlight in summer and allow low altitude sunlight in winter. While, vertical fins are good for east and west orientation windows, because east and west orientation has very low altitude sun and horizontal shading cannot block low altitude sunlight, only vertical fins can block low altitude sunlight (O'Connor, Lee & Selkowitz, 1997).

Designing the appropriate depth of shading devices is very important for daylighting strategies. Sun path diagram is the best tool to calculate the shading devices depth for both horizontal and vertical shadings. Multiple overhangs or fins can be used on one window to minimize the projection of shading devices.

2.4.5 Indoor Space

Reflectance of walls, ceilings, floors and furniture play an important role for uniform distribution of daylighting in the space. Light colour and high reflectance of wall and ceiling provides the best distribution of daylight and electrical lights. More than 80 percent of reflectance for ceiling, 50 to 70 percent of reflectance for walls and 20 to 40 percent of reflectance for floor is preferable (O'Connor, Lee & Selkowitz, 1997, Meek & Wymelenberg, 2011). "*Sunlight distribution should influence interior layout and detailing. Partioning, equipment, and furnishing should not block any more light than necessary and should be light in color when practicl"* (Lam, 1986). During the planning of interior space furniture, it is necessary to consider the workstation or the partition should not block the daylight and the view (Meek & Wymelenberg, 2011).

Seating positions can also influence the comfort of daylighting in the space. If the window is at the back of the person, it can create a shadow on their task and the tasks can become too dark to see. Similarly, if the person is working on the computer, computer screen will reflect the window light and makes it difficult to see the computer screen. If the person is seated in front of the window and the task is placed in front of the window, that arrangement can create harsh contrast between view field and the tasks. This situation can irritate the person's eyes. The most comfortable seating arrangement is the seat and the task should be placed to the side of the window. This seating arrangement will provide good illumination on the task as well as no direct light source irritating the eyes (O'Connor, Lee & Selkowitz, 1997).

3 Overview of the Building under Study

The Civil Engineering Building (MON) of Ryerson University located at 341 Church Street, at the intersection of Gerrard Street East and Church Street, Toronto, was selected for this study. The building was built by Monetary Times Printing Company in 1929-30. Now this building is in the protected list of Toronto historical buildings because it is old heritage building turning a century old. (http://www.ryerson.ca/maps/#).

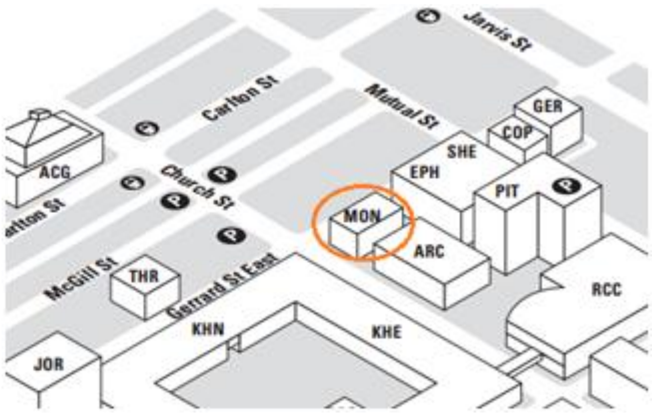


Figure 1: MON building Location map (http://www.ryerson.ca/maps)

The MON building is presently being used by the Civil Engineering Department at Ryerson University. The building area is 5884 sq. ft and dimensions are 110'-6" x 53'-3". It has four floors with the ground floor having a height of 13 feet while the rest of the floors have a height of 10 feet. The building has simple rectangular shape and the longer sides have the north, south orientations. The building has big windows, 7.5 feet high and 11 to 18 feet wide, regardless of orientations (As shown in Figure 22).

Figure 2: Monetary Times Building north-west orientation

Internal plan, rooms are designed on north-south perimeters, all the large rooms are located on the north perimeter and the small rooms are located on the south perimeter at the ground floor, third floor and fourth floor. Whereas, on the second floor the south perimeter has a wide passage and the north perimeter has small offices, while the big rooms are in the middle. Presently the building is only using electrical lights during working hours, regardless of any time of the day, seasons and sky conditions. Figure 3 shows that the blinds were pulled down and the electrical lights were being used.

Figure 3: Electrical lights were using in daytime

3.1 Merits for the study

The MON building has large windows on all four sides and has higher window-to-wall ratio. The large sides of the building have south and north orientation. Apparently, the building has good daylighting potential but presently, the building is using 100 percent electrical lighting during working hours, regardless time, season, and sky condition. The building users' are mostly highly qualified engineers and they have awareness about daylighting benefits; it means there are some problems that force them to avoid the daylighting and use the electrical lightings. These problems need to be study and for that reason, the MON building has been chosen for this study.

4 Validation of Simulation Model with Field Measurement

The simulation model was developed in AGi32 lighting software (Lighting Analysts, 2012) for the existing building to evaluate the daylighting potential in the MON building. To validate the simulation model, field measurements were carried out and compared with the simulation model's calculation results. Then the simulation model was used to analyze the daylighting design strategies, predict the illuminance levels in the spaces and calculate the cost benefits. Sun path study was performed for windows on each of the floor sides to develop the daylighting strategies.

The site survey and field measurements were performed during the months of May and June. The MON building was not fully operated in the summer term and most of the rooms were not accessible to take measurements. The site measurements were conducted only in the accessible rooms during their operating time. Six rooms of different orientation and location were used for field measurements. 3'x3' grid points were marked in the drawings for taking field measurements and only unobstructed grid points at site were used to take measurements.

To calibrate sky illuminance of the simulation model with field measurements, unobstructed outdoor horizontal illuminance were measured and divided by calculated sky illuminance to obtain absolute zenith lumens factor (Lighting Analysts, 2012). These absolute zenith lumen factors were used to calibrate the sky illuminance in the simulation model.

$$\mathit{ABSOLUTE\ ZENITH\ LUMENS\ FACTOR} = \frac{\mathit{MEASURED\ ILLUMINES\ VALUE}}{\mathit{CALCULATED\ ILLUMINES\ VALUE}} \text{--------------------[1]}$$

AGi32 library objects were used to develop the simulation model. Due to the limitation of software library, some furniture was not matched with the site furniture. For that reason, some field measurement points were not matched with the calculation results. Two EXRECT HD450 data logging light meters were used for taking indoor and outdoor illuminance simultaneously to calibrate the sky model. Four rooms' field measurements and comparison results are shown below while the rest of two rooms' comparison results are shown in appendix-B.

4.1 Room 102, Environmental Lab

Room 102 is located at ground floor on a north perimeter of the building and currently is being used as an environmental lab. The room dimensions are 18'-3" wide on the north perimeter by 21'-3" long and the ceiling height is 13'-0". The room has two windows on a north orientation and installed 5'-0" above the floor level. Both windows are 8'-0" wide by 7'-6" high and the window-to-wall ratio (WWR) is 50.6 percent. These windows are double glazed gray tinted and reflective glass with aluminium frame. The walls are painted light gray, the ceiling is white and the floor has dark gray colour carpet. The desks in the center of the room, chairs, some cubicle desk along with both side of the walls, filing cabinets, book shelves and some other room objects are located in the room. Reflectance for the walls 60 percent and 65 percent for the ceiling were assumed for simulation model (Appendix-C). Room's furniture and objects were used from the software objects library to match the existing room condition. The field measurements were done on June 13, 2012 at 4.45 pm under clear sky condition.

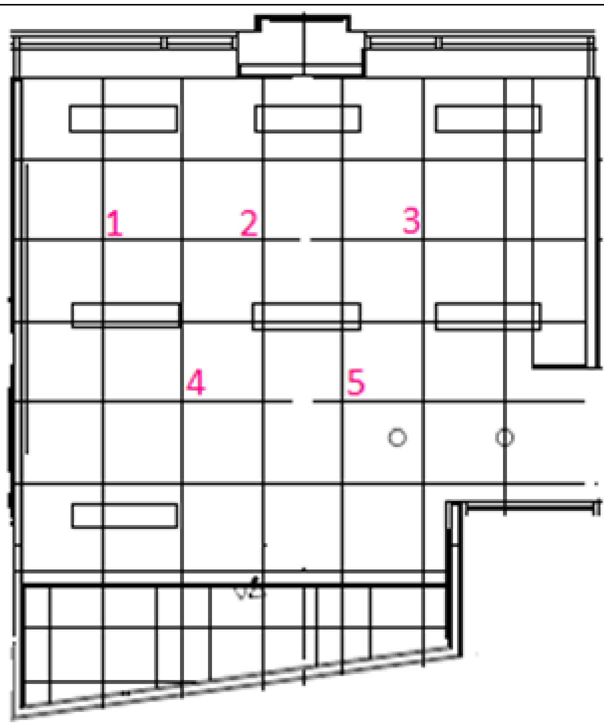


Figure 4: Field measurement grid points for Room-102

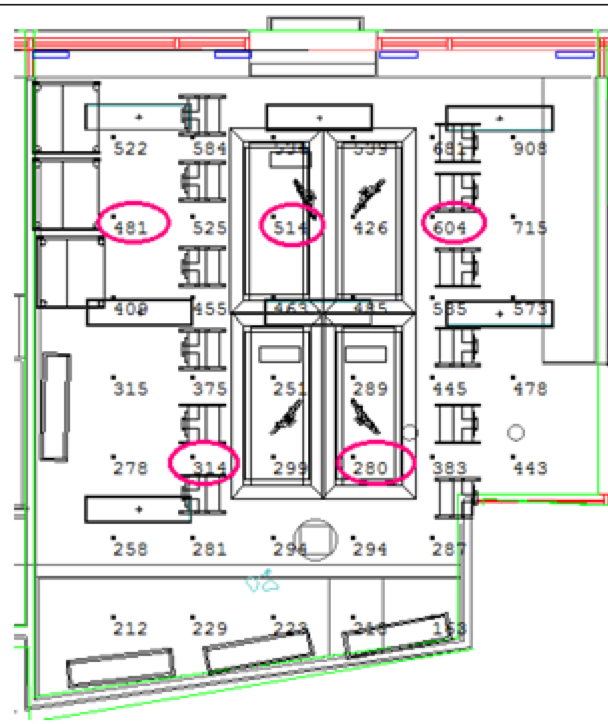


Figure 5: Calculation result for Room-102

Table 1 Comparison b/w field measurement with calculation results for Room-102

Field Measurement Location Number	Field Measurement Illuminance Lux	Simulation Calculation Lux	Difference	
			Lux	%
1	549	481	-68	12
2	543	514	-29	5
3	549	604	55	9
4	287	314	27	8
5	277	280	3	1

Figure 4 shows grid points, where the field measurements were carried out and Figure 5 above shows the simulation model's calculation results. The circled points represent the matched points with the field measurements grid points. Table-1 above shows the comparison between field measurement and the simulation calculation results. Comparison shows that the difference between field measurements and the calculation results are 1 to 12 percent. This little difference is due to the room objects, which were not the same as the software library objects.

4.2 Room-214, Faculty Lounge

Room 214 is located at second floor on north-west corner of the building and it is presently being used as faculty lounge. The room is 16'-3" long on a west orientation by 10'-0" wide on a north orientation. It has two windows; one is 12'-6' wide by 7'-6" high on a west orientation, other window is 8'-3" wide by 7'-6" high and the window-to-wall ratio (WWR) is 59 percent. The windows are double glazed gray tinted and reflective glass with aluminium frame. The walls are painted light grey and the ceiling is white, and the floor has dark gray carpet. Reflectance for the walls 60 percent and 75 percent for the ceiling were assumed for the simulation model (Appendix-C). For the floor, a carpet was used from the software library database. Existing room has a dining table, chairs, a sofa, corner table and a refrigerator. All the furniture and room objects were at or below the task level, except for the refrigerator, so, there was no obstruction for daylighting in the room. Furniture and the room objects similar to the site were used from software library database for the simulation model. The field measurement was carried out on June 13, 2012 at 3.30 pm under clear sky condition.

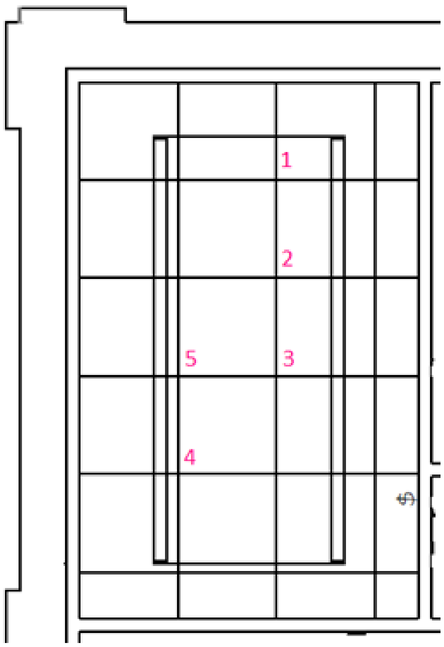


Figure 6:Grid points for measurement Room-214

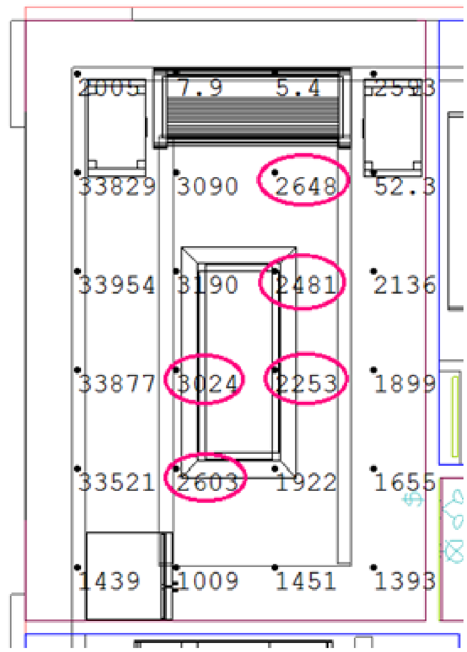


Figure 7: Simulation calculation result Room-214

Table 2 Comparison b/w field measurement and calculation results for Room-214

Field Measurement Point Number	Field Measurement Illuminance Lux	Simulation Calculation Lux	Difference	
			Lux	%
1	2495	2648	153	6
2	2404	2481	77	3
3	2361	2253	-108	4
4	2541	2603	62	2
5	2890	3024	134	4

The field measurement grid points are shown in Figure 6 above and the simulation model's calculation results are shown in Figure 7 above, whereas, the circle marked calculation points are the matching points with field measurements points. Table-2 is showing the comparison between field measurement and the simulation model's calculation results. The comparison shows that the field measurements have just 2 to 6 percent differences with simulation calculation results. Almost all the measurements matched with the simulation calculation results.

4.3 Room 217, Faculty Office

Room-217 is located at second floor on a north perimeter of the building; the room is 9'-6" wide by 11'-6" long. This room is being used as a faculty office. It has one window on a north orientation. The window size is 7'-9" wide by 7'-6" in height and the window-to-wall ratio (WWR) is 61 percent. The window is double glazed, gray tinted and reflective glass with aluminium frame. The walls are painted light gray color, the ceiling is white and the floor has a dark gray carpet. The room has a black workstation, chairs, shelves, file cabinets and other office objects like computers, wall frames and miscellaneous objects. Reflectance for the walls 60 percent, for the ceiling 73 percent were assumed for the simulation model (Appendix-C). While, the carpet, furniture and other room objects were used matching objects from software library database. The field measurements were performed on June 13, 2012 at 2.15 pm under clear sky condition.

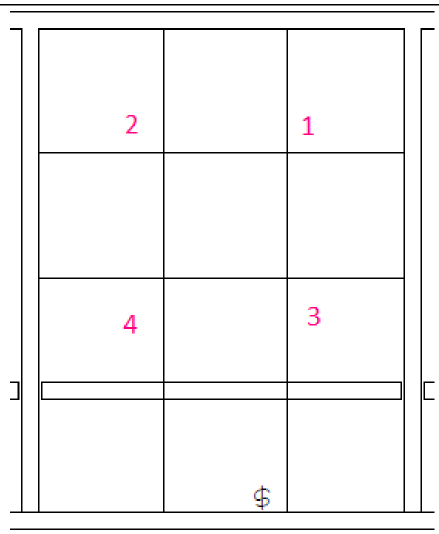


Figure 8: Field measurement grid point Room-217

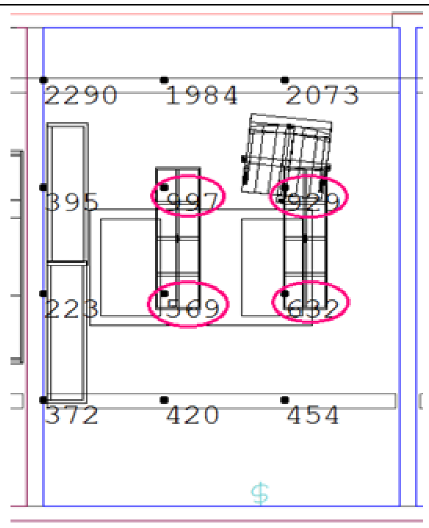


Figure 9: Calculation result Room-217

Table 3 Comparison b/w field measurement and calculation result for room 217

Measurement Grid Point #	Field Measurement Lux	Simulation Calculation Lux	Difference Lux	Difference %
1	845	929	84	9
2	928	997	69	7
3	623	632	9	1
4	602	569	33	5

The field measurements grid points from 1 to 4 are shown in Figure 8 above and the simulation model's calculation results are shown in Figure 9 above. The circle marked simulation calculation points are matched points with field measurements grid points. Table-3 above shows the comparison between the field measurements and the simulation calculation results. Comparison shows that the all four field measurement points were matched with simulation calculation results and the differences are just 1 to 9 percent, which is in the acceptable range.

4.4 Room -305, Faculty Office

Room-305 is located at third floor, having a south orientation and being used as a faculty office. The room is 9'-3" wide by 9'-9" in depth. It has one window on a south orientation. The window is 7'-3" wide and its height is 7'-6" and the window-to-wall ratio (WWR) is 73.5 percent. The window has aluminium frame with double glazed, gray tinted and reflective glass. The room has the fall ceiling at 2' down from the actual ceiling. The room walls are painted light gray and the floor has a dark gray carpet. This room has a black colour workstation, a book shelf, a file cabinet and miscellaneous objects. For the simulation model, 60 percent reflectance for the walls were assumed (Appendix-C) and the close matched fall ceiling, carpet and the furniture were chosen from the AGi32 library data. The field measurements were performed on June 15, 2012 at 4.20 pm, under the Sky condition type 11 in the CIE sky model (Appendix D). Grid points 3'x3' were made in the drawing for taking site measurements.

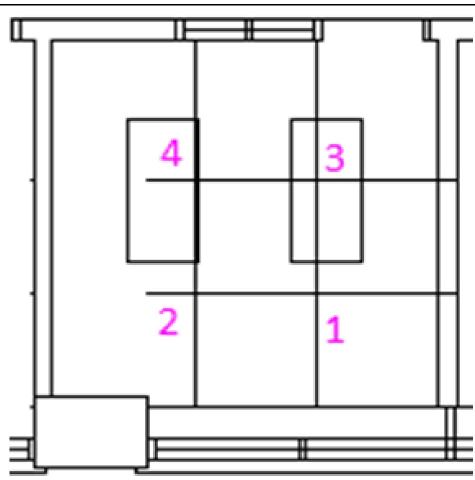


Figure 10: Field measurement grid point Room-305

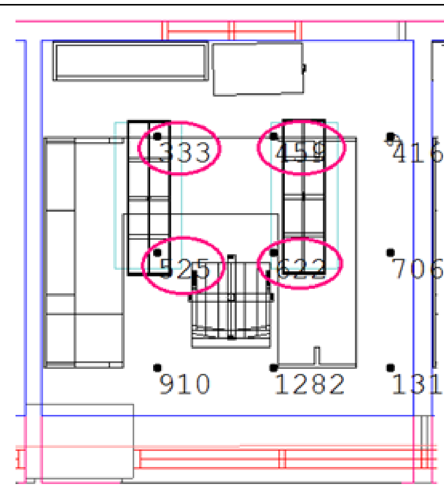


Figure 11: Calculation result Room-305

Table 4 Comparison b/w field measurement and calculation results, Room-305

Measurement Point Number	Site Measurement Lux	Simulation Calculation Lux	Difference Lux	Difference %
1	512	622	110	17
2	521	525	4	1
3	388	459	71	15
4	321	333	12	4

The field measurements grid points in number 1 to 4 are shown in above Figure 10 and the simulation calculation results are shown in above Figure 11, whereas, the circles marked points are the matched points with field measurement points. Table-4 above shows the comparison between the field measurements and the simulation calculation results. The comparison shows that the site measurements and calculation results almost matched. Two points were matched closely while the other two points have differences less than 18 percent. These differences are because the existing room objects and the software library objects were not matched and other limitation as mentioned earlier.

4.5 Validation Summery

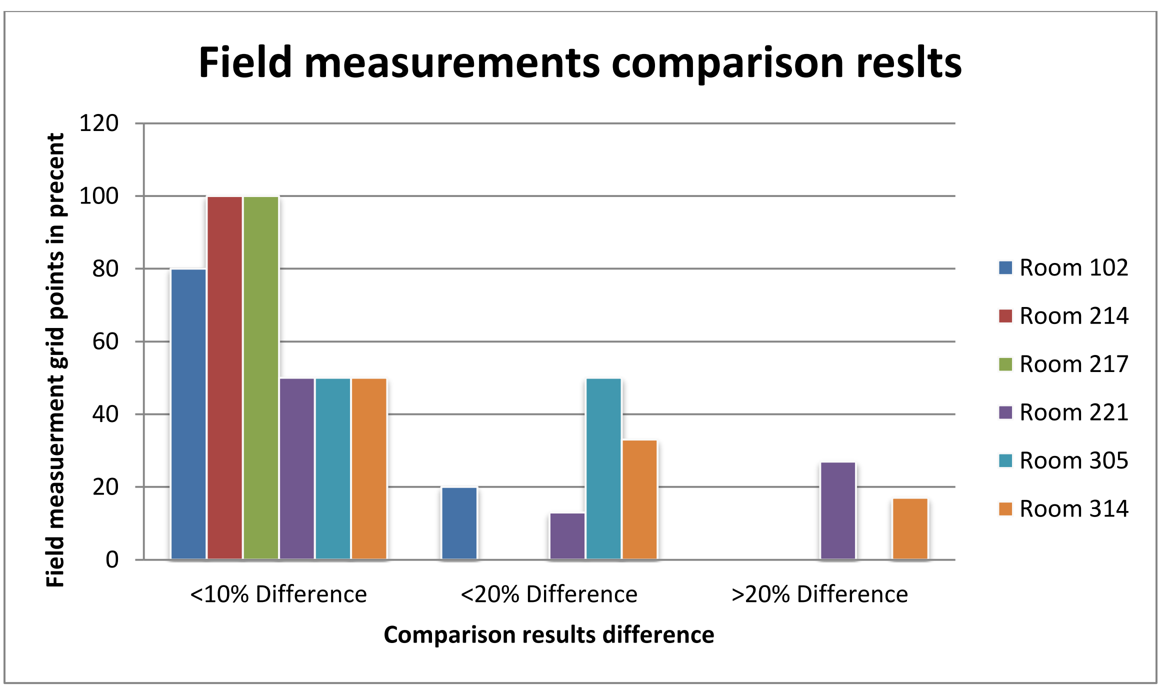


Chart 1 Overall comparison results b/w field measurements and simulation calculations

In total 38 grid points from six rooms were used to measure the illuminance levels on the site and compared with the simulation model's results. Chart-1 above shows that the rooms 214 and 217 have difference of less than ten percent in their comparison between field measurement and simulation calculation results. Room 102 has difference of less than ten percent in its 80 percent field measurements and simulation calculation results. While, the rooms 221, 305 and 314 have difference of less than ten percent in their 50 percent field measurement and simulation calculation results. Only 18 percent of field measurements points had differences more than 20 percent from simulation calculation results. On the other hand, 82 percent field measurements have matched with differences of less than 20 percent. IESNA handbook 9th edition mentioned that the illuminance can be measured up to 25 percent below from the true illuminance.

5 Problems with Daylighting in the MON Building

During the site survey, following problems have been identified.

- 100 percent electrical lightings were in used regardless time and season
- Internal horizontal blinds were down all the time
- Large windows without external shadings
- Small faculty offices have higher window-to-wall ratio
- Rooms on west perimeter have problems with high altitude sun as well as low altitude sun
- Internal layout and seating positions

Presently, the MON building uses 100 percent electrical lights during working hours, regardless of seasons, time and sky conditions (as shown in Appendix A). All windows have horizontal blinds and they are pulled down at all times, despite orientations. At the time of the building survey it is observed that all the windows blinds were pulled down and 100 percent of electric lights were being used, while, outside it was a sunny day (as shown in Figure 12).

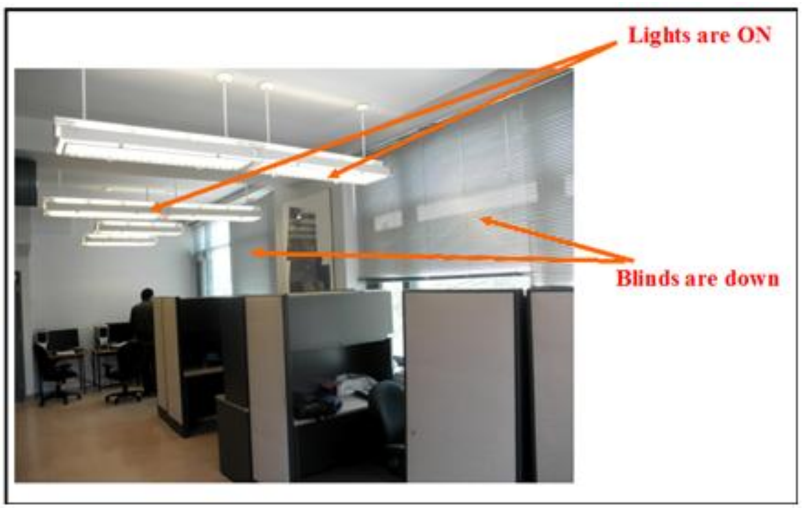


Figure 12: Shows the use of electrical lights and down blinds

The MON building has large windows and a higher window-to-wall ratio, while the faculty offices are very small and have a much higher window-to-wall ratio. There are no external shadings on any of the windows to control direct sunlight as shown in Figure 13.

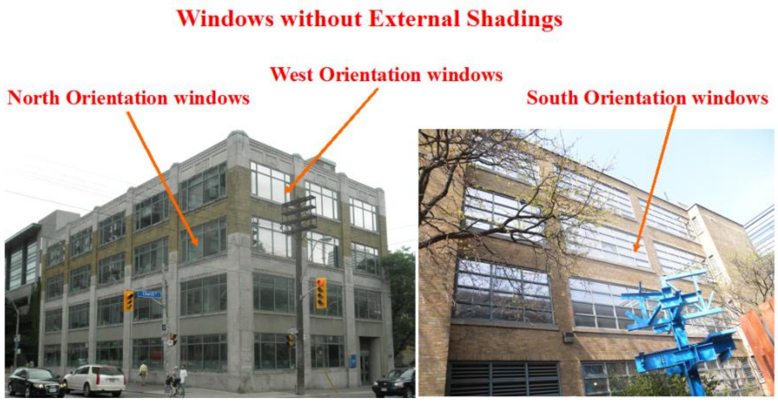


Figure 13: Showing windows without external shadings

These large windows are causing problems for occupants instead of providing the benefits of daylighting and a pleasant indoor environment. The direct sunlight passing through the windows are causing discomfort glare for performing tasks, solar heat gain and increased cooling loads in the summer. Even if there is no direct sunlight, these windows still create excessive brightness for tasks. As a result, occupants use blinds permanently, regardless of window orientation and season.

Faculty offices, room numbers 303, 305, 307, 309, and 311 are on the third floor and room numbers 403, 405, 407, 409 and 411 are on the fourth floor at the south perimeter of the building, they are facing higher problems in summer as well as in the winter because of their large windows. Their window-to-wall ratios are 60 to 70 percent and occupants are sitting close to the windows. These windows create a harsh environment for the occupants under the direct sunlight, cause glare and overheat the rooms. Even, if there is no direct sunlight, these windows create over brightness for the tasks. During the summer, these large windows cause too much heat gain and that fails the cooling system.

Faculty offices, room numbers 212 and 213 are on the second floor, at the west perimeter of the building, they are having significant problems with afternoon sun. These rooms have 80 percent and 64 percent window-to-wall ratio respectively. The direct sunlight hits these rooms in two directions; at higher altitude sunlight and at lower altitude sunlight. Lower altitude solar direct light penetrates deep inside the room.

Faculty Lounge in room 214 on the second floor, the Graduate Studies room 318 on the third floor and 418 on the fourth floor, are at the corner of northwest orientation of the building and have 60 percent window-to-wall ratio. These rooms also have difficulty with direct sunlight from afternoon to the sunset, with high altitude sun to low altitude sun. In these rooms, direct sunlight starts to enter in afternoon and penetrate deep into the room until sunset (as shown in Figure 14). Additionally, direct sunlight enters these rooms from the north windows before sunset during the summer.

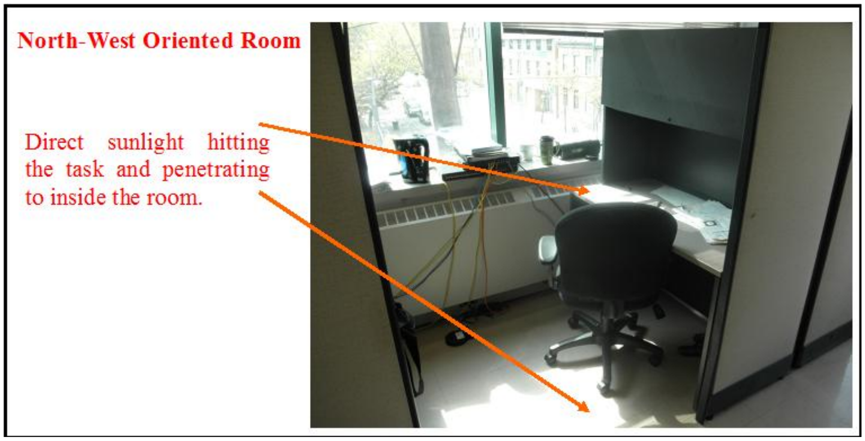


Figure 14: Direct sunlight hitting the task and penetrating to inside the room

During the site survey, another problem has been found in the building, specifically, the internal layout of the faculty offices and administration office. Professors and staff spend their time on reading, writing and working on computers in these rooms and they need comfortable light for their tasks. Their desks were placed close to the windows and the windows were behind their seats (as shown in Figure 15). This position creates shadow on their task and makes it dark and if they were working on the computer, the computer screen would reflect the brighter window light and make it difficult to see the computer screen clearly. For that reason, they put the blinds on the windows all the time.

Figure 15: Sitting position and room layout

6 Daylighting Design Strategies

6.1 Sun Path Study with Obstruction Angle Analysis

Sun path study is necessary in evaluating the daylight potential in the building and in the design of external solar shading. Earth coordinate points i.e. Latitude and longitude, are required to draw the Sun path diagram from Laboratories web site (University of Oregon Solar Radiation Monitoring Laboratory, 2012). The MON building is situated at Latitude 43.66 and Longitude 79.378 West. Figure 16 below shows the sun path around the MON building, on June 21, the longest solar day of the year, December 21, the shortest solar day of the year and March 21/September 21, the equal day and night time of the year.

Figure 16 below shows sun rise, sunset angle and time; as well as solar altitude with respect to time and date at this location. The MON building has 107.87-degree orientation from north.

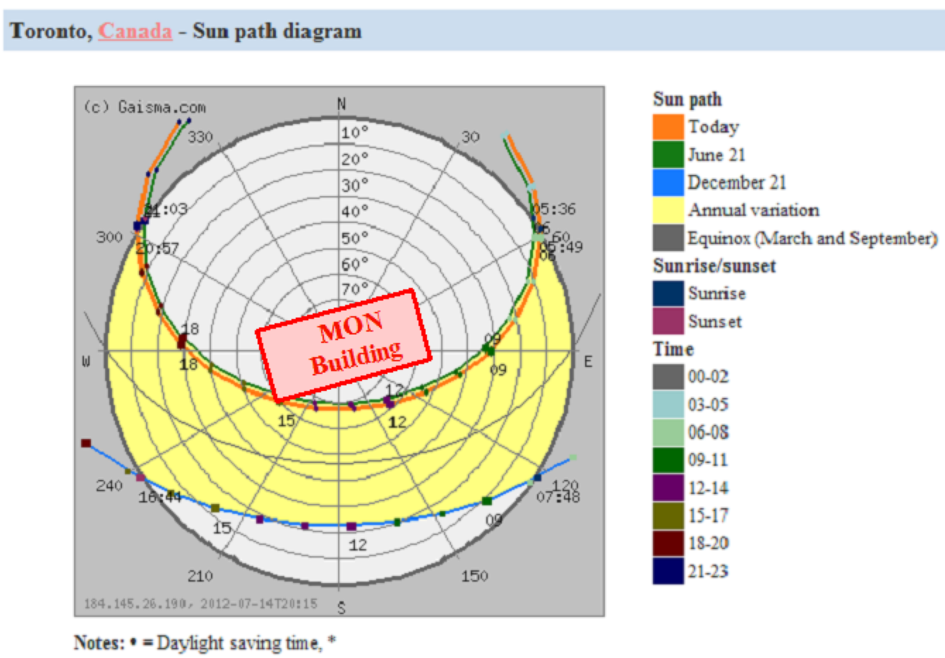


Figure 16: Sun rise and sun set time and angle with SunPath (www.gaisma.com)

On longest day of the year i.e. June 21, sun rises from 62° northeast and sets at 302° north-west. On shortest day of the year sun rises from 118° south-east and sets at 238° south-west and on equal day and night time of the year i.e. March 21 and September 21, sun rises from 90^o east and sets on 270^o west (as shown in Table 5).

Table 5: Sunrise and sunset angles on that location

Date	Sun rise	Sunset
June 21	62^o north-east	302^o north-west
December 21	118^o south-east	238^o south-west
March 21 & September 21	90^o east	270^o west

Obstruction angle is the angle between occupant's elevation and the heights of adjacent structure. The obstruction angles were calculated for windows on each of the floor sides to evaluate the direct sunlight potentials. To calculate the obstruction angles, the 3D models, as shown in figure 17, were used to find adjacent buildings heights and distances.

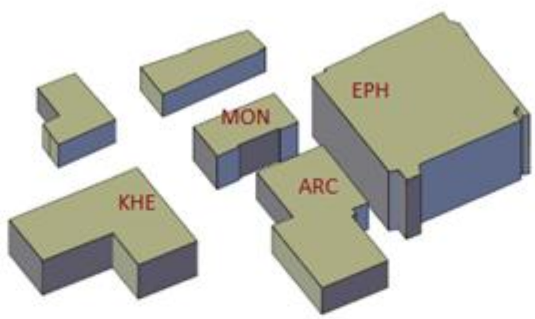


Figure 17: 3D model showing adjacent building's obstruction

Sun path study and obstruction angles analysis were carried out for windows on each of the floor sides of the MON building. The details of the sun path study are presented in the following section.

6.1.1 South Perimeter

6.1.1.1 Windows on ground floor

The room 101 Student Lounge and the room 105 Machine Shop on the ground floor have windows at the south orientation. These windows have an azimuth angle 164^o from true north and the aperture angles (direct sunlight potential angle) from, 90^o, to, 240^o, from north. These windows have obstructions from the EPH building on east, the ARC building on south and the KHE building on west side. The obstruction angles were calculated as, 46^o on southeast side with EPH building, 45^o on south with ARC building and, 19^o, on the west with the KHE building (Appendix E). The south windows on the ground floor get direct sunlight only during the months of April to August as shown in Figure 18.

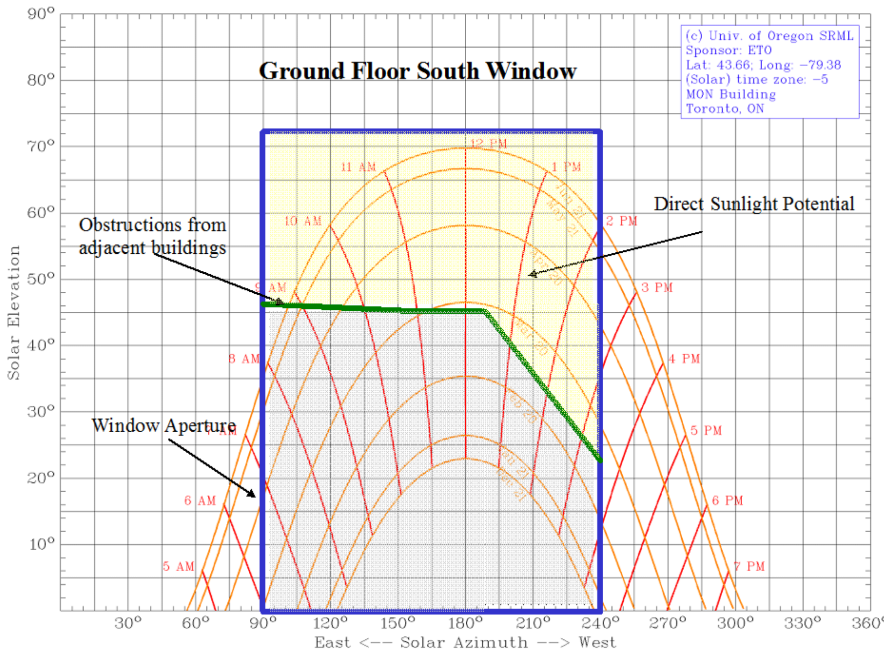


Figure 18: Sunlight potential and obstructions for south windows on ground floor

Table 6 is showing the numbers of hours of direct sunlight that the MON building can received in each month through the south windows on ground floor. The rooms 101 and 105 can received more than five hours of direct sunlight in cooling season from April to August. These direct sunlight hours are enough to increase the cooling load significantly.

Table 6: Direct sunlight potential hours for south window on ground floor

	Solar Altitude at the window	Sunlight (Solar Time) Start Time	End Time	Numbers of hours on 21st	Numbers of hours in the month
Dec-21	-				
Jan-21	-				
Feb-21	-				
Mar-21	46°	11.15 am	3.15 pm	4	40 (10 Days)
Apr-21	57°	9.30 am	2.40 pm	5.16	154.8
May-21	63°	9.00 am	2.15 pm	5.25	162.75
Jun-21	70°	8.45 am	2.00 pm	5.25	157.5
Jul-21	63°	9.00 am	2.15 pm	5.25	162.75
Aug-21	57°	9.30 am	2.40 pm	5.16	160
Sep-21	46°	11.15 am	3.15 pm	4	40 (10 Days)
Oct-21	-				
Nov-21	-				
				Total =	**877.80 hr/year**

6.1.1.2 Windows on second floor

South perimeter has a wide corridor on the second floor and there are three windows on south orientation. These windows have an azimuth angle, 164°, from true north and aperture angles (direct sunlight potential angle) from, 90°, to, 240°, from north. These windows have obstructions from the EPH building on east and, the ARC building and the KHE building on west side. The obstruction angles were calculated as, 41°, on southeast side with the EPH building, 32°, on south with the ARC building and 13° on west with the KHE building (Appendix - E). Figure 19 (please see the following page) shows that the south windows on the second floor, only at high altitude sun, have direct sunlight from February to October.

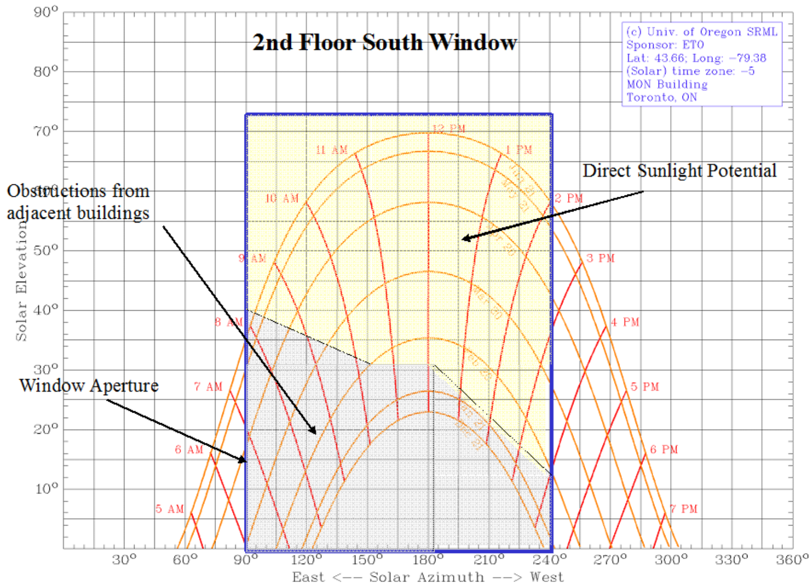


Figure 19: Sunlight potential and obstructions for south windows on second floor

Table-7 shows that the number of hours of direct sunlight received the MON building through the south windows on second floor in each month of the year. These windows received 5.5 hours to 6 hours direct sunlight per day in cooling season. This direct sunlight offset the cooling and as a result, corridor become uncomfortable hot for it user.

Table 7: Sunlight potential hours for south windows on second floor

	Solar Altitude at the window	Sunlight (Solar Time) Start Time	End Time	Numbers of hours on 21st	Numbers of hours in the month
Dec-21	-				
Jan-21	-				
Feb-21	35°	10.15 am	3.45 pm	5.5	159.5
Mar-21	46°	9.30 am	3.00 pm	5.5	170.5
Apr-21	57°	8.40 am	2.40 pm	6	180
May-21	67°	8.20 am	2.05 pm	5.75	178.25
Jun-21	70°	8.15 am	2.00 pm	5.75	172.5
Jul-21	67°	8.20 am	2.05pm	5.75	187.25
Aug-21	57°	8.45 am	2.40 pm	6	186
Sep-21	46°	9.30 am	3.00 pm	5.5	165
Oct-21	35°	10.15 am	3.45 pm	5.5	170.5
Nov-21	-				
				Total =	1569 hr/year

6.1.1.3 Windows on third floor

South perimeter has Faculty offices room 303, 305, 307, 309 and 311on the third floor and they have three windows at south orientation. These windows have an azimuth angle 164° from true north and aperture angles (direct sunlight potential angle) are from 90° to 240° from north. These windows have obstructions from the EPH building on east, the ARC building on south and the KHE buildings on west. Obstruction angles were calculated as, 36° on southeast side with the EPH building, 18° on south with the ARC building and 9° on west with KHE building (Appendix E). Figure 20 showed that the south windows on the third floor have direct sunlight, whole year from December to November.

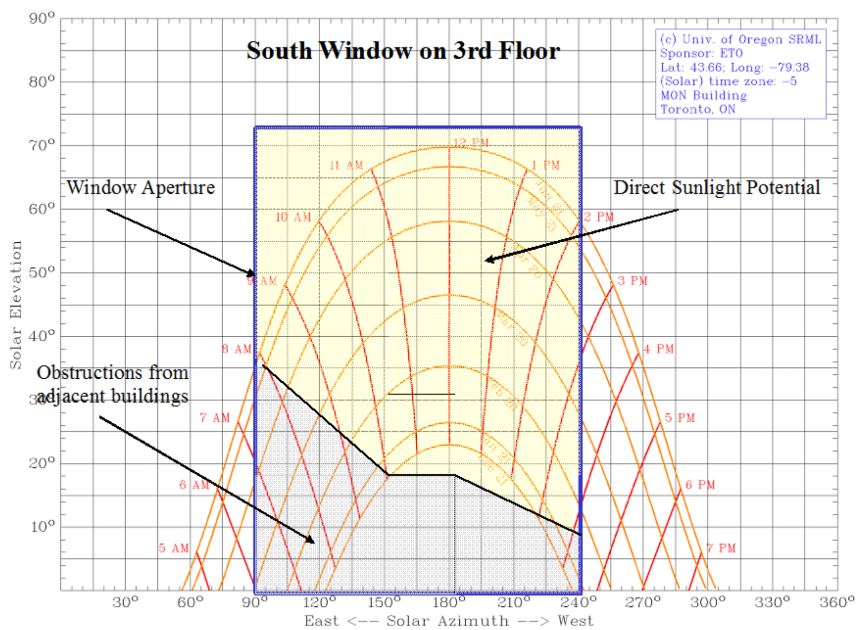


Figure 20: Sunlight potential and obstructions for south windows on third floor

Table 8 is showing the number of hours of direct sunlight can receive the faculty offices on the third floor through their south windows. Faculty offices are very small rooms and they have more than 60 percent window-to-wall ratio. They are receiving more than 6 hours of sunlight per day. These are quite enough to make room temperature uncomfortable for their occupants.

Table 8: Sunlight potential hours for south windows at third floor

	Solar Altitude at the window	Sunlight (Solar Time) Start Time	End Time	Numbers of hours on 21st	Numbers of hours in the month
Dec-21	23°	10.00 am	3.00 pm	5	155
Jan-21	27°	9.50 am	3.10 pm	5.33	165.23
Feb-21	35°	9.10 am	4.00 pm	6.84	191.52
Mar-21	46°	8.40 am	3.00 pm	6.34	196.54
Apr-21	57°	8.15 am	2.45 pm	6.5	195
May-21	67°	8.00 am	2.05 pm	6.08	210.8
Jun-21	70°	8.00 am	2.00 pm	6	180
Jul-21	67°	8.00 am	2.05 pm	6.08	188.48
Aug-21	57°	8.15 am	2.45 pm	6.5	201.5
Sep-21	46°	8.40 am	3.00 pm	6.34	190.5
Oct-21	35°	9.10 am	4.00 pm	6.84	212.04
Nov-21	27°	9.50 am	3.10 pm	5.33	160
				Total =	**2246.61 hr/year**

6.1.1.4 Windows on fourth floor

The faculty offices rooms 403, 405, 407, 409 and 411 on the fourth floor, have windows at the south orientation. These windows have an azimuth angle 164° from true north and aperture angles (direct sunlight potential angle) are from 90° to 240° from north. These windows have only obstruction from the EPH building on east. Obstruction angles were calculated as, 31° on east and 18° on the southeast from the EPH building (Appendix E). On south with the ARC building and on west with the KHE building there is no obstruction for sunlight. Figure 21 showed that the faculty offices have unobstructed sunlight whole year.

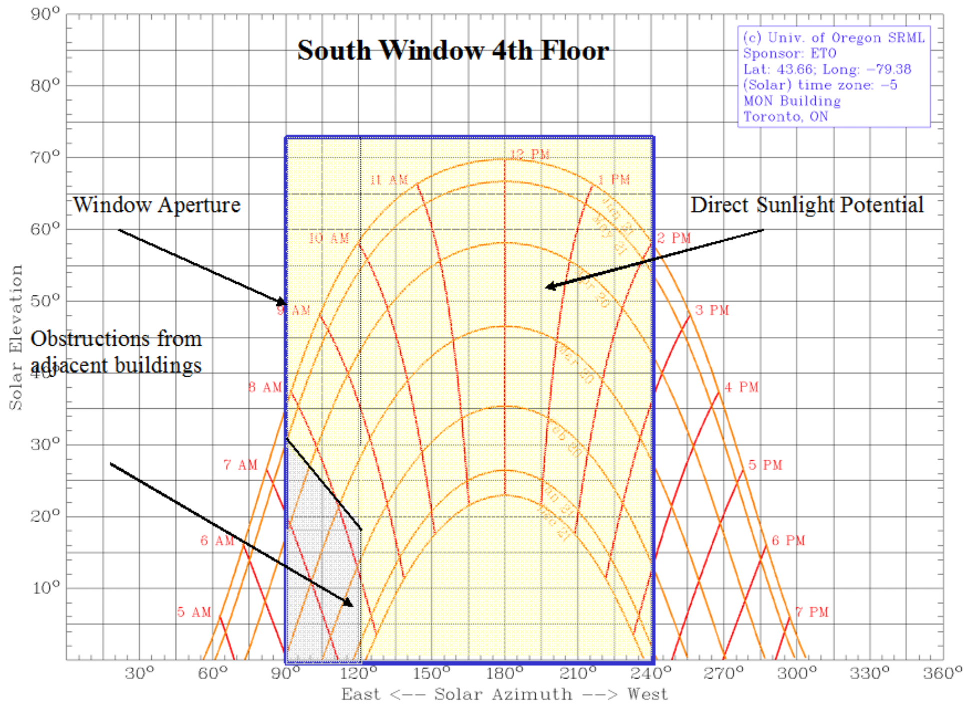


Figure 21: Sunlight potential and obstructions for south windows on fourth floor

Table 9 shows that the faculty offices at fourth floor can receive six to nine hours of direct sunlight per day throughout the year, through its south windows. The faculty offices are very small and have more than 60 percent window-to-wall ratio, these direct sunlight hours are good enough to fail the cooling system in the summer and force the occupants to keep the blind down in the winter too to avoid glare and over brightness.

Table 9: Direct sunlight potential hours for south windows on fourth floor

	Solar Altitude at the window	Sunlight (Solar Time)		Numbers of hours on 21st	Numbers of hours in the month
		Start Time	End Time		
Dec-21	23°	7.30 am	4.30 pm	9	279
Jan-21	27°	7.15 am	4.15 pm	9	279
Feb-21	35°	8.00 am	4.00 pm	8	224
Mar-21	46°	8.00 am	3.15 pm	7.25	224.75
Apr-21	57°	7.45 am	2.45 pm	7	210
May-21	67°	7.30 am	2.05 pm	6.6	204.6
Jun-21	70°	8.00 am	2.00 pm	6	180
Jul-21	67°	7.30 am	2.05 pm	6.6	204.6
Aug-21	57°	7.45 am	2.45 pm	7	217
Sep-21	46°	8.00 am	3.15 pm	7.25	217.5
Oct-21	35°	8.00 am	4.00 pm	8	248
Nov-21	27°	7.15 am	4.15 pm	9	270
				Total =	**2758.45 hr/year**

6.1.2 West Perimeter

6.1.2.1 Windows on ground floor

The Concrete Lab Room 104 has two windows on the west elevation. These windows have 255° an azimuth angle from true north and, 180°, to, 330°, the aperture angles (sunlight potential angle). The obstruction angles for these windows were calculated as, 18°, angle on south-west from the KHE, 31°, angle on west with the KHE while Gerrard Street is on north-west side (Appendix-E). Figure 22 showed that the west windows on ground floor get direct sunlight from afternoon to until sunset, throughout the whole year from December to January. These windows allow direct sunlight from high altitude sun to low altitude sun at 20°.

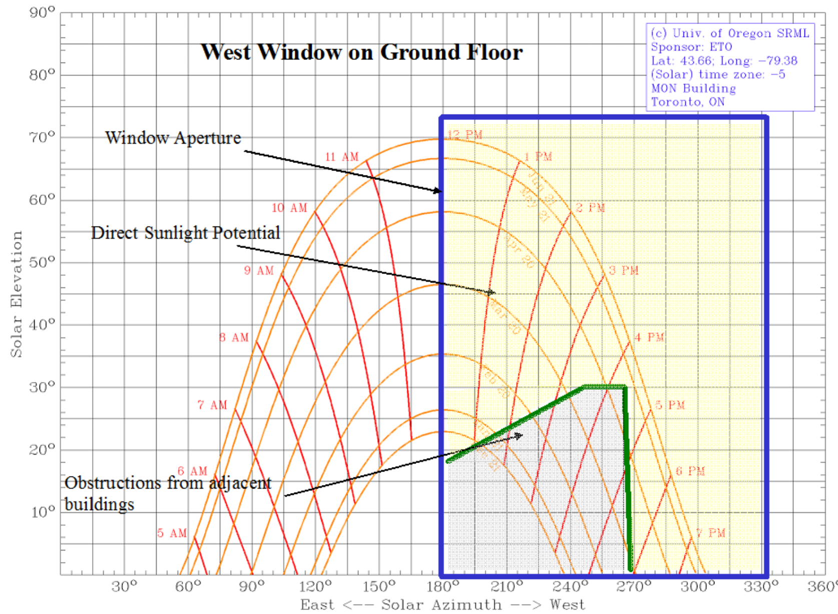


Figure 22: Sunlight potential and obstructions for west windows on ground floor

Table 10 below shows that the sunlight potential hours for the room 104 through the west windows at ground floor in each month and per year. This room can receive 6.5 hours to 7.5 hours of direct sunlight per day during cooling season from April to August.

Table 10: Direct sunlight potential hours for west window on ground floor

	Solar Altitude at the window	Sunlight (Solar Time)		Numbers of hours on 21st	Numbers of hours in the month
		Start Time	End Time		
Dec-21	23°	12.00 pm	1.00 pm	1	31
Jan-21	27°	12.00 pm	1.30 pm	1.5	46.5
Feb-21	35°	12.00 pm	2.30 pm	2.5	72.5
Mar-21	46°	12.00 pm	3.15 pm	3.25	100.75
Apr-21	57°	12.00 pm	6.30 pm	6.5	195
May-21	67°	12.00 pm	7.15 pm	7.25	224.75
Jun-21	70°	12.00 pm	7.30 pm	7.5	225
Jul-21	67°	12.00 pm	7.15 pm	7.25	224.75
Aug-21	57°	12.00 pm	6. 30 pm	6.5	201.5
Sep-21	46°	12.00 pm	3.15 pm	3.25	97.5
Oct-21	35°	12.00 pm	2.30 pm	2.5	77.5
Nov-21	27°	12.00 pm	1.30 pm	1.5	45
				Total =	**1541.75 hr/year**

6.1.2.2 Windows on second floor

The faculty offices rooms 212, 213 and the faculty lounge room 214 have windows at the west elevation. These windows have 255° an azimuth angle from true north and 180° to 330° aperture angles (sunlight potential angle). Obstruction angles were calculated for these windows (Appendix-E) as, 13° on south-west from the KHE, 23°, on west from the KHE and the Gerrard Street on north-west side. Figure 23 below shows that the west windows on the second floor get direct sunlight from the afternoon, during whole year from January to December. These windows allow direct sunlight from the high altitude sun to low altitude sun at 20° to enter the rooms.

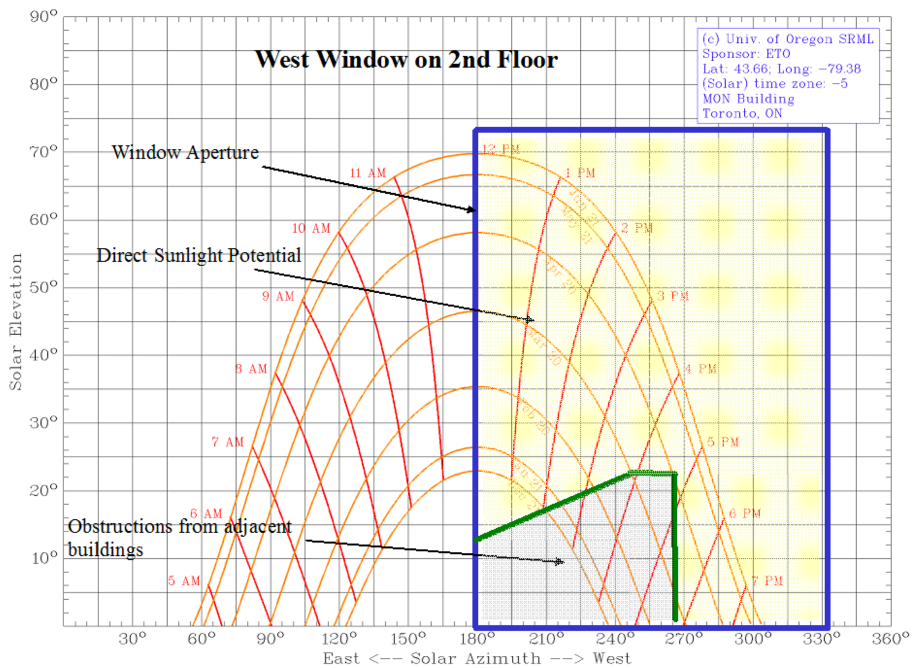


Figure 23: Sunlight potential and obstructions for west windows on second floor

Table 11 below shows that the sunlight potential hours for faculty offices on the second floor through their west windows in each month per year. These rooms can receive 6.75 to 7.5 hours of direct sunlight through their west windows in summer. The faculty offices are very small and they have higher window-to-wall ratio. These hours of direct sunlight are enough to fail any conditioning system in this kind of room.

Table 11: Direct sunlight potential hours for west windows on second floor

	Solar Altitude at the window	Sunlight (Solar Time)		Numbers of hours on 21st	Numbers of hours in the month
		Start Time	End Time		
Dec-21	23°	12.00 pm	2.00 pm	2	62
Jan-21	27°	12.00 pm	2.10 pm	2.16	66.96
Feb-21	35°	12.00 pm	3.00 pm	3	84
Mar-21	46°	12.00 pm	4.00 pm	4	124
Apr-21	57°	12.00 pm	6.45 pm	6.75	202.5
May-21	67°	12.00 pm	7.15 pm	7.25	224.75
Jun-21	70°	12.00 pm	7.30 pm	7.5	225
Jul-21	67°	12.00 pm	7.15 pm	7.25	224.75
Aug-21	57°	12.00 pm	6.45 pm	6.75	209.25
Sep-21	46°	12.00 pm	4.00 pm	4	120
Oct-21	35°	12.00 pm	3.00 pm	3	93
Nov-21	27°	12.00 pm	2.10 pm	2.16	64.8
				Total =	**1701 hr/year**

6.1.2.3 Windows on third floor

The Graduate Studies room 318 on the third floor has two windows at the west elevation. These windows have 255° azimuth angle from true north and 180° to 330° aperture angle (sunlight potential angle). Obstruction angles calculated for these windows (Appendix-E) are 9° on south-west from the KHE and 16° on west from the KHE. The Gerrard Street is on north-west side. Figure 24 showed that the west windows get direct sunlight from afternoon till sunset and whole year from January to December. These windows allow direct sunlight from the high altitude sun, as well as the low altitude sun. The low altitude sunlight penetrates deep inside the room.

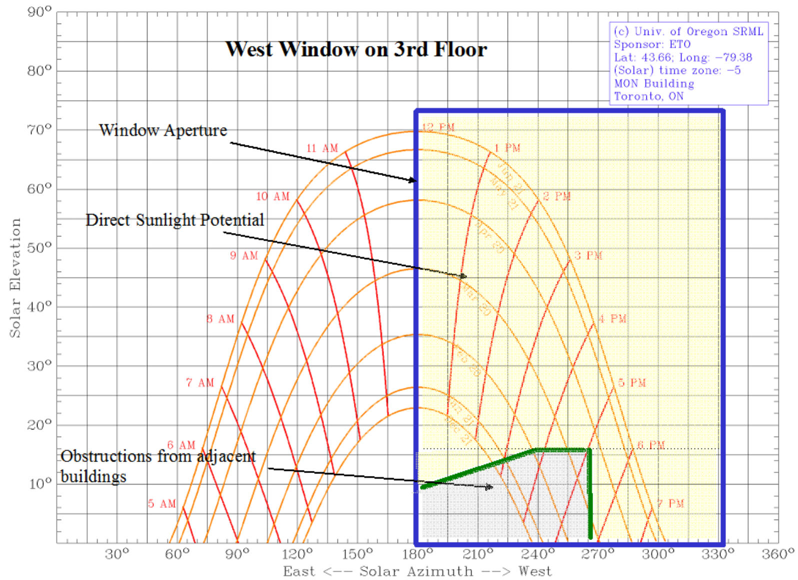


Figure 24: Sunlight potential hours and obstructions for west windows on third floor

Table 12 shows that the graduate studies room 318 can receive 6.75 to 7.50 hours of direct sunlight per day through its west windows in cooling season. These direct sunlight hour are enough to make room uncomfortable and significantly increase the cooling loads.

Table 12: Direct sunlight potential hours for west windows on third floor

	Solar Altitude at the window	Sunlight (Solar Time)		Numbers of hours on 21st	Numbers of hours in the month
		Start Time	End Time		
Dec-21	23°	12.00 pm	2.45 pm	2.75	85.25
Jan-21	27°	12.00 pm	3.00 pm	3	93
Feb-21	35°	12.00 pm	3.45 pm	3.75	105
Mar-21	46°	12.00 pm	4.30 pm	4.5	139.5
Apr-21	57°	12.00 pm	6.45 pm	6.75	202.5
May-21	67°	12.00 pm	7.15 pm	7.25	224.75
Jun-21	70°	12.00 pm	7.30 pm	7.5	225
Jul-21	67°	12.00 pm	7.15 pm	7.25	224.75
Aug-21	57°	12.00 pm	6.45 pm	6.75	209.25
Sep-21	46°	12.00 pm	4.30 pm	4.5	135
Oct-21	35°	12.00 pm	3.45 pm	3.75	116.25
Nov-21	27°	12.00 pm	3.00 pm	3	90
				Total =	**1850.25 hr/year**

6.1.2.4 Window on fourth floor

The Graduate Studies room 418 on the fourth floor has two windows at the west elevation. These windows have 255^o azimuth angle from true north and the aperture angles are 180^o to 330^o. Obstruction angles were calculated as (Appendix-E), 5^o angle on south-west from the KHE and 9^o angle on the west from the KHE. Gerrard Street is on north-west side. Figure 25 showed that the west windows on the fourth floor have direct sunlight potential from afternoon to sunset, almost whole year. These windows allow direct sunlight from the high altitude sun, as well as low altitude sun.

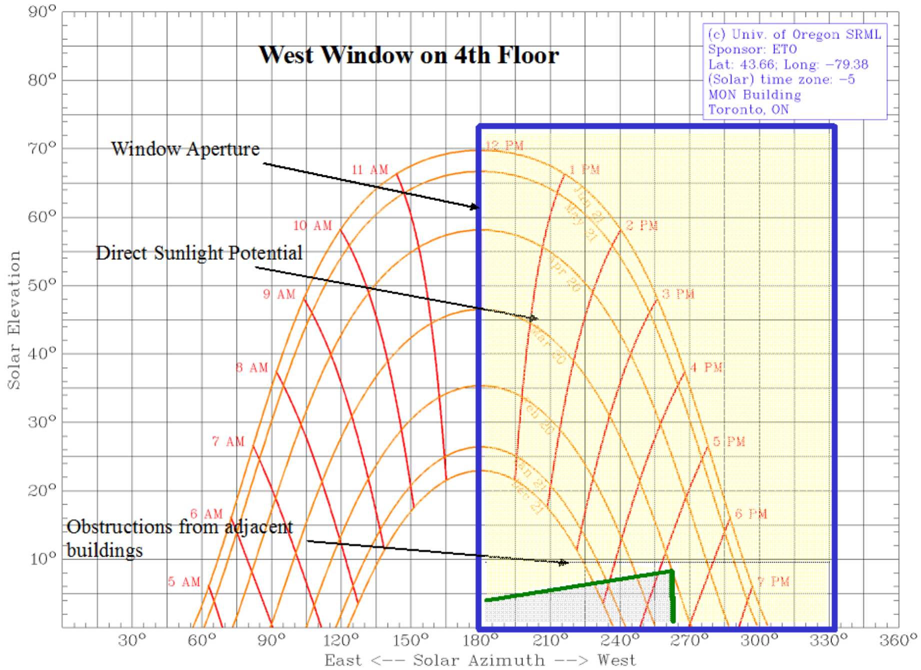


Figure 25: Direct sunlight potential and obstructions for west window on fourth floor

Table 13 (please see the following page) shows that Graduate Studies room 418 can receive 4 to 7.5 hours per day of direct sunlight through its west windows throughout the year and during the summer it can receive 6 to 7.5 hours per day of direct sunlight. These hours of direct sunlight offset the cooling efforts and make the room uncomfortably hot.

Table 13: Direct sunlight potential hours for room 418 through west windows

	Solar Altitude at the window	Sunlight (Solar Time)		Numbers of hours on 21st	Numbers of hours in the month
		Start Time	End Time		
Dec-21	23°	12.00 pm	3.45 pm	3.75	116.25
Jan-21	27°	12.00 pm	4.00 pm	4	124
Feb-21	35°	12.00 pm	4.30 pm	4.5	126
Mar-21	46°	12.00 pm	6.00 pm	6	186
Apr-21	57°	12.00 pm	6.45 pm	6.75	202.5
May-21	67°	12.00 pm	7.15 pm	7.25	224.75
Jun-21	70°	12.00 pm	7.30 pm	7.5	225
Jul-21	67°	12.00 pm	7.15 pm	7.25	224.75
Aug-21	57°	12.00 pm	6.45 pm	6.75	209.25
Sep-21	46°	12.00 pm	4.30 pm	6	180
Oct-21	35°	12.00 pm	3.45 pm	4.5	139.5
Nov-21	27°	12.00 pm	3.00 pm	4	120
				Total =	**2078 hr/year**

6.1.3 North Perimeter

6.1.3.1 Windows on all floors

The north windows have 343° azimuth angle from true north and these window have aperture angles 270° to 55° from north. The MON building has the Gerrard Street on north side and it has an east-west direction. Sun does not move to north and its maximum azimuth angle is 300° from north on June 21. As a result, there is no need to calculate the obstruction angle for north direction. These windows get direct sunlight from lower altitude sun in the evening before sunset (as shown in Figure 26).

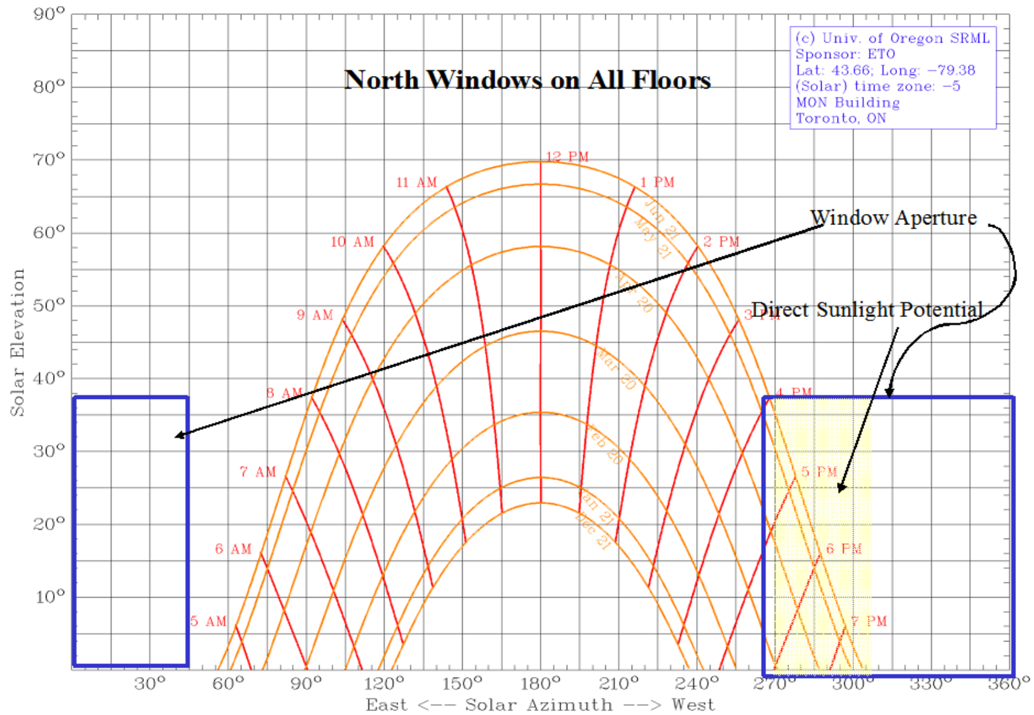


Figure 26: Sunlight potential for north windows

Table 14: Direct sunlight potential hours for north windows

	Solar Altitude at the window	Sunlight (Solar Time) Start Time	End Time	Numbers of hours on 21st	Numbers of hours in the month
Dec-21	-				
Jan-21	-				
Feb-21	-				
Mar-21	-				
Apr-21	15°	5.00 pm	7.00 pm	2	60
May-21	30°	4.30 pm	7.15 pm	2.75	85.25
Jun-21	35°	4.00 pm	7.30 pm	3.5	105
Jul-21	30°	4.30 pm	7.15 pm	2.75	85.25
Aug-21	15°	5.00 pm	7.00 pm	2	62
Sep-21	-				
Oct-21	-				
Nov-21	-				
				Total =	397.50 hr/year

Table 14 above shows that the MON building can receive 2 to 3.5 hours of direct sunlight through its north windows on all floors from April to August. These are the evening hours and they have low altitude sun in the evening from 4.00 pm until sunset.

6.1.4 East Perimeter

6.1.4.1 Windows at ground floor

The MON building has one window on east elevation on the ground floor in Room 102A. This window has an azimuth angle 74^{o} from north and the aperture angel 0^{o} to 145^{o}. The east window has the EPH building on east side and Gerrard Street on north side. Obstruction angles were calculated 67^{o} on east direction with the EPH building (Appendix-E) and 26^{o} on southeast direction with the EPH building. Figure 27 below shows that direct sunlight potential through the east window on ground floor. It has half hour from March to two hours in June before noon direct sunlight potential.

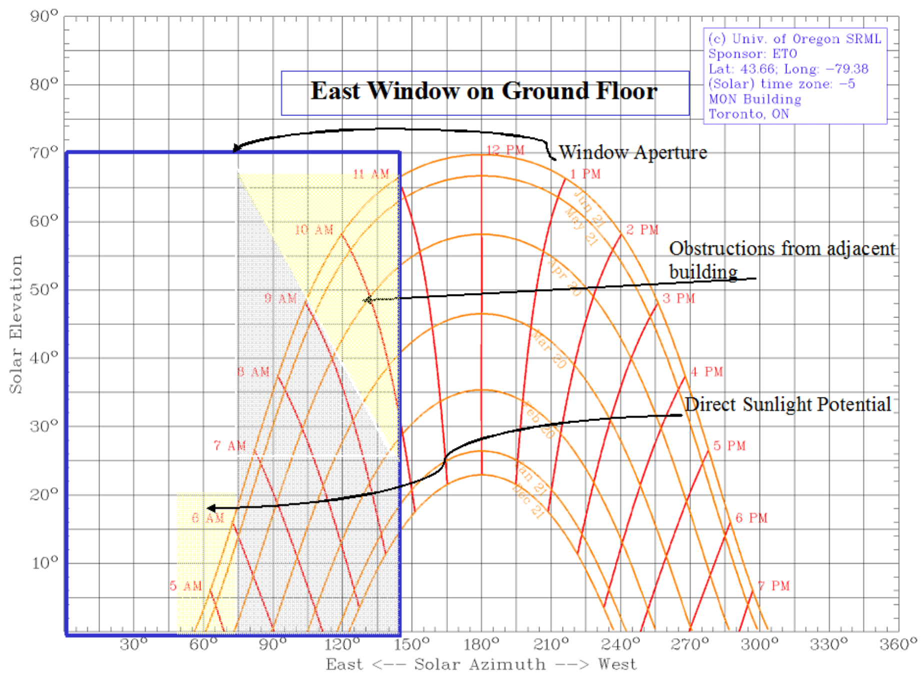


Figure 27: Sunlight potential and obstructions for east window on ground floor

6.1.4.2 Windows on second floor

The MON building has two windows on the second floor at the east elevation, in the administration office room 221. These windows have an azimuth angle 74^{o} and the aperture angels (sunlight potential angle) 0^{o} to 145^{o} from north. East window has the EPH building on east and the Gerrard Street on north side. The obstruction angles were calculated as 64^{o} on east direction and 23^{o} on southeast with the EPH building (Appendix-E). Figure 28 showed that the direct sunlight potential through the east window on second floor. They have direct sunlight potential from 15 minutes on February 21 to two hours on June 21 before noon.

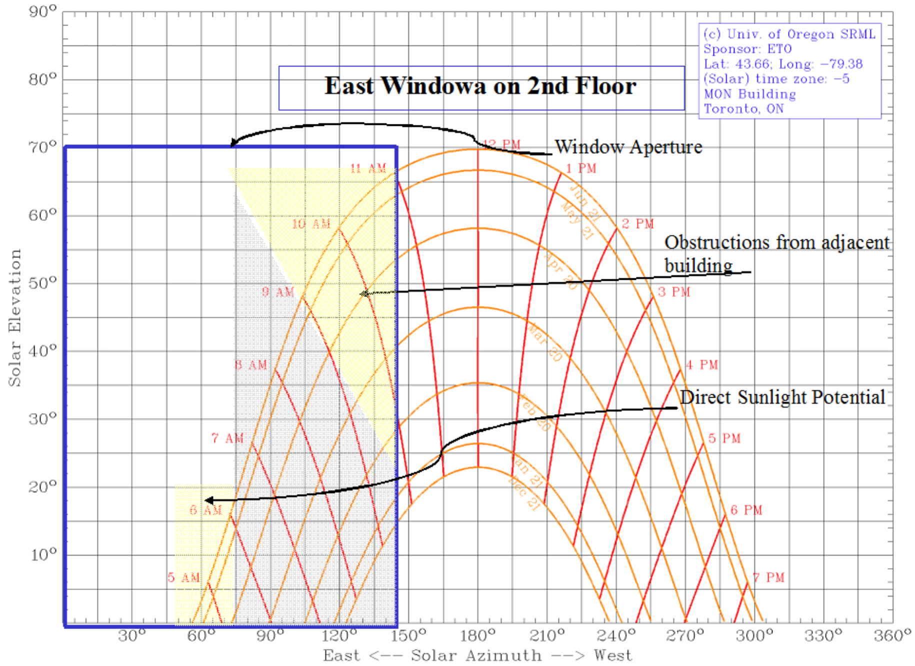


Figure 28: Sunlight potential and obstructions for east windows on second floor

6.1.4.3 Windows on third floor

The MON building has two windows on east elevation on the third floor in the Graduate Studies room 302 and the room 304. These windows have an azimuth angle 74^{o} from north and the aperture angels are (sunlight potential angle) 0^{o} to 145^{o} from north. The east windows have the EPH building on east and the Gerrard Street is on north side. Obstruction angles were calculated as 60^{o} on east direction and 20^{o} on southeast with the EPH building (Appendix-E). Figure 29 showed that the east windows on the third floor have least direct sunlight potential. They have only one and a half hour early morning sunlight before 6.00 a.m. and half hour from February to two hours on June 21 before 11.00 a.m.

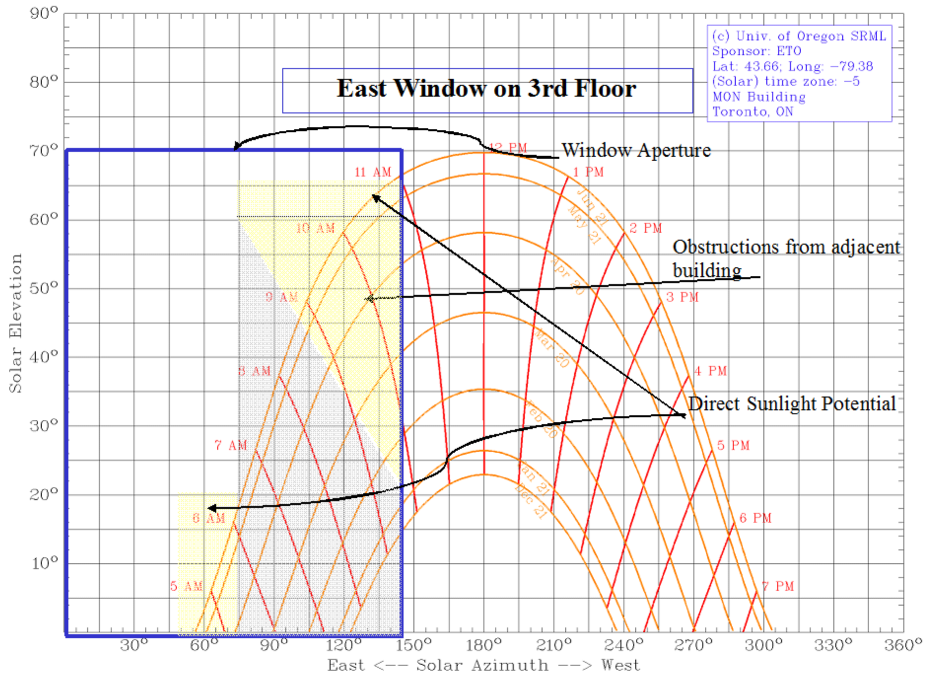


Figure 29: Sunlight potential and obstructions for east windows on third floor

6.1.4.4 Window on fourth floor

The MON building has two windows at east elevation on the fourth floor in the Road safety lab room 404 and Research Thesis room 402. These windows have an azimuth angle 74^{o} from north and the aperture angels are 0^{o} to 145^{o}. The east windows have the EPH building on the east side and the Gerrard Street on north side. An obstruction angle was calculated as, 55^{o} on east direction and 16^{o} on southeast direction with the EPH building (Appendix-E). Figure 30 showed that the east windows on the fourth floor have least direct sunlight potential. They have only one and a half hour early morning sun before 6.00 am and one hour before 11.00 am in the months of May, June and July.

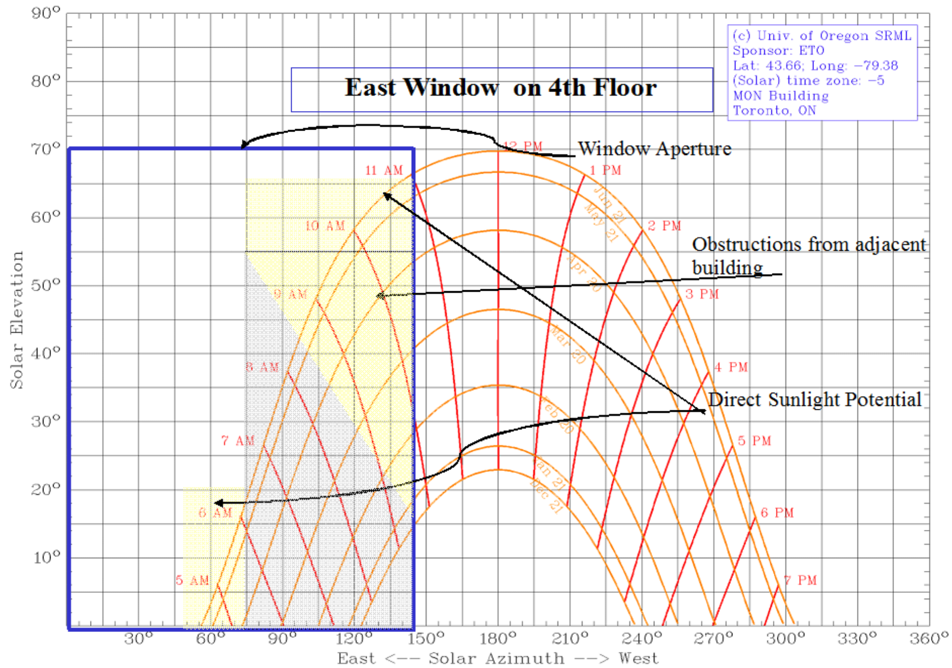
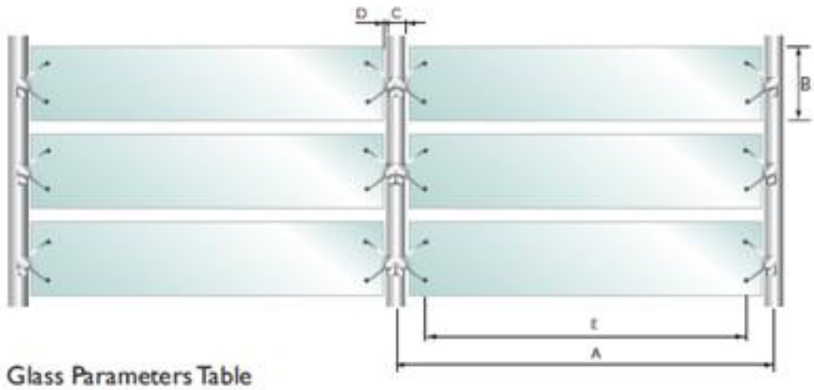


Figure 30: Sunlight potential and obstructions for east windows on fourth floor.

6.2 External Shadings

Sun path study as mentioned above, was used to design external shading system for the MON building. External shadings are the best daylight design strategy to control direct sunlight, over brightness, and solar heat gain in summer. Moveable external horizontal louvers on south orientation windows and moveable external vertical fins on west and north orientations were employed in the simulation model in order to evaluate daylight potential. Depths of the horizontal and the vertical shadings were calculated according to the windows orientation and sun path. Moveable shading louvers and fins provide better performance, control of direct sunlight and privacy. Colt Shadoglass louver shading system by American Warming and Ventilation were used. These systems consist of translucent glass louvers and metal carriers (as shown in Figure 31). This system provides good diffused daylight, privacy and enough daylight, even if the louvers are completely closed. Shadoglass solar shading system can be installed in both directions; horizontal and vertical.



Glass Parameters Table

Dimensions	LS2-30	LS2-301
A in. (max)	78	78
B in.	19.50	19.50
C in.	2.50	2.50
D in.	.50	.50
E in.	66.25	66.25
Angle of rotation°	0 - 100	0 - 100

Note: Table to be used as a guide only. Allowable dimensions depend upon the specific requirements of the project.

Figure 31: Shadoglass external shading system

6.2.1 Sizing for Horizontal and Vertical Shadings

Shading devices depth is very important for daylight design strategies. Shading devices' depth control the penetration of direct sunlight, they block the unwanted direct sunlight in summer to avoid heat gain and glare and allow in winter, when it would be needed because heat gain in winter is good for heating load. Appropriate depth for horizontal shadings and vertical fins were calculated using the formula mentioned below.

6.2.1.1 South facing windows

Moveable multiple horizontal louvers were used for south facing windows. Moveable louvers provide large shadow with less louvers depth. Moreover it can be completely closed for provide privacy. Louvers depth was calculated from the equation-2 below;

$$h = \frac{D \text{ x} \tan(solar\ altitude)}{Cos(solar\ azimuth - window\ azimuth)} \quad \text{-------------------------} \ [2]$$

Where, h is the required shadow height on window and D is the depth of the shading device. Solar altitude, 45^o, has been used to block the direct sunlight from March 15 to September 15. Solar noon has been used for solar azimuth angle, i.e. 180^o from the north. Window azimuth, 164^o, was already determined earlier in chapter 8.2.1. The height of the window is 7.5'.

To make smaller depth for shading louvers, the window's height was divided into 5 parts and each part has 1.5' in height or h is equal to 1.5'. Louver minimum depth was calculated as 1.44'(Appendix - F).

6.2.1.2 West facing windows

Both horizontal overhangs and vertical fins were used for west orientation windows. Horizontal overhangs were used to block high altitude sunlight and vertical fins, to block low altitude sunlight. The horizontal overhang depth was calculated with the same formula as mentioned above. For this calculation solar altitude 45^o has been used to block the direct sunlight from March 15 to September 15. Solar azimuth 225^o at 2.00 pm solar time has been used to block high altitude sunlight. Window azimuth 255^o was already determined in chapter 8.2.2. Half of the window height has been used to calculate the overhang depth. Horizontal overhang depth was calculated as 3.25' (Appendix - F).

Moveable vertical louvers or fins have been used to block the low altitude sunlight. Moveable vertical fins provide better performance and wider shadow with lower width than the fixed one. Vertical fins width was calculated with the equation-3 mentioned below.

$$w = D \text{ x} \tan(solar\ azimuth - window\ azimuth) \text{ ----------------------- [3]}$$

Where, w is the required shadow width and D is the fins depth. For calculating the fin's depth, 300^o, solar azimuth was used for evening sun at the lowest altitude. Window width was divided into 2.00' wide multiple parts and used 2.00' width for shadow. Vertical fins depth was calculated 2.00' (Appendix - F). Vertical fins are moveable so, fins depth can reduce from 2.00' to 1.5'. Fins depth can further reduce if the shadow width reduces.

6.2.1.3 North facing window

North orientation windows have only low altitude sunlight. Thus, moveable vertical shadings have been used. Vertical fins depth was calculated at solar azimuth of 300^o, window azimuth of 345^o and the shadow depth 2.00'. Vertical fins depth was calculated as 2.00' (Appendix - F).

6.2.1.4 East facing window

East facing windows have direct sunlight mainly from a high altitude sun before noon for short period of time. Solid horizontal overhangs are good to block high altitude sunlight. Therefore, solid overhangs were used for east windows to block high altitude sunlight. Overhang depth was calculated at solar azimuth of 120^o, solar altitude of 45^o and shadow depth 5'. Overhang depth was calculated as 3.5'.

7 Daylighting in the MON Building

7.1 Strategies Employed

During this research study, it was found that the MON building has very good daylighting potential and the building was designed to get maximum daylight throughout the year. The problem that was found during this study is that the building design was missing daylighting control. There was no system available to control excessive daylighting, glare and heat gain in summer except internal blinds. To address these issues, external shading devices were simulated in the MON building. Moveable horizontal translucent glass louvers were installed on south perimeter windows (as shown in Figure 32) to block high altitude sunlight. Furthermore, it can also be adjusted to block the direct sunlight at any time of the year, while the translucent glass will provide soft diffuse daylight.

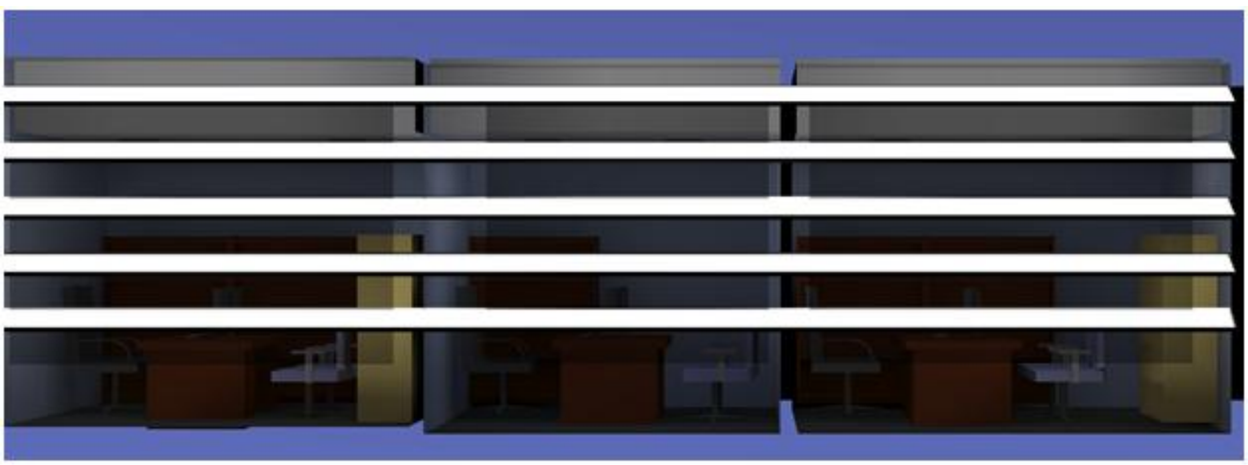


Figure 32: Horizontal moveable louvers on south facing windows

The combination of horizontal solid overhangs and moveable vertical fins were used for the west perimeter offices and rooms because the west perimeter rooms have low altitude as well as high altitude sunlight. A solid horizontal overhang was installed to block high altitude sunlight, while the moveable translucent vertical fins were installed to block low altitude sunlight and provide soft diffuse daylight. Figure 33 shows horizontal overhang and vertical fins on the west facade of the building.

Figure 33: Horizontal solid overhang and moveable vertical fins on west facing windows

7.2 Critical rooms analysis

The east and south perimeter rooms are the most critical rooms in the morning sunlight while west perimeter rooms are critical in the afternoon and evening sunlight. After the installation of the solar shadings, the simulation was performed for the most critical day, June 21 at 10.00 am under clear sky condition. The result showed that the east perimeter room on third floor has evenly distributed daylight and the illuminance level is from 400 lx to 1100 lx as shown in Figure 34 and rendering showing in Figure 35.

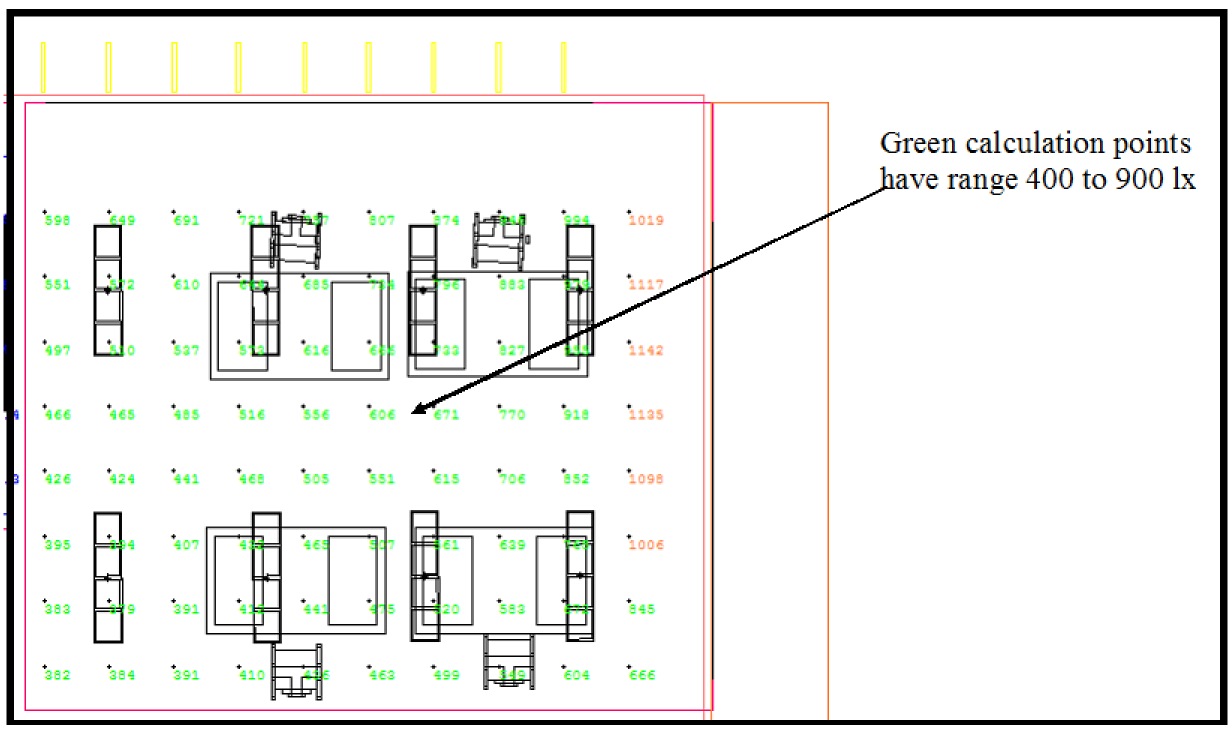


Figure 34: Calculation result for east perimeter room

Figure 35: Rendering for east perimeter rooms on third floor

The simulation calculation was done under a clear sky at 10.00 am with no day light saving time for south perimeter office. The simulation results showed that the rooms at south perimeter also have soft daylight, its illuminance level is from 400 lx to 900 lx as shown in Figure 36, and the rendering showed in Figure 37.

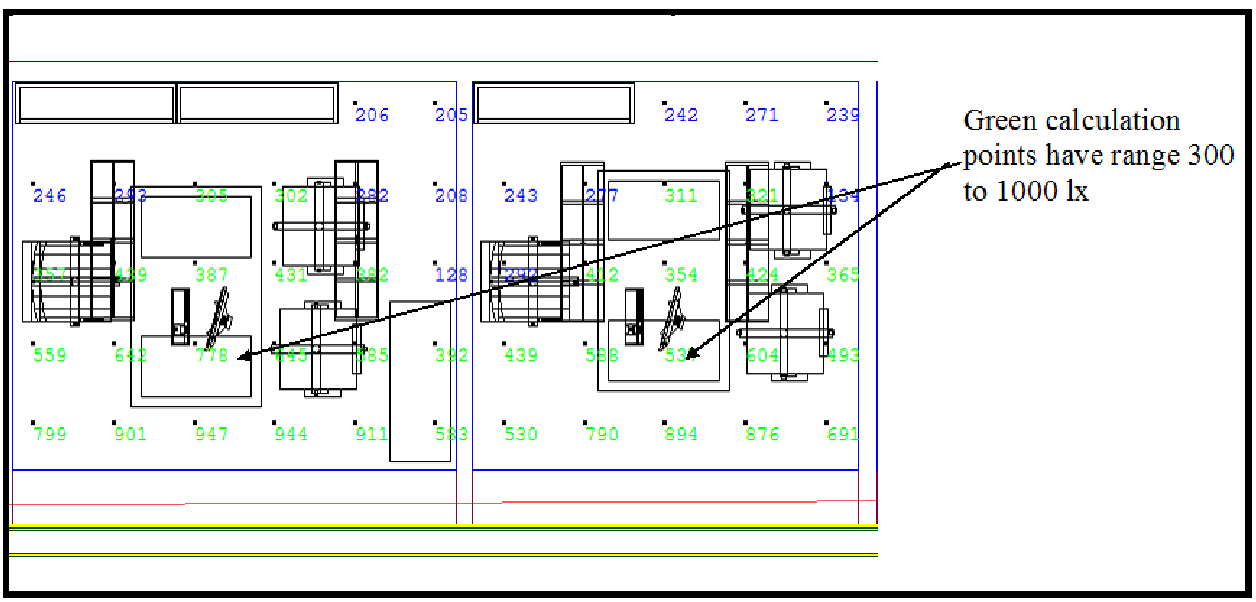


Figure 36 simulation calculation showing illuminance level in the south perimeter rooms at fourth floor

Figure 37: Rendering shows the south perimeter offices

For the west perimeter rooms, simulation was carried out under clear sky condition and on the most critical day June 21 at 3.00 pm with no daylight saving time. The result showed that the room 418 have soft diffused daylight (as shown in Figure 38).

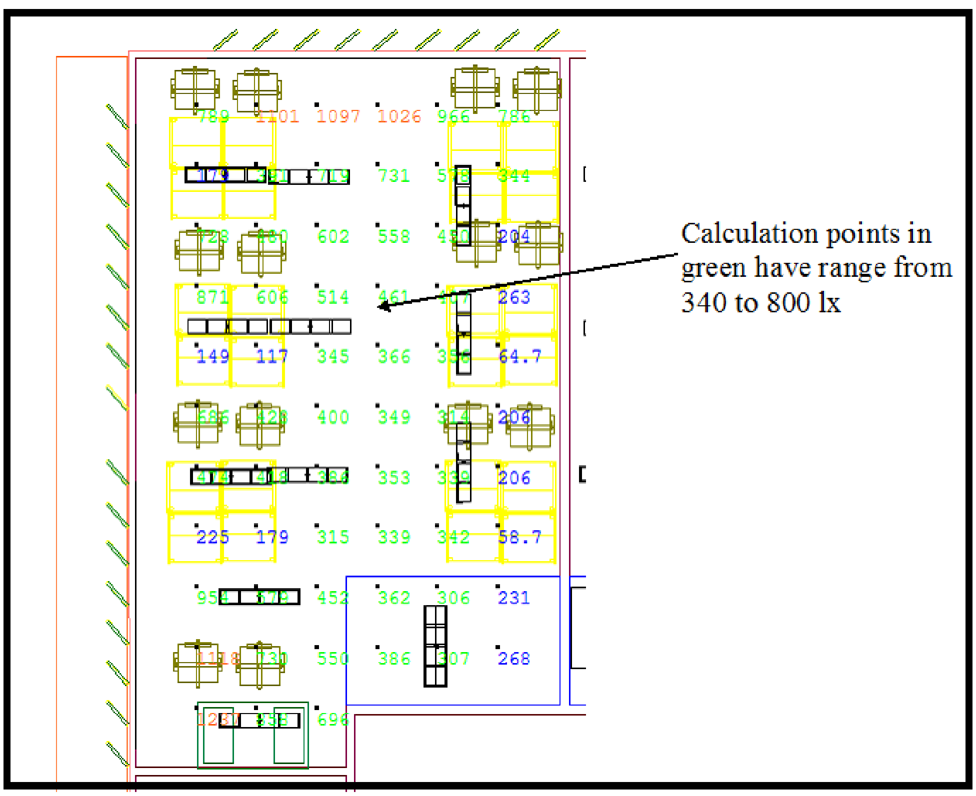


Figure 38: Simulation result for the west perimeter room on fourth floor

Figure 39: Rendering for graduate studies room at west perimeter on fourth floor

7.3 Design analysis

After employed the daylighting strategies, internal illuminance was calculated through AGi32 simulation model under three significant sky conditions; overcast sky, partly cloudy and clear sky conditions. The detail discussions and results are on the following sections. The results show that the rooms have now diffused and adequate levels of illuminance under partly cloudy and clear sky conditions. The rooms' area has illuminance over 300 lux under three sky conditions; overcast sky, partly cloudy sky and clear sky, are shown in the Tables 15 to 17. Illuminating Engineering Society of North America (IESNA) is recommended the minimum level of illuminance 300 lux/30 fc for common office task in category D (IESNA, 2000), recommended illuminance Table shown in appendix G. The room illuminance level depends on months of year, time of the day, sky conditions, orientations and room sizes.

7.3.1 Overcast Sky Condition

The internal illuminance levels were calculated for three significant days, December 21 the shortest solar day of the year, March/ September 21 equal day and night time of the year and June 21 the longest day of the year under overcast sky condition. Table 15 (please see the following page) shows that the calculation results for the worst-case scenario i.e. December 21, the room102A on ground floor and room 221 on second floor at northeast corner have illuminance levels over 300 lx on 100 percent of the area. The rooms at north and north-west perimeter have illuminance levels over 300 lx on 15 to 30 percent of the room area depending on the room's depth, while, the rooms at south perimeter need 100 percent electrical lights.

The calculation results for March 21/ September 21 show that the rooms on all floors at north-east corner of the building, rooms 105 at south perimeter on ground floor and room 214 at north-west perimeter on second floor have illuminance level over 300 lx on 100 percent area of the room. The rooms at north perimeter on all the floors have illuminance levels over 300 lx on 40 to 60 percent area, depending on room's size and window's size. While, the rooms at south perimeter on third and fourth floors and the rooms at west perimeters on second floor have illuminance levels over 300 lx on 15 to 40 percent areas of the room, it also depends on the time of the day.

The calculation results for the longest day of the year i.e. June 21 show that the rooms 102A, 221, 304 and 404 at northeast corner of the building and room 105 and 214 have illuminance levels over 300 lx on 100 percent of the room area. The north perimeter rooms on all floors have illuminance levels over 300 lx on 60 to 80 percent of the room area. While the faculty rooms at south on third and fourth floors and at west perimeter on second floor have illuminance levels over 300 lx on 30 to 60 percent of the room area.

The calculation results show that the MON building has over 300 lx on overall more than 50 percent of the room area under overcast sky condition except December 21. During the month of December under overcast sky condition, the building needs 100 percent electrical lights.

Table 15 Room area in percent has minimum level of illuminance 300 Lux under Overcast Sky Condition

	Overcast Sky Percentage of room area have minimum illuminance of 300 Lux								
Date	21-Dec			March 21/ Sep 21			21-Jun		
Time	10:00 AM	12:00 PM	2:00 PM	10:00 AM	12:00 PM	3:00 PM	10:00 AM	12:00 PM	3:00 PM
Ground Floor	%	%	%	%	%	%	%	%	%
Room 101 (S)	0	0	0	1	3	0	20	30	20
Room 102A (NE)	100	100	100	100	100	100	100	100	100
Room 102 (N)	10	30	22	45	60	45	70	80	70
Room 104 (N)	10	30	20	50	70	50	80	90	80
Room 105 (S)	0	20	0	95	100	90	100	100	100
2nd Floor									
Room 212 (W)	0	10	10	25	50	25	40	50	100
Room 213 (W)	0	10	10	20	50	20	35	35	100
Room 214 (NW)	30	70	70	95	98	95	98	99	100
Room 215 (N)	10	15	15	40	50	40	60	75	100
Room 216 (N)	15	15	15	40	40	40	50	60	90
Room 217 (N)	15	15	15	40	50	40	50	70	95
Room 218 (N)	15	20	20	30	40	30	60	70	100
Room 219 (N)	20	25	25	50	60	40	70	80	100
Room 220 (N)	20	30	30	70	80	70	95	98	100
Room 221 (N)	90	95	95	98	99	98	100	100	100
3rd Floor									
Room 302 (E)	0	15	10	20	30	30	30	30	30
Room 303 (S)	0	0	0	15	40	20	70	90	60
Room 304 (NE)	20	70	30	90	95	75	100	100	100
Room 305 (S)	0	0	0	15	35	5	25	30	25
Room 306 (N)	20	20	20	60	40	40	50	60	60
Room 307 (S)	0	0	0	15	40	15	60	90	60
Room 309 (S)	0	0	0	15	35	5	30	50	30
Room 311 (S)	0	0	0	15	40	10	60	60	60
Room 314 (N)	5	10	10	25	25	25	25	35	35
Room 316 (N)	10	10	10	20	25	25	25	35	35
Room 318 (NW)	10	25	20	40	70	40	70	75	70
4th Floor									
Room 402 (E)	0	15	10	20	30	30	30	30	30
Room 403 (S)	0	0	0	15	40	20	70	90	60
Room 404 (NE)	20	70	30	90	95	75	100	100	100
Room 405 (S)	0	0	0	15	35	5	25	30	25
Room 406 (N)	0	20	20	60	40	40	50	60	60
Room 407 (S)	0	0	0	15	40	15	60	90	60
Room 409 (S)	0	0	0	15	35	5	30	50	30
Room 411 (S)	0	0	0	15	40	10	60	60	60
Room 412 (N)	5	10	10	25	25	25	25	35	35
Room 414 (N)	10	10	10	20	25	25	25	35	35
Room 418 (NW)	10	25	20	40	70	40	70	75	70

7.3.2 Partly Cloudy Sky Condition

For the average sky condition, the internal illuminance levels were calculated under partly sky condition (general sky condition) for December 21, March 21/ September 21 and June 21 at before noon, at noon and at afternoon. Table 16 (please see the following page) shows that the calculation results for December 21, the building has internal illuminance levels more than 300 lx on 100 percent area of the rooms at northeast, northwest and rooms at south perimeter on all floors. 50 percent area of the rooms 302 and 402 at east perimeter on third and fourth floor, 90 percent area of the rooms 212 and 213 at west perimeter on second floor and 35 to 50 percent area of the rooms at north perimeter on all floors have illuminance levels over 300 lx.

The calculation results for March 21/September 21 show that the all rooms have internal illuminance levels over 300 lx except the rooms 314 and 316 on third floor and rooms 412 and 414 on fourth floor at north perimeter, they have illuminance levels over 300 lx on 40 to 50 percent of their room area. The calculation results for June 21 show that the rooms 314 and 316 on third floor and rooms 412 and 414 on fourth floor at north perimeter have illuminance over 300 lx on 60 to 70 percent of their room area, while, rest of the rooms have illuminance levels over 300 lx on 100 percent of their room area.

The calculation results show that the MON building has illuminance levels over 300 lx under partly sky condition over all on 100 percent of the room area except the month of December and the rooms at north perimeter.

Table 16 Room area in percent has minimum level of illuminance 300 Lux under Partly Cloudy Sky Condition

	Partly Cloudy Sky Percentage of room area have minimum illuminance of 300 Lux								
Date	21-Dec			March 21/ Sep 21			21-Jun		
Time	10:00 AM	12:00 PM	2:00 PM	10:00 AM	12:00 PM	3:00 PM	10:00 AM	12:00 PM	3:00 PM
Ground Floor									
Room 101 (S)	90	100	100	100	100	95	100	100	90
Room 102A (NE)	100	100	100	100	100	100	100	100	100
Room 102 (N)	20	40	50	80	90	95	100	100	100
Room 104 (N)	40	80	90	96	100	100	100	100	100
Room 105 (S)	100	100	100	100	100	100	100	100	100
2nd Floor									
Room 212 (W)	30	90	100	70	100	100	100	100	100
Room 213 (W)	30	90	90	50	100	100	98	100	100
Room 214 (NW)	98	100	100	100	100	100	100	100	100
Room 215 (N)	35	35	35	95	100	98	100	100	100
Room 216 (N)	30	35	35	80	95	80	100	100	100
Room 217 (N)	35	40	35	98	98	80	100	100	100
Room 218 (N)	30	45	40	100	100	100	100	100	100
Room 219 (N)	40	50	50	100	100	100	100	100	100
Room 220 (N)	70	90	80	100	100	100	100	100	100
Room 221 (N)	99	100	99	100	100	100	100	100	100
3rd Floor									
Room 302 (E)	50	50	30	100	100	80	100	100	100
Room 303 (S)	100	100	100	100	100	100	100	100	100
Room 304 (NE)	100	100	95	100	100	100	100	100	100
Room 305 (S)	100	100	100	100	100	100	100	100	100
Room 306 (N)	40	35	50	95	100	100	100	100	100
Room 307 (S)	100	100	100	100	100	100	100	100	100
Room 309 (S)	100	100	100	100	100	100	100	100	100
Room 311 (S)	100	100	100	100	100	100	100	100	100
Room 314 (N)	20	25	25	40	50	50	60	70	80
Room 316 (N)	20	25	25	40	50	50	60	70	70
Room 318 (NW)	70	100	100	100	100	100	100	100	100
4th Floor									
Room 402 (E)	50	50	30	100	100	80	100	100	100
Room 403 (S)	100	100	100	100	100	100	100	100	100
Room 404 (NE)	100	100	95	100	100	100	100	100	100
Room 405 (S)	100	100	100	100	100	100	100	100	100
Room 406 (N)	40	35	50	95	100	100	100	100	100
Room 407 (S)	100	100	100	100	100	100	100	100	100
Room 409 (S)	100	100	100	100	100	100	100	100	100
Room 411 (S)	100	100	100	100	100	100	100	100	100
Room 412 (N)	20	25	25	40	50	50	60	70	80
Room 414 (N)	20	25	25	40	50	50	60	70	70
Room 418 (NW)	70	100	100	100	100	100	100	100	100

7.3.3 Clear Sky Condition

For maximum daylighting intensity, the internal illuminance levels were calculate under clear sky condition for December 21, March 21/September 21 and June 21 at before noon, at noon and at afternoon. Table 17 (please see the following page) shows that the calculation results for December 21, the rooms at south, northeast and northwest perimeter on all floors have illuminance levels over 300 lx on 100 percent of the room area. The rooms at north perimeter on all four floors have illuminance level over 300 lx on 25 to 70 percent of the room area and the rooms 212 and 213 at west perimeter have illuminance levels over 300 lx on 90 percent of the room area.

The calculation results for March 21/September 21 shows that the all rooms on all floors have illuminance levels more than 300 lx on 100 percent of the room area. The rooms 314, 316 on third floor and rooms 412, 414 on fourth floor at north perimeter on the other hand have illuminance levels over 300 lx on 40 percent of the room area. The calculation results for June 21 shows that the rooms 314 and 316 on third floor and rooms 412, 414 on fourth floor at north perimeter have illuminance levels over 300 lx on 50 percent of the room area. Remaining rooms on all floors have illuminance levels over 300 lx on 100 percent of the room area.

The calculation results show that the MON building has illuminance levels over 300 lx under clear sky condition overall on 100 percent of the room area, except the rooms at north perimeter.

Table 17 Room area in percent has minimum level of illuminance 300 Lux under Clear Sky Condition

	Clear Sky Percentage of room area have minimum illuminance of 300 Lux								
Date	**21-Dec**			**March 21/ Sep 21**			**21-Jun**		
Time	10:00 AM	12:00 PM	2:00 PM	10:00 AM	12:00 PM	3:00 PM	10:00 AM	12:00 PM	3:00 PM
Ground Floor									
Room 101 (S)	100	100	100	100	100	60	95	95	50
Room 102A (NE)	100	100	100	100	100	100	100	100	100
Room 102 (N)	20	50	30	50	50	50	80	90	90
Room 104 (N)	30	80	90	95	95	95	96	98	100
Room 105 (S)	100	100	100	100	100	100	100	100	100
2nd Floor									
Room 212 (W)	30	70	100	60	95	100	80	100	100
Room 213 (W)	30	50	100	50	90	100	75	95	100
Room 214 (NW)	100	100	100	100	100	100	100	100	100
Room 215 (N)	45	50	45	95	95	95	100	100	100
Room 216 (N)	25	25	25	45	70	75	80	90	100
Room 217 (N)	30	35	30	55	100	70	100	100	100
Room 218 (N)	35	45	30	98	100	98	100	100	100
Room 219 (N)	50	80	70	100	100	100	100	100	100
Room 220 (N)	90	100	95	100	100	100	100	100	100
Room 221 (N)	100	100	100	100	100	100	100	100	100
3rd Floor									
Room 302 (E)	75	50	50	100	100	100	100	100	100
Room 303 (S)	100	100	100	100	100	100	100	100	100
Room 304 (NE)	100	100		100	100	100	100	100	100
Room 305 (S)	100	100	100	100	100	100	100	100	100
Room 306 (N)	40	70	70	95	95	95	95	95	95
Room 307 (S)	100	100	100	100	100	100	100	100	100
Room 309 (S)	100	100	100	100	100	100	100	100	100
Room 311 (S)	100	100	100	100	100	100	100	100	100
Room 314 (N)	10	30	30	40	40	40	50	50	50
Room 316 (N)	15	35	35	40	40	40	50	50	50
Room 318 (NW)	75	100	100	100	100	100	100	100	100
4th Floor									
Room 402 (E)	75	50	50	100	100	100	100	100	100
Room 403 (S)	100	100	100	100	100	100	100	100	100
Room 404 (NE)	100	100		100	100	100	100	100	100
Room 405 (S)	100	100	100	100	100	100	100	100	100
Room 406 (N)	40	70	70	95	95	95	95	95	95
Room 407 (S)	100	100	100	100	100	100	100	100	100
Room 409 (S)	100	100	100	100	100	100	100	100	100
Room 411 (S)	100	100	100	100	100	100	100	100	100
Room 412 (N)	10	30	30	40	40	40	50	50	50
Room 414 (N)	15	35	35	40	40	40	50	50	50
Room 418 (NW)	75	100	100	100	100	100	100	100	100

7.4 Energy Savings

The goal for daylight design strategies is to provide a pleasant environment and energy savings. For this study, only electrical lighting energy savings were calculated. Saving in air-conditioning energy and the reduction in air-conditioning system size were not calculated. Furthermore, the increases in energy consumption in heating load in winter were also not calculated. Energy saving depends directly on the room illuminance level, which varies from season to season, sky conditions, room orientations and depths. For the energy saving calculation, it has been assumed that the electrical lightings have been operated according to the room illuminance and sky conditions. To predict the sky conditions, hourly climate data of Toronto was used as shown in Table 18.

Table 18: Hourly climate date for Toronto (Environment Canada)

	Number of days	Clear Sky Hours	Partly Cloudy Hours	Overcast Sky Hours	Total Hours
December	31	122.70	102.30	519.00	**744.00**
January	31	137.10	103.80	503.10	**744.00**
February	28	142.00	106.00	430.60	**678.60**
March	31	197.40	117.00	429.60	**744.00**
April	30	188.20	126.80	405.00	**720.00**
May	31	208.10	151.70	384.20	**744.00**
June	30	197.30	189.40	333.30	**720.00**
July	31	228.60	222.30	293.20	**744.10**
August	31	226.80	206.70	310.50	**744.00**
September	30	218.00	167.60	334.40	**720.00**
October	31	198.20	146.90	399.00	**744.10**
November	30	114.90	107.40	497.80	**720.10**
Total		**2179.30**	**1747.90**	**4839.70**	**8766.90**

Illuminance levels for rooms have been calculated through AGi32 simulation model for each month. The room areas that had over 300 lx illuminance have been used for energy saving calculations (as shown in Appendix-H). Summarized hourly energy savings for the whole building in three sky conditions, clear sky, partly cloudy and overcast sky are shown below in Table 19 (please see the following page).

Table 19: Energy savings per hour for the whole building

Month	Clear Sky watts/hr	Partly Cloudy Sky watts/hr	Overcast Sky watts/hr
December	17151.60	14761.10	5892.10
January	16800.70	16767.35	6621.20
February	19461.10	18773.60	9143.05
March	19672.65	20948.98	11335.80
April	20249.30	24730.10	15917.00
May	20774.10	22567.90	16676.50
June	20885.80	23973.28	16295.60
July	20774.10	22567.90	26556.50
August	20249.30	24730.10	14722.10
September	19672.65	20948.98	11446.00
October	19461.10	18773.60	9280.75
November	16800.70	16767.35	7734.00
Total			

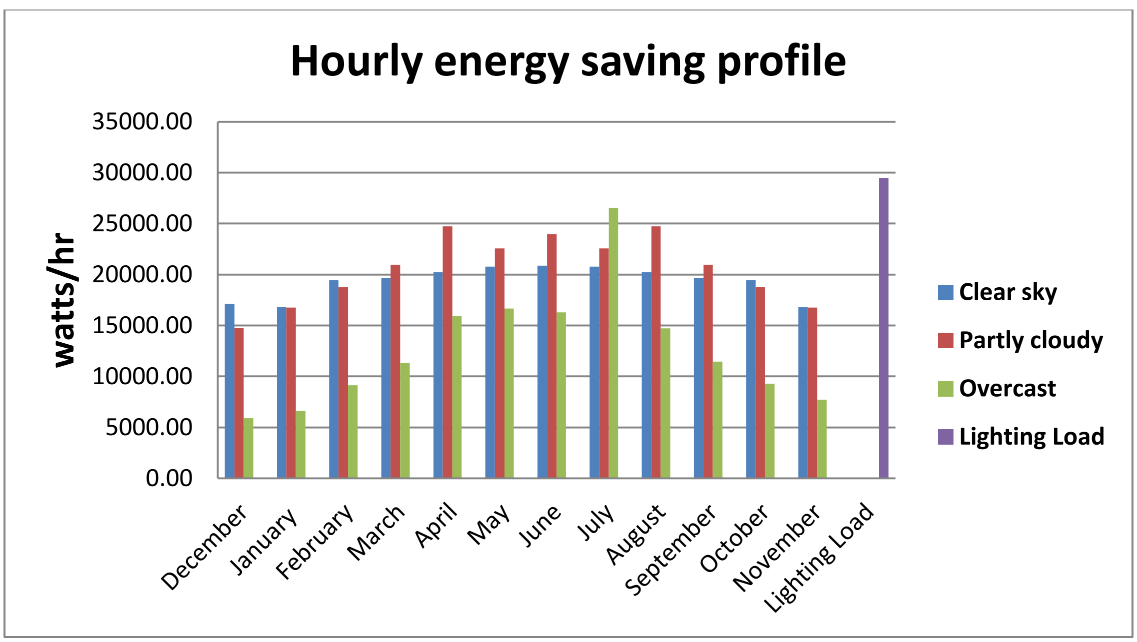


Chart 2: Hourly energy saving profile

The MON building's total electrical lighting load was estimated 29453 watts per hour (Appendix-I). The lighting energy savings were estimated in Table 19 and showed, for the worst case scenario, December 21 under overcast sky condition, that the daylighting strategies can provide 5892.1 watts/hr energy savings in lighting and that is 20 percent of its per hour lighting loads. During summer months, this energy savings can go up to 26556.5 watts per hour and that is 90 percent of it's per hour lighting loads. The average energy savings in under all sky conditions was estimated at 15403.21 watts per hour and that is 52 percent of total per hour lighting loads.

135038.4KWh, of electrical lighting energy can be saved in a year and the highest energy savings months are from April until September as shown in Table 20 below. If this energy is not saved through daylighting, it will increase the building's cooling load and energy cost. The energy savings are shown below in Table 20, the most of energy that has been saved during the peak demand charges months and it is higher price time for energy use. As a result, this energy savings give higher cost benefit as well as reduce the peak load demand.

Table 20: Energy savings per month for the whole building

Month	Clear Sky KWh	Partly Cloudy Sky KWh	Overcast Sky KWh	Total KWh
December	2104.5	1510.06	3058	**6672.56**
January	2303.38	1740.45	3331.03	**7374.86**
February	2763.48	1990	3937	**8690.48**
March	3883.38	2451.03	4869.88	**11204.29**
April	3810.91	3135.78	6446.88	**13393.57**
May	4323.09	3423.55	6407.1	**14153.74**
June	4120.77	4540.54	5431.32	**14092.63**
July	4748.96	5016.84	7786.35	**17552.15**
August	4592.53	5111.71	4571.21	**14275.45**
September	3470.47	3511.05	3827.54	**10809.06**
October	3141.31	2757.84	3703.02	**9602.17**
November	1566.64	1800.81	3849.99	**7217.44**
Total	**40829.42**	**36989.66**	**57219.32**	**135038.4**

Toronto Hydro monthly rates were used to calculate the cost saving benefits (as shown in Table 21). Table 21 shows that during May to August savings can reach up to $2,050.00 per month and the annual energy saving can go up to $14,872.09.

Table 21: Cost Savings (http://www.torontohydro.com)

	Energy Savings	Energy Rate	Savings
	KWh	CD$	CD$
December	**6672.56**	0.10	667.26
January	**7374.86**	0.10	737.49
February	**8690.48**	0.10	869.05
March	**11204.29**	0.10	1120.43
April	**13393.57**	0.10	1339.36
May	**14153.74**	0.12	1655.99
June	**14092.63**	0.12	1648.84
July	**17552.15**	0.12	2053.60
August	**14275.45**	0.12	1670.23
September	**10809.06**	0.12	1264.66
October	**9602.17**	0.12	1123.45
November	**7217.44**	0.10	721.74
Total			**14872.09**

7.4.1 Cost and Payback Period

The cost for installation of this type of external shading system is aproximate $45/sq.ft, this cost was provided by Alex Stuhldeher, Sales Engineer, American Warming and ventilation (personal comunication).

Table 22: Cost for external shading systems

Floor	Window orientation	Window Size sq.ft	Number of windows	Shading system	Rate $	Cost $
Ground Floor	South	90.00	2	Horizontal	45.00	8100.00
	West	97.50	2	Vertical	45.00	8775.00
	North	120.00	5	Vertical	45.00	27000.00
	East	45.50	1	Horizontal	45.00	2047.50
second Floor	South	135.00	3	Horizontal	45.00	18225.00
	West	97.50	3	Horizontal	45.00	13162.50
	North	120.00	5	Horizontal	45.00	27000.00
	East	45.50	2	Vertical	45.00	4095.00

third Floor	South	135.00	3	Horizontal	45.00	18225.00
	West	97.50	3	Vertical	45.00	13162.50
	North	120.00	5	Vertical	45.00	27000.00
	East	45.50	2	Horizontal	45.00	4095.00
fourth Floor	South	135.00	3	Horizontal	45.00	18225.00
	West	97.50	3	Vertical	45.00	13162.50
	North	120.00	5	Vertical	45.00	27000.00
	East	45.50	2	Horizontal	45.00	4095.00
Total						**233370.00**

The total cost for daylighting design strategies were estimated $ 233,370.00 including installation and materials. The simple payback period was calculated from cost for the system divided by savings per year.

$$Simple\ payback\ period = \frac{Cost\ for\ the\ system}{Savings\ per\ year}$$

$$Simple\ payback\ period = \frac{233370}{14872.09} = 15.7 \text{ years}$$

The payback period was estimated up to 15.7 years. It can be reduce, if the energy savings associated with cooling load and HVAC system are added. In addition, the payback period may be increase if the heating loads in winter are added. High performance daylighting system can save 25 percent in cooling load energy and three percent in fan energy and it can increase one percent in heating energy consumptions in winter (Energy Center of Wisconsin, 2005).

8 Discussions and Results

The sun path study in chapter 8.2 showed that the south perimeter offices on the third and fourth floor have 5.5 hours to 6.5 hours, and west perimeter offices and rooms on the second, third and fourth floor have 6.5 hours to 7.75 hours of direct sunlight in cooling period. This direct sunlight forces the occupants to put down the blinds and use the electrical lights, but this strategy cannot satisfy the occupants' needs. Blinds can block the sunlight but it cannot stop the heat gain and electrical light also generate heat so the cooling load increases. Moreover, these rooms have more than 60 percent window-to wall ratio. Instead of providing daylight, the windows are the significant source of heat gain. This situation fails the air-conditioning system and increases the building's energy consumption tremendously.

After employing daylight strategies, calculation results in chapter 9.1 showed that the MON building has only three months November, December and January with the lowest illuminance levels, up to 25 percent under the overcast sky condition, but in the same months under partly cloudy sky and clear sky condition has illuminance on more than 50 percent of the rooms area. While, from March to October the building has illuminance on 50 percent to 80 percent of the room area in all sky condition. Furthermore, moveable external shadings can control illuminance level under 1000 Lux in bright sunny day and provide soft cool daylight.

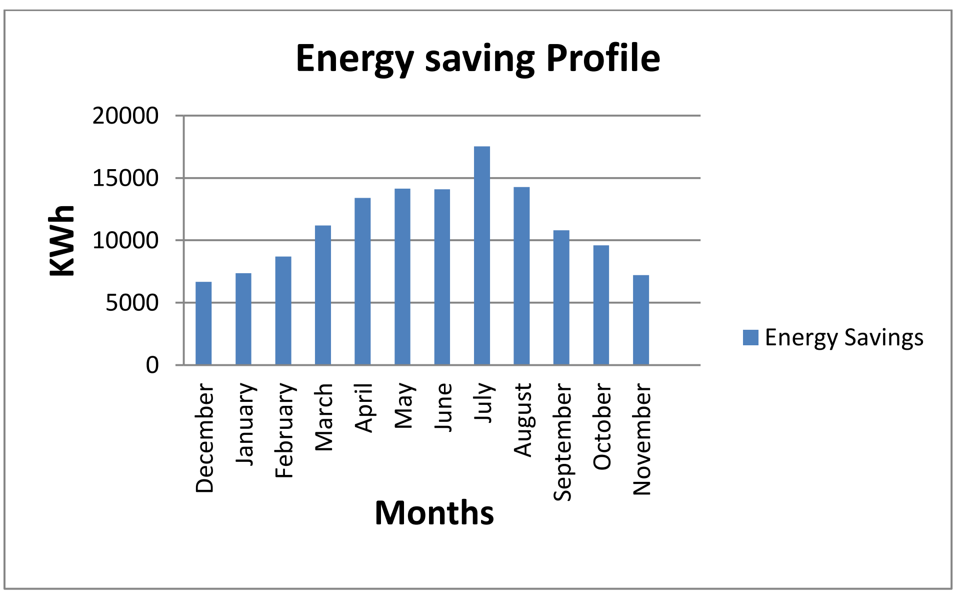


Chart 3: Monthly energy saving profile

The energy savings calculation in ch-9.2 showed that the 135038.4KWh or 61.76KWh/m^2 energy could be save in a year, just in the electrical lighting account. This energy savings can go much higher if the energy savings in cooling were added. The highest energy saving month are April to October and it can save up to 17,500KWh in a month (as shown in chart 8). If this energy is not saved through daylighting, it will increase the cooling load through heat generation from electric light and the energy cost as well. These energy savings also minimize the heat gain associated with electrical lights through fenestration. Ultimately, it will reduce the cooling load and cooling energy as mentioned earlier chapter 3.2.

Cost savings calculation shows that the $14,872.09 can be saved annually in electric lighting bills with the above daylighting strategies. The daylighting strategies are cost $233,370 and its simple payback time is 15.7 years, when only electrical light savings are counted. This payback period can be reduced significantly, if the cooling energy savings were added.

9 Conclusion

Daylighting design is not just to install large windows and provide maximum daylighting. Uncontrolled daylighting creates over brightness and glare near perimeter zones, increased cooling load in cooling season, increases energy consumption and outweighs the benefit of daylighting. The purpose of daylighting design strategies is to provide controlled daylight with uniform and adequate levels of illuminance in the space. In this study, external shading devices were used as a daylighting design strategy in the MON building and evaluate the daylight illuminance and energy savings.

The MON building has good daylighting potential but instead of using daylighting, the building uses 100 percent electrical lighting, regardless of the seasons, sky conditions and room orientations. The building has large windows that can provide good daylighting but currently it causes glare and heat gain. During the sun path study, it was also found that the south and west perimeter rooms have more than five hours of direct sunlight potential per day. To solve this problem, external shading was employed on the windows, for south orientation windows horizontal moveable louvers, for west orientation windows horizontal overhang and vertical moveable fins, for north windows moveable vertical fins and for the east windows horizontal overhang was employed. The study results showed that the building could save 135038.4KWh of energy per year with daylight control in electrical lighting account. Furthermore, the above daylighting strategy is cost effective, it can saves energy during the high price peak-load demand time and save $14,872.09 per year. The cost for daylighting strategies can be payback in up to 15 years.

10 References:

- Ander, Gregg D. (2002). *Daylighting Performance and Design.* (second edition). New Jersey, USA: John Wiley and Sons Inc.
- Ander, Gregg D., (2011). Daylighting. *WBDG National Institute of Building Science.* Retrieved on March 18, 2012 from http://www.wbdg.org/resources/daylighting.php
- Boubekri, Mohamed, (2008). *Daylighting, Architecture and Health; Building Designer Strategies.* Oxford. Architectural Press.
- Boubekri, Mohamed, (2004). An argument for daylighting legislation because of health. *Journal of the Human-Environment System, vol. 7(No. 2),* 51 – 56.
- Bommel, WJM van & Beld, GJ van den, (2004). Lighting for work: a review of visual and biological effects. *Lighting Research Technologies. Vol. 36,* No. 4. pp. 255-269.
- Brainard, George C. & Glickman, Gena, (2004). The biological potency of light in human: Significance to health and behavior. *Light and Human Health.* I-22 – I-27. Retrieved on May 01, 2012 from http://www.belok.se/docs/dagsljus/7_Biologisk_synpunkt.pdf
- Cuttle, Christopher, (2003). *Lighting by design.* Oxford. Architectural Press.
- CIBSE (1999). *Daylighiting and window design.* The Chartered Institutional Building Engineers, London, UK.
- Dubois, Catherine, Demers, Claude & Potvin, Andre, (2007). The influence of daylighting on occupants; Comfort and diversity of luminous ambiences in architecture. *Conference Proccedings of American Solar Society,* SOLAR 2007, 7 – 12, Cleveland, Ohio.
- *Daylighting in Buildings,* (2010). Energy Conservation in buildings & Community Systems & Solar heating and Cooling Programes. ECBCS Annex 29 / SHC Task 21. Retrieved on May 05, 2012 from http://www.ecbcs.org/docs/ECBCS_Annex_29_PSR.pdf
- *Daylighting Guide for Canadian Commercial Buildings*, (2002). Public Works and Government Services, Canada. Retrieved on March 18, 2012 from http://www.enermodal.com/pdf/DaylightingGuideforCanadianBuildingsFinal6.pdf

- *Daylight Dividends; Case study, Harmony Library*, (2004). Rensselaer Polytechnic Institute, USA. Retrieved on March 18, 2012 from http://www.lrc.rpi.edu/programs/daylighting/pdf/HarmonyLibraryCaseStudy.pdf
- *Daylight Dividends; Case study, Smith Middle School*, (2004). Rensselaer Polytechnic Institute, USA. Retrieved on March 18, 2012 from http://www.lrc.rpi.edu/programs/daylighting/pdf/SmithCaseStudyFinal.pdf
- *Daylighting in Buildings; A source book on daylighting system and components*, (2000). A report of IEA SHC Task 21/ ECBCS Annex 29. IEA, Energy Conservation in Buildings and Community Systems Programme, USA.
- *Daylight in Buildings: Application guide for daylight responsive lighting control*, (2001). IEA Task 21, IEA, Solar Heating and Cooling Program. USA.
- Endocrine central nervous. (2012), In Wikipedia, the free encyclopedia. Retrieved May 12, 2012, from http://en.wikipedia.org/wiki/File:Endocrine_central_nervous_en.svg
- Energy Center of Wisconsin (2005). *Energy saving from daylighting, A controlled experiment*, ECW Report number 233-1, May 2005. Retrieved on July 20, 2012 from http://www.ecw.org/prod/233-1.pdf
- Environment Canada (2012). *National Climate Data and Information Archive*, *Canadian climate Normals 1971-2000.* Retrieved on July 18, 2012, from http://climate.weatheroffice.gc.ca/climate_normals/results_e.html?stnID=5097&lang=e&dCode=1&StationName=TORONTO&SearchType=Contains&province=ALL&provBut=&month1=0&month2=12
- Gordon, Gary, (2003). *Interior Lighting for Designers, fourth edition.* New Jersey, USA. John Wiley & Sons, Inc.
- Hansen, Veronica Garcia, (2006).*Innovative daylighting systems for deep-plan commercial buildings*. (Doctoral thesis). Retrieve on April 24, 2012 from http://eprints.qut.edu.au/16709/1/Veronica_Hansen_Thesis.pdf
- Heschong, Lisa, (2002). Daylighting and human performance. *ASHRAE Journal, Vol. 44, No. 6,* p.65.
- Horwitz-Bennett, Barbara & Sullivan, C.C, (2009). Integrating Lighting and Daylighting. *Building Design and Construction.* 50.11, p111.

- Ho, Ming-Chin, Chiang, Che-Ming, Chou, Po-Cheng, Chang, Kuei-Feng & Lee, Chia-Yen, (2008). Optimal sun-shading design for enhanced daylight illumination of subtropical classrooms. *Energy and buildings, Vol. 40*, p.1844-1855.
- Hviid, Christian Anker, Nielsen, Toke Rammer & Svendsen, Svend, (2008). Simple tool to evaluate the impact of daylight on building energy consumption. *Solar Energy, Volume 82, Issue 9*, Pares 787-798.
- Hakkarainen, Pekka, (2005). Daylighting design: A balance act. *Lighting Products World,Volume 8, Issue 9*, pg 35.
- I., Ana, Marrero, Palmero & Oliveira, Armando C., (2010). Effect of louver shading device on building energy requirements. *Applied Energy, Vol. 87*, p. 2040-2049.
- Ihm, Pyonchan, Nemri, Abderrezek & Krarti, Moncef, (2009). Estimation of lighting energy savings from day lighting. *Building and Environment.* Vol. 44, 5099 -514.
- Isoardi, Gillian, Cowling, Ian & Coyne, Steve (2006). Engineering daylight into commercial buildings. *Journal of Light & Visual Environment. Vol. 30*, Issue 3, p. 122.
- Kalogirou, Soteris A. 2009; *Solar Energy Engineering, Process and System;* Elsevier USA.
- Karlen, Mark & Benya, James R, (2004). *Lighting Design Basics;* Hoboken, New Jersey, John Wiley & Sons.
- Katz, David, (2005). Daylighting Harvesting Technologies. *Energy Engineering.* Vol. 102, No. 1 page 40.
- Kim, Ji-Hyun, Yang, Kyoung-Wn, Park, Young-Joon, Lee, Kyung-Hee, Yeo, Myoung-Souk & Kim, Kwang-Woo, (2007). An experimental study for the evaluation of the environmental performance by the application of the automated ventian blind. *Proceedings CLIMA 2007- Wellbeing Indoors*, Helsinki. Retrieved on May 02, 2012 from http://www.inive.org/members_area/medias/pdf/Inive/clima2007/B02/B02L1678.pdf
- Koo, So Young, Yeo, Myoung Souk & Kim, Kwang Woo (2010). Automated blind control to maximize the benefits of daylighting in the buildings. *Building and Environment*. 45, 1508 – 1520.
- Laforgue, P., Souyri, B., Fontoynont, M. & Achard G., (1997). Simulation of visual and therml comfort related to daylighting and solar radiation in office buildings. Retrieved on

May 05, 2012 from http://www.ibpsa.org/%5Cproceedings%5CBS1997%5CBS97_P148.pdf

- Lam, William M.C., (1986). *Sunlighting as formgiver for architecture.* New York, USA. Van Nostrand Reinhold Company.
- Lam, Joseph C. & Li, Danny H.W., (1998). Daylighting and energy analysis for air-conditioned office buildings. *Energy, Vol. 23,* No. 2, 79-89.
- Lechner, Norbert, (2008). *Heating, Cooling, and Lighting: Sustainable Design Methods for Architects. Third edition.* New York. John Wiley & Sons, Inc.
- Leslie, Russell, Smith, Aaron, Radetsky, Leora, Figueiro, Mariana & Yue, Lisa, (2010). *Patterns to daylight schools for people and sustainability.* Rensselaer Polytechnic Institute, USA. Retrieved on March 18, 2012 from http://www.lrc.rpi.edu/programs/daylighting/pdf/DaylightingPatternBook_Final.pdf
- Li, Danny H.W, (2010). A review of daylight illuminance determination and energy implications. *Applied Energy.* 87, 2109 – 2118.
- Li, Danny H.W. & Wong, S.L., (2007). Daylighting and energy implications due to shading effects from nearby buildings. *Applied Energy, Vol. 84,* 1199-1209.
- Li, Danny H.W. & Lam, Joseph C. (2001). Evaluation of lighting performance in office buildings with daylight controls. *Energy and Buildings Vol.33.* p. 793-803.
- Lighting Analysts (2012). AGi32 Version 2.3 [Computer software]. *Lighting Analysts, illumination engineering software*. Colorado, USA: Lighting Analysts, Inc. Available on http://www.agi32.com/index.php
- Mardaljevic, J; Heschong, L. & Lee, E., (2009). Daylighting metrics and energy savings. *Lighting Research and Technology, 41 (3),* 261-283.
- Meek, Christopher & Wymelenberg, Kevin van Den, (2011). A guide to day light success. *Lighting Research & Education LD+A, Illumination Engineering Society, New York, USA.* Retrived on May 11 from http://www.ies.org/lda/hottopics/lre/1.cfm
- Moore, Taylor, (1998). Harvesting daylight inside buildings. *EPRI Journal 23.4,* p.18.
- O'Connor, Jennifer, Lee, Eleanor, Rubinstein, Francis & Selkowitz, Stephen, (1997). Tips for daylightin with windows; the integrated approach. *Building Technologies Program, Energy & Environment Division, Ernest Orlando Lawrence Berkeley National*

Laboratory, University of California, CA, USA. Retrieved on April 29, 2012 from http://windows.lbl.gov/daylighting/designguide/dlg.pdf

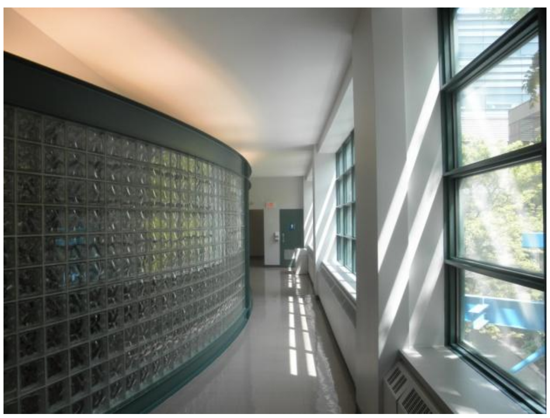
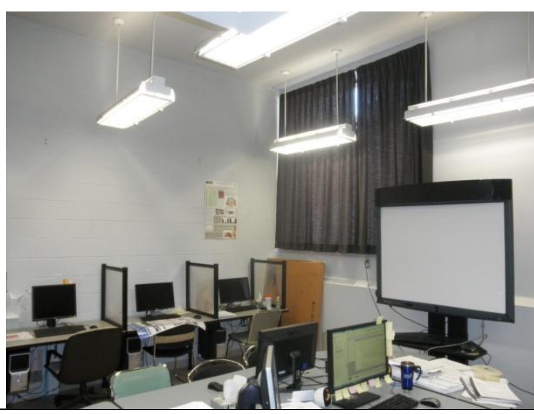
- Phillips, Derek, (2004). *Daylighting; Natural Light in Architecture.* Burlington, USA. Architectural Press.
- Reinhart, Christoph F., Mardaljevic, John & Rogers, Zack, (2006). Dynamic daylighting performance metrics for sustainable building design. *Leukos, Vol. 3,* No.1, Pages 7-31.
- Serra, Rafael, (1998). Daylighting. *Renewable and Sustainable Energy Reviews. Vol.2, I* p. 115- 155.
- Simpson, Robert S., (2003). *Lighting Control- Technology and Applications.* Oxford. Focal Press.
- Simons, R.H. & Bean A.R., (2001). *Lighting Engineering; Applied calculations.* Oxford. Architectural Press.
- *The IESNA Lighting Handbook; Reference & Application,* (2000), Ninth edition. Illuminating Engineering Society of North America. New York, USA.
- The SLL Lighting Handbook, (2009). The Society of Light and Lighting, CIBSE. UK.
- University of Oregon Solar Radiation Monitoring Laboratory, (2012). *Sun path chart program*. Eugene, Oregon. Retrieved on May 15, 2012, from http://solardat.uoregon.edu/SunChartProgram.html
- Vitamin D Deficiency, (2011). *Vitamin D Deficiency Guide*, retrieved on November, 2011 from http://www.vitaminddeficiencyguide.com/
- Tanteri, Matthew, (2006). Planning for Daylighting; introducing daylighting into the traditional design process. *Architectural Lighting*; Apr/May 2006; 20, 3; Page 61.

APPENDIX-A

Monetary Times building's Existing condition

APPENDIX A: Existing condition of Monetary Times building

	North orientation windows
	South orientation windows
	East orientation windows

	Blind were down and electrical light was opened
	Electrical light was opened during sunny period
	During day time curtain was down and electrical light was on.

APPENDIX-B

Validation Results for Rooms 221 and 314

Room 221, Administration Office

Room 221 is located at second floor on a north-east corner of the building and the room is in "**L**" shaped. This room is presently being used as administration office for the Civil Engineering department. The room is 22'-3" wide on a north perimeter by 29'-6" long on an east perimeter. The room has 3 windows, one is on a north orientation and the other two are on an east orientation. The north window is 16'-1" wide by 7'-6"high, the one east window is 14'-3" wide by 7'-6" high and the second window is 11'-3" wide by 7'-6" high. The window-to-wall ratio (WWR) is 60 percent. The field measurements were done on June 13, 2012 at 3.00 pm under clear sky condition.

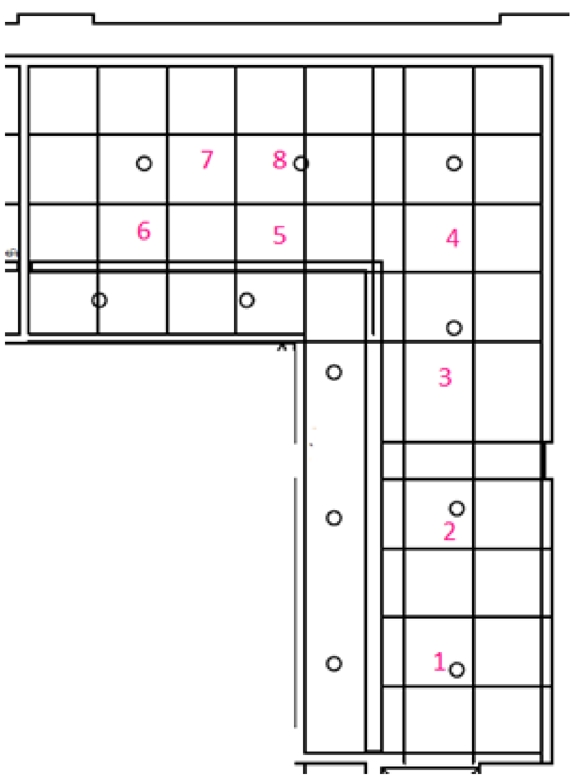


Figure 40: Grid points for field measurements Room 221

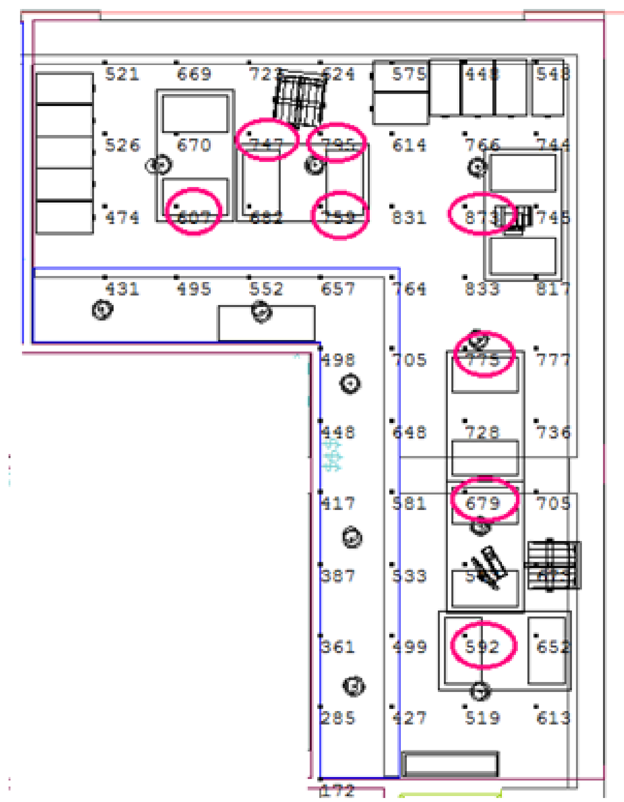


Figure 41: Simulation model's calculation result Room 221

. To calibrate the sky model with the field measurement sky illuminance, absolute zenith luminance factor 1.2 was used for simulation calculation. This absolute zenith luminance factor was calculated from measured unobstructed sky illuminance divided by calculated sky illuminance at the same location. The sky illuminance was measured 120 K.lux to122 K.lux and calculated sky illuminance was 99.5 K.lux under clear sky condition.

The comparison between the field measurement and the simulation model's calculation results are shown in Table 23 below. The comparison shows that the four calculation result points have 5-8 percent differences from the field measurements and the only 3 calculation results have differences from 22 to 32 percent. These differences are due to the software limitation for the room objects and sky illuminance to calibrate the actual site sky condition. However, more than 50 percent field measurements were a close matched.

Table 23: Comparison b/w field measurement and calculation results Room-221

Field Measurement Point Number	Field Measurement Illuminance Lux	Simulation Calculation Lux	Difference	
			Lux	%
1	667	592	-75	11
2	724	679	-45	6
3	818	775	-43	5
4	923	873	-50	5
5	1053	759	-294	28
6	663	607	-56	8
7	1093	747	-346	32
8	1020	795	-225	22

Digital Mapping Lab Room-314

Digital mapping lab Room-314 is located at third floor and has a north orientation. The room size is 32'-3" wide by 30'-6" in depth. The room has two windows with a north orientation and their dimensions are 16'-10" x 7'-6" and 8'-3"x7'-6", and the window-to-wall ratio (WWR) is 58.25 percent. Reflectance for the walls was 60 percent, 73 percent for the ceiling and for the floor 45 percent were used in the simulation model. The field measurements were taken on June 13, 2012 at 1.30 pm under clear sky condition.

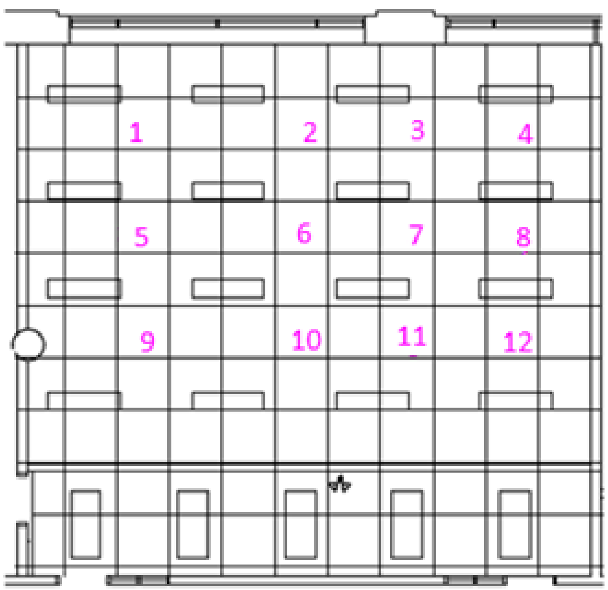


Figure 42: Field measurement points

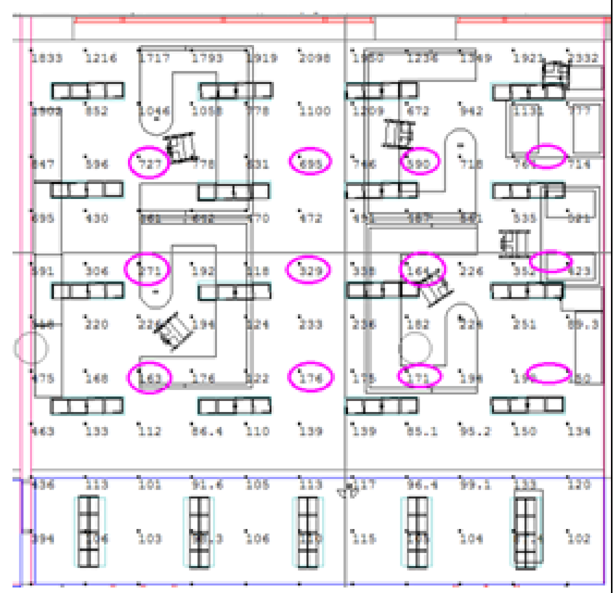


Figure 43: Simulation calculation result

Table 24 below is showing comparison between the field measurements and the simulation calculation results. Six field measurements are matched with the simulation calculation results, while four field measurement points have 11 to 20 percent differences with calculation results. These differences are tolerated because the site cubicles were not matched with simulation model. Only two simulation calculation points have significant differences with field measurement points. More than 50 percent field measurements are matched with the calculation results.

Table 24: Comparison between field measurement and calculation results for room 314

Measurement Point Number	Field Measurement Lux	Calculation Result Lux	Difference Lux	Difference %
1	674	727	53	7
2	694	695	-1	0
3	401	590	189	32
4	745	739	-6	1
5	235	271	36	13
6	335	329	-6	2
7	168	164	-4	2
8	361	388	27	7
9	53	163	110	67
10	157	176	19	11
11	145	171	26	15
12	135	170	35	21

APPENDIX-C

Assumed Properties of Rooms

APPENDIX C Assumed properties of the rooms

Room	Wall Reflection	Ceiling Reflection	Floor Reflection
Room 102, Environmental Lab	60%	65%	Carpet from object library
Room 214, Faculty Lounge	60%	75%	Carpet from object library
Room 217, Faculty Office	60%	73%	Carpet from object library
Room 221, Administration Office	60%	75%	Carpet from object library
Room 305, Faculty Office	60%	73%	Carpet from object library
Room 314, Digital Mapping Lab	60%	73%	45%

APPENDIX-D

CIE Standard General Skies

APPENDIX D: CIE standard general skies

CIE Standard General Skies

The CIE mathematically defines fifteen sky types in CIE Publication S 011/E:2003, Spatial Distributions of Daylight - CIE Standard General Skies. The relative sky luminance distributions are described in the following table:

Type	Gradation Group	Indicatrix Group	Description of luminance distribution
1	I	1	CIE Standard Overcast Sky Steep luminance gradation towards zenith, azimuthal uniformity.
2	I	2	Overcast, with steep luminance gradation and slight brightening towards the sun.
3	II	1	Overcast, moderately graded with azimuthal uniformity.
4	II	2	Overcast, moderately graded and slight brightening towards the sun.
5	II	1	Sky of uniform luminance.
6	III	2	Partly cloudy sky, no gradation towards zenith, slight brightening towards the sun.
7	III	3	Partly cloudy sky, no gradation towards zenith, brighter circumsolar region.
8	III	4	Partly cloudy sky, no gradation towards zenith, distinct solar corona.
9	III	2	Partly cloudy, with obscured sun.
10	IV	3	Partly cloudy, with brighter circumsolar region.
11	IV	4	White-blue sky with distinct solar corona.
12	V	4	CIE Standard Clear Sky, low luminance turbidity.
13	V	5	CIE Standard Clear Sky, polluted atmosphere.
14	VI	5	Cloudless turbid sky with broad solar corona.
15	VI	6	White-blue turbid sky with broad solar corona.

Gradation Group - indicates the gradation between horizon and zenith.

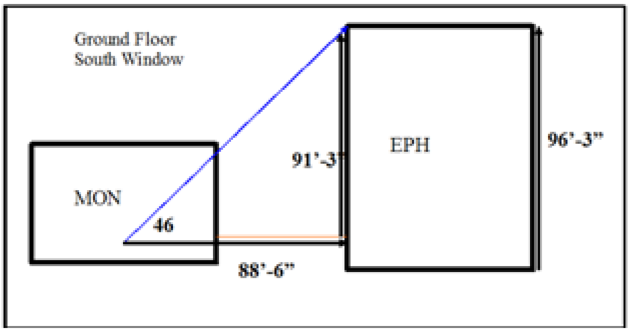
Indicatrix Group - indicates the scattering function, which relates the luminance of a sky element to its angular distance to the sun.

APPENDIX-E

Obstruction Angles Calculations

APPENDIX E: Calculation for obstruction angles

South windows on ground floor

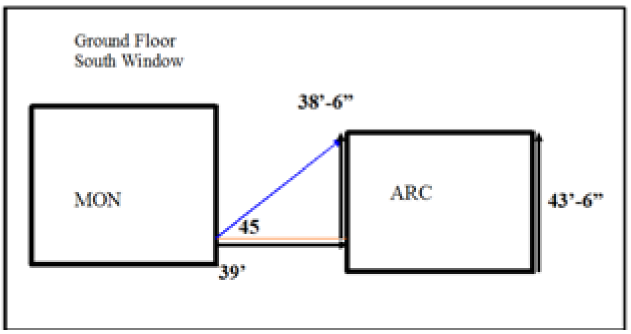


With EPH building

$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{91.25}{88.5}$$

Obstruction angle = $\theta = 46^{o}$

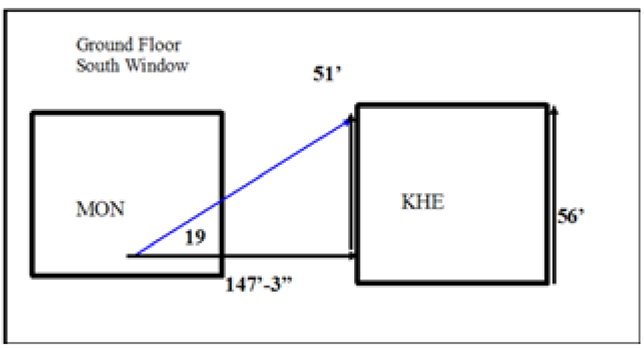


With ARC building

$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{38.5}{39}$$

Obstruction angle = $\theta = 45^{o}$



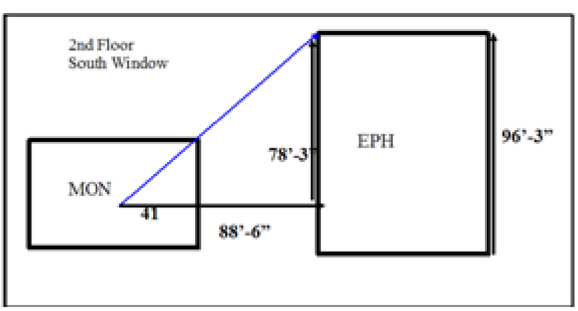
With KHE building

$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{51}{147.25}$$

Obstruction angle = $\theta = 19^{o}$

South windows on second floor

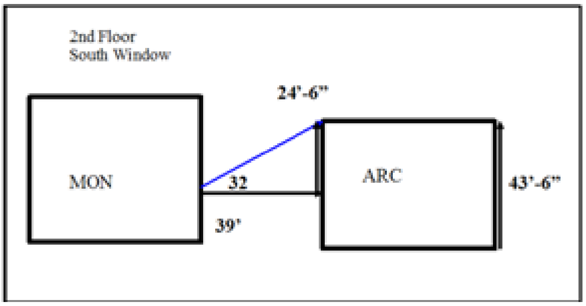


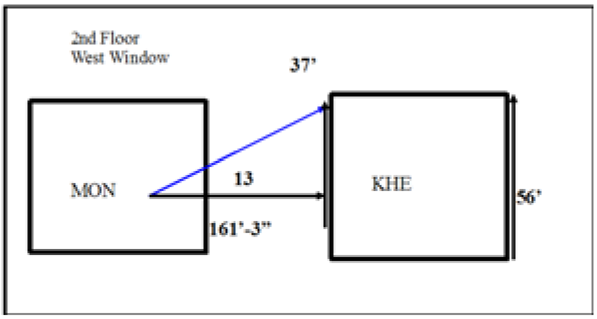
With EPH building

$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{78.25}{88.5}$$

Obstruction angle = $\theta = 41^{o}$





With ARC building

$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{24.5}{39}$$

Obstruction angle = $\theta = 32^o$

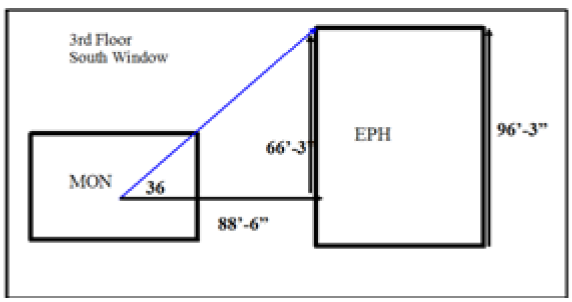
With KHE building

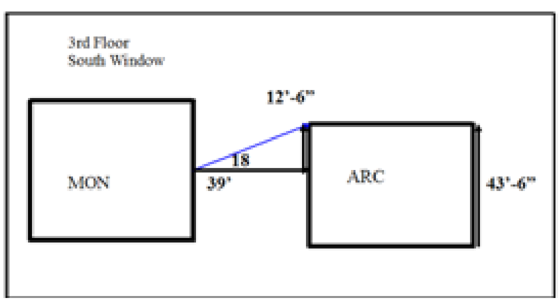
$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{37}{161.25}$$

Obstruction angle = $\theta = 13^o$

South windows on third floor





With EPH building

$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{66.25}{88.5}$$

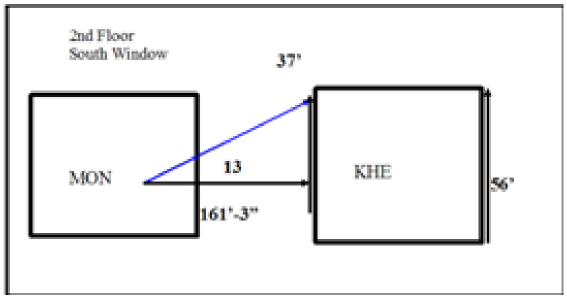
Obstruction angle = $\theta = 41^o$

With ARC building

$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{12.5}{39}$$

Obstruction angle = $\theta = 18^o$



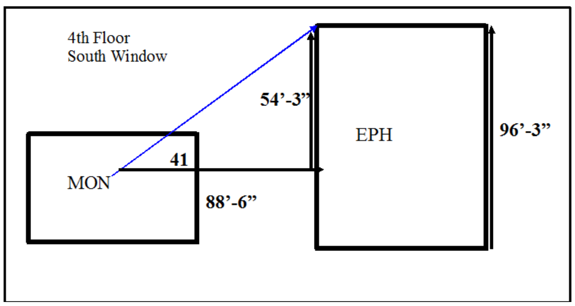
With KHE building

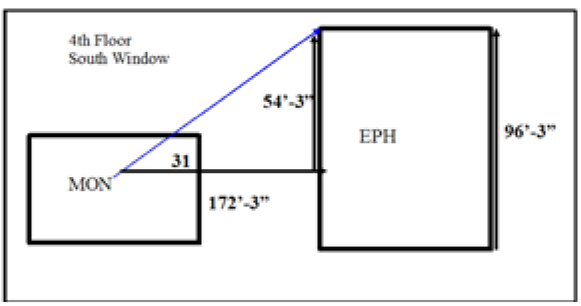
$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{37}{161.25}$$

Obstruction angle = $\theta = 13^{o}$

South windows on fourth floor





With EPH building on east side

$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{54.25}{88.5}$$

Obstruction angle = $\theta = 41^{o}$

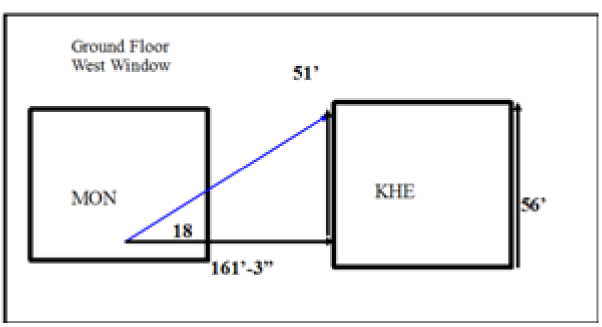
With EPH building on south-east side

$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{54.25}{172.25}$$

Obstruction angle = $\theta = 31^{o}$

West windows on ground floor

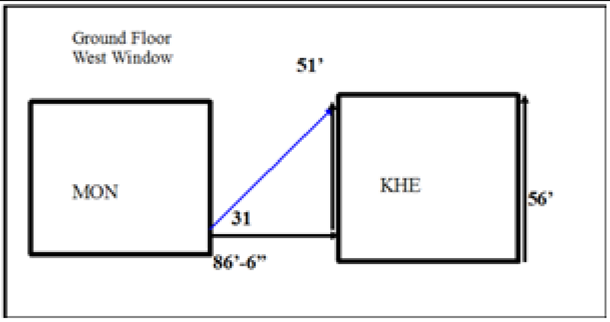
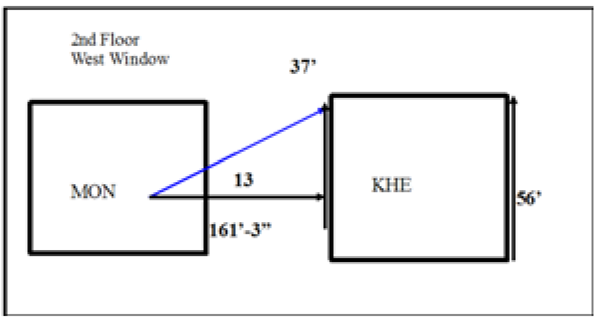
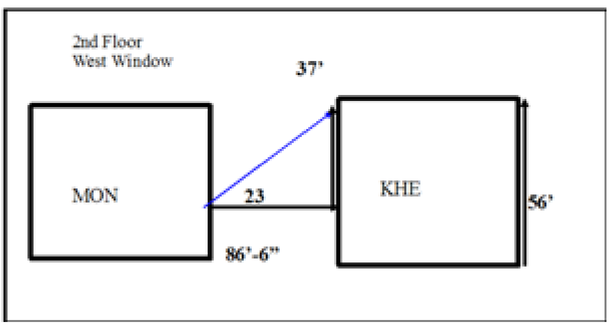
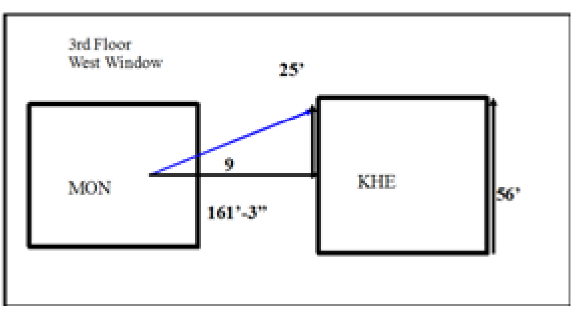


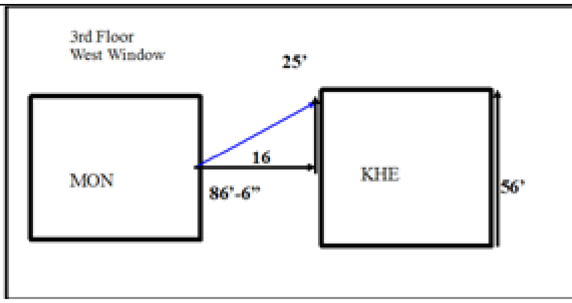
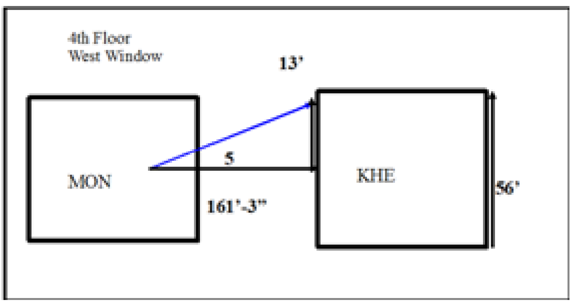
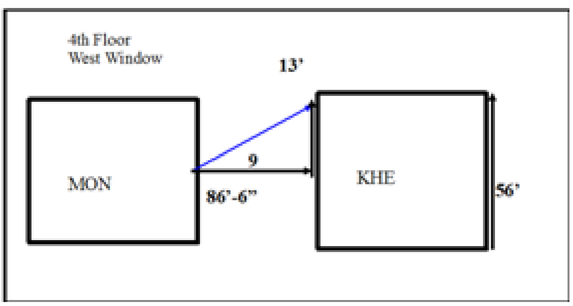
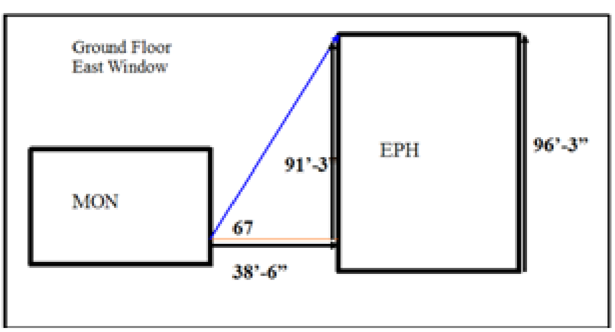
With KHE building

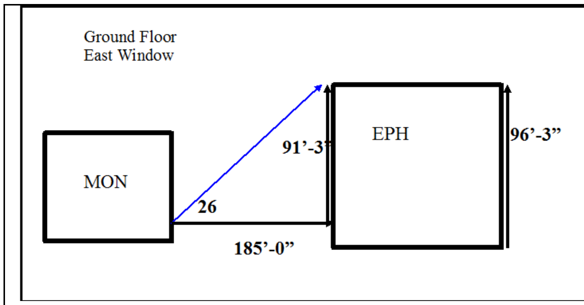
$$tan\theta = \frac{perpendicular}{base}$$

$$tan\theta = \frac{51}{161.25}$$

Obstruction angle = $\theta = 18^{o}$

 	With KHE building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{51}{86.5}$ Obstruction angle = $\theta = 31^{o}$
West windows on second floor   	With KHE building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{37}{161.25}$ Obstruction angle = $\theta = 13^{o}$ With KHE building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{37}{86.5}$ Obstruction angle = $\theta = 23^{o}$
West windows on third floor  	With KHE building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{25}{161.25}$ Obstruction angle = $\theta = 9^{o}$

 	With KHE building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{25}{86.5}$ Obstruction angle = $\theta = 16^{o}$
West window on fourth floor   	With KHE building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{13}{161.25}$ Obstruction angle = $\theta = 5^{o}$ With KHE building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{13}{86.5}$ Obstruction angle = $\theta = 9^{o}$
East windows on ground floor  	With EPH building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{91.25}{38.5}$ Obstruction angle = $\theta = 67^{o}$



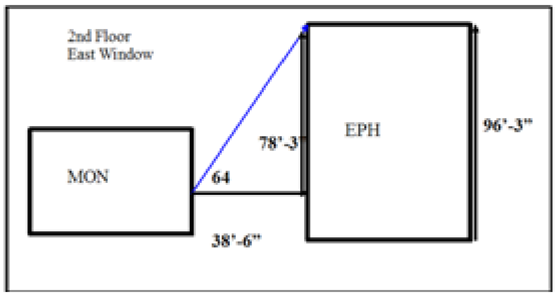
With EPH building

$$\tan\theta = \frac{perpendicular}{base}$$

$$\tan\theta = \frac{91.25}{185}$$

Obstruction angle = $\theta = 26^{o}$

East window on second floor

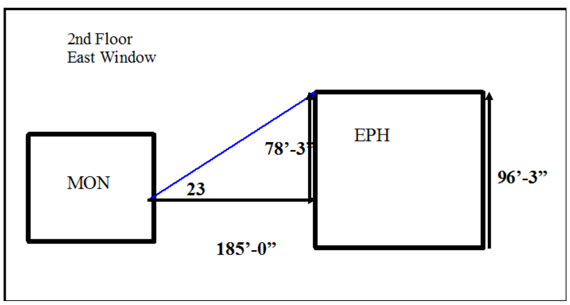


With EPH building

$$\tan\theta = \frac{perpendicular}{base}$$

$$\tan\theta = \frac{78.25}{38.5}$$

Obstruction angle = $\theta = 64^{o}$



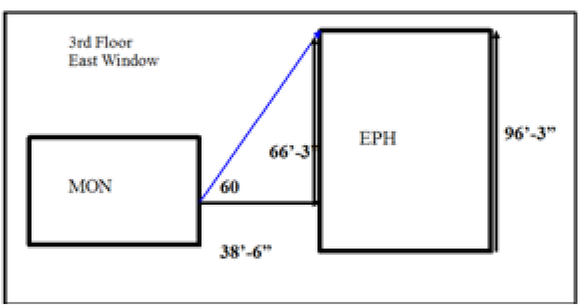
With EPH building

$$\tan\theta = \frac{perpendicular}{base}$$

$$\tan\theta = \frac{78.25}{185}$$

Obstruction angle = $\theta = 23^{o}$

East window on third floor

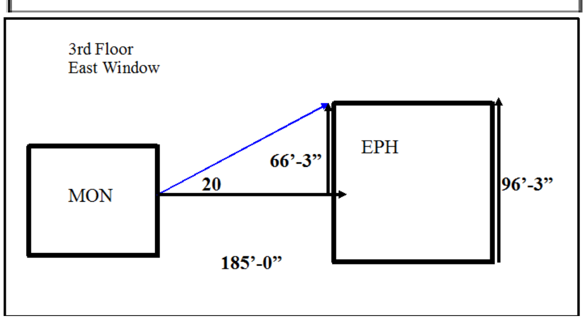


With EPH building

$$\tan\theta = \frac{perpendicular}{base}$$

$$\tan\theta = \frac{66.25}{38.5}$$

Obstruction angle = $\theta = 60^{o}$

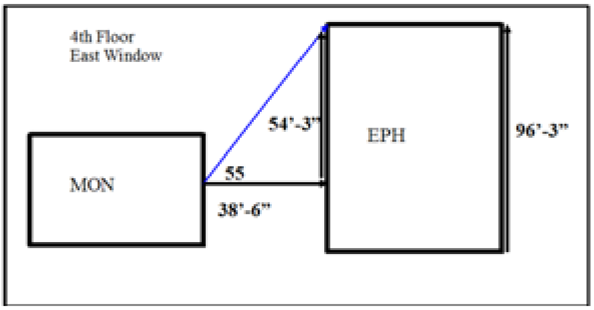
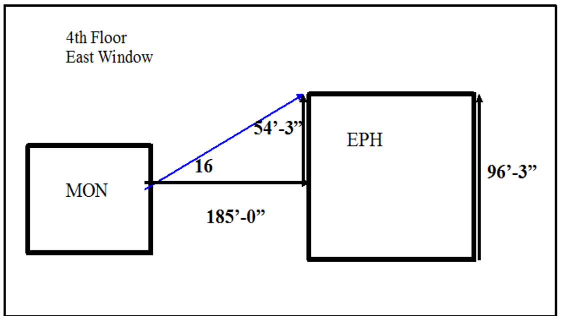


With EPH building

$$\tan\theta = \frac{perpendicular}{base}$$

$$\tan\theta = \frac{66.25}{38.5}$$

Obstruction angle = $\theta = 20^{o}$

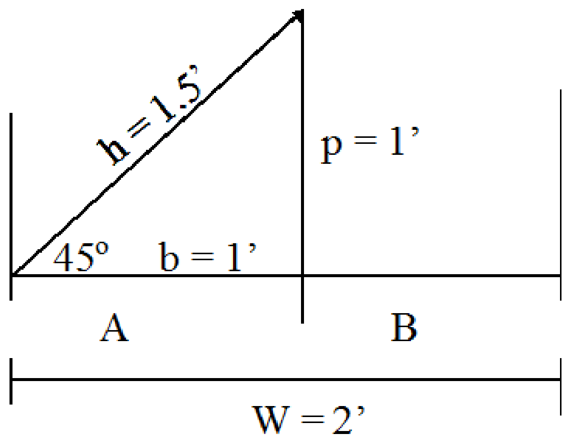
East Window on fourth floor	
	With EPH building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{54.25}{38.5}$ Obstruction angle = $\theta = 55^o$ With EPH building $tan\theta = \frac{perpendicular}{base}$ $tan\theta = \frac{54.25}{38.5}$ Obstruction angle = $\theta = 16^o$

APPENDIX-F

Shading Devices Depth Calculations

APPENDIX F: Shading device depth calculation

Horizontal louver depth *D* for south windows	
$$h = \frac{D \text{ x} \tan(solar\ altitude)}{Cos(solar\ azimuth - window\ azimuth)}$$ $$1.5 = \frac{D \text{ x} \tan(45)}{Cos(180 - 164)}$$ $$1.5 = \frac{D \text{ x} \tan(45)}{Cos(16)}$$ $$1.5 = \frac{D \text{ x } 1}{0.96}$$ $$D = 1.44'$$	Louvers depth = D Solar Altitude = 45^{o} Solar azimuth = 180^{o} Window azimuth = 164^{o} Required Shadow height = h h = 1.5'
Horizontal overhang depth *D* for west windows	
$$h = \frac{D \text{ x} \tan(solar\ altitude)}{Cos(solar\ azimuth - window\ azimuth)}$$ $$3.75 = \frac{D \text{ x} \tan(45)}{Cos(225 - 255)}$$ $$3.75 = \frac{D \text{ x} \tan(45)}{Cos(-30)}$$ $$3.75 = \frac{D \text{ x } 1}{0.866}$$ $$D = 3.25'$$	Overhang depth = D Solar Altitude = 45^{o} Solar azimuth = 225^{o} Window azimuth = 255^{o} Required Shadow height = h h = 3.75'
Vertical fins depth *D* for west windows	
$$w = D\ X \tan(solar\ azimuth - window\ azimuth)$$ $$2.00 = D\ X\ \tan(300 - 255)$$ $$2.00 = D\ X\ \tan(45)$$ $$2.00 = D\ X\ 1$$ $$D = 2.00'$$	Fins depth = D Solar azimuth = 300^{o} Window azimuth = 255^{o} Required Shadow width = w w = 2.00'

Vertical fins depth D for north windows $w = D\ X\ \tan(solar\ azimuth - window\ azimuth)$ $2.00 = D\ X\ \tan(300 - 345)$ $2.00 = D\ X\ \tan(-45)$ $2.00 = D\ X\ 1$ $D = 2.00'$	Fins depth = D Solar azimuth = 300^o Window azimuth = 345^o Required Shadow width = w w = 2.00'
Moveable fins depth  Cos θ = b/h Cos 45^o = b/1.5' 0.707 = b/1.5' b = 1' Sin θ = p/h Sin 45^o = p/1.5' 0.707 = p/1.5' p = 1'	Required shadow width = W W = 2' Reduced shadow width due to moveable fins = B = 1' Fins depth = h =1.5'

APPENDIX-G

IESNA Illumination Standard Table

APPENDIX G: IESNA determination of illuminance categories

Category	Space/Task	Recommended Illuminance
Orientation and simple visual tasks	Visual performance is largely unimportant. These task are found in public spaces where reading and visual inspection are only occasionally performed. Higher levels are recommended for task where visual performance is occasionally important	
A	Public spaces	30 lx (3 fc)
B	Simple orientation for short visit	50 lx (5 fc)
C	Working space where simple visual tasks are performed	100 lx (10 fc)
Common visual tasks	Visual performance is important. These tasks are found in commercial, industrial and residential applications. Recommended illuminance levels differ because of the characteristics of the visual task being illuminated. Higher levels are recommended for visual tasks with critical elements of low contrast or small size.	
D	Performance of visual task of high contrast and large size	300 lx (30 fc)
E	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	500 lx (50 fc)
F	Performance of visual tasks of low contrast and small size	1000 lx (100 fc)
Special visual tasks	Visual performance is of critical importance. These tasks are very specialized, including those with very small or very low contrast critical elements. Recommended illuminance levels should be achieved with supplementary task lighting. Higher recommended levels are often achieved by moving the light source to the task.	
G	Performance of visual tasks near threshold	3000 to 10,000 lx (300 to 1000 fc)

APPENDIX-H

Detailed Energy Savings Data

APPENDIX H: Detailed energy savings data

	Energy Savings under Clear Sky Condition									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	December			January			February		
	watts/hr	Area %	watts/hr	122.7 hrs in month	Area %	watts/hr	137.1hrs in month	Area %	watts/hr	142 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	312	1	312	38.2824	1	312	42.7752	1	312	44.304
Room 102A (NE)	192	1	192	23.5584	1	192	26.3232	1	192	27.264
Room 102 (N)	448	0.5	224	27.4848	0.5	224	30.7104	0.5	224	31.808
Room 104 (N)	2944	0.8	2355.2	288.983	0.8	2355.2	322.8979	0.8	2355.2	334.4384
Room 105 (S)	704	1	704	86.3808	1	704	96.5184	1	704	99.968
2nd Floor										
Room 212 (W)	256	0.7	179.2	21.98784	0.7	179.2	24.56832	7	1792	254.464
Room 213 (W)	256	0.5	128	15.7056	0.5	128	17.5488	0.6	153.6	21.8112
Room 214 (NW)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 215 (N)	256	0.5	128	15.7056	0.6	153.6	21.05856	0.9	230.4	32.7168
Room 216 (N)	256	0.25	64	7.8528	0.3	76.8	10.52928	0.3	76.8	10.9056
Room 217 (N)	256	0.35	89.6	10.99392	0.4	102.4	14.03904	0.5	128	18.176
Room 218 (N)	256	0.45	115.2	14.13504	0.5	128	17.5488	0.95	243.2	34.5344
Room 219 (N)	256	0.8	204.8	25.12896	0.85	217.6	29.83296	1	256	36.352
Room 220 (N)	512	1	512	62.8224	1	512	70.1952	1	512	72.704
Room 221 (N)	286	1	286	35.0922	1	286	39.2106	1	286	40.612
Staircase (E W)	192	1	192	23.5584	1	192	26.3232	1	192	27.264
3rd Floor										
Room 302 (E)	256	0.5	128	15.7056	0.75	192	26.3232	0.85	217.6	30.8992
Room 303 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 304 (NE)	512	1	512	62.8224	1	512	70.1952	1	512	72.704
Room 305 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 306 (S)	256	0.7	179.2	21.98784	0.5	128	17.5488	0.5	128	18.176
Room 307 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 309 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 311 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 314 (N)	1536	0.3	460.8	56.54016	0.25	384	52.6464	0.3	460.8	65.4336
Room 316 (N)	1152	0.35	403.2	49.47264	0.25	288	39.4848	0.3	345.6	49.0752
Room 318 (NW)	832	1	832	102.0864	1	832	114.0672	1	832	118.144
Staircase (E W)	192	1	192	23.5584	1	192	26.3232	1	192	27.264
4th Floor										
Room 402 (E)	256	0.5	128	15.7056	0.75	192	26.3232	0.85	217.6	30.8992
Room 403 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 404 (NE)	512	1	512	62.8224	1	512	70.1952	1	512	72.704
Room 405 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 406 (N)	256	0.7	179.2	21.98784	0.5	128	17.5488	0.5	128	18.176
Room 407 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 409 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 411 (S)	256	1	256	31.4112	1	256	35.0976	1	256	36.352
Room 412 (N)	1536	0.3	460.8	56.54016	0.25	384	52.6464	0.3	460.8	65.4336
Room 414 (N)	1152	0.35	403.2	49.47264	0.25	288	39.4848	0.3	345.6	49.0752
Room 418 (NW)	832	1	832	102.0864	1	832	114.0672	1	832	118.144
Staircase (E W)	192	1	192	23.5584	1	192	26.3232	1	192	27.264
Total			**13916.4**	**1707.54**		**13634.8**	**1869.33**		**15849.2**	**2250.59**

	Energy Savings under Clear Sky Condition									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	**March**			**April**			**May**		
	watts/hr	Area %	watts/hr	197.4 hrs in month	Area %	watts/hr	188.2 hrs in month	Area %	watts/hr	208.1 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	312	1	312	61.5888	1	312	58.7184	1	312	64.9272
Room 102A (NE)	192	1	192	37.9008	1	192	36.1344	1	192	39.9552
Room 102 (N)	448	0.5	224	44.2176	0.6	268.8	50.58816	0.8	358.4	74.58304
Room 104 (N)	2944	0.95	2796.8	552.0883	0.95	2796.8	526.3578	1	2944	612.6464
Room 105 (S)	704	1	704	138.9696	1	704	132.4928	1	704	146.5024
2nd Floor										
Room 212 (W)	256	0.95	243.2	48.00768	1	256	48.1792	1	256	53.2736
Room 213 (W)	256	0.9	230.4	45.48096	0.9	230.4	43.36128	0.95	243.2	50.60992
Room 214 (NW)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 215 (N)	256	0.95	243.2	48.00768	1	256	48.1792	1	256	53.2736
Room 216 (N)	256	0.7	179.2	35.37408	0.75	192	36.1344	0.8	204.8	42.61888
Room 217 (N)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 218 (N)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 219 (N)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 220 (N)	512	1	512	101.0688	1	512	96.3584	1	512	106.5472
Room 221 (N)	286	1	286	56.4564	1	286	53.8252	1	286	59.5166
Staircase (E W)	192	1	192	37.9008	1	192	36.1344	1	192	39.9552
3rd Floor										
Room 302 (E)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 303 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 304 (NE)	512	1	512	101.0688	1	512	96.3584	1	512	106.5472
Room 305 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 306 (S)	256	0.95	243.2	48.00768	0.85	217.6	40.95232	0.9	230.4	47.94624
Room 307 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 309 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 311 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 314 (N)	1536	0.4	614.4	121.2826	0.5	768	144.5376	0.5	768	159.8208
Room 316 (N)	1152	0.4	460.8	90.96192	0.45	518.4	97.56288	0.5	576	119.8656
Room 318 (NW)	832	1	832	164.2368	1	832	156.5824	1	832	173.1392
Staircase (E W)	192	1	192	37.9008	1	192	36.1344	1	192	39.9552
4th Floor										
Room 402 (E)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 403 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 404 (NE)	512	1	512	101.0688	1	512	96.3584	1	512	106.5472
Room 405 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 406 (N)	256	0.95	243.2	48.00768	0.85	217.6	40.95232	0.9	230.4	47.94624
Room 407 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 409 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 411 (S)	256	1	256	50.5344	1	256	48.1792	1	256	53.2736
Room 412 (N)	1536	0.4	614.4	121.2826	0.5	768	144.5376	0.5	768	159.8208
Room 414 (N)	1152	0.4	460.8	90.96192	0.45	518.4	97.56288	0.5	576	119.8656
Room 418 (NW)	832	1	832	164.2368	1	832	156.5824	1	832	173.1392
Staircase (E W)	192	1	192	37.9008	1	192	36.1344	1	192	39.9552
Total			**15919.6**	**3142.53**		**16374**	**3081.59**		**16777.2**	**3491.34**

	Energy Savings under Clear Sky Condition									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	June			July			August		
	watts/hr	Area %	watts/hr	197.3 hrs in month	Area %	watts/hr	228.6 hrs in month	Area %	watts/hr	226.8 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	312	0.95	296.4	58.47972	1	312	71.3232	1	312	70.7616
Room 102A (NE)	192	1	192	37.8816	1	192	43.8912	1	192	43.5456
Room 102 (N)	448	0.9	403.2	79.55136	0.8	358.4	81.93024	0.6	268.8	60.96384
Room 104 (N)	2944	1	2944	580.8512	1	2944	672.9984	0.95	2796.8	634.3142
Room 105 (S)	704	1	704	138.8992	1	704	160.9344	1	704	159.6672
2nd Floor			0			0	0		0	0
Room 212 (W)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 213 (W)	256	0.95	243.2	47.98336	0.95	243.2	55.59552	0.9	230.4	52.25472
Room 214 (NW)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 215 (N)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 216 (N)	256	0.9	230.4	45.45792	0.8	204.8	46.81728	0.75	192	43.5456
Room 217 (N)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 218 (N)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 219 (N)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 220 (N)	512	1	512	101.0176	1	512	117.0432	1	512	116.1216
Room 221 (N)	286	1	286	56.4278	1	286	65.3796	1	286	64.8648
Staircase (E W)	192		192	37.8816	1	192	43.8912	1	192	43.5456
3rd Floor			0			0	0		0	0
Room 302 (E)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 303 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 304 (NE)	512	1	512	101.0176	1	512	117.0432	1	512	116.1216
Room 305 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 306 (S)	256	0.95	243.2	47.98336	0.9	230.4	52.66944	0.85	217.6	49.35168
Room 307 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 309 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 311 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 314 (N)	1536	0.5	768	151.5264	0.5	768	175.5648	0.5	768	174.1824
Room 316 (N)	1152	0.5	576	113.6448	0.5	576	131.6736	0.45	518.4	117.5731
Room 318 (NW)	832	1	832	164.1536	1	832	190.1952	1	832	188.6976
Staircase (E W)	192	1	192	37.8816	1	192	43.8912	1	192	43.5456
4th Floor			0			0	0		0	0
Room 402 (E)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 403 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 404 (NE)	512	1	512	101.0176	1	512	117.0432	1	512	116.1216
Room 405 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 406 (N)	256	0.95	243.2	47.98336	0.9	230.4	52.66944	0.85	217.6	49.35168
Room 407 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 409 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 411 (S)	256	1	256	50.5088	1	256	58.5216	1	256	58.0608
Room 412 (N)	1536	0.5	768	151.5264	0.5	768	175.5648	0.5	768	174.1824
Room 414 (N)	1152	0.5	576	113.6448	0.5	576	131.6736	0.45	518.4	117.5731
Room 418 (NW)	832	1	832	164.1536	1	832	190.1952	1	832	188.6976
Staircase (E W)	192	1	192	37.8816	1	192	43.8912	1	192	43.5456
Total			**16857.6**	**3326**		**16777.2**	**3835.27**		**16374**	**3713.62**

	Energy Savings under Clear Sky Condition									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	**September**			**October**			**November**		
	watts/hr	Area %	watts/hr	218 hrs in month	Area %	watts/hr	198.2 hrs in month	Area %	watts/hr	114.9 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	312	1	312	68.016	1	312	61.8384	1	312	35.8488
Room 102A (NE)	192	1	192	41.856	1	192	38.0544	1	192	22.0608
Room 102 (N)	448	0.5	224	48.832	0.5	224	44.3968	0.5	224	25.7376
Room 104 (N)	2944	0.95	2796.8	609.7024	0.8	2355.2	466.8006	0.8	2355.2	270.6125
Room 105 (S)	704	1	704	153.472	1	704	139.5328	1	704	80.8896
2nd Floor			0	0		0	0		0	0
Room 212 (W)	256	0.95	243.2	53.0176	7	1792	355.1744	0.7	179.2	20.59008
Room 213 (W)	256	0.9	230.4	50.2272	0.6	153.6	30.44352	0.5	128	14.7072
Room 214 (NW)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 215 (N)	256	0.95	243.2	53.0176	0.9	230.4	45.66528	0.6	153.6	17.64864
Room 216 (N)	256	0.7	179.2	39.0656	0.3	76.8	15.22176	0.3	76.8	8.82432
Room 217 (N)	256	1	256	55.808	0.5	128	25.3696	0.4	102.4	11.76576
Room 218 (N)	256	1	256	55.808	0.95	243.2	48.20224	0.5	128	14.7072
Room 219 (N)	256	1	256	55.808	1	256	50.7392	0.85	217.6	25.00224
Room 220 (N)	512	1	512	111.616	1	512	101.4784	1	512	58.8288
Room 221 (N)	286	1	286	62.348	1	286	56.6852	1	286	32.8614
Staircase (E W)	192	1	192	41.856	1	192	38.0544	1	192	22.0608
3rd Floor			0	0		0	0		0	0
Room 302 (E)	256	1	256	55.808	0.85	217.6	43.12832	0.75	192	22.0608
Room 303 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 304 (NE)	512	1	512	111.616	1	512	101.4784	1	512	58.8288
Room 305 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 306 (S)	256	0.95	243.2	53.0176	0.5	128	25.3696	0.5	128	14.7072
Room 307 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 309 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 311 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 314 (N)	1536	0.4	614.4	133.9392	0.3	460.8	91.33056	0.25	384	44.1216
Room 316 (N)	1152	0.4	460.8	100.4544	0.3	345.6	68.49792	0.25	288	33.0912
Room 318 (NW)	832	1	832	181.376	1	832	164.9024	1	832	95.5968
Staircase (E W)	192	1	192	41.856	1	192	38.0544	1	192	22.0608
4th Floor			0	0		0	0		0	0
Room 402 (E)	256	1	256	55.808	0.85	217.6	43.12832	0.75	192	22.0608
Room 403 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 404 (NE)	512	1	512	111.616	1	512	101.4784	1	512	58.8288
Room 405 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 406 (N)	256	0.95	243.2	53.0176	0.5	128	25.3696	0.5	128	14.7072
Room 407 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 409 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 411 (S)	256	1	256	55.808	1	256	50.7392	1	256	29.4144
Room 412 (N)	1536	0.4	614.4	133.9392	0.3	460.8	91.33056	0.25	384	44.1216
Room 414 (N)	1152	0.4	460.8	100.4544	0.3	345.6	68.49792	0.25	288	33.0912
Room 418 (NW)	832	1	832	181.376	1	832	164.9024	1	832	95.5968
Staircase (E W)	192	1	192	41.856	1	192	38.0544	1	192	22.0608
Total			**15919.6**	**3470.47**		**15849.2**	**3141.31**		**13634.8**	**1566.64**

	Energy Saving under Partly Cloudy Sky									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	December			January			February		
	watts/hr	Area %	watts/hr	102.3 hrs in month	Area %	watts/hr	103.8 hrs in month	Area %	watts/hr	106 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	312	1	312	31.9176	1	312	32.3856	1	312	33.072
Room 102A (NE)	192	1	192	19.6416	1	192	19.9296	1	192	20.352
Room 102 (N)	448	0.4	179.2	18.33216	0.45	201.6	20.92608	0.6	268.8	28.4928
Room 104 (N)	2944	0.8	2355.2	240.937	0.85	2502.4	259.7491	0.9	2649.6	280.8576
Room 105 (S)	704	1	704	72.0192	1	704	73.0752	1	704	74.624
2^{nd} Floor			0	0		0	0		0	0
Room 212 (W)	256	0.9	230.4	23.56992	0.8	204.8	21.25824	1	256	27.136
Room 213 (W)	256	0.9	230.4	23.56992	0.75	192	19.9296	0.9	230.4	24.4224
Room 214 (NW)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 215 (N)	256	0.35	89.6	9.16608	0.4	102.4	10.62912	0.9	230.4	24.4224
Room 216 (N)	256	0.35	89.6	9.16608	0.3	76.8	7.97184	0.5	128	13.568
Room 217 (N)	256	0.4	102.4	10.47552	0.4	102.4	10.62912	0.7	179.2	18.9952
Room 218 (N)	256	0.45	115.2	11.78496	0.45	115.2	11.95776	0.85	217.6	23.0656
Room 219 (N)	256	0.5	128	13.0944	0.5	128	13.2864	1	256	27.136
Room 220 (N)	512	0.9	460.8	47.13984	0.95	486.4	50.48832	1	512	54.272
Room 221 (N)	286	1	286	29.2578	1	286	29.6868	1	286	30.316
Staircase (E W)	192	1	192	19.6416	1	192	19.9296	1	192	20.352
3^{rd} Floor			0	0		0	0		0	0
Room 302 (E)	256	0.5	128	13.0944	0.7	179.2	18.60096	1	256	27.136
Room 303 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 304 (NE)	512	1	512	52.3776	1	512	53.1456	1	512	54.272
Room 305 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 306 (S)	256	0.35	89.6	9.16608	0.6	153.6	15.94368	0.6	153.6	16.2816
Room 307 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 309 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 311 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 314 (N)	1536	0	0	0	0.25	384	39.8592	0.35	537.6	56.9856
Room 316 (N)	832	0	0	0	0.2	166.4	17.27232	0.35	291.2	30.8672
Room 318 (NW)	192	1	192	19.6416	1	192	19.9296	1	192	20.352
Staircase (E W)	192	1	192	19.6416	1	192	19.9296	1	192	20.352
4^{th} Floor			0	0		0	0		0	0
Room 402 (E)	256	0.5	128	13.0944	0.7	179.2	18.60096	1	256	27.136
Room 403 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 404 (NE)	512	1	512	52.3776	1	512	53.1456	1	512	54.272
Room 405 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 406 (N)	256	0.35	89.6	9.16608	0.6	153.6	15.94368	0.6	153.6	16.2816
Room 407 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 409 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 411 (S)	256	1	256	26.1888	1	256	26.5728	1	256	27.136
Room 412 (N)	1536	0	0	0	0.25	384	39.8592	0.35	537.6	56.9856
Room 414 (N)	1152	0	0	0	0.2	230.4	23.91552	0.35	403.2	42.7392
Room 418 (NW)	832	1	832	85.1136	1	832	86.3616	1	832	88.192
Staircase (E W)	192	1	192	19.6416	1	192	19.9296	1	192	20.352
Total			**11350**	**1161.11**		**12876.4**	**1336.57**		**14450.8**	**1531.78**

	Energy Saving under Partly Cloudy Sky									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	March			April			May		
	watts/hr	Area %	watts/hr	117 hrs in month	Area %	watts/hr	126.8 hrs in month	Area %	watts/hr	151.7 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	312	1	312	36.504	1	312	39.5616	1	312	47.3304
Room 102A (NE)	192	1	192	22.464	1	192	24.3456	1	192	29.1264
Room 102 (N)	448	0.9	403.2	47.1744	0.95	425.6	53.96608	1	448	67.9616
Room 104 (N)	2944	1	2944	344.448	1	2944	373.2992	1	2944	446.6048
Room 105 (S)	704	1	704	82.368	1	704	89.2672	1	704	106.7968
2nd Floor			0	0		0	0		0	0
Room 212 (W)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 213 (W)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 214 (NW)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 215 (N)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 216 (N)	256	0.95	243.2	28.4544	1	256	32.4608	1	256	38.8352
Room 217 (N)	256	0.98	250.88	29.35296	1	256	32.4608	1	256	38.8352
Room 218 (N)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 219 (N)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 220 (N)	512	1	512	59.904	1	512	64.9216	1	512	77.6704
Room 221 (N)	286	1	286	33.462	1	286	36.2648	1	286	43.3862
Staircase (E W)	192	1	192	22.464	1	192	24.3456	1	192	29.1264
3rd Floor			0	0		0	0		0	0
Room 302 (E)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 303 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 304 (NE)	512	1	512	59.904	1	512	64.9216	1	512	77.6704
Room 305 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 306 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 307 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 309 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 311 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 314 (N)	1536	0.5	768	89.856	0.6	921.6	116.8589	0.75	1152	174.7584
Room 316 (N)	832	0.5	416	48.672	0.6	499.2	63.29856	0.7	582.4	88.35008
Room 318 (NW)	192	1	192	22.464	1	192	24.3456	1	192	29.1264
Staircase (E W)	192	1	192	22.464	1	192	24.3456	1	192	29.1264
4th Floor			0	0		0	0		0	0
Room 402 (E)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 403 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 404 (NE)	512	1	512	59.904	1	512	64.9216	1	512	77.6704
Room 405 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 406 (N)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 407 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 409 (S)	256	1	256	29.952	11	2816	357.0688	1	256	38.8352
Room 411 (S)	256	1	256	29.952	1	256	32.4608	1	256	38.8352
Room 412 (N)	1536	0.5	768	89.856	0.6	921.6	116.8589	0.75	1152	174.7584
Room 414 (N)	1152	0.5	576	67.392	0.6	691.2	87.64416	0.7	806.4	122.3309
Room 418 (NW)	832	1	832	97.344	1	832	105.4976	1	832	126.2144
Staircase (E W)	192	1	192	22.464	1	192	24.3456	1	192	29.1264
			16119.3	**1885.96**		**19225.2**	**2437.76**		**17346.8**	**2631.51**

	Energy Saving under Partly Cloudy Sky										
	Percentage of room area have minimum illuminance of 300 Lux										
	Electrical Lighting	June			July			August			
	watts/hr	Area %	watts/hr	189.4 hrs in month	Area %	watts/hr	222.3 hrs in month	Area %	watts/hr	206.7 hrs in month	
Ground Floor				KWh			KWh			KWh	
Room 101 (S)	312	1	312	59.0928	1	312	69.3576	1	312	64.4904	
Room 102A (NE)	192	1	192	36.3648	1	192	42.6816	1	192	39.6864	
Room 102 (N)	448	1	448	84.8512	1	448	99.5904	0.95	425.6	87.97152	
Room 104 (N)	2944	1	2944	557.5936	1	2944	654.4512	1	2944	608.5248	
Room 105 (S)	704	1	704	133.3376	1	704	156.4992	1	704	145.5168	
2nd Floor			0	0		0	0		0	0	
Room 212 (W)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 213 (W)	256	0.98	250.88	47.51667	1	256	56.9088	1	256	52.9152	
Room 214 (NW)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 215 (N)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 216 (N)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 217 (N)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 218 (N)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 219 (N)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 220 (N)	512	1	512	96.9728	1	512	113.8176	1	512	105.8304	
Room 221 (N)	286	1	286	54.1684	1	286	63.5778	1	286	59.1162	
Staircase (E W)	192	1	192	36.3648	1	192	42.6816	1	192	39.6864	
3rd Floor			0	0		0	0		0	0	
Room 302 (E)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 303 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 304 (NE)	512	1	512	96.9728	1	512	113.8176	1	512	105.8304	
Room 305 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 306 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 307 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 309 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 311 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 314 (N)	1536	0.6	921.6	174.551	0.75	1152	256.0896	0.6	921.6	190.4947	
Room 316 (N)	832	0.6	499.2	94.54848	0.7	582.4	129.4675	0.6	499.2	103.1846	
Room 318 (NW)	192	1	192	36.3648	1	192	42.6816	1	192	39.6864	
Staircase (E W)	192	1	192	36.3648	1	192	42.6816	1	192	39.6864	
4th Floor			0	0		0	0		0	0	
Room 402 (E)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 403 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 404 (NE)	512	1	512	96.9728	1	512	113.8176	1	512	105.8304	
Room 405 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 406 (N)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 407 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 409 (S)	256	1	256	48.4864	1	256	56.9088	11	2816	582.0672	
Room 411 (S)	256	1	256	48.4864	1	256	56.9088	1	256	52.9152	
Room 412 (N)	1536	0.6	921.6	174.551	0.75	1152	256.0896	0.6	921.6	190.4947	
Room 414 (N)	1152	0.6	691.2	130.9133	0.7	806.4	179.2627	0.6	691.2	142.871	
Room 418 (NW)	832	1	832	157.5808	1	832	184.9536	1	832	171.9744	
Staircase (E W)	192	11	2112	400.0128	1	192	42.6816	1	192	39.6864	
			18602.5	**3523.31**		**17346.8**	**3856.19**		**19225.2**	**3973.85**	

	Energy Saving under Partly Cloudy Sky									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	September			October			November		
	watts/hr	Area %	watts/hr	167.6 hrs in month	Area %	watts/hr	146.9 hrs in month	Area %	watts/hr	107.4 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	312	1	312	52.2912	1	312	45.8328	1	312	33.5088
Room 102A (NE)	192	1	192	32.1792	1	192	28.2048	1	192	20.6208
Room 102 (N)	448	0.9	403.2	67.57632	0.6	268.8	39.48672	0.45	201.6	21.65184
Room 104 (N)	2944	1	2944	493.4144	0.9	2649.6	389.2262	0.85	2502.4	268.7578
Room 105 (S)	704	1	704	117.9904	1	704	103.4176	1	704	75.6096
2nd Floor			0	0		0	0		0	0
Room 212 (W)	256	1	256	42.9056	1	256	37.6064	0.8	204.8	21.99552
Room 213 (W)	256	1	256	42.9056	0.9	230.4	33.84576	0.75	192	20.6208
Room 214 (NW)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 215 (N)	256	1	256	42.9056	0.9	230.4	33.84576	0.4	102.4	10.99776
Room 216 (N)	256	0.95	243.2	40.76032	0.5	128	18.8032	0.3	76.8	8.24832
Room 217 (N)	256	0.98	250.88	42.04749	0.7	179.2	26.32448	0.4	102.4	10.99776
Room 218 (N)	256	1	256	42.9056	0.85	217.6	31.96544	0.45	115.2	12.37248
Room 219 (N)	256	1	256	42.9056	1	256	37.6064	0.5	128	13.7472
Room 220 (N)	512	1	512	85.8112	1	512	75.2128	0.95	486.4	52.23936
Room 221 (N)	286	1	286	47.9336	1	286	42.0134	1	286	30.7164
Staircase (E W)	192	1	192	32.1792	1	192	28.2048	1	192	20.6208
3rd Floor			0	0		0	0		0	0
Room 302 (E)	256	1	256	42.9056	1	256	37.6064	0.7	179.2	19.24608
Room 303 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 304 (NE)	512	1	512	85.8112	1	512	75.2128	1	512	54.9888
Room 305 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 306 (S)	256	1	256	42.9056	0.6	153.6	22.56384	0.6	153.6	16.49664
Room 307 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 309 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 311 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 314 (N)	1536	0.5	768	128.7168	0.35	537.6	78.97344	0.25	384	41.2416
Room 316 (N)	832	0.5	416	69.7216	0.35	291.2	42.77728	0.2	166.4	17.87136
Room 318 (NW)	192	1	192	32.1792	1	192	28.2048	1	192	20.6208
Staircase (E W)	192	1	192	32.1792	1	192	28.2048	1	192	20.6208
4th Floor			0	0		0	0		0	0
Room 402 (E)	256	1	256	42.9056	1	256	37.6064	0.7	179.2	19.24608
Room 403 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 404 (NE)	512	1	512	85.8112	1	512	75.2128	1	512	54.9888
Room 405 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 406 (N)	256	1	256	42.9056	0.6	153.6	22.56384	0.6	153.6	16.49664
Room 407 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 409 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 411 (S)	256	1	256	42.9056	1	256	37.6064	1	256	27.4944
Room 412 (N)	1536	0.5	768	128.7168	0.35	537.6	78.97344	0.25	384	41.2416
Room 414 (N)	1152	0.5	576	96.5376	0.35	403.2	59.23008	0.2	230.4	24.74496
Room 418 (NW)	832	1	832	139.4432	1	832	122.2208	1	832	89.3568
Staircase (E W)	192	1	192	32.1792	1	192	28.2048	1	192	20.6208
			16119.3	**2701.59**		**14450.8**	**2122.82**		**12876.4**	**1382.93**

	Energy Savings under Overcast Sky									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	December			January			February		
	watts/hr	Area %	watts/hr	519 hrs in month	Area %	watts/hr	503.1 hrs in month	Area %	watts/hr	430.6 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	162	0	0	0.000	0	0	0	0	0	0.000
Room 102A (NE)	228	1	228	118.332	1	228	114.7068	1	228	98.177
Room 102 (N)	586	0.3	175.8	91.240	0.3	175.8	88.44498	0.4	234.4	100.933
Room 104 (N)	4187	0.3	1256.1	651.916	0.3	1256.1	631.94391	0.45	1884.15	811.315
Room 105 (S)	988	0.4	395.2	205.109	0.5	494	248.5314	0.95	938.6	404.161
2nd Floor			0	0.000		0	0		0	0.000
Room 212 (W)	306	0.15	45.9	23.822	0.15	45.9	23.09229	0.25	76.5	32.941
Room 213 (W)	306	0.1	30.6	15.881	0.1	30.6	15.39486	0.2	61.2	26.353
Room 214 (NW)	416	0.7	291.2	151.133	0.75	312	156.9672	0.9	374.4	161.217
Room 215 (N)	306	0.15	45.9	23.822	0.15	45.9	23.09229	0.3	91.8	39.529
Room 216 (N)	306	0.15	45.9	23.822	0.15	45.9	23.09229	0.3	91.8	39.529
Room 217 (N)	306	0.15	45.9	23.822	0.15	45.9	23.09229	0.3	91.8	39.529
Room 218 (N)	306	0.15	45.9	23.822	0.15	45.9	23.09229	0.3	91.8	39.529
Room 219 (N)	306	0.15	45.9	23.822	0.15	45.9	23.09229	0.35	107.1	46.117
Room 220 (N)	612	0.3	183.6	95.288	0.3	183.6	92.36916	0.5	306	131.764
Room 221 (N)	198	0.95	188.1	97.624	0.95	188.1	94.63311	0.95	188.1	80.996
Staircase (E W)	228	1	228	118.332	1	228	114.7068	1	228	98.177
3rd Floor			0	0.000		0	0		0	0.000
Room 302 (E)	304	0	0	0.000	0.2	60.8	30.58848	0.25	76	32.726
Room 303 (S)	306	0	0	0.000	0	0	0	0.2	61.2	26.353
Room 304 (NE)	608	0.7	425.6	220.886	0.7	425.6	214.11936	0.7	425.6	183.263
Room 305 (S)	306	0	0	0.000	0.05	15.3	7.69743	0.05	15.3	6.588
Room 306 (S)	306	0.2	61.2	31.763	0.25	76.5	38.48715	0.2	61.2	26.353
Room 307 (S)	306	0	0	0.000	0	0	0	0.15	45.9	19.765
Room 309 (S)	306	0	0	0.000	0	0	0	0.05	15.3	6.588
Room 311 (S)	306	0	0	0.000	0	0	0	0.1	30.6	13.176
Room 314 (N)	1981	0.1	198.1	102.814	0.15	297.15	149.49617	0.25	495.25	213.255
Room 316 (N)	1371	0.1	137.1	71.155	0.2	274.2	137.95002	0.2	274.2	118.071
Room 318 (NW)	989	0.25	247.25	128.323	0.25	247.25	124.39148	0.35	346.15	149.052
Staircase (E W)	228	1	228	118.332	1	228	114.7068	1	228	98.177
4th Floor			0	0.000		0	0		0	0.000
Room 402 (E)	304	0.15	45.6	23.666	0.2	60.8	30.58848	0.25	76	32.726
Room 403 (S)	306	0	0	0.000	0	0	0	0.2	61.2	26.353
Room 404 (NE)	608	0.7	425.6	220.886	0.7	425.6	214.11936	0.7	425.6	183.263
Room 405 (S)	306	0	0	0.000	0.05	15.3	7.69743	0.05	15.3	6.588
Room 406 (N)	306	0.2	61.2	31.763	0.25	76.5	38.48715	0.2	61.2	26.353
Room 407 (S)	306	0	0	0.000	0	0	0	0.15	45.9	19.765
Room 409 (S)	306	0	0	0.000	0	0	0	0.05	15.3	6.588
Room 411 (S)	306	0	0	0.000	0	0	0	0.1	30.6	13.176
Room 412 (N)	1981	0.1	198.1	102.814	0.15	297.15	149.49617	0.25	495.25	213.255
Room 414 (N)	1371	0.1	137.1	71.155	0.2	274.2	137.95002	0.2	274.2	118.071
Room 418 (NW)	989	0.25	247.25	128.323	0.25	247.25	124.39148	0.35	346.15	149.052
Staircase (E W)	228	1	228	118.332	1	228	114.7068	1	228	98.177
Total			**5892.1**	**3058.000**		**6621.2**	**3331.126**		**9143.05**	**3936.997**

	Energy Savings under Overcast Sky Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	March			April			May		
	watts/hr	Area %	watts/hr	429.6 hrs in month	Area %	watts/hr	405 hrs in month	Area %	watts/hr	384.2 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	162	0	0	0	0.2	32.4	13.122	0.25	40.5	15.5601
Room 102A (NE)	228	1	228	97.9488	1	228	92.34	1	228	87.5976
Room 102 (N)	586	0.6	351.6	151.04736	0.6	351.6	142.398	0.7	410.2	157.59884
Room 104 (N)	4187	0.7	2930.9	1259.1146	1	4187	1695.735	0.8	3349.6	1286.91632
Room 105 (S)	988	1	988	424.4448	1	988	400.14	1	988	379.5896
2nd Floor			0	0		0	0		0	0
Room 212 (W)	306	0.5	153	65.7288	0.4	122.4	49.572	0.45	137.7	52.90434
Room 213 (W)	306	0.5	153	65.7288	0.4	122.4	49.572	0.4	122.4	47.02608
Room 214 (NW)	416	0.98	407.68	175.13933	0.98	407.68	165.1104	1	416	159.8272
Room 215 (N)	306	0.5	153	65.7288	0.5	153	61.965	0.7	214.2	82.29564
Room 216 (N)	306	0.4	122.4	52.58304	0.5	153	61.965	0.6	183.6	70.53912
Room 217 (N)	306	0.5	153	65.7288	0.5	153	61.965	0.7	214.2	82.29564
Room 218 (N)	306	0.4	122.4	52.58304	0.6	183.6	74.358	0.75	229.5	88.1739
Room 219 (N)	306	0.6	183.6	78.87456	0.8	244.8	99.144	0.8	244.8	94.05216
Room 220 (N)	612	0.8	489.6	210.33216	0.95	581.4	235.467	0.98	599.76	230.427792
Room 221 (N)	198	0.99	196.02	84.210192	1	198	80.19	1	198	76.0716
Staircase (E W)	228	1	228	97.9488	1	228	92.34	1	228	87.5976
3rd Floor			0	0		0	0		0	0
Room 302 (E)	304	0.3	91.2	39.17952	0.35	106.4	43.092	0.4	121.6	46.71872
Room 303 (S)	306	0.4	122.4	52.58304	0.8	244.8	99.144	0.9	275.4	105.80868
Room 304 (NE)	608	0.95	577.6	248.13696	1	608	246.24	1	608	233.5936
Room 305 (S)	306	0.35	107.1	46.01016	0.3	91.8	37.179	0.5	153	58.7826
Room 306 (S)	306	0.4	122.4	52.58304	0.5	153	61.965	0.7	214.2	82.29564
Room 307 (S)	306	0.4	122.4	52.58304	0.7	214.2	86.751	0.9	275.4	105.80868
Room 309 (S)	306	0.35	107.1	46.01016	0.6	183.6	74.358	0.7	214.2	82.29564
Room 311 (S)	306	0.4	122.4	52.58304	0.7	214.2	86.751	0.7	214.2	82.29564
Room 314 (N)	1981	0	0	0	0.3	594.3	240.6915	0.4	792.4	304.44008
Room 316 (N)	1371	0	0	0	0.3	411.3	166.5765	0.4	548.4	210.69528
Room 318 (NW)	989	0.7	692.3	297.41208	0.75	741.75	300.40875	0.8	791.2	303.97904
Staircase (E W)	228	1	228	97.9488	1	228	92.34	1	228	87.5976
4th Floor			0	0		0	0		0	0
Room 402 (E)	304	0.3	91.2	39.17952	0.35	106.4	43.092	0.4	121.6	46.71872
Room 403 (S)	306	0.04	12.24	5.258304	0.8	244.8	99.144	0.9	275.4	105.80868
Room 404 (NE)	608	0.95	577.6	248.13696	1	608	246.24	1	608	233.5936
Room 405 (S)	306	0.35	107.1	46.01016	0.3	91.8	37.179	0.5	153	58.7826
Room 406 (N)	306	0.4	122.4	52.58304	0.5	153	61.965	0.7	214.2	82.29564
Room 407 (S)	306	0.4	122.4	52.58304	0.7	214.2	86.751	0.9	275.4	105.80868
Room 409 (S)	306	0.35	107.1	46.01016	0.6	183.6	74.358	0.7	214.2	82.29564
Room 411 (S)	306	0.4	122.4	52.58304	0.7	214.2	86.751	0.7	214.2	82.29564
Room 412 (N)	1981	0	0	0	0.3	594.3	240.6915	0.4	792.4	304.44008
Room 414 (N)	1371	0	0	0	0.3	411.3	166.5765	0.4	548.4	210.69528
Room 418 (NW)	989	0.7	692.3	297.41208	0.75	741.75	300.40875	0.8	791.2	303.97904
Staircase (E W)	228	1	228	97.9488	1	228	92.34	1	228	87.5976
Total			**11335.84**	**4869.877**		**15916.98**	**6446.377**		**16676.5**	**6407.0959**

	Energy Savings under Overcast Sky									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	June			July			August		
	watts/hr	Area %	watts/hr	333.3 hrs in month	Area %	watts/hr	293.2 hrs in month	Area %	watts/hr	310.5 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	162	0.3	48.6	16.19838	0.25	40.5	11.8746	0.2	32.4	10.0602
Room 102A (NE)	228	1	228	75.9924	1	228	66.8496	1	228	70.794
Room 102 (N)	586	0.8	468.8	156.251	0.7	410.2	120.2706	0.6	351.6	109.1718
Room 104 (N)	4187	0.9	3768.3	1255.974	0.8	3349.6	982.1027	0.7	2930.9	910.0445
Room 105 (S)	988	1	988	329.3004	11	10868	3186.498	1	988	306.774
2nd Floor			0	0		0	0		0	0
Room 212 (W)	306	0.5	153	50.9949	0.45	137.7	40.37364	0.4	122.4	38.0052
Room 213 (W)	306	0.35	107.1	35.69643	0.4	122.4	35.88768	0.4	122.4	38.0052
Room 214 (NW)	416	0.99	411.84	137.2663	1	416	121.9712	0.98	407.68	126.5846
Room 215 (N)	306	0.75	229.5	76.49235	0.7	214.2	62.80344	0.5	153	47.5065
Room 216 (N)	306	0.6	183.6	61.19388	0.6	183.6	53.83152	0.5	153	47.5065
Room 217 (N)	306	0.7	214.2	71.39286	0.7	214.2	62.80344	0.5	153	47.5065
Room 218 (N)	306	0.7	214.2	71.39286	0.75	229.5	67.2894	0.6	183.6	57.0078
Room 219 (N)	306	0.8	244.8	81.59184	0.8	244.8	71.77536	0.8	244.8	76.0104
Room 220 (N)	612	0.98	599.76	199.9	0.98	599.76	175.8496	0.95	581.4	180.5247
Room 221 (N)	198	1	198	65.9934	1	198	58.0536	1	198	61.479
Staircase (E W)	228		228	75.9924	1	228	66.8496	1	228	70.794
3rd Floor			0	0		0	0		0	0
Room 302 (E)	304	0.3	91.2	30.39696	0.4	121.6	35.65312	0.35	106.4	33.0372
Room 303 (S)	306	0.9	275.4	91.79082	0.9	275.4	80.74728	0.8	244.8	76.0104
Room 304 (NE)	608	1	608	202.6464	1	608	178.2656	1	608	188.784
Room 305 (S)	306	0.3	91.8	30.59694	0.5	153	44.8596	0.3	91.8	28.5039
Room 306 (S)	306	0.6	183.6	61.19388	0.7	214.2	62.80344	0.5	153	47.5065
Room 307 (S)	306	0.9	275.4	91.79082	0.9	275.4	80.74728	0.7	214.2	66.5091
Room 309 (S)	306	0.5	153	50.9949	0.7	214.2	62.80344	0.6	183.6	57.0078
Room 311 (S)	306	0.6	183.6	61.19388	0.7	214.2	62.80344	0.7	214.2	66.5091
Room 314 (N)	1981	0.35	693.35	231.0936	0.4	792.4	232.3317	0.3	594.3	184.5302
Room 316 (N)	1371	0.35	479.85	159.934	0.4	548.4	160.7909	0.3	411.3	127.7087
Room 318 (NW)	989	0.75	741.75	247.2253	0.8	791.2	231.9798	0.75	741.75	230.3134
Staircase (E W)	228	1	228	75.9924	1	228	66.8496	1	228	70.794
4th Floor			0	0		0	0		0	0
Room 402 (E)	304	0.3	91.2	30.39696	0.4	121.6	35.65312	0.35	106.4	33.0372
Room 403 (S)	306	0.9	275.4	91.79082	0.9	275.4	80.74728	0.8	244.8	76.0104
Room 404 (NE)	608	1	608	202.6464	1	608	178.2656	1	608	188.784
Room 405 (S)	306	0.3	91.8	30.59694	0.5	153	44.8596	0.5	153	47.5065
Room 406 (N)	306	0.6	183.6	61.19388	0.7	214.2	62.80344	0.5	153	47.5065
Room 407 (S)	306	0.9	275.4	91.79082	0.9	275.4	80.74728	0.7	214.2	66.5091
Room 409 (S)	306	0.5	153	50.9949	0.7	214.2	62.80344	0.6	183.6	57.0078
Room 411 (S)	306	0.6	183.6	61.19388	0.7	214.2	62.80344	0.7	214.2	66.5091
Room 412 (N)	1981	0.35	693.35	231.0936	0.4	792.4	232.3317	0.3	594.3	184.5302
Room 414 (N)	1371	0.35	479.85	159.934	0.4	548.4	160.7909	0.3	411.3	127.7087
Room 418 (NW)	989	0.75	741.75	247.2253	0.8	791.2	231.9798	0.75	741.75	230.3134
Staircase (E W)	228	1	228	75.9924	1	228	66.8496	1	228	70.794
Total			**16296**	**5431.32**		**26556**	**7786.35**		**14722**	**4571.21**

	Energy Savings under Overcast Sky									
	Percentage of room area have minimum illuminance of 300 Lux									
	Electrical Lighting	September			October			November		
	watts/hr	Area %	watts/hr	334.4 hrs in month	Area %	watts/hr	399 hrs in month	Area %	watts/hr	497.8 hrs in month
Ground Floor				KWh			KWh			KWh
Room 101 (S)	162	0	0	0	0	0	0	0	0	0
Room 102A (NE)	228	1	228	76.2432	1	228	90.972	1	228	113.4984
Room 102 (N)	586	0.6	351.6	117.575	0.4	234.4	93.5256	0.3	175.8	87.51324
Room 104 (N)	4187	0.7	2930.9	980.093	0.45	1884.15	751.7759	0.5	2093.5	1042.144
Room 105 (S)	988	1	988	330.3872	0.95	938.6	374.5014	0.5	494	245.9132
2nd Floor			0	0		0	0		0	0
Room 212 (W)	306	0.5	153	51.1632	0.25	76.5	30.5235	0.15	45.9	22.84902
Room 213 (W)	306	0.5	153	51.1632	0.2	61.2	24.4188	1	306	152.3268
Room 214 (NW)	416	0.98	407.68	136.3282	0.9	374.4	149.3856	0.75	312	155.3136
Room 215 (N)	306	0.5	153	51.1632	0.3	91.8	36.6282	0.15	45.9	22.84902
Room 216 (N)	306	0.4	122.4	40.93056	0.3	91.8	36.6282	0.15	45.9	22.84902
Room 217 (N)	306	0.5	153	51.1632	0.3	91.8	36.6282	0.15	45.9	22.84902
Room 218 (N)	306	0.4	122.4	40.93056	0.3	91.8	36.6282	0.15	45.9	22.84902
Room 219 (N)	306	0.6	183.6	61.39584	0.35	107.1	42.7329	0.15	45.9	22.84902
Room 220 (N)	612	0.8	489.6	163.7222	0.5	306	122.094	0.3	183.6	91.39608
Room 221 (N)	198	0.99	196.02	65.54909	0.95	188.1	75.0519	0.95	188.1	93.63618
Staircase (E W)	228	1	228	76.2432	1	228	90.972	1	228	113.4984
3rd Floor			0	0		0	0		0	0
Room 302 (E)	304	0.3	91.2	30.49728	0.25	76	30.324	0.2	60.8	30.26624
Room 303 (S)	306	0.4	122.4	40.93056	0.2	61.2	24.4188	0	0	0
Room 304 (NE)	608	0.95	577.6	193.1494	0.7	425.6	169.8144	0.7	425.6	211.8637
Room 305 (S)	306	0.35	107.1	35.81424	0.5	153	61.047	0.05	15.3	7.61634
Room 306 (S)	306	0.4	122.4	40.93056	0.2	61.2	24.4188	0.25	76.5	38.0817
Room 307 (S)	306	0.4	122.4	40.93056	0.15	45.9	18.3141	0	0	0
Room 309 (S)	306	0.35	107.1	35.81424	0.05	15.3	6.1047	0	0	0
Room 311 (S)	306	0.4	122.4	40.93056	0.1	30.6	12.2094	0	0	0
Room 314 (N)	1981	0	0	0	0.25	495.25	197.6048	0.15	297.15	147.9213
Room 316 (N)	1371	0	0	0	0.2	274.2	109.4058	0.2	274.2	136.4968
Room 318 (NW)	989	0.7	692.3	231.5051	0.35	346.15	138.1139	0.25	247.25	123.0811
Staircase (E W)	228	1	228	76.2432	1	228	90.972	1	228	113.4984
4th Floor			0	0		0	0		0	0
Room 402 (E)	304	0.3	91.2	30.49728	0.25	76	30.324	0.2	60.8	30.26624
Room 403 (S)	306	0.4	122.4	40.93056	0.2	61.2	24.4188	0	0	0
Room 404 (NE)	608	0.95	577.6	193.1494	0.7	425.6	169.8144	0.7	425.6	211.8637
Room 405 (S)	306	0.35	107.1	35.81424	0.05	15.3	6.1047	0.05	15.3	7.61634
Room 406 (N)	306	0.4	122.4	40.93056	0.2	61.2	24.4188	0.25	76.5	38.0817
Room 407 (S)	306	0.4	122.4	40.93056	0.15	45.9	18.3141	0	0	0
Room 409 (S)	306	0.35	107.1	35.81424	0.05	15.3	6.1047	0	0	0
Room 411 (S)	306	0.4	122.4	40.93056	0.1	30.6	12.2094	0	0	0
Room 412 (N)	1981	0	0	0	0.25	495.25	197.6048	0.15	297.15	147.9213
Room 414 (N)	1371	0	0	0	0.2	274.2	109.4058	0.2	274.2	136.4968
Room 418 (NW)	989	0.7	692.3	231.5051	0.35	346.15	138.1139	0.25	247.25	123.0811
Staircase (E W)	228	1	228	76.2432	1	228	90.972	1	228	113.4984
Total			**11446**	**3827.54**		**9280.8**	**3703.02**		**7734**	**3849.99**

APPENDIX-I

Electrical lighting load for the whole Building

APPENDIX I: Electrical lighting load for the building

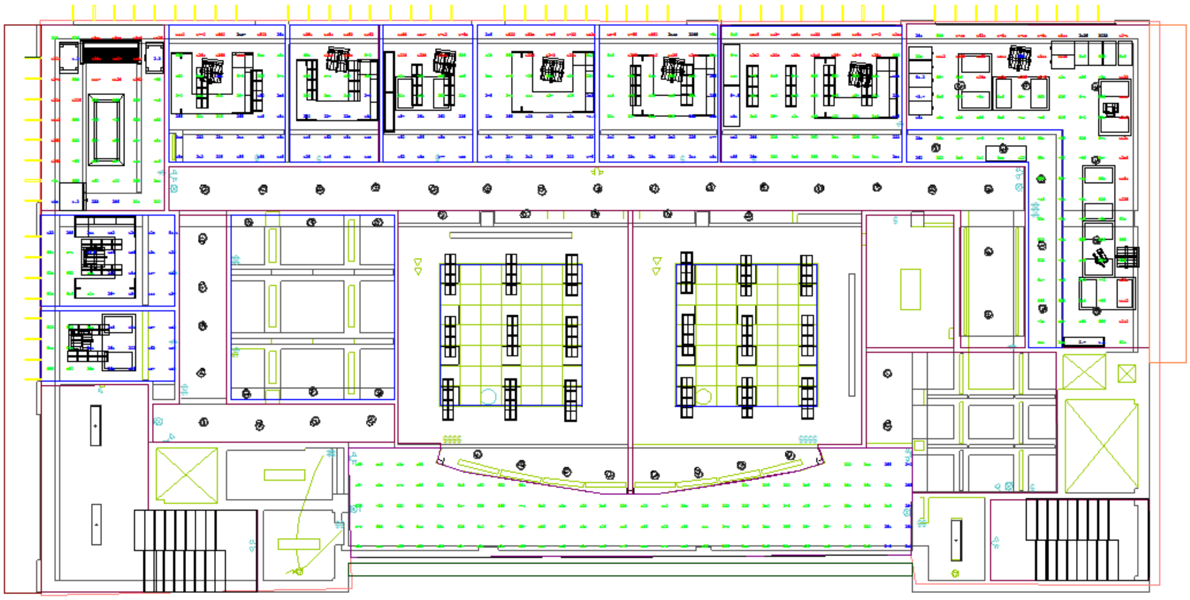
	Fixture type	Lamp type	Number of lamps/Fixture	Luminary watts/hr	Number of Fixtures	Total watts/hr
Ground Floor						
Room 101	Down light, open metal reflector	CFL-18T	1	18	9	162
Room 102 A	Fluoresent lamp luminary zlf1	T8	2	76	3	228
Room 102	zlf1	T8	2	76	7	532
	Down light	CFL-18T	1	18	3	54
Room 103	WLS-HBT	T8	4	153	2	306
Room 104	zlf1	T8	2	76	41	3116
	WLS-HBT	T8	4	153	7	1071
Room 105	zlf1	T8	2	76	13	988
Washroom	zlf1	T8	2	76	2	152
	Down light	CFL-18T	1	18	2	36
Corridor	Down light	CFL-18T	1	18	18	324
	Cove light	T5	2	52	6	312
	Down light	CFL-18T	1	18	18	324
					Total	**7605**
2nd Floor						
Corridor	Down light	CFL-18T	1	18	27	486
	Cove light	T5	2	52	8	416
Washroom	zlf1	T8	2	76	3	228
Staircase	zlf1	T8	2	3	76	228
Room 212	WLS-HBT	T8	4	2	153	306
Room 213	WLS-HBT	T8	4	2	153	306
Room 214	Cove light	T5	2	8	52	416
Room 215	WLS-HBT	T8	4	2	153	306
Room 216	WLS-HBT	T8	4	2	153	306
Room 217	WLS-HBT	T8	4	2	153	306
Room 218	WLS-HBT	T8	4	2	153	306
Room 219	WLS-HBT	T8	4	2	153	306
Room 220	WLS-HBT	T8	4	4	153	612
Room 221	Down light	CFL-18T	1	11	18	198
					Total	**4726**

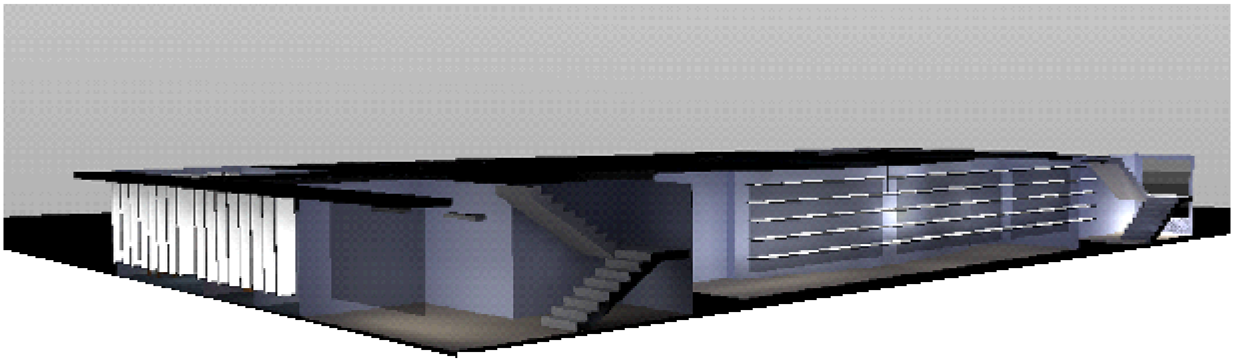
3rd Floor						
Corridor	Down light	CFL-18T	1	14	18	252
	Cove light	T5	2	14	52	728
Staircase	zlf1	T8	2	3	76	228
Washroom	zlf1	T8	2	3	76	228
	Down light	CFL-18T	1	2	18	36
Room 302	zlf1	T8	2	4	76	304
Room 303	WLS-HBT	T8	4	2	153	306
Room 304	zlf1	T8	2	8	76	608
Room 305	WLS-HBT	T8	2	2	153	306
Room 306	WLS-HBT	T8	4	2	153	306
Room 307	WLS-HBT	T8	4	2	153	306
Room 309	WLS-HBT	T8	4	2	153	306
Room 311	WLS-HBT	T8	4	2	153	306
Room 314	zlf1	T8	2	16	76	1216
	WLS-HBT	T8	4	5	153	765
Room 316	zlf1	T8	2	12	76	912
	WLS-HBT	T8	4	3	153	459
Room 318	zlf1	T8	2	11	76	836
	WLS-HBT	T8	4	1	153	153
					Total	**8561**
4th Floor						
Corridor	Down light	CFL-18T	1	14	18	252
	Cove light	T5	2	14	52	728
Staircase	zlf1	T8	2	3	76	228
Washroom	zlf1	T8	2	3	76	228
	Down light	CFL-18T	1	2	18	36
Room 402	zlf1	T8	2	4	76	304
Room 403	WLS-HBT	T8	4	2	153	306
Room 404	zlf1	T8	2	8	76	608
Room 405	WLS-HBT	T8	2	2	153	306
Room 406	WLS-HBT	T8	4	2	153	306
Room 407	WLS-HBT	T8	4	2	153	306
Room 409	WLS-HBT	T8	4	2	153	306
Room 411	WLS-HBT	T8	4	2	153	306
Room 412	zlf1	T8	2	16	76	1216
	WLS-HBT	T8	4	5	153	765
Room 414	zlf1	T8	2	12	76	912
	WLS-HBT	T8	4	3	153	459
Room 418	zlf1	T8	2	11	76	836
	WLS-HBT	T8	4	1	153	153
					Total	**8561**
Total						**29453**

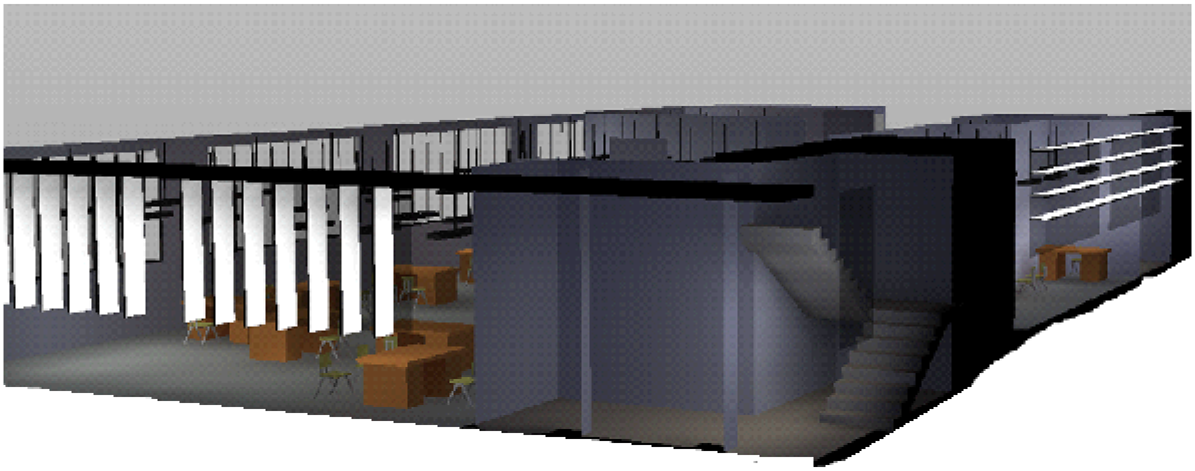
APPENDIX-J

Simulation Results and Rendering

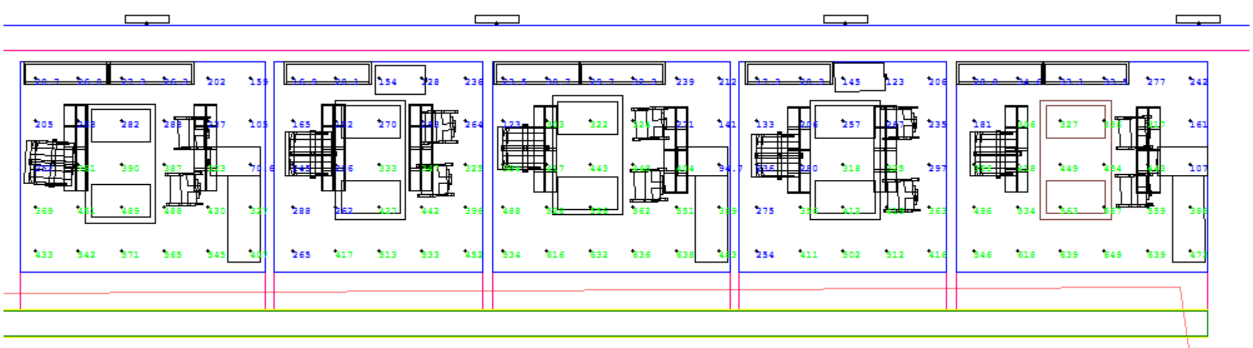
APPENDIX J: Simulation results and rendering



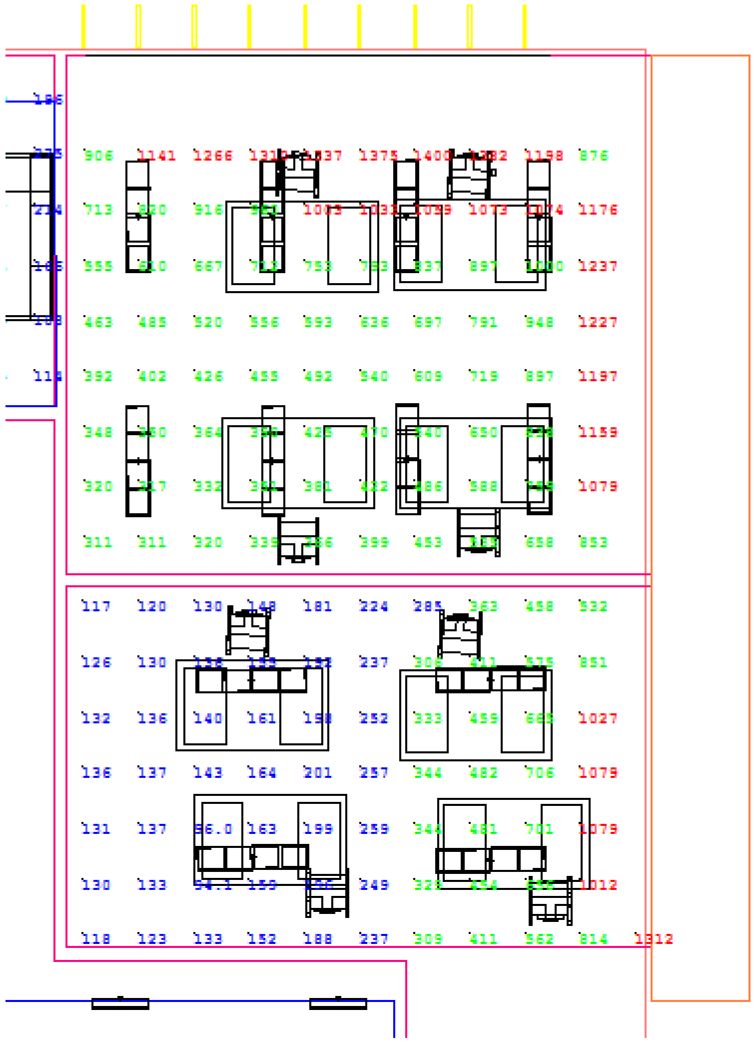


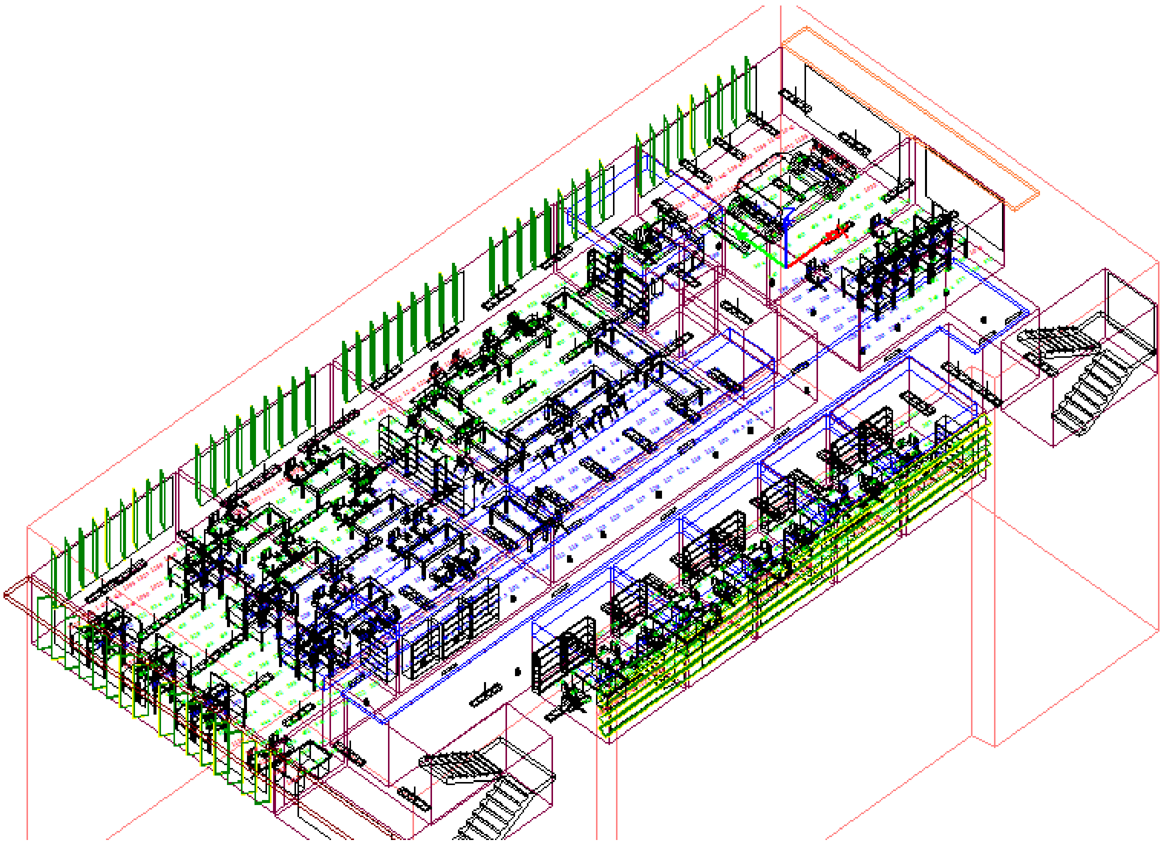


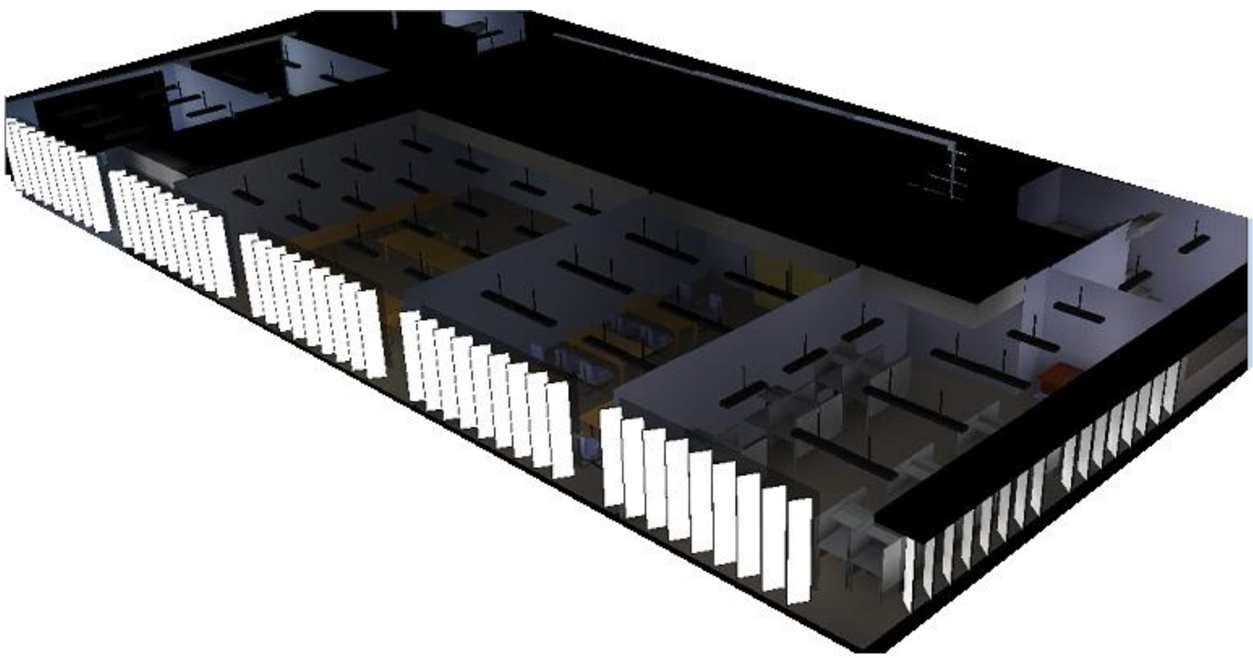
Faculty offices on south perimeter, simulation result for June 21 at 10.00 am undercast sky.

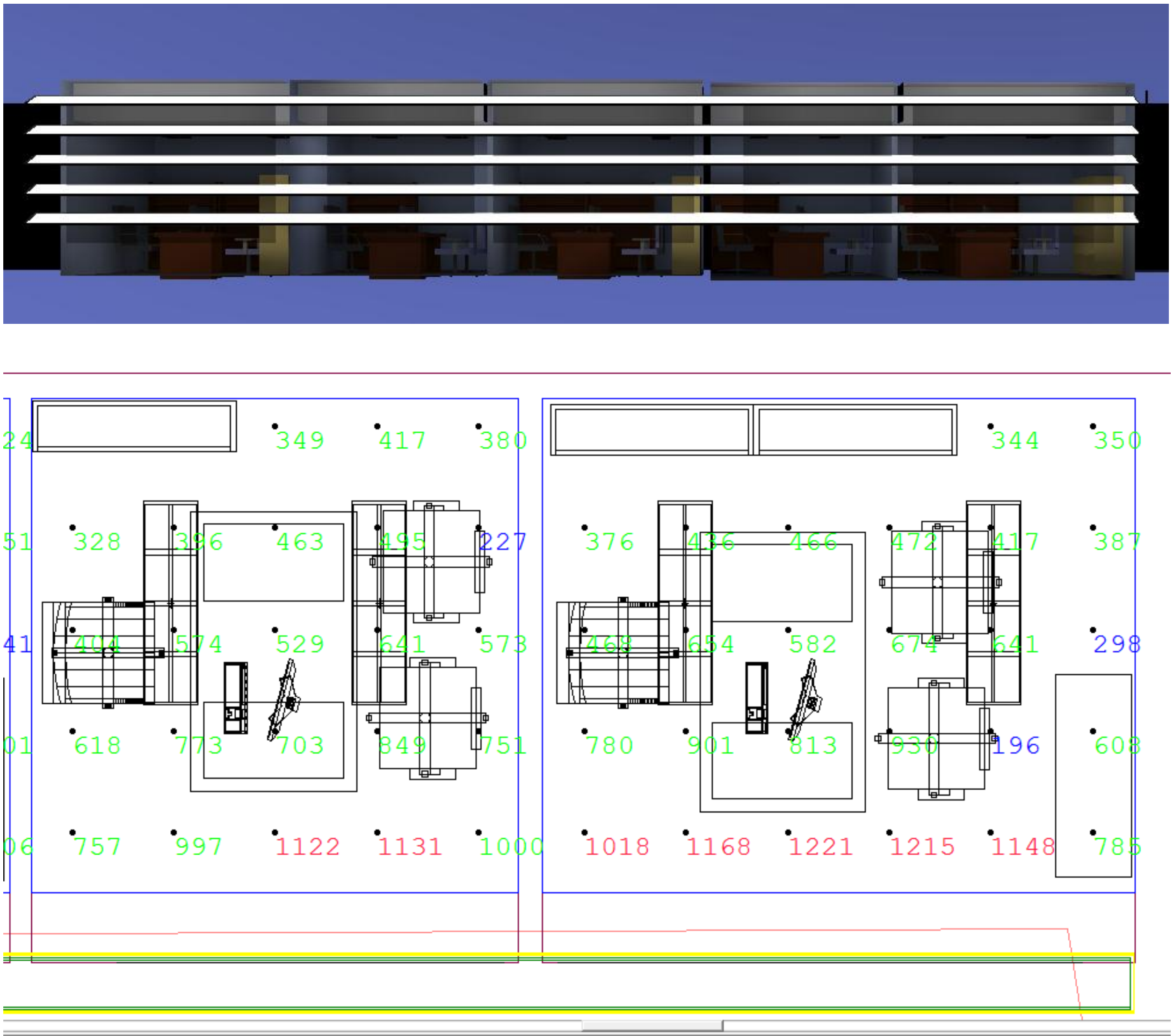


East and east-north facing graduate office simulation results for June 21 at 10.00 am under overcast sky.









South perimeter faculty offices simulation results on June 21 at 2.00 pm under clear sky