The Pennsylvania State University

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College of Engineering

TOPLIGHTING AND ENERGY SAVING IMPLICATIONS FOR CLASSROOMS IN MUSCAT-OMAN

A Thesis in

Architectural Engineering

by

Nablus Al-Jahadhmy

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The thesis of Nablus Aljahdhamy was reviewed and approved* by the following:

Richard G. Mistrick
Associate Professor of Architectural Engineering
Thesis Advisor

Kevin W. Houser
Professor of Architectural Engineering

James D. Freihaut
Professor of Architectural Engineering

Chimay J. Anumba
Professor of Architectural Engineering
Head of Department

*Signatures are on file in the Graduate School

ABSTRACT

One of the driving forces for a country's economy is its energy consumption. With a rise in electricity prices, fossil fuels being a finite resource, and their major role in producing greenhouse gas emissions (Environmental Protection Agency, 2013), it is important to minimize energy use and or convert to alternative energy sources. The use of natural daylight for lighting the interior of buildings can reduce prime energy demand and lower negative impacts on the environment.

This research study provides some design guidance of toplighting systems for school classrooms in hot climates such as in Muscat, Oman. This work can serve to advice not only engineers, but also architects by providing an understanding of the relationship between daylight delivered through rooftop fenestration systems and the heat gain resulting from these systems. Usually, for architects, the focus is on building design and less emphasis is placed upon building performance and its effectiveness. Integration of energy simulation tools into the design process can help assess the performance of toplighting and its correlation to energy savings within a space. The aim of this study is to assess appropriate dayligthing conditions that do not significantly over-light a space while providing a favorable energy balance between cooling and electrical lighting loads.

A classroom analysis of a 9 meter (30 feet) wide by 7.6 meter (25 feet) deep by 3 meter (10 feet) high space was conducted using two simulation programs: DAYSIMps and IES-VE. Three types of rooftop fenestration were analyzed: skylights, clerestory roof monitors, and roof monitor. Standards for the base model follow the ASHRAE 90.1/ IESNA 2013 prescriptive fenestration guidelines. Aperture placement, glazing type, size, and shape are variables that determine illumination and heat gain levels present in the classroom. Adjustments to these parameters were analyzed and compared to the baseline model with no toplighting fenestration in order to assess illumination, glare, energy, and savings response.

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ACKNOWLEDGEMENTS

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1 BACKGROUND

“The cast glass, which makes up the outer layer of the façade, sporadically reflects the light and periodically shrouds the gleaming metal writing behind it. In this way, the light is the only material around the building which is forever changing.”- Roger Diener

1.1 Introduction

As the world transforms into a whole web of integrated technologies, building systems should evolve in the same direction; where the building interior and facade communicate effectively with its external surround (see Figure 1.1). Daylighting has been used as a method of illumination in buildings since ancient times. The Pyramids of Giza, Taj Mahal in India, and the Pantheon in Rome are all inspiring precedents that have incorporated natural light as part of their design scheme. Natural lighting use is not limited to illuminating dark spaces, but also utilized as a mean of enhancing space aesthetics, increasing occupant performance, improving the health of occupants, and providing significant energy savings. A certain aspect that makes daylighting variable is its dependence on geographic location. As a result, it interacts uniquely with each building, architecture, orientation, and surround. The Sultanate of Oman, a country located in the South-Eastern quarter of the Arabian Peninsula, is bestowed with abundant sunlight throughout the year. Allowing daylight infiltration into internal spaces should enhance indoor environmental quality, if measured design is put into consideration. One space type that would qualify for such investigation is that of a school classroom.

This introduction section will first discuss the purpose of this study and its significance in relation to energy consumption. Subsequently, the local climate and sky types will be presented. A section discussing the importance of solar position relative to the building façade follows. After that, the main features of the architecture in Oman and structural implications in relation to school buildings are outlined. Finally a closeout related to the comfort of occupants and heat gain considerations is explained.

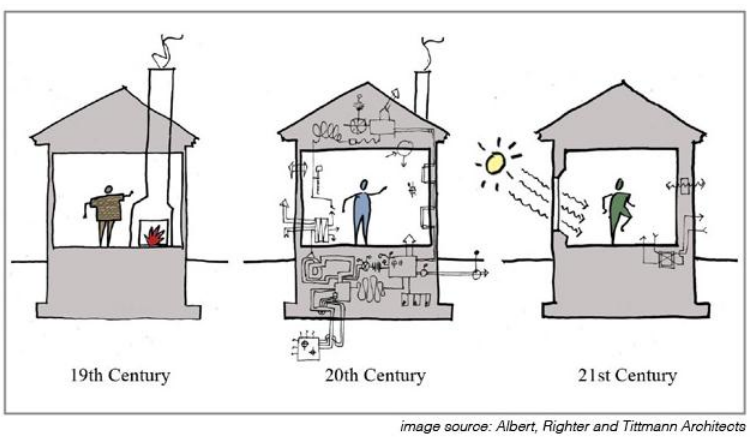

Figure 1-1: Evolution towards Less Energy Consumption

Source: Albert, Righter and Tittmann Architects

1.2 Research Purpose

Concerns on energy source exhaustion and pollution that results from these sources has led the industry into reforming building design strategies that serve energy conservation and reduce environmental impacts worldwide. In Oman, most buildings have small window openings, which implies a constant struggle between admitting daylight or blocking heat from entering the interior (see Figure 1-2**)**. In general, it is rare to see buildings that deploy natural light in this climate setting, let alone implementation of a system such as skylights. The overlying purpose of this study is to create a general reference for Architects and Engineers who are interested in implementing toplighting in classrooms within the Middle East or in similar climates. This research examines the use of different roof fenestration types in order to discuss the opportunities and pitfalls of each system and their performance with regards to energy savings.

Figure 1-2: Typical School Fenestrations in Oman

Source: beta uniandi, Lee Blog

1.2.1 Research Hypothesis

The Hypothesis statement that is assumed for this study is as follows:

Appropriate toplighting systems will result in an overall annual energy savings in a classroom space for hot climates such as in Muscat, Oman.

1.3 Oman's Energy Consumption

Energy usage plays an important role in the economic growth of a country. There is a linear relationship between the consumption of energy and a county's gross domestic product (GDP). The main driving force for energy utilization in Oman is its climate; where cooling represents the major energy usage throughout the year. The International Energy Agency (IEA) collected data worldwide on total energy consumption for the year of 2010. The results indicated that Oman falls under the range of 250-400 millions of British Thermal Units (BTU) per person, which ranks second on the bar scale as shown in In Figure 1-3. Oman, the main fuel source of electrical production comes from natural gas at 82%, whereas the rest comes from oil (see Figure1- 4).

Due to the abundance of natural gas and oil, the cost of electricity in Oman is inexpensive. Depending on the kilowatt hour (kWh) usage, electricity rates ranges from 10 baiza-30 baiza ($0.026-0.07) per kWh for governmental and residential buildings. Note this is what the consumers pay depending on kWh peak use, where usage of 10,000 or more kWh is charged 3 times more than a usage of 3,000 kWh. For buildings under the commercial sector, the charges are 20 baiza ($0.05) per kWh. The government subsidizes 50% of the total cost, which means that primary cost would be 40 baiza ($0.10) per kWh. Reduction in energy use will offer savings not only for the consumer but also for the government.

The economic growth of Oman has been steadily rising since the 1980's, and simultaneously its energy usage. Currently, the population of Oman is around three million, and one third of it are foreigners. As reported by the IEA, the electricity consumption per capita in Oman is 6,292 kWh, which is approximately half of the electricity use per capita in the USA at 13, 246 kWh (see Figure 1-5). The energy consumption per capita in Oman doubled from 2000 to 2011. As global population increases and with the advancement of technology, energy demand may likewise increase. This demand increase, if dependent solely on fossil fuels, will result in an increased carbon footprint. Although electricity use in Oman is about 50% of the USA's per capita, its carbon dioxide (CO_2) emission is approximately 14% higher than in the USA (see Figure 1-6). The values for CO_2 have tripled from the 1980's to 2010 in Oman, where Oman is considered third highest in the Middle East area for CO_2 emissions per capita (see Figure 1-7)**.** This increase presents a concern to the negative environmental impacts associated with greenhouse gas emissions.

Historically, Oman has exported most of its oil and gas output to maximize revenues. According to the US. Energy Information Agency (EIA), in 2013 Oman exported more than 97% of its oil to countries located in Asia, with 60% of the exports directed to China. Contract obligations with other countries demand Oman to export 55% of gas reserves. These contracts are due for renewal by 2020, therefore the government created the Omani Vision 2020. One of the primary foci of this Vision is reducing the reliance on oil and gas and providing electrical power from inexpensive sources to meet domestic, commercial and industrial demands. The 2020 Vision also plans to gradually cut down on government incentives and reduce its role in providing public services, therefore electricity prices will not stay the same. With the unstable production of oil and gas, these exports have led to a shortage of primary resources that generate electricity to meet domestic demands, especially during seasonal peak times. Oman has only one natural gas pipeline called the Dolphin pipeline. This pipeline runs through the United Arab Emirates to Qatar, where around 5-7 million cubic meters (180- 200 million cubic feet) is imported from Qatar per day, ranging from about 5-8% of the total gas production in Oman. Likewise, the fluctuating price of oil and gas has lead the Omani government to promote studies where other energy resources are substituted. To date, no effective alternatives to replace the current natural sources have been implemented, but efforts are being made towards utilizing sources that reduce demand usage of oil and gas to create electricity.

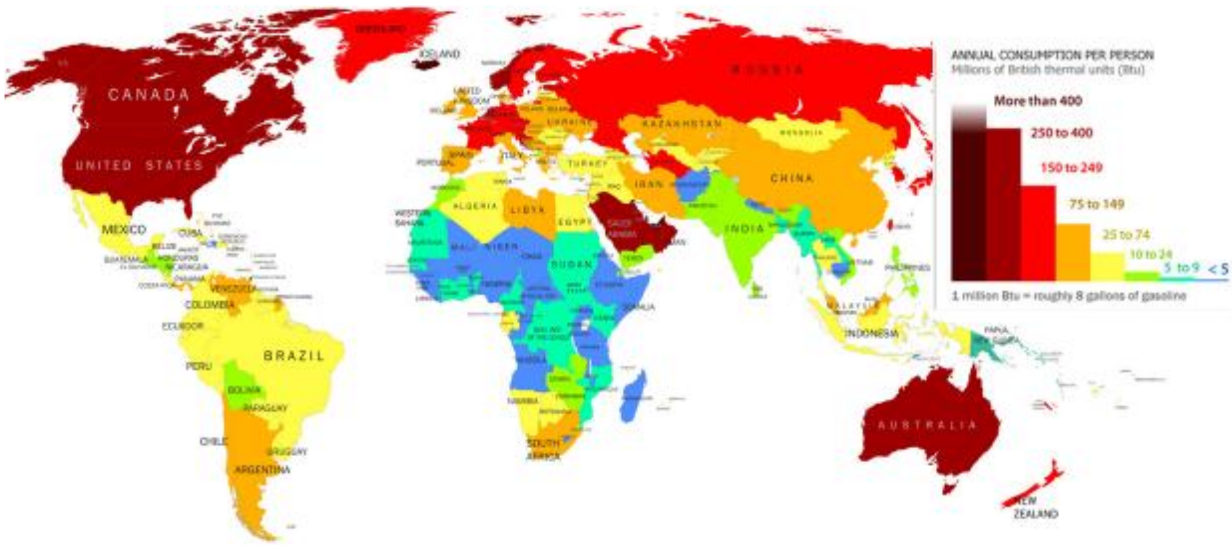

Figure 1-3: Total Energy Consumption per Person, By Country, 2010

Source: International Energy Agency

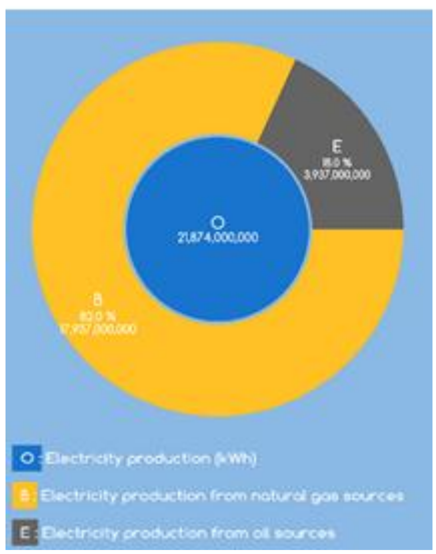

Figure 1-4: Source of Electricity Production in Oman, 2010

Source: Macro Economy Meter

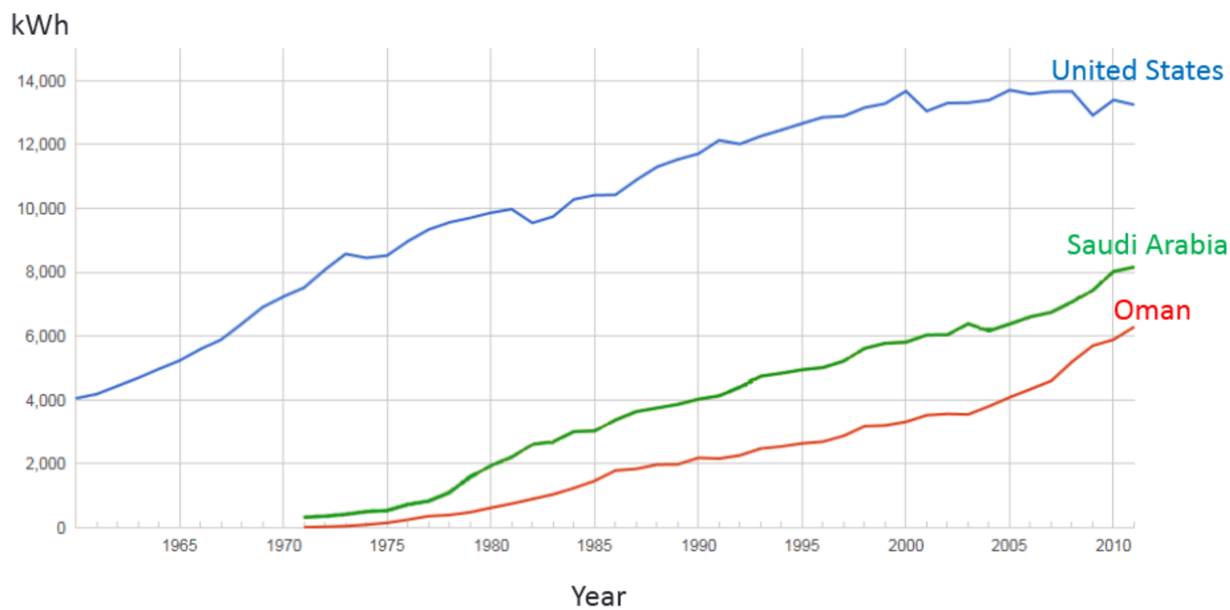

Figure 1-5: Electrical Consumption Per Capita, USA, Saudi Arabia, Oman, 2011

Source: The World Bank, 2014

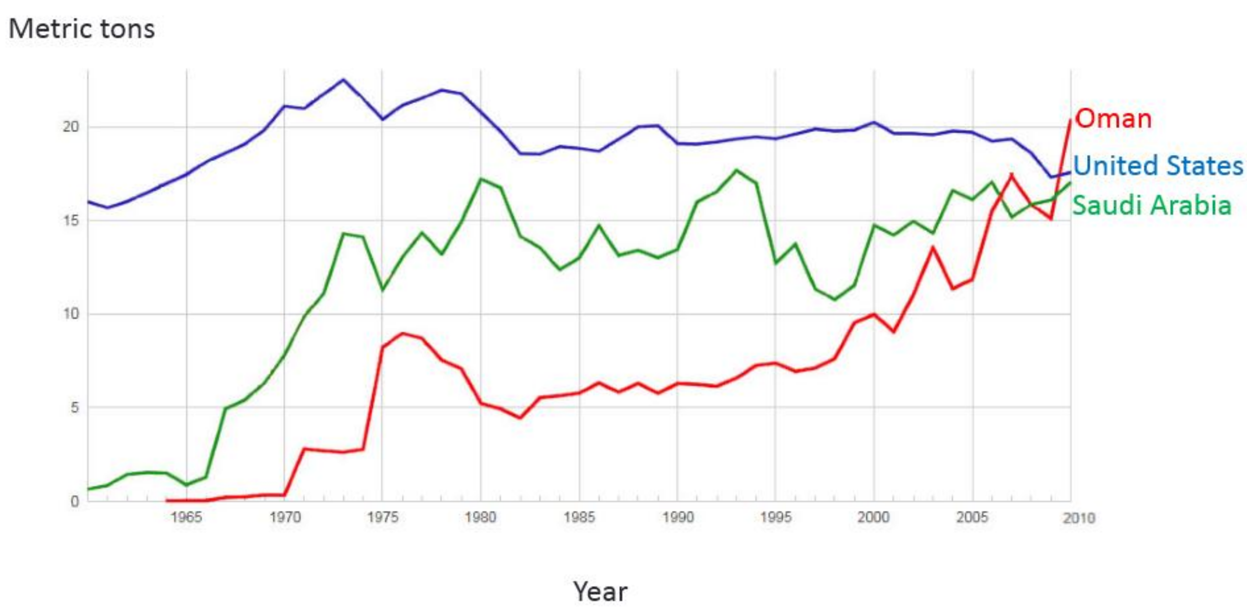

Figure 1-6: Co2 Emissions Per Capita, USA, Saudi Arabia, Oman, 2011

Source: The World Bank, 2014

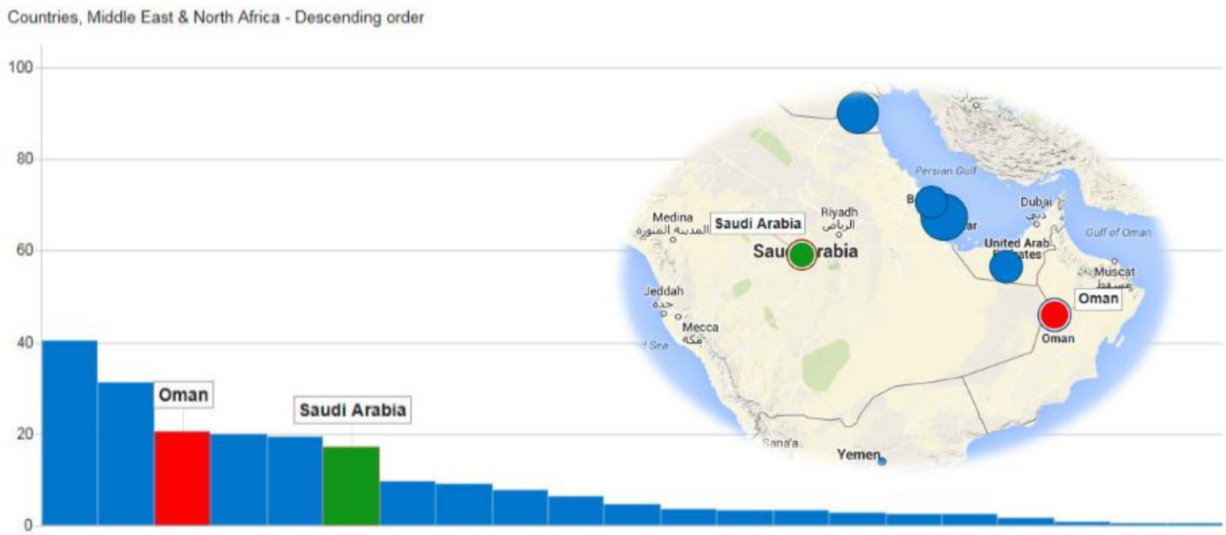

Figure 1-7: Co2 Emission Per Capita (Middle East), 2010

Source: The World Bank, 2014

1.4 Location, Climate and Sky Types

The Sultanate of Oman is situated between the latitudes of 16° and 28° North and longitudes of 52° and 60° East. The country's size is approximately 300,000 km² (115,000 mi²) which is close to the size of Arizona in the United States of America, and it has a coast line of 1,700 Km (1,000 mi). Muscat, the capital city of Oman was chosen as a study location for this report. The North city of Muscat, falls at a latitude of 23.58 degrees North, and a longitude of 58.28 degrees East (see Figure 1-8). This location falls very near the Tropic of Cancer where the sun can lie directly overhead during the summer (see Figure 1-9).

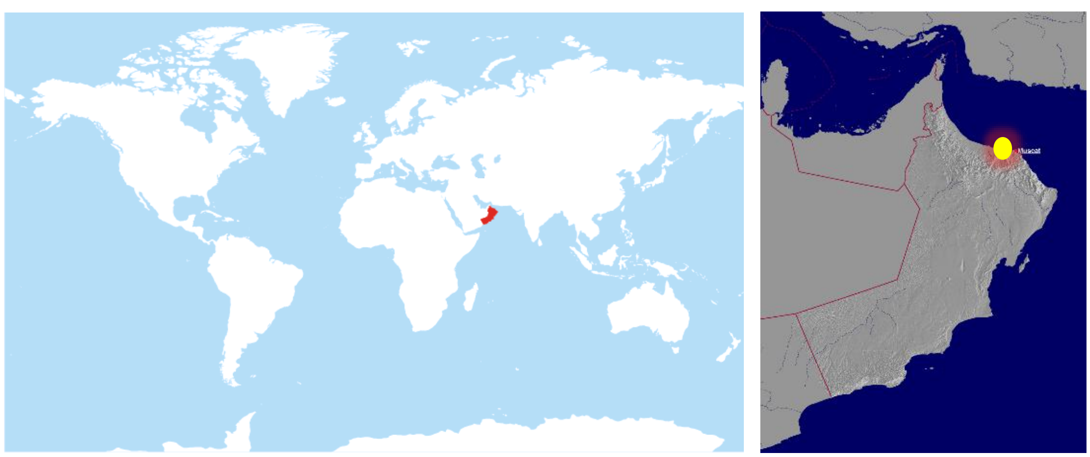

Figure 1-8: Oman's Location-Muscat

Source: Free World Maps

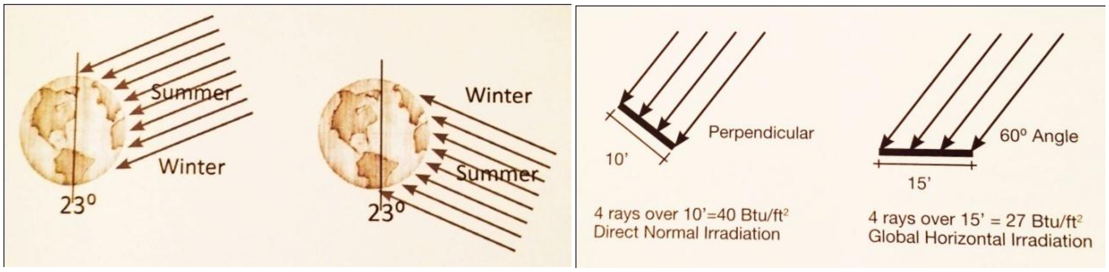

Figure 1-9: Sun's Rays Angle Striking the Earth Based on Latitude

Source: Design Energy Simulation for Architects

The weather in Oman generally represents a hot and arid climate in the desert region and hot and humid along the coast most of the year with the exception of scattered rainfall that averages approximately 4 inches per year (National Oceanic and Atmospheric Administration, 1990) . The average low temperature is 17.3 C (63.1 F) during the month of January with an average high of 40.4 C (104.7 F) during the month of June (see Figure 1-10). Relative humidity ranges between 42-67% throughout the year and is at its peak during the summer. Though an ideal humidity level would depend on ambient temperature; humans are usually comfortable within the 50-60% range. The mean sunshine hours per year are 3,493.3 hours, which indicates that approximately 80% of the time during the year the sky would be clear in Muscat. Three main categories of skies are usually studied: clear, overcast and partly cloudy. The sky breakdown for Muscat will be addressed in the methodology section of this report using the Perez Sky clearness categories.

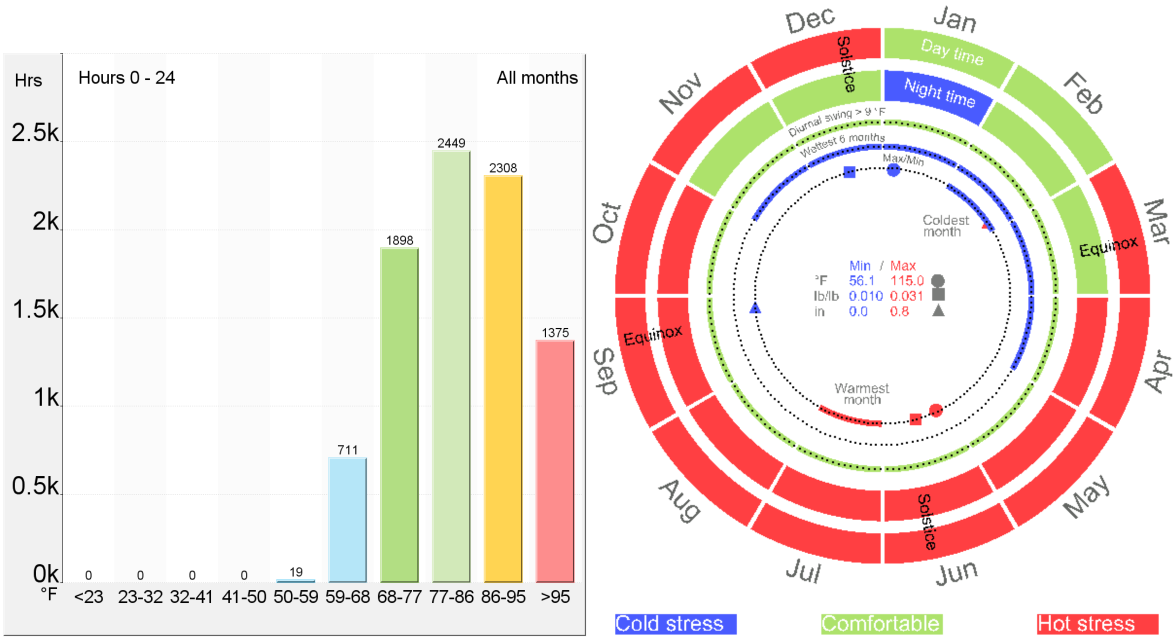

Figure 1-10: Temperature Distribution and Summary Metrics, Muscat

Source: IES-VE Software

1.5 Sun's Position Relative to Location and Facade Orientation

Elements such as the sun angle, time of the day, and building orientation affect the levels and magnitude of daylight and heat entering a space. The two parameters that describe the position of the sun in the sky are the sun's altitude and azimuth. The vertical angle between the horizon and the center of the sun's disc is defined as the sun's altitude and the horizontal angle of the sun in relation to a cardinal direction is referred to as the azimuth. These angles can be determined using the charts from the Illuminating Engineering Society Handbook (Dilaura, Houser, Mistrick, & Steffy, 2011) Or via an online sun chart calculator. Noontime altitude angles for Muscat range between 85-90 degrees during the summer (May-July) the highest being during the month of June, and between 41-45 degrees at solar noon during the winter (November-January), with December being the lowest (see Figure 1-12). Overall, the sun's altitude is relatively high throughout the year, and lower by approximately 45 degrees during the winter. During the summer in June the azimuth angle is between (70E -290W) with little direct sun to the South facing exposure (see f Figure 1-11). The azimuth angle is between (116 E-243W) during the month of December at sunrise and sunset of East and West, with no direct sun to the North facing exposure. The position of the sun generally infers that the areas mainly affected by the intensity of direct sunlight and heat are façades facing South, West, East and the rooftop. During summer at noon, the sun's altitude is nearly perpendicular to the horizontal plane; therefore we would expect equally intense exposure for flat or skylight rooftops during solar noon. We would also expect intense irradiance on the East and West facade during morning and evening hours especially during the summer and equinoxes of March and September. The Northern façade would mainly get indirect sunlight. Precaution is needed to minimize cooling loads when adding glazing to the roof, South, West, and East facing façades.

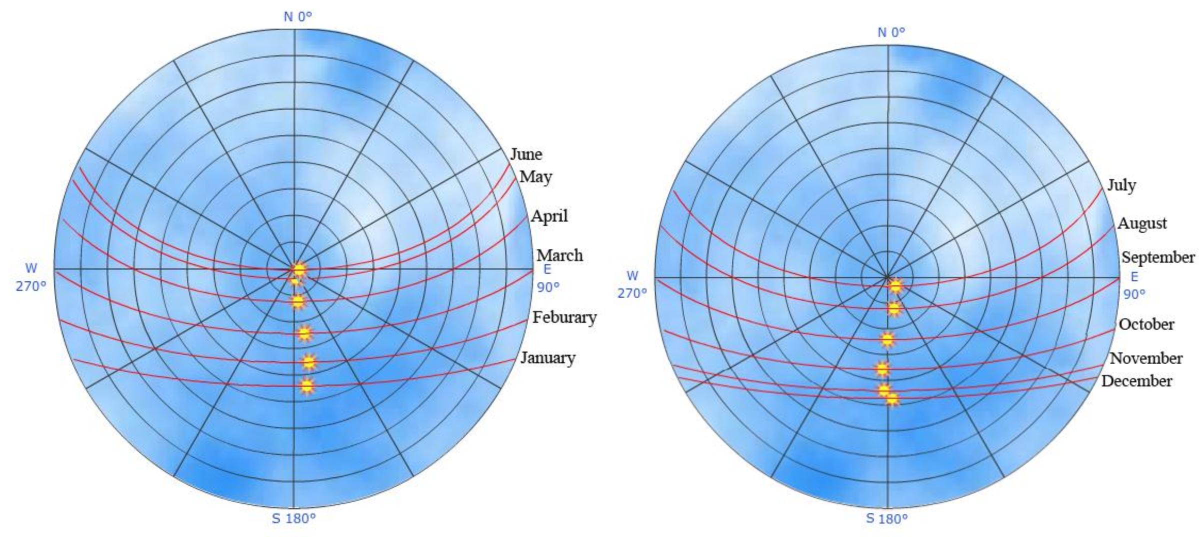

Figure 1-11: Solar Path Diagram with Suns Showing Monthly Solar Position at Solar Noon for Muscat-Oman

Source: Pv Education

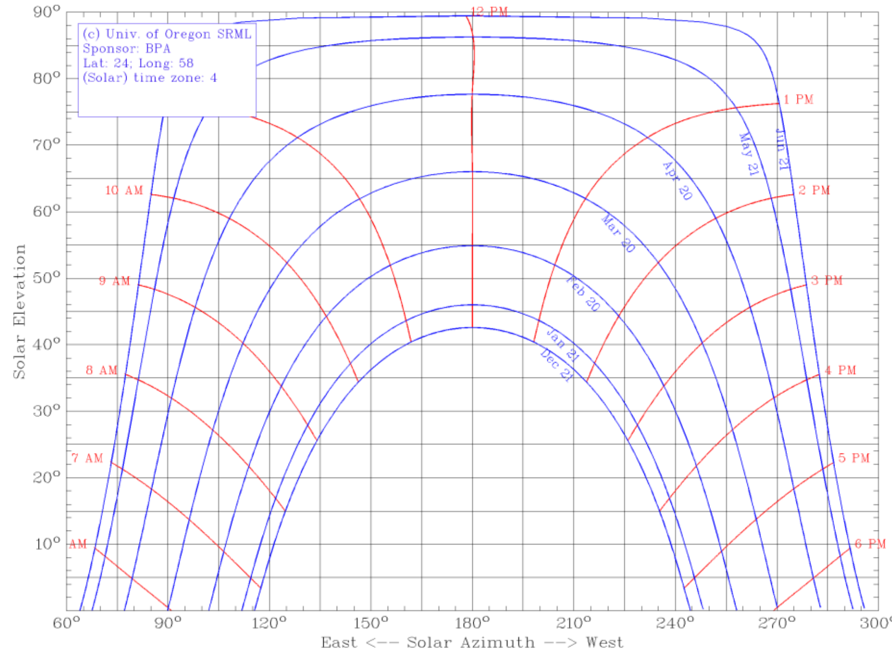

Figure 1-12: Solar Azimuth and Altitude Relative to Solar Time for Muscat-Oman

Source: University Of Oregon

1.6 Oman's Architecture

The elements that shaped building design in Oman have evolved and revolved around rejecting solar heat. Because of the hot arid nature of the country, most building surfaces and roofs are painted white to reflect the sun's rays off the facade, therefore providing less heat gain. The roofs of the buildings are flat and generally contain the MEP equipment. Windows are symmetrically placed and structured throughout the façade with no regards to sun direction. These windows are usually shaded using blinds, fabric or external shading such as Masharabiya; a projecting window enclosed with wooden latticework creating a screen that filters light through the window into the room (Feeney, 1974) (see Figure 1-13). The wall of the buildings consist of concrete blocks that serve as a thermal barrier keeping the building cool from the inside, especially during high summer peaks.

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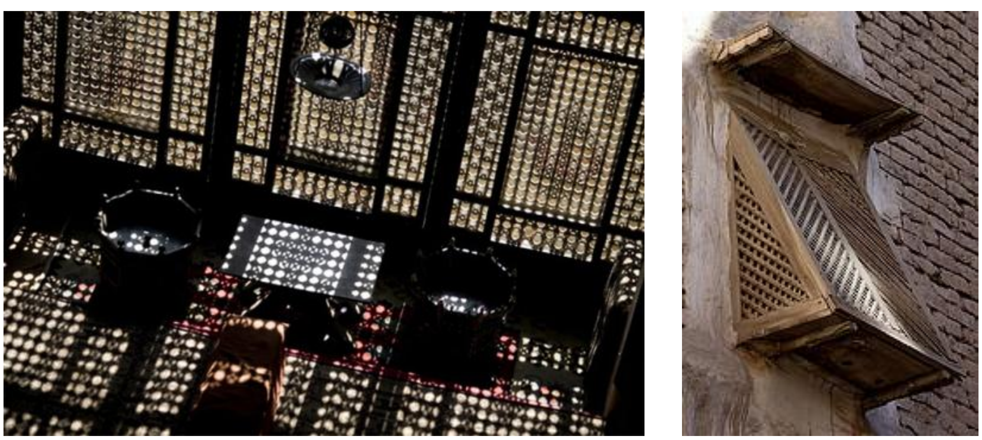


Figure 1-13: Masharabiya System and Daylight

Source: Qela, Erick Lafforgue

1.7 Daylighted School Spaces

A typical school layout in Oman would consist of a large central courtyard with surrounding arcades that lead into classrooms. The combination of courtyards and arcades play a role in adding soft illumination throughout the hallways during certain times of the day. Nowadays, even the courtyards are covered with canopies in order to avoid intense solar illumination (see Figure 1-14). Most school buildings are one to two stories resulting in a wide footprint spread when compared to existing office buildings of ten stories. This extensive roof layout makes it more amenable to adding rooftop fenestration. Usually the method for providing daylight into classrooms is via windows, yet a lot of times this daylight transmission is restricted and blocked via shading devices. Incorporating a method such as a skylight with appropriate glazing material could assist in providing quality illumination that is uniformly distributed over the room.

Figure 1-14: Typical School External Layout, Oman

Source: QPS-Oman

1.7.1 Structural Implications

Studying the structure of a roof in a building is a crucial part in determining the type, spacing, size and feasibility of installing rooftop fenestration. A typical roof structure in Oman uses reinforced concrete. Usually the slab for school buildings in Oman has a depth around 15-20 cm (6-8 inches) with beam spans of 3-4 meters (9-12 feet) and beam depth of 0.5 meters (1.5 feet) (see Figure 1-15). Since rebar, mesh and beams run though this type of structure in both directions; it would be impractical to add skylights to existing buildings with a similar slab arrangement. On the other hand, a precast hollow core concrete plank can span a maximum of 9 m (30 feet) for the same slab depth range in new construction. These planks are typically 1.2 x 1.5 meters (4 x 6 feet), where the skylight could be situated using a metal saddle to hold it in place between the planks. Although a double tee slab structure may have a longer span, it is restricted in beam spacing and depth (see Table 1-1). For example, if spacing between one tee and another is 1.5 meters (5 feet) a minimum beam depth of 0.5 meters (24 inches) is required.

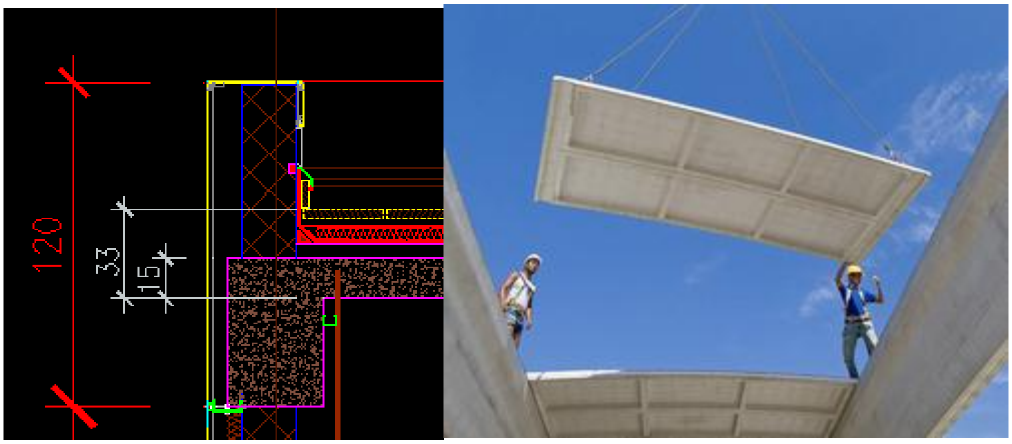


Figure 1-15: Typical Concrete Slab for School Building in Muscat (Left), Precast Slab (Right)

Source: e-Space, Archiproducts

Reinforced concrete (From ACI 318-05), Table 9.5(a)

	cantilever*	simply supported	continuous one side	continuous both sides
slab	10	20	24	28
beam	8	16	18.5	21

Prestressed hollow core concrete plank

	cantilever*	simply supported	continuous one side	continuous both sides
slab	10	45		
beam				

Prestressed concrete double tees and girders

	cantilever*	simply supported	continuous one side	continuous both sides
slab				
beam	8	20		

Table 1-1: Summary Span/Depth Ratio For Concrete Systems

Source: AE422-Dr.Boothby

1.8 Occupant Comfort

Since buildings are built as habitats for people, it is important to take into consideration comfort measures that would satisfy the average occupant. As per the ASHRAE 90.1 standard, the benchmark for assessing comfort level is that 80% of occupants are satisfied. There are two concerns that should be considered when assessing comfort with skylights: thermal comfort and visual comfort.

Heat gain in buildings located in hot regions is a major comfort concern. There are two sources of heat gain for a building: external and internal gains. External gains result from: roofs, walls, skylights, windows, ventilation and infiltration. Internal heat gain consists of heat emitted from lights, people, and equipment such as projectors and printers (Spitler, 2010) (see Figure 1-16). These heat gains show up in a space either as immediate or latent loads that could surface after hours of storage in certain materials. Careful design should consider the effect of both gains to assure occupant thermal comfort.

Thermal comfort is based on the ability of people to shed heat. Good human comfort is generally possible between the ranges from 70-75 F (21 C-24 C) depending on the climate and location. The temperature of the internal core of a human is 98.6 F (37 C) (Anderson, 2014). Having direct sunlight from window fenestration may cause asymmetrical discomfort, where mean radiant temperature would vary significantly, especially for students sitting next to the window. This asymmetrical distribution of heat, where direct sun hits one side of the human body, could cause high discomfort where a person is not able to shed heat evenly. When a proper skylight system with translucent glazing is used, this problem should be eliminated.

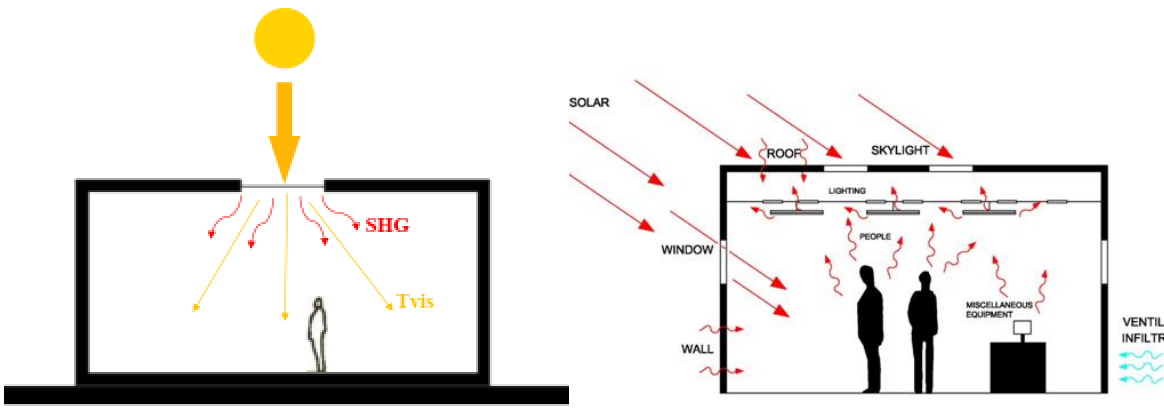


Figure 1-16: Solar Radiation and Heat Gains inside a Building

Source: Photoshop, Engineer Pro Guides

Visual comfort for roof fenestration includes glare assessment. One source for glare discomfort could be from the glazing type chosen. Selection of the glazing plays an important role in glare reduction. Using materials with diffusing properties would reduce the intensity of direct beam radiation entering a space. Another problem that could arise with skylights being a discomfort source to the eye, could be in the high contrast between the ceiling and the skylight. Although proper design of a skylight well can prevent direct view into the skylight, and thus reduce glare, most roof structures for public schools in Oman consist of a thin concrete slab system that does not allow for a well. Also, selecting direct/indirect luminaires could help in minimizing this effect.

1.9 Heat Gain Considerations

When radiant energy is absorbed by a material, it is released over a period of time either through conduction, convection or radiation. The time interval it takes to release solar energy highly depends on the thermal mass properties of that material. Similar to the relation of solar transmittance and heat gain, solar design and thermal storage have an inseparable association. Thermal mass is the ability for a material to absorb, store, and later release heat. A material with higher thermal mass has the ability to store heat for a longer period of time. Similarly, a material with higher thermal diffusivity will release heat into a space more rapidly than a material with less diffusivity. The U-value (thermal transmittance), and R-value (thermal resistance), alone are not adequate to represent heat transfer from material assemblies into a space and do not consider the thermal mass effect of delayed heat load. Most buildings in Oman are constructed from masonry blocks and concrete, which serves as an advantage because of their high thermal mass properties. These materials have a capacity of absorbing radiant heat slowly and releasing it up to 3-5 hours later. This effect is a very important consideration when designing for peak AC systems cooling loads.

When the building envelope is of higher thermal mass, less heating and cooling loads appear as indoor temperature fluctuations and spikes, which leads to a more balanced load on the mechanical system and less energy consumption. This advantage could also lead to a shift in energy demand during the electrical demand peak load time and transfer the load to periods where utility rate charges are lower. In some cases within a hot climate, where low temperatures occur during nighttime, the building mass can be allowed to cool down via natural ventilation and then absorb heat again during the daytime. During peak outdoor temperatures, the indoor space remains cool due to heat storage into the mass, which improves building performance, especially in hot climates. In cold climates this advantage can be used to collect and store heat that is later used to heat a space.

2 LITERATURE REVIEW

"It is impossible to overestimate the important influence of natural light on the interior and exterior forms of buildings and on those who dwell in them. So daylight is the natural beginning"-Derek Phillips

2.1 Introduction

The current trend in lighting design has been moving towards incorporating daylight as an integrated design approach that not only benefits the occupants but also provides energy savings. To support this research effort, the following literature review will first demonstrate the significance of energy efficiency and codes. Then, benefits of natural light in relation to health, occupant productivity, and energy savings is discussed. Second, skylight systems in schools will be addressed. Next, the topic of skylights, their advantages, types, and shapes will be presented. Then, an examination of typical climates for skylight application is introduced, followed by an explanation of glazing material selection for hot climates. Finally, work involving the use of skylights in hot climates is presented.

2.2 Energy Savings and Codes

Since the building industry has undergone various environmental and energy challenges in response to reducing the contribution of buildings to climate change, many new commercial buildings are targeting Ed Maziria's net-zero challenge by 2030 (see Figure 2-1). At present, organizations such as ASHRAE are working towards mandating baseline construction codes that exceed current LEED requirements for building energy efficiency. The way building construction has to transform, if net-zero is to be achieved, is through better envelope integration, daylighting, and daylight harvesting, and upgraded system technologies.

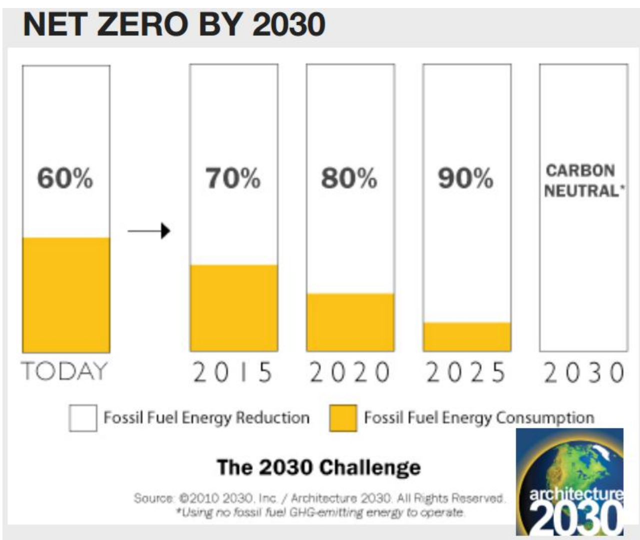


Figure 2-1: Net Zero Challenge

Source: Architecture 2030

About half of the USA energy consumption and greenhouse gas emissions comes from the building sector (U.S Department of Energy, 2012). The building sector consumes as much energy as the industry and transportation sector all together. The goal for the building industry is to reduce energy demand and usage. In order to achieve this, the building industry energy consumption needs to be reduced. In the USA 75% of all the electricity produced is used to operate buildings, 40% of that, which accounts for electrical usage, and 27% in total energy usage, is for commercial buildings. In comparison, Energy consumption of Oman's building sector is around 55% of the country's total energy demand and it has increased by 59% from 2005 to 2010, which is more than half (Ministry of National Economy, 2010). This increased demand results in an increase in CO_2 emissions. According to the Earth Trends report for 2003, electricity produces the most CO_2 emission into the atmosphere in Oman where it accounts for 30% of the total emission with manufacturing and construction after it (see Figure 2-2).

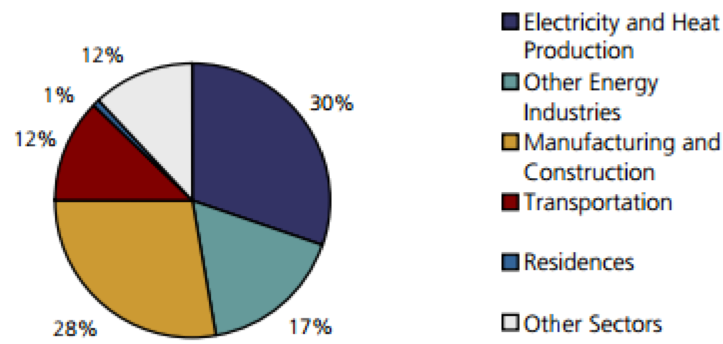


Figure 2-2: Percentage of Co2 Emission by Sector, Oman 1999

Source: Earth Trends

According to US. DOE, refined building energy standards and codes have the potential of saving the U.S.A consumers $330 billion by 2040, which is equivalent to 80 quads of energy savings and over 6.2 billion metric tons of CO_2 emissions (U.S Department of Energy, 2014). In Oman there are no specific dedicated government agencies that promote energy efficiency. Therefore, no definite code is followed. The Oman Green Building Council (OGBC) was formed in 2009 under the Oman Society of Engineering and consists of professionals from different academic backgrounds, sectors, and government officials. This agency focuses on bringing awareness towards sustainable design and forming building solutions that serve the environment. Portions of codes, such as ASHRAE 90.1, are adopted by certain government bodies as guidelines but not as regulated code requirements.

Energy codes provide minimum codes for building construction, however nowadays there is a shift in these minimum code regulations where they are becoming more stringent. In the USA codes geared towards energy consumption and savings are a product of different governmental agencies and organizations such as ASHRAE, ICC, IES, and ANSI. The United States Department of Energy, created in 1977 as a response to the oil crisis in 1973, funds and sponsors a majority of the national laboratory research in relation to building energy efficiency. The U.S. DOE supports the energy code refinements process administrated by ASHREA and ICC. These funded research activities are used to shape energy codes in the USA

Following the process of code compliance is important where the appropriate energy code needs to be selected in relation to the building type. A compliance path needs to be chosen next within the applicable energy code, and a familiarity with the code requirements needs to be established. After that, the building must be designed to meet the requirements of these codes. Documentation comes next with the plans and specifications, followed by the construction of the building, and documentation of the as-built conditions. Following these steps may not always reward an energy efficient building. Commissioning of the building systems and subs-systems needs to be performed and verified as to whether they are meeting design intent. In addition, a continuous improvement building loop system needs to be implemented in order to obtain constant improvement towards reducing energy use.

2.3 Daylighting Benefits

2.3.1 Health

Radiation from the sun can be beneficial to the human body and harmful at the same time (Tregenza & Wilson, 2011). A balance between damaging exposure and the optimum level of daylight should be considered when designing a building. Several studies have addressed the possible link between illnesses and lack of sunlight (Lam et al., 2006). Daylight is also a vital source of vitamin D. Studies have shown that insufficiency in vitamin D could increase the risk of cancers, autoimmune diseases and osteoporosis. Recent research indicated that vitamin D deficiency is a problem affecting the Omani community. In the study, 87.5% of Omani participants were categorized as vitamin D deficient (Abiaka, Delghandi, Kaur, & Al-Saleh, 2013). Although most glazing blocks the shorter ultraviolet B (UVB) rays that are responsible for the vitamin's synthesis process inside the human body; school buildings that incorporate open courtyards and spaces permit direct sunlight exposure to the skin when students are outdoors. Currently, there is no typical glazing material that would admit UVB rays into a building, while at the same time not admitting the intense direct sunbeam.

Seasonal Affective Disorder (SAD) is an illness that has been linked to a deficiency of natural light during gloomy seasons (Ashkenazy, Einat, &Kronfeld-Schor, 2009). A study conducted in a small Russian village, located at 70 degrees North latitude, reported that 27% of the population experienced symptoms of SAD during winter time. These symptoms included depravation of sleep, depression, and fatigue. In the experiment conducted by Hansen and others, it was noted that patients suffering from SAD got relief from their symptoms when exposed to daily doses of light (Hansen, Lund, & Smith-Sivertsen, 1998). This experiment lacked assessments that incorporated natural light into its findings; and instead focused on artificial sources. Evidence was presented that when the eye is exposed to less than 1 kilo-lux of illumination per day, a greater risk of experiencing SAD exists (Tregenza & Wilson, 2011).

Ulrich (1984), found that patients that were provided a daylit window with a view to the outside environment experienced faster recovery than those who had a view of a brick wall (Ulrich, 1984). A study that was conducted within a two year period in Johnston County, North Carolina, observed six schools in which students attended classes. This study compared students who were assigned to a classroom with full spectrum lighting fixtures verses a classroom that used conventional lighting. The study observed that students under the full electrical light spectrum influence were healthier, attended school more frequently and maintained a better mood than their peers who studied under typical light sources (Nicklas, 2009). This study did not observe the effect of natural daylight on students.

The brightness of natural daylight enhances spaciousness and openness of an area. Visual health is an important aspect for an individual's well-being. Eyestrain is considered a major health problem facing occupants in enclosed environments such as an office building or a classroom setting. This condition occurs when the eye is not allowed to focus at different distances over a long time period (Edwards & Torcellini, 2002). Considering a view to the exterior, the balanced range of sunlight spectrum provides the eye with an improved ability to focus and re-adjust. Additionally, proper daylight levels provide a suitable and optimum range for eyesight (Franta & Anstead, 1994). Although this study focuses primarily on toplighting, it is important to consider the element of an occupant's view to the exterior for further research.

2.3.2 Productivity

A study that established the relationship between daylight and productivity was conducted in 2002 (Figueiro et al., 2002). This study suggested that daylight plays a role in circadian rhythm regulation and concluded that workers placed next to a window focused better on work tasks in comparison to co-workers who had no daylight exposure through fenestration. Another study concluded that the presence of skylights, among other factors, was the third most important element in designing a retail space (Heschong, Wright, & Okura, 2002). During the 1980's, the benefits of sunlight were considered crucial; many countries in Europe required staff desks to be located at a minimum of 8 meters (27 feet) from a window (Franta & Anstead, 1994).

Daylighting has also been proven to enhance the mood of students in school facilities (Nicklas el al., 2009.). This improvement yields greater motivation and higher achievement. The National Clearinghouse for Education has established a study "Do School Facilities Affect Academic Outcome" and reported that increased student achievement and reduction of poor behavior was a product of increased daylight in classrooms (NCE, 2005). Another study investigated the link between daylighted elementary schools and productivity from three different schools (Heschong, Wright, & Okura, 2003). Even though this study was conducted for different school districts with different environments and climates: California, Washington, and Colorado; one factor remained constant within these studies. This factor presented a significant correlation between the student's productivity and increased daylight in classrooms.

2.3.3 Mental Performance

Not only productivity improvements but mental enhancement was also linked to the availability of sunlight in a study environment. Researchers have stated that the lack of lighting in schools can substantially affect a student's ability to learn. In general, children can spend up to 40 hours per week under artificial light in a school building, especially if after school activities are involved. A 1999 case study, commissioned by the Pacific Gas and Electric Company, observed a strong correlation between schools that reported improvements in grades and the amount of daylight present in a classroom (Heschong et al., 1999). This study stated that students exposed to more daylight in the classroom progressed 20% faster on their math tests and 26% faster in their reading tests. To follow up on the study done by the Heschong Mahone Group, another study was done in 2003 comparing different variables such as daylighting, HVAC type and classroom type to assess their correlation to improved learning. Daylight was proven to have a consistently strong association with learning improvements, where students in elementary schools showed up to 21% increase in learning rates (Heschong, 2003).

2.4 Energy Savings

Nowadays, the focus in construction has shifted to buildings that have the lowest negative impact on the environment (Selkowitz, 1998). Financed by the United States Department of Energy (DOE), a protocol was developed for assessing the benefits of green buildings. Through this protocol, the Daylight Dividends research program was established. Daylight Dividends inspected the effectiveness of daylight use in several types of non-residential buildings. Formed in 2003, the research program investigated multiple case studies of different building types and reported on their energy performance. These studies focused on improving indoor environment quality, comfort, and building performance. The research also addressed the challenges that face projects that use daylight, such as school buildings. Daylighting evaluation was performed under the program for four schools that have similar footprints in Northern California. Roof monitors and clerestories were the main focus of this study. Elements such as baffles, shades, light shelves and overhangs and their incorporation with rooftop fenestration were evaluated. Some of the challenges faced were inappropriate design of rooftop fenestration. For example, baffles added to a roof monitor facing North in a gymnasium space for one of the schools did not serve any purpose; and in fact blocked most of the useful daylight from entering the space (Eckerlin, 2005).

Typically, a majority of working hours are during daytime; and a significant amount of electric output can be reduced through these peak hours of electrical use with daylight. Reduction of electric light usage is usually associated with significant energy savings. The National Clearinghouse for Education also stated that classrooms with effective daylight systems produced lower electric loads and experienced reduced cooling and heating loads (NEC, 2005). According to the U.S. DOE, 15% of the electricity consumed in the United States comes from electric lighting in buildings (Wymelenberg, 2014). A recent study in New York City indicated that daylight systems can potentially offer energy savings of over $70 million dollars when incorporated into office buildings in that city (Hinge, 2012). Research findings related to photocell control show that lighting electrical consumption can be reduced by 20% to 60% if a proper daylight control system is implemented (Littlefair, 2001). Controlling electric light via photosensors is becoming mandatory for building design in certain cities in the United States of America (U.S Department of Energy, 2012).

2.5 The use of Toplight in Schools

A detailed study that provided guidelines to manufacturers and specifiers in 2013 touched upon the subject of photosensor performance in a classroom using different fenestration configurations (Mistrick & Sarkar, 2013). This study showed that a savings of 40-50% can be achieved depending on the lighting system used and occupancy schedule. The research also indicated that dimming two to three rows of the luminaires would result in the most savings. This study was done using the advanced computer software, Radiance. Since the study results were based on a simulation tool, it would be interesting to compare the findings in an actual classroom setting. Another study was done in the same year that focused on the photosensor settings using closed-loop control and its performance in a classroom (Ranasinghe & Mistrick, 2013). One of the conclusions of this study is that an acceptable photosensor location in a classroom would be 3 meters (10 feet) away from the window with a ceiling height of 3.65 meters (12 feet). This study was focused on the calibration of photosensors in a room with windows only and did not study calibration impacts for toplighting. Currently in the USA, energy codes require automatic control or minimal manual control of electrical lighting in areas where sunlight is available (US DOE, 2012)

In the USA, several cities have implemented skylights into their school design scheme. Energy codes have started mandating skylight installations in large spaces such as warehouses or school gymnasiums. An example of skylight implementation in school buildings is the Capistrano Unified School District in Southern California. The district has constructed a total of sixteen schools that incorporated skylights as part of a Board resolution on mandating natural light in the early 1980s (Edison International, 2003). Experimenting with different skylighting configurations, the system that seemed to work best is a splayed skylight that utilized an inverted plastic pyramidal prismatic Diffuser to disperse light evenly across the classroom (see Figure 2-3).

Figure 2-3: Daylight through Skywells

Source: CUS- California

A collaborative research project done via the Sultan Qaboos University in 2003 investigated different passive measures such as envelope insulation, glazing, and shading in relation to the variation in cooling load for school buildings in Oman. For the glazing, it was concluded that using a triple glazing material reduced the peak cooling load by 7.7% for the month of June. Since this study evaluated an existing school building plan, it only examined vertical windows, and it did not consider different orientations for the fenestration (Zurigat, Al-Hinai, Jubran, & Al-Masoud, 2003).

2.6 Toplight Size, Shape, and Type

Roof fenestration can vary in shape, size and structure. In general, deeper skylight wells produce a more focused distribution of light compared to wells with shorter depth. It has been determined that splaying a well's sides can significantly improve efficiency, and at the same time provide for a wider beam distribution (Serres & Murdoch, 1990). In 2013, a new method was developed to calculate splayed well efficiency (Mistrick, 2013). This method reinforced that splayed wells provide for more efficient delivery of daylight than vertical wells. Under the ASHRAE and IESNA Standard 90.1-2010, the general provisions for envelope compliance contain mandatory provisions that must be satisfied. This standard lists two compliance options: a prescriptive option and a performance method. The prescriptive path consists of following minimum code compliance, whereas the performance method has less implied restrictions in lieu to codes, with the condition of demonstrating minimum energy achievements. For the prescriptive building method, the ratio of skylight area to roof area cannot exceed 5% in ASHRAE 90.1-2010(ANSI/ASHRAE/IES, 2010). This ratio has been increased in ASHRAE 90.1-2013 to a maximum of 6%, providing that a photocell lighting control system is implemented. Although size and configuration of toplighting is important, it is equally vital to consider the position of the roof fenestration. South-facing clerestory glazing would contribute additional heat gain and glare, especially during the winter, in comparison to a North facing clerestory.

Another toplighting method that has been established in the markets recently is tubular skylighting. A light tube typically contains a 25-54 cm (10-21 inch) diameter shaft with a rooftop solar collector that collects and delivers sunlight through it. Because of its shaft design, a light tube transmits less heat during the daytime. Both splayed well and tubular skylights have limitations as they could only be located on the story connected to the roof, therefore a reliable substitute system that could deliver sunlight to multiple stories via the rooftop is worthy of exploration. Another drawback to using both systems in Oman is that both systems require a deep roof slab height which does not conform to most school building roof structures depths in Oman.

2.7 Climate Features Appropriate for Skylighting

Skylights are commonly used in cold to moderate environments. There are few skylight applications in regions of high temperature. Fenestration in warm climates is usually associated with an increase in cooling load. A study conducted in 1985 for non-residential buildings in hot climates indicated that total energy savings is associated with mechanical, electrical, and plumbing systems as an integrated whole (Arasteh, Johnson, Selkowitz, & Connell, 1985). Toplights that produce higher illumination require higher cooling loads; consequently it is important to consider a proper lighting control strategy that integrates with a building's electrical lighting system (Department of Energy, 2012).

A 2005 article suggested that the application of skylights in hot and humid climates such as Florida could add to electricity consumption rather than facilitate energy savings (Sheinkopf, 2003). For instance, a 1.2 x 0.6 meter (2 x 4 foot) clear skylight can increase the air-conditioning load by approximately 240 kWh annually. This amounts to 4 dollars per month per skylight. Considering the high angle of the sun in that location, two or four more times the heat is transferred into a space than produced from vertical windows. A translucent skylight for hot climates is much more effective than a transparent one, since it can disperse the direct sunlight, creating ambient illumination. The article also suggested locating skylights on a porch next to a window, where heat gain is reduced and reflected light enters the room. In contrary to adding the opening to the roof, the porch technique does not allow for uniform distribution since most of the light will be distributed through a vertical aperture.

2.8 Glazing Material for Hot Climates

Material selection plays an important role when it comes to skylight performance. While it is desirable to have transparent glazing as a mean of maximizing external view, the position of the sun in the sky may cause glare from direct sunlight through clear glass. For skylights, the angles causing glare would be higher than that of a vertical window. White translucent acrylic or prismatic clear material provide diffuse light that is emitted into the room providing minimal glare for skylights. In the case of a clerestory or roof monitor this may vary depending on the facing direction glazing opening. For example, the North facing façade of a roof monitor for Muscat's location will not acquire the problem of glare since there is no direct sunbeam entering the space from that orientation both during winter and summer. Therefore, such a setting may not require a translucent material.

In order to acquire diffuse light, most manufacturers add white pigment to acrylic and polycarbonate glazing. This pigmentation absorbs light and reduces the visible light transmittance. Thus, a balance of the pigment needs to be maintained for optimal diffusion with higher transmittance (Stanford University, 2014). Prismatic glazing does not require pigmentation and therefore performs better than acrylic material.

With skylights, there is radiative heat that is produced from the sun and conductive heat that passes through the skylight materials. The material type not only determines the glare percentage, but also the amount of heat that passes through it. Most skylights transmit long and short wave-length radiation through its aperture. The shorter waves, within the visible spectrum, provide for vision, whereas the long waves radiate heat into the space. This solar heat transfer may be useful in a cold climate setup where heating loads can be reduced, but in hot climates it may have the opposite effect and increase cooling loads.

Another important method of heat transfer for a skylight is conduction. The temperature difference between the outside and the inside dictates the amount of heat gain or loss through the glazing medium. Since the concern for a cooling season is the heat gain inside a space, the thermal conductivity (U-Factor) is a value to be considered for the complete skylight structure.

Since heat gain is a major concern when selecting glazing material in hot climates, usually a double or triple pane unit is recommended. The additional glass pane reduces the amount of light transmittance, and therefore reduces heat transfer. For example a double glass layer allows for approximately 75% of light to pass through (see Table 2-1). A low-emittance (Low-E) coating, where a thin metallic oxide layer is deposited on the glazing surface, is also suggested for hot climates. Coating a glass surface with a low-E material blocks a significant amount of radiant heat transfer, thus lowering the total heat flow through an aperture. Acoording to a study of "Daylighting of Buildings in a Hot Climate" a clear 4 mm (1/8 inch) thick glass will transmitt 89% of the visible light. A tinted glass however could have a visible light transmittance between 25 and 45% (Ne'eman & Shrifteilig, 1982). Admitting less light from the sun may reduce heat gain inside a space, but the electric lighting load may increase as a result. In general, glazing materials with low solar heat gain coefficient (SHGC), appropriate visible light transmittance (T-vis) and high light to solar gain ratio (LSG) work best for a hot climate (Dilaura et al., 2011).

The National Fenestration Rating Council **(**NFRC) provides ratings on energy efficiency for windows, doors and skylights. A test procedure, NFRC-300, was developed in 1994 to calculate the overall transmittance of glazing materials. There are limitations to the test procedure since it is expensive and manufacturers cannot provide the test for their entire product line (Russo, McKown, Roger, & Brotzman, 2001). Another limitation to the test is that the U-factor; the amount of heat transferred through a material, is calculated only for the glazing part in contrast to calculating heat conduction for the whole skylight material including the frame.

Solar (Heat) Transmission Values for Typical Glass Types

Glazing Type	Solar Transmission	Equivalent U-Value
Clear, Single	75%–89%	1.11
Clear, Double	68%–75%	0.49
Low-e, Double, Clear	35%–55%	0.38
Low-e, Tinted, Gray	30%–45%	0.38
Low-e, Argon	45%–55%	0.3

Table 2-1: Solar Transmission for Different Glass Types

2.9 Previous Study of Toplighting in Hot Climates

Most research conducted with skylights is limited to locations in the United States and focus on moderate to cold climates at high latitudes. A few cases are studied in tropical climate settings such as an analysis conducted in Indonesia. The study in Indonesia indicated that incorporating a 3 in 1 louver shading device skylight that may serve as an element that permits daylight inside a space (see Figure 2-4), while at the same time collecting heat to provide hot water (Mintorogo, 2005). As per the study, this system provides an effective method of reducing solar radiation gain, while offering energy savings of as much as 634,500 Btu per day for a 10 hours of solar radiation exposure. The investigation also indicated that using reflective glazing blocks approximately 12% more solar radiation than that of a polycarbonate material (see Figure 2-8). Another interesting finding in this study was the demonstration that a higher SFR (Skylight to Floor Ratio) does not necessarily lead to higher energy consumption if a proper system is used. Using the 3 in 1 system, as indicated by the report, a 10% SFR yielded cooling load savings of up to 9 times than that of a 1% SFR (See Table 2-2)

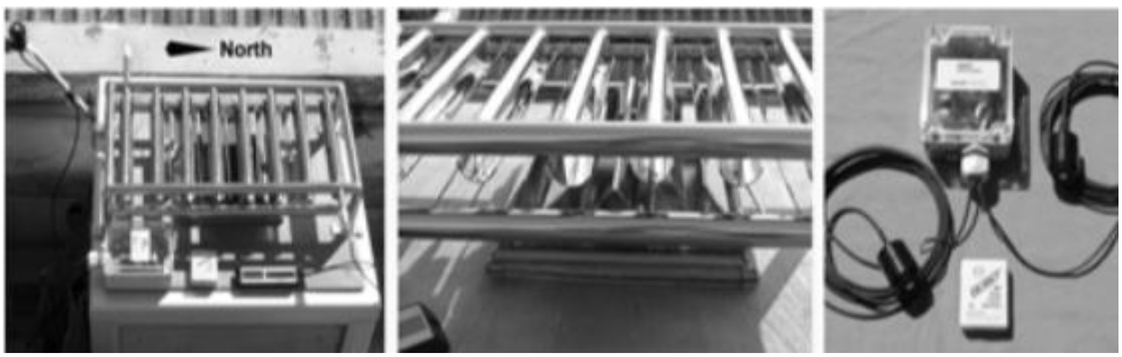


Figure 2-4: Research 3 in 1 Skylight System

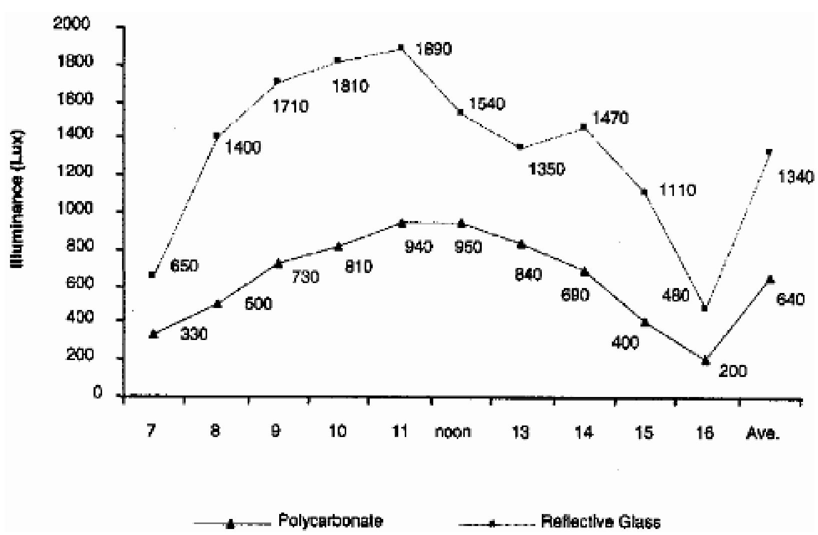


Figure 2-5: Iluminanace Values for Polycarbonate and Reflected Glass

	SFR 1%	SFR 2%	SFR 4%	SFR 6%	SFR 8%	SFR 10%
Energy Saved (Btuh)	6,345	12,692	25,385	38,078	50,771	63,450
Energy Saved in (Ton Btu)	63	127	254	381	508	635

Table 2-2: SFR and Cooling Loads Energy Savings

Although the findings were quite interesting, the report only mentioned the Tvis (Visible Transmittance) value for the polycarbonate system, and the Shading Coefficient (SC) for the reflective glazing material. No other heat coefficient values for the glazing systems were mentioned.

In the book "Energy-efficient Buildings in India" written by Mili Majumdar in 2001, it was recommended to have rooftops clerestory that face North and South in hot humid climates for residential buildings (Majumdar, 2001). The author mentions that proper glazing and overhangs for roof monitors facing North and South would be a better system than a horizontal glazing system such as a skylight, where the monitors allow better illumination during the winter and less direct sunlight during the summer.

A comprehensive report on cost-effective energy in school design guidelines, that include the building envelope in its recommendations, was prepared by the DOE for school buildings in a tropical island climate (U.S. Department of Energy, 2004). This guideline suggested energy saving tactics for school buildings in hot humid climates. The report also referenced that out of all the typically high performance systems used, daylighting has the greatest impact in terms of energy conservation. The study suggested that roof monitors are ideal if facing North, but if oriented to the South, baffles and overhangs would need to be part of the design. Another suggestion is to paint the roof in highly reflective paint such as white in order to add more daylight through the monitors. These guidelines were design recommendations for new or existing construction. Although challenging, a comparison of actual building data and simulation data needs to be developed to confirm these results.

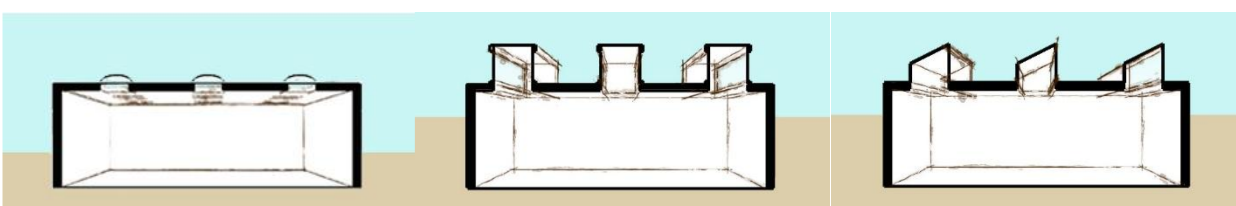
3 METHODOLOGY

"Space and light and order. Those are the things that men need just as much as they need bread or a place to sleep"-Le Corbusier

3.1 Introduction

This section will describe the methods to be used in this research in order to assess the viability of toplighting for a school classroom in Oman. Since daylighting design involves two elements: light quality and energy performance, two main simulation tools are used to evaluate the results. To assess daylight quantity and quality, DAYSIMps, a Radiance-based daylighting simulation engine, is utilized. For energy evaluation, the Integrated Environment Solution-Virtual Environment (IES-VE), a suite of analysis tools that assesses building performance, is incorporated. The IES-VE simulation tool also integrates Radiance as one of its methods to generate daylighting calculations through a graphical user interface.

A rectangular classroom analysis was built to perform the simulations. Three baseline model types were created. Domed skylights (Type1), clerestory roof monitors (Type2) and single direction roof monitor (Type3) scenarios were investigated as baseline studies (see Figure 3-1). Skylight to roof ratios (SFR), orientations, glazing material and shape were adjustable parameters within these rooftop Types. Different factors within these scenarios were adjusted in order to reach an optimized quality, quantity and savings. Lux levels, distribution at the work-plane, and glare were the metrics used to evaluate the lighting quality and quantity portion of this study. Lighting load and cooling loads were the metrics used to evaluate energy savings (see Table 3-1). A baseline model with no rooftop glazing was built to be compare each adjusted scenario's performance for thermal analysis.



Type1: Domed Skylight Type2: Clerestory Roof Monitors Type3: Roof Monitors

Figure 3-1: Toplighting Types to Be Investigated

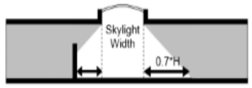
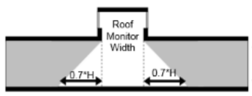
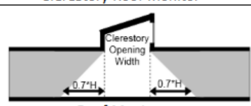
T	Toplighting	Orientation	Glazing Material	Glazing Shape	Illumination	Glare	Lighting Load	Cooling Load
1	 Domed Skylight	N	Translusive Low-E	Domed	DA SDA UDI	DGP	kWh	kWh
2	 Clerestory Roof Monitor	N + E	Clear-Low-E + Translusive	Flat	DA SDA UDI	DGP	kWh	kWh
3	 Roof Monitor	N+E+W+S	Clear-Low-E + Translusive	Flat	DA SDA UDI	DGP	kWh	kWh

Table 3-1: Toplighting Types to Be Investigated

The following sections will present the tools, setups, and parameters applied to perform the research simulations.

3.1.1 Space Function and Condition

The space simulated will serve as a general classroom. The dimensions for this space will represent a typical classroom in Oman, which has an average of 25-35 students per class. The dimensions of the classroom is set to 9 meters (30 feet) wide by 7.6 meters (25 feet) deep by 3 meters (10 feet) high and with a roof slab of 20 centimeters (8 inches) deep (see Figure 3-2). In general, 2 square meter (22 square feet) is required per student for space in a classroom (Arizona State University, 2011). For a 750 square feet classroom, maximum of 31 total of students and a teacher were considered (see Table 3-2).

For the illumination calculations, the work-plane for this study was placed at 0.75 meters (2.5 feet) above floor level. The room is maintained at a constant indoor temperature of 24°C (75 F). As per the minimum ventilation rates in breathing zone per ANSI/ASHRAE Standards 62.1, this was set to 0.12 cfm/ft2. The reflectance values were set to 70/50/20 for the ceiling, walls and floor, respectively as per ASHRAE/IES Advanced Energy Design Guides recommendation reflections for schools (see Table 3-3). The roof reflectance was set to 80% and the ground to 20%.

Maximum sensible gain for computers was set to 1 W/ft^2 with a 0.22 radiant factor. For the fluorescent lights the LPD was set to 0.83 W/ft^2. For people gain the maximum sensible gain was set to 225 Btu/h per person, and maximum latent gain was set at 105 Btu/h per person.

ROOM CAPACITY = (Total Sq. Ft. - sq. ft. instructor area) X Station Factor

INSTRUCTOR AREA = width of room x distance to front row of seats

TYPE OF SEATING	STATION FACTOR
Movable Furniture:	
tablet armchairs	15-17 sq. ft.
tables and chairs	20 sq. ft.

TYPE OF SEATING	STATION FACTOR
Fixed Furniture:	
chairs w/ folding tablet arms	12-15 sq. ft.
theater seats w/ folding tablet arms	12-15 sq. ft.
continuous tables	15-20 sq. ft.

Table 3-2: Method of Calculating Students Number per Classroom Size

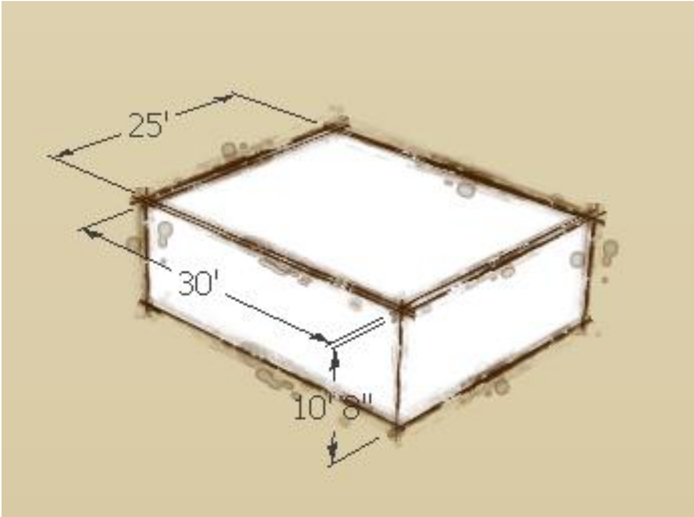


Figure 3-2: Classroom Space Dimension

Office	K-12 School	Small Retail	Small Hospital and Healthcare
Ceiling: ≥80% (90% if indirect lighting) Walls: ≥70% (same for >2.5-ft. vertical partitions)	Ceiling: 70% (preferred 80-90%) Walls: 50% Floor: 20%	Ceiling: 80% (80+% if daylight zone) Wall: 50% (70+% if daylight zone) Floor: 20%	Ceiling: 85% (direct lighting) and at least 90% (indirect and/or daylighting) Walls: 50% (70% for walls adjacent to daylight apertures) Floor: 20%

Table 3-3: Recommended Reflectance Values- ASHRAE Advanced Energy Design Guide

3.1.2 Occupancy File

Generally public schools start at 7am in the morning and end around 2 pm. Some schools do incorporate after-hour activities therefore that was also considered into the schedule. The occupancy schedule was set from 6 am to 4 pm for both the electric lighting and HVAC systems (see Figure 3-3). Daylight time savings are not applicable in Oman.

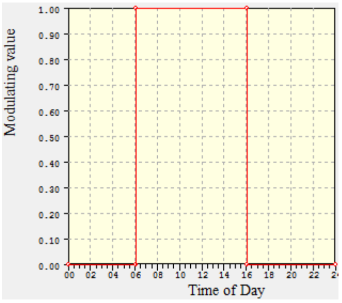


Figure 3-3: Occupancy Schedule (IES-VE)

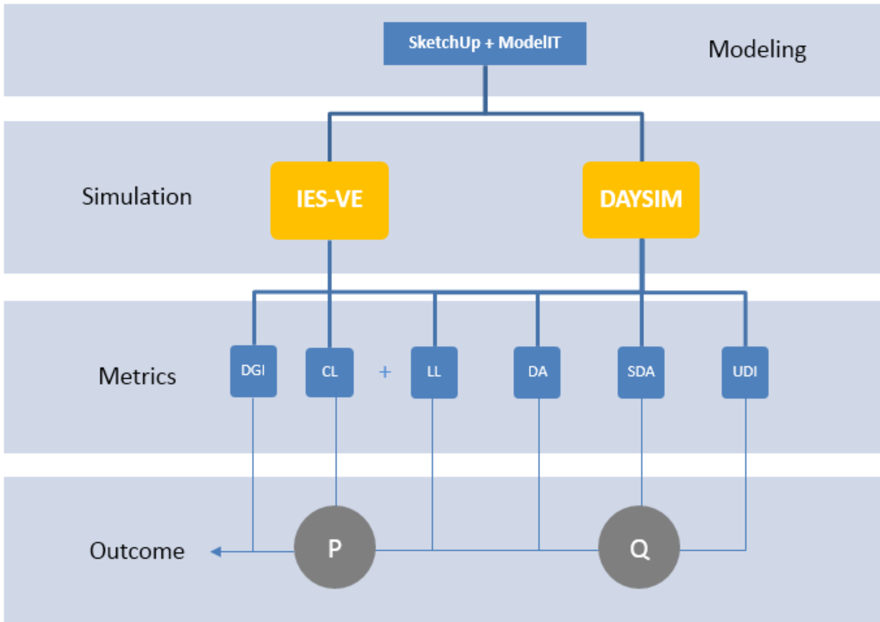
3.2 Tools

This section will breakdown each software simulation and the inputs required for each (see Figure 3-4). Since students in a classroom are subjected to different daylight exposure depending on the time of day and weather conditions; adequate light levels and comfortable temperature should be maintained during occupied times. This requires a simulation tool that does hourly-based analysis. Both simulation tools, DAYSIMps and IES-VE, perform a time-step series analysis for a one-year period. These one year analyses, consisting of 8,760 hours of annual output, were aggregated into monthly data.

The program DAYSIMps incorporates the Perez sky model into its simulation calculations using daylight coefficients and backward raytracing. DAYSIMps calculates Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) based on these daylighting coefficients. One advantage that DAYSIMps has over IES-VE is that it utilizes a critical point to locate the area in the room that requires the most light for photosensor system calibration, where if the target illuminance is met at the critical point, then adequate illuminance levels should be sufficient at all other work-plane points (Dilaura et al., 2011) . It also calculates the DA, UDI, sDA, whereas IES-VE does not put these metrics into consideration.

To calculate Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) based on the weather file for Muscat, there are several steps that were followed. As a starting point, the basic classroom model was created in SketchUp Pro 2014. After that, a RAD file for each scenario was extracted from SketchUp using a Radiance plugin tool that was installed in SketchUp. These RAD files contain the geometry of the classroom. Another material RAD file was created where the reflectance and transmittance of each surface was assigned. A local weather file was uploaded. An occupancy schedule, representing typical school hours in Oman, was created. To set up the illuminance points, an analysis array with a grid spacing of 0.6 x 0.6 meters (2 x 2 feet) was created resulting in a total of 180 points for the classroom area. An electrical lighting layout and schedule was also established, meeting the target illuminance of 400 lux (40 fc), in order to analyze the dimming system performance in relation to daylight output. Metrics such as DA, sDA, cDA, UDI, and illuminance threshold were analyzed for each scenario. These metrics were bases for the location of the work plane critical point, where it was located at the grid point that required the most electrical light output within the room, for each layout Type, throughout the year.

Next, the IES-VE tool was used to assess the heat gain, cooling loads, and energy savings breakdowns. The same EPW weather data was imported into the program as well as the occupancy schedule. Model geometry matching the SketchUp model parameters for all three classroom configurations were created in the ModelIT interface within IES-VE for this analysis. The construction templates for the classroom envelope was setup for the walls, floor, ceiling, roof and glazing system. For the wall, floor, ceiling and roof material, the construction layers were setup with thermal properties such as material thickness, conductivity, and specific heat capacity input to determine the total U-value, mass, and thermal mass of these material elements. The thermal construction layers for the glazing was set up as well, where properties such as thickness, conductivity and Tvis were input. Adjusting these inputs provides an output of total glazing SHGC and U-values. IES-VE also provided net U-value including the frames of the toplighting. Room conditions such as cooling profile and cooling set point were adjusted to the desired targets. Internal gains such as lighting and people were added. A typical AC split package that is used in Oman classrooms and system air flow were selected as per required Cubic Feet per Minute (CFM) for the classroom, and required loads from external and internal gains. The heat gain was broken into sections to assess the percentage of gain from each material, i.e. glass, roof, floor, etc. Annual mechanical loads were calculated and compared to savings from the electrical lighting loads. Finally, a glare analysis was performed to compare the best visual setting.



CL: Cooling loads
DA: Daylight Autonomy
UDI:Useful Daylight Illuminance
P: Performance

LL: Lighting Loads
SDA: Useful Daylight Autonomy
DGP: Daylight Glare probability
Q: Quality

Figure 3-4: Process Breakdown

3.3 Simulation Tools Input

3.3.1 Weather Data

As a starting point, a weather data file is needed in order to assess the climate's influence on building design. Inputs such as solar irradiation, temperature, humidity, and wind are factors that have an impact on building simulation and design. For this study, Typical Metrological Year (TMY) weather data was used. TMY data is a range of annual weather phenomena, usually collected in a period of 20 years, then averaged out for a particular location. The first TMY data was collected between 1948 and 1980, followed by TMY2 within the period 1961 and 1990, and lastly TMY3 data represents data collected from the period of 1991-2005 (Wilcox & Marion, 2008). Since the weather file for Muscat represents a 1995 meteorological one-year set, it is therefore considered a TMY3 file. This weather data was generated by the Seeb International Airport in Oman and translated into an EPW file format. The file includes climate data plus information such as longitude, latitude, time zone, and site elevation. The following metrics are usually included in a weather file:

direct and Diffuse irradiance
dry bulb temperature
dew point temperature
wet bulb temperature
wind speed and direction

global horizontal radiation
relative humidity
absolute humidity
cloud cover
rainfall

Using IES-VE to assess Oman's climate zone, the EPW file was input, Oman is categorized as a 1B climate zone (hot and dry) climate per ASHRAE 90.1, 2010 zoning (see Figures 3-5 and 3-6). A further analysis for sky clearness was conducted using the direct and diffuse irradiance values from the EPW file. The method used to evaluate cloud cover was the Perez sky clearness index (see Table 3-4). A calculation using the formula for the eight Perez skies was formed to determine the clearness of the sky as follows:

$$\epsilon = [(Dh + I)/Dh + \kappa Z^3]/[1 + \kappa Z^3]$$

Where:
ϵ = Sky clearness
Dh = horizontal Diffuse irradiance
I = normal incidence direct irradiance
K = constant equal to 1.041 for Z in radians
Z = Solar Zenith Angle

Table 1. Discrete sky clearness categories

ε category	lower bound	upper bound
1. Overcast	1	1.065
2.	1.065	1.230
3.	1.230	1.500
4.	1.500	1.950
5.	1.950	2.800
6.	2.800	4.500
7.	4.500	6.200
8. Clear	6.200	--

Table 3-4: Perez Sky Clearness Categories

The results for the sky clearness count will be discussed in the results section.

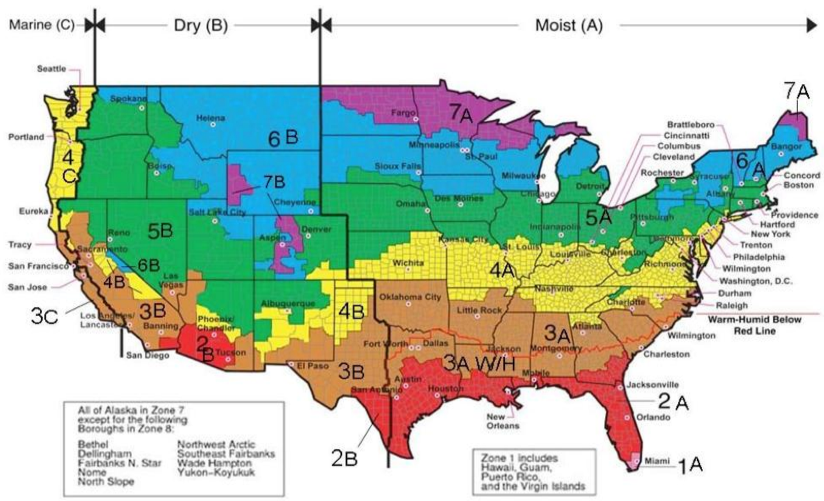


Figure 3-5: ASHRAE 90.1 Climate Zoning Breakdown for the USA

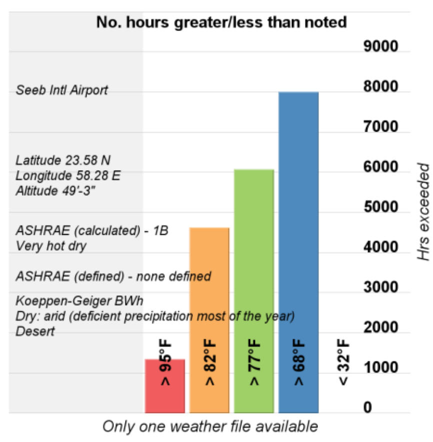


Figure 3-6: Climate and Weather for Muscat-Oman

Source: IES-VE

3.3.2 Building Envelope

For the building envelope, material layering were selected in order to meet the ASHRAE 90.1 minimum requirement for climate zone 1 (see Tables 3-5 to 8-3).

Table 5.5-1 Building Envelope Requirements for Climate Zone 1 (A,B,C)*

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20 c.i.	U-0.039	R-25 c.i.	U-0.218	R-3.8 c.i.
Metal Building[a]	U-0.041	R-10 + R-19 FC	U-0.041	R-10 + R-19 FC	U-0.115	R-10
Attic and Other	U-0.027	R-38	U-0.027	R-38	U-0.081	R-13
Walls, above Grade						
Mass	U-0.580	NR	U-0.151[b]	R-5.7 c.i.[b]	U-0.580	NR
Metal Building	U-0.094	R-0 + R-9.8 c.i.	U-0.094	R-0 + R-9.8 c.i.	U-0.352	NR
Steel Framed	U-0.124	R-13	U-0.124	R-13	U-0.352	NR
Wood Framed and Other	U-0.089	R-13	U-0.089	R-13	U-0.292	NR
Wall, below Grade						
Below Grade Wall	C-1.140	NR	C-1.140	NR	C-1.140	NR
Floors						
Mass	U-0.322	NR	U-0.322	NR	U-0.322	NR
Steel Joist	U-0.350	NR	U-0.350	NR	U-0.350	NR
Wood Framed and Other	U-0.282	NR	U-0.282	NR	U-0.282	NR

Table 3-5: ASHRAE 90.1 2013 Building Envelope Requirement for Zone 1

Source: ANSI/ASHRAE/IES Standard 90.1-2013

Material (outside to inside)	Thickness in	Conductivity Btu-in/h-ft²-°F	Density lb/ft³	Specific Heat Capacity Btu/lb-°F	Resistance ft²-h-°F/Btu	Vapour Resistivity (perm-in)^-1	Category
[USSU0000] STUCCO - HF-A1	1.00"	4.999	165.996	0.1999	-	0.000	Screeds &
[USCH0003] HW CONCRETE UNDRIED AGGREGATE - HF-C12	8.00"	11.995	140.026	0.1999	-	0.000	Concretes
[USIN0001] INSULATION BOARD - HF-B5	2.00"	0.298	5.681	0.1999	-	0.000	Insulating
[USGP0000] GYPSUM/ PLASTER BOARD - HF-E1	0.75"	1.109	50.005	0.1999	-	0.000	Plaster

Performance

U-value 0.1099 Btu/h·ft²·°F ASHRAE Thickness 11.75" in Thermal mass Cm 0.6264 Btu/ft²·F

Total R-value 8.2531 ft²·h·°F/Btu Mass 111.2639 lb/ft² Very lightweight

Table 3-6: Wall Construction Layers (IES-VE)

Material (outside to inside)	Thickness in	Conductivity Btu-in/h-ft²-°F	Density lb/ft³	Specific Heat Capacity Btu/lb-°F	Resistance ft²-h-°F/Btu	Vapour Resistivity (perm-in)^-1	Category
[LNDN0003] LONDON CLAY	29.53"	9.776	118.613	0.2388	-	-	Sands, Stones
[BRCK0001] BRICKWORK (OUTER LEAF)	9.84"	5.824	106.128	0.1911	-	-	Brick &
[CSTC0003] CAST CONCRETE	3.94"	7.835	124.856	0.2388	-	-	Concretes
[DNSP0000] DENSE EPS SLAB INSULATION - LIKE STYROFOAM	1.97"	0.173	1.873	0.3344	-	-	Insulating
[CHPB0000] CHIPBOARD	1.97"	1.040	49.942	0.4999	-	-	Timber
[CT] CONCRETE TILES	0.39"	7.627	131.099	0.1999	-	0.729	Tiles

Performance

U-value	0.0510	Btu/h·ft²·°F	ASHRAE	Thickness	47.64"	in	Thermal mass Cm 4.9554 Btu/ft²·F
Total R-value	15.4934	ft²·h·°F/Btu		Mass	432.6741	lb/ft³	Lightweight

Table 3-7: Floor Construction Layers (IES-VE)

Material (outside to inside)	Thickness in	Conductivity Btu-in/h-ft²-°F	Density lb/ft³	Specific Heat Capacity Btu/lb-°F	Resistance ft²-h-°F/Btu	Vapour Resistivity (perm-in)^-1	Category	A90.1 Status
[RFNS0000] ROOF INSULATION (ASHRAE) R-20	4.00"	0.200	1.500	0.2000	-	0.000	Insulating	R
[MD2] Metal Deck (ASHRAE)	0.37"	1109.355	174.798	0.2140	-	0.000	Metals	R

Performance

U-value	0.0481	Btu/h·ft²·°F	ASHRAE	Thickness	4.37"	in	Thermal mass Cm 1.1671 Btu/ft²·F
Total R-value	20.0003	ft²·h·°F/Btu		Mass	5.9537	lb/ft³	Very lightweight

Table 3-8: Roof Construction Layers (IES-VE)

3.3.3 Glazing System Input

Current glazing systems that are used for windows in Muscat are comprised of aluminum frame, double-glazed, 6 mm (1/4 inch) thick clear float glass with 12 mm (1/2 inch) air gap and 6 mm (1/4 inch) thick tinted reflective glass on the outside. Glazing with moderately low U-value, low SHGC, and high Tvis are desired for a hot climate. ASHRAE 90.1-2010 has set standards for the U-value, SHGC in climate zone 1. For vertical fenestration, these standards require a maximum U-factor of 1.2 and SHGC of 0.25. For horizontal fenestration a range from 1.98-1.36 for the U-factor is required, depending on the skylight construction. ASHRAE 90.1-2013 has updated these values (see Table 3-9). In addition a range of 0.36-0.19 for the SHGC is required for skylights, depending on the skylight to roof area. Values that matched the ASHRAE 90.1, 2010 glazing requirement for vertical fenestration in zone-1 were found from PPG glazing with a 25% SHGC, 52% Tvis, and 23% U factor. For domed skylight values, a 26% SHGC, 54% Tvis, and 45% U factor glazing material from Bristolite is available. These values were later matched in the simulation tools and experimented with.

The final glazing construction for the vertical fenestration consisted of a triple glazed window with a Net U-value of 1.50 W/m^{2}k (0.26 Btu/hr-ft^2-F). The Tvis and SHGC were 52% and 25% respectively. Availability of glazing Materials from the market with similar values were verified (see Table 3-10). For the horizontal glazing the net U-value added up to 1.54 W/m^{2}k (0.27 Btu/hr-ft^2-F). The Tvis and SHGC were calculated to 53% and 26% (see Table 3-11).

Table 5.5-1 Building Envelope Requirements for Climate Zone 1 (A,B,C)*

Fenestration	Nonresidential Assembly Max. U	Nonresidential Assembly Max. SHGC	Nonresidential Assembly Min. VT/SHGC	Residential Assembly Max. U	Residential Assembly Max. SHGC	Residential Assembly Min. VT/SHGC	Semiheated Assembly Max. U	Semiheated Assembly Max. SHGC	Semiheated Assembly Min. VT/SHGC
Vertical Fenestration, 0%–40% of Wall	(for all frame types)			(for all frame types)			(for all frame types)		
Nonmetal framing, all	U-0.50[c]			U-0.50[c]			U-0.93		
Metal framing, fixed	U-0.57[c]			U-0.57[c]			U-1.20		
Metal framing, operable	U-0.65[c]	SHGC-0.25	1.10	U-0.65[c]	SHGC-0.25	1.10	U-1.20	NR	NR
Metal framing, entrance door	U-1.10[c]			U-1.10[c]			U-1.10[c]		
Skylight, 0%–3% of Roof									
All types	U-0.75	SHGC-0.35	NR	U-0.75	SHGC-0.35	NR	U-1.80	NR	NR

Table 3-9: Fenestration Requirements ASHRAE 90.1-2013

Source: ANSI/ASHRAE/IES Standard 90.1-2013

COLOR	PRODUCT & IGU	THICKNESS	VLT (%)	EXT. REFL. (%)	SHGC	WINTER U-VALUE ENGLISH	WINTER U-VALUE METRIC	THERMAL STRESS RISK
	OUTDOOR LITE: 6mm Solarban® 70XL (2) on Solexia™ AIRSPACE: 1/2 " (12.7 mm) Air INDOOR LITE: 6mm Sungate® 600 (4) on Clear	1 "	52	11	0.25	0.23	1.28	High

	Bristol Acrylic	Coollite Solar Heat Blocker Acrylic	Quasar Low-E
VLT Light Transmission	53%	54%	49%
SHGC Solar Heat Gain Coefficient	0.50	0.26	0.26
U Factor / Insulating Value	0.56	0.45	0.17
Haze / Light Diffusion	100%	100%	100%

Table 3-10: Example of Products Available in the Market, Vertical Glazing (Left), and Horizontal Glazing (Right)

Source: PPG Glass (Left), Bristolite Daylighting Systems

Construction layers (outside to inside)

Material	Thickness in	Conductivity Btu·in/h·ft²·°F
[EXTW1114] solar 6MM	0.24"	7.349
Cavity	0.47"	
[EXTW2] CLEAR FLOAT 6MM	0.24"	7.349
Cavity	0.47"	
[EXTW3] CLEAR FLOAT 6MM	0.24"	7.349

Short-wave shading coefficient	0.1131
Long-wave shading coefficient	0.1820
Total shading coefficient	0.2951
SHGC (center-pane)	0.2568

Short-wave shading coefficient	0.1100
Long-wave shading coefficient	0.1811
Total shading coefficient	0.2911
SHGC (center-pane)	0.2533

Performance — H

Net U-value (including frame)	0.2712	Btu/h·ft²·°F	U-value (glass only)	0.2338	Btu/h·ft²·°F	
Net R-value	4.2765	ft²·h·°F/Btu	g-value (EN 410)	0.2667	Visible light normal transmittance	0.53

Performance — V

Net U-value (including frame)	0.2653	Btu/h·ft²·°F	U-value (glass only)	0.2301	Btu/h·ft²·°F	
Net R-value	4.3465	ft²·h·°F/Btu	g-value (EN 410)	0.2671	Visible light normal transmittance	0.52

Table 3-11: Glazing Construction Layers (IES-VE)

3.4 Glazing Parameters

3.4.1 Glazing Area

In ASHRAE 90.1, 2010, the maximum vertical fenestration area limit is 40% or less of the gross wall area. As for a horizontal maximum, the limit is 5% or less of the roof area. Changes were made in ASHRAE 90.1, 2013 where the limit was reduced to a maximum of 3% for horizontal glazing and this limit can be increased up to 6% provided that: the glazing material haze factor is greater than 90%, Tvis is greater than 40%, photocontrols are used, and daylight area is greater than half of the floor area. As for toplighting area provisions in ASHRAE 90.1, 2013, the minimum toplighting glazing area is mandated by the LPD provided daylight area rather than the square footage of the space. For example, ASHRAE 90.1, 2013 requires that a minimum of 50% of the floor area directly under a roof with an LPD of greater than 5 W/m^2 (0.5 W/ft^2) should be in the daylight area. An area with an LPD between 11 W/m^2 (1 W/ft^2) and 14 W/m^2 (1.4 W/ft^2) requires a minimum 3.3% toplighting area to daylight area ratio, provided that there is photosensor control for the electrical lighting system (see Table 3-12).

~~General~~ Lighting Power Density or Lighting Power Allowances in Daylight ~~Zone~~ Area W/ft^2 (W/m^2)	Minimum Toplighting Area to Daylight ~~Zone~~ Area Ratio
1.4 W/ft^2 (14 W/m^2) < LPD	3.6%
1.0 W/ft^2 (10 W/m^2) < LPD < 14 W/m^2 (1.4 W/ft^2)	3.3%
0.5 W/ft^2 (5 W/m^2) < LPD < 1.0 W/ft^2 (10 W/m^2)	3.0%

Table 3-12: Minimum Toplight Area ASHRAE 90.1-2013, Table 8.3.4.1

Source: ANSI/ASHRAE/IES Standard 90.1-2013

Each skylight for Type1 was circular with a diameter of 0.6 meter (2 feet). Note that later on in the study Type1 was modified to to (3'x3') square shaped skylight with domed glazing values, since it is more common to use square-shaped skylighst opening. With 9 skylights of 2 feet diameter, the skylight to roof ratio for Type1 is 3.8%. The dimensions for the Type2 clerestory roof monitor glazing are 6.7 meters (22 feet) by 1 meter (3 feet). This glazing is on both sides of each monitor resulting in a SRR of 52% for this setting, where the total glazing area for three monitors sum up to 36 square meter (396 Square feet) and the total roof area is 69.7 square meters (750 square feet). The amount of glazing for Type3 is half the glazing for Type2 resulting in a total skylight to roof ratio (SRR) of 26%. (see Figures 3-7-3-9)

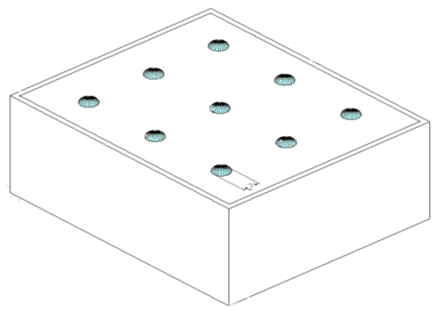


Figure 3-7: Type1 Glazing 1x1 Meter (3x3 Feet)

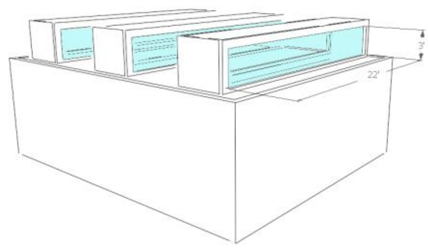


Figure 3-8: Type2 Glazing 6.7 X1 Meter (22x3 Feet) On Both Sides

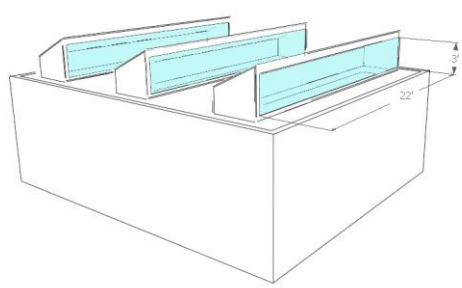


Figure 3-9: Type3 Glazing 6.7 X1 Meter (22x3 Feet)

3.4.2 Preliminary Study of Skylight Glazing Area

For the Type1 domed skylight, three configurations were examined to arrive at the final SFR discussed in the section bellow. SkyCalc, a Microsoft Excel-based tool, was preliminarily used for optimizing the domed skylight layout and numbers. SkyCalc uses typical hourly weather data to compute the energy impacts (lighting, cooling, and heating) in a given space that contains skylights, for a given city. It also predicts average hourly illumination, by month and time of day, for a given horizontal skylight design. Since SkyCalc only considers for horizontal skylight glazing orientation, only the Type1 skylight was examined using this tool. Phoenix, Arizona's weather file was used as a location that has approximate weather to that of Muscat, Oman.

First, several dome diameters were input into SkyCalc to determine the most efficient size for this room configuration. As seen in Figure 3-10, a 19.2% SFR domed skylight performs relatively poorly in comparison to a 4.9% SFR dome diameter.

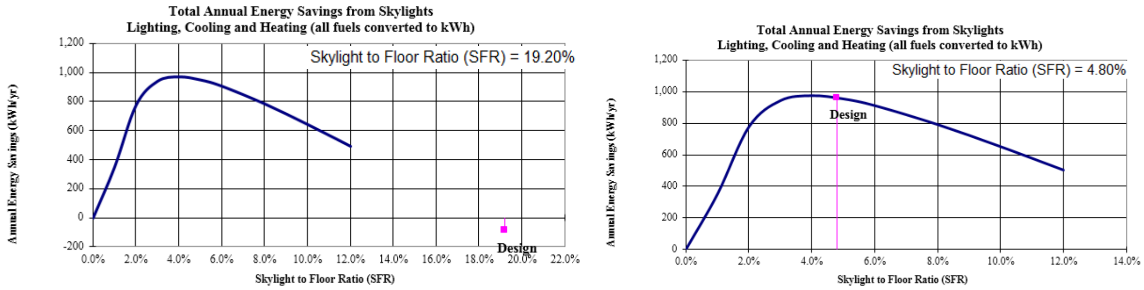


Figure 3-10: Type3 Comparing 4 Feet vs. 2 Feet Glazing Diameter Energy Performance for 9 Domed Skylights-SkyCalc

Next, three different skylight layouts having 6, 8, and 9 skylights, respectively, with SFR values of 3.2%, 4.3%, and 4.8% were studied for energy performance and savings . The results showed that annual energy savings for the three numbers were not that different; which amounted to approximately 1,000 kWh/year (see Figure3-11). Average daylight illumination values did not show significant differences between the three layouts (see Figure 3-12). It was also noted that introducing skylights aided in the energy savings for electric lighting that outweighed energy losses from cooling (see Table 3-13). After that, the layout of these numbers were arranged across the roof and a selection of 9 skylights was made since it would provide a more even distribution along the walls, where posters and blackboards would be located in a classroom (see Figure3-13).

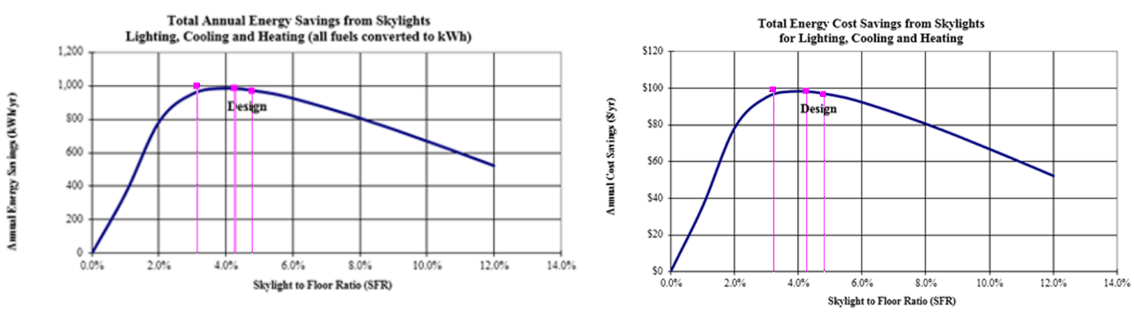


Figure 3-11: Type3 Comparing Number and Configuration Energy Performance –SkyCalc

Annual Itemized Energy Savings from Skylights (kWh/yr)

SFR	Lighting	Cooling	Heating	Total Energy
0.0%	0	0	0	0
1.0%	395	-26	0	369
2.0%	804	-2	0	802
3.0%	1,006	-34	0	973
4.0%	1,102	-93	0	1,009
5.0%	1,157	-164	0	993
6.0%	1,193	-239	0	954
8.0%	1,239	-397	0	842
10.0%	1,267	-559	0	708
12.0%	1,290	-724	0	566

Table 3-13: Type3 Comparing Number and Configuration Energy Performance –Skycalc

Dome Skylight   Effective Aperture = 0.83%,   Skylight to Floor Ratio (SFR) = 3.20%

Average daylight footcandles (fc)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	1	6	17	28	36	40	38	31	21	9	1	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	3	11	25	37	44	49	46	39	29	16	5	0	0	0	0	0	0
Mar	0	0	0	0	0	0	1	6	20	33	46	53	57	57	50	38	25	10	2	0	0	0	0	0
Apr	0	0	0	0	0	0	4	16	34	48	60	67	70	67	59	46	30	15	3	0	0	0	0	0
May	0	0	0	0	0	1	8	23	40	54	65	71	73	70	62	51	36	20	8	1	0	0	0	0
Jun	0	0	0	0	0	2	9	24	41	55	63	70	73	71	64	53	39	23	9	2	0	0	0	0
Jul	0	0	0	0	0	1	7	20	37	53	65	70	74	73	68	56	41	24	9	1	0	0	0	0
Aug	0	0	0	0	0	0	4	17	34	48	60	68	72	69	61	51	35	19	5	0	0	0	0	0
Sep	0	0	0	0	0	0	3	12	30	45	57	64	65	62	55	40	24	9	2	0	0	0	0	0
Oct	0	0	0	0	0	0	1	8	22	36	46	52	54	50	42	29	14	3	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	3	13	25	36	41	43	39	30	19	7	1	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	1	7	17	27	34	35	32	26	16	5	1	0	0	0	0	0	0

Design Illuminance = 40 fc

< 1 fc;   < 20 fc;   < 40 fc;   > 40 fc;

Dome Skylight   Effective Aperture = 1.11%,   Skylight to Floor Ratio (SFR) = 4.27%

Average daylight footcandles (fc)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	1	9	23	38	48	53	51	42	28	12	2	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	4	15	34	49	59	65	62	52	39	22	6	1	0	0	0	0	0
Mar	0	0	0	0	0	0	1	9	27	44	61	71	76	76	66	50	33	13	3	0	0	0	0	0
Apr	0	0	0	0	0	0	5	21	45	65	80	89	93	89	78	61	40	19	5	0	0	0	0	0
May	0	0	0	0	0	2	11	31	54	72	87	94	97	93	83	69	48	27	8	1	0	0	0	0
Jun	0	0	0	0	0	2	12	33	55	73	84	93	97	95	86	71	52	31	12	2	0	0	0	0
Jul	0	0	0	0	0	1	9	27	49	71	86	94	99	97	90	75	55	32	11	2	0	0	0	0
Aug	0	0	0	0	0	0	6	22	45	64	80	91	96	92	81	67	47	25	7	1	0	0	0	0
Sep	0	0	0	0	0	0	4	17	40	61	76	85	87	83	73	53	32	12	2	0	0	0	0	0
Oct	0	0	0	0	0	0	2	10	29	47	61	70	72	66	55	38	18	4	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	5	18	33	48	55	58	52	40	26	9	2	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	2	10	23	36	45	47	42	34	21	7	1	0	0	0	0	0	0

Design Illuminance = 40 fc

< 1 fc;   < 20 fc;   < 40 fc;   > 40 fc;

Dome Skylight   Effective Aperture = 1.24%,   Skylight to Floor Ratio (SFR) = 4.80%

Average daylight footcandles (fc)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	1	10	26	42	54	59	57	47	31	14	2	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	4	17	38	55	66	73	69	59	44	25	7	1	0	0	0	0	0
Mar	0	0	0	0	0	0	2	10	30	50	69	80	85	85	75	57	37	15	3	0	0	0	0	0
Apr	0	0	0	0	0	0	6	24	50	73	90	##	##	##	88	69	45	22	5	0	0	0	0	0
May	0	0	0	0	0	2	12	34	60	81	98	##	##	##	94	77	55	30	9	1	0	0	0	0
Jun	0	0	0	0	0	3	14	37	61	82	95	##	##	##	96	80	59	35	13	3	0	0	0	0
Jul	0	0	0	0	0	2	10	31	55	80	97	##	##	##	##	84	62	36	13	2	0	0	0	0
Aug	0	0	0	0	0	0	6	25	51	72	90	##	##	##	91	76	53	28	8	1	0	0	0	0
Sep	0	0	0	0	0	0	4	19	45	68	85	95	98	93	82	60	36	14	3	0	0	0	0	0
Oct	0	0	0	0	0	0	2	11	32	53	69	79	81	74	62	43	21	5	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	5	20	37	54	62	65	59	45	29	10	2	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	2	11	26	41	51	52	47	39	23	8	1	0	0	0	0	0	0

Design Illuminance = 40 fc

< 1 fc;   < 20 fc;   < 40 fc;   > 40 fc;

Figure 3-12: Type3 Average Illuminance for 3 Configurations–Skycalc

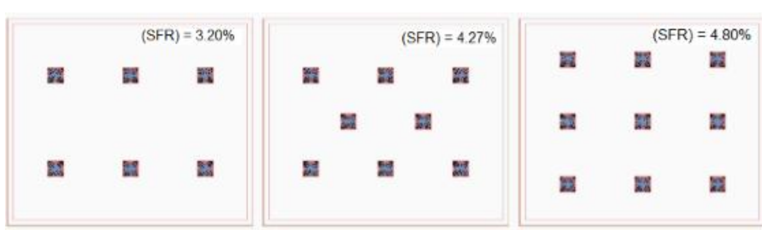


Figure 3-13: Type3 Comparing Number of Skylights and Configurations

3.4.3 Adjusting Toplighting Glazing Area and Shape

Modifications and adjustments were perfomed for each of Type1, 2, and 3 toplighting systems resulting in Type1a, 2a, and 3a (see Figure 3-14). Since it is more common to use square-shaped skylighst, the circular domed skylight was modified to (3'x3') sqaures for Type1 and (2'x2') squares for Type1a at the slab opening, using values from domed shaped skylights in the simulation. For the Type2 toplight, the shape of the clerestory was modified to where it contained only 2 glazing panes in comparison to 6 panels. This reduced the area to 12 square meter (132 square feet), which is 33% less glazing area than the original geometry, leading to Type2a. The glazing area for Type3 was modified to 50% less glazing leading to Type3a. The resulting heat gain and illuminance values are discussed in the results section of this report.

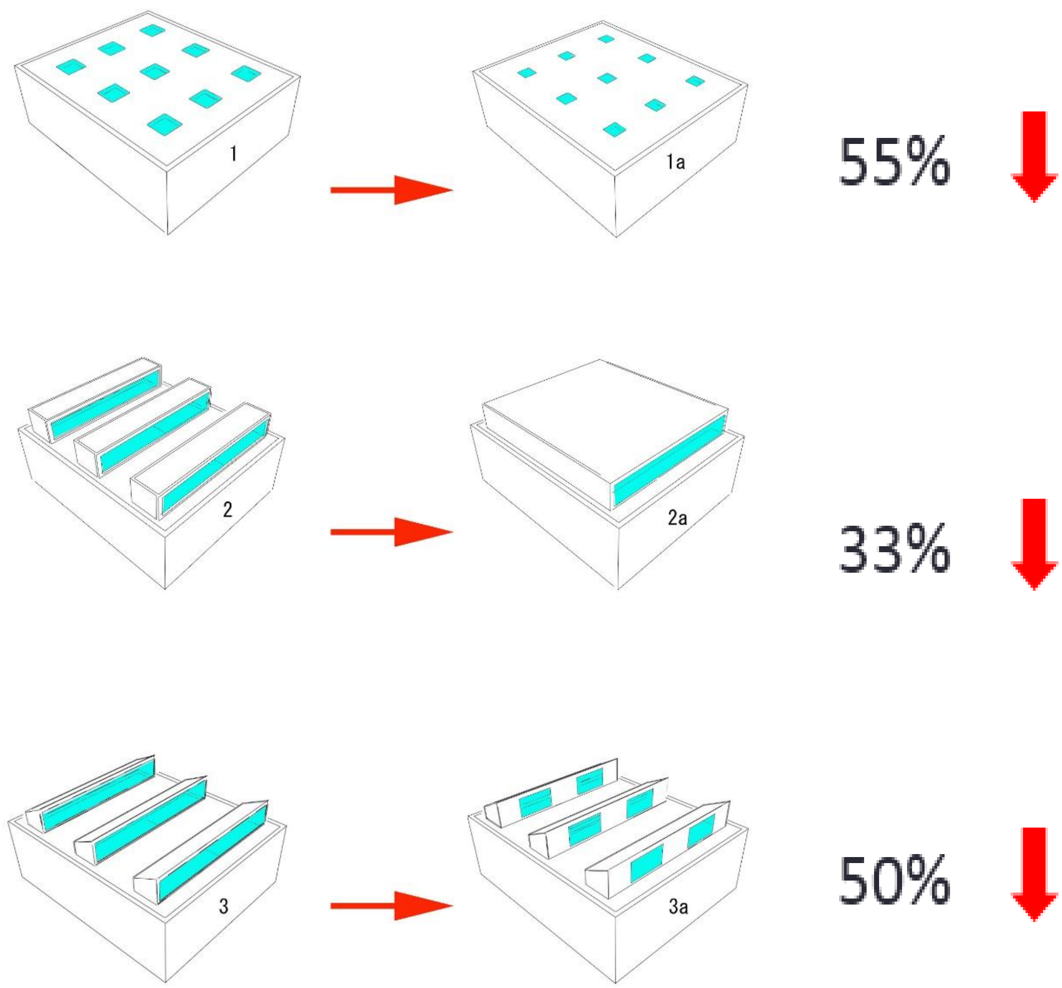


Figure 3-14: Type1, 2, And 3 and Modified Versions

3.5 Lighting Requirements

The design illumination level for a classroom as per IESNA 10th Edition Handbook is 400 lux for the horizontal level with a ratio of 2:1 for the average to minimum illuminance at work-plane level. As for the vertical plane, a standard of 150 lux on the surfaces is recommended. For daylight, usually up to 2000 lux (200 fc) of daylight illuminance for the interior is acceptable.

3.5.1 Lighting Fixtures

The general characteristics of the luminaire to be used for evaluation of energy savings is a ceiling mounted semi-direct fluorescent fixture with a dimmable ballast. For this research there would be only one zone of luminaires that is dimmed. Two different luminaires were chosen (see Figures 3-15- 3-16). Eight units of Fixture A are used for each classroom setting with Type2 and Type3 roof monitors. Twelve units of Fixture B are used for Type1 domed skylights Fixture A consists of two 32-watt T8 linear Fluorescent lamp and Fixture B of a three 32-watt T8 linear Fluorescent lamp. Both fixtures have lumen output of 2,850 per lamp.

As per ASHRAE 90.1-2013, the Lighting Power Density (LPD) requirement for a classroom, using the space by space method, is 1.24 W/ft^2. For a 750 ft^2 classroom, the maximum wattage allowed with a LPD of 1.24 is 930 watts. Considering the ballast factor of 88% for a 32 watt lamp, the total wattage for both Fixture A and B layout is 672 watts (8 units x 3 lamps x 28 Watts) and (12 units x 2 lamps x 28 Watts) with an LPD of 0.83 which is below the allowed maximum per ASHRAE 90.1-2013 requirements. When the electrical lights are constantly on all day for 10 hours, 6720 watt-hours are consumed per day (6.72 kWh). For a month this adds up to 201.6 kWh. If this usage is assumed to be constant for 7 days a week, it results in a total of 2,419 kWh yearly of electrical lighting energy consumption. Using a dimming system should result in the total reduction of electrical light energy consumption.

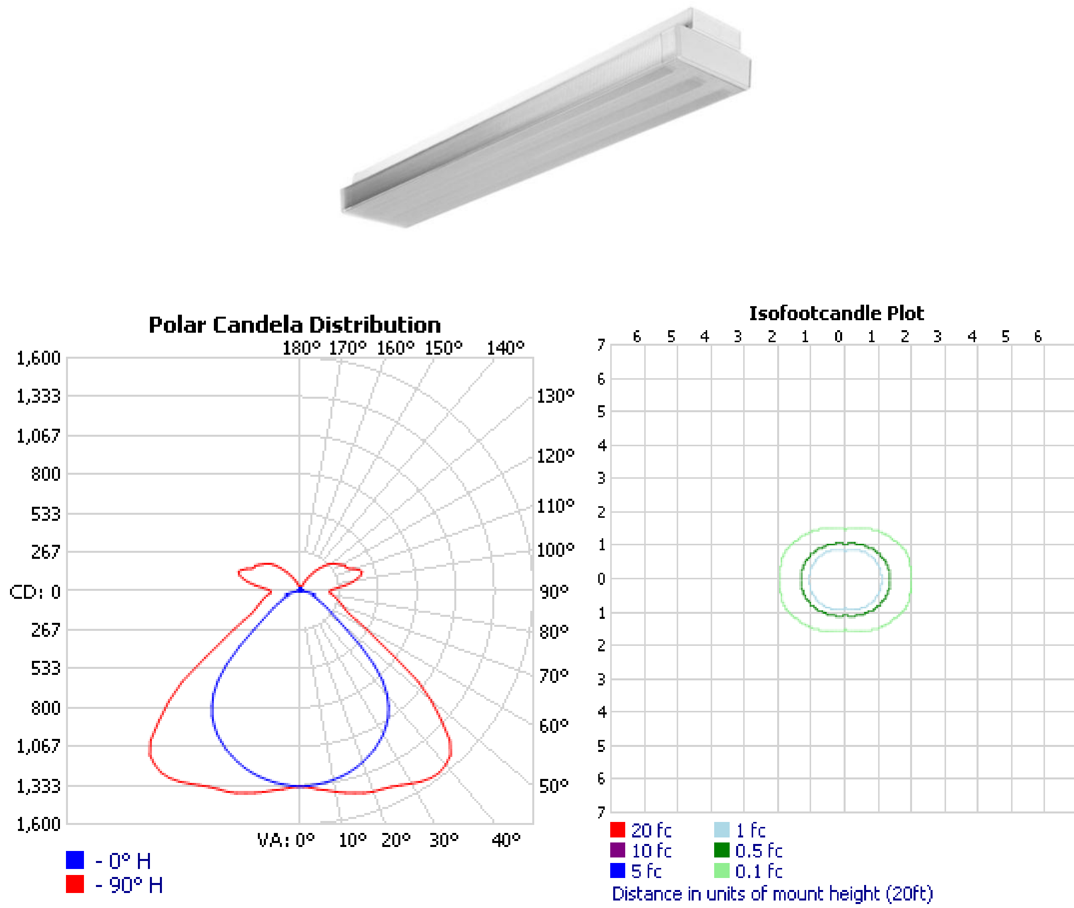


Figure 3-15: Fixture A

Source: Lithonia Lighting

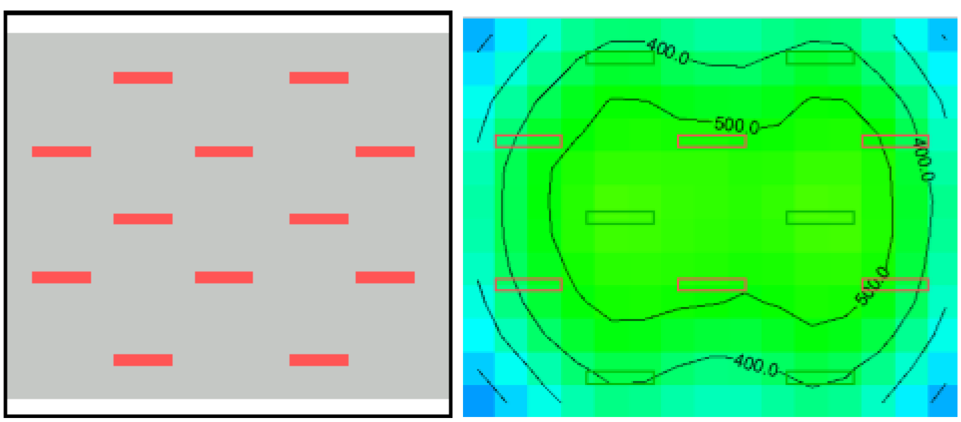


Figure 3-16: Fixture a Layout (DAYSIMps)

Source: DAYSIMps

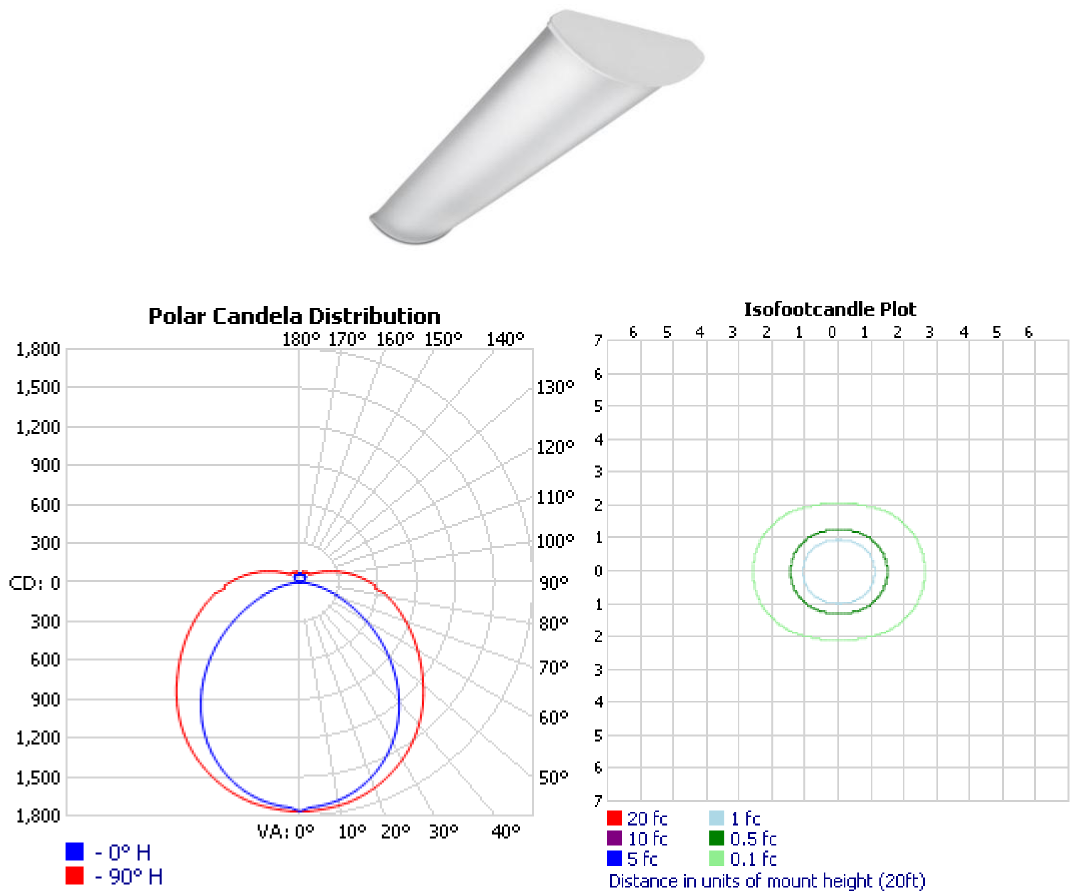


Figure 3-17: Fixture B

Source: Lithonia Lighting

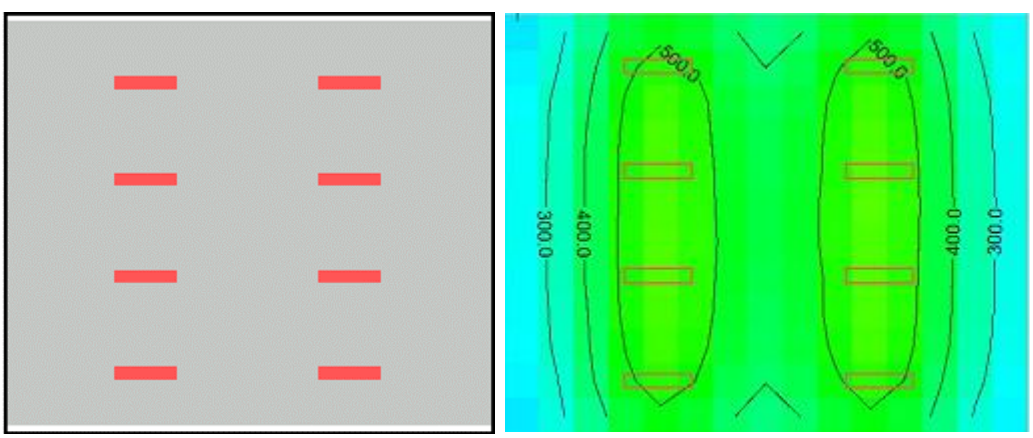


Figure 3-18: Fixture B Layout

Source: DAYSIMps

3.5.2 Dimming Controls

The dimming system will consist of a closed-loop proportional (sliding set-point) dimming algorithm. For spatial illumination detection a cosine response 120-degree cutoff sensor was applied at ceiling level. The dimming system for the T8 lamps has a maximum ballast factor of 0.88 and a minimum ballast factor of 0.05, with a maximum and minimum input power of 59, and 14 watts respectively. (see Table 3-15)

QUICKTRONIC® High Efficiency Full Range Dimming PROStart® Systems

32 T8 POWERSENSE® T8 Dimming Systems (120-277V) — Full Range Dimming — NEMA Premium

Item Number	OSRAM SYLVANIA Description		Input Current (AMPS)	Lamp Type	Rated Lumens (lm)	No. of Lamps	Ballast Factor (BF)	System Lumens	Mean Lumens	Input Power (W)	System Efficacy[2] (lm/W)	BEF[1]
NORMAL BALLAST FACTOR (100% through 5%)												
50705	QTP 1x32T8/UNV DIM-TC	(@100%)	0.27/0.12	F032/XPS	3100	1	0.88	2730	2565	30	91	2.93
		(@5%)				1	0.05	155	145	8		
50707	QTP 2x32T8/UNV DIM-TC	(@100%)	0.54/0.24	F032/XPS	3100	2	0.88	5455	5130	59/57	92/96	1.54
		(@5%)				2	0.05	310	290	14		
50714	QTP 3x32T8/UNV DIM-TCL	(@100%)	0.73/0.30	F032/XPS	3100	3	0.88	8185	7695	87/84	94/97	1.05
		(@5%)				3	0.05	465	435	20		
50716	QTP 4x32T8/UNV DIM-TCL	(@100%)	0.96/0.40	F032/XPS	3100	4	0.88	10,910	10,255	114/110	96/99	0.80
		(@5%)				4	0.05	620	585	27		

T8 POWERSENSE® models above also operate F025, F017, F030/SS, F028/SS, F025/SS, FB032, FB031, FB024, FB016. See full specifications for details and controls.

Table 3-14: 32 W T8 Lamp Dimming Ballast

Source: Osram Sylvania

3.5.3 Glare

High contrast in luminance levels within the human field of vision causes glare. Glare sensitivity varies from one person to another therefore lighting conditions are typically accounted by their probability or potential. Depending on the person's location in a room and view direction, glare potential may differ. Glare could be caused for different reasons which include: any direct light source with no diffusion for direct the sunlight, reflections from specular surfaces, surfaces that are adjacent yet differ significantly in luminance levels, such as a bright light Diffused from translucent fenestration in a dim room. Considering these causes of glare, the choice of a direct fixture may result in high contrast produced between the ceiling and skylight causing glare. Therefore, direct/indirect fixtures may be desirable in rooftop fenestration settings, even though typical schools in Oman use direct mounted fixtures. Shading may also be required depending on glazing orientation, time of day, and seasonal variations to block direct sunlight. IES-VE considers six different Glare indices:

The Guth Visual Probability
CIE Glare Index
Unified Glare Rating
Daylight glare index
BRS Glare Rating
Guth Disability Glare

Since this study is focused on glare resulting from the sun, Daylight Glare Index (DGI) was the metric chosen to evaluate glare, where it considers glare from large daylight apertures and the sky. The other indices were mainly designed to detect glare from luminaire sources. For the DGI, a value of 31 or greater is considered a source of glare potential and intolerable. On the opposite end, a value of 18 and less is considered barely noticeable by the human eye.

4 RESULTS AND ANALYSIS

And not by Eastern windows only, when daylight comes, comes in the light, In front the sun climbs slow, how slowly, But Westward, look, the land is bright. Arthur Hugh Clough

4.1 Introduction

This section of the report breaks down and analyzes the outcomes resulting from the different model geometries, orientations, glazing transmittance values, and thermal properties, such as the solar heat gain coefficient. The section also includes results outcome of the sky clearness analyzed from the weather data of Muscat-Oman. Furthermore, the investigation focuses on the lighting aspects of the study, then moves into the heat gain aspect, after that compares the energy impacts of each scenario, and finally concludes with the glare potential analysis for selected scenes.

The metrics that are compared for the lighting portion of this study are: DA, sDA, and UDI. These metrics are useful because they take into account the dynamic behavior of daylight in a space throughout the year. DA is one of the first annual daylight metrics created in 1989 and then improved by Christoph Reinhart (Reinhart, Mardaljevic, & Roger, 2006). Daylight Autonomy (DA) measures the percentage of occupied hours at a certain grid point where the illumination level exceeds a specific target. It is correlated to times where electric light can be turned off. Continuous Daylight Autonomy is similar to DA with the exception that it awards partial credit for times where a portion of the target value is met by daylight. For example, if the target illuminance is set to 400 lux, and 200 lux is picked up by the sensor at a certain grid point, half of a credit-hour is received at this time. The cDA is useful when dimming is used and where daylight falls below the minimum threshold. Spatial Daylight Autonomy measures the percentage of space area that achieves a certain target illuminance at least 50% of the occupied hours. Useful Daylight Autonomy UDI is a metric that measures the occupied time between two illuminance values. Additionally, UDI ranges also provides the percentage of time below or above a specified threshold to quantify hours with low and extreme daylight levels.

The metric that was used for the cooling and lighting loads is the kilowatt hour (kWh). kWh is a unit measure of energy similar to Btu and Joules, in contrast to kW which is a measure of power or the rate of energy that is used, similar to Joules per second or Watts. In order to accurately calculate energy savings, kWh measures need to be compared for the same period of time in each situation. For example kWh for a three month consumption period cannot be compared to kWh for annual consumption.

4.2 Weather Data Results

The examination of the weather file indicated that not only does the constant change in the sun's position relative to building orientation and location present a challenge, but also the unpredictability of the cloud cover distribution and change in surrounding environment complicates design for daylight. When analyzing the irradiance both from sun and sky from the EPW file data, it was noted that the irradiance from the sun was less in summer than during the winter time. It was also noted that the irradiance from the sky was inversely correlated to that of the sun where it increased during the summer and decreased during the winter (see Figure 4-1).

Using the Perez sky cleanness index, as indicated in the methods section, it was determined that approximately 77% of the time the sky was classified as partly cloudy, 10% clear, and 13% cloudy (see Figure 4-2). This obscure finding may have been due to having higher humidity levels during the summer that absorb and scatter the sunlight. Also, the possibility of dust particles present in the air that could disperse the light through the atmosphere resulting in a more Diffuse irradiance condition. Note that the city of Muscat is subject to wind coming from the North-West during the spring and summer, called the Shamal winds. These winds peak at daytime and carry dust through the air and decrease during the nighttime (Ali, 1994).

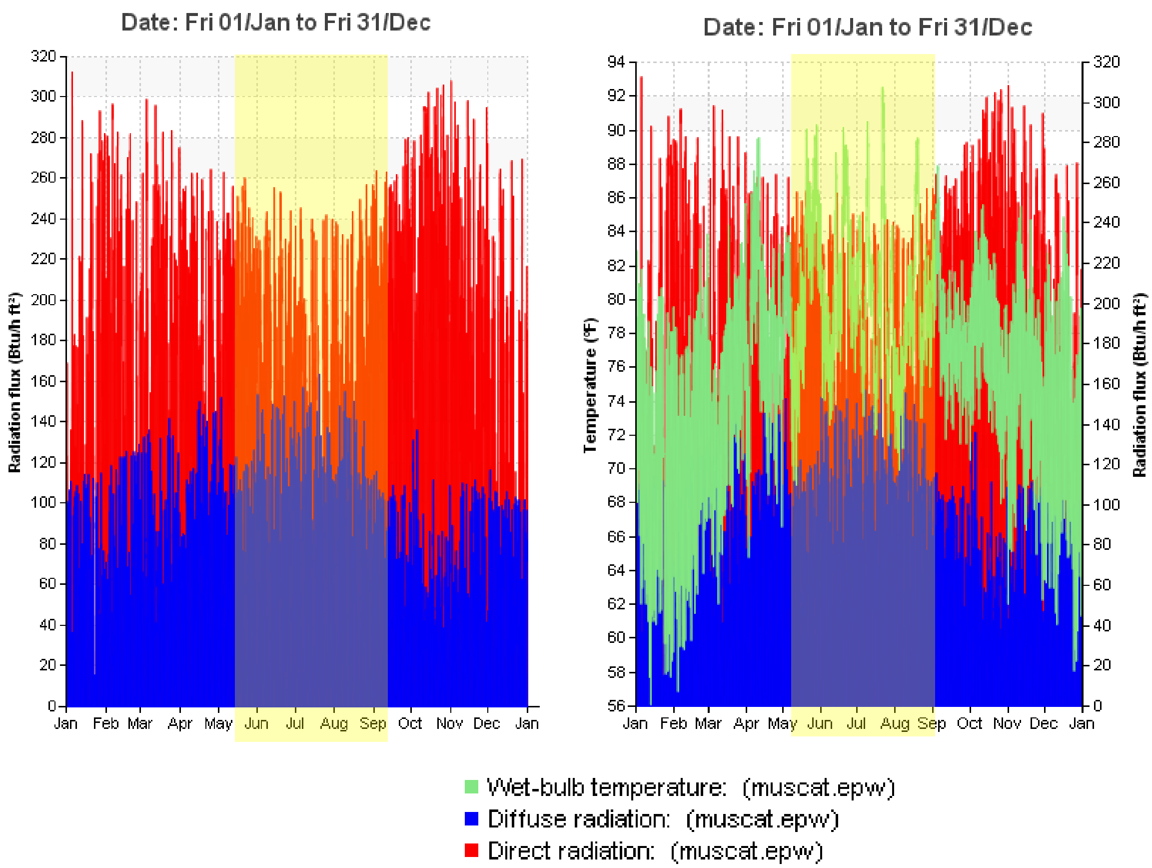


Figure 4-1: Solar Irradiance-Muscat (IES-VE)

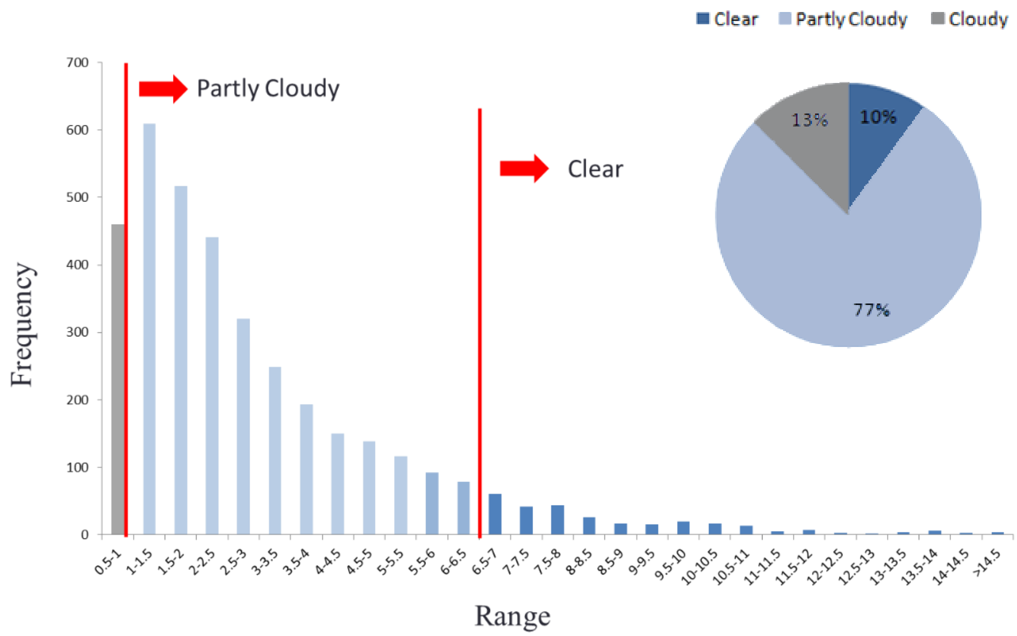


Figure 4-2: Counts of Sky Clearness for Muscat-Oman

4.3 Illumination Results and Analysis

4.3.1 Daylight Autonomy

DA for Types 1, 2, and 3 were investigated. For DA_{400} most of the grid points fell under 80-100% DA_{400}. This meant that the target illuminance of 400 lux was met and exceeded most of the time during the year for these conditions. Consequently, DA_{1000} was examined to see the percentage of time that the illuminance was exceeded at this target for each grid point per year (see Figures 4-14). A percentage range of where these points fell was determined using the illuminance file output from $DAYSIM_{PS}$ and were calculated in an Excel sheet. The cumulative frequency of these ranges were then calculated to determine the percent of room area meeting a certain target DA.

For Type1 Diffuse, 100% of the room floor area was covered at 55% $DA_{1000.}$ This meant that 100% of the floor area reached the target value of 1000 lux at least 55% of the time. This floor area coverage decreased as the DA percentage increased above 55%. For Type2 clear the percent of DA_{1000} increased where approximately 65% DA gave 100% coverage for both orientations. For the Diffuse glazing of Type2 this value went back down to 55% for 100% of floor area. For Type3 clear, coverage was achieved at only a DA 25%, with South orientation having the highest area coverage as DA percentage increased. When the glazing was changed into Diffuse for Type3, a 100% room coverage was met at a DA percent of only 15%. Note that the North orientation had the lowest room area percent coverage, since the glazing is in shade for nearly the entire year (see Figures 4-3 to 4-6).

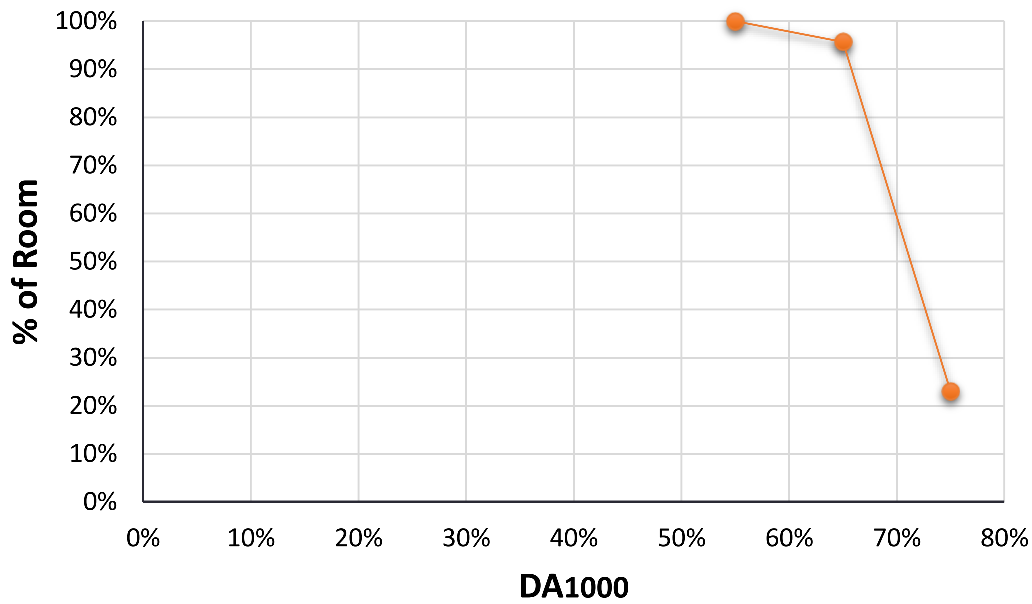


Figure 4-3: Type 1 Diffuse Tvis53: % Of Room Area Meeting a Specified Da

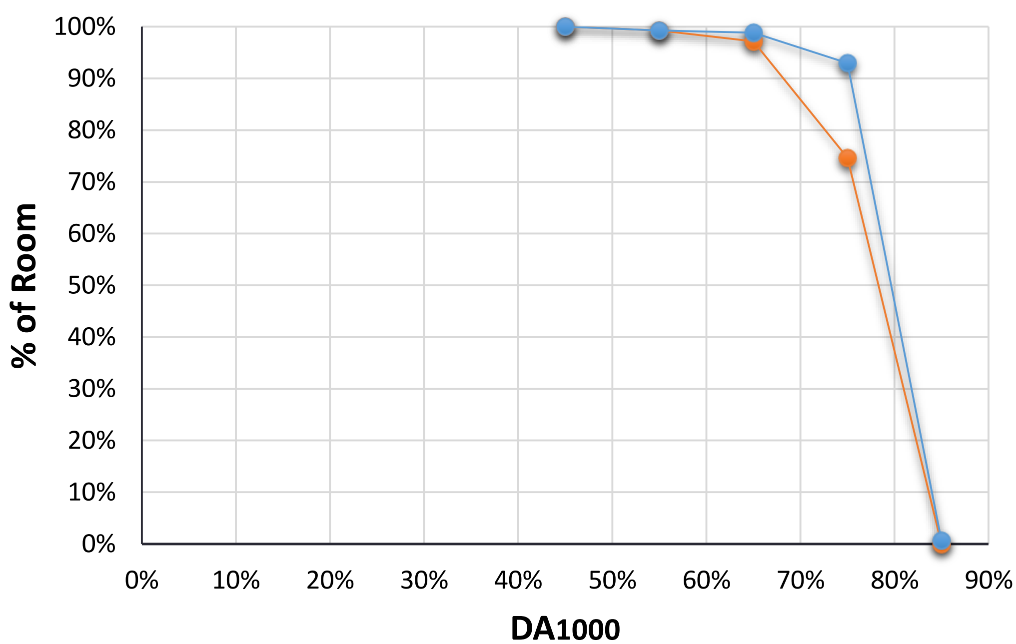


Figure 4-4: Type 2 Clear Tvis52: % of Room Area Meeting a Specified DA

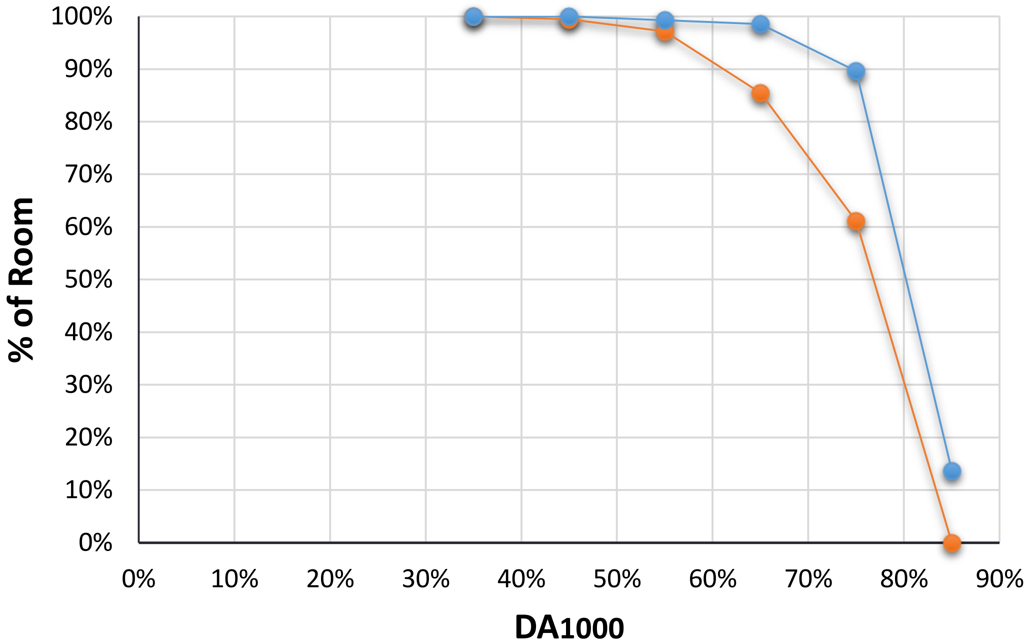


Figure 4-5: Type 2 Diffuse Tvis32: % of Room Area Meeting a Specified DA

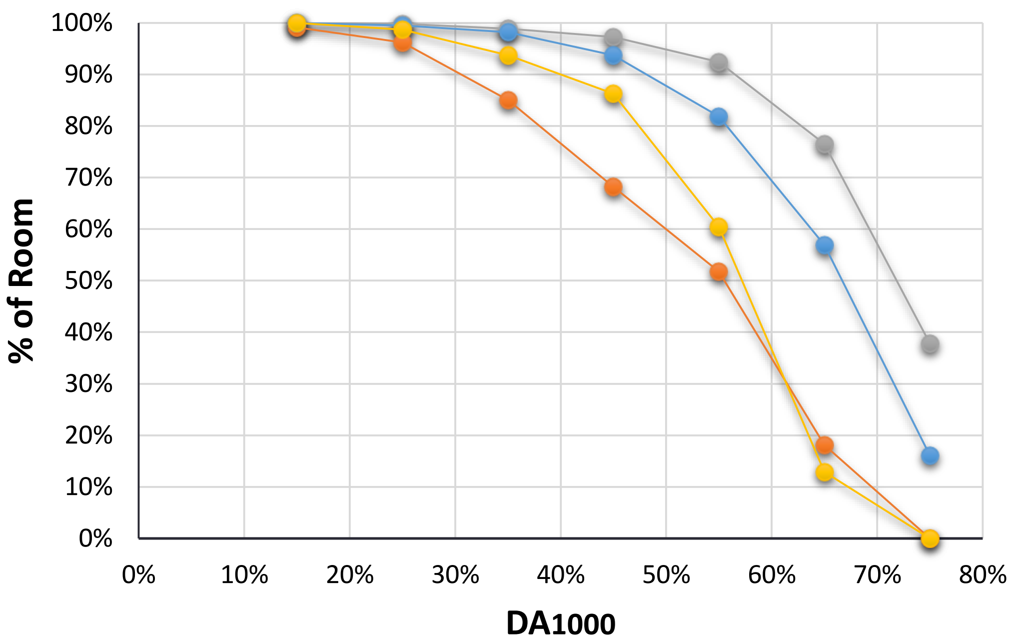


Figure 4-6: Type 3 Clear Tvis52: % of Room Area Meeting a Specified DA

DA for Types 1a, 2a, and 3a were also investigated. The DA_{1000} values for were low for most of the models therefore DA_{400} was investigated for the scenarios with less glazing area (see Figure 4-16). For Type1a Diffuse, 100% of the room floor area was covered at 55% DA_{400}. This meant that 100% of the floor area reached the target value of 400 lux at least 55% of the time. This floor area coverage decreased as the DA percentage increased above 55%. For Type2a clear the percent of DA_{400} decreased where approximately 45% DA gave 100% coverage for both orientations. For the Diffuse glazing of Type2a this value remained at 45% for 100% of floor area with the exception of a further decrease in the NS orientation as DA increased. For Type3 clear, coverage was achieved at only a DA 25%, with South orientation having the highest area coverage as DA percentage increased and North having the lowest value. When the glazing was changed into Diffuse for Type3, a 100% room coverage was met at a DA percent of only 15%. Similarly, the North orientation had the lowest room area percent coverage (see Figures 4-7 to 4-11).

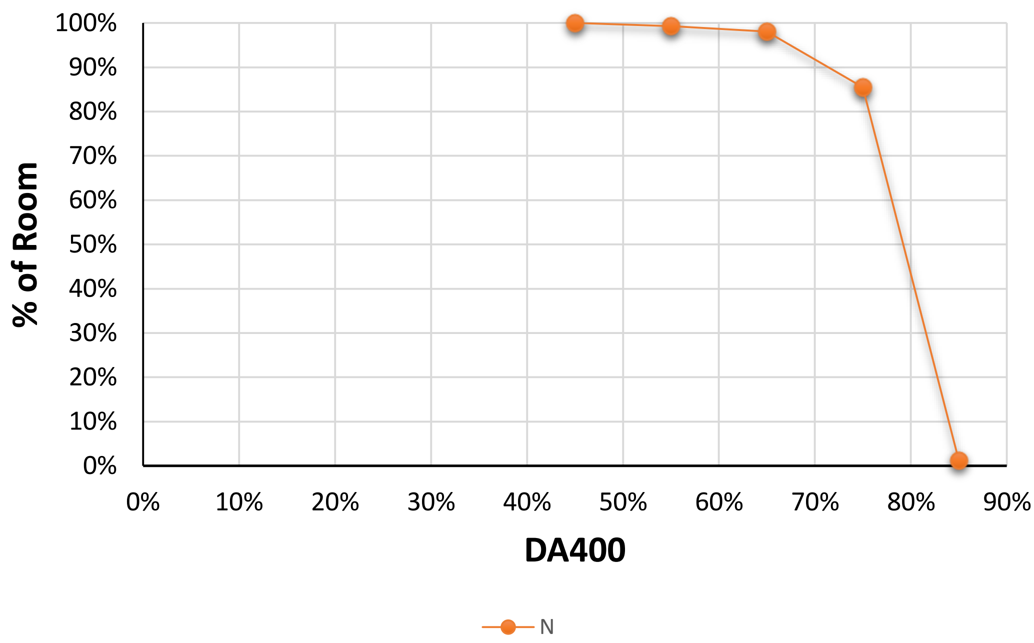


Figure 4-7: Type 1a Diffuse Tvis53: % Of Room Area Meeting a Specified Da

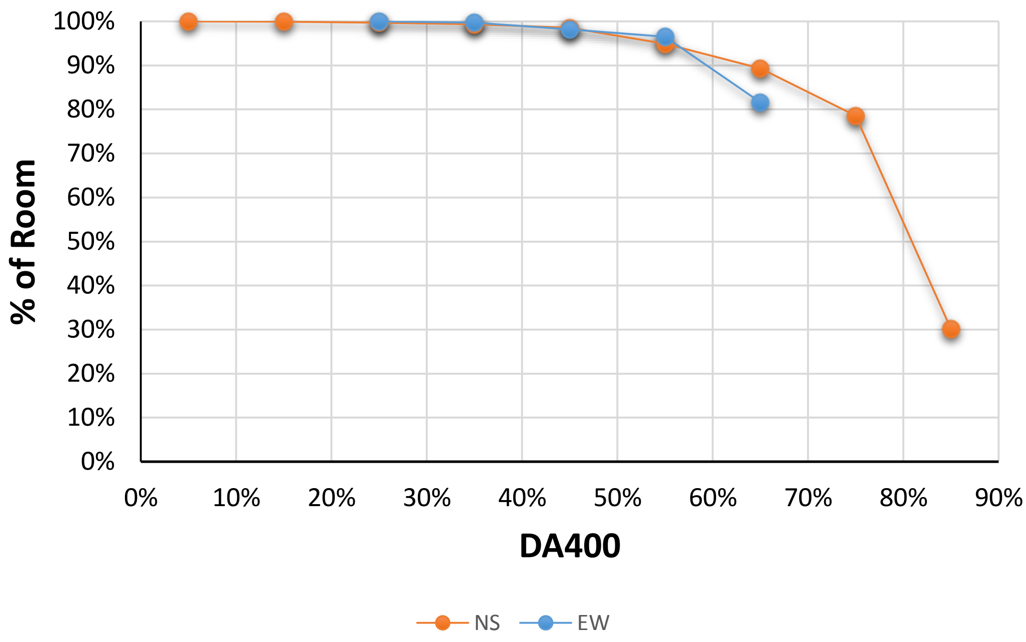


Figure 4-8: Type 2a Clear Tvis52: % of Room Area Meeting a Specified DA

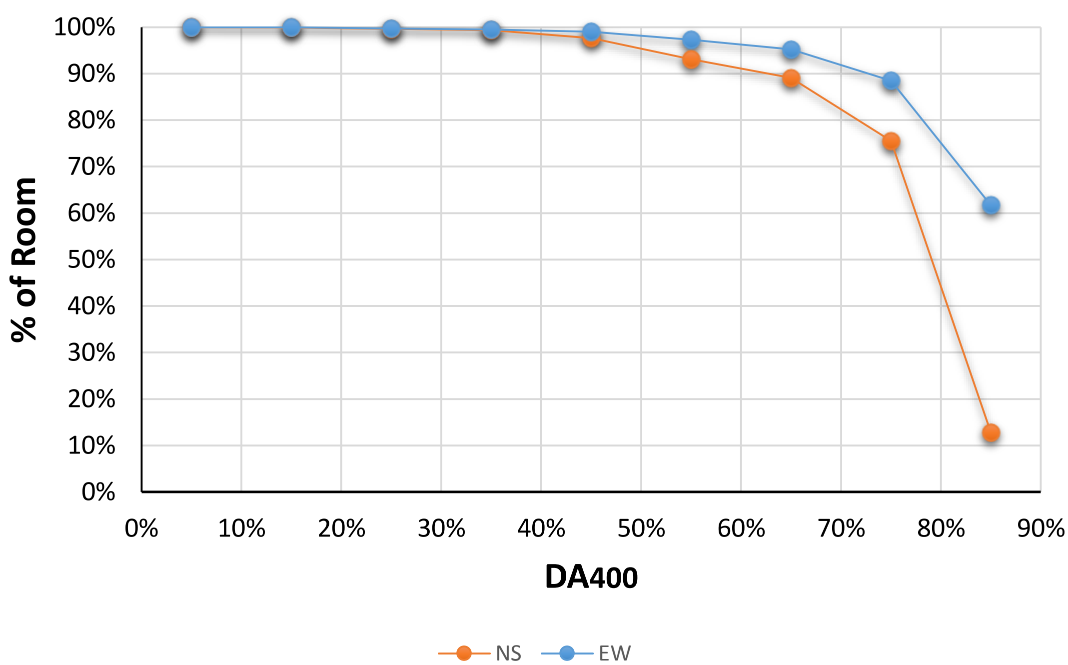


Figure 4-9: Type 2a Diffuse Tvis32: % Of Room Area Meeting a Specified DA

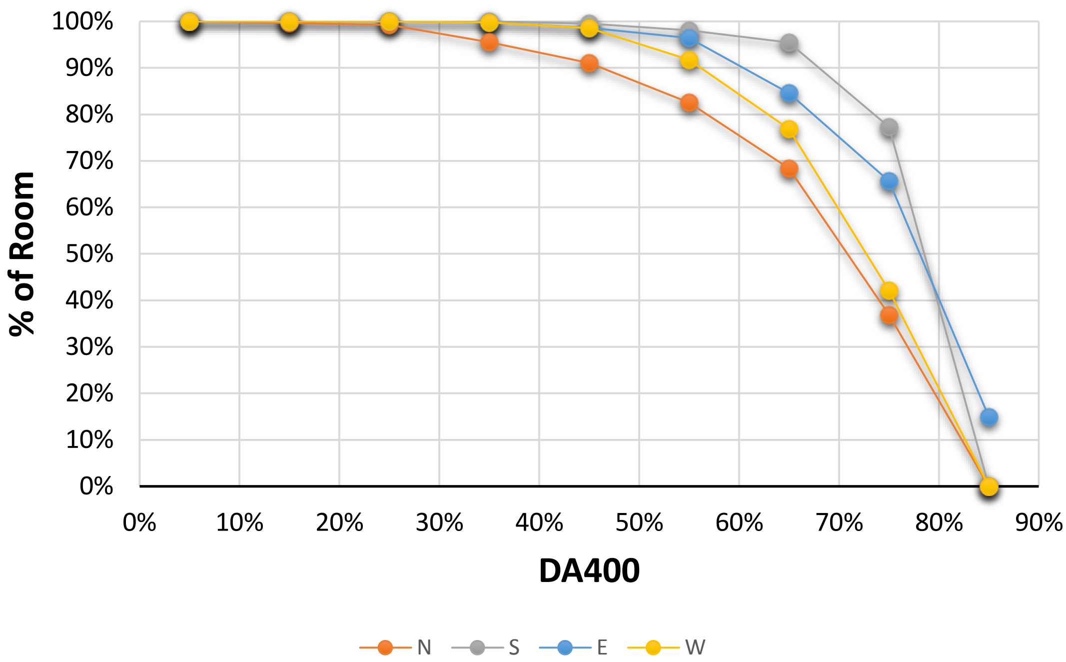


Figure 4-10: Type 3a Clear Tvis52: % of Room Area Meeting a Specified DA

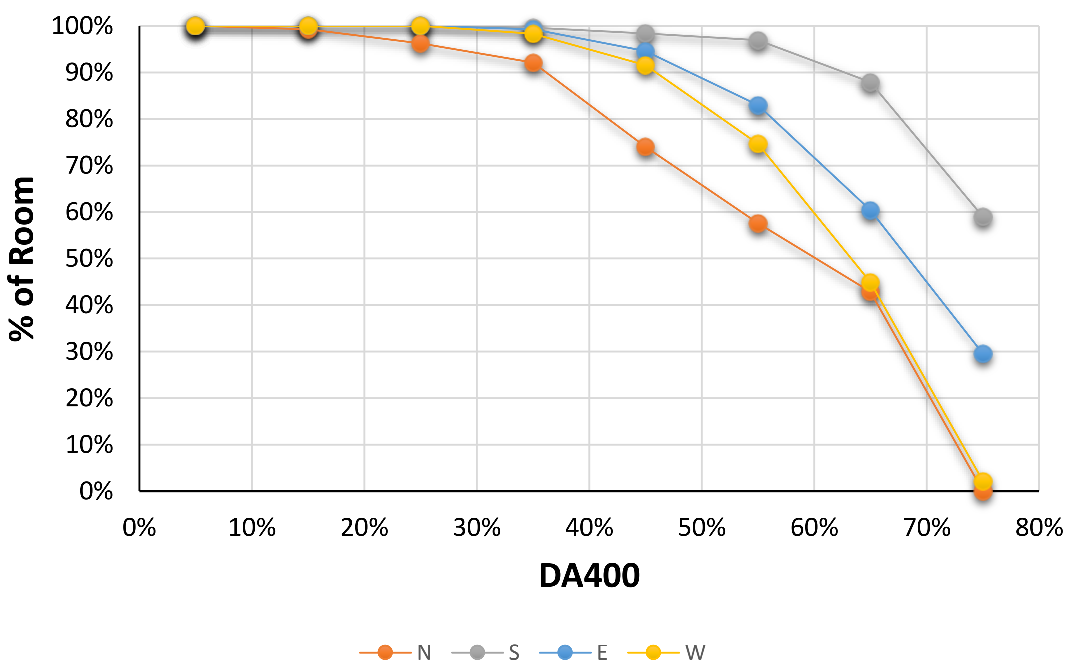


Figure 4-11: Type 3a Diffuse Tvis32: % of Room Area Meeting a Specified DA

4.3.2 Spatial Daylight Autonomy

It was noted that all large glazing area Types (1, 2, and 3) for different orientations yielded 100% $sDA_{400, 50\%}$. This means that the target illuminance is met over100% of the floor space, for at least 50% of the occupied schedule from 6 am - 4 pm. Next, $sDA_{1000, 50\%}$ was studied to examine the percentage area coverage at a higher target (see Figure 4-16). For $sDA_{1000, 50\%,}$ it was observed that most of the scenarios had an sDA that exceeded 50% of the room area. The exceptions were Type3 Clear North, and Type3 Diffuse North. Since Type3 has glazing only on one side, the low sDA value for the North orientation is most likely due to light entering the space only from diffuse and reflected light from the ground, roof and sky (see Figure 4-12).

For modified geometries and glazing areas of Types 1a, 2a, and 3a $sDA_{400, 50\%}$ did not cover 100% of the floor area for all cases (see Figure 4-13). Since the modified models contain less glazing, $sDA_{400, 50\%}$ was analyzed for this case. All cases exceeded 50% of floor area with the expectation of Type3a Diffuse. In this case, Type3a North, clear glass provides a more appropriate glazing, since it admits more Diffused and reflected light.

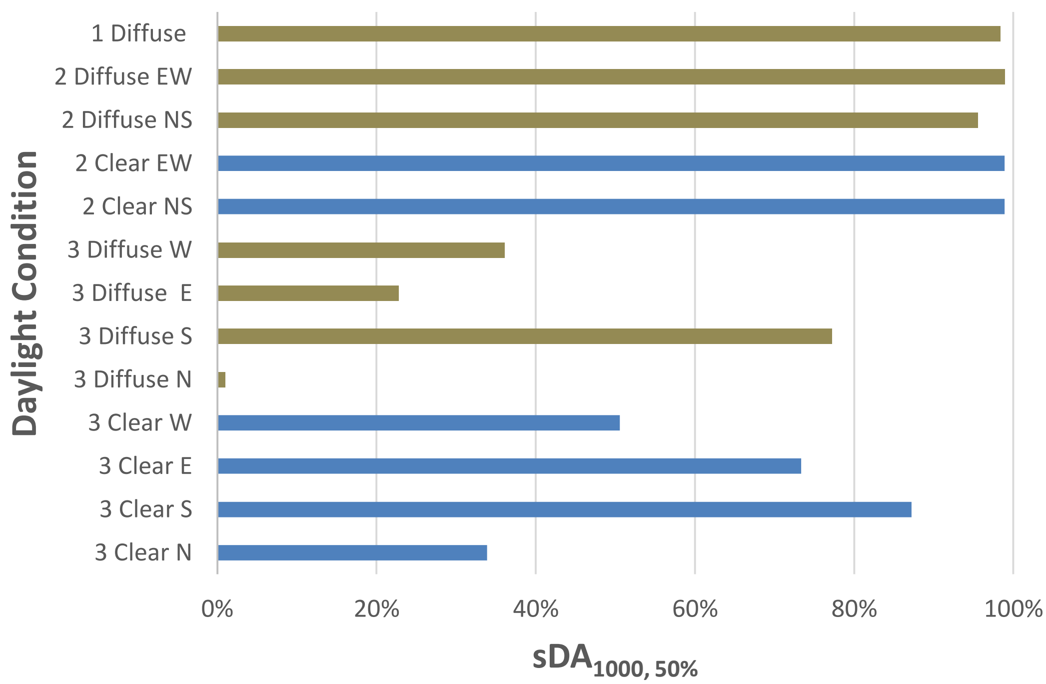


Figure 4-12: SDA $_{1000, 50\%}$ for Type1, Type2, Type3, and all orientations, clear and diffuse glazing materials

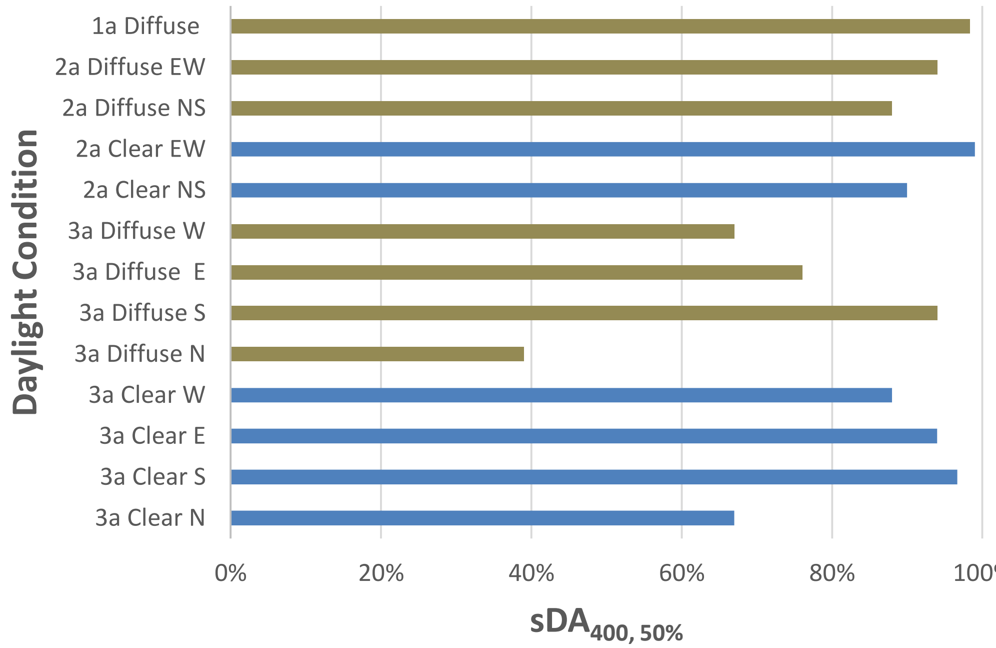


Figure 4-13: SDA $_{400,\ 50\%}$ for Type1a, Type2a, Type3a, and all orientations, clear and diffuse glazing materials

4.3.3 Useful Daylight Autonomy

Just because a space meets 100% sDA for a specified occupancy condition does not necessary mean that it is a well-designed daylit area. Similarly, the percent of time a certain grid point meets or exceeds target illuminance does not guarantee quality illuminance. Exceeding target illuminance may result in having too much light is the space which may cause glare and unwanted heat gain, therefore UDI was analyzed to detect hours with extreme lows and highs in illuminance levels. Two parts for UDI were studied. The first part was for UDI $_{400\text{-}2000}$ to determine the percentage of hours when useful illuminance between 400 to 2000 lux was detected. The second part was for UDI $_{2000+}$ where hours with illuminance at 2000 lux or above are tallied for the purpose of quantifying excessive daylight conditions that may cause glare or discomfort.

For the large glazing area Types, it was noted that Type1, 2 East-West Clear and Diffuse, 2 North-South Clear and Diffuse, 3 South Clear and Diffuse had illuminance hour percentages that fell between the 30%- 60% of the hour range (see Figure 4-15). These values may cause discomfort to the students in the classrooms, where hot spots occur. Also high luminance values resulting from extreme daylight entering the space may cause discomfort glare for the eyes, especially facing the vertical glazing surfaces.

When examining the UDI $_{400\text{-}2000}$ and UDI $_{2000+}$ for the modified model Types 1a, 2a, and 3a, it was noted that all of models had high hour percentages within the 400 and 2000 lux UDI range, but varied in their distribution intensity on the floor plane depending on the glazing size and room orientation (see Figure 4-23. Furthermore, there were very few hours falling above 2000 lux within the grid area, since the glazing area was reduced for each Type (see Figure 4-17).

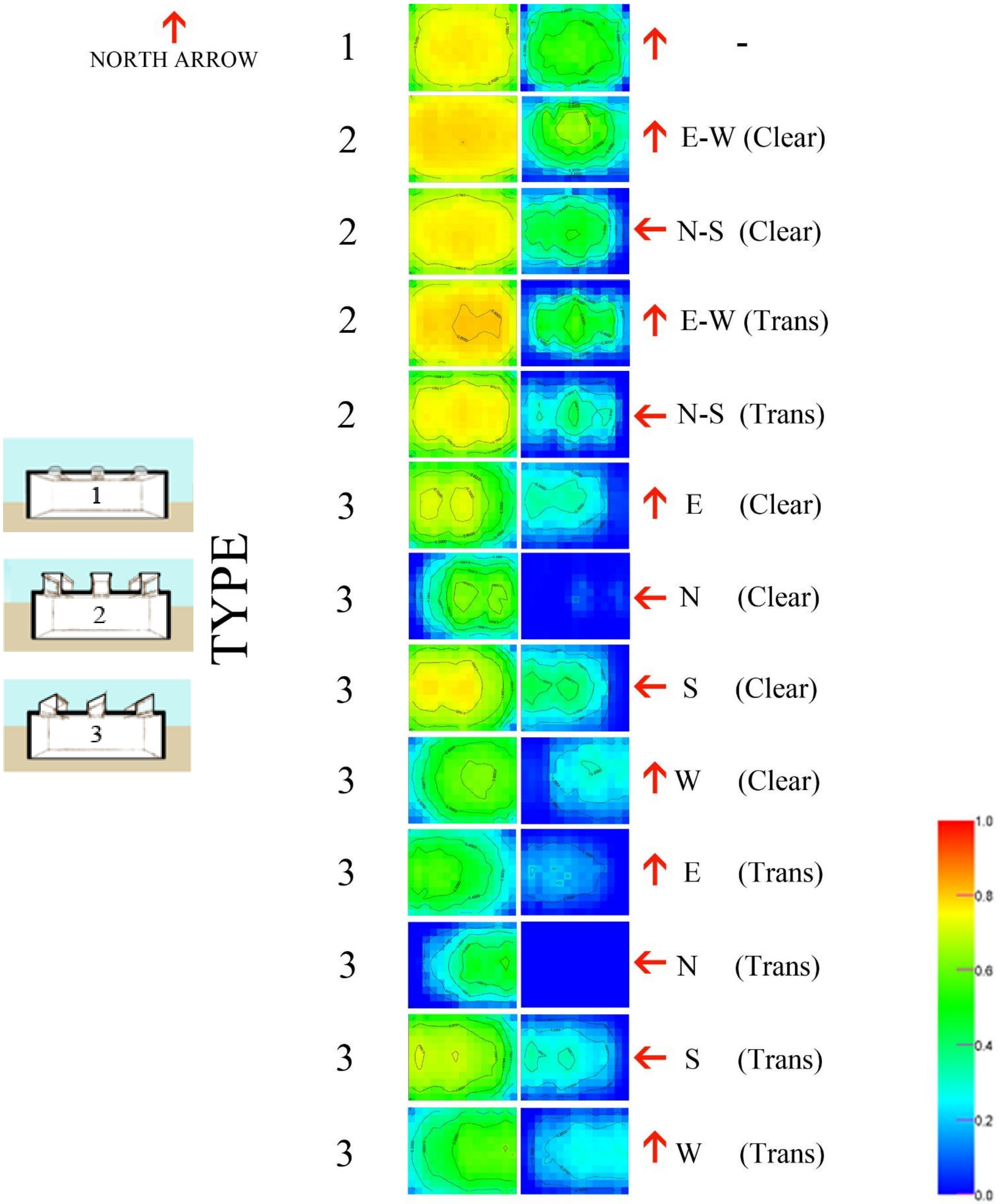


Figure 4-14: DA 1000 (Left), DA 2000 (Right) For Different Types and Orientations

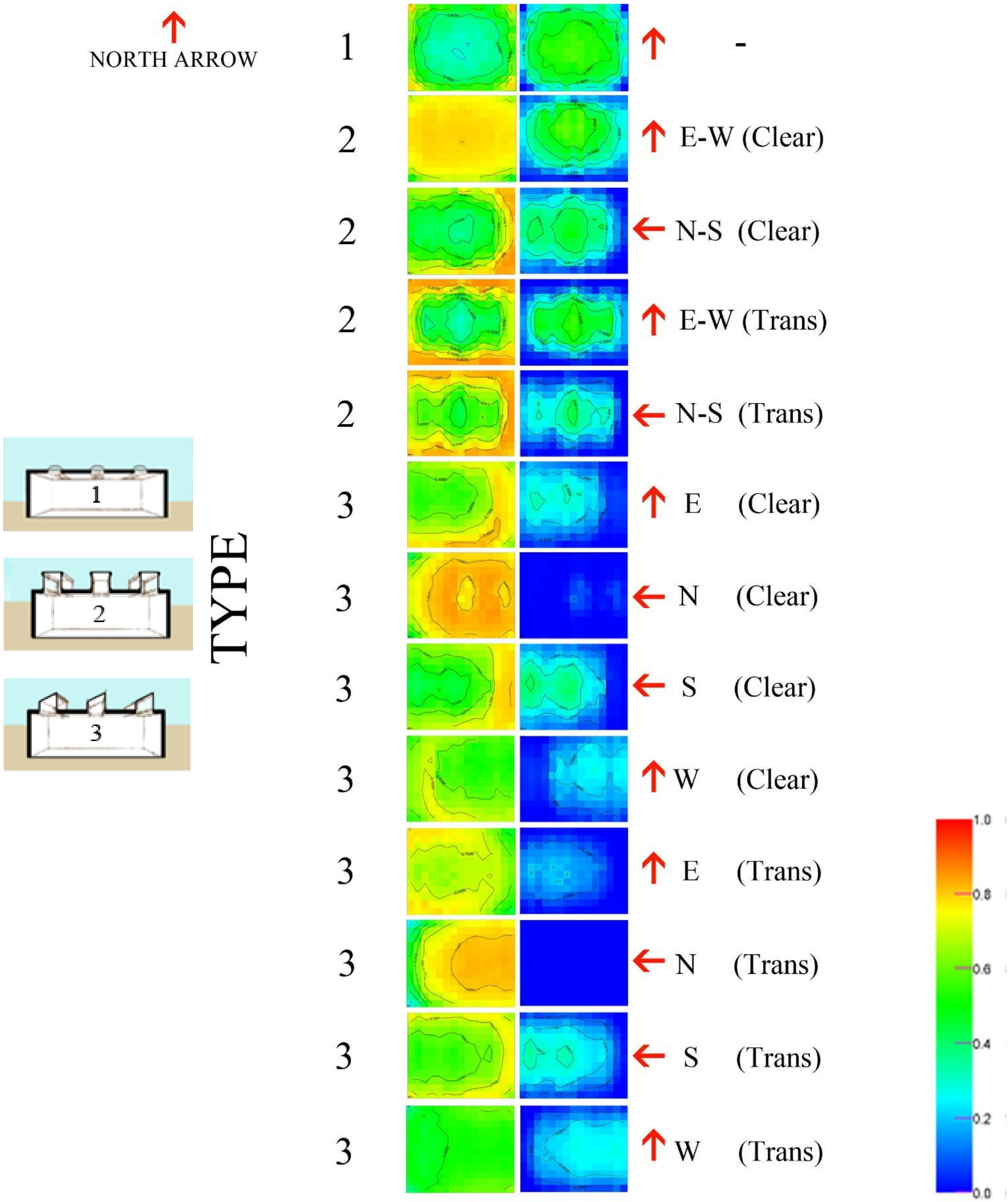


Figure 4-15: UDI 400-2000 (Left), UDI 2000+ (Right) For Different Types and Orientations

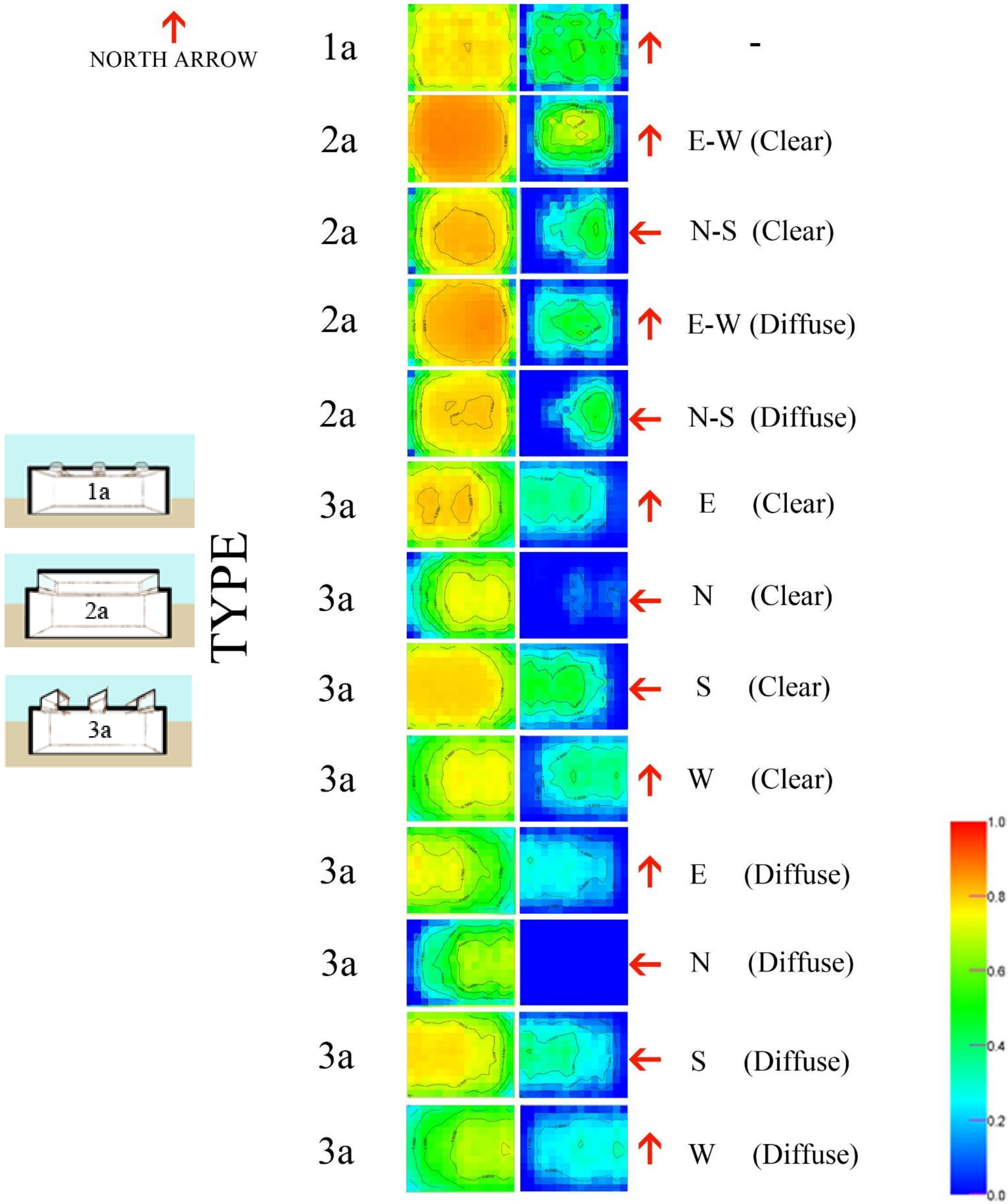


Figure 4-16: DA 400 (Left), DA 1000 (Right) For Different Types and Orientations

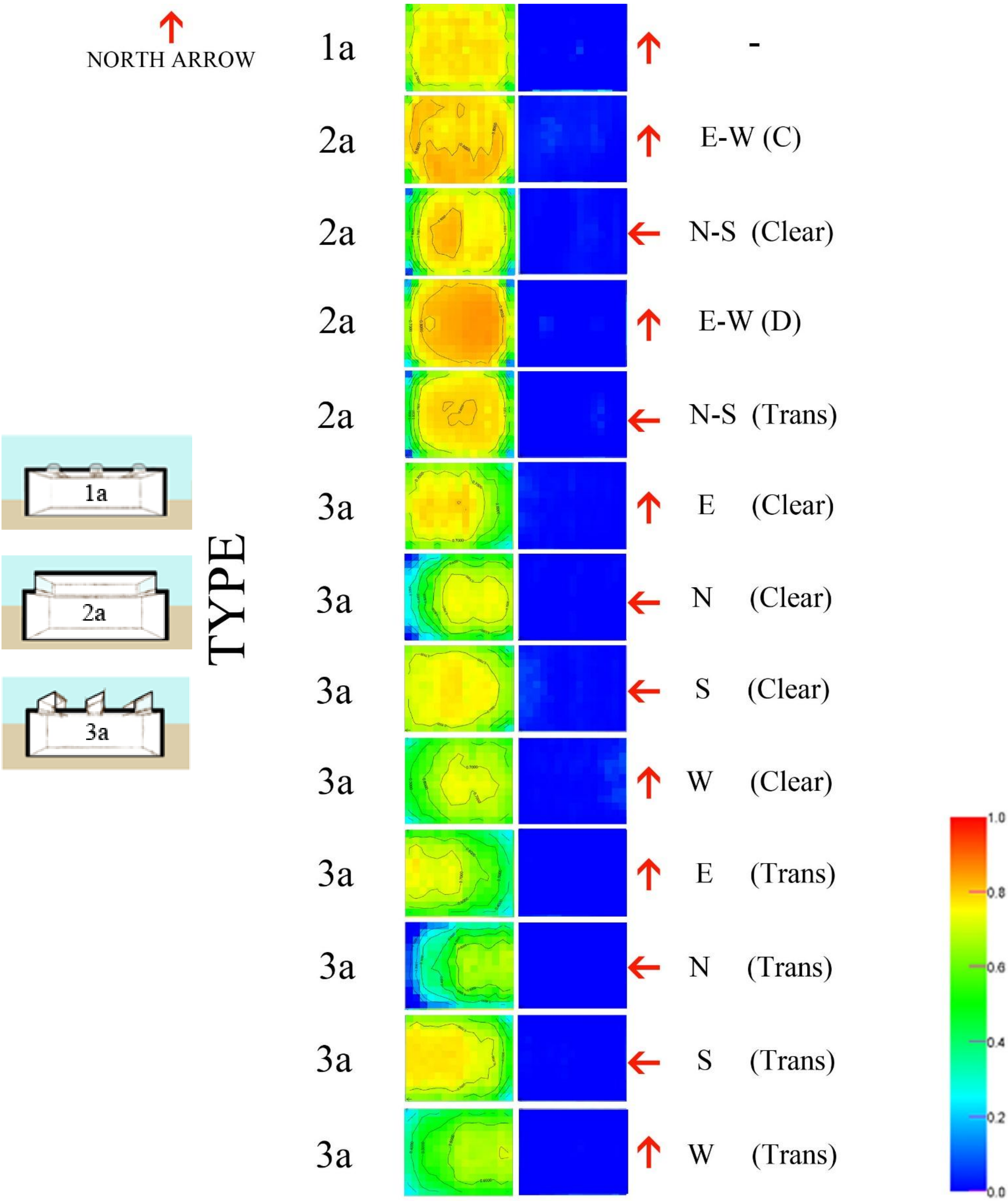


Figure 4-17: UDI 400-2000 (Left), UDI 2000+ (Right) For Different Types and Orientations

4.4 Energy Performance Results and Analysis

4.4.1 Heat Gain Breakdown

An analysis of the conduction heat gain from the wall, ground and glazing was conducted. Also the radiative heat gain from the glazing was obtained (see Table 4-1). It was noted that when the shorter side of the building faces North and South, and the longer side of the building faces East and West, higher conduction gains on the wall were observed. For example, the conduction gain for the base model was 9719 kBtu when the shorter side faced East and increased to 9836 kBtu, when facing North. Although this is a 1.2% increase, this is due to the minor different in wall length, where the room dimensions are 25' x30'. When comparing the conduction heat from the glazing for each scenario, the least conduction heat was observed in Type1a (see Figure 4-19). The highest conduction gain was observed in Type2, since this model contained the most glazing area and the placement of this glazing was vertical. Another observation was that the lower the glazing area present in the model, the higher the wall conduction, mainly in Types 2 and 3, where the alteration included less glazing area and added more wall area to the monitors and clerestories. Conductions gain from the roof and glazing were also analysed and compared thoughout the year (see Figure 4-20). One of the reasons that conduction from Type2, Type2a, Type3, Type3a were higher at 8,000 kBtu than Type1 and Type1a at 6,500 kBtu could be due to more roof area in these models. We also note that the lower the glazing area, the lower is the conducted heat. Type2 has the most conduction gain and Typ1a with the least.

Another observation that was made is that horizontal glazing, in Type1 and Type1a, had more potential to lose heat during the nighttime in comparison to the vertical glazing (see Figure 4-18). Since the AC schedule is set to operate from 6 am to 4pm, a lot of the heat is released through the building envelope, and radiated to the sky. This phenomenon may be beneficial in decreasing the cooling load required in the morning. Another finding that was observed is that when the glazing was switched from triple to double, this change allowed for more radiative exchange between the glass and sky, especially during night and lower cooling loads peak at morning (see Table 4-2).

Referring to Figure 4-21, the solar radiation from the glazing is shown for each orientation. It was noted that Type2 has the most radiation gain. This gain was reduced by more than 50% when the model was modified to Type2a. Type1a and Type3a North had the least radiation. Although it was thought that Type1 would gain a lot of radiation, especially with the sun's high altitude in summer, due to the hazing effect of the sky; lower direct solar radiation is obtained during the summer months. This may be one reason for less solar gain through the horizontal glazing surfaces.

The correlation between inside temperature of a room and the sensible cooling load required was graphed for the entire year (see Figure 4-22). Due to the increase in outside temperature during the summer, the temperature in the room increases as well. The higher the glazing area, the higher the inside temperature due to conduction and radiation, which results in an increase in cooling loads.

Type	Wall-k	% of Total	Ground-k	% of Total	Glazing-k	% of Total	Glazing-λ
b	9836	90%	1123	10%	NA	NA	NA
1	9507	90%	910	9%	-158	1%	10455
1a	9725	90%	1034	10%	-56	1%	4658
2	11277	77%	889	6%	2534	17%	16406
2a	11962	85%	1016	7%	1087	8%	5907
3	12058	84%	1018	7%	1359	9%	5741
3a	12815	88%	1060	5%	683	5%	2674
			South				
Type	Wall-k	% of Total	Ground-k	% of Total	Glazing-k	% of Total	Glazing-λ
b	9836	90%	1123	10%	NA	NA	NA
1	9469	90%	912	9%	-157	1%	10455
1a	9763	90%	1032	10%	-56	1%	4658
2	11205	77%	892	6%	2539	17%	16401
2a	12020	85%	1012	7%	1085	8%	5910
3	11474	82%	935	7%	1519	11%	11345
3a	12816	88%	1008	7%	786	5%	5294
			East				
Type	Wall-k	% of Total	Ground-k	% of Total	Glazing-k	% of Total	Glazing-λ
b	9719	90%	1131	10%	NA	NA	NA
1	9358	90%	918	9%	-155	1%	10453
1a	9605	90%	1041	10%	-55	1%	4657
2	10730	79%	796	6%	2108	15%	20784
2a	11462	85%	959	7%	1106	8%	7847
3	11673	85%	1506	7%	968	9%	12073
3a	12908	88%	1030	7%	777	5%	5615
			West				
Type	Wall-k	% of Total	Ground-k	% of Total	Glazing-k	% of Total	Glazing-λ
b	9705	90%	1132	10%	NA	NA	NA
1	9394	90%	916	9%	-155	1%	10455
1a	9652	90%	1038	10%	-55	1%	4658
2	10722	79%	796	15%	2107	6%	20793
2a	11463	85%	959	8%	1107	7%	7862
3	11184	83%	864	7%	1140	11%	10226
3a	12571	88%	984	7%	670	5%	4769

Table 4-1: Heat Gain Breakdown for All Orientations

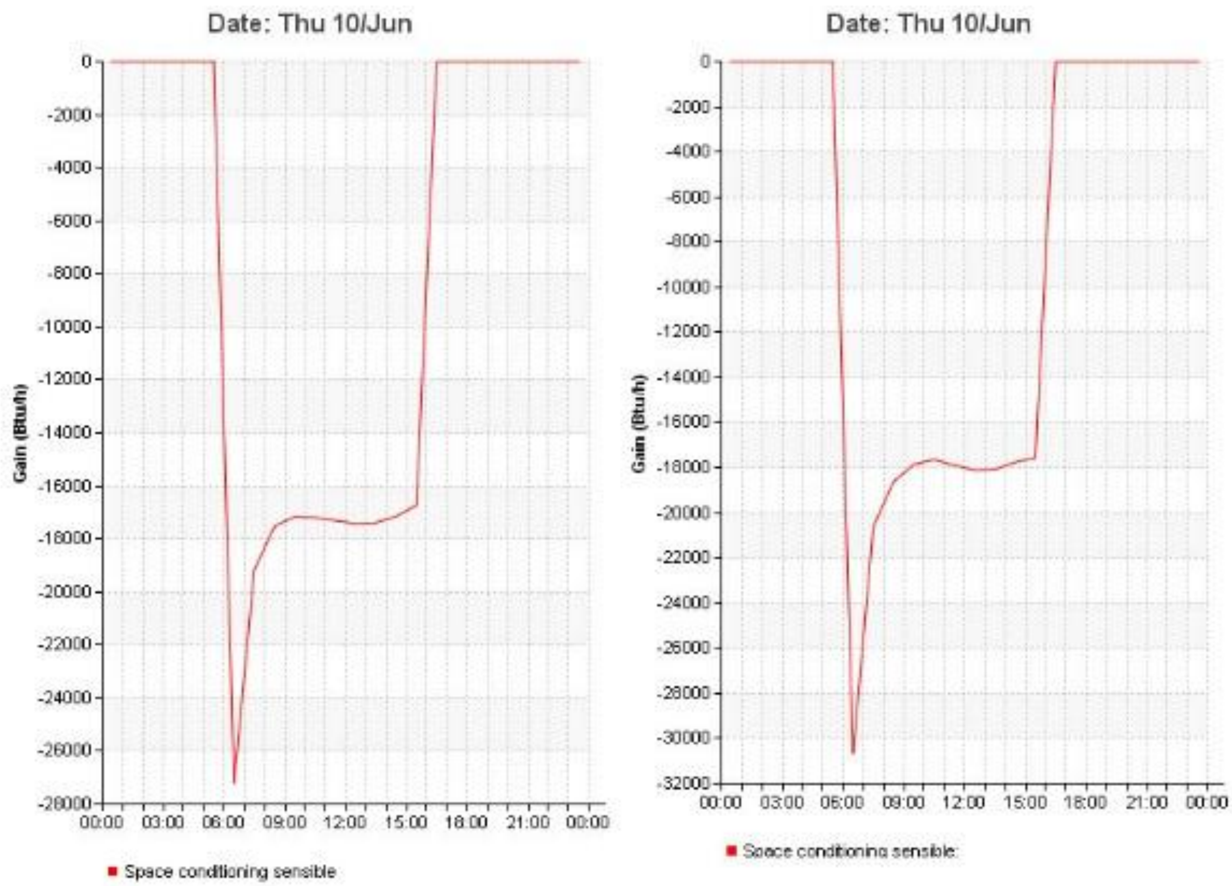


Figure 4-18: Sensible Cooling Loads For Type1a On Left And Type 2a On Right For June The 10th , Peak Resulted Due To Heat Accumulation During Evening Hours

Date	Triple Gazing AC Sensible (kWh)	Double Gazing AC Sensible (kWh)
Jan 01-31	959	893
Feb 01-28	926	857
Mar 01-31	1,254	1,180
Apr 01-30	1,485	1,421
May 01-31	1,796	1,735
Jun 01-30	1,798	1,750
Jul 01-31	1,803	1,755
Aug 01-31	1,686	1,627
Sep 01-30	1,618	1,548
Oct 01-31	1,556	1,481
Nov 01-30	1,232	1,150
Dec 01-31	1,045	984
Total	17,157	16,380

Table 4-2: Sensible Cooling Loads for Triple Glazing vs Double Glazing

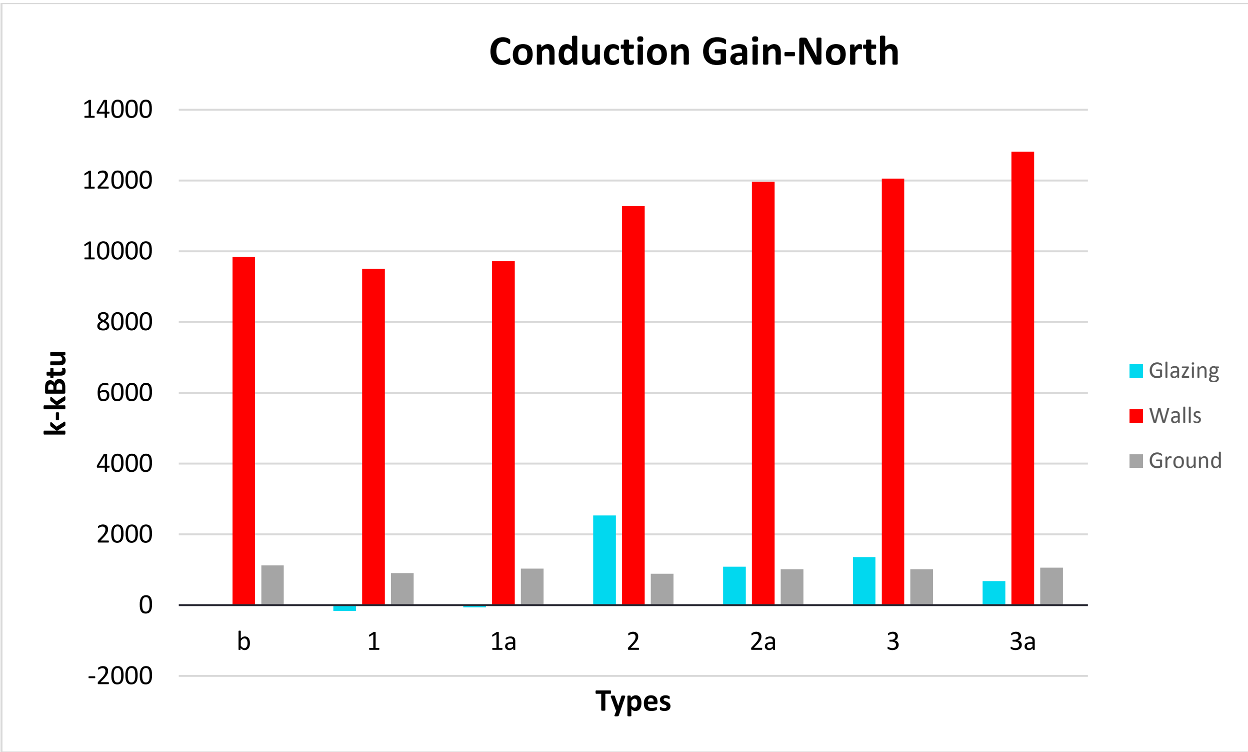


Figure 4-19: Conduction Gain through External Walls, Floors, and Glazing Facing North

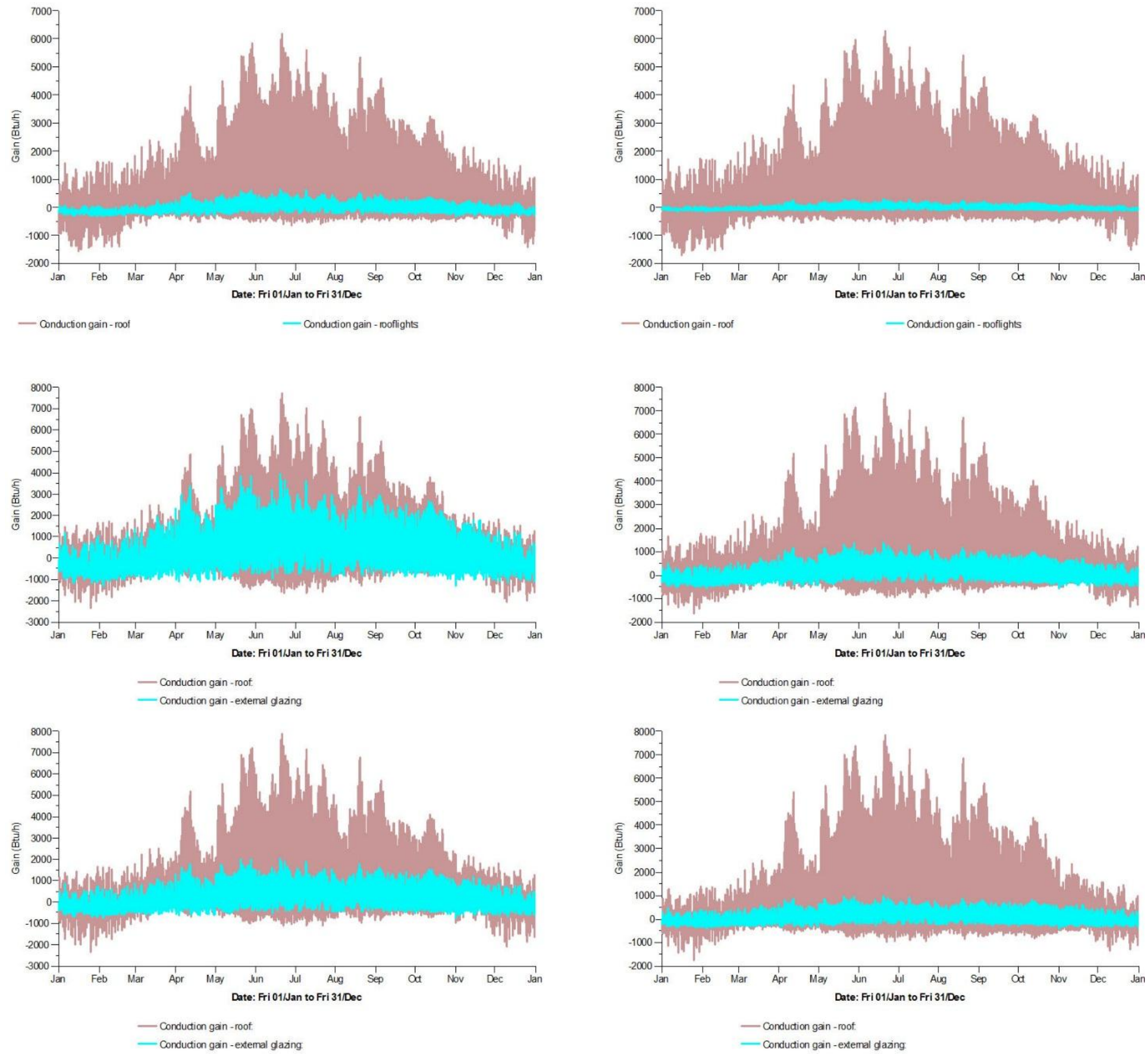


Figure 4-20: Conduction Gain Roof and Glazing, Type1, Type2, Type3 on Left (Top to Bottom). Tyep1a, Type2a, Type3a on Right (Top to Bottom)

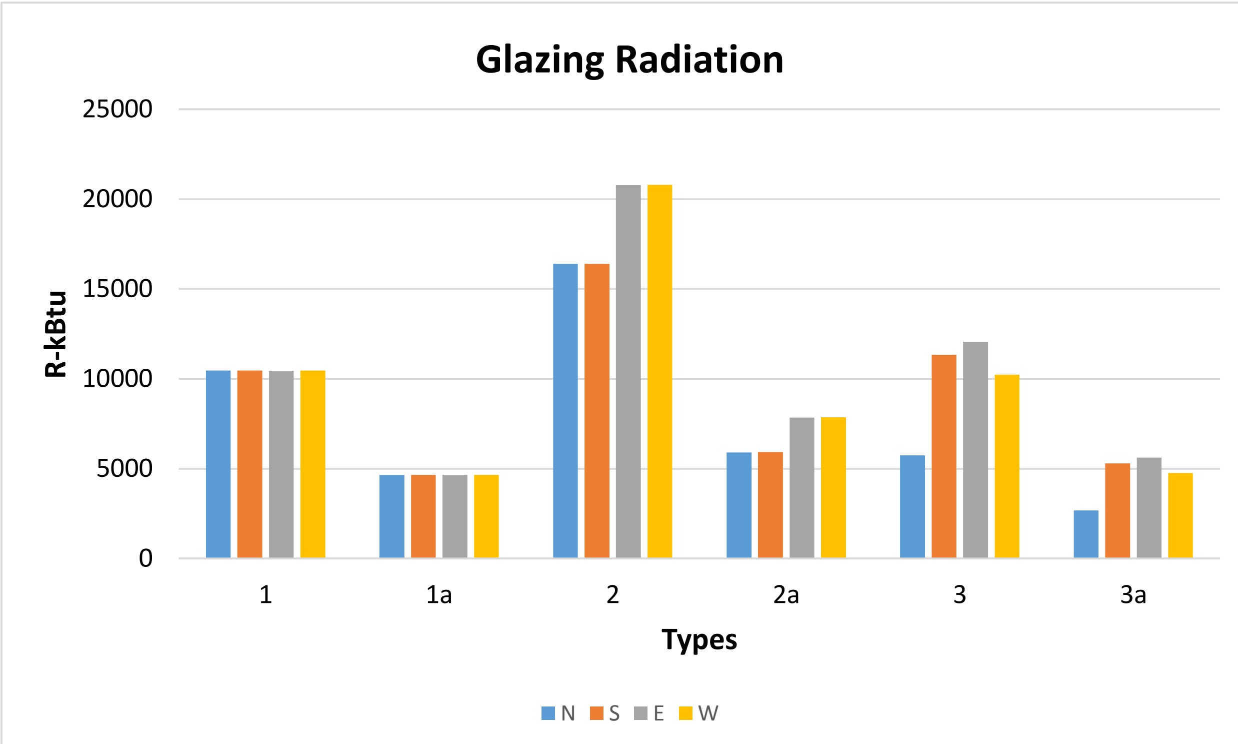


Figure 4-21: Radiation Gain through Glazing per Year

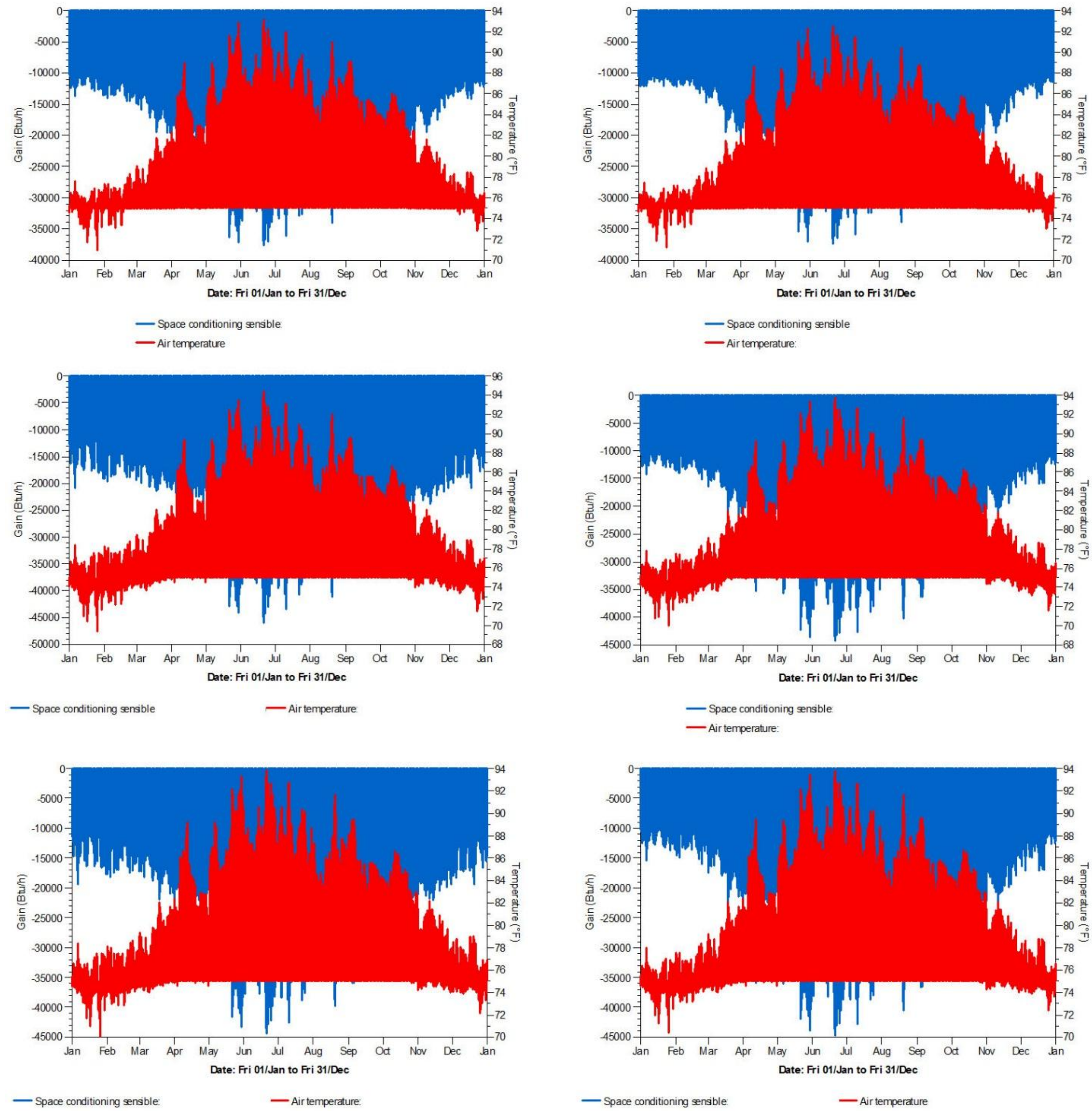


Figure 4-22: Annual Space Cooling Sensible and Room Temperature (North Orientation)

4.4.2 Lighting and AC Gain

The total annual lighting energy consumption was calculated to be 2,272 kWh (7,753 kBtu) and the total annual sensible space conditioning was 17,146 kWh (58,505 kBtu) for the base model with no toplighting (see Figure 4-23). These values were set as a baseline to calculate the energy savings for each scenario. Although in reality energy consumption is represented in positive values, In IES-VE Sensible cooling loads are represented in negative values and heating loads in positive values.

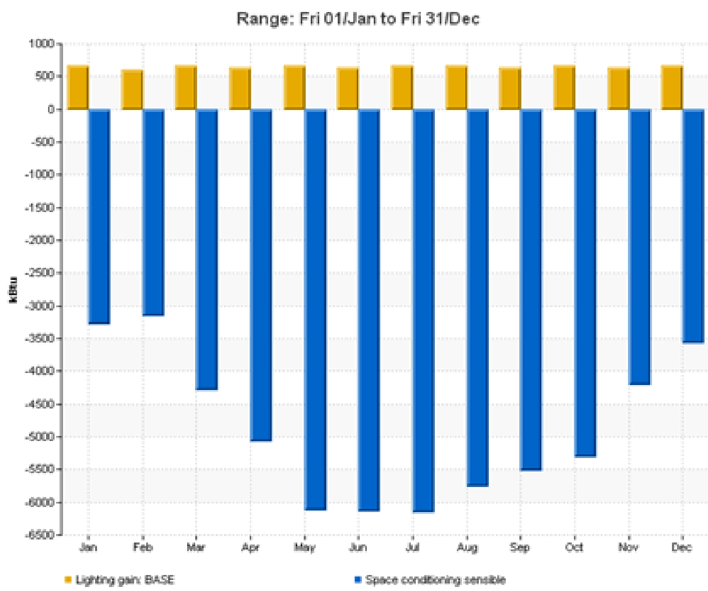


Figure 4-23: Base Model with No Toplighting: Lighting and Cooling Energy Consumption

Using a Diffuse material of 53% T_{vis} and a SHGC of 25% for all Types and orientation, we gain the most savings from Type1a at 2,157 kWh (7,355 kBtu), and the least savings from Type2 East-West Diffuse with a loss at-2,735 (-9584 kBtu). This is expected due to the high glazing ratio where the cooling energy exceeds the reduction in lighting energy. Since the North façade has the least exposure from direct sun, where only Diffuse light from the sky and reflected light from the ground and roof are available, both Diffuse and Clear materials were explored for the North orientation. When the material was changed from Diffuse to clear for Type3 in the North orientation, we observe that we gain total energy saving of 369 kWh (1,258 kBtu), where with the Diffuse material there was an energy increase (see Figure 4-24). There were no energy savings for Type2 and Type3 for all orientations and glazing Types, with the exception of the North Clear for Type3. All Type2a resulted in energy savings with a maximum value of 933 kWh (3,183 kBtu) for the North-South Diffuse Type (see Figure 4-25). The only savings from Type3a were the South Diffuse and South Clear.

When Type1a was analyzed in terms of lighting and cooling loads we note that we had reduction in energy consumption for both loads (see Figure 4-26). In addition it was observed that although Type2 North had a less total lighting loads, but due to the glazing area, the heat permitted into the building resulted in a total energy reduction (see Figure 4-27).

In general, when studying the 3 different toplighting Types, the most energy savings resulted from Type1a Diffuse at 2,157 kWh (7,355 kBtu), followed by Type1 Diffuse at 1,242 kWh (4234 kBtu), then Type2a at North-South Diffuse at 933 kWh (3,183 kBtu) (see Figure 4-28).

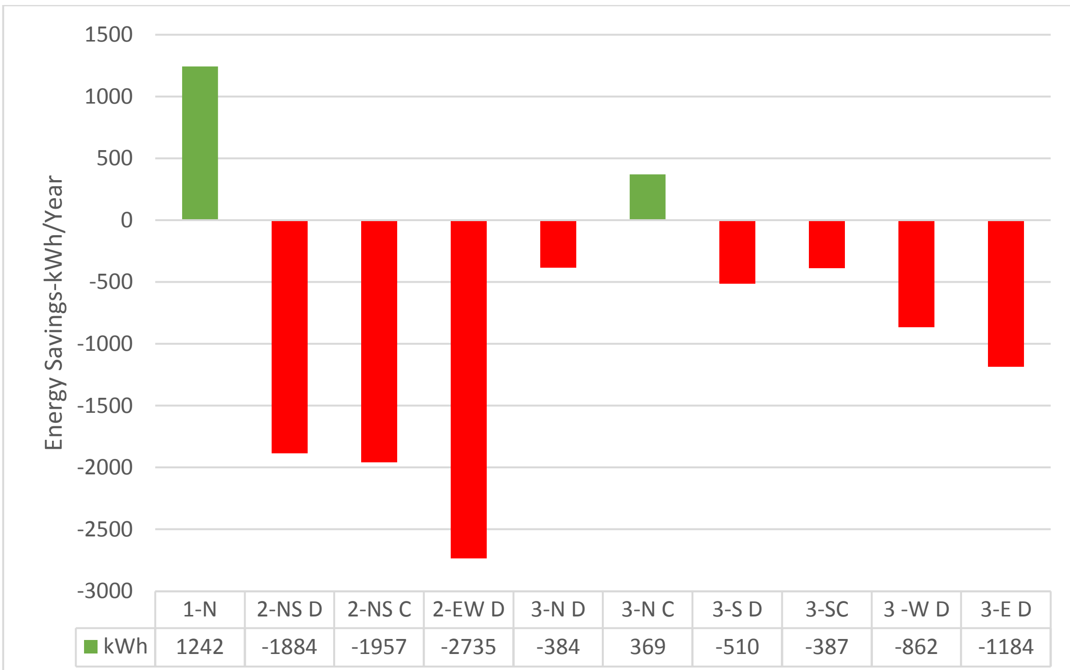


Figure 4-24: Total Energy Savings for Type1, 2 and 3 for different orientations and material type

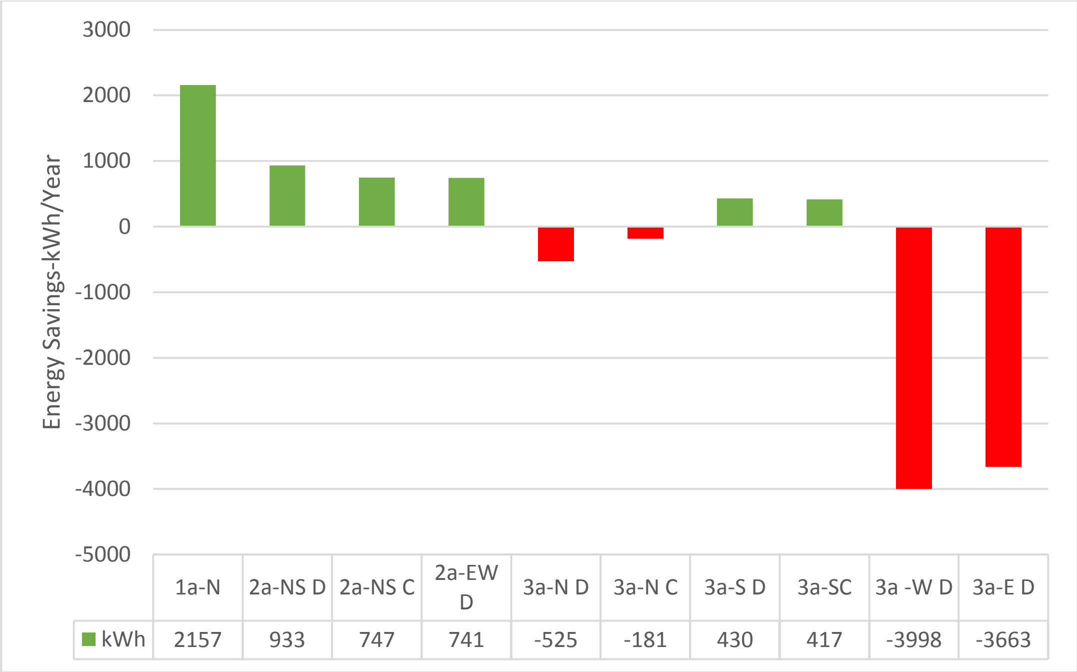


Figure 4-25: Total Energy Savings for Type1a, 2a and 3a For Different Orientations and Material Types

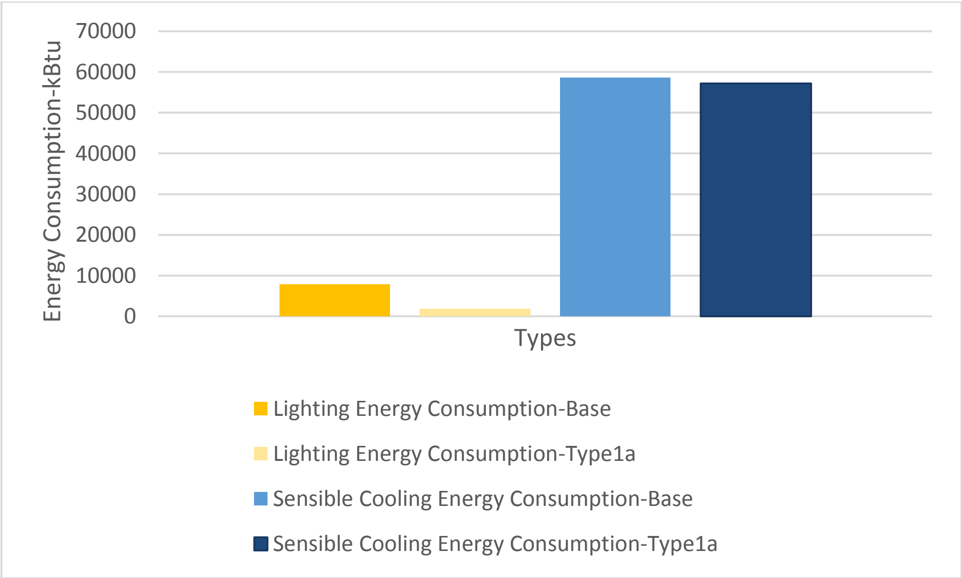


Figure 4-26: Lighting and Cooling Load Gains, Base vs Type1a

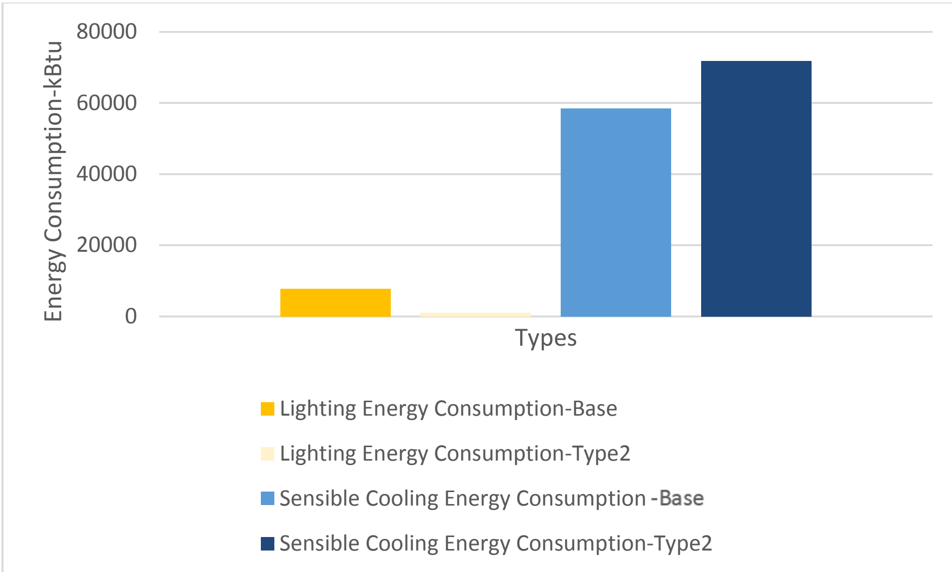


Figure 4-27: Lighting and Cooling Load Gains, Base vs. Type2

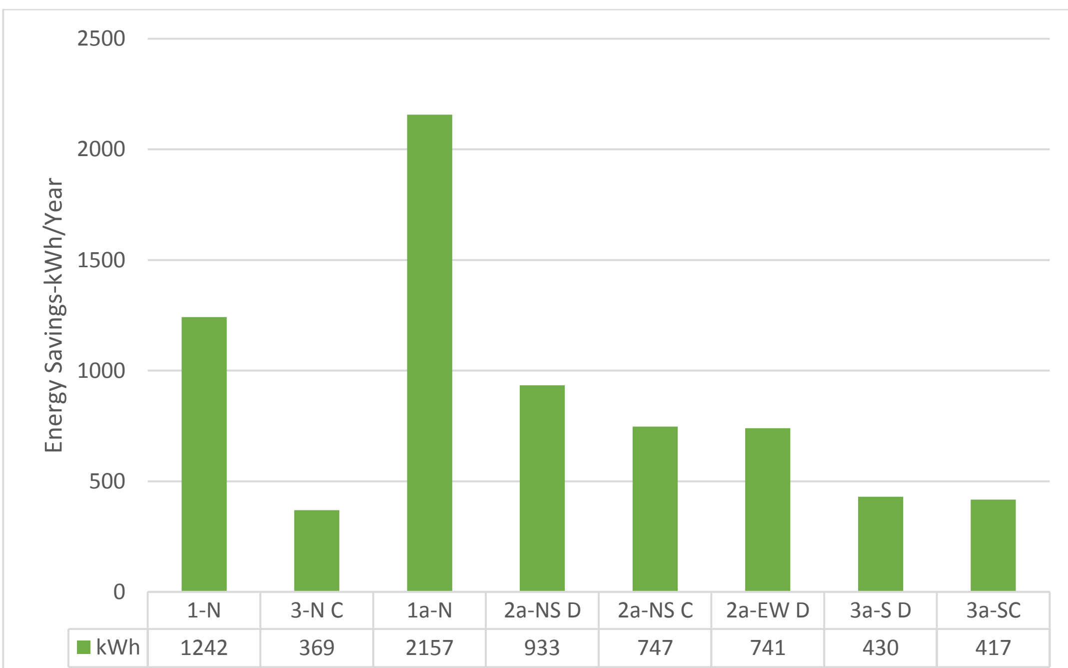


Figure 4-28: Comparison of the Different Types with Total Energy Savings

4.4.3 Glare

The models with the best savings from each Type were selected for a glare analysis. For the Type1 classification, Type1a South Diffuse was selected. Since orientation is not as crucial as the time of the day and month for the square skylights, the day was picked at October 20 from the weather file, where there was significant contribution from the sun at solar noon and where the solar altitude is high and almost perpendicular to the glazing surface. For the category Type2, Type2a North Diffuse was selected. For this geometry Type, a time where the solar altitude is low was selected during the winter at 11 am, where the irradiance from the sun is high. For Type3 category, Type3a West Diffuse was analyzed for glare. For this scenario, October 10 was selected at 3 pm where significant solar radiation was striking the façade glazing (see Figure 4-29).

The eye view position was set to 3 feet, where the student was considered at a seated position, and the eye focus point was set to 3.5'. For all Types there were a few conditions where the luminance levels were 7 times higher than the threshold luminance Although Type3a has less glazing area than Type2a, it resulted in a higher luminance threshold. This may be due to the high contrast between the dark wall adjacent to the fenestration opening and brightness of the glazing (see Figure 4-30). As for the Daylight Glare Index (DGI), for all scenario, values were below the threshold of 31, which indicated tolerable glare to the human eye, where the pupil of the eye can adapt from one level of brightness to another with ease. At certain angles the DGI was below 18, which indicates barely noticeable glare (see Table 4-3). Overall there was no discomfort glare detected as per the DGI measure.

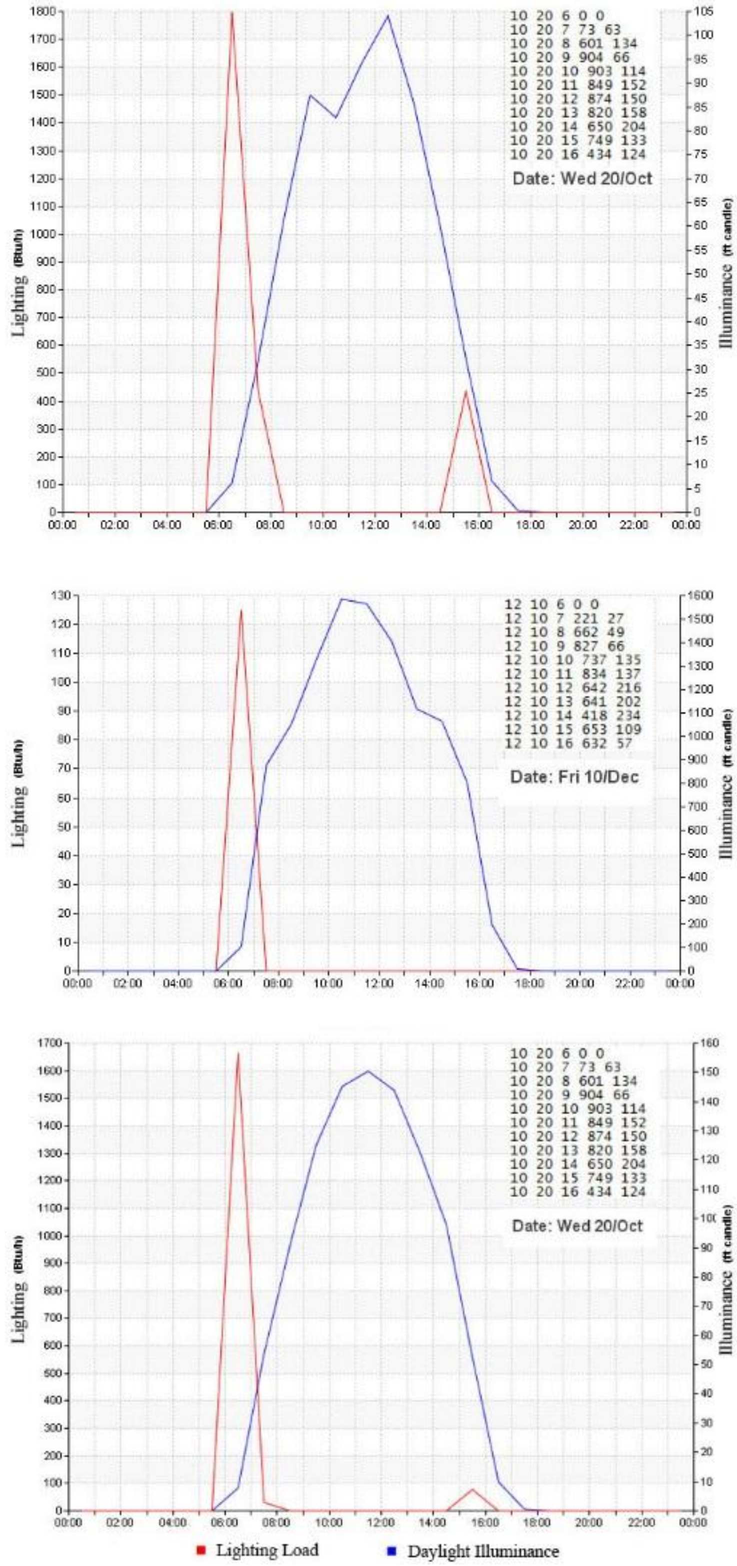


Figure 4-29: Daylight Illuminance Values for Each Day Selected for Glare Analysis

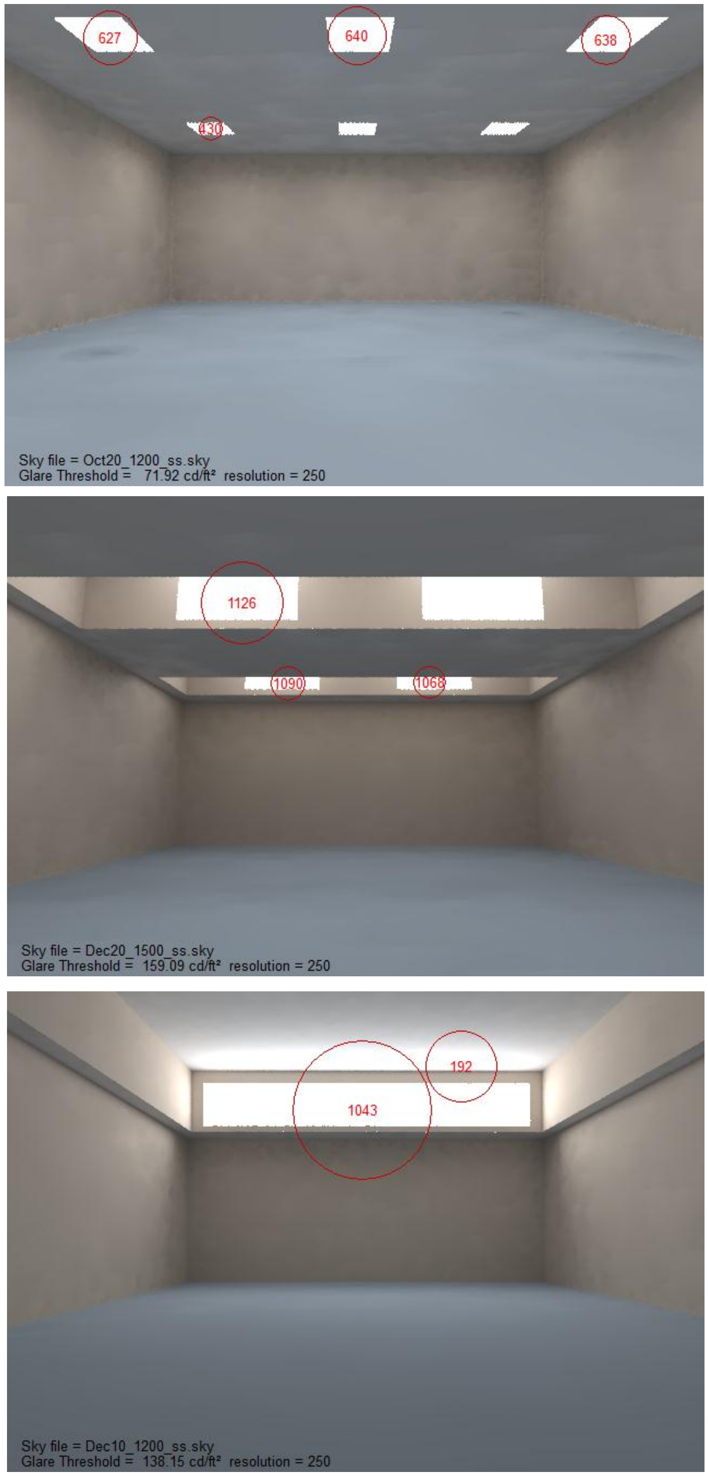


Figure 4-30: Luminance Values Type1a, 2a, 3a, respectively for Selected Dates and Times

View Angle	60	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
DGI	-1.00	19.47	19.81	20.25	20.47	20.57	20.73	20.62	20.59	20.38	20.01	19.70	19.13

View Angle	60	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
DGI	16.28	18.35	20.10	21.53	22.59	23.15	23.20	23.17	22.77	21.81	20.46	18.79	16.79

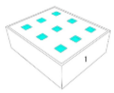
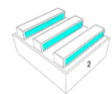
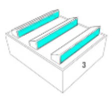
View Angle	60	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
DGI	21.13	22.55	23.59	24.58	25.56	26.14	25.68	26.11	25.63	24.69	23.67	22.70	21.34

Table 4-3: DGI Glare Analysis for Type1a, 2a, 3a, respectively

4.5 Results Summary and Recommendations

The summary Table 4-4 shows the overall matrices that were discussed previously. For the greater glazing area of Types 1, 2, and 3, the DA_{1000} value was set to 70%. For example, Type1 indicated that 70% of the time 60% of the room area receives a 1000 lux. The DA values for Types1a, 2a, and 3a were set to 400 due to very low illuminance values at 1000 lux and beyond. The sDA_{1000} and sDA_{400} were considered for 50% of the occupancy hours and most orientations resulted in high sDA values with the exception of the North diffused. It is also noted that all Types1a, 2a, 3a had no UDI values above 2000 lux, which aided in reducing glare, hot spots, and cooling loads.

In general, we could see that greater savings were achieved from less glazing area, with the exception of Type3a North, where Type3 Clear North yielded the most savings at 369 kWh. Since the North façade scenarios require no shading devices, a recommendation could be to Increase the glazing area, admitting indirect daylight through the glazing and allowing for additional energy savings. Despite earning some energy savings for the South facing glazing façades in both Types3a Diffuse and Clear, precaution should be taken during winter time where the solar altitude is at a low of 45 degrees for Muscat, Oman. Shading devices or overhangs may be appropriate for the South orientation to block direct sunlight that may enter the space. Similarly for Type 2a East-West, the low angle of the sun in the morning and late in the afternoon should be avoided using vertical shading devices. Providing these shading elements may aid in reducing the cooling loads as well. Type1a was the only case where savings were achieved for both lighting and cooling. Another recommendation for Oman's climate weather is that using a double glazed material rather than a triple glazed for the horizontal glazing surfaces could lead to more energy savings (see Table 4-5).

Type		Orientation	Room % at 70% DA1000	SDA1000 50%	UDI 2000+ (20-30%)	Lighting Savings (kWh/year)	Cooling Savings (kWh/year)	Total Savings (kWh/year)
	1	N-Diffuse	60%	98%	9%	2,030	-789	1,242
	2	NS-Diffuse	73%	96%	38%	2,003	-3,886	-1,884
	2	NS-Clear	86%	99%	14%	1,963	-3,943	-1,979
	2	EW-Diffuse	94%	99%	15%	2,039	-4,776	-2,737
	3	N-Diffuse	0%	1%	0%	1,189	-1,573	-384
	3	N-Clear	9%	34%	0%	1,581	-1,212	369
	3	S-Diffuse	21%	77%	57%	1,842	-2,352	-510
	3	S-Clear	57%	87%	31%	1,906	-2,293	-387
	3	East-Diffuse	0%	23%	7%	1,634	-2,818	-1,184
	3	West-Diffuse	4%	36%	63%	1,409	-2,271	-862

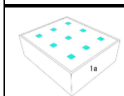
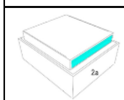
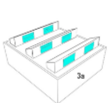
Type		Orientation	Room % at 70% DA400	SDA400 50%	UDI 2000+ (20-30%)	Lighting Savings (kWh/year)	Cooling Savings (kWh/year)	Total Savings (kWh/year)
	1a	N-Diffuse	93%	98%	0%	1,751	406	2,157
	2a	NS-Diffuse	82%	88%	0%	1,861	-927	933
	2a	NS-Clear	84%	90%	0%	1,760	-1,004	757
	2a	EW-Diffuse	92%	94%	0%	1,968	-1,234	734
	3a	N-Diffuse	21%	39%	0%	673	-1,198	-525
	3a	N-Clear	53%	69%	0%	852	-1,033	-181
	3a	S-Diffuse	66%	94%	0%	1,519	-1,089	430
	3a	S-Clear	88%	97%	0%	1,512	-1,095	417
	3a	East-Diffuse	43%	76%	0%	1,321	-4,983	-3,663
	3a	West-Diffuse	22%	67%	0%	1,055	-5,053	-3,998

Table 4-4: Matrixes Summary Table for Investigated Toplighing Systems, Highest Values with Lighter Shade

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1a Light Energy Gain (kBtu)	Type1a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	302	-3118	356	-151	507
Feb 01-28	595	-3156	184	-2995	411	-161	572
Mar 01-31	658	-4276	157	-4151	501	-125	626
Apr 01-30	637	-5064	111	-4968	526	-96	622
May 01-31	658	-6123	48	-6061	610	-62	672
Jun 01-30	637	-6130	108	-6094	529	-36	565
Jul 01-31	658	-6148	142	-6102	516	-46	562
Aug 01-31	658	-5749	103	-5663	555	-86	641
Sep 01-30	637	-5518	45	-5394	592	-124	716
Oct 01-31	658	-5307	106	-5156	552	-151	703
Nov 01-30	637	-4200	172	-4013	465	-187	652
Dec 01-31	658	-3564	304	-3404	354	-160	514
Summed total	7753	-58505	1782	-57121	5971	-1384	7355

Type1a Light Energy Gain (kBtu)	Type1a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
304	-3044	354	-225	579
203	-2922	392	-234	626
153	-4024	505	-252	757
112	-4844	525	-220	745
47	-5917	611	-206	817
104	-5967	533	-163	696
143	-5984	515	-164	679
114	-5547	544	-202	746
57	-5277	580	-241	821
111	-5051	547	-256	803
166	-3921	471	-279	750
327	-3357	331	-207	538
1843	-55855	5910	-2650	8560

Table 4-5: Electrical Lighting vs Sensible Cooling Energy Consumption and Total Energy Savings for Type1a Triple Glazing (Left), Double Glazing (Right)

Note: the negative values in tables 4-5 for the cooling energy consumption represents values from IES-VE software. In reality these values are denoted as a positive. For example AC energy consumption for Type1a with -5,7121 kBtu is a decrease of 1,384 kBtu from the Base case.

5 CONCLUSIONS

"A room is not a room without natural light"-Louis Khan

5.1 Summary

Three base models, Type1, Type2, and Type3 were selected for daylight analysis in the climate settings of Muscat, Oman. Tvis values and SHGC values that were similar to available values in the market were input for each Type. Orientations varied for each scenario depending of the geometry of the toplighing system. Diffuse and clear glazing were part of the fenestration material selection. These models were studied in DAYSIMps to make sure adequate illuminance, as per target requirements, was met. Metrics such as DA, sDA, and UDI were evaluated. These models were then simulated in IES-VE to assess heat gain breakdown. Based on observation of conduction and radiant heat gain from the glazing for each scenario, modifications were made to the glazing area, where it was reduced for each aperture Type. Heat gain was then re-examined. These modified Types were simulated again in DAYSIMps for daylight metrics evaluation. Energy savings were evaluated for each scenario. Glare was checked for the one optimum arrangement from each Type, where high glare potential might occur.

It was concluded that Type1a 2'x2' skylight resulted in the best total savings in terms of lighting and cooling for Oman's climate within the tested models. Type1a also had the least glare potential out of the three study cases and met illumination requirements. When UDI $_{2000+}$ was examined for this Type, no illumination values that exceeded the 2000 lux threshold were observed (see Figure 5-1). Other systems such as Type1, Type2a (North-South, East-West) and Type3a North yielded energy savings as well. Material choices had an impact on allowable heat transfer and lighting transmittance. For example, double glazing material resulted in 15% increase in total savings for Type1a when compared to triple glazing savings for the same Type. This result does not only serve energy savings but also reduces cost implications where the cost of a triple glazing system could range from 10-20% more than that of a double glazing.

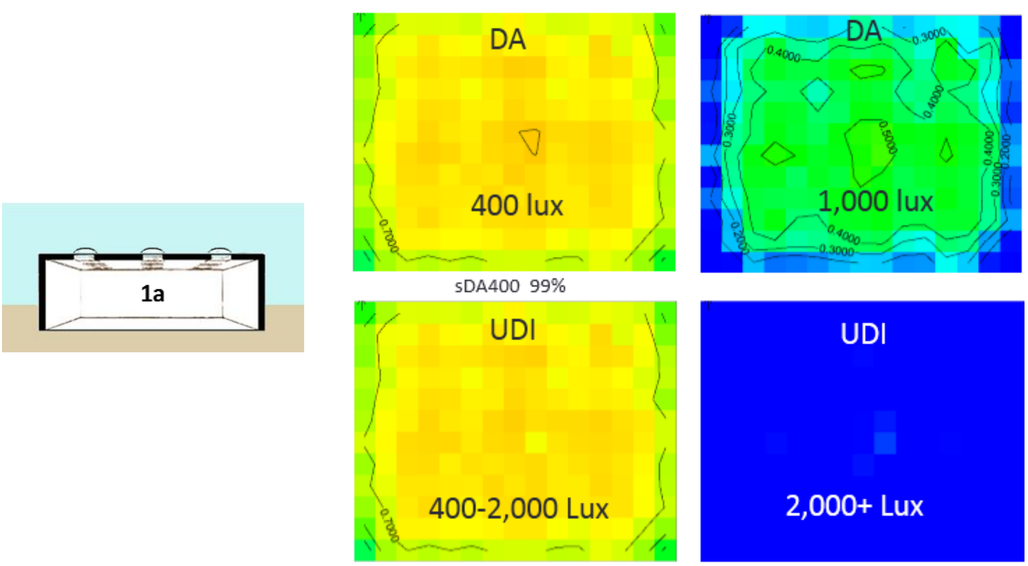


Figure 5-1: Typ1a, Most Appropriate Toplighing Type for Muscat Oman Climate within Simulation Studies

Generally, glazing area, Geometry, and orientation were factors in the result outcome in this research. In addition, Climate factors such as the atmosphere's clearness contributed to the final results. Furthermore, material choices, such as diffuse and clear, and visible light transmittance had an impact on the end results.

Results from this study are expected to provide an overall basis for architects and engineers to follow when designing toplighing in a similar climate. These findings are meant to improve the indoor quality for school occupants, provide energy savings for both consumers and government, and reduce harmful emissions for the environment as a whole. This research also shows the significance of integrating the lighting and mechanical systems when accounting for energy savings. Since one type of toplighting may allow substantial amount of savings in electric lighting loads, but due to the climate, added heat to the room, results in overall less or no energy saving.

In conclusion, this study demonstrates that, if appropriately designed, toplighting systems does result in an overall annual energy savings in a classroom space for hot climates such as in Muscat, Oman. The correct application of rooftop systems could lead to better indoor quality, enhanced environment and energy savings.

Figure 5-2: Students Well-Being, Energy Efficiency and Environment

Source: Cognition Education

5.2 Limitations

There are some limitations to this study where the climate focus was for the city of Muscat and Oman has a variation of climates within its geography. No windows were considered in this investigation, where typical classrooms in Oman are built with at least some view glazing areas. The T_{vis} of 52%, 53%, and 32% and the SHGC values of 25% and 26% were studied in this investigation. Different glazing material properties for the T_{vis} and the SHGC could be explored in further studies. For further investigation, variety of geometry and glazing modifications can be applied to where optimum saving levels can be achieved for each study case. In addition, other toplighting systems such as tube skyights could be explored. This study was based on simulation tools, comparing case studies observed in actual buildings for the same climate settings is importance for results verifications and comparison. Overhangs and shading devices were not part of this study.

GLOSSARY

Toplighting: daylighting system that primarily delivers light to interior spaces from the roof

Skylight: fenestration surface having a slope of less than 60 degrees from the horizontal plane

Clerestory: that part of a building that rises clear of the roofs or other parts and whose walls contain windows for lighting the interior

Monitor: vertical fenestration integral to the roof

Visible Light Transmittance (Tvis): a percentage (0-100%) of the fraction of incident flux (visible light) arriving at a normal angle of incidence (on surface) that passes through a material. The higher the Tvis the less glazing area is required to illuminate a space. A material that is opaque has a Tvis value of zero

Light to Solar Gain (LSG): the ratio of Tvis over SHGC. It is a metric to compare material suitability in hot climates. High LSG helps in minimizing the cooling loads yet permitting more light and promotes energy efficiency. It is not good for cold climates where having heat during cold seasons is desirable.

Solar Heat Gain Coefficient (SHGC): a value from (0.0-1.0) represents the fraction of incident solar radiation transmitted through a glazing material into a space either through direct transmission or through absorption and subsequent radiation, conduction or convection it considers the transmission of UV and inferred radiation. When a space needs to be cooled a glazing material that transmits visible wavelengths and reject none-visible wavelength is desirable.

Lighting Power Density (LPD): the maximum lighting power per unit area of a building classification of space function.

Skylight to Roof Ratio (SRR): the net glazing area divided by the gross roof area

Skylight to Floor Ratio (SRR): the net glazing area divided by the gross floor area

Note: definitions were referenced from the ASHRAE 90.1/ IESNA 2013 and the Illuminating Engineering Society Handbook

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APPENDIX

The following appendix provides details for energy consumption and savings for all Types. From the tables we can see the patterns of increase or decrease of both lighting and AC loads energy consumption as per toplighting fenestration Type, glazing area, orientations and variation in seasons (see Tables 8-1-8-6). Note that the negative values in tables bellow for the cooling energy consumption represents values from IES-VE software. In reality these values are denoted as a positive.

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1 Light Energy Gain (kBtu)	Type1 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)	Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1a Light Energy Gain (kBtu)	Type1a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	176	-3224	482	-45	527	Jan 01-31	658	-3269	302	-3118	356	-151	507
Feb 01-28	595	-3156	91	-3178	504	22	482	Feb 01-28	595	-3156	184	-2995	411	-161	572
Mar 01-31	658	-4276	81	-4490	577	214	363	Mar 01-31	658	-4276	157	-4151	501	-125	626
Apr 01-30	637	-5064	45	-5375	592	311	281	Apr 01-30	637	-5064	111	-4968	526	-96	622
May 01-31	658	-6123	7	-6619	651	496	155	May 01-31	658	-6123	48	-6061	610	-62	672
Jun 01-30	637	-6130	44	-6569	593	439	154	Jun 01-30	637	-6130	108	-6094	529	-36	565
Jul 01-31	658	-6148	59	-6533	599	385	214	Jul 01-31	658	-6148	142	-6102	516	-46	562
Aug 01-31	658	-5749	26	-6100	632	351	281	Aug 01-31	658	-5749	103	-5663	555	-86	641
Sep 01-30	637	-5518	8	-5861	629	343	286	Sep 01-30	637	-5518	45	-5394	592	-124	716
Oct 01-31	658	-5307	47	-5533	611	226	385	Oct 01-31	658	-5307	106	-5156	552	-151	703
Nov 01-30	637	-4200	73	-4217	564	17	547	Nov 01-30	637	-4200	172	-4013	465	-187	652
Dec 01-31	658	-3564	174	-3495	484	-69	553	Dec 01-31	658	-3564	304	-3404	354	-160	514
Summed total	7753	-58505	830	-61194	6923	2689	4234	**Summed total**	7753	-58505	1782	-57121	5971	-1384	7355
Date	**Base Light Energy Gain (kBtu)**	**Base Cooling Energy Gain (kBtu)**	**Type2 Light Energy Gain (kBtu)**	**Type2 Cooling Energy Gain (kBtu)**	**Light Energy (Base-Type)**	**Cooling Energy (Base-Type)**	**Total Energy Saving (kBtu)**	**Date**	**Base Light Energy Gain (kBtu)**	**Base Cooling Energy Gain (kBtu)**	**Type2a Light Energy Gain (kBtu)**	**Type2a Cooling Energy Gain (kBtu)**	**Light Energy (Base-Type)**	**Cooling Energy (Base-Type)**	**Total Energy Saving (kBtu)**
Jan 01-31	658	-3269	148	-3967	510	698	-188	Jan 01-31	658	-3269	184	-3261	474	-8	482
Feb 01-28	595	-3156	84	-3861	511	705	-194	Feb 01-28	595	-3156	120	-3162	475	6	469
Mar 01-31	658	-4276	92	-5147	566	871	-305	Mar 01-31	658	-4276	122	-4371	536	95	441
Apr 01-30	637	-5064	70	-6040	567	976	-409	Apr 01-30	637	-5064	116	-5318	521	254	267
May 01-31	658	-6123	12	-7428	646	1305	-659	May 01-31	658	-6123	53	-6549	605	426	179
Jun 01-30	637	-6130	77	-7544	560	1414	-854	Jun 01-30	637	-6130	147	-6683	490	553	-63
Jul 01-31	658	-6148	109	-7568	549	1420	-871	Jul 01-31	658	-6148	190	-6713	468	565	-97
Aug 01-31	658	-5749	58	-6928	600	1179	-579	Aug 01-31	658	-5749	105	-6119	553	370	183
Sep 01-30	637	-5518	11	-6737	626	1219	-593	Sep 01-30	637	-5518	29	-5830	608	312	296
Oct 01-31	658	-5307	47	-6824	611	1517	-906	Oct 01-31	658	-5307	65	-5685	593	378	215
Nov 01-30	637	-4200	65	-5398	572	1198	-626	Nov 01-30	637	-4200	84	-4383	553	183	370
Dec 01-31	658	-3564	150	-4315	508	751	-243	Dec 01-31	658	-3564	193	-3595	465	31	434
Summed total	7753	-58505	924	-71757	6829	13252	-6423	**Summed total**	7753	-58505	1408	-61667	6345	3162	3183
Date	**Base Light Energy Gain (kBtu)**	**Base Cooling Energy Gain (kBtu)**	**Type3 Light Energy Gain (kBtu)**	**Type3 Cooling Energy Gain (kBtu)**	**Light Energy (Base-Type)**	**Cooling Energy (Base-Type)**	**Total Energy Saving (kBtu)**	**Date**	**Base Light Energy Gain (kBtu)**	**Base Cooling Energy Gain (kBtu)**	**Type3a Light Energy Gain (kBtu)**	**Type3a Cooling Energy Gain (kBtu)**	**Light Energy (Base-Type)**	**Cooling Energy (Base-Type)**	**Total Energy Saving (kBtu)**
Jan 01-31	658	-3269	495	-3369	163	100	63	Jan 01-31	658	-3269	578	-3306	80	37	43
Feb 01-28	595	-3156	418	-3296	177	140	37	Feb 01-28	595	-3156	506	-3226	89	70	19
Mar 01-31	658	-4276	394	-4574	264	298	-34	Mar 01-31	658	-4276	528	-4481	130	205	-75
Apr 01-30	637	-5064	264	-5572	373	508	-135	Apr 01-30	637	-5064	453	-5468	184	404	-220
May 01-31	658	-6123	99	-6819	559	696	-137	May 01-31	658	-6123	315	-6682	343	559	-216
Jun 01-30	637	-6130	114	-6896	523	766	-243	Jun 01-30	637	-6130	275	-6699	362	569	-207
Jul 01-31	658	-6148	163	-6931	495	783	-288	Jul 01-31	658	-6148	337	-6740	321	592	-271
Aug 01-31	658	-5749	195	-6378	463	629	-166	Aug 01-31	658	-5749	394	-6249	264	500	-236
Sep 01-30	637	-5518	250	-6059	387	541	-154	Sep 01-30	637	-5518	441	-5980	196	462	-266
Oct 01-31	658	-5307	402	-5829	256	522	-266	Oct 01-31	658	-5307	534	-5739	124	432	-308
Nov 01-30	637	-4200	413	-4442	224	242	-18	Nov 01-30	637	-4200	524	-4384	113	184	-71
Dec 01-31	658	-3564	489	-3705	169	141	28	Dec 01-31	658	-3564	574	-3636	84	72	12
Summed total	7753	-58505	3698	-63868	4055	5363	-1308	**Summed total**	7753	-58505	5459	-62590	2294	4085	-1791

Table 0-1: North Diffuse- Electrical Lighting Vs Sensible Cooling Energy Consumption for All Types

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1 Light Energy Gain (kBtu)	Type1 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	225	-3272	433	3	430
Feb 01-28	595	-3156	175	-3258	420	102	318
Mar 01-31	658	-4276	143	-4553	515	277	238
Apr 01-30	637	-5064	75	-5407	562	343	219
May 01-31	658	-6123	32	-6645	626	522	104
Jun 01-30	637	-6130	70	-6595	567	465	102
Jul 01-31	658	-6148	84	-6557	574	409	165
Aug 01-31	658	-5749	57	-6130	601	381	220
Sep 01-30	637	-5518	33	-5890	604	372	232
Oct 01-31	658	-5307	99	-5583	559	276	283
Nov 01-30	637	-4200	143	-4283	494	83	411
Dec 01-31	658	-3564	295	-3608	363	44	319
Summed total	7753	-58505	1429	-61782	6324	3277	3047

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1a Light Energy Gain (kBtu)	Type1a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	499	-3298	159	29	130
Feb 01-28	595	-3156	369	-3162	226	6	220
Mar 01-31	658	-4276	311	-4288	347	12	335
Apr 01-30	637	-5064	240	-5083	397	19	378
May 01-31	658	-6123	140	-6143	518	20	498
Jun 01-30	637	-6130	204	-6181	433	51	382
Jul 01-31	658	-6148	241	-6191	417	43	374
Aug 01-31	658	-5749	182	-5732	476	-17	493
Sep 01-30	637	-5518	180	-5511	457	-7	464
Oct 01-31	658	-5307	321	-5352	337	45	292
Nov 01-30	637	-4200	394	-4215	243	15	228
Dec 01-31	658	-3564	515	-3598	143	34	109
Summed total	7753	-58505	3594	-58756	4159	251	3908

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2 Light Energy Gain (kBtu)	Type2 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	176	-3994	482	725	-243
Feb 01-28	595	-3156	101	-3880	494	724	-230
Mar 01-31	658	-4276	113	-5171	545	895	-350
Apr 01-30	637	-5064	59	-6047	578	983	-405
May 01-31	658	-6123	17	-7436	641	1313	-672
Jun 01-30	637	-6130	79	-7548	558	1418	-860
Jul 01-31	658	-6148	123	-7583	535	1435	-900
Aug 01-31	658	-5749	66	-6946	592	1197	-605
Sep 01-30	637	-5518	16	-6761	621	1243	-622
Oct 01-31	658	-5307	54	-6832	604	1525	-921
Nov 01-30	637	-4200	74	-5407	563	1207	-644
Dec 01-31	658	-3564	181	-4343	477	779	-302
Summed total	7753	-58505	1058	-71949	6695	13444	-6749

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2a Light Energy Gain (kBtu)	Type2a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	225	-3295	433	26	407
Feb 01-28	595	-3156	160	-3194	435	38	397
Mar 01-31	658	-4276	163	-4402	495	126	369
Apr 01-30	637	-5064	159	-5351	478	287	191
May 01-31	658	-6123	83	-6573	575	450	125
Jun 01-30	637	-6130	148	-6681	489	551	-62
Jul 01-31	658	-6148	185	-6706	473	558	-85
Aug 01-31	658	-5749	129	-6136	529	387	142
Sep 01-30	637	-5518	67	-5856	570	338	232
Oct 01-31	658	-5307	95	-5708	563	401	162
Nov 01-30	637	-4200	103	-4396	534	196	338
Dec 01-31	658	-3564	234	-3630	424	66	358
Summed total	7753	-58505	1750	-61927	6003	3422	2581

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3 Light Energy Gain (kBtu)	Type3 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	388	-3271	270	2	268
Feb 01-28	595	-3156	298	-3185	297	29	268
Mar 01-31	658	-4276	228	-4421	430	145	285
Apr 01-30	637	-5064	139	-5457	498	393	105
May 01-31	658	-6123	25	-6750	633	627	6
Jun 01-30	637	-6130	90	-6874	547	744	-197
Jul 01-31	658	-6148	138	-6908	520	760	-240
Aug 01-31	658	-5749	98	-6290	560	541	19
Sep 01-30	637	-5518	86	-5909	551	391	160
Oct 01-31	658	-5307	237	-5676	421	369	52
Nov 01-30	637	-4200	258	-4298	379	98	281
Dec 01-31	658	-3564	375	-3600	283	36	247
Summed total	7753	-58505	2361	-62639	5392	4134	1258

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3a Light Energy Gain (kBtu)	Type3a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	531	-3263	127	-6	133
Feb 01-28	595	-3156	453	-3177	142	21	121
Mar 01-31	658	-4276	445	-4404	213	128	85
Apr 01-30	637	-5064	381	-5402	256	338	-82
May 01-31	658	-6123	290	-6658	368	535	-167
Jun 01-30	637	-6130	288	-6710	349	580	-231
Jul 01-31	658	-6148	329	-6733	329	585	-256
Aug 01-31	658	-5749	334	-6194	324	445	-121
Sep 01-30	637	-5518	362	-5908	275	390	-115
Oct 01-31	658	-5307	456	-5667	202	360	-158
Nov 01-30	637	-4200	457	-4322	180	122	58
Dec 01-31	658	-3564	524	-3589	134	25	109
Summed total	7753	-58505	4849	-62027	2904	3522	-618

Table 0-2: North Clear- Electrical Lighting Vs Sensible Cooling Energy Consumption for All Types

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1 Light Energy Gain (kBtu)	Type1 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	175	-3225	483	-44	527
Feb 01-28	595	-3156	93	-3183	502	27	475
Mar 01-31	658	-4276	81	-4495	577	219	358
Apr 01-30	637	-5064	46	-5380	591	316	275
May 01-31	658	-6123	7	-6621	651	498	153
Jun 01-30	637	-6130	42	-6570	595	440	155
Jul 01-31	658	-6148	59	-6534	599	386	213
Aug 01-31	658	-5749	27	-6102	631	353	278
Sep 01-30	637	-5518	6	-5864	631	346	285
Oct 01-31	658	-5307	49	-5537	609	230	379
Nov 01-30	637	-4200	73	-4219	564	19	545
Dec 01-31	658	-3564	176	-3498	482	-66	548
Summed Total	7753	-58505	832	-61229	6921	2724	4197

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1a Light Energy Gain (kBtu)	Type1a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	304	-3119	354	-150	504
Feb 01-28	595	-3156	203	-3010	392	-146	538
Mar 01-31	658	-4276	153	-4143	505	-133	638
Apr 01-30	637	-5064	112	-4966	525	-98	623
May 01-31	658	-6123	47	-6058	611	-65	676
Jun 01-30	637	-6130	104	-6089	533	-41	574
Jul 01-31	658	-6148	143	-6102	515	-46	561
Aug 01-31	658	-5749	114	-5671	544	-78	622
Sep 01-30	637	-5518	57	-5399	580	-119	699
Oct 01-31	658	-5307	111	-5159	547	-148	695
Nov 01-30	637	-4200	166	-4004	471	-196	667
Dec 01-31	658	-3564	327	-3425	331	-139	470
Summed total	7753	-58505	1843	-57145	5910	-1360	7270

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2 Light Energy Gain (kBtu)	Type2 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	150	-3970	508	701	-193
Feb 01-28	595	-3156	86	-3865	509	709	-200
Mar 01-31	658	-4276	94	-5155	564	879	-315
Apr 01-30	637	-5064	67	-6054	570	990	-420
May 01-31	658	-6123	11	-7431	647	1308	-661
Jun 01-30	637	-6130	77	-7546	560	1416	-856
Jul 01-31	658	-6148	110	-7572	548	1424	-876
Aug 01-31	658	-5749	57	-6938	601	1189	-588
Sep 01-30	637	-5518	6	-6751	631	1233	-602
Oct 01-31	658	-5307	47	-6826	611	1519	-908
Nov 01-30	637	-4200	65	-5398	572	1198	-626
Dec 01-31	658	-3564	152	-4316	506	752	-246
Summed total	7753	-58505	923	-71823	6830	13318	-6488

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2a Light Energy Gain (kBtu)	Type2a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	186	-3259	472	-10	482
Feb 01-28	595	-3156	119	-3156	476	0	476
Mar 01-31	658	-4276	124	-4365	534	89	445
Apr 01-30	637	-5064	115	-5310	522	246	276
May 01-31	658	-6123	46	-6539	612	416	196
Jun 01-30	637	-6130	142	-6676	495	546	-51
Jul 01-31	658	-6148	186	-6707	472	559	-87
Aug 01-31	658	-5749	104	-6113	554	364	190
Sep 01-30	637	-5518	31	-5823	606	305	301
Oct 01-31	658	-5307	64	-5680	594	373	221
Nov 01-30	637	-4200	84	-4379	553	179	374
Dec 01-31	658	-3564	194	-3593	464	29	435
Summed total	7753	-58505	1395	-61601	6358	3096	3262

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3 Light Energy Gain (kBtu)	Type3 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	142	-3739	516	470	46
Feb 01-28	595	-3156	80	-3611	515	455	60
Mar 01-31	658	-4276	90	-4758	568	482	86
Apr 01-30	637	-5064	114	-5547	523	483	40
May 01-31	658	-6123	116	-6802	542	679	-137
Jun 01-30	637	-6130	254	-6967	383	837	-454
Jul 01-31	658	-6148	255	-6966	403	818	-415
Aug 01-31	658	-5749	132	-6359	526	610	-84
Sep 01-30	637	-5518	31	-6237	606	719	-113
Oct 01-31	658	-5307	51	-6383	607	1076	-469
Nov 01-30	637	-4200	65	-5096	572	896	-324
Dec 01-31	658	-3564	141	-4060	517	496	21
Summed total	7753	-58505	1472	-66525	6281	8020	-1739

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3a Light Energy Gain (kBtu)	Type3a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	184	-3278	474	9	465
Feb 01-28	595	-3156	120	-3173	475	17	458
Mar 01-31	658	-4276	137	-4351	521	75	446
Apr 01-30	637	-5064	196	-5294	441	230	211
May 01-31	658	-6123	336	-6688	322	565	-243
Jun 01-30	637	-6130	459	-6840	178	710	-532
Jul 01-31	658	-6148	466	-6835	192	687	-495
Aug 01-31	658	-5749	244	-6134	414	385	29
Sep 01-30	637	-5518	79	-5835	558	317	241
Oct 01-31	658	-5307	73	-5740	585	433	152
Nov 01-30	637	-4200	89	-4449	548	249	299
Dec 01-31	658	-3564	189	-3604	469	40	429
Summed total	7753	-58505	2572	-62219	5181	3714	1467

Table 0-3: South Diffuse- Electrical Lighting Vs Sensible Cooling Energy Consumption for All Types

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1 Light Energy Gain (kBtu)	Type1 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	228	-3273	430	4	426
Feb 01-28	595	-3156	179	-3259	416	103	313
Mar 01-31	658	-4276	141	-4546	517	270	247
Apr 01-30	637	-5064	75	-5403	562	339	223
May 01-31	658	-6123	28	-6639	630	516	114
Jun 01-30	637	-6130	69	-6593	568	463	105
Jul 01-31	658	-6148	82	-6554	576	406	170
Aug 01-31	658	-5749	56	-6127	602	378	224
Sep 01-30	637	-5518	37	-5888	600	370	230
Oct 01-31	658	-5307	98	-5580	560	273	287
Nov 01-30	637	-4200	142	-4280	495	80	415
Dec 01-31	658	-3564	297	-3608	361	44	317
Summed total	7753	-58505	1432	-61751	6321	3246	3075

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1a Light Energy Gain (kBtu)	Type1a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	486	-3288	172	19	153
Feb 01-28	595	-3156	388	-3183	207	27	180
Mar 01-31	658	-4276	310	-4292	348	16	332
Apr 01-30	637	-5064	250	-5096	387	32	355
May 01-31	658	-6123	155	-6161	503	38	465
Jun 01-30	637	-6130	199	-6178	438	48	390
Jul 01-31	658	-6148	239	-6192	419	44	375
Aug 01-31	658	-5749	184	-5736	474	-13	487
Sep 01-30	637	-5518	188	-5525	449	7	442
Oct 01-31	658	-5307	324	-5357	334	50	284
Nov 01-30	637	-4200	381	-4206	256	6	250
Dec 01-31	658	-3564	509	-3594	149	30	119
Summed total	7753	-58505	3614	-58809	4139	304	3835

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2 Light Energy Gain (kBtu)	Type2 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	177	-3994	481	725	-244
Feb 01-28	595	-3156	102	-3878	493	722	-229
Mar 01-31	658	-4276	111	-5165	547	889	-342
Apr 01-30	637	-5064	54	-6025	583	961	-378
May 01-31	658	-6123	17	-7433	641	1310	-669
Jun 01-30	637	-6130	84	-7550	553	1420	-867
Jul 01-31	658	-6148	114	-7573	544	1425	-881
Aug 01-31	658	-5749	66	-6936	592	1187	-595
Sep 01-30	637	-5518	18	-6744	619	1226	-607
Oct 01-31	658	-5307	54	-6830	604	1523	-919
Nov 01-30	637	-4200	73	-5405	564	1205	-641
Dec 01-31	658	-3564	182	-4344	476	780	-304
Summed total	7753	-58505	1053	-71877	6700	13372	-6672

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2a Light Energy Gain (kBtu)	Type2a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	225	-3299	433	30	403
Feb 01-28	595	-3156	158	-3197	437	41	396
Mar 01-31	658	-4276	162	-4408	496	132	364
Apr 01-30	637	-5064	157	-5355	480	291	189
May 01-31	658	-6123	78	-6573	580	450	130
Jun 01-30	637	-6130	153	-6688	484	558	-74
Jul 01-31	658	-6148	186	-6710	472	562	-90
Aug 01-31	658	-5749	130	-6142	528	393	135
Sep 01-30	637	-5518	62	-5859	575	341	234
Oct 01-31	658	-5307	89	-5708	569	401	168
Nov 01-30	637	-4200	103	-4400	534	200	334
Dec 01-31	658	-3564	235	-3632	423	68	355
Summed total	7753	-58505	1739	-61971	6014	3466	2548

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3 Light Energy Gain (kBtu)	Type3 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	162	-3757	496	488	8
Feb 01-28	595	-3156	100	-3629	495	473	22
Mar 01-31	658	-4276	121	-4787	537	511	26
Apr 01-30	637	-5064	81	-5516	556	452	104
May 01-31	658	-6123	55	-6747	603	624	-21
Jun 01-30	637	-6130	134	-6857	503	727	-224
Jul 01-31	658	-6148	173	-6892	485	744	-259
Aug 01-31	658	-5749	99	-6328	559	579	-20
Sep 01-30	637	-5518	33	-6238	604	720	-116
Oct 01-31	658	-5307	57	-6388	601	1081	-480
Nov 01-30	637	-4200	72	-5104	565	904	-339
Dec 01-31	658	-3564	164	-4081	494	517	-23
Summed total	7753	-58505	1252	-66324	6501	7819	-1318

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3a Light Energy Gain (kBtu)	Type3a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3269	215	-3306	443	37	406
Feb 01-28	595	-3156	155	-3205	440	49	391
Mar 01-31	658	-4276	190	-4399	468	123	345
Apr 01-30	637	-5064	182	-5280	455	216	239
May 01-31	658	-6123	300	-6655	358	532	-174
Jun 01-30	637	-6130	348	-6738	289	608	-319
Jul 01-31	658	-6148	369	-6746	289	598	-309
Aug 01-31	658	-5749	284	-6171	374	422	-48
Sep 01-30	637	-5518	118	-5870	519	352	167
Oct 01-31	658	-5307	104	-5767	554	460	94
Nov 01-30	637	-4200	106	-4465	531	265	266
Dec 01-31	658	-3564	225	-3637	433	73	360
Summed total	7753	-58505	2597	-62240	5156	3735	1421

Table 0-4: South Clear- Electrical Lighting Vs Sensible Cooling Energy Consumption for All Types

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1 Light Energy Gain (kBtu)	Type1 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)	Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1a Light Energy Gain (kBtu)	Type1a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3273	176	-3229	482	-44	526	Jan 01-31	658	-3273	302	-3122	356	-151	507
Feb 01-28	595	-3156	91	-3182	504	26	478	Feb 01-28	595	-3156	184	-2996	411	-160	571
Mar 01-31	658	-4265	81	-4487	577	222	355	Mar 01-31	658	-4265	157	-4144	501	-121	622
Apr 01-30	637	-5044	45	-5363	592	319	273	Apr 01-30	637	-5044	111	-4953	526	-91	617
May 01-31	658	-6101	7	-6600	651	499	152	May 01-31	658	-6101	48	-6040	610	-61	671
Jun 01-30	637	-6113	44	-6554	593	441	152	Jun 01-30	637	-6113	108	-6077	529	-36	565
Jul 01-31	658	-6133	59	-6520	599	387	212	Jul 01-31	658	-6133	142	-6088	516	-45	561
Aug 01-31	658	-5728	26	-6085	632	357	275	Aug 01-31	658	-5728	103	-5646	555	-82	637
Sep 01-30	637	-5498	8	-5852	629	354	275	Sep 01-30	637	-5498	45	-5379	592	-119	711
Oct 01-31	658	-5304	47	-5532	611	228	383	Oct 01-31	658	-5304	106	-5153	552	-151	703
Nov 01-30	637	-4204	73	-4223	564	19	545	Nov 01-30	637	-4204	172	-4017	465	-187	652
Dec 01-31	658	-3569	174	-3501	484	-68	552	Dec 01-31	658	-3569	304	-3409	354	-160	514
Summed total	7753	-58388	830	-61128	6923	2740	4183	**Summed total**	7753	-58388	1782	-57023	5971	-1365	7336

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2 Light Energy Gain (kBtu)	Type2 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)	Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2a Light Energy Gain (kBtu)	Type2a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3273	169	-3693	489	420	69	Jan 01-31	658	-3273	204	-3203	454	-70	524
Feb 01-28	595	-3156	87	-3740	508	584	-76	Feb 01-28	595	-3156	117	-3144	478	-12	490
Mar 01-31	658	-4265	77	-5409	581	1144	-563	Mar 01-31	658	-4265	95	-4467	563	202	361
Apr 01-30	637	-5044	46	-6623	591	1579	-988	Apr 01-30	637	-5044	63	-5486	574	442	132
May 01-31	658	-6101	4	-8276	654	2175	-1521	May 01-31	658	-6101	10	-6814	648	713	-65
Jun 01-30	637	-6113	45	-8157	592	2044	-1452	Jun 01-30	637	-6113	64	-6830	573	717	-144
Jul 01-31	658	-6133	60	-8094	598	1961	-1363	Jul 01-31	658	-6133	84	-6817	574	684	-110
Aug 01-31	658	-5728	32	-7566	626	1838	-1212	Aug 01-31	658	-5728	46	-6300	612	572	40
Sep 01-30	637	-5498	4	-7250	633	1752	-1119	Sep 01-30	637	-5498	10	-5996	627	498	129
Oct 01-31	658	-5304	40	-6810	618	1506	-888	Oct 01-31	658	-5304	52	-5707	606	403	203
Nov 01-30	637	-4204	65	-5037	572	833	-261	Nov 01-30	637	-4204	81	-4298	556	94	462
Dec 01-31	658	-3569	173	-4020	485	451	34	Dec 01-31	658	-3569	217	-3533	441	-36	477
Summed total	7753	-58388	801	-74673	6952	16285	-9333	**Summed total**	7753	-58388	1043	-62596	6710	4208	2502

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3 Light Energy Gain (kBtu)	Type3 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)	Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3a Light Energy Gain (kBtu)	Type3a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3273	347	-3385	311	112	199	Jan 01-31	658	-3273	428	-3021	230	-252	482
Feb 01-28	595	-3156	270	-3367	325	211	114	Feb 01-28	595	-3156	353	-3154	242	-2	244
Mar 01-31	658	-4265	259	-4736	399	471	-72	Mar 01-31	658	-4265	351	-5052	307	787	-480
Apr 01-30	637	-5044	229	-5809	408	765	-357	Apr 01-30	637	-5044	333	-6778	304	1734	-1430
May 01-31	658	-6101	195	-7208	463	1107	-644	May 01-31	658	-6101	299	-8934	359	2833	-2474
Jun 01-30	637	-6113	215	-7208	422	1095	-673	Jun 01-30	637	-6113	328	-8988	309	2875	-2566
Jul 01-31	658	-6133	247	-7182	411	1049	-638	Jul 01-31	658	-6133	358	-8841	300	2708	-2408
Aug 01-31	658	-5728	214	-6637	444	909	-465	Aug 01-31	658	-5728	330	-8031	328	2303	-1975
Sep 01-30	637	-5498	175	-6347	462	849	-387	Sep 01-30	637	-5498	293	-7619	344	2121	-1777
Oct 01-31	658	-5304	224	-6019	434	715	-281	Oct 01-31	658	-5304	326	-6965	332	1661	-1329
Nov 01-30	637	-4204	229	-4516	408	312	96	Nov 01-30	637	-4204	325	-4753	312	549	-237
Dec 01-31	658	-3569	344	-3717	314	148	166	Dec 01-31	658	-3569	430	-3482	228	-87	315
Summed total	7753	-58388	2948	-66131	4805	7743	-2938	**Summed total**	7753	-58388	4155	-75618	3598	17230	-13632

Table 0-5: West Diffuse- Electrical Lighting Vs Sensible Cooling Energy Consumption for All Types

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1 Light Energy Gain (kBtu)	Type1 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3273	177	-3229	481	-44	525
Feb 01-28	595	-3157	91	-3179	504	22	482
Mar 01-31	658	-4267	79	-4480	579	213	366
Apr 01-30	637	-5048	47	-5359	590	311	279
May 01-31	658	-6101	7	-6597	651	496	155
Jun 01-30	637	-6113	43	-6552	594	439	155
Jul 01-31	658	-6134	58	-6519	600	385	215
Aug 01-31	658	-5732	27	-6080	631	348	283
Sep 01-30	637	-5503	12	-5848	625	345	280
Oct 01-31	658	-5304	47	-5529	611	225	386
Nov 01-30	637	-4204	72	-4221	565	17	548
Dec 01-31	658	-3568	176	-3503	482	-65	547
Summed total	7753	-58402	834	-61097	6919	2695	4224

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type1a Light Energy Gain (kBtu)	Type1a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3273	310	-3123	348	-150	498
Feb 01-28	595	-3157	194	-3002	401	-155	556
Mar 01-31	658	-4267	156	-4137	502	-130	632
Apr 01-30	637	-5048	115	-4951	522	-97	619
May 01-31	658	-6101	51	-6040	607	-61	668
Jun 01-30	637	-6113	102	-6071	535	-42	577
Jul 01-31	658	-6134	155	-6099	503	-35	538
Aug 01-31	658	-5732	106	-5646	552	-86	638
Sep 01-30	637	-5503	57	-5383	580	-120	700
Oct 01-31	658	-5304	109	-5154	549	-150	699
Nov 01-30	637	-4204	153	-3997	484	-207	691
Dec 01-31	658	-3568	310	-3412	348	-156	504
Summed total	7753	-58402	1819	-57014	5934	-1388	7322

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2 Light Energy Gain (kBtu)	Type2 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3273	168	-3693	490	420	70
Feb 01-28	595	-3157	89	-3742	506	585	-79
Mar 01-31	658	-4267	76	-5410	582	1143	-561
Apr 01-30	637	-5048	46	-6621	591	1573	-982
May 01-31	658	-6101	4	-8279	654	2178	-1524
Jun 01-30	637	-6113	44	-8159	593	2046	-1453
Jul 01-31	658	-6134	62	-8096	596	1962	-1366
Aug 01-31	658	-5732	32	-7557	626	1825	-1199
Sep 01-30	637	-5503	4	-7252	633	1749	-1116
Oct 01-31	658	-5304	40	-6813	618	1509	-891
Nov 01-30	637	-4204	65	-5038	572	834	-262
Dec 01-31	658	-3568	173	-4019	485	451	34
Summed total	7753	-58402	802	-74678	6951	16276	-9325

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type2a Light Energy Gain (kBtu)	Type2a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3273	206	-3202	452	-71	523
Feb 01-28	595	-3157	115	-3142	480	-15	495
Mar 01-31	658	-4267	95	-4468	563	201	362
Apr 01-30	637	-5048	62	-5486	575	438	137
May 01-31	658	-6101	9	-6815	649	714	-65
Jun 01-30	637	-6113	63	-6829	574	716	-142
Jul 01-31	658	-6134	83	-6816	575	682	-107
Aug 01-31	658	-5732	46	-6301	612	569	43
Sep 01-30	637	-5503	9	-5996	628	493	135
Oct 01-31	658	-5304	50	-5708	608	404	204
Nov 01-30	637	-4204	84	-4300	553	96	457
Dec 01-31	658	-3568	215	-3529	443	-39	482
Summed total	7753	-58402	1037	-62592	6716	4190	2526

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3 Light Energy Gain (kBtu)	Type3 Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3273	289	-3470	369	197	172
Feb 01-28	595	-3157	200	-3439	395	282	113
Mar 01-31	658	-4267	186	-4907	472	640	-168
Apr 01-30	637	-5048	145	-5982	492	934	-442
May 01-31	658	-6101	121	-7455	537	1354	-817
Jun 01-30	637	-6113	147	-7356	490	1243	-753
Jul 01-31	658	-6134	162	-7336	496	1202	-706
Aug 01-31	658	-5732	129	-6851	529	1119	-590
Sep 01-30	637	-5503	112	-6545	525	1042	-517
Oct 01-31	658	-5304	180	-6207	478	903	-425
Nov 01-30	637	-4204	207	-4679	430	475	-45
Dec 01-31	658	-3568	303	-3784	355	216	139
Summed total	7753	-58402	2181	-68011	5572	9609	-4037

Date	Base Light Energy Gain (kBtu)	Base Cooling Energy Gain (kBtu)	Type3a Light Energy Gain (kBtu)	Type3a Cooling Energy Gain (kBtu)	Light Energy (Base-Type)	Cooling Energy (Base-Type)	Total Energy Saving (kBtu)
Jan 01-31	658	-3273	365	-2990	293	-283	576
Feb 01-28	595	-3157	284	-3116	311	-41	352
Mar 01-31	658	-4267	278	-5041	380	774	-394
Apr 01-30	637	-5048	241	-6760	396	1712	-1316
May 01-31	658	-6101	216	-8940	442	2839	-2397
Jun 01-30	637	-6113	239	-8965	398	2852	-2454
Jul 01-31	658	-6134	254	-8809	404	2675	-2271
Aug 01-31	658	-5732	224	-8014	434	2282	-1848
Sep 01-30	637	-5503	199	-7588	438	2085	-1647
Oct 01-31	658	-5304	267	-6955	391	1651	-1260
Nov 01-30	637	-4204	295	-4755	342	551	-209
Dec 01-31	658	-3568	389	-3462	269	-106	375
Summed total	7753	-58402	3250	-75395	4503	16993	-12490

Table 0-6: East Diffuse- Electrical Lighting Vs Sensible Cooling Energy Consumption for All Types