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Glazing Performance in the Patient Care Setting

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GLAZING PERFORMANCE OF HOSPITAL INPATIENT ROOMS

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ABSTRACT

Windows can have positive effects on hospital staff and patient health and well-being. Proper window design can also significantly benefit hospital energy conservation, consequentially reducing environmental impact. However, often the glazing and fenestration design of the hospital envelope can be heavily impacted by building components like structural and mechanical systems. The location of these building components at the exterior wall can lead to a reduction of glazing area, increase the use of electric lighting, and limit the potential benefits that glazing design can provide to occupants.

The health benefits of glazing for building occupants have been well documented. Natural daylight and views to the outdoors have shown benefits to hospital patients and staff. The application of glazing in the hospital can have effects on patient well-being, reducing recovery time, length of stay, stress, depression, and medication use, improving patient satisfaction. Likewise, access to windows in the workplace improves staff well-being, increasing productivity, and job satisfaction, while reducing staff absenteeism, and turnover.

Hospital occupants are involved in various types of activity resulting in a wide range of preferred lighting and thermal conditions. This makes it challenging to maintain ideal occupant lighting and thermal

comfort levels and leads to a dependence on electric lighting and mechanical air conditioning. Hospitals have a high energy intensity due to their complexity, density, and continuous occupancy. This energy intensity is further compounded by the size and scale of these buildings. The layout of glazing effects energy consumption for electric lighting and mechanical air conditioning, emissions and the resulting impact on the environment. This research will study the design factors effecting the application of glazing and their impact on the conditions within the patient room.

An in depth literature review studying the effects of glazing design on patient, staff, and environmental outcomes, along with documentation of established benchmarks and best practices will inform and quantify lighting, thermal, and energy metrics. A comparative case study research and analysis of three different approaches to glazing design in the patient room will evaluate varying built design factors and their impact on lighting, thermal, and energy performance. Using building information modelling alongside energy simulation and analysis software, it is possible to weigh the effects of various physical design considerations. Analyzing the lighting and thermal characteristics of three different approaches to window design in the patient room, this research will document the relationships between built features that impact fenestration design and the lighting and thermal metrics which are found to affect occupant health outcomes and building energy performance.

DEDICATION

To my family and friends for all of your love and support.

ACKNOWLEDGEMENTS

To my thesis committee Dina Battisto, Vincent Blouin, and Daniel Harding for all of your guidance, direction, and encouragement.

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1 INTRODUCTION

Glass was first developed nearly 2,000 years ago. When it was introduced as a building product it served as a means to seal openings in the fenestration of the building envelope. Until the introduction of window glazing, penetrations in the building skin that were intended to provide light and views to the outdoors were open to the elements allowing wind, water, sound, and fire to penetrate into the building. The introduction of window glazing allowed the transmission of light into the building while reducing the impact of the outside elements from affecting the conditions within the building.

Windows have several functions. Beyond providing natural daylight and views to the outdoors, windows can provide ventilation, thermal insulation, sound insulation, radiation control, and fire protection. Windows provide protection against the weather and elements like rain, wind and cold. In addition to serving the practical purpose of sealing the envelope while providing daylight and views, the application of glazing can have an impact on building energy performance and has been shown to benefit the health and well-being of building occupants. Glazing in the healthcare environment has been shown to have a significant impact on patient and staff health and well-being as well as building performance metrics.

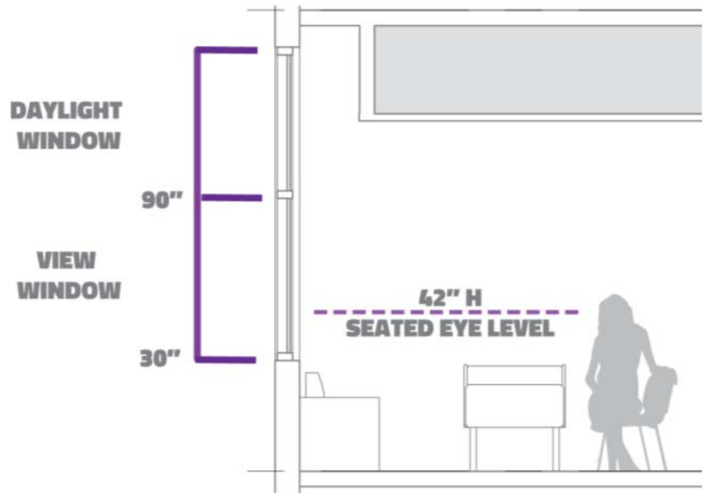


Figure 01: Window placement for daylighting and views (LEED EQc8.2 Daylight and Views)

Windows serve two main purposes to the occupant: to provide daylight penetration into the room and to provide a view to the outdoors. These two functions, while each important, also can vary in their application, due to variations in window placement, height, and area, to achieve either goal. This presents the need for separate individual windows or glazing areas suited to provide both daylighting and view.

The sizing and placement of glazing can vary depending upon the intended role of the window. Daylighting windows are positioned above view windows. Daylight glazing is placed greater than 90" above the finish floor height up to ceiling height in order to provide the greatest daylight penetration into the room. View windows are positioned at mid-height. Vision glazing or view windows are considered to be any glazing located between 30" to 90" above the finish floor level according to LEED EQc8.2 Daylight and Views – Views for 90% of spaces.

Incorporating aspects of both daylight and view glazing into the fenestration design is ideal. The use of solely a view window without the added support of a daylighting window may provide a view, but limits the potential daylight penetration into the room. The use of a daylight window without a vision window will provide natural daylight but lack views to the outdoors. Integrating both daylight and vision glazing into a complementary system provides more potential impact building occupants.

Glazing & Patient Health

The daylight and views provided by window glazing have been associated with several benefits to hospital patients and staff. Glazing has been shown to improve patient well-being, by reducing stress (Ulrich, K, et al. 1991). Windows have been shown to reduce depression in patients (Beauchemin, K, et al. 1996). Patient medication use also declines with window views (Ulrich, K, et al. 1984). Access to windows has shown to reduce patient length of stay (Brown, et al. 2005). Window layout should be a primary consideration in the design of spaces like the patient room as an effective tool for providing daylighting and views shown to improve patient health and recovery.

Glazing & Staff Occupational Health

Windows in the workplace provide several benefits for health care staff. Staff prefer to have access to windows at work (MrocZek, J, et al. 2005). Glazing in the workplace improves staff well-being and job satisfaction (Leather, Pyrgas, et al. 1998). Access to windows has been shown to improve staff productivity (Browning, et al. 2012). Staff access to windows reduces absenteeism, turnover, and associated staff costs (Browning, et al. 2012). Considering the benefits that windows can have on hospital staff, glazing design may be an effective tool to improve health care delivery by improving staff working conditions.

Glazing & Energy Performance

The energy performance of a building can be affected by its glazing fenestration design. The layout and sizing of windows can affect both lighting and thermal conditions within the building. This in turn effects energy consumption for electric lights and mechanical air conditioning. Hospitals are very energy intense buildings due to their reliance on electric lighting and mechanical HVAC systems. Improved daylighting can reduce energy consumption for electric lighting reducing the need for mechanical hvac systems to cool internal heat gains.

Problem Statement

Windows can offer several benefits to hospital staff and patients by improving occupant health and well-being. The use of natural daylighting can significantly reduce hospital energy consumption, and consequently environmental impact. However, the layout of fenestration on the hospital facade is often dictated by building components like structural and mechanical systems which drive ceiling heights and impact window wall ratios. This reduces the potential area to accommodate glazing, increasing reliance on electric lighting and limiting the occupant benefits of daylighting and views to the outdoors.

Purpose of Research

This research will focus on the effect that these built design factors have on window glazing and fenestration layout. Studying three different window conditions in three varying patient rooms this research will analyze how design factors like room layout, ceiling configuration, structural, and mechanical systems affect the application of glazing and solar screening methods. Through simulation and analysis, this case study comparison will measure the potential for these design factors to impact the metrics which have been shown to affect occupant health and well-being as well as building energy performance.

Research Questions

How does the layout of building systems impact the fenestration and glazing design of the patient room? How can these building systems be incorporated to allow for the most performative layout of fenestration and glazing. What design characteristics provide the most optimal lighting and thermal conditions? How can lighting, thermal, and energy considerations be balanced to benefit the occupant and environment?

A study of the impact that built design factors have on the sizing and placement of fenestration and window glazing will inform a comparison of varying approaches to glazing design in the patient room. Using simulation and analysis, three different approaches to patient room fenestration design will be studied in relation to lighting thermal and energy metrics. It will also study the impact that solar screening methods can have on regulating the levels of solar radiation that reach the window, and in turn the lighting and thermal conditions within the building. The simulation and analysis research will measure the impact of various built design factors on fenestration layout, and the resulting lighting and thermal conditions affecting occupant comfort and building energy performance.

A literature review focused on the impact that glazing design can have on patient, staff, and building performance outcomes will identify the established benefits. Understanding the benefits that glazing design can have on building occupant and the environment will aid in selecting lighting, thermal, and energy metrics for data collection and analysis.

Definitions

Lighting Metrics

Lighting metrics that will be studied include daylight factor, Illuminance, and Luminance. First, daylight factor describes the amount of available daylight outside of the building that is present inside the building. Daylight factor is expressed as a percentage. This is helpful in analyzing the use of available natural daylight. Daylight factor can help to assess natural lighting conditions within the building as well as potential reductions in electric lighting energy. In addition to reductions in energy consumption for electric lighting, the use of natural daylight can often reduce mechanical air conditioning energy as well. Typically electric lighting generates greater heat than natural daylight. The use of natural daylighting can reduce the draw on mechanical systems to cool internal gains in order to maintain thermal comfort.

Second, Illuminance or the amount of light falling on a surface is used to assess the quantity of light, in this case useful daylight. Illuminance can be measured in lux or foot candles. Luminance can express the intensity of light levels from electric or natural light sources. The study will use illuminance to measure the quantity of useful daylight within each room configuration. Comparison of illuminance levels between differing room configurations will quantify the impact that built design factors have on useful daylighting levels within the patient room. These levels of useful daylight illuminance can also impact energy consumption by reducing the use of electric lighting.

Third, Luminance represents the amount of light reflected off of a surface. Luminance is often used to assess the quality of light. This can be affected by many factors to include not only the intensity of lighting illuminance but surface color, texture, reflectivity and angle to the light source. These factors can affect luminance levels which are often used to evaluate the potential human perception of lighting conditions impacting visual comfort like excessive brightness and glare. Luminance is measured in candelas per meter sq. (cd/m2). High luminance levels can cause excessive brightness while abrupt variations in luminance levels can create the perception of glare.

Thermal Metrics

The layout of fenestration and glazing design affects not only the lighting conditions within the patient room but the thermal conditions as well. Natural daylighting typically generates less heat than electric lighting. This provides potential for HVAC energy savings during daylight hours by employing natural daylighting methods. Internal heat gains from electric lighting can be reduced using natural daylight. However increased glazing area for daylighting also creates potential for increased solar heat gain

There are many factors that influence the natural lighting within a space, making the proper design approach to the application of glazing a complex process. The potential for natural lighting can be affected by outside conditions such as location, season, weather conditions, and obstructions, like other buildings or trees. The designer must work within the existing conditions and account for building orientation and massing, room layout, glazing size, and placement to make the most of natural lighting.

The design of glazing has the potential to impact the occupant's visual and thermal comfort by affecting both lighting and thermal conditions within a space. Design decisions like glazing size and position can have an impact not only on the occupant, but also on the environment . Natural lighting conditions affect the energy use of electric lighting while thermal considerations affect the use of mechanical HVAC systems. This presents a design challenge in cooling dominated climates. While increased glazing area improves natural daylight, it also allows for increased solar heat gain that requires additional reliance on mechanical HVAC systems to maintain occupant thermal comfort

Occupant Thermal Comfort in Health Care Settings

Thermal Comfort is a representative measure of occupant satisfaction with thermal conditions. There are many factors that go into a person's thermal comfort including their metabolic rate, or activity level, insulation from clothing and thermal conditions like air temperature, mean radiant temperature, relative humidity, and air velocity. Achieving thermal comfort in healthcare facilities is a complex task given the occupants varying levels of activity and desired thermal conditions.

The range of occupant activity levels from active to resting, along with varying thermal comfort preferences; make providing thermal comfort in healthcare difficult. Historically, it has been "relatively challenging to provide suitable thermal comfort conditions and appropriate indoor environment quality because of the diverse conditions required for different types of occupants." (ASHRAE, 2010) The size and sophistication of health care facilities also presents a challenge, in meeting thermal comfort needs as "hospital and health care buildings are complex indoor facilities with numerous occupants and diverse end users of indoor spaces and functions"(ASHRAE, 2010). The scope and complexity of providing thermal comfort in health care facilities has led to a strong reliance on mechanical HVAC equipment to achieve steady thermal conditions.   The necessity to provide thermal comfort is essential in healthcare facilities to promote recovery and healing.

Given the function of hospitals as places of healing, it is important to provide comfortable thermal conditions to support in recovery. Thermal comfort is considered “vital for provision of human comfort and for facilitating the healing process.”(ASHRAE, 2010) The significance of maintaining occupant thermal comfort is essential, given the potential impact that thermal comfort can have on recovery. Thermal comfort is considered to be vital in healthcare facilities, as “more so than in any other type of building, it is essential to establish comfortable environmental conditions..”(ASHRAE, 2010) The effect that glazing can have on thermal comfort will be studied to see whether variations in glazing design can have a substantial effect on thermal conditions and HVAC energy consumption.

The thermal conditions found to be most comfortable for patients in the healthcare setting take into account air temperature, humidity, mean radiant temperature and air velocity. These factors represent the “steady-state conditions preferred by the patients. These were an air temperature of between 21.5 degrees and 22 degrees C (70.7-71.6 degrees F) and a relative humidity of between 30%-70%, where

Patient Preferred Thermal Conditions

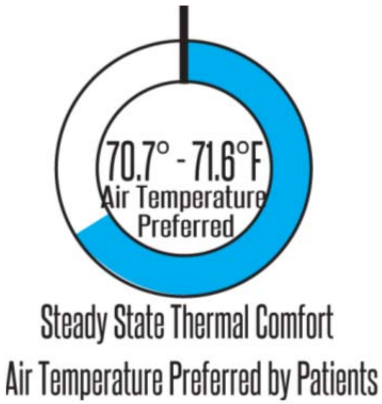


Figure 02: Patient preferred air temperature (ASHRAE, 2010)

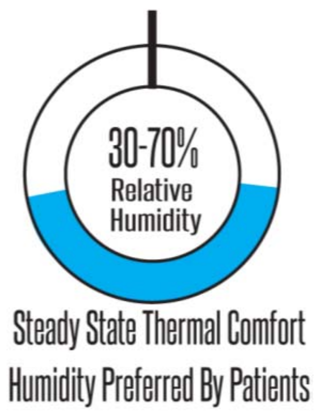


Figure 03: Patient preferred humidity levels (ASHRAE, 2010)

the air velocity was less than 0-1 m/s and the mean radiant temperature was close to air temperature." (ASHAE, 2010) Providing consistent thermal comfort in healthcare settings can be challenging given the range of conditions that make up one's thermal comfort. However the conditions preferred by patients will serve as the benchmark for this analysis.

Guidelines for Thermal Comfort

ANSI/ASHRAE Standard 55 (ASHRAE, 2010) provides comprehensive general guidelines on thermal environmental conditions for human occupancy, specifying the combinations of thermal environmental factors and personal factors.

ASHRAE Handbook--Fundamentals (ASHRAE, 2009) lists the fundamentals of human comfort in terms of useful parameters for operating systems and for providing comfort to building occupants

The Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD) are the most widely used methods of determining occupant thermal comfort. They are used by ANSI, ISO, and ASHRAE. Variations in external factors like radiant and air temperature, humidity, and air velocity, along with personal factors like metabolic rate and clothing insulation, can all affect a person's thermal comfort. Through research, testing, and analysis of these thermal factors methods have been developed into a thermal comfort index. The Predicted Mean Vote and Predicted Percentage Dissatisfied provide target metrics to quantify occupant thermal comfort.

The Predicted Mean Vote is measured on a scale of -3 to +3 describing the sensation of thermal comfort from cold to hot. PMV ranges from -3 representing cold, -2 meaning cool, and -1 slightly cool, to 1 or slightly warm, 2 for warm and 3 for hot. Neutral thermal comfort between slightly cool and slightly warm is represented by 0. The ideal range for indoor thermal comfort is within -.05 to .05, according to ASHRAE Standard 55.

As the predicted mean vote or PMV moves further from neutral, it increases the percentage of people dissatisfied (PPD). The predicted percentage dissatisfied represents a calculated prediction of the percentage of people that will be dissatisfied with their thermal comfort level, given the various thermal factors present. ASHRAE Standard 55 recommends interior spaces to maintain a Predicted Percentage Dissatisfied of less than 10%. “Calculation of the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) associated with other environmental conditions enables the analytical investigation and interpretation of thermal comfort.” (ASHRAE 2010) Predicted Mean Vote & Predicted Percentage Dissatisfied are recognized by ANSI, ISO, and ASHRAE to quantify the perception of thermal comfort, and to specify the necessary conditions to achieve it.

Energy & Environmental Impact Metrics

These various lighting and thermal considerations will be weighed in comparative simulations that will take into account various design factors studying the effect that fenestration design can have on energy consumption and the resulting environmental impact. The simulations will consider energy consumption for mechanical HVAC systems measured in btus per hour (btus/hr). Environmental impact will be reflected in carbon dioxide emissions and measured in pounds of carbon dioxide emitted annually (lbs. co2/yr)

These lighting thermal and energy metrics can all be affected by the placement and layout of glazing and fenestration design. These factors are quite relevant to take into account for health care design given to the nature of health care facilities and their occupants. The density, occupancy, and activity level of healthcare facilities makes them one of the most energy intensive building types. This energy intensity is compounded by the size and scale of most hospitals. Fenestration design has the potential to improve building energy performance while improving thermal and lighting conditions for patients and staff.

2 LITERATURE REVIEW

Access to windows in the hospital patient room is linked to numerous positive patient outcomes. A reduction in length of stay (Choi, J, et al. 2011), reduction in medication intake (Center for Health Design), reduced stress (Ulrich, K, et al. 1991), resulting in improved patient well-being (Wilson, L, et al. 1972), and patient satisfaction (Verderber, S, et al. 1986) have all been attributed to windows in the patient room. Considering that access to windows provides several positive health implications for patients, thoughtful design of patient room glazing should be employed as a measure to improve patient health. As places of healing and recovery, hospitals should place an increased emphasis on improved glazing design as a means of achieving these potential patient benefits.

Similarly, windows in the workplace have been linked with several beneficial staff outcomes. Access to windows is the design feature most preferred by staff (worldgbc), as windows improve staff well-being, mood, and temperament (Leather, Pyrgas, et al. 1998), leading to increased productivity (Browning, et al. 2012), job satisfaction, reductions in turnover (Leather, Pyrgas, et al. 1998), and absenteeism (Browning, et al. 2012). Healthcare staff often work long hours under demanding conditions in order to provide quality care to patients. The proper application of glazing design has the potential to improve patient care by improving staff working conditions.

U.S. hospitals are energy intensive buildings due to their size, complexity, and continuous 24 hour occupancy. These factors lead to a reliance on mechanical HVAC systems and electric lighting. This reliance on electric lighting and mechanical HVAC systems leads to natural resource dependence through increased energy consumption. This impacts the environment not only from natural resource consumption but the resulting carbon dioxide emissions as well. The design of glazing at the building envelope has the potential to reduce lighting energy consumption lowering operating costs and greenhouse gas emissions.

The application of glazing design can have numerous effects on occupant's thermal and visual comfort, the energy performance of the building, and the impact that the building may have on the environment. Considering these implications to occupant and environment, several design factors should be taken into account to provide the most performative approach to glazing design in the patient room.

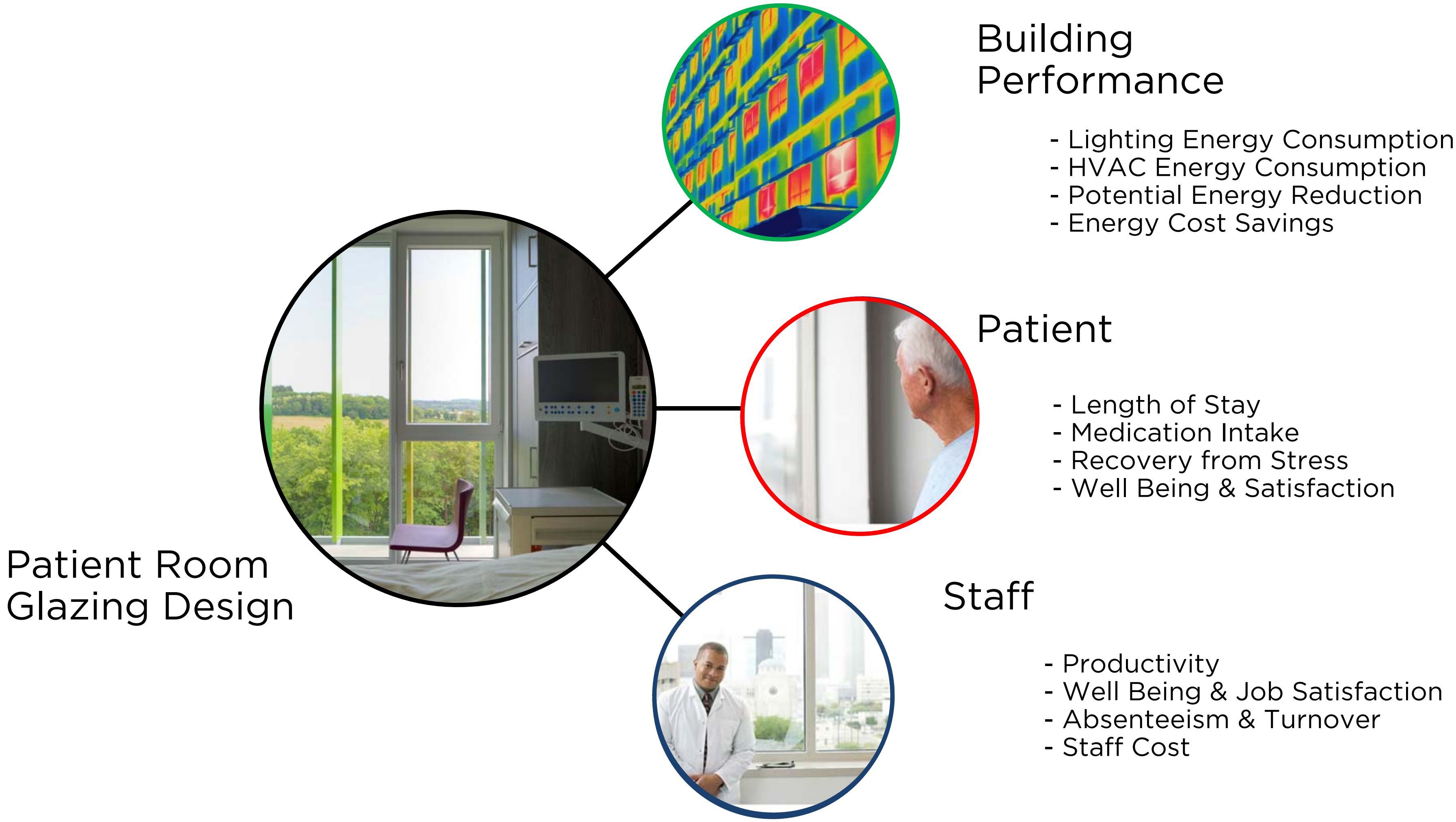


Figure 4: Patient Room Glazing Design Effect

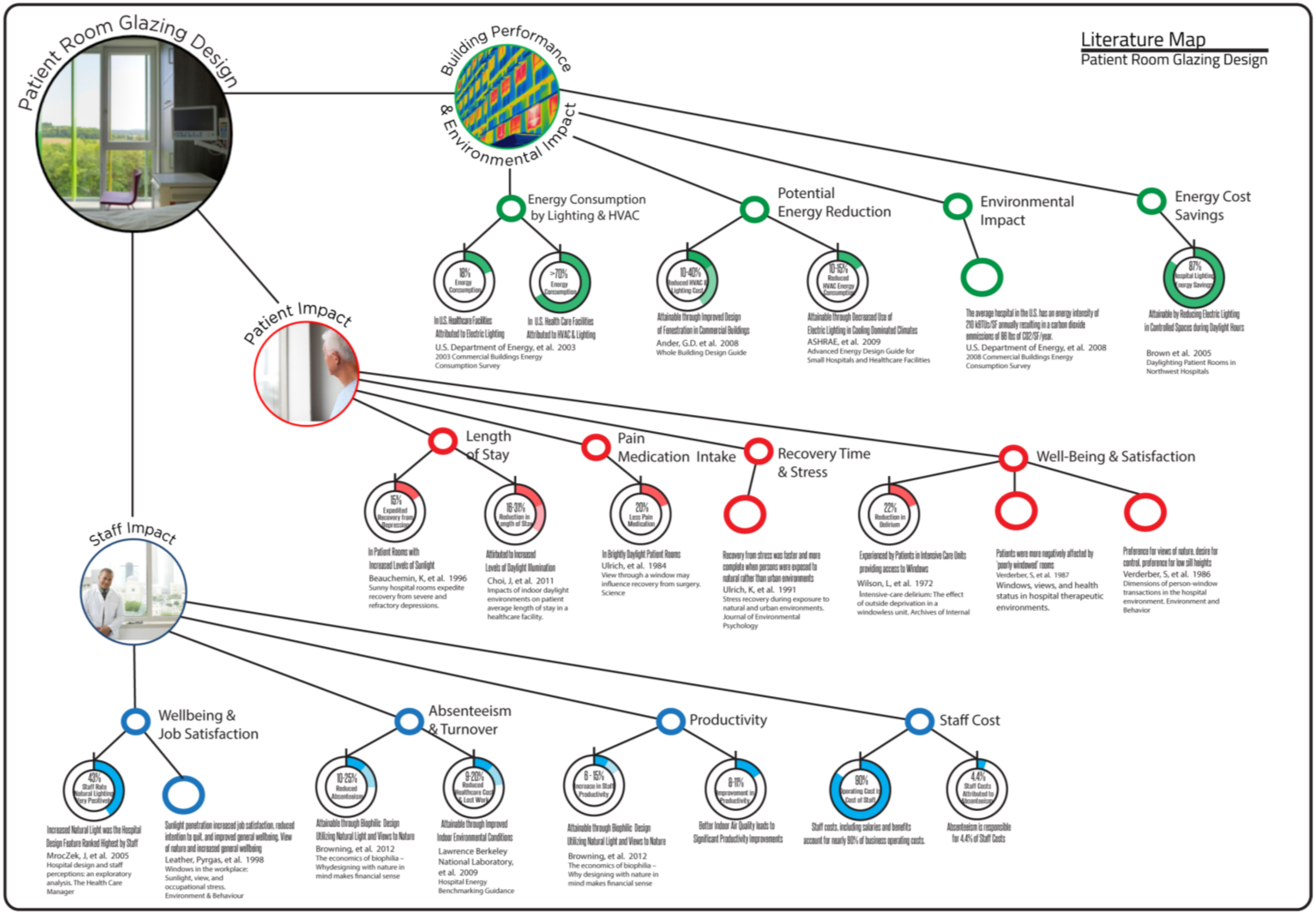


Figure 5: Literature Map

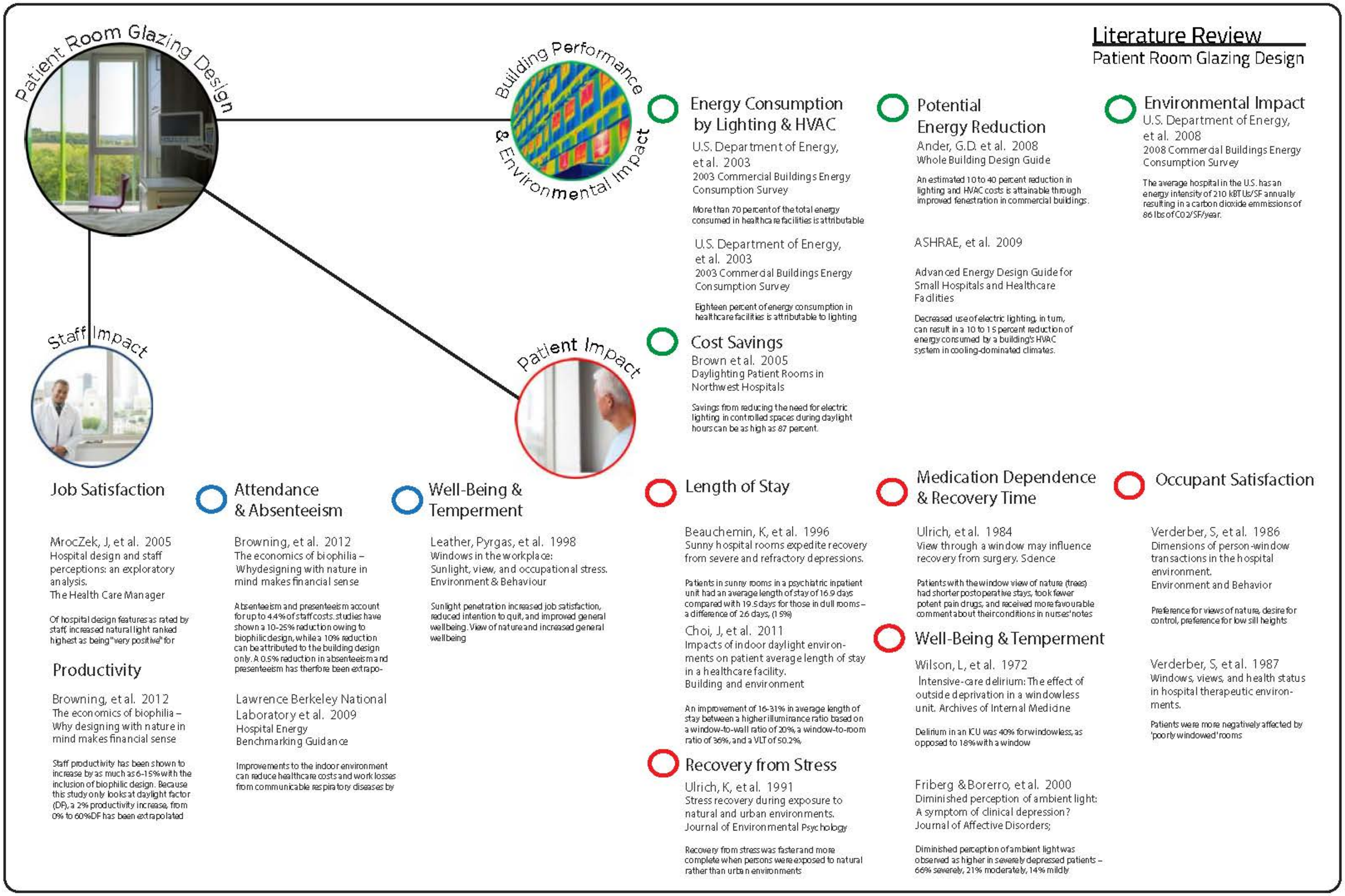


Figure 6: Literature Review

2.1 Building Energy Performance & Environmental Impact

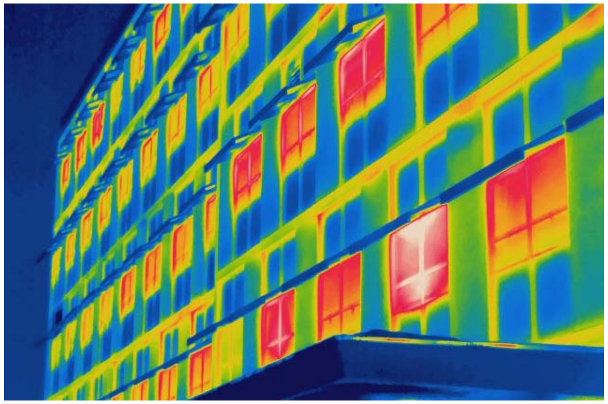


Figure 7: Thermal Imaging of Hospital Façade

Energy Consumption by Lighting & HVAC

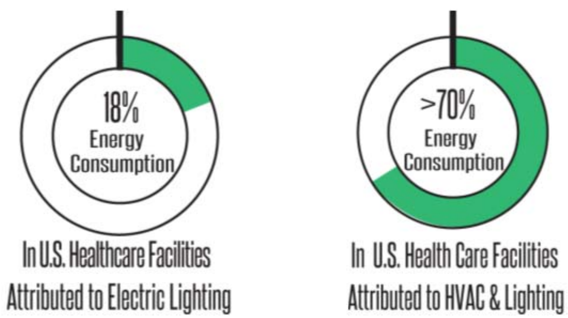


Figure 8: Health Care Energy Consumption
(U.S. Department of Energy, et al. 2003)

There is great potential within healthcare facilities for improvements in building energy performance resulting in reduced environmental impact. This is because hospitals in the United States are one of the most energy consuming building typologies. According to the 2008 Commercial Building Energy Consumption Survey, the average U.S hospital has an energy intensity of 210 kBTUs/SF annually, resulting in carbon dioxide emissions of 86 lbs. of C02/SF/year (U.S. Department of Energy, et al. 2008). The size and complexity of health care facilities leads to a reliance on mechanical systems for cooling and heating, as well as electric lighting. Considering that healthcare facilities like hospitals typically have very large footprints this high energy intensity is multiplied on a large scale, making the overall environmental impact far greater than most other building typologies.

This high energy intensity is due largely to the hospitals reliance on mechanical HVAC systems and electric lights to control thermal and lighting conditions. In 2003 artificial lighting was responsible for 18% of the average hospitals energy consumption, while HVAC and lighting together represented more than 70% of the total energy consumed in healthcare facilities (U.S. Department of Energy, et al. 2003). These rates of energy usage and resulting environmental impact present the need for increased building performance through

Potential Energy Cost Savings During Daylight Hours

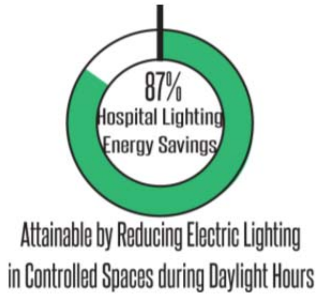


Figure 9: Potential Health Care Energy Savings (Brown, et al. 2005)

Lighting & HVAC Energy Reduction through Daylighting

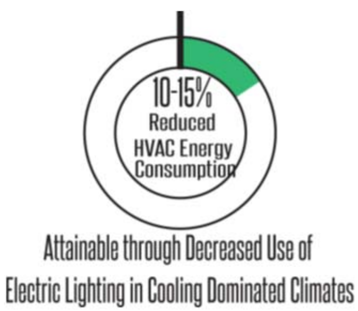


Figure 10: Potential Energy Reduction (ASHRAE, et al. 2009)

improvements in natural daylighting and the use of solar control methods to improve thermal characteristics.

This high level of energy intensity along with the large size of healthcare facilities presents great potential to reduce the overall energy consumption and carbon emissions of hospitals through the use of passive natural lighting and thermal strategies. Studies have shown that great reductions in energy consumption can be realized through the use of increased natural daylighting, as, "reducing the need for electric lighting during daylight hours in controlled spaces like the patient room can result in savings of up to 87%" (Brown, et al. 2005) These energy reductions in electric lighting do not account for the additional associated energy consumption from mechanical systems to maintain occupant thermal comfort

The use of artificial lighting increases energy consumption not only to power electric lights but for the mechanical systems in turn to offset the internal heat gains produced by the lighting. In cooling dominated climates, energy consumed by a buildings mechanical HVAC systems can be reduced as much as 10-15% by utilizing natural daylighting strategies rather than artificial lighting (ASHRAE, et al. 2009). These substantial reductions in HVAC energy consumption can be attributed to a reduction in internal heat gains created by

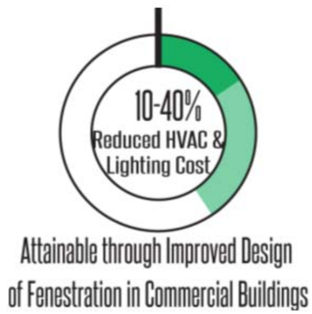


Figure 11: Potential Energy Reduction
(Ander, G.D. et al. 2008)

artificial lighting. Limiting the hours of the day that artificial lighting is used, in turn reduces the amount of heat that is given off by electric lights within the room. In cooling dominated climates, this reduction in internal heat gains from lighting reduces the overall burden on mechanical systems to maintain occupant thermal comfort, as the HVAC system does not have to compete with the heat generated by electric lights in order to keep the room temperature within a given comfort zone.

While the use of natural daylight can substantially reduce lighting energy consumption during daylight hours, the overall energy savings from reduced usage of mechanical systems can be a trade-off between internal heat gains generated by electric lights versus solar heat gain generated by the suns energy when utilizing natural daylight. This trade-off emphasizes the need for performative glazing design in order to utilize natural daylight while limiting the thermal impact of solar heat gains from the envelope. In doing so, greater energy savings in both lighting and HVAC can be realized, as "improvements in fenestration design of commercial buildings can result in an additional 10-40% reduction in energy consumed by electric lighting and mechanical systems combined (Ander, G.D. et al. 2008). Providing natural daylighting while using solar control and shading strategies presents an opportunity to reduce not only electric lighting usage, but also HVAC energy as well.

2.2 Patient Impact

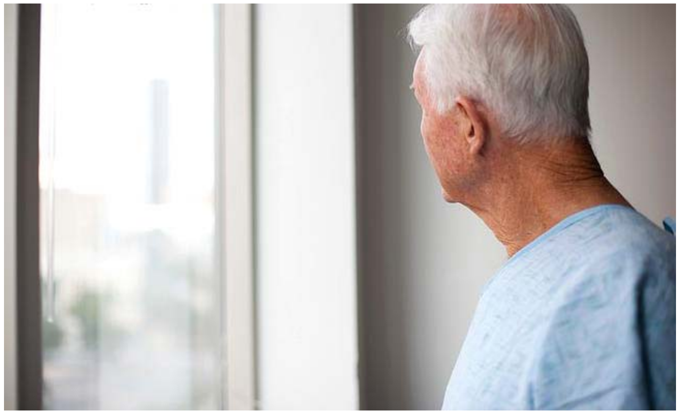


Figure 12: Patient interaction with windows

Patient Length of Stay

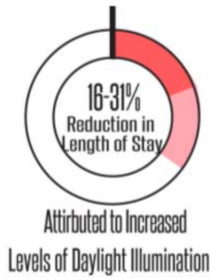


Figure 13: Reduced Patient Length of Stay (Choi, J, et al. 2011)

Research has shown a correlation between window design and patient outcomes. Patients have been found to be negatively affected by rooms with poor window design (Verderber, S, et al. 1987). This is due in part to inadequate glazing area that neglects the two main purposes that windows serve for the occupant; to provide views to the outdoors, and to allow natural daylight into the building. Natural light has been found to be an effective measure to improve recovery time, reduce stress, pain, medication cost, and length of stay.

Patient length of stay is one of the key indicators of progress in the patient's recovery process. Length of stay has not only physical but economic implications given the associated cost of health care and hospitalization. Improved daylighting can aid in the recovery process by reducing patient length of stay. Studies suggest that "increased levels of daylight illumination in the patient room have been found to reduce average patient length of stay by 16-31% (Choi, J, et al. 2011). Considering the substantial role that effective daylighting can play in the length of a patients stay, as well as the physical and economic significance of length of stay to the patient, it is imperative to provide greater access to daylight within the patient room.

Reduce Patient Pain Medication Use & Recovery Time

Figure 14: Reduced Pain Medication (Center for Health Design)

In addition to daylighting, views to nature have been associated with benefits to recovery. These benefits include not only reduced length of stay, but also a reduced dependence on pain medication. The benefits of daylighting and views are evidenced in studies which suggest that, "patients in rooms with windows providing a view of nature following surgery saw a reduction in pain medication and shorter post-operative stays in the hospital (Ulrich, et al. 1984). Just as patient length of stay, the reduction in pain medication is an indicator of the patients physical recovery, and like length of stay, medication costs have a significant effect on the patient's overall cost of healthcare. The effect of daylighting on medication intake was found to be substantial. According to the Center for Health Design, brightly daylit patient rooms have been reduced pain medication costs by 20% (Center for Health Design). Considering the potential positive impact that daylighting and views have on patient recovery time and medication consumption, it is essential to provide design solutions to make the most of available daylight and views to the outdoors.

Reduced Patient Depression & Stress

In addition to shorter length of stay, recovery time, and reduced medication use, improved daylighting in the patient room may reduce patient depression and perceived stress. Daylight has been shown to work effectively, aiding in recovery as an antidepressant. Patient rooms with ample sunlight have been shown to "expedite recovery from depression by 15% over dull rooms with lower levels of natural light" (Beauchemin, K, et al. 1996). The impact that daylight can have in recovery from depression also may be linked to reductions in stress when exposed to nature.

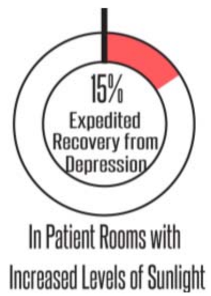


Figure 15: Recovery from Depression (Beauchemin, K, et al. 1996)

These reductions in stress may be inherently related with the biological tendency for people to react favorably to natural environments. It was found that "exposure to natural environments resulted in faster, more complete recovery from stress" (Ulrich, K, et al. 1991). Hospitalization can put patients and family members into an already potentially stressful condition given the nature of the patient's health circumstances. Knowing the benefits that natural light and views can have on recovery from stress, presents the opportunity to take approaches to patient room design that can ease an already stressful experience. Considering the implications that improved daylighting and views can have on reducing patient stress and depression, it is vital to consider approaches to improve daylighting and views within the patient room.

Patient Well-Being & Satisfaction

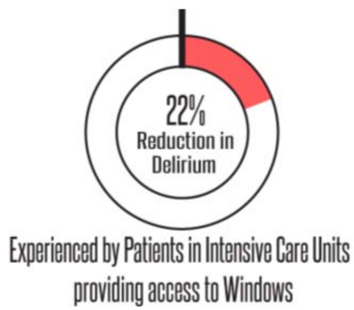


Figure 16: Reduction in Delirium
(Wilson, L, et al. 1972)

The importance of windows on patient well-being is not exclusive to the patient room. The use of windows also has been shown to impact outcomes in other patient care environments. "Windows in Intensive Care Units have been shown to reduce delirium by 22% (Wilson, L, et al. 1972). Since intensive care patients are likely at their most vulnerable, it is critical to leverage every possible measure to support their stability in the recovery process. Taking into account the evident benefits that windows can have on the condition of intensive care patients, raises the prospect for considerable improvements in patient well-being through glazing design.

The evidence to support the benefits that daylighting and views can have on patients is wide ranging and comprehensive. These factors reduced recovery time, medication use, and lead to shorter length of stay. Improved daylight and views also reduced depression and stress encouraging improved well-being and satisfaction. Considering the established benefits that windows and glazing design can influence on patient outcomes, it is consistent that patients were more satisfied in rooms with a greater glazing area. Research shows that "low sill height and views to nature were also found to be preferred" (Verderber, S, et al. 1986). The representative preference of patients for greater glazing area, and the range of evidence for the value of improved daylight and views

2.3 Staff Impact

Figure 17: Staff access to windows

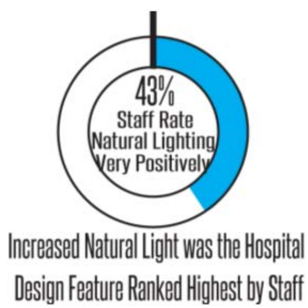


Figure 18: Health care staff preference for daylight (Mroczeck, J, et al. 2005)

for patients health provides strong support for evidence based design approaches to glazing in healthcare.

Research has shown a link between positive staff outcomes and access to windows, yet staff areas of many hospitals have been located within the dense footprint of the building. This disconnects the staff from the beneficial characteristics of windows, which provide daylight and views to the outside.

Access to windows and in turn daylight and views to the outdoors has been shown to be one of the most desired features in a hospital, according to staff. Studies have found that, “Staff of healthcare facilities ranked an increase in natural light as the hospital design feature with the greatest positive feedback, and 43% of staff rated natural light very positive” (MrocZek, J, et al. 2005). Windows in the workplace have been shown to improve staff well-being, job satisfaction, and productivity, while reducing absenteeism, turnover, and staff associated costs.

Staff Well-Being & Job Satisfaction

The preference of health care staff for natural light and views to the outdoors is one of the main drivers impacting the staff well-being and, in turn, job satisfaction. Access to views of the outdoors has been shown to improve staff outcomes, as “staff general well-being was found to improve with views of nature in the workplace” (Leather, Pyrgas, et al. 1998). The staff’s perception of their general well-being in the workplace is also reflected in the level of staff job satisfaction. These factors can have a direct impact on future retention of staff, “Daylight penetration increased staff general well-being and job satisfaction while reducing staff intent to quit” (Leather, Pyrgas, et al. 1998). The role of glazing to provide not only daylighting, but views to the outdoors has been shown to be a primary factor impacting the staff’s impression of their working conditions. Staff well-being and job satisfaction can directly influence reliability and retention as evidenced in the relative rates of staff turnover and absenteeism.

Staff Absenteeism & Turnover

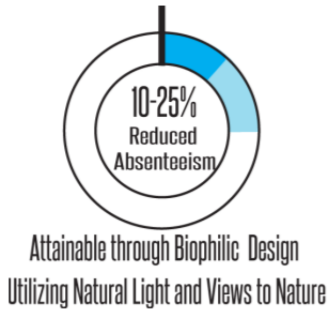


Figure 19: Reduced staff absenteeism (Browning, et al. 2012)

Poor natural lighting can adversely impact staff perceptions of their work conditions leading to a decreased sense of personal well-being and job satisfaction. Reduced job satisfaction can cause increased incidence of staff turnover and absenteeism. Research has shown that improved daylight penetration reduced the staff intent to quit, consequently decreasing the rate of staff turnover. Lowering staff turnover has the potential to reduce staff associated costs. Glazing design also has shown significant implications on staff absenteeism as, studies have found "biophilic design considerations including natural light and views of nature to reduce staff absenteeism by 10-25%" (Browning, et al. 2012). Reductions in staff absenteeism and turnover should also yield improved levels of staff productivity and reduce staff associated costs.

Staff Productivity

Figure 20: Increased Staff Productivity (Browning, et al. 2012)

The capacity of glazing design to impact staff job satisfaction, absenteeism, and turnover also is reflected in the potential effect on staff productivity. Improved staff productivity can be a direct outcome resulting from reductions in staff absenteeism and turnover, as more time on the job should equate to more potential production. In addition, further improvements in staff productivity have been attributed directly to the natural aspects that glazing design can provide, with "improved productivity as high as 6-15% having been associated with the implementation of biophilic design considerations" (Browning, et al. 2012). The potential gains in staff productivity that can result from incorporating natural aspects, like improved daylighting and views, are significant. Considering the benefits to staff productivity that glazing design considerations can impart, it would seem that providing for improved glazing design features would have a positive return on investment.

Reductions in staff absenteeism and turnover parallel increased levels of staff productivity. Each of these factors has an effect on overall staff associated costs. Considering the expense for skilled healthcare staff capable of providing quality care to patients, it is critical to improve conditions. Given the ability for improved glazing design to impact staff job satisfaction, absenteeism, turnover, and staff productivity, it is vital to incorporate ways to increase potential access to the outdoors at the building envelope.

Staff Associated Costs

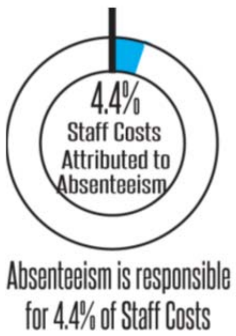


Figure 21: Absenteeism and staff costs (Browning, et al. 2012)

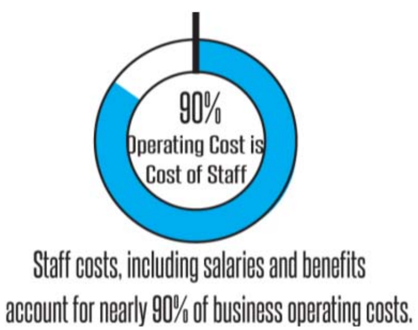


Figure 22: Staff and business operating cost (World GBC, n.d.)

The application of glazing in healthcare facilities has a wide range of implications on healthcare staff. Improvements in staff well-being and job satisfaction, correlate with reductions in absenteeism which in turn reduces staff associated operating costs. The effects of staff absenteeism are evident as a contributor to operating cost as, "absenteeism represents up to 4.4% of staff costs (Browning, et al. 2012) Considering that a significant amount of healthcare provider resources go toward staff costs, it would be worthwhile to offset that cost by investing in glazing design solutions that could improve staff working conditions.

The application of glazing design has the potential to improve staff working conditions, enabling access to daylight and views. A large proportion of healthcare provider operating expenses are associated with staff related costs. Improving staff well-being through access to daylighting and views could be a valuable approach, considering "up to 90% of business operating costs can be attributed to staff related expenses including salaries and benefits." (World GBC, n.d.) Given the overwhelming investment that healthcare providers make toward staff to provide quality care, it would be a cost effective measure to invest in ideal glazing configurations that would serve to improve staff outcomes and in turn enhance quality of patient care.

3 RESEARCH DESIGN & METHODS

3.1 Research Design

The positive effects of glazing design have been thoroughly documented through studies which show benefits for patients, staff, energy and environmental outcomes. This study seeks to document the impact of built design factors that affect the lighting and thermal conditions shown to result in these occupant and energy outcomes. Using comparative case study research to identify key design elements present in three varying patient room configurations, this research will measure the significance of various design features in driving lighting and thermal conditions within the patient room.

This study will use simulation and analysis to weigh the effects of these built design features on various thermal, lighting, and energy performance metrics resulting from each patient room configuration. Built design factors include room layout, room adjacency, structural and mechanical layouts and their impact on ceiling and window configuration. Using lighting thermal and energy simulation software, this study seeks to link the design features in each patient room configuration with the lighting thermal and energy metrics known to impact occupants and the environment. The lighting thermal and energy performance of each patient room configuration will be tested using the simulation and analysis software. The results will then be compared to identify the lighting and thermal characteristics of each design approach.

The analysis of the simulations data from each patient room glazing configuration will then serve as a reference to inform how specific lighting and thermal characteristics can be improved through the application of various solar control strategies. The solar control methods will then be tested to see what benefits they may have to lighting, thermal, and energy outcomes. The solar control strategies tested will include projections, horizontal louvers, and vertical louvers.

An analysis of lighting and thermal characteristics can help determine, the best approach to the design of glazing systems in the patient room to improve occupant outcomes and reduce energy consumption. How can we use glazing to balance the tradeoffs between lighting and thermal factors to best optimize patient, staff, and sustainable outcomes? How do we implement proper glazing design strategies in the patient room, in order to provide the most performative system to benefit both the occupants and the environment?

3.2 Data Collection & Analysis

Using simulation and analysis software for lighting, thermal, and energy comparison this study seeks to correlate built design factors with the resulting conditions within the patient room using descriptive statistics. Lighting simulations are performed using Radiance Software. Radiance is a lighting visualization simulation and analysis software used by designers and researchers to quantify lighting conditions through a range of lighting metrics. A mixed method approach will consider both lighting quantity, and lighting quality metrics to include daylight factor (%df), illuminance (lux), and luminance (cd/m2). These metrics contribute to lighting qualities like shadows, reflections, and glare effecting visual comfort, and lighting quantities like useful daylight which can impact energy consumption for electric lighting and mechanical HVAC systems.

Thermal and Energy simulations are performed using Ecotect Software. Ecotect is sustainable design software used to analyze lighting, thermal and energy simulations of building models based on a specific location, climate data, and timeframe. Ecotect will be used to measure incident solar radiation (w/m2), solar heat gain (shgc), and their effect on energy consumption for mechanical systems (btus/yr), as well as the resulting environmental impact from carbon emissions (lbs. co2 /yr). The thermal and lighting simulations will take into account comparable location and climate data of the case study configurations.

The positioning and sizing of fenestration openings drives the quality and quantity of natural day lighting within a room, however the sizing and positioning of fenestration openings can be impacted by the presence of building structure and mechanical hvac systems. Often times these building systems are concentrated near the building envelope reducing available head heights and window wall area. The impact on glazing design can be reduced by taking these components into account in the design using structural and mechanical layouts that allow for greater potential glazing area and head heights at the envelope.

This research will study three window configurations. Each window configuration is driven by differing approaches to structural and mechanical systems along with other design factors which impact glazing and fenestration design. These built design factors are evident in three varying patient room case studies which are representative of differing approaches to fenestration design in the patient room.

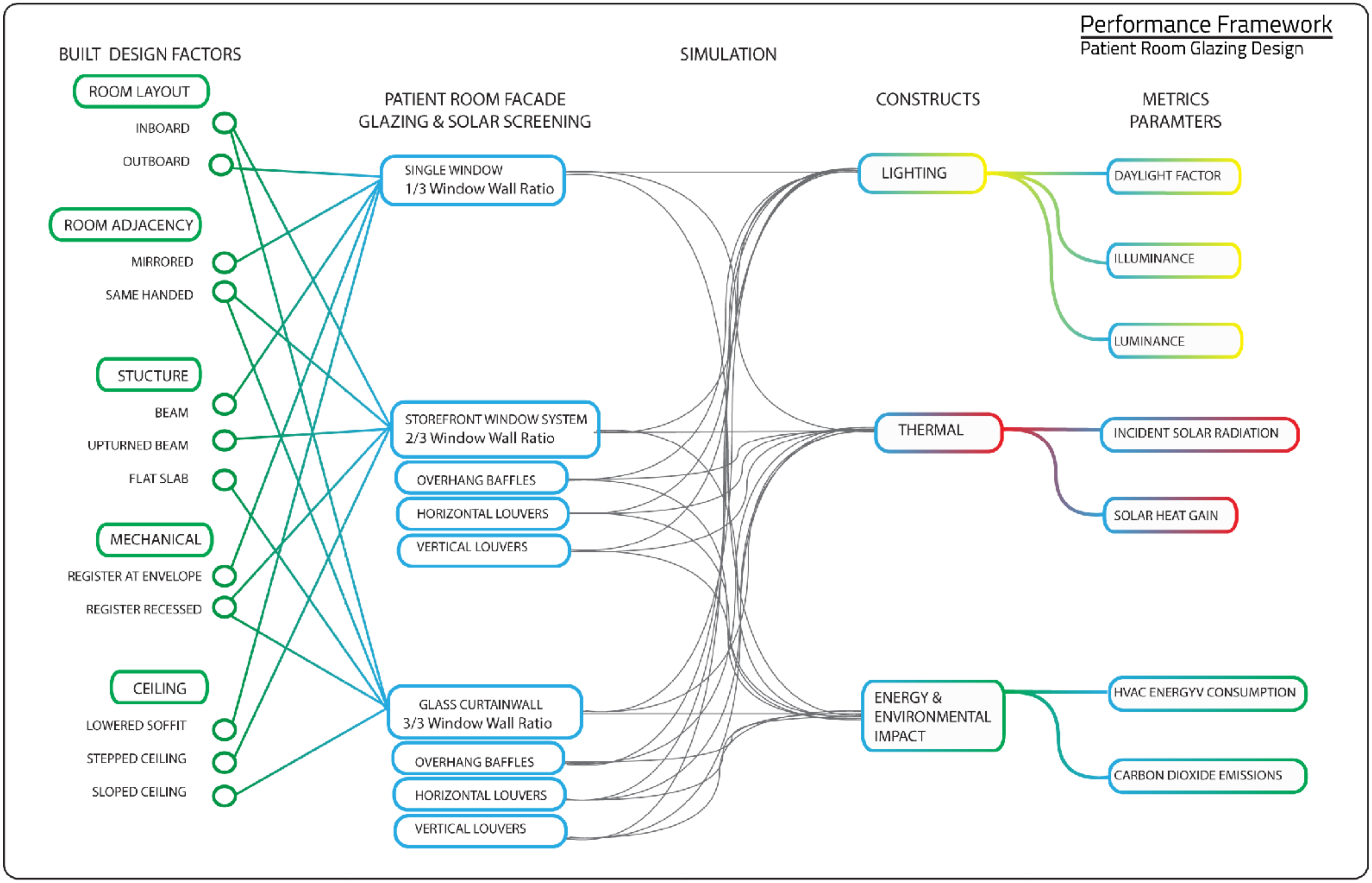


Figure 23: Performance Framework

The first configuration uses a double hung window that provides about 1/3 window wall ratio of glazing area. The second configuration uses a storefront window system that provides about 2/3 window wall ratio of glazed area. The third configuration is a full height glass curtainwall system that uses 3/3 of the full window wall area. Each of these patient room fenestration configurations is impacted by design factors like structural and mechanical layouts which affect the design of the exterior wall and ceiling.

The patient room with the single window and approximately 1/3 window wall ratio uses a traditional approach to the structural and mechanical systems. The window head height is limited by the structural beams at the envelope which sit below the floor slab reducing the potential ceiling and window head heights. In addition the mechanical systems also contribute to a lack of available daylight penetration due to the placement the ductwork.

Often times supply ductwork is mounted near the exterior wall in order to combat the thermal gains and/or losses that occur at the envelope through the exterior wall and wall penetrations. This placement of supply ductwork creates a thermal barrier between the envelope and the rest of the room in order to maintain a steady temperature and occupant thermal comfort. However, placing ductwork near the envelope creates a physical barrier limiting potential ceiling and window head heights. The ceiling height at the exterior wall is impacted by these structural and mechanical systems with a lowered soffit which limits potential window head height and daylight penetration.

The second patient room configuration uses the storefront window system which accounts for approximately 2/3 of the window wall area. The increase in window height and area is enabled by considering structural and mechanical design factors into the fenestration design. Unlike the first configuration which used a traditional beam at the envelope, configuration 2 utilizes an upturned beam which relocates the beam at the envelope from below the floor slab to above the floor slab. This allows for a greater window head height as it removes the physical barrier created by the structural beam from the upper area of the exterior wall. In addition the mechanical systems are placed further inboard to the room. This accommodates greater window head height and greater daylight penetration into the room.

The third patient room configuration uses the full height glass curtainwall system which is enabled by structural and mechanical considerations which free the exterior wall from obstructions. The structure uses a steel reinforced concrete flat slab which eliminates the need for a beam at the exterior wall. This creates an unobstructed floor to floor height area which removes structural obstructions from the envelope. In addition the mechanical registers are placed further inboard in the room to allow for a sloped ceiling configuration.

These design factors amongst others can all affect the lighting and thermal conditions within the patient room. This can affect occupant comfort as well as building performance, energy consumption, and environmental impact. These outcomes can also be impacted by the application of solar screening methods.

The thermal and lighting conditions of rooms with significant glazing area can be regulated using the application of external solar screening methods. The solar screening methods that will be measured include projections, horizontal louvers, and vertical louvers. These methods of screening incident solar radiation will be analyzed for their impact on lighting and thermal conditions as well as energy consumption and environmental impact metrics.

3.3 Site Context & Climate

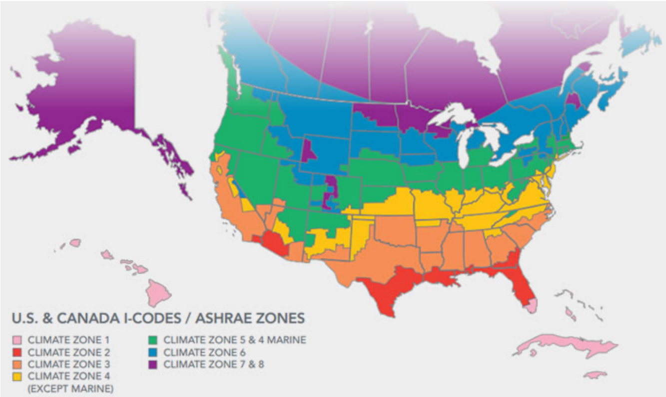


Figure 24: ASRAE climate zones (ASHRAE 2010)

ZONE	ASHRAE 90.1 - 2004 (IECC 2006)	ASHRAE 90.1 - 2007 (IECC 2009)	ASHRAE 189.1 - 2009	ASHRAE 90.1 - 2010
Zone 1	R-15	R-15	R-20	R-20
Zone 2	R-15	R-20	R-25	R-25
Zone 3	R-15	R-20	R-25	R-25
Zone 4	R-15	R-20	R-25	R-30
Zones 5 & 4 Marine	R-15	R-20	R-25	R-30
Zone 6	R-15	R-20	R-30	R-30
Zones 7 & 8	R-15/R-20	R-20	R-35	R-35

Table 1: ASRAE climate zones (ASHRAE 2010)

Location: South Florida

Climate: ASHRAE Climate Zone 1 & 2

In order to conduct a comparison between three different design methodologies using a balanced and impartial approach, it helps to control the conditions for the comparison. For the sake of this analysis, the geography and climate will serve as one control. As we analyze three differing design approaches to glazing, it is important to ensure that each example is subjected to the same or very similar environmental and climatic conditions. The site provides physically taxing and demanding environmental and climatic conditions in order to provide the greatest opportunity for the performance of the glazing system and its design to demonstrate its advantages and reveal its disadvantages.

The state of Florida is known for its long summers and mild winters. Due to its location as one of the southernmost states and its proximity to the equator, Florida receives intense UV exposure from the sun, and is known as “The Sunshine State”. This level of UV exposure along with the tropical climate give Florida the second highest average annual temperature of all U.S. states.

While the geographic location results in temperate winters, with the second lowest heating cost index in the nation, the intense UV exposure results in a dependence on HVAC mechanical equipment, specifically for cooling during the long summers. Out of all U.S. states, Florida ranks No. #2 in the nation on the cooling cost index, which indicates the relative cooling cost for a geographic area. This overdependence on mechanical systems in response to the heat of the natural climate presents an opportunity to offset the cooling cost through glazing technology and design. The natural geography and subtropical climate makes Florida an ideal location to analyze the impact of glazing design in the Patient Care Environment.

Climate Construction & Recommended R-Values

Due to the location of the selected sites along the Atlantic coast of South Florida in Orlando, Miami, and Hollywood, the buildings fit within ASHRAE Climate Zones 1 and 2 as well as U.S. Department of Energy Zone 1 and 2. These two external factors will guide the design of the building as far as the parameters used to meet thermal comfort and performance criteria. The heating and cooling methods will adhere to ASHRAE direction for Region 1 and 2, and the R-Values and Construction type will follow the recommendation of the US Department of Energy for Zone 1 and 2.

Temperature & Comfort Zone

The state of Florida has a fairly moderate climate in general, although there are extremes on either end of the temperature spectrum. The intent is to design the building to meet the areas comfort zones for both winter and summer. The summer comfort zone is shown to be within 76-80 degrees while the winter comfort zone is listed at 68-76 degrees. For the purpose of this analysis, we will design for an interior temperature of 71 degrees during both seasons as this is the steady state air temperature preferred by patients for thermal comfort. For exterior temperature in Summer we will use the design high for June which is 90 degrees, for Winter we will use the December mean temperature of 45 degrees.

4 PATIENT ROOM CASE STUDIES

Figure 25: Nemours Children's Hospital

Patient Room with Full Glazing Area - Glass Curtain Wall System
Nemours Children's Hospital, Orlando Florida - LEED Gold
Project Architect: Stanley Beaman Sears, Atlanta, GA
& Perkins + Will, Boston, MA
Construction: SKANSKA USA Building
Owner: The Nemours Foundation, Jacksonville, FL
Project Size: 630,000 Sq. Ft.
Project Budget:$260 Million
Completion Date: 2009 Masterplan, 2012 Phase 1 Implementation

Figure 26: Joe DiMaggio Children's Hospital

Patient Room with 2/3 Glazing Area - Glass Storefront System
Joe DiMaggio Children's Hospital, Hollywood Florida - LEED Gold
Project Architect: Stanley Beamen Sears, Atlanta, GA
Construction: ANF Group Inc. South Florida
Owner: Memorial Healthcare System
Project Size: 180,000 Sq. Ft.
Project Budget: $80 Million
Completion Date: 2011

Figure 27: West Kendall Baptist Hospital

Patient Room with 1/3 Glazing Area- Single Fixed Window
West Kendall Baptist Hospital, Miami Florida - LEED Gold
Architect: MGE Architects, Coral Gables Fl, &
Wilmot Sanz Architecture & Planning, Gaithersburg, MD
Construction: Robins & Morton, Birmingham Al, Orlando Fl
Owner: Baptist Health South
Project Size: 290,000-314,000 Sq Ft.
Capacity: 134 Beds expandable to 300 beds
Project Budget: $121 Million
Completion Date: April, 2011

Figure 28: Patient Room with Full Height Curtainwall
Nemours Children's Hospital

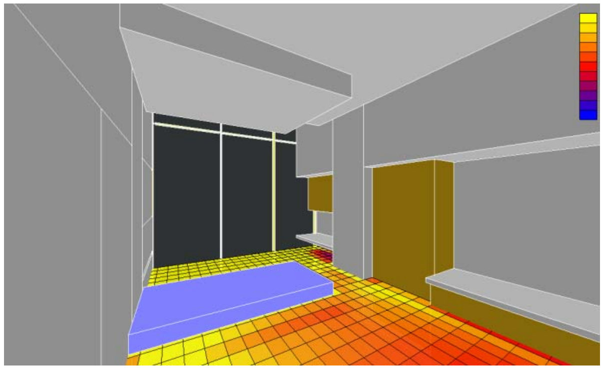


Figure 29: Patient Room with Full Height Curtainwall
Nemours Children's Hospital – Daylight Hours

Figure 30: Patient Room with Storefront Window System
Joe DiMaggio Children's Hospital

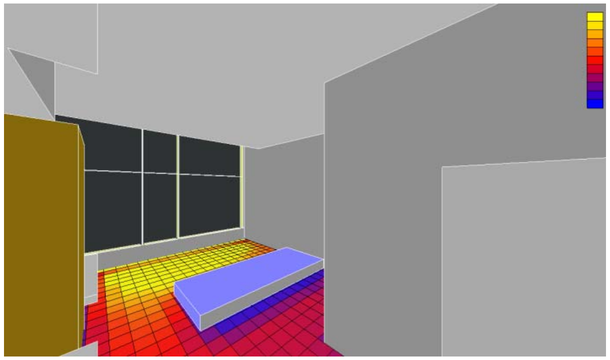


Figure 31: Patient Room with Storefront Window System
Joe DiMaggio Children's Hospital– Daylight Hours

Figure 32: Patient Room with Single Window
West Kendall Baptist Hospital

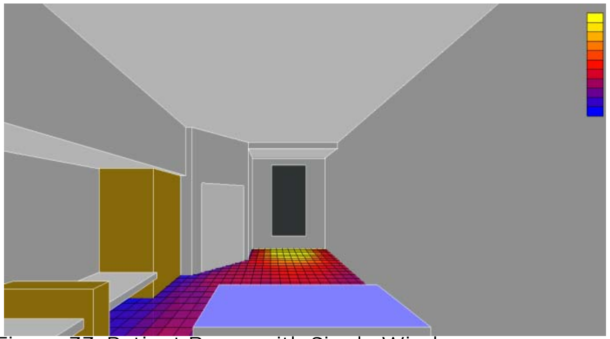


Figure 33: Patient Room with Single Window
West Kendall Baptist Hospital– Daylight Hours

4.1 Patient Room with Single Window

Physical Features

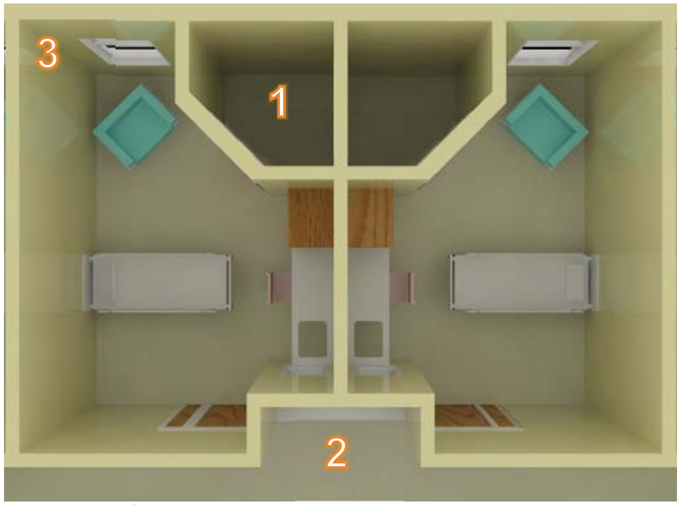


Figure 34: Plan Perspective
Patient Room with Single Window

Figure 35: Perspective Section
Patient Room with Single Window

1 Room Layout - Outboard Toilet Room-

No feature has a greater impact on the size of the glazing area in the patient room than the location of the toilet room. This is most evident in the case of the outboard toilet room. Although it provides, a greater level of staff efficiency in some respects, it also limits the potential glazing area of the room, reducing patient access to daylighting and views. Staff access from the corridor to the patient bed is streamlined by the positioning of the toilet room outboard of the patient bed, reducing conflicts between the toilet room and patient room access. This added staff efficiency comes at the expense of patient satisfaction as the toilet room location reduces potential glazing area to less than half the area of the outboard wall.

2 Room Adjacency - Mirrored Adjacency-

The Mirrored Room adjacency provides visibility of two rooms simultaneously from a single corridor charting station. In addition the mirrored layout can slightly reduce construction cost by utilizing a single wet wall to run the piping for two neighboring toilet rooms, as well as sinks at the Staff Zone. However, in the case of the outboard toilet room, which limits window area, a mirrored adjacency layout can result in less regular lighting and thermal conditions both within the room, and from room to room due to the mirrored adjacency of the toilet room. This is because the change in room orientation that is associated with mirroring results in irregular patterns of incident solar radiation in the way of direct sunlight penetration into the room. This means that because of the travel and position of the sun, the head of one patient bed may be in direct sunlight while that of the mirrored adjacent patient room is in full shadow.

This creates thermal fluctuations throughout the patient room and between neighboring rooms in the same unit.

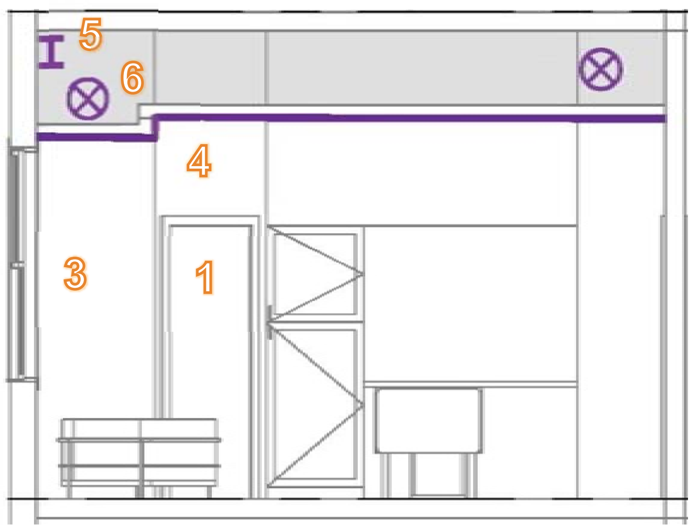


Figure 36: Section West –Patient Room with Single Window

3 Window Configuration- Single Operable Double Hung Window-

The daylighting potential of the single double hung window is reduced due to its limited glazing area. The orientation of the window to the patient's point of view is located at an axis requiring the patient to rotate onto their side to access the window. Even then, the limited size of glazing area prohibits the window from serving it's primary purpose of providing daylight, or a direct view to nature. As a daylighting instrument, the double hung window does not offer adequate height to provide a sufficient angle for daylight to penetrate far enough into the room to provide ample enough passive lighting. As a view window, the double hung configuration does not afford enough glazing area to provide a decent view from the perspective of the patient bed. The field of view is limited by the 36" width and 72" height dimensions of the window. From the distance of the patient bed, the double hung window provides limited daylighting and views.

4 Ceiling Configuration – Lowered Soffit at Envelope

The drop ceiling is constructed of 2' x 2' acoustic ceiling tile on a suspended metal grid system throughout the room, except for lowered soffit areas at the Staff Zone and Family Zone that are sheathed in gypsum wall board. The lowered soffit with the most notable impact on both room and glazing configuration is located in the area adjacent to the building envelope. This is significant because it can impact the room design and the occupant's environmental conditions. Patient rooms with a lowered soffit at the exterior wall, generally use this approach to contain and mask building systems, utilizing the soffit as a chase to run mechanical ductwork, piping, and outboard building structure. While this is functional for these purposes, as described below, it limits window head height at the exterior envelope, adversely impacting daylight penetration.

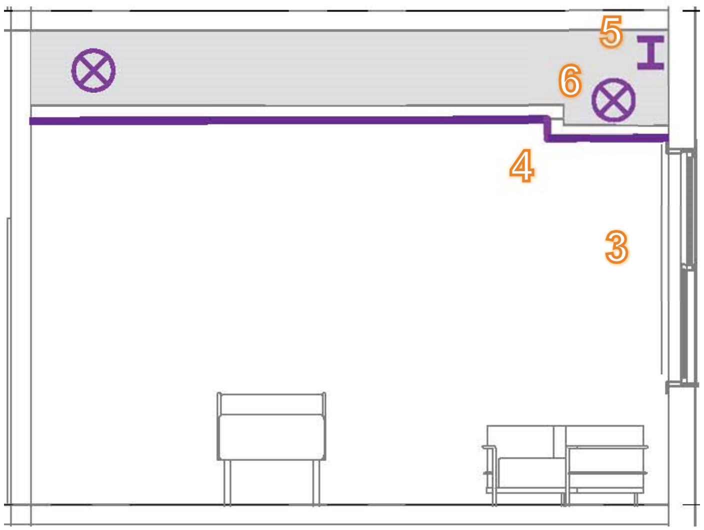


Figure 37: Section East- Patient Room with Single Window

5 Structure – Outboard Girder

This configuration utilizes a steel girder at the perimeter, which in turn supports beams that hold the floorplate. This approach, while efficient at transferring the structural loads of the building, presents a limitation caused by the conflicting interests of the structure, and the desire to clear the outboard wall of obstructions, to provide space for fenestration openings at the building envelope. Reducing the outboard structural mass of the building would provide the ability to utilize a greater window area and head height at the exterior wall, generating greater opportunity for daylight penetration and views from the patient bed.

6 Mechanical – Register at Envelope

The mechanical ductwork is located adjacent to the outboard wall to provide supply air through registers that are placed to counteract and offset thermal gains and losses that originate at the envelope, thus creating a thermal barrier between the patient and temperature fluctuations. This approach is capable of regulating environmental conditions by creating a thermal barrier. However, it also creates a physical barrier that reduces window head height and in turn lowers the opportunity for further daylight penetration.

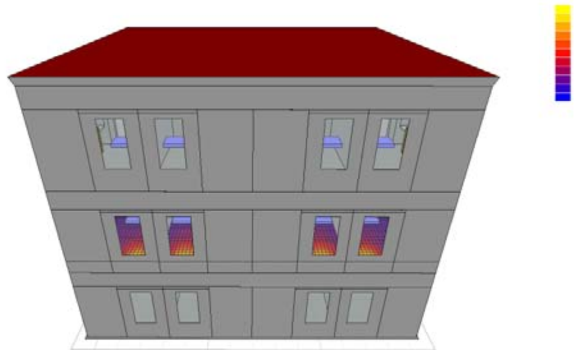


Figure 38: Exterior Facade – Patient Room with Single Window

<u>Patient Room with Single Window – 1/3 Glazing Area</u>
West Kendall Baptist Hospital, Miami Florida - LEED Gold

Window Wall Area – .33

Window Floor Ratio – .25

Ceiling Height – 9' - 0" to 9' - 6"

Ceiling Configuration – Lowered Soffit at Envelope

Figure 39: Daylight at 1:00 PM –
Patient Room with Single Window

Figure 40: Interior Photo –
Patient Room with Single Window

Figure 41: Patient Perspective –
Patient Room with Single Window

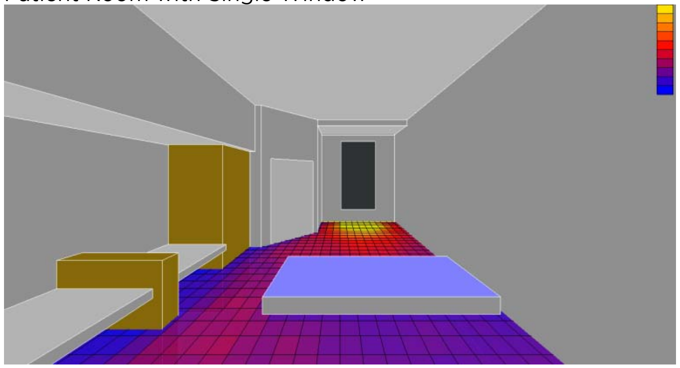
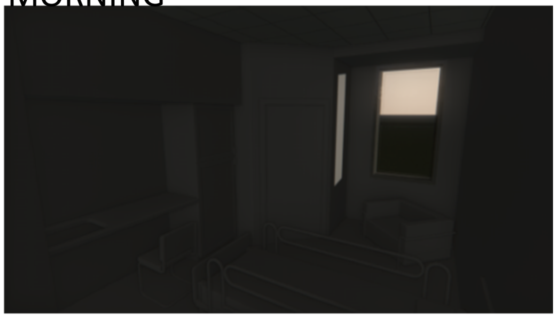
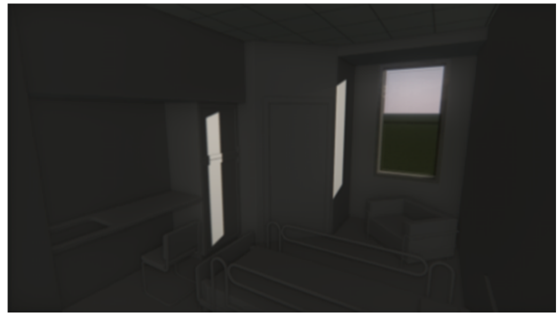


Figure 42: Daily Daylight Hours –
Patient Room with Single Window

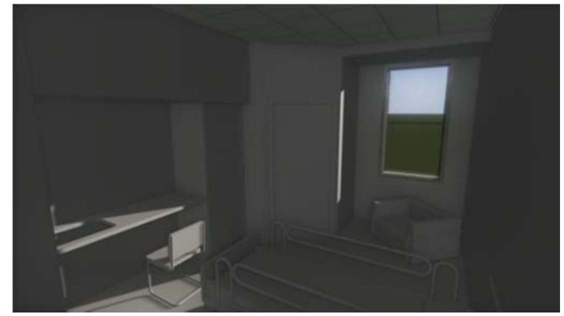
MORNING



8:30 AM

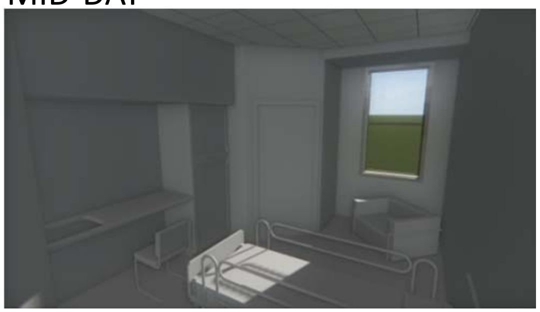


9:30 AM

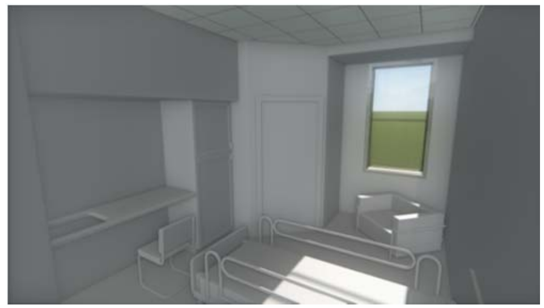


10:30 AM

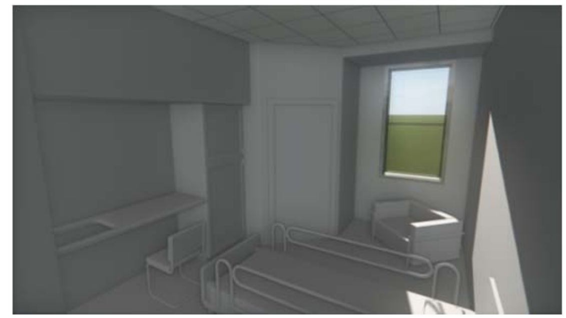
MID-DAY



11:30 AM



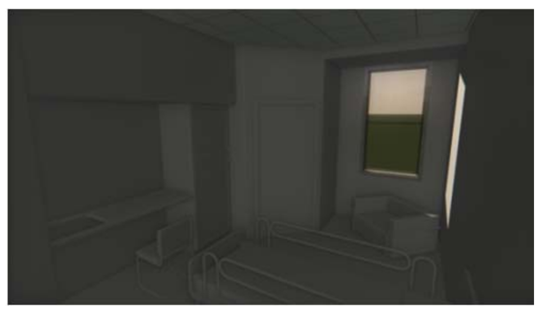
12:30 PM



1:30 PM

AFTERNOON

2:30 PM



3:30 PM

Figure 43: Daylight Study – Patient Room with Single Window

MORNING- There are very low light levels during the morning hours reducing the potential effectiveness of sunlight on the patient's circadian rhythm or wake-sleep cycle.
MID-DAY- Light levels throughout the room remain generally low as the limited window area restricts potential daylight penetration throughout the room
AFTERNOON- The light levels begin to reduce dramatically earlier in the afternoon as the majority of the room falls in shadow.

4.2 Patient Room with Storefront System

Physical Features

Figure 44: Plan Perspective
Patient Room with Storefront Window System

Figure 45: Perspective Section
Patient Room with Storefront Window System

1 Room Layout – Inboard Toilet Room

The Inboard Toilet Room allows the utilization of the full length of exterior wall to be dedicated to the installation of window system. This configuration also permits greater levels of patient privacy as the toilet room acts as a physical barrier between the corridor and the patient room. In addition to providing privacy, a nurse charting station is provided for staff visibility. In terms of staff operational efficiency the location of the Toilet Room as a physical barrier between the corridor and patient room also can create certain functional issues, as the conflicting doorswings illustrate. On the other hand it can streamline staff efficiency within the room and reduce construction cost by locating all of the wet areas of the Staff Zone and Toilet Room in close vicinity to one another. Most notably for the effect on glazing design is the added opportunity for greater exterior wall area afforded for the application of window systems.

2 Room Adjacency – Same Handed Adjacency, Patient Left Side to Door

The same handed room adjacency in this configuration provides some of the benefits of a mirrored layout without it's disadvantages. Unlike a mirrored layout, keeping the Patient Room Layout the same in each room, improves design control over the glazing configuration, creating similar indoor environmental effects throughout the day, as they are impacted by variable factors like sun path and travel. In addition, backing the Sink area of the Staff Zone up to the same wet wall that is being utilized for the Toilet Room of the neighboring Patient Room, reduces redundancy in the plumbing in much the same way that a mirrored adjacency does.

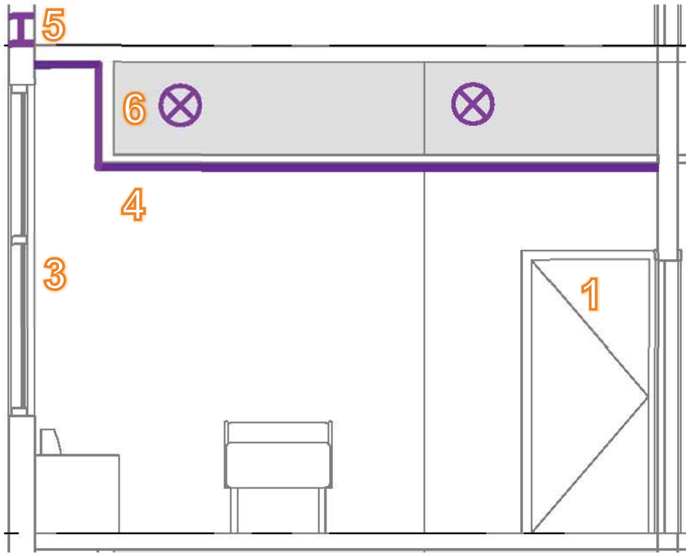


Figure 46: Section West –
Patient Room with Storefront Window System

Staff efficiency for visibility is reduced in the corridor as the same hand adjacency with inboard toilet layout requires individual rather than shared charting stations. Efficiency within the room is improved as the nurses approach to the patient bedside remains same-handed and unchanged. In addition patient travel to the restroom is on the same side as the nurse approach increasing access if assistance is needed. It also allows for positioning any patient associated wheeled equipment on the same side, closest to the toilet room reducing equipment travel distance, and most importantly, associated patient fall hazards while using the restroom.

3 Window Configuration - Fixed Storefront Window System

The Fixed Storefront Window System runs the uninterrupted width of the patient room thanks to the inboard toilet room placement. Due to the stepped ceiling configuration, the window system is able to be placed at a greater height just below the floorplate. This is enabled by the design approach that considers the location of structural and mechanical systems to create opportunity for greater head height at the envelope. The sill height of the window system is driven by building structure contained within the lower area of the wall.

4 Ceiling Configuration – Stepped Ceiling Raised at Envelope

Utilizing a Stepped Ceiling that is raised at the envelope affords the ability to use nearly the full height of the outboard wall up to the underside of the floorplate. This is made possible by incorporating an upturned girder which removes this structural obstruction in the ceiling area of the outboard wall and places it at the floor.

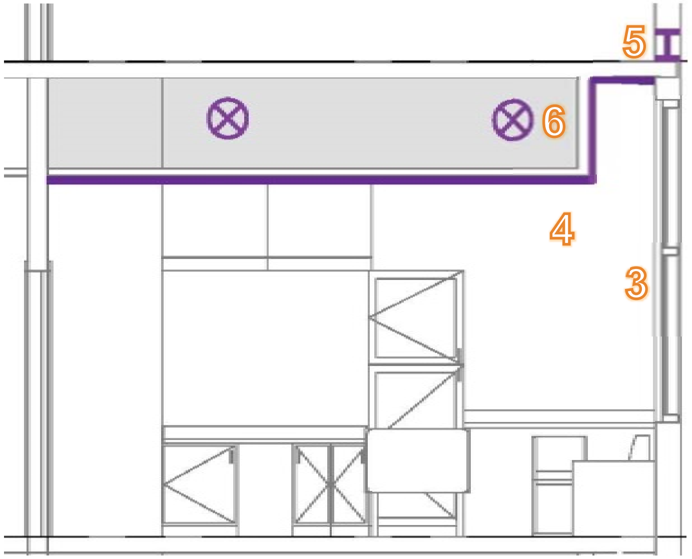


Figure 47: Section East-
Patient Room with Storefront Window System

Figure 48: Patient Room, Joe DiMaggio Children's Hospital

5 Structure – Upturned Girder

Suspending the floor from the girder rather than resting on top of it, the Upturned Girder removes the outboard structural mass from the ceiling area adjacent to the exterior wall and places it above the floorplate. This structural placement opens the upper area of the outboard wall allowing for higher window head height and greater window area. Locating the girder in such a way also places the mass in an area that often remains unused for the application of glazing, at floor level. Although this obstructs the ability for a true full height curtainwall to reach the floor, it also provides wall area resulting in added insulation qualities, and thermal mass that aids in stabilizing thermal conditions in the room through admittance, the storage and release of thermal energy.

6 Mechanical – Supply Register Recessed from Envelope

The conventional approach to mechanical ventilation in the patient room is to place a supply duct at the exterior wall to offset the thermal gains and losses at the window area. This supply ventilation provides an additional level of temperature control as a thermal barrier between the envelope and patient bed. While it does create a thermal barrier it poses a physical barrier that lowers the ceiling head height at the envelope. Developments in window design and manufacturing have resulted in less air infiltration associated with drafts, as well as better window insulation qualities, allowing the relocation of supply vents further from the envelope, and clearing the area for a stepped ceiling configuration.

2/3 Glazing Area - Glass Storefront System
Joe DiMaggio Children's Hospital, Hollywood Florida - LEED Gold

Window Wall Area – .67

Window Floor Ratio - .50

Ceiling Height – 9'-6" to 12'-6"

Ceiling Configuration – Stepped Ceiling Raised at Envelope

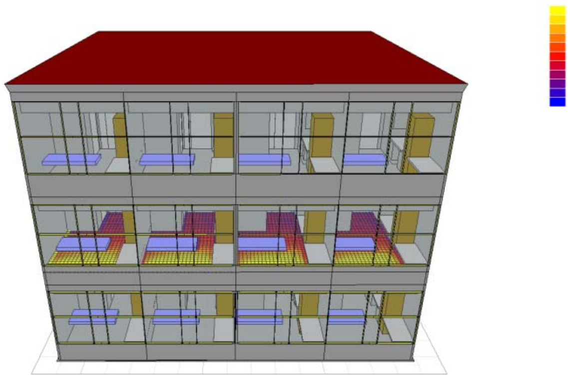


Figure 49: Exterior Envelope –
Patient Room with Storefront Window System

Figure 50: Daylight at 1:00 PM
Patient Room with Storefront Window System

Figure 51: Patient Room with Storefront Window System
Joe DiMaggio Children's Hospital

Figure 52: Patient Perspective
Patient Room with Storefront Window System

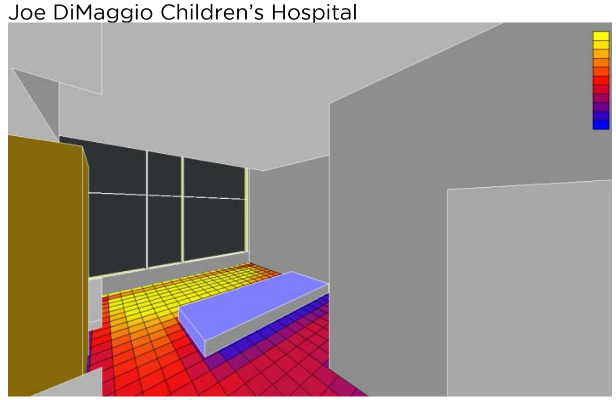
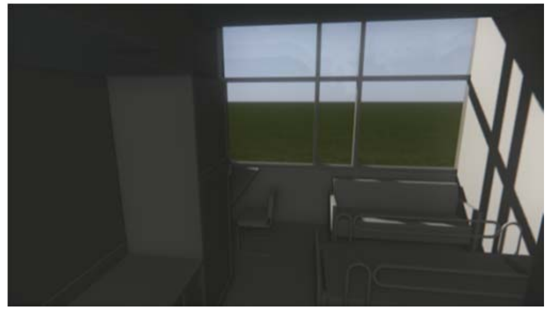


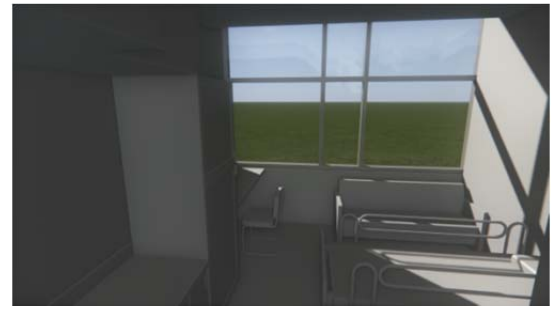
Figure 53: Daylight Hours
Patient Room with Storefront Window System

MORNING

8:30 AM

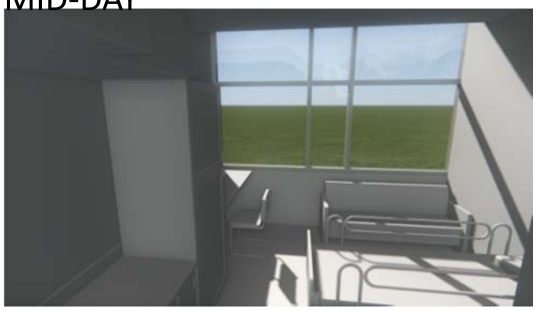


9:30 AM

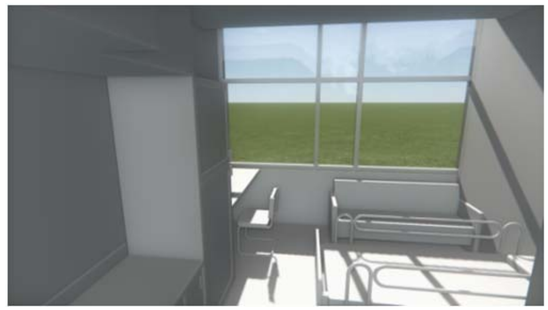


10:30 AM

MID-DAY



11:30 AM



12:30 PM

1:30 PM

AFTERNOON

2:30 PM

3:30 PM

Figure 54: Daylight Study –
Patient Room with Storefront Window System

MORNING- Daylight begins to reach the patient bed by mid to late morning, due to the increased window area.
MID-DAY- Daylight fills the room and covers the entire patient bed in the late morning through early afternoon
AFTERNOON- The room remains relatively more day-lit fairly later into the afternoon, although the patient bed begins to fall out of direct sunlight and into shadow

4.3 Patient Room with Glass Curtainwall Physical Features

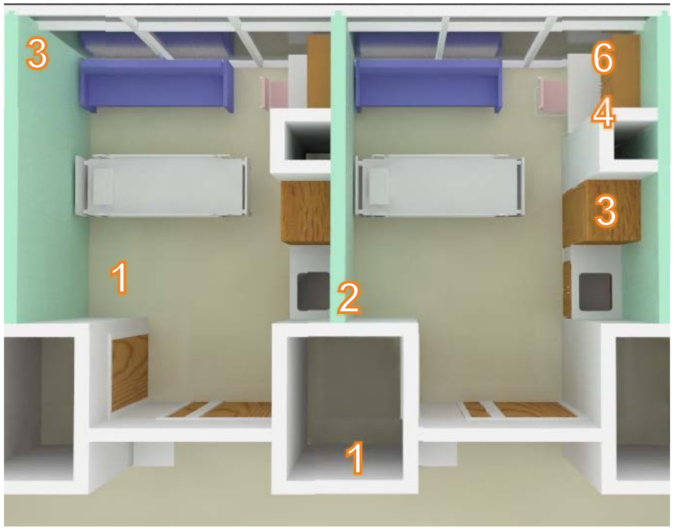


Figure 55: Plan Perspective
Patient Room with Glass Curtainwall

Figure 56: Perspective Section
Patient Room with Glass Curtainwall

1 Room Layout – Inboard Toilet Room at Headwall

The inboard toilet room layout locates the physical mass and area of the toilet room at the inboard corridor side of the room. This permits greater area at the exterior wall to be utilized for glazing applications, over the outboard toilet room layout which limits potential glazing area at the envelope. The inboard toilet room layout also has several implications for both patient privacy and staff efficiency and access. By locating the physical mass of the toilet room between the patient bed and inboard corridor, increased privacy is provided for the patient. This privacy, however, can come as a trade-off, at the expense of staff visibility, and efficiency, as the same physical barrier that provides patient privacy, presents challenges for ingress and egress as well as vision from the corridor charting station. This is evident in the conflicting doorswings as well as obstruction in direct line of sight to the head of the patient bed shown on the plan.

2 Room Adjacency – Same-Handed Adjacency, Patient Right Side to Door

The same handed room adjacency allows more regular lighting and thermal conditions between rooms by maintaining the same layout and orientation. Keeping these factors the same between rooms allows daylight and shadows to fall similarly within neighboring rooms of the same orientation. This can lead to more even illuminance levels throughout the room, and greater impact from efficiencies gained by daylighting and shading strategies. Room adjacency also can impact staff visibility and charting efficiency. In the case of a mirrored adjacency, each charting station at the corridor can view two patient rooms at once.

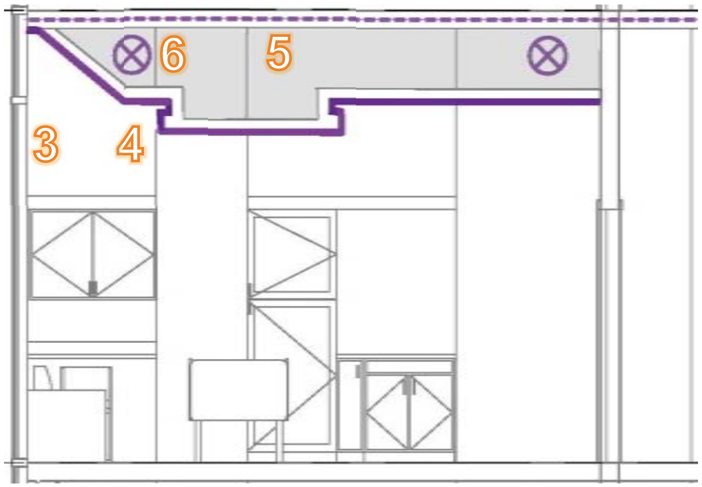


Figure 57: Section West –Patient Room with Glass Curtainwall

However, the same-handed adjacency approach requires that the charting station be repeated at each room, reducing visibility by increasing travel distance to monitor patient rooms from the corridor. This same handed configuration utilizes an approach to plumbing more evident in mirrored adjacencies, by sharing a common wet wall for piping between the Toilet Room and adjacent Staff Zone sink area reducing the necessary space and associated plumbing cost.

3 Window Configuration- Full Height Curtainwall

The glass curtainwall system runs the full height and width of the exterior envelope. This is made possible by the sloped ceiling configuration which uses the innovative integration of structural and mechanical systems into an approach that maximizes available window area, providing the greatest opportunity to affect room conditions though glazing design.

4 Ceiling Configuration – Sloped Ceiling Raised at Envelope

The sloped ceiling configuration allows the full height of the exterior wall to be utilized for additional window surface area. This creates an opportunity for greater daylight penetration by removing the barrier of the dropped ceiling from the area immediately adjacent to the envelope. This approach considers the location of building structural and mechanical systems into the design, increasing the glazing area made available to the occupant.

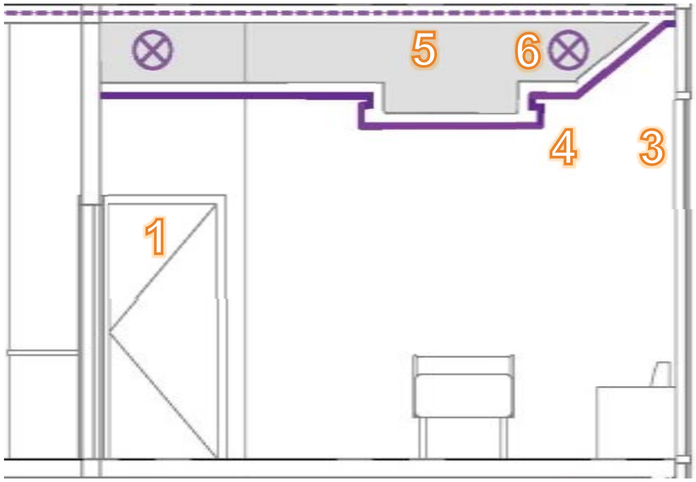


Figure 58: Section East- Patient Room with Glass Curtainwall

Figure 59: Patient Room, Nemours Children's Hospital

5 Structure – Steel Reinforced Concrete Flat Slab

The flat slab construction integrates the structure into the floorplate reducing the depth of profile required by the structural system. This is done by integrating the system of beams and girders into the floorplate using pre-stressed or post tension steel reinforcement within the concrete slab. While integrating the structure into the slab may increase the depth of the floorplate itself, it also eliminates the depth of large steel w-sections used for the conventional structural steel framed beams and girders located beneath the floorplate. This streamlines the profile of the interstitial space between the ceiling and underside of the floor slab, allowing more room for other building systems, and reducing the depth of the interstitial space. Most notably, it provides area for the application of the sloped ceiling at the envelope.

6 Mechanical – Register Recessed from Envelope

A traditional approach to patient room design often places a supply register adjacent to the exterior wall to offset thermal gains and losses at the envelope, most evident at the glazing surface and frame. In order to control the thermal conditions between the envelope and patient zone, supply ductwork is often run near the outboard wall. Advances in the insulative qualities of glazing and framework that make up modern window systems have reduced the need for supply registers immediately adjacent to windows at the exterior wall. This enables the movement of the supply ductwork further inboard, to allow for the application of a sloped ceiling that will permit a greater head height for glazing at the envelope.

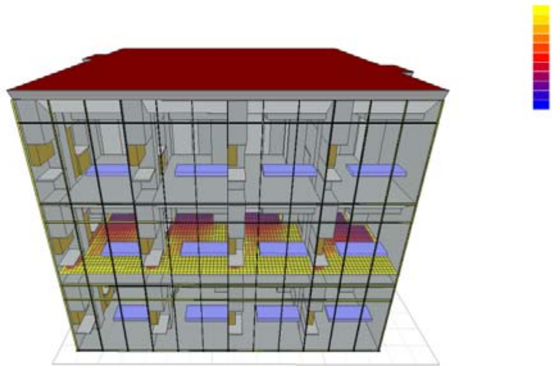


Figure 60: Exterior Envelope –
Patient Room with Glass Curtainwall

Figure 61: Daylight at 1:00 PM
Patient Room with Glass Curtainwall

Figure 63: Patient Perspective
Patient Room with Glass Curtainwall

Full Glazing Area - Glass Curtain Wall System
Nemours Children's Hospital, Orlando Florida - LEED Gold

Window Wall Area – .99

Window Floor Ratio - .75

Ceiling Height – 9' - 6" to 12' - 6"

Ceiling Configuration – Sloped Ceiling Raised at Envelope

Figure 62: Patient Room with Glass Curtainwall

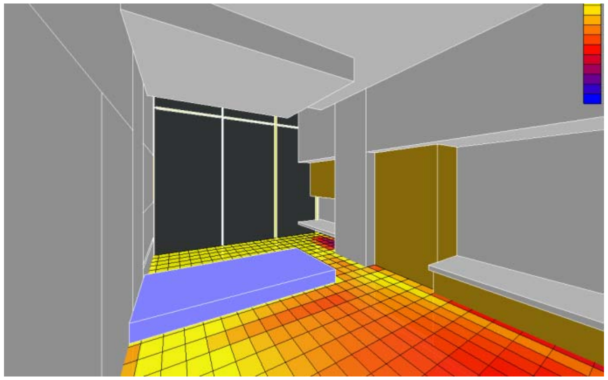


Figure 64: Daylight Hours
Patient Room with Glass Curtainwall

MORNING

8:30 AM

9:30 AM

10:30 AM

MID-DAY

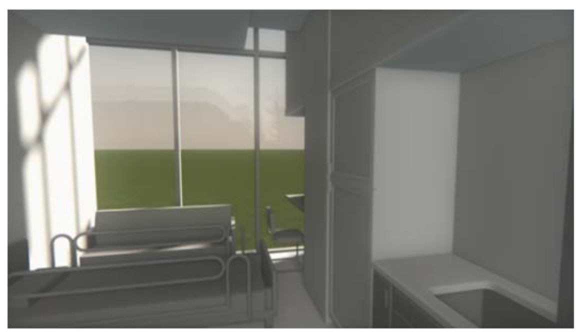
11:30 AM

12:30 PM

1:30 PM

AFTERNOON

2:30 PM



3:30 PM

Figure 65: Daylight Study- Patient Room with Glass Curtainwall

MORNING- The full window area and increased head height results in greater daylight levels earlier in the morning. This is the most consistent with outdoor conditions, encouraging a more natural circadian rhythm.
MID-DAY- Light levels become very intense by late morning through early afternoon. This can create the perception of glare, resulting in visual discomfort.
AFTERNOON- Most of the room falls out of direct daylight, but remains fairly well day- lit later in the day, as there are no obstructions at the envelope to cast shadows in the room.

5 COMPARING PATIENT ROOM CONDITIONS

5.1 Solar Exposure – Incident Solar Radiation

Much of the energy from the sun's rays can be seen in natural lighting conditions, or felt in its impact on thermal conditions. A considerable amount of the sun's energy that reaches an occupant from solar exposure or incident solar radiation however cannot always be seen. Solar radiation covers the entire spectrum of light to include infrared and ultraviolet light. These spectrums of the sun's rays may not be visually perceptible but nonetheless still impact patient health and well-being.

Incident solar radiation can have a range of human health implications. Normal amounts of incident solar radiation are beneficial for human health, and can strengthen immune, circulatory and musculoskeletal systems. Ultraviolet radiation is used to treat several skin and other diseases. The suns' radiation provides Vitamin D which helps to fortify and sustain healthy bones, circulatory, and immune systems. The pattern of the sunrise and sunset also drives the body's circadian rhythm or wake-sleep cycle promoting better rest which is fundamental to aid in recovery.

While controlled levels of incident solar radiation can be beneficial to occupant health and well-being, excess levels of UV radiation from solar exposure can also have adverse health effects. Excess levels of UV exposure can cause damage to immune system, skin, and eyes.

UV radiation has been linked to carcinoma and melanoma skin cancers. Excess UV radiation can also cause inflammation of the eyes leading to cataracts and even blindness. In addition excess levels of UV radiation can suppress function of the immune system leading to immune deficiencies that enhance the risk of infectious disease.

Incident Solar Radiation is one of the main factors driving the building performance considerations as well as occupant visual and thermal comfort considerations that will be tested through the simulation and analysis of the three varying glazing design approaches. Incident solar radiation represents the amount of the suns' energy that reaches a surface or area over a period of time whether daily or annually. Incident solar radiation is expressed in units of energy received over a period of time, per area. The simulation and analysis methods quantified incident solar radiation, also known as insolation in $BTU/hr/ft^2$.

Incident solar radiation can affect both lighting as well thermal conditions through increased daylight illuminance levels and indirect solar gains or solar heat gain. These can impact lighting energy consumption as well as HVAC energy consumption. Natural light levels generally coincide with levels of incident solar radiation. Greater levels of incident solar radiation typically result in improved daylighting which can result in a decrease in the use of artificial lighting during daylight hours. This can reduce energy consumption for electric lighting.

Levels of incident solar radiation are also associated with levels of solar heat gain. Typically greater amounts of incident solar radiation result in increased solar heat gain. In cooling dominated climates this increased solar heat gain results in increased energy consumption. This is due to a reliance on mechanical systems used to combat the heat gain at the envelope, in order to maintain temperatures within the occupant thermal comfort zone. This increased energy consumption from use of mechanical HVAC systems in turn has an adverse environmental impact resulting from additional carbon dioxide emissions.

The distribution of incident solar radiation has numerous effects on thermal and lighting conditions within the patient room. These considerations are wide ranging, effecting not only lighting and thermal conditions but building performance and environmental impact through energy consumption and carbon emissions. In addition incident solar radiation can play a substantial role in occupant health and well-being. Considering the various outcomes that the distribution of solar radiation can have on occupants, building performance, and the environment, it is an important factor to regulate incident solar radiation in order to manage the conditions which will contribute to these outcomes.

The three approaches to glazing design ranging from a single window with approximately 1/3 window wall ratio to a storefront system with 2/3 window wall ratio, and a glass curtainwall with 3/3 window wall ratio provide varying levels of incident solar radiation. The levels of incident solar radiation registered throughout the room were reflective of the differences in the physical features of each patient room configuration. Physical features like ceiling profiles, room layout and toilet room location, all affected the sizing and placement of the glazing at the exterior envelope. These design considerations affected the levels of incident solar radiation that passed through the glazing as well as the distribution within the space.

These varying levels of incident solar radiation have been shown to effect occupant health and well-being, as well as lighting and thermal aspects that impact building performance and occupant visual and thermal comfort. Through lighting and thermal simulation and analysis we will see how incident solar radiation in turn relates to lighting and thermal conditions.

Case Study Comparison - Incident Solar Radiation

Nemours
Full Height Curtain Wall
Incident Solar Radiation –
-Greatest Solar Penetration
-Greatest Daylight Levels
-Greatest Heat Gain

Joe DiMaggio
2/3 Height Storefront System
Incident Solar Radiation–
- Moderate Solar Penetration
- Moderate Daylight Levels
- Moderate Heat Gain

West Kendall
1/3 Area Fixed Window
Incident Solar Radiation –
-Least Solar Penetration
-Least Daylight Levels
-Least Heat Gain

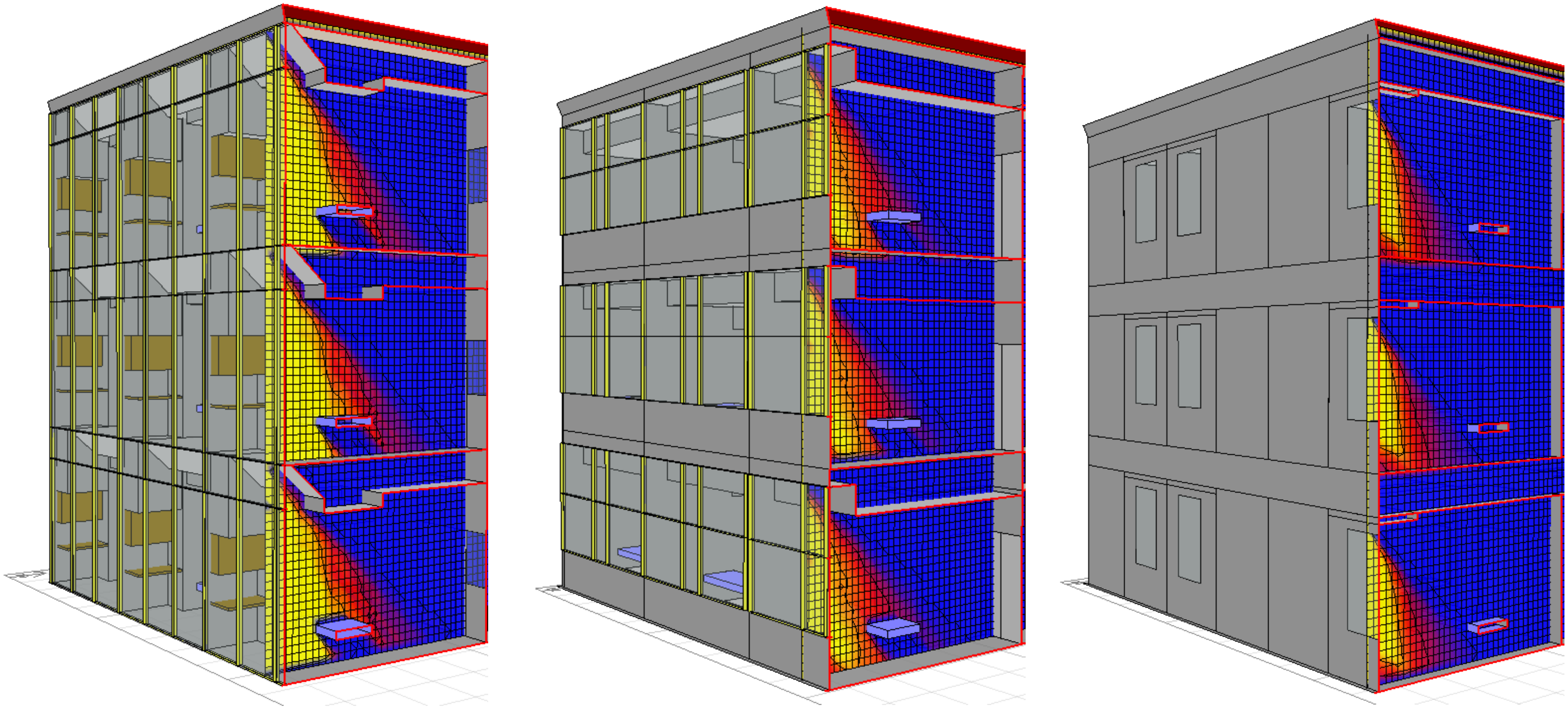
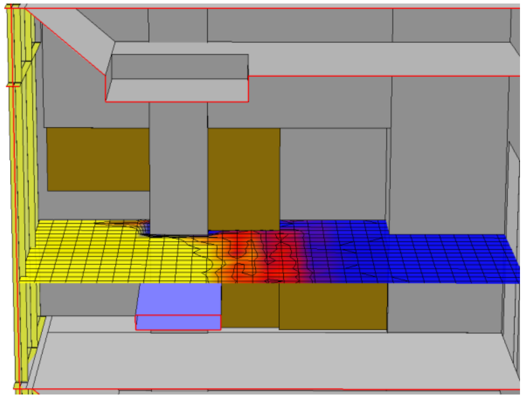
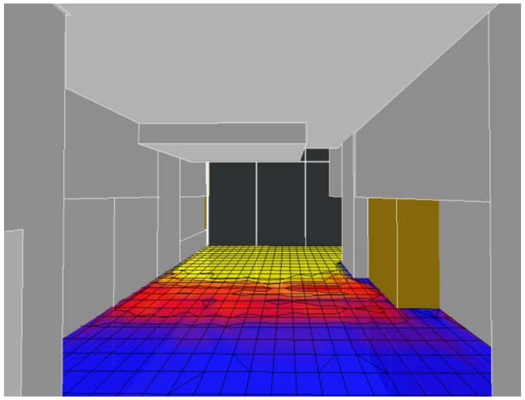


Figure 66: Solar Exposure Comparison– Incident Solar Radiation

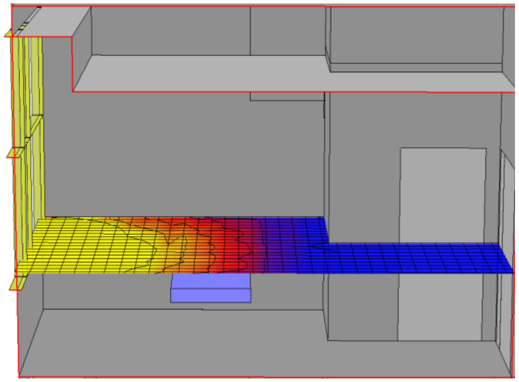
Case Study Comparison -
Incident Solar Radiation

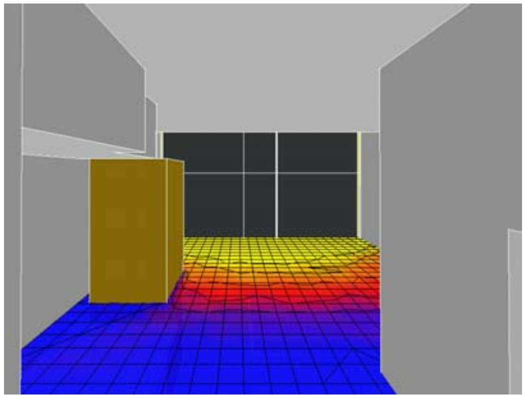
Nemours
Full Height Curtain Wall
Incident Solar Radiation –



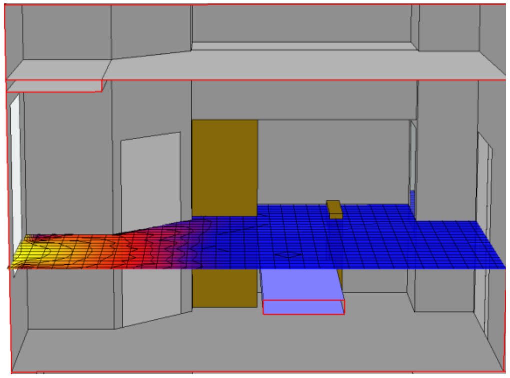


Joe DiMaggio
2/3 Height Storefront System
Incident Solar Radiation –





West Kendall
1/3 Area Fixed Window
Incident Solar Radiation –



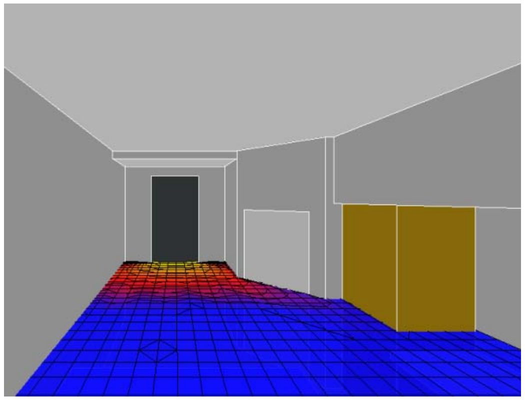


Figure 67: Solar Exposure Comparison–
Incident Solar Radiation

5.2 Daylight Factor

Daylight Factor represents a ratio of the light level inside of a structure to the light level outside of the structure. This is useful as a tool to measure the quantity of useful daylight reaching the interior during daylight hours. Daylight factor represents the use of available natural daylight within a space. Daylight factor can be used to assess natural lighting conditions to consider whether available natural daylight is adequate for visual acuity to perform various normal functions. Daylight Factor can also be used as a means of determining the potential energy impact from the use of electric lighting during daylight hours.

Daylight Factor is expressed as a percentage. It is the ratio of the interior illuminance light level to the exterior illuminance light level. Daylight Factor = (Ei/Eo) x 100%. A Daylight Factor under 2% is considered to require the use of electric lighting to provide adequate lighting levels and is considered not well day-lit. A Daylight Factor Between 2% and 5% is considered to require electric during only part of the potential daylight hours and considered an adequate level of natural lighting. A Daylight Factor above 5% is considered not to require electric lighting during daylight hours other than at dusk and dawn. A Daylight Factor above 5% is considered to be well day lit. While higher daylight factors can mean a reduction in electric lighting energy during daylight hours, Daylight factors in excess of

Daylight Factor

Patient Room with Full Height Curtainwall

these levels may also present potential for visual discomfort caused by glare, and thermal issues caused by excess solar heat gain. The daylight factor in the family zone at the envelope is excessive.

The family zone receives nearly 15% daylight factor due to the open expanse of the glass curtain wall. This excessive level of daylight could result in glare leading to visual discomfort, and increased solar heat gain leading to thermal discomfort. The Daylight Factor at the patient bed is well day lit with a daylight factor ranging from 3-7%. The staff work surface remains poorly day lit due to obstructions which block potential daylight penetration further into the room.

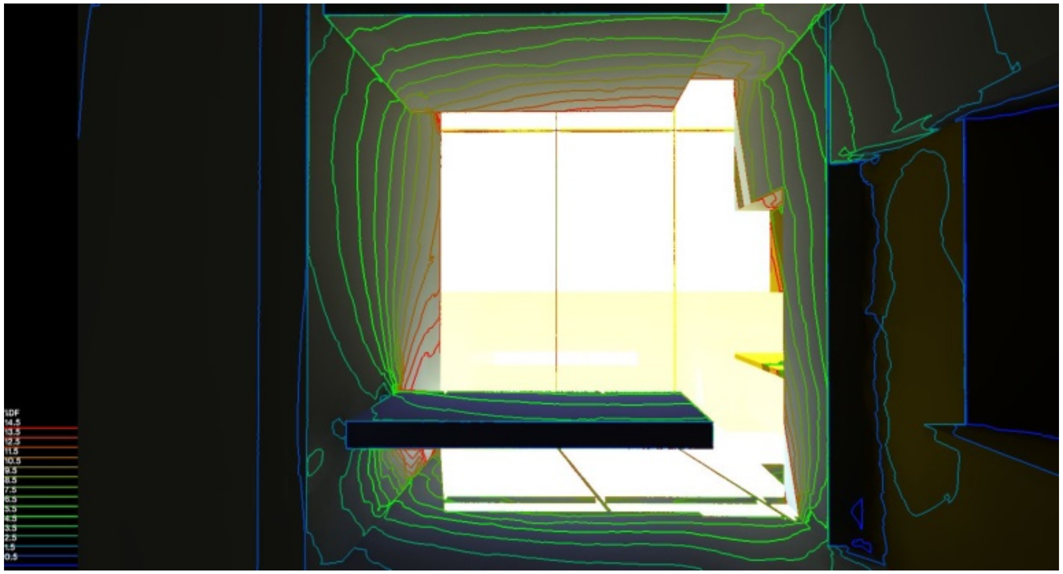


Figure 68: Daylight Factor- Patient Room with Full Height Curtainwall

Case Study Comparison
Daylight Factor
Patient Room with Storefront Windows

The Daylight Factor at the patient bed is considered well daylit, registering a daylight factor of approximately 6.5-7%. Levels of daylight at the staff work surface are limited, recording a daylight factor of approximately 1%. This lack of adequate daylighting at the staff work surface is due to the placement of casework which creates a barrier between the glazing at the envelope and the staff work surface where it would be used to perform staff functions. This is apparent in the contrasting lighting conditions at the surface in the visitor zone which remains well -lit with a daylight factor from 7-11%.

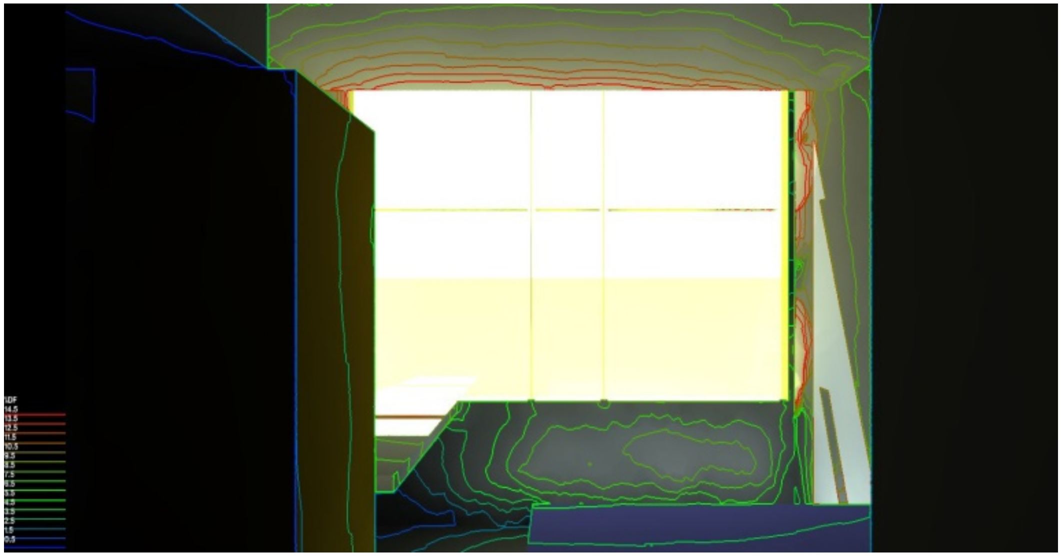


Figure 69: Daylight Factor- Patient Room with Storefront Window System

Case Study Comparison
Daylight Factor
Patient Room with Single Window

The limited glazing area of the single fixed window does not provide sufficient daylight throughout the room. Daylight Factor at the patient bed is inadequate. The patient bed receives a daylight factor of only 0%. This poor utilization of available daylight is also evident at the staff area. The staff work surface registers a daylight factor of 0%.   This nonexistent daylight factor throughout the majority of the room including patient bed and staff work area illustrates that the limited glazing area provided by a single window of approximately 1/3 window wall ratio, provides an insufficient amount of daylight within the room, in relation to the amount of available daylight outside.

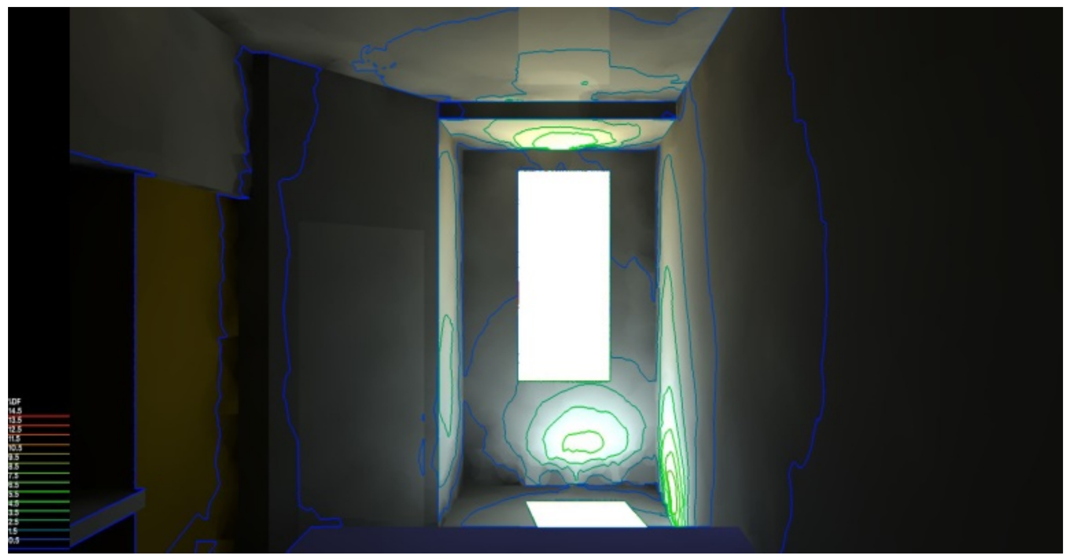


Figure 70 Daylight Factor- Patient Room with Single Window

5.3 Useful Daylight - Illuminance Levels

Illuminance quantifies the measure of the amount of light falling onto a surface, object, or area. This is important to building occupants in that various tasks performed in the patient room by either the patient or staff require a wide range of visual acuity. Providing appropriate light levels for all given tasks promotes safety and quality of care. Illuminance levels created by solar exposure or daylighting from glazing features like windows or skylights is sometimes referred to as useful daylight. Useful daylight can decrease energy costs and environmental impact by reducing the need for electric lighting. Useful daylight also can provide a better quality of light than artificial lighting depending on the conditions.

Illuminance levels or useful daylight can be measured in lux or foot candles. The U.S.or Imperial measurements for Illuminance are in foot candles. This represents the illumination of a surface from a candela located one foot away. The International System of Units or SI unit measurement for Illuminance is lux (lx). The simulations were performed using lux levels (lx), the international illumination measurement as the metric. Less than 100 lx is considered to be insufficient daylight. Between 100 and 2000 lx is considered useful daylight. More than 2000 lx is excessive daylight and can result in visual and thermal discomfort.

Case Study Comparison
Useful Daylight Illuminance Levels-
Patient Room with Full Height Curtainwall

The lighting illuminance levels within the patient room with full height glass curtain wall vary. Useful daylight levels in the visitor area at the envelope are generally high averaging 1369 lux. The patient bed receives adequate levels of useful daylight with an average illuminance of approximately 523 lux. The illuminance levels at the staff work surface remain low with an average of only 138 lux. This drop in useful daylight at the staff zone is due in part to physical obstructions which block available daylight penetration from reaching further.

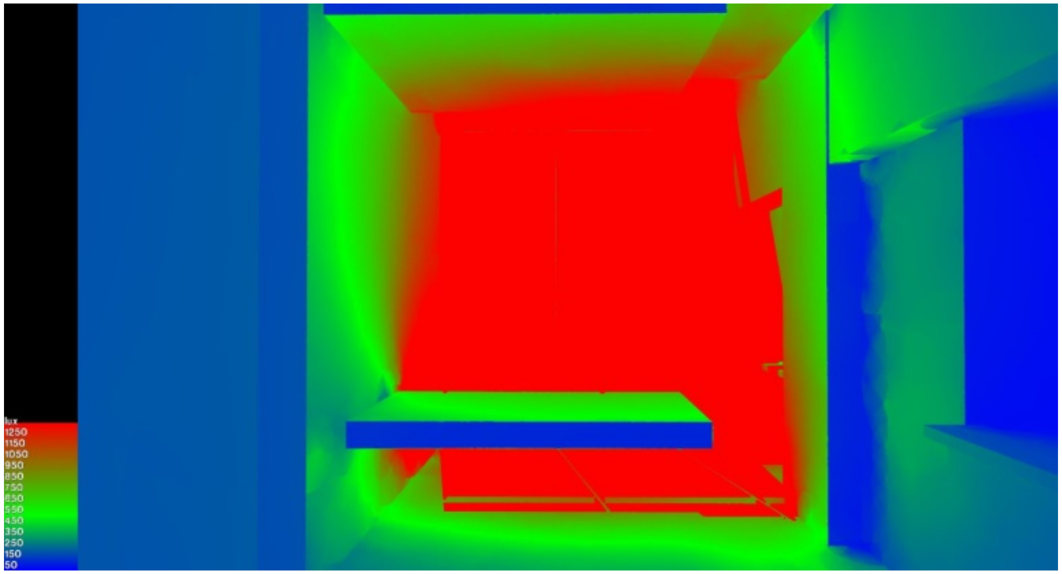


Figure 71: Useful Daylight Illuminance- Patient Room with Full Height Curtainwall

Case Study Comparison
Useful Daylight Illuminance Levels-
Patient Room with Storefront Windows

Useful Daylight Illumination levels in the visitor area of the patient room with the storefront windows were high and averaged 1077 lux. The patient bed is well day lit with an average illumination of 486 lux. Useful daylight illumination at the staff zone was poor, providing only 29 lux at the staff work surface. The placement of casework obstructs natural light from reaching further into the room, leaving the staff work surface in shadow while the surface in the visitor zone adjacent to the casework remains well day lit.

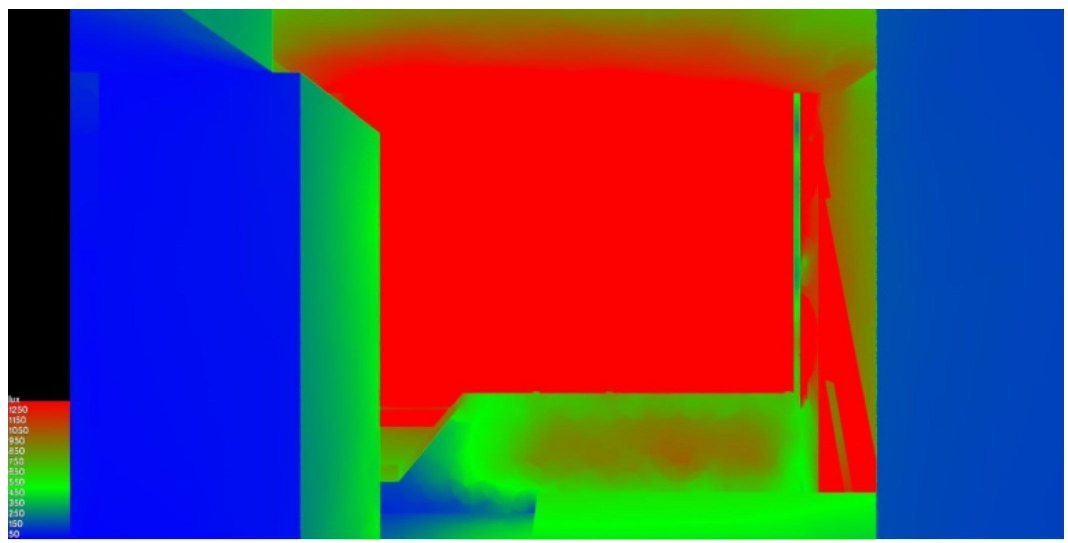


Figure 72: Useful Daylight Illuminance- Patient Room with Storefront Windows

Case Study Comparison
Useful Daylight Illuminance Levels- Patient Room with Single Window

Patient Room Option C provides inconsistent useful daylight illumination at the family visitor zone near the window, which ranges from 0-1250. The limited daylight allowed through the window creates a lighting hot spot among areas that remain shaded. Overall the daylight illumination at the family zone is low, averaging 228 lux. The natural daylighting at the patient bed is inadequate, as the patient bed receives only 70 lux of natural daylight. The staff work area does not benefit from any natural light receiving only 10 lux. This creates a dependence on electric lights for illumination during daylight hours leading to increased lighting energy consumption in order to undertake normal tasks.

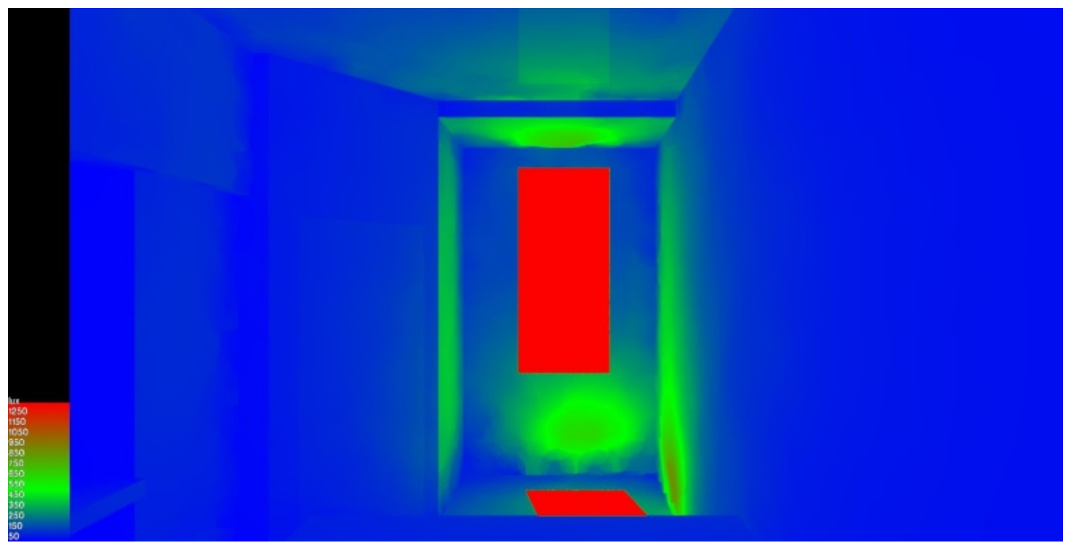


Figure 73: Useful Daylight Illuminance- Patient Room with Single Window

Case Study Comparison
Useful Daylight
Illuminance Levels

Patient Room Comparison
Lux Levels

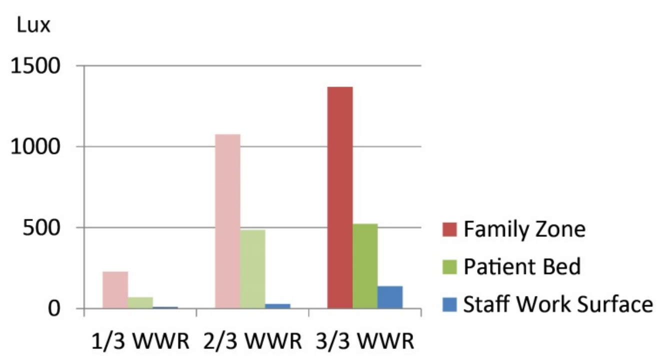


Figure 74: Patient Room Comparison

Illuminance Image –Lux Levels throughout the room

The Useful Daylight or Illuminance Levels in each patient room configuration were tested through lighting simulation and analysis using Ecotect and Radiance software. Access to Useful Daylight in each patient room configuration seems to directly correlate with the varying window wall ratios or glazing areas of each option. This is evidenced in the varying levels of illumination registered on several surfaces at different depths in the room consistently in each model configuration.

The case study configuration with the least glazing area with nearly 1/3 window wall ratio (WWR) provides insufficient illumination throughout the room with relatively little daylight potential at the staff work surface and patient bed. This configuration provided low useful light even near the envelope at the family zone. The configuration with approximately 2/3 window wall ratio provides better lighting conditions at the patient bed, and family zone. However, useful daylight at the staff work surface remains low. The configuration with the full 3/3 window wall area again increased illuminance levels at the family zone located near the envelope. While Illuminance levels at the patient bed do not increase dramatically over the 2/3 WWR configuration, there is a substantial increase in daylight penetration farther into the room providing greater useful daylight at the staff work surface.

5.4 Light Quality & Visual Comfort

Luminance Levels

Luminance is the amount of light reflected off of a surface. Luminance is measured in candelas per meter squared (cd/m2). This measure of the intensity of light for a given area reflects the quality of light perceived by our eyes from a specific vantage point. Luminance levels are often used to study visual comfort and can express potential lighting quality considerations like brightness, light distribution, and glare.

These factors can be affected by the illuminance or quantity of light falling onto a surface, as well as the angle of the surface to the light source, and point of view. Properties like material texture, color, and reflectance of the surface itself can also affect levels of luminance. Brightness is often associated as the perception of luminance from a light source or reflected from a surface. Higher luminance levels are perceived as brighter. Excess luminance levels perceived as too bright can lead to visual discomfort. Light Distribution is an important factor in considering the quality of lighting conditions. Evenly distributed luminance levels are more ideal while contrasting variations in luminance levels or brightness can lead to the perception of glare.

Excessive levels of glare can cause visual discomfort and even health affects like retinal damage. The perception of glare can be reduced by decreasing contrasting variations in luminance levels within the field of view. Contrasts in luminance levels greater than 10:1 make it more difficult to perform visually demanding tasks. Contrasts of 20:1 can cast shadows. Contrasts in luminance of 50:1 within the field of view can cause visual discomfort.

Case Study Comparison

Luminance Levels

Patient Room with Single Window

The work plane luminance levels within patient room with single window are quite low due to the limited 1/3 window wall ratio. While this presents less possibility for visual discomfort from glare, it is due mostly to the fact that there is insufficient penetration of available daylight as evidenced earlier by the low daylight factor and illuminance levels throughout the room. The majority of the room, most notably the patient bed and staff work zone, remain in shadow due to the lack of sufficient glazing area at the envelope. The physical barrier created by the outboard toilet room layout limits potential glazing area. The light levels within the family visitor zone are inconsistent due to the lighting hot spot created by the single window.

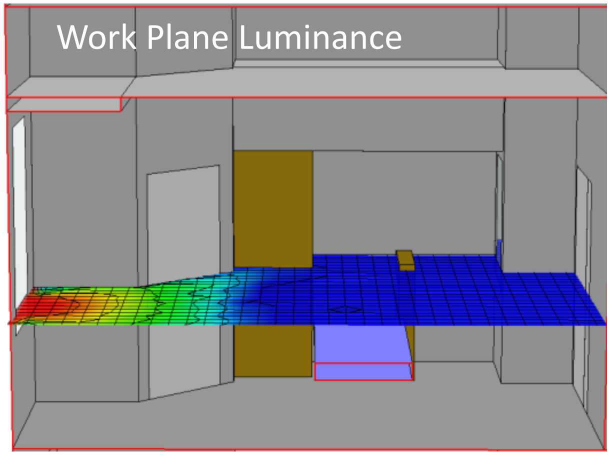


Figure 75: Work Plane Luminance
Patient Room with Single Window

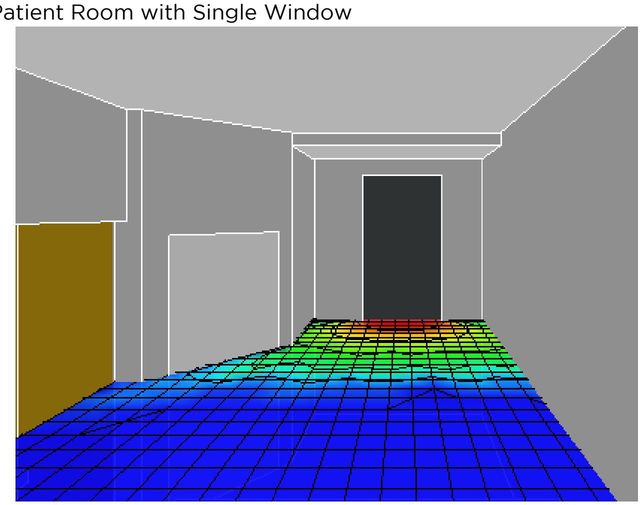


Figure 76: Work Plane Luminance
Patient Room with Single Window

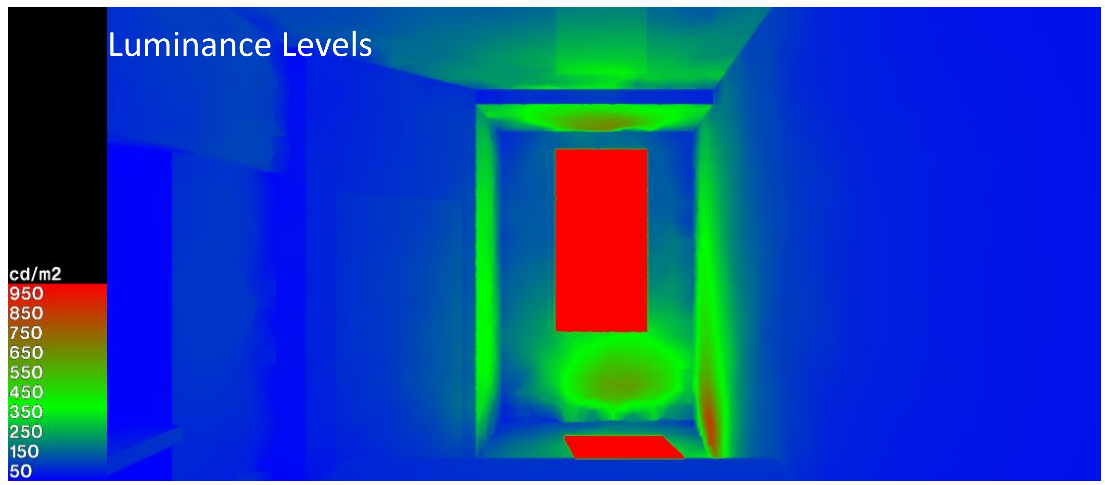


Figure 77: Luminance levels throughout the room
Patient Room with Single Window

Case Study Comparison

Luminance Levels

Patient Room with Storefront Windows

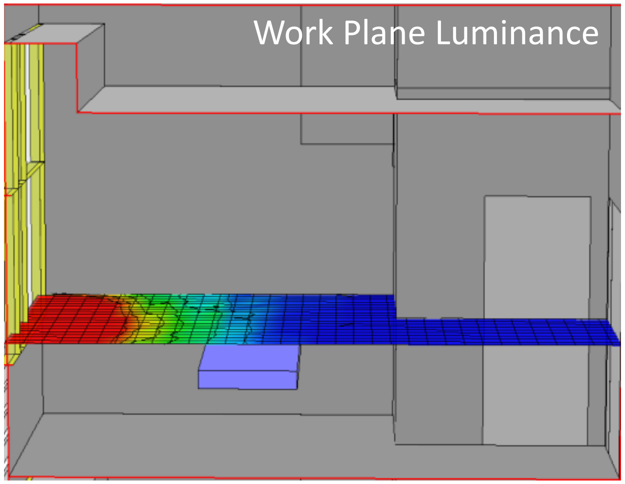


Figure 78: Work Plane Luminance
Patient Room with Storefront Window System

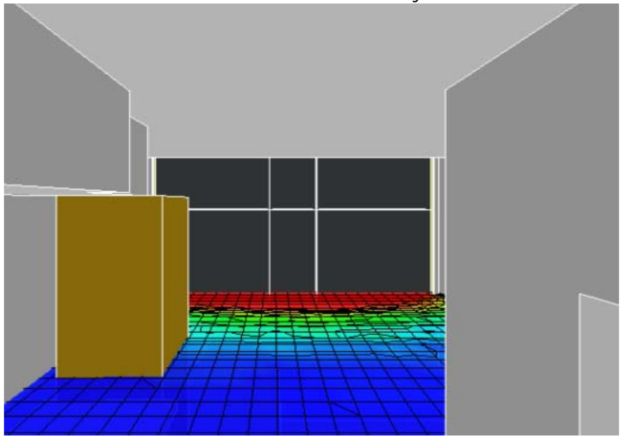


Figure 79: Work Plane Luminance
Patient Room with Storefront Window System

The increased glazing area and head height of the storefront window system utilized in the patient room with 2/3 WWR sustains greater daylight factors deeper into the room. In this configuration, the patient bed begins to receive more adequate light levels than in the patient room with the single window. It is notable however, that even with the inboard toilet room layout, furniture and systems can still become barriers to daylight levels in the same way as the outboard toilet room was in the first example. In this case, the casework, located between the glazing at the envelope and the staff work surface farther into the room, casts a shadow on the staff work surface. The location of the casework reduces daylight access in the staff work zone, while the surface in the family zone immediately adjacent on the other side of the casework remains well lit.

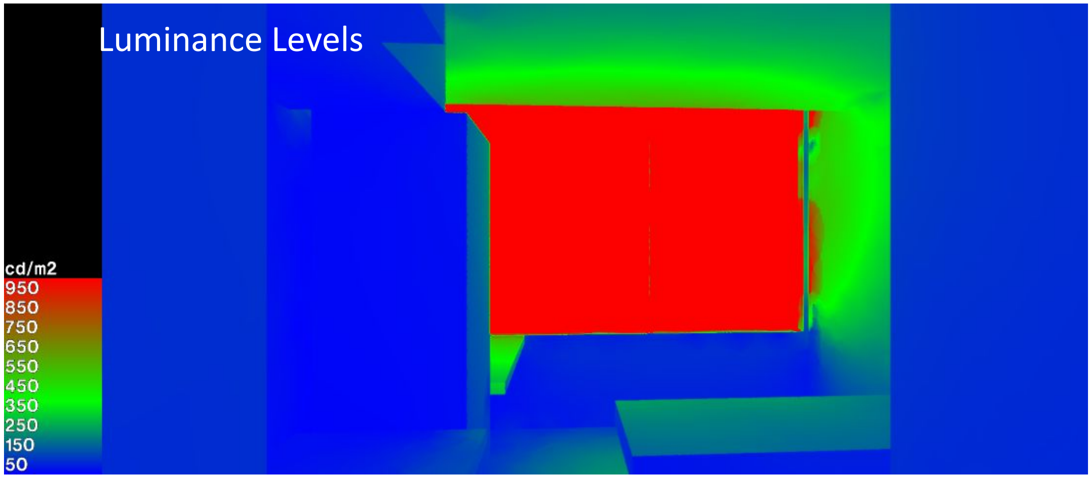


Figure 80: Luminance levels throughout the room
Patient Room with Storefront Window System

Case Study Comparison
Luminance Levels
Patient Room with Full Height Curtainwall

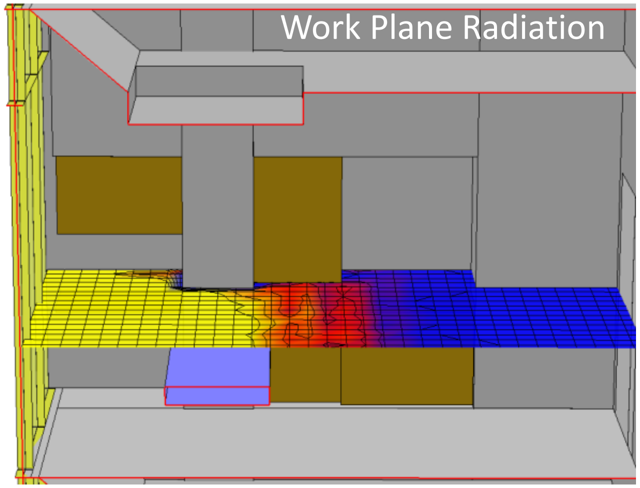


Figure 81: Work Plane Radiation
Patient Room with Full Height Curtainwall

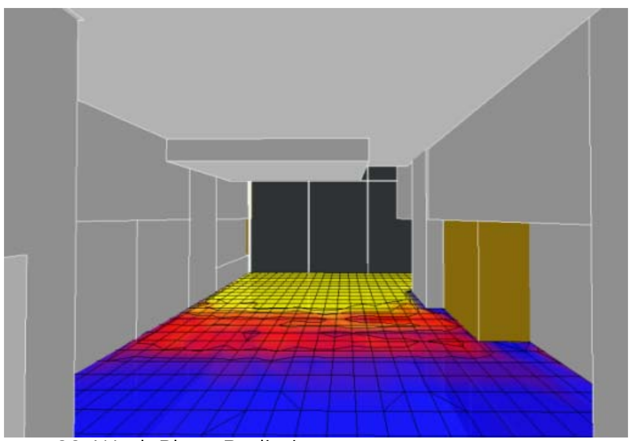


Figure 82: Work Plane Radiation
Patient Room with Full Height Curtainwall

The full glazing area of the glass curtain wall configuration provides far higher potential daylight penetration utilizing more of the available sunlight as evidenced by a more consistent daylight factor deeper into the room. Although this provides greater lighting levels at the staff work surface and patient bed, this may come at the expense of visual and thermal comfort. The expanse of the glass curtainwall could result in the potential for visual discomfort in the form of glare from direct sunlight, illustrated in high luminance levels at the envelope represented in red. The high levels of solar radiation shown in yellow; at both the family zones and patient bed area also can lead to solar heat gains causing higher temperatures that affect thermal comfort.

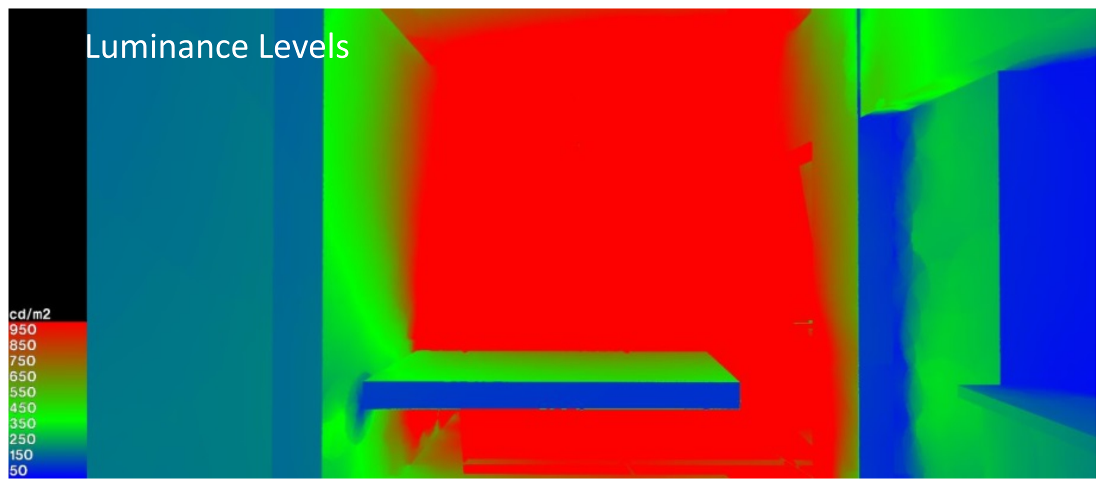


Figure 83: Luminance levels throughout the room
Patient Room with Full Height Curtainwall

5.5 Solar Heat Gain

Although greater glazing area provides increased daylighting potential, the increased area for incident solar radiation to penetrate also can result in effects on the thermal characteristics of the space through solar heat gain. Typically greater glazing area provides more potential for the suns' radiation to generate higher temperatures within the room. Depending on the climate this can be used as an advantage. However, in other climates this creates more of a challenge.

In cooling dominated climates, for example the Northeast United States, increased solar heat gain can be used to offset heating costs and reduce energy consumption and related carbon dioxide emissions. However, in cooling dominated climates such as the Southeast United States where the case study configurations, simulation and analysis take place in ASHRAE climate zones 1 and 2, increased solar heat gain presents a detriment to the thermal comfort of occupants. Increased solar heat gain in cooling dominated climates creates an increased reliance on mechanical systems for cooling, resulting in increased energy consumption and carbon dioxide emissions. This creates a design challenge in that increased daylight improves occupant health and well-being and lowers lighting energy costs, however in cooling dominated climates, providing increased daylight through greater glazing area also can result in greater reliance on mechanical HVAC systems for cooling.

Case Study Comparison

Annual Solar Heat Gain

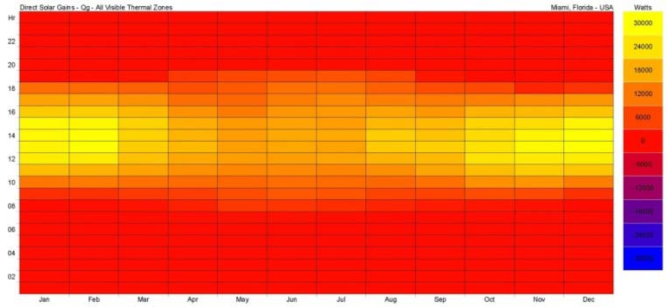


Figure 84: Patient Room with Full Height Glass Curtainwall
Annual Solar Heat Gain – Max 30,000 Watts

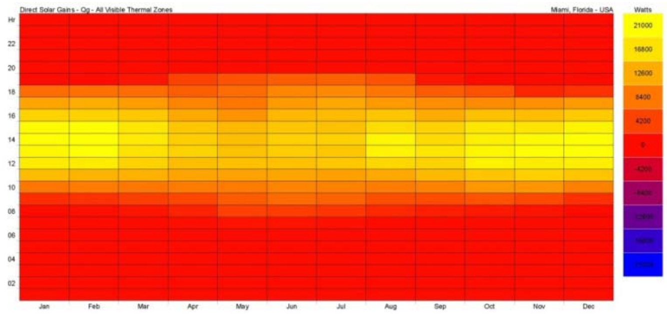


Figure 85: Patient Room with Storefront Window System
Annual Solar Heat Gain – Max 21,000 Watts

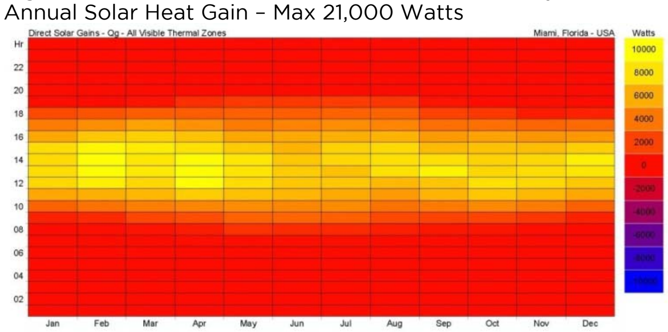


Figure 86: Patient Room with Single Window
Annual Solar Heat Gain – Max 10,000 Watts

The annual solar heat gain of each patient room configuration is reflective of the size of the glazing area, or window wall ratio (WWR) of each. Configuration A with the glass curtainwall has the greatest glazing area with 3/3 window wall ratio. This configuration has a maximum annual solar heat gain of 30,000 watts. The annual solar heat gain of the patient room configuration with the full window wall ratio will serve as the reference point for comparison of the other glazing configurations with varying window wall ratios.

The patient room with the glass storefront has approximately 2/3 window wall ratio. This configuration in turn registers 21,000 watts. This represents approximately two thirds the maximum annual solar heat gain of the full glass curtainwall, which registered 30,000 watts annually. These corresponding figures demonstrate the parallel between window wall ratio and solar heat gain.

The patient room with the double hung window has the least glazing area, with nearly 1/3 window wall ratio. This results in 1/3 of the amount of maximum annual solar heat gain than that of the configuration with the full glazing area. The patient room configuration with 1/3 window wall ratio receives 10,000 watts of annual solar heat gain. This represents about one third the annual solar heat gain of the patient room with the glass curtainwall .

The solar heat gain of each glazing configuration is representative of their respective window wall ratios. This illustrates a direct correlation between window wall ratio or glazing area and the solar heat gain or passive solar gain within a given space, in this case three south facing patient rooms with varying glazing sizes.

6 COMPARING PATIENT ROOM CONDITIONS WITH APPPLIED SOLAR SCREENING METHODS

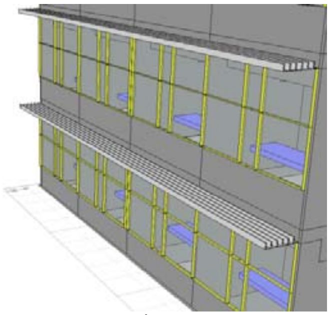


Figure 87: Overhang Baffles on 2/3 WWR Storefront Window System

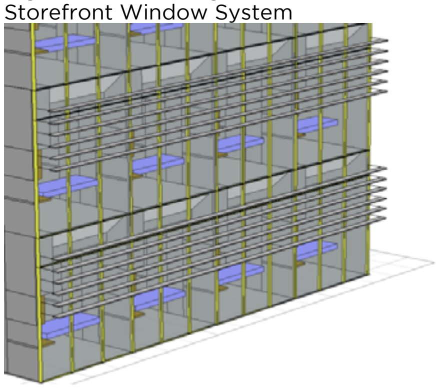


Figure 88: Horizontal Louvers on 3/3 WWR Full Height Curtain Wall System

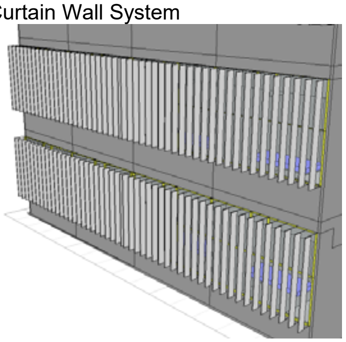


Figure 89: Vertical Louvers on 2/3 WWR Storefront Window System

The Orientation of the exterior wall and window drive the orientation of shading devices. Windows facing both east and west benefit from a vertical louver orientation due to the low angle of morning and evening sun, while windows facing south benefit from horizontal louvers due to the higher sun angle. In the northern hemisphere windows facing north are typically shaded by the building itself.

The most common exterior shading method is a solid overhang that shields the entirety of direct solar radiation. Mounting louvers in place of solid overhangs can create shade while allowing greater levels of diffuse lighting into the room. Shading devices can be sized in response to sun angle, which varies dependent upon both time of day, and season. In cooling dominated climates, varying the depth of shading devices can allow for increased shade during summer months when the sun is high, while at the same time allow for greater daylight penetration and direct solar heat gain during winter months when the sun is lower in the sky.

The application of solar control methods can influence and affect measureable change in occupant visual and thermal comfort characteristics as well as building performance metrics. Solar screening methods can either provide shade, and/or redirect light, and some are designed to do both. They can be effective in promoting visual comfort by blocking unwanted glare from direct sunlight. In cooling dominated climates solar control methods can help to achieve occupant thermal comfort by lowering unwanted heat gain which also reduces the energy demand on mechanical systems to maintain thermal comfort.

Solar screening methods can be applied to the exterior façade or mounted internally. This study focuses on exterior mounted solar control and shading methods as internally mounted features are not effective in blocking solar heat gain, and in some cases actually increase solar gains as they may collect the suns' energy within the room rather than blocking it outside of the envelope.
There are various considerations to take into account when designing solar control methods. Some of these considerations include climate, orientation, and intended results such as occupant visual and thermal comfort and building energy performance. For the purposes of this study, one of the major goals or intended results is to maximize glazing area to increase the benefits to occupant health and well-being through natural daylighting and views. However, in doing so, mitigating the negative thermal effects associated with increased glazing area such as increased solar heat gain which leads to additional energy consumption by HVAC and mechanical systems in cooling dominated climates.

6.1 Solar Screening Comparison –
Incident Solar Radiation
Patient Room with Storefront System

Overhang Baffles–
-Least Even Lighting Levels
-Least Restricted View

Horizontal Louvers-
-Fairly Even Lighting Levels
-Slightly Restricted View

Vertical Louvers–
-Most Even Lighting Levels
-Fairly Restricted View

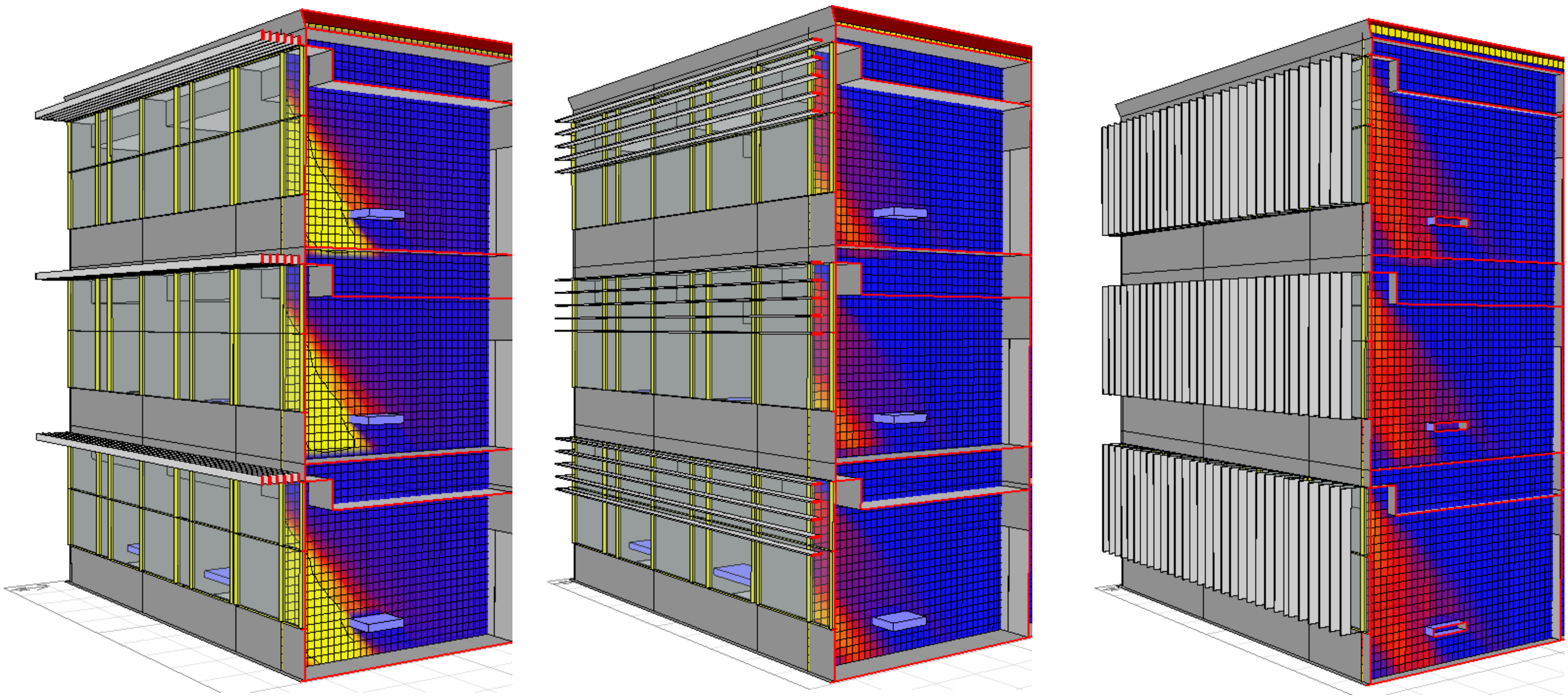


Figure 90: Solar Screening Comparison
Incident Solar Radiation- Patient Room with Storefront System

Solar Screening Comparison -
Incident Solar Radiation
Patient Room with Storefront System

Overhang Baffles-
Joe DiMaggio
Incident Solar Radiation

Horizontal Louvers-
Joe DiMaggio
Incident Solar Radiation

Vertical Louvers-
Joe DiMaggio
Incident Solar Radiation

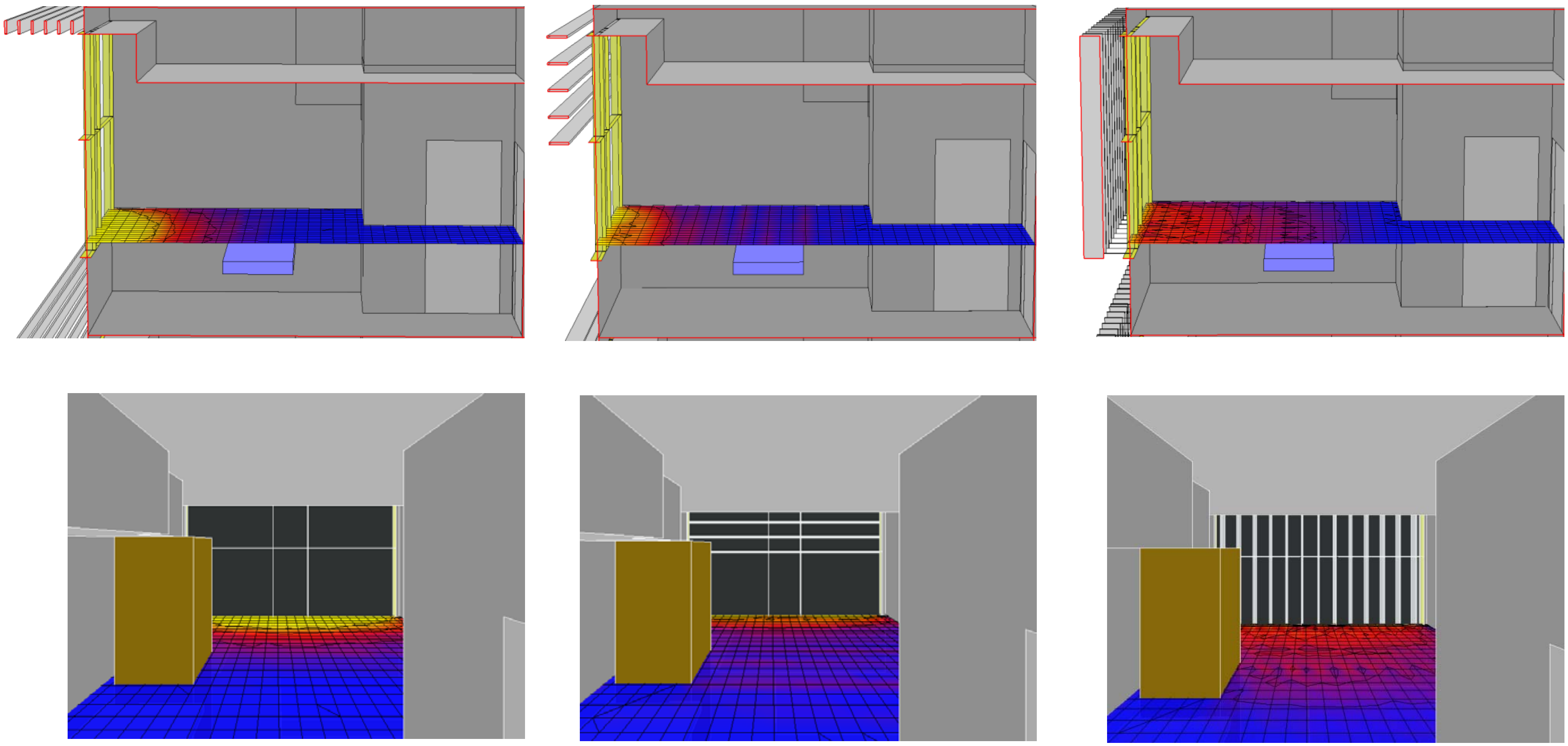


Figure 91: Solar Screening Comparison
Incident Solar Radiation- Patient Room with Storefront System

Solar Screening Comparison -
Incident Solar Radiation
Patient Room with Full Height Curtainwall

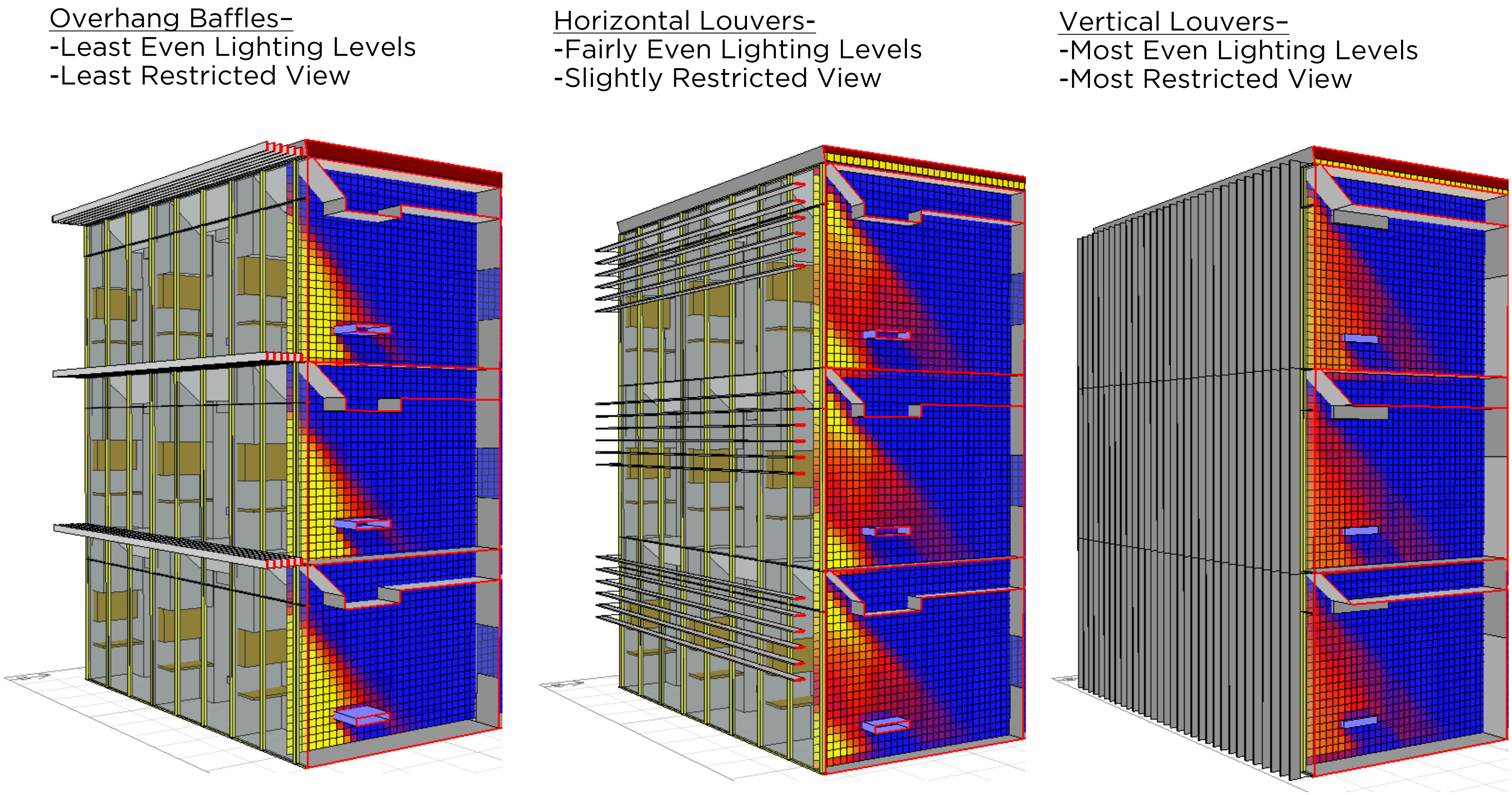


Figure 92: Solar Screening Comparison
Incident Solar Radiation- Patient Room with Glass Curtainwall

Solar Screening Comparison -
Incident Solar Radiation
Patient Room with Full Height Curtainwall

<u>Overhang Baffles –</u>
Nemours
Incident Solar Radiation

<u>Horizontal Louvers-</u>
Nemours
Incident Solar Radiation

<u>Vertical Louvers-</u>
Nemours
Incident Solar Radiation

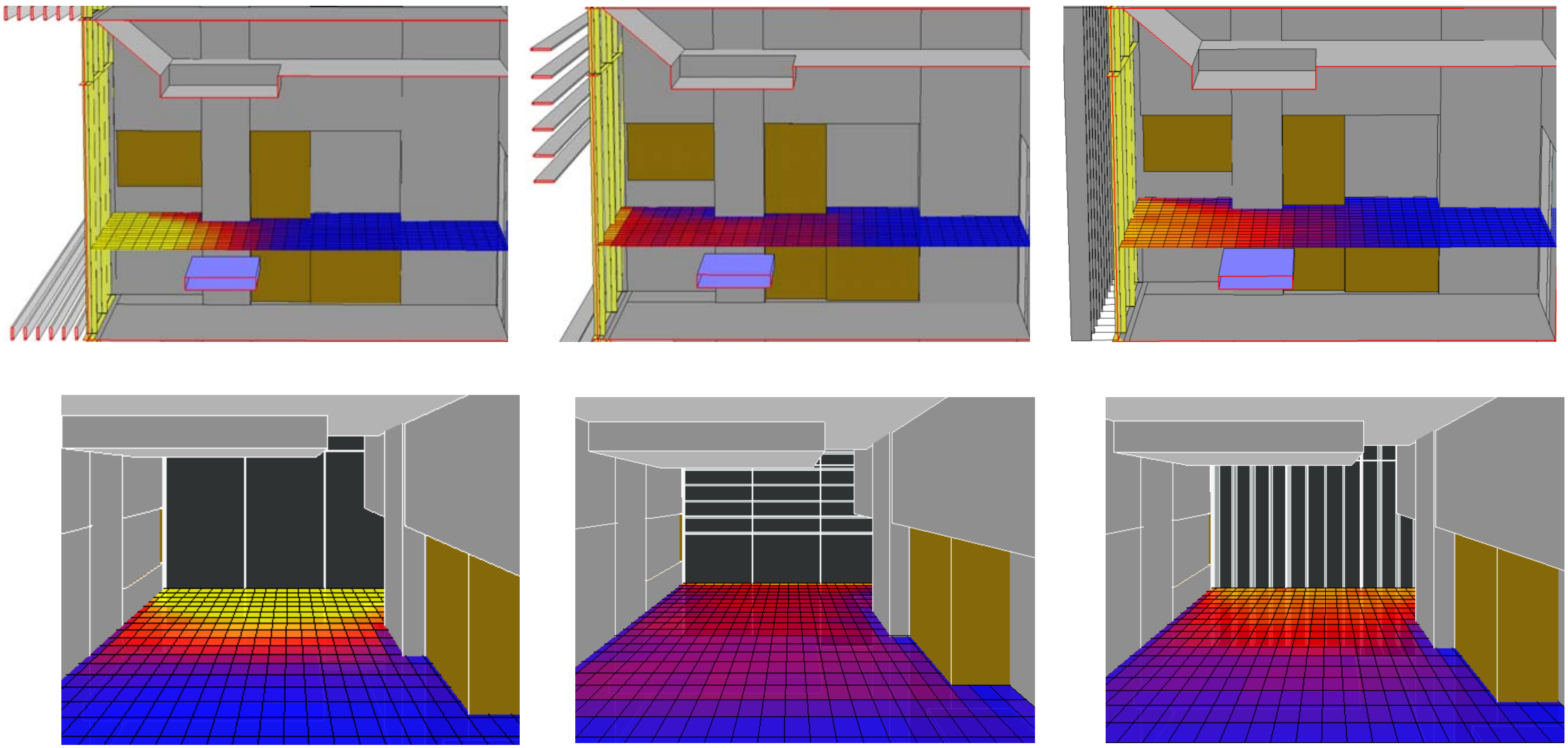


Figure 93: Solar Screening Comparison
Incident Solar Radiation- Patient Room with Glass Curtainwall

Solar Screening Methods
Effect on Incident Solar Radiation

Incident solar radiation is often used by designers and researchers as a metric that can represent likely thermal and lighting outcomes. This makes incident solar radiation an important metrics to measure for its impact on both lighting and thermal conditions within the patient room. As solar radiation can be associated with both light and heat, the effect that each solar control method had on incident solar radiation may be reflected similarly in lighting and thermal outcomes.

The projecting baffles provided the least restrictive view due to their height. However the baffles also provided the least even distribution of incident solar radiation. The projection blocked the majority of radiation at the top of the window limiting potential daylight penetration while allowing radiation to pass through the rest of the window, providing little shade for visual or thermal comfort at the envelope. The horizontal louvers provided even levels of incident solar radiation at the work plane height. This varied somewhat at different heights as the horizontal louvers are mounted on the upper half of the glazing area. The vertical louvers provided the most even incident solar radiation levels. However the vertical louvers also create the most restrictive view as they span both daylight and vision glazing heights.

6.2 Solar Screening Comparison – Daylight Factor

Patient Room with Storefront System & Overhang with Baffles

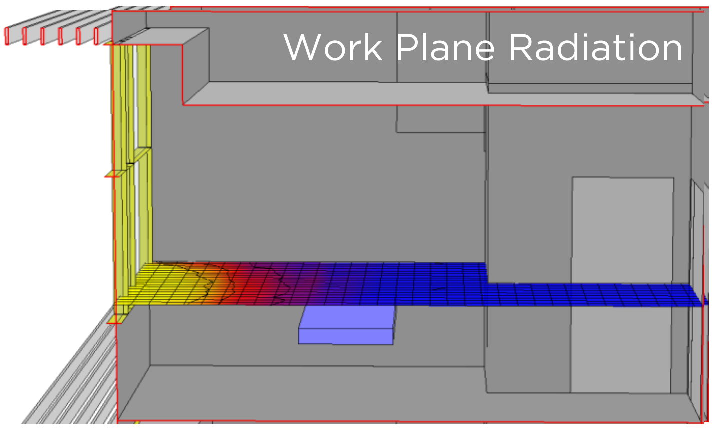


Figure 94: Work Plane Radiation –
Patient Room with Storefront System & Overhang Baffles

The daylight factor in the family zone at the envelope is inconsistent due to the location and orientation of the overhang baffles. This is evidenced in the variations of daylight factor at the work surface in the family visitor zone which range from 14% down to 2%.

The patient bed receives 2% daylight factor requiring electric lighting during much of the day. The staff work surface does not receive any available daylight due to the placement of casework which inhibits potential daylight penetration.

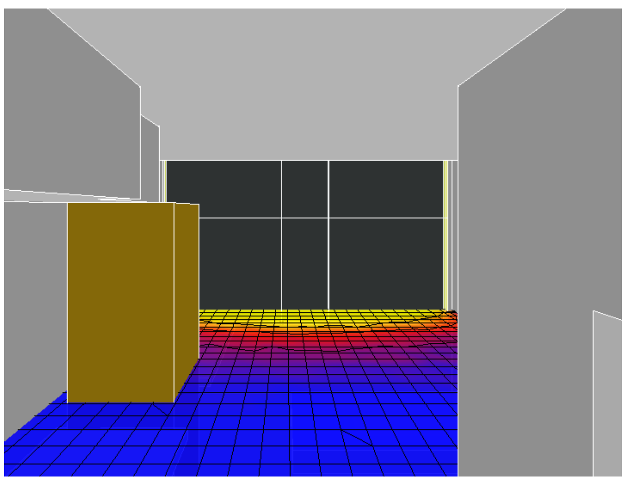


Figure 95: Work Plane Radiation –
Patient Room with Storefront System & Overhang Baffles

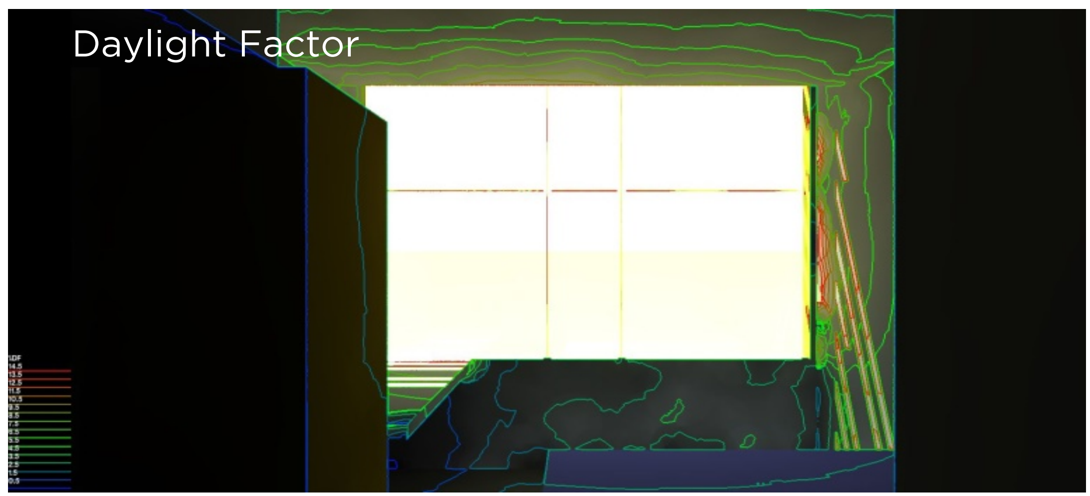


Figure 96: Daylight Factor - Patient Room with Storefront Window System & Overhang Baffles

Solar Screening Comparison
Daylight Factor-
Patient Room with Storefront System &
Horizontal Louvers

The horizontal louvers reduced the available daylight at the envelope. The daylight factor was limited to under 2% within much of the visitor zone. The work plane height remains well day lit with a daylight factor of 5% at the work surface in the visitor zone. The patient bed receives a daylight factor of 4% which would not require electric lighting during much of the day. The staff work zone remains in shadow with a lack of available day light. The poor placement of the casework creates barrier to natural daylighting reaching the staff work area requiring electric lighting during daylight hours.

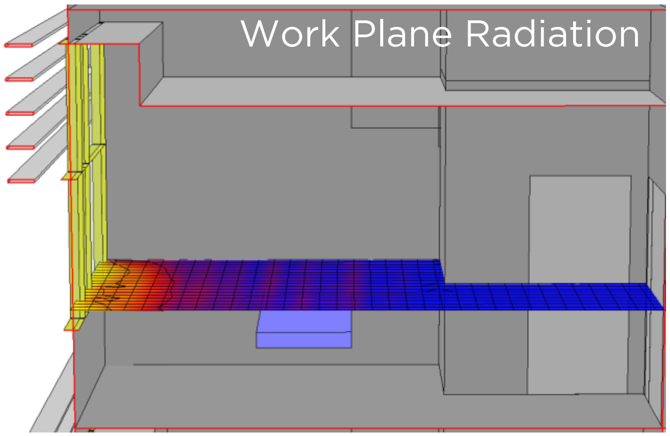


Figure 97: Work Plane Radiation –
Patient Room with Storefront System & Horizontal Louvers

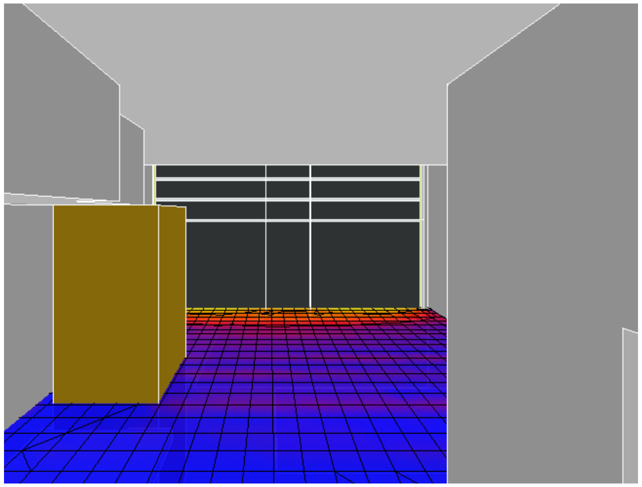


Figure 98: Work Plane Radiation –
Patient Room with Storefront System & Horizontal Louvers

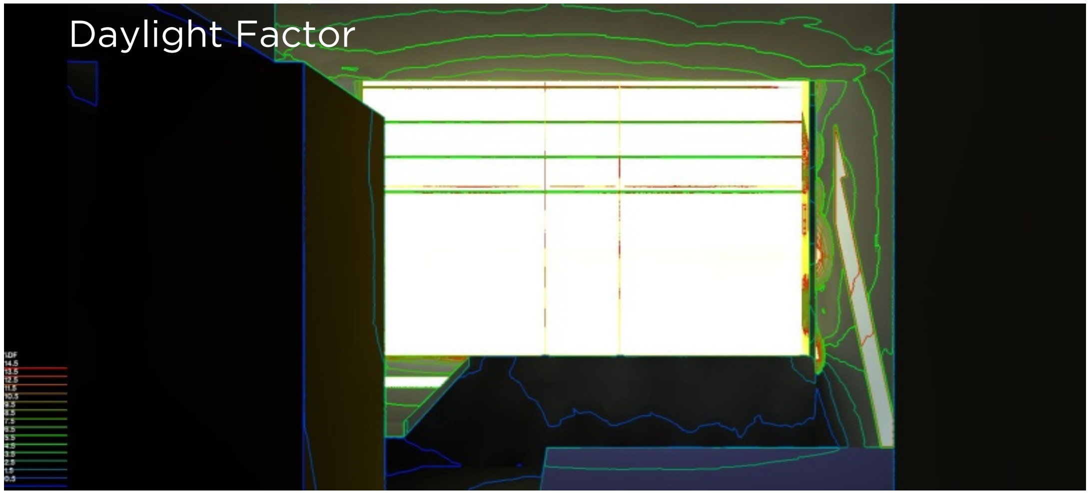


Figure 99: Daylight Factor – Patient Room with Storefront System & Horizontal Louvers

Solar Screening Comparison
Daylight Factor-
Patient Room with Storefront System &
Vertical Louvers

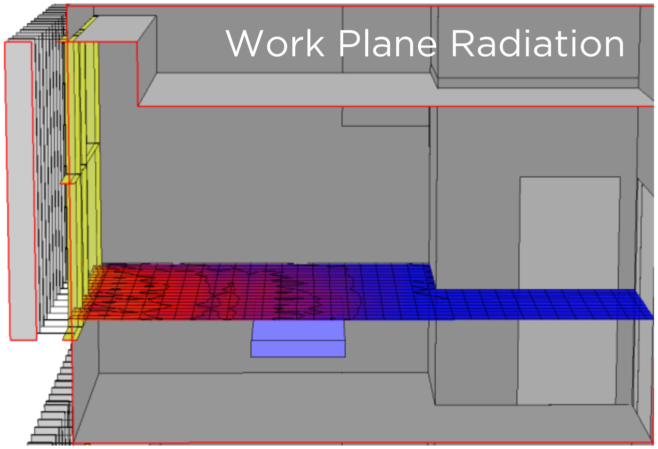


Figure 100 Work Plane Radiation-
Patient Room with Storefront System & Vertical Louvers

The vertical louvers allow more daylight penetration throughout the room. The family zone is well day lit with a daylight factor of 5-6% at the work surface. The patient bed receives a daylight factor of 3% requiring electric lighting during only part of the potential daylight hours. Although the vertical louvers provide greater potential daylight penetration, the staff work zone still does not receive any natural daylight. This is due to the placement of the casework which creates a physical barrier blocking potential natural daylight penetration from reaching the staff zone.

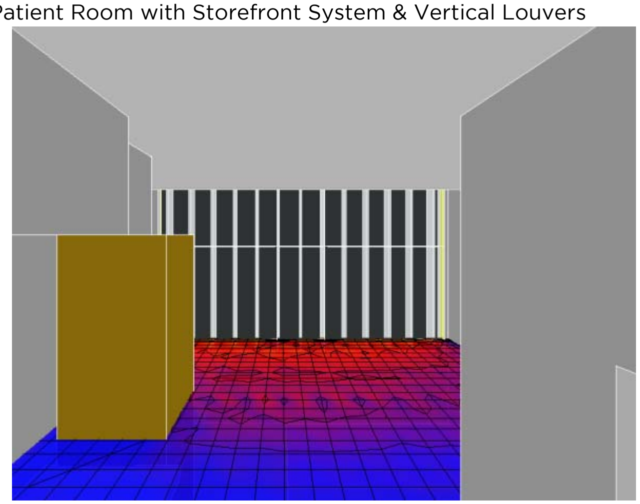


Figure 101: Work Plane Radiation-
Patient Room with Storefront System & Vertical Louvers

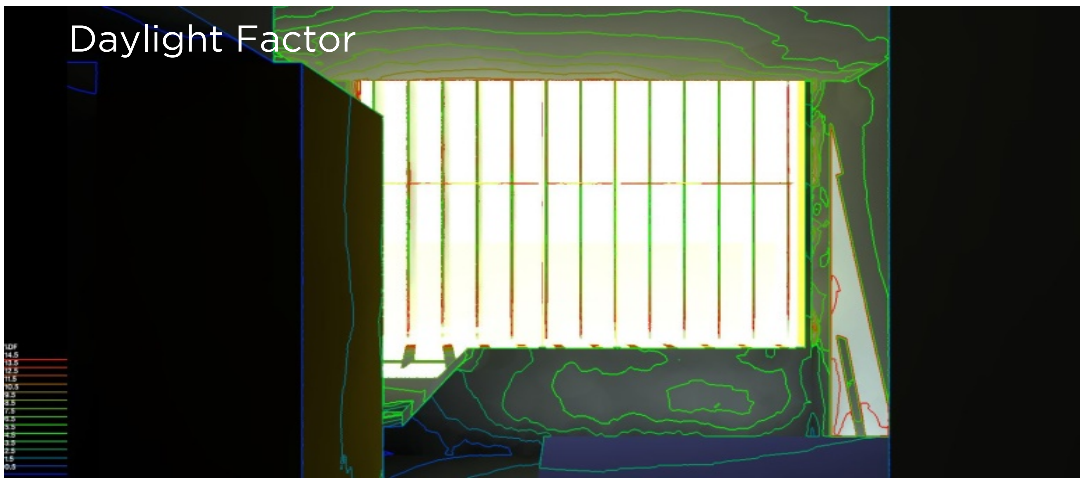


Figure 102: Daylight Factor- Patient Room with Storefront System & Vertical Louvers

Solar Screening Comparison
Daylight Factor-
Patient Room with Glass Curtain Wall &
Overhang Baffles

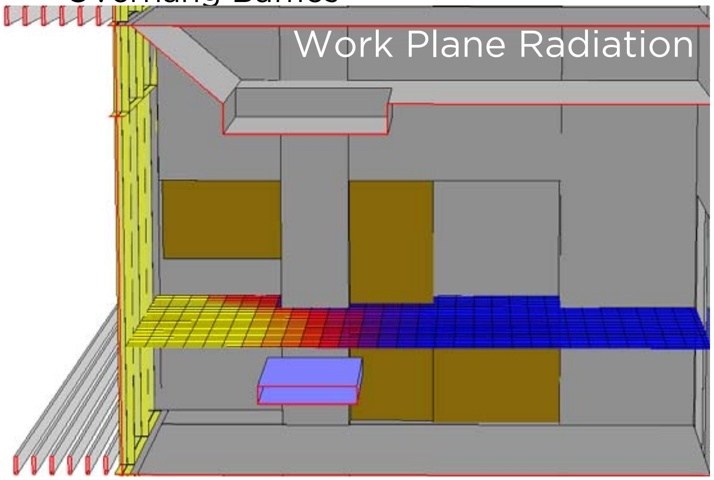


Figure 103: Work Plane Radiation –
Patient Room with Glass Curtain Wall & Overhang Baffles

The size, position, and orientation of the overhang baffles do little to mitigate the excessive levels of daylight allowed by the full height curtainwall. The family visitor zone near the envelope registered a daylight factor of nearly 15% which could potentially result in glare or heat gain. The patient bed receives a daylight factor 4-5% requiring electric lighting only at dawn, dusk or non-daylight hours. The staff work zone is poorly day lit receiving a daylight factor of only 0-1%. This is due to the obstructions between the envelope and the staff work surface necessitating electric lighting during daylight hours.

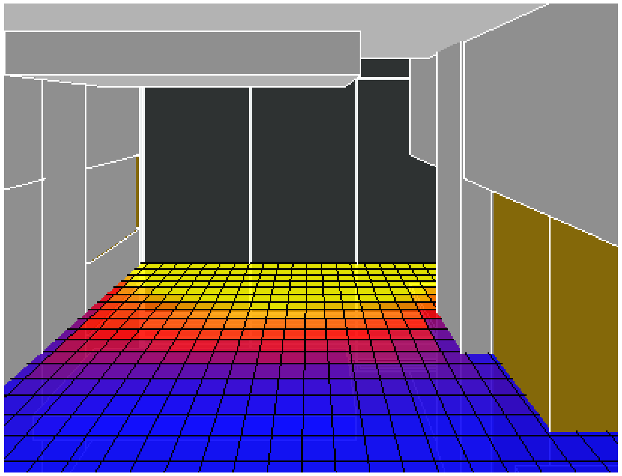


Figure 104: Work Plane Radiation –
Patient Room with Glass Curtain Wall & Overhang Baffles

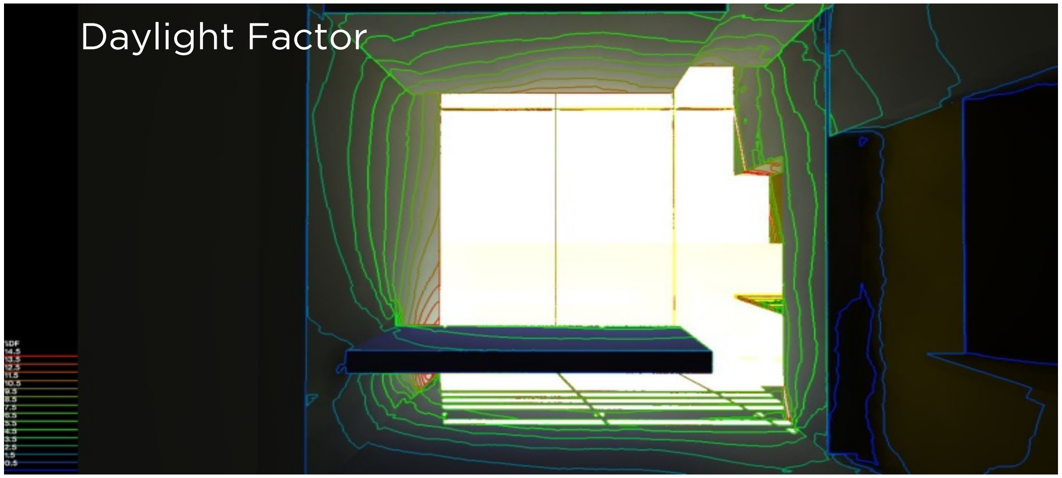


Figure 105: Daylight Factor throughout the Room- Glass Curtain Wall & Overhang Baffles

Solar Screening Comparison
Daylight Factor-
Patient Room with Glass Curtain Wall & Horizontal Louvers

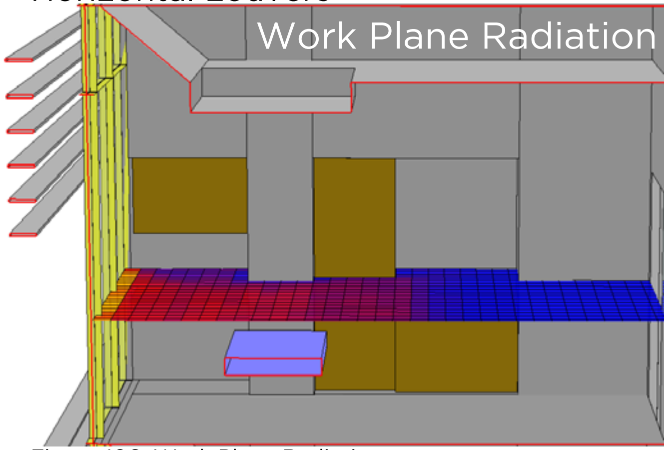


Figure 106: Work Plane Radiation –
Patient Room with Glass Curtain Wall & Horizontal Louvers

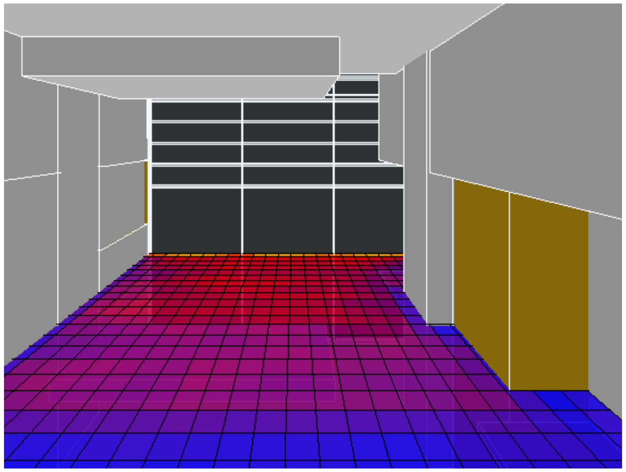


Figure 107: Work Plane Radiation –
Patient Room with Glass Curtain Wall & Horizontal Louvers

The horizontal louvers provide adequate shading at the envelope. while allowing an average daylight factor as high as 8% within the visitor zone. The patient bed receives a daylight factor of 3-4% which would not require electric lighting for most available daylight hours. The staff zone again receives inadequate daylighting with a daylight factor of only 0-1% requiring use of electric lighting in order to light the staff work surface during daylight hours.

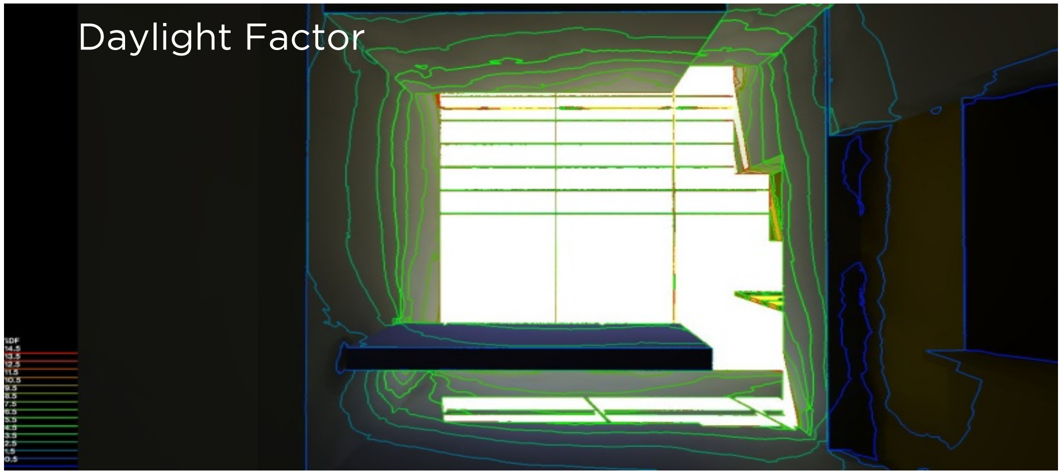


Figure 108: Daylight Factor throughout the Room- Glass Curtain Wall & Horizontal Louvers

Solar Screening Comparison
Daylight Factor-
Patient Room with Glass Curtain Wall &
Vertical Louvers

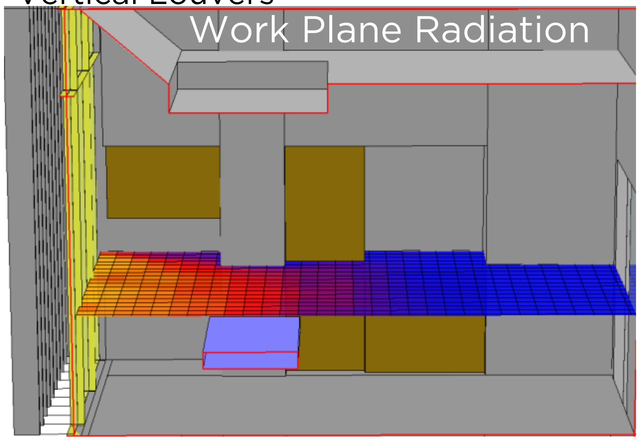


Figure 109: Work Plane Radiation –
Patient Room with Glass Curtain Wall & Vertical Louvers

Vertical louvers are not well suited to south elevations due to their orientation to the angle of incident solar radiation. This makes vertical louvers more appropriate for east or west elevations due to the suns travel and position lower in the sky. On a south elevation when the sun is higher in the sky, the vertical louvers allow much of the available daylight into the room. This is evident at the envelope of the full height curtain wall which received a daylight factor high as 10%. The daylight factor at the patient bed ranged from 2-3% requiring limited use of electric lighting during daylight hours, while daylight was lacking at the staff zone with only 0-1% daylight factor.

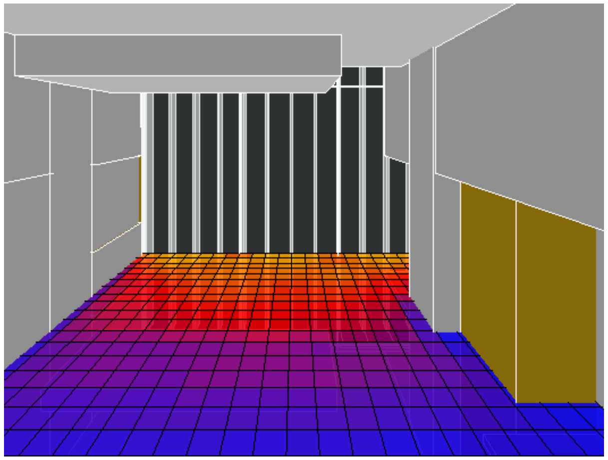


Figure 110: Work Plane Radiation –
Patient Room with Glass Curtain Wall & Vertical Louvers

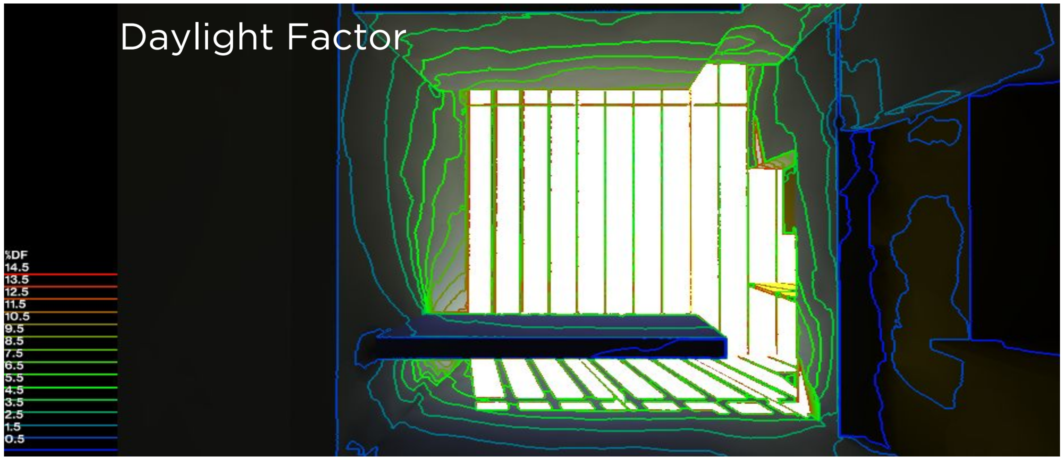


Figure 111: Daylight Factor throughout the Room- Glass Curtain Wall & Vertical Louvers

6.3 Solar Screening Comparison – Useful Daylight Illuminance

Illuminance or useful daylight quantifies the levels of light that fall onto a surface, in this case measured at the work plane at the height of the patient bed, staff work surface, and the eye level of a seated visitor. This work plane height reflects useful lighting levels at the most relevant point to represent the conditions experienced by the occupants. Depending upon the task, differing light levels are recommended for visual acuity. For instance lower light levels are required for a patient resting in bed than for a staff member charting records or administering medication. Providing adequate levels of useful daylight for a given task also can reduce the reliance on electric lighting and decrease lighting energy consumption, associated cost, and environmental impact. Adequate useful daylight illumination levels also can decrease internal heat gains from electric lighting.

The work plane useful daylight illumination simulations were performed using the international metric for illumination levels measured in lux (lx). Illuminance levels from natural daylighting begin to be considered useful daylight at a minimum of 100 lx. Less than 100 lx is inadequate to perform most tasks, while visually oriented tasks requiring greater visual acuity can range up to 2000 lx. Visual and thermal discomfort can become evident above 2000 lx where illumination levels begin to be considered excessive.

Solar Screening Comparison – Useful Daylight Illuminance Patient Room with Storefront System & Overhang with Baffles

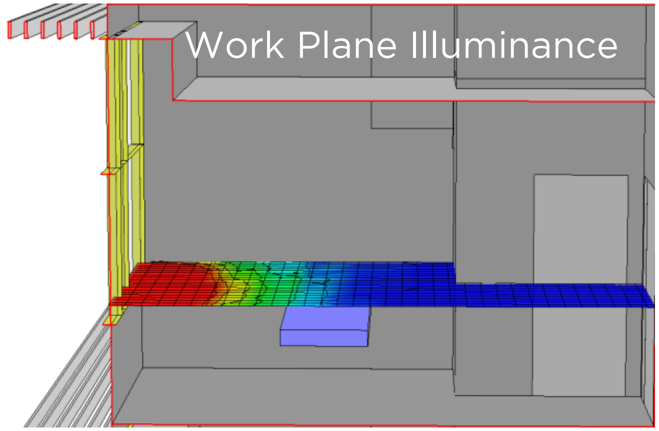


Figure 112: Work Plane Illuminance – Patient Room with Storefront System & Overhang Baffles

The location, size, and orientation of the overhang baffles did little to reduce lighting levels in the family visitor zone at the envelope where work plane illuminance lighting conditions registered as high as 877 lx representing a 23% reduction from 1077 lx. The height and projection of the overhang baffles provided shade further into the room at the patient bed where useful daylight illuminance averaged 377 lx, a reduction of 33% in comparison to 486lx at the patient bed without any solar control methods used. The staff work surface registered only 23 lx due to the placement of the casework which blocks daylight from reaching the work surface at the staff zone.

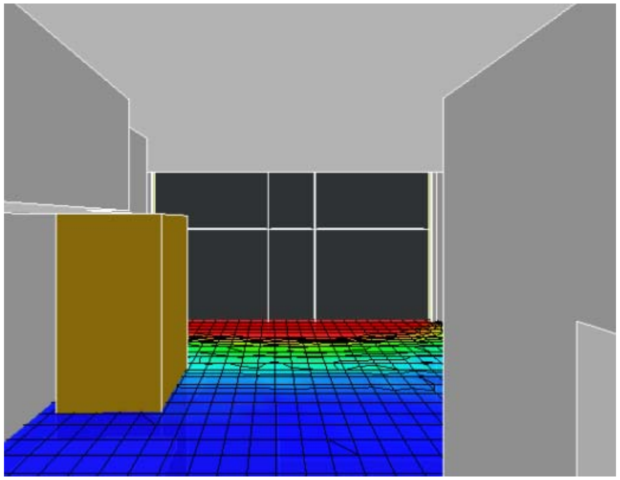


Figure 113: Work Plane Illuminance – Patient Room with Storefront System & Overhang Baffles

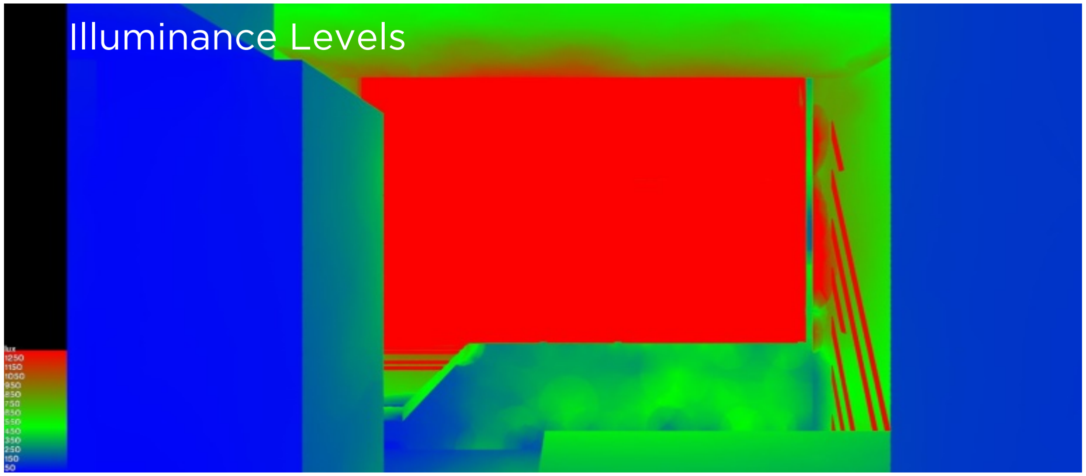


Figure 114: Illuminance Levels throughout the Room- Storefront Window System & Overhang Baffles

Solar Screening Comparison – Useful Daylight Illuminance Patient Room with Storefront System & Horizontal Louvers

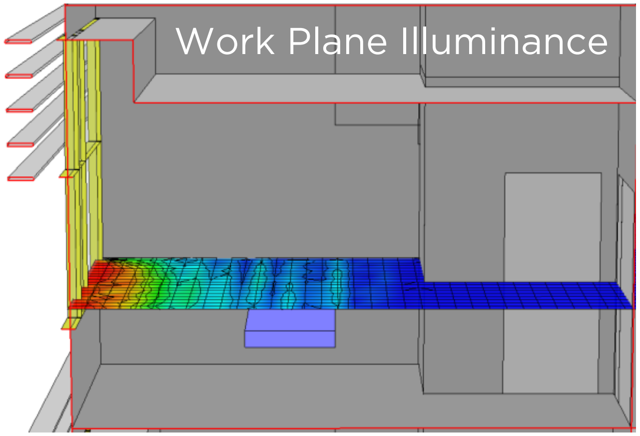


Figure 115: Work Plane Illuminance – Patient Room with Storefront System & Horizontal Louvers

The spacing and angle of the horizontal louvers are effective in combatting incoming incident solar radiation at the envelope, reducing useful daylight illuminance levels in the family visitor zone from 1077 to an average of 602 lx, a 44% reduction from the model with no solar control methods used. The patient bed registers an illuminance of 344 lx which represents a 29% reduction from 486lx with no shading strategy used. The work plane height at the staff zone receives only 16 lx of useful daylight illuminance requiring a dependence on electric lighting to illuminate the work surface during daylight hours. This is due to the location of the casework which impedes further daylight penetration to the staff zone.

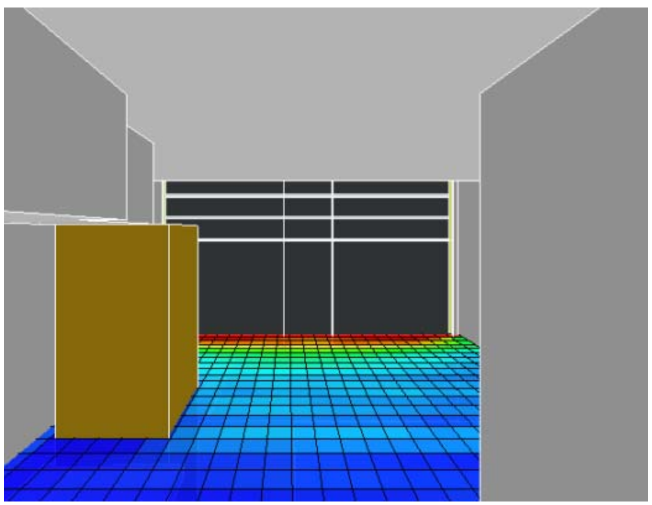


Figure 116: Work Plane Illuminance – Patient Room with Storefront System & Horizontal Louvers

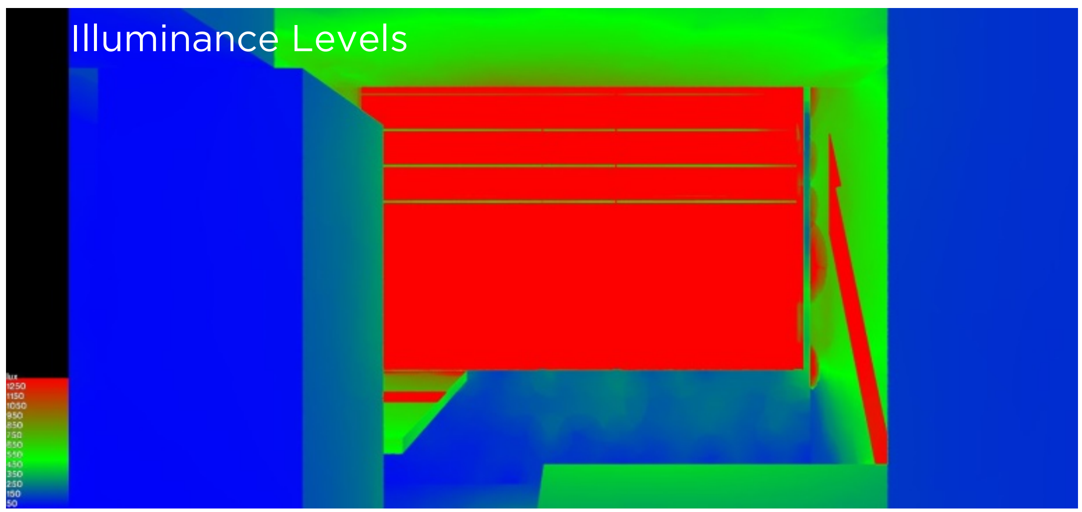


Figure 117: Illuminance Levels throughout the Room- Storefront Window System & Horizontal Louvers

Solar Screening Comparison –
Useful Daylight Illuminance
Patient Room with Storefront System
& Vertical Louvers

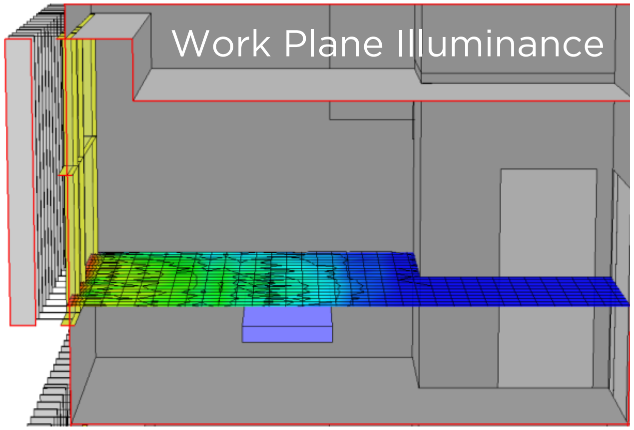


Figure 118: Work Plane Illuminance –
Patient Room with Storefront System & Vertical Louvers

The vertical louvers had the least impact on lighting illuminance levels at the envelope. This is due to their vertical placement and orientation on the southern elevation which is not ideal to redirect the angle of incident solar radiation. The vertical louvers allowed the greatest illuminance levels on the work surface in the family visitor zone which averaged 1025 lx, only a 5% reduction to the model with no shading methods. The vertical louvers had the least impact of the three solar control options on the lighting illuminance levels at the envelope. Further into the room the vertical louvers provide more regular diffuse daylight registering 366 lx at the patient bed. The staff zone requires dependence on electric lighting with a daylight illuminance of only 20 lx.

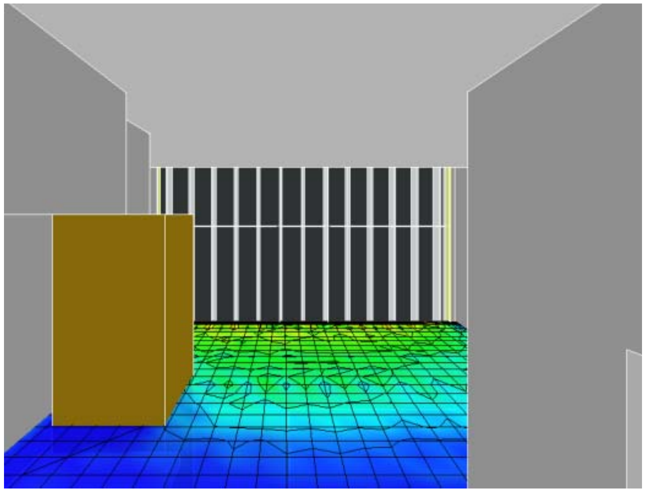


Figure 119: Work Plane Illuminance –
Patient Room with Storefront System & Vertical Louvers

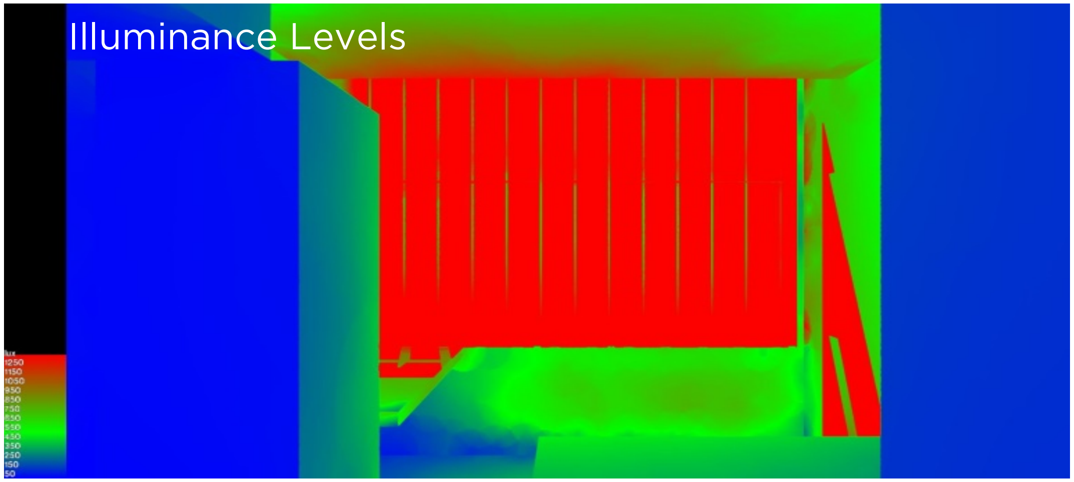


Figure 120: Illuminance Levels throughout the Room- Storefront Window System & Vertical Louvers

Useful Daylight Comparison
Solar Screening Comparison –
Useful Daylight Illuminance
Patient Room with Storefront System

The varying solar control methods provide differing levels of illuminance from sunlight also known as useful daylight, within the room. While each of these methods had little effect deeper into the room at the staff work surface, there was a measurable effect in illumination levels at the patient bed, and most notably in the family/visitor zone at the envelope. While each of the shading strategies performed similarly at the patient bed averaging illumination levels of 363 lx, there was more of a notable difference between each method closer to the envelope where lux levels varied from 1025lx for vertical louvers, to 876 lx for baffles, and 603lx for horizontal louvers.

Figure 121: Average Illuminance measured in Lux (lx) Levels of light FALLING ON each surface. South facing room at mid-day.

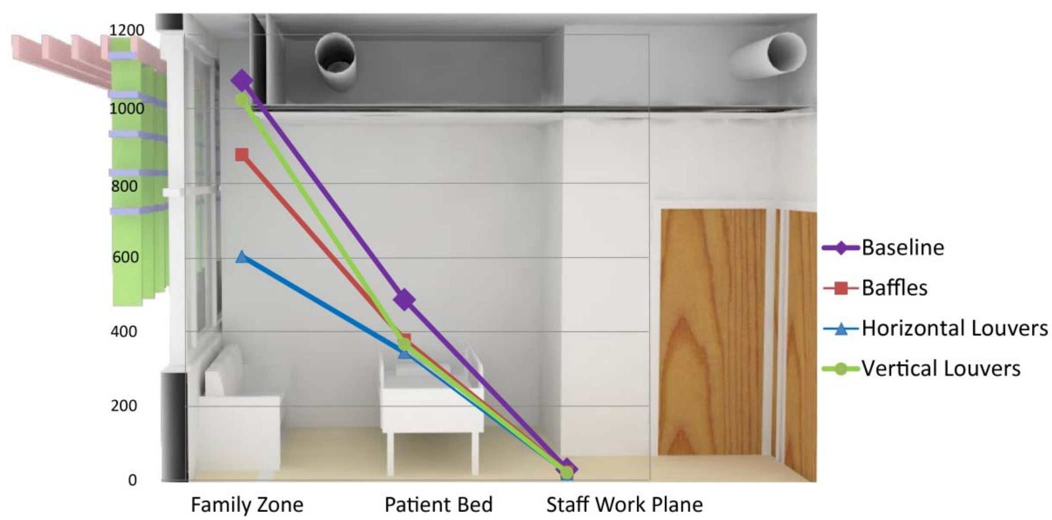


Figure 122: Solar Control Method Comparison- Illuminance – Lux levels throughout the room Patient Room with Storefront Window System

Solar Screening Comparison – Useful Daylight Illuminance Patient Room with Glass Curtain Wall

The increased glazing area of the full height glass curtain wall system affords the greatest opportunity for higher levels of useful daylight within the room. Useful daylight is measured in Illuminance, which represents the amount of light falling onto a surface. While illuminance can be from any light source including electric lighting, Illuminance levels measured in the simulation are from daylight alone. Illuminance representing useful daylight was measured on a work plane surface at 42" above finish floor level to represent the patient bed level, staff work surface, and visitor seated eye level at the envelope.

Illuminance or the intensity of illumination is expressed in lux which represents the light falling onto a surface. Lux (lx) is a measure of illumination per area, as the perceived intensity of illumination from a light source will vary by the area that is being illuminated. One lux is equal to one lumen per square meter. Less than 100 lux would be afforded by a very dark overcast day and in terms of useful daylight would be perceived to provide insufficient lighting. Electric lighting in an office environment is typically designed to provide 300-500 lux. Useful daylight can range in lux levels. A sunrise or sunset on a clear day will provide 400 lux up to several thousand lux at mid-day. Greater than 2000 lux is considered excessive for visual and thermal comfort.

Solar Screening Comparison-
Useful Daylight Illuminance
Patient Room with Glass Curtain Wall & Overhang Baffles

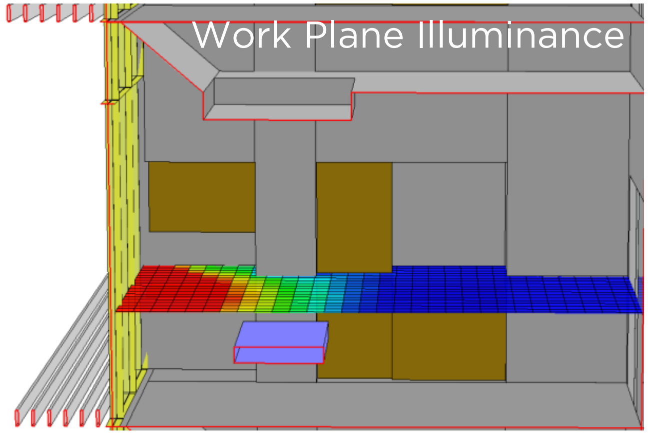


Figure 123: Work Plane Illuminance-
Patient Room with Glass Curtainwall & Overhang Baffles

The overhang baffles were unable to mitigate much of the excessive daylight illuminance levels allowed by the full height curtain wall. Due to their mounting height, and the depth that they project, the overhang baffles provided limited shading at the envelope. The family visitor area received an average of 1053 lx at the work plane, representing a 23% reduction in illuminance when compared to the model with no solar shading methods used. Daylight penetration at the work plane was sustained into the room. The patient bed averaged 436 lx, a 17% reduction in illuminance. The staff work zone is poorly lit. Due to its recessed location the staff work surface receives only a 108 lx.

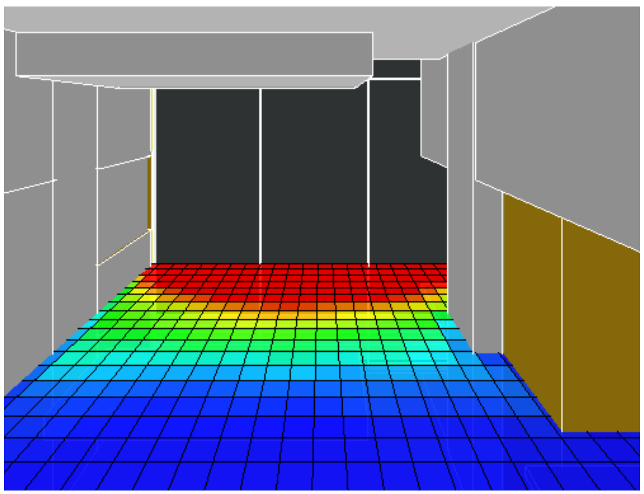


Figure 124: Work Plane Illuminance-
Patient Room with Glass Curtainwall & Overhang Baffles

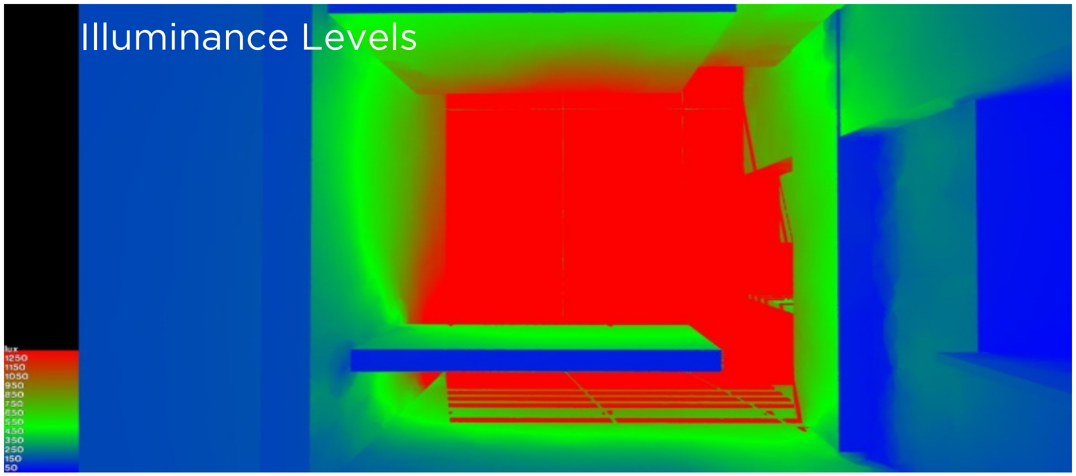


Figure 125: Illuminance Levels throughout the Room- Glass Curtainwall & Overhang Baffles

Solar Screening Comparison-
Useful Daylight Illuminance
Patient Room with Glass Curtain Wall &
Horizontal Louvers

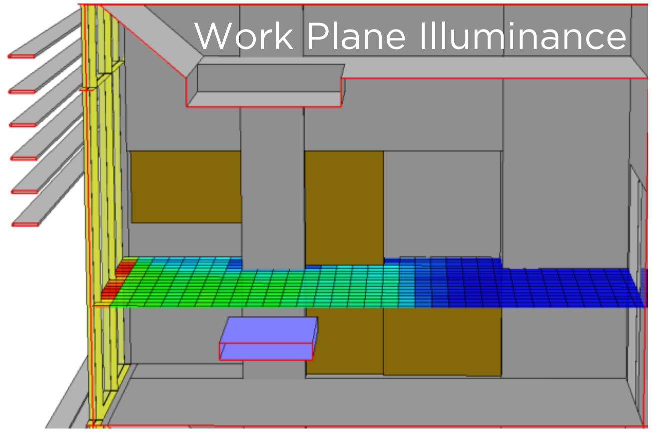


Figure 126: Work Plane Illuminance-
Patient Room with Glass Curtainwall & Horizontal Louvers

The horizontal louvers provided the most even daylight illuminance levels at the work plane throughout the room. The horizontal louvers provided the most protection against incident solar radiation at the envelope, reducing illuminance levels in the family visitor zone by 53% to an average illuminance of 683 lux. Useful daylight was adequate at the patient bed with an illuminance of 382 lux, a 27% reduction from the 523 lux of the baseline model. The staff work zone lacks adequate useful daylight providing an average illuminance of only 104 lux at the work surface, and requiring the use of electric lighting for adequate illumination of the staff work area.

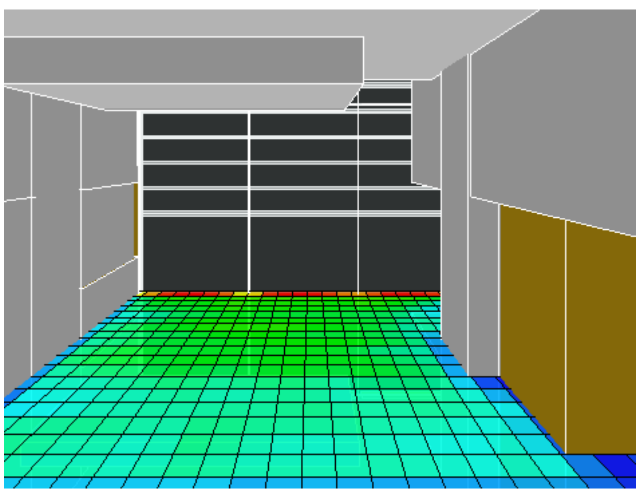


Figure 127: Work Plane Illuminance-
Patient Room with Glass Curtainwall & Horizontal Louvers

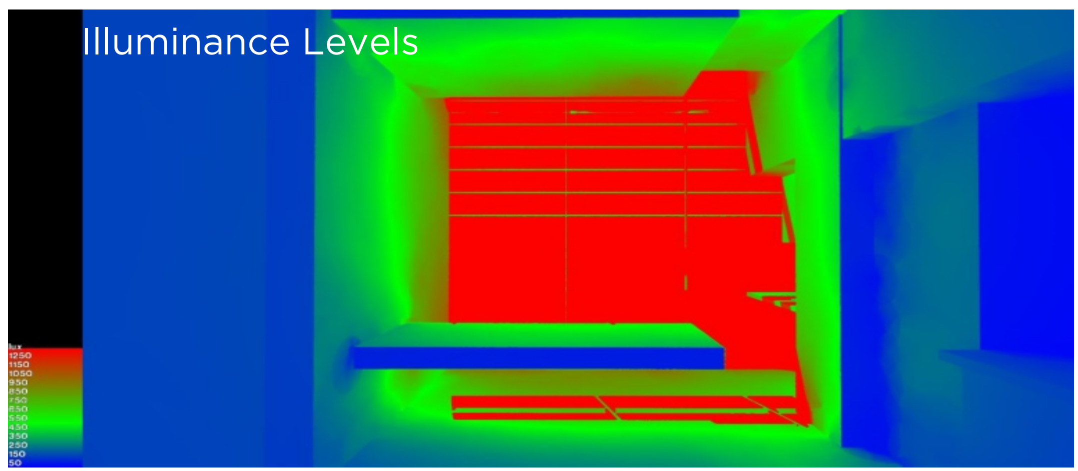


Figure 128: Illuminance Levels throughout the Room- Glass Curtainwall & Horizontal Louvers

Solar Screening Comparison-
Useful Daylight Illuminance
Patient Room with Glass Curtain Wall & Vertical Louvers

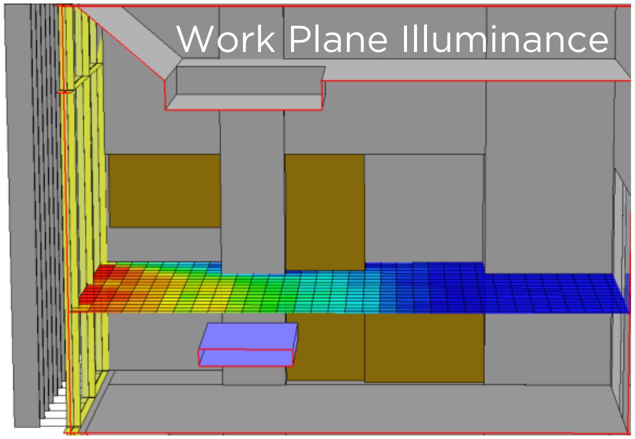


Figure 129: Work Plane Illuminance-
Patient Room with Glass Curtainwall & Vertical Louvers

The vertical louvers reduce useful daylight illuminance at the envelope by 40% throughout the family visitor zone, limiting average work plane illuminance from 1369 lx to 815 lx. The patient bed receives adequate useful daylight with an average illuminance of 373 lux, a reduction of 29%.   The staff work area remains dependent on electric lighting during daylight hours. This is due to a lack of useful daylight caused by several physical obstructions to daylight penetration reaching the staff zone. The staff work surface receives an average of only 75lx, a reduction of 46%.

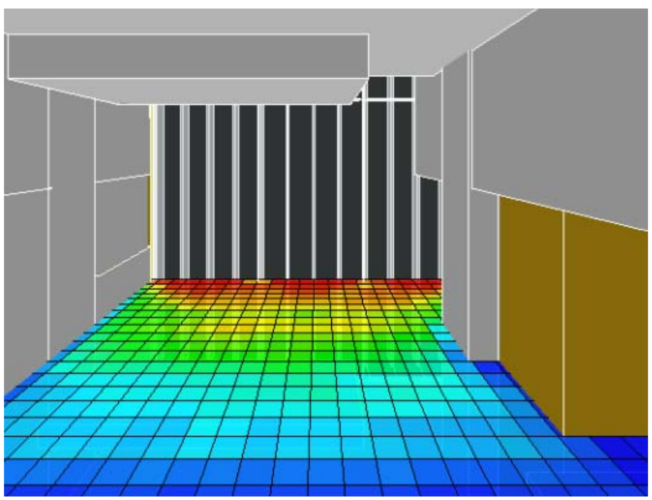


Figure 130: Work Plane Illuminance-
Patient Room with Glass Curtainwall & Vertical Louvers

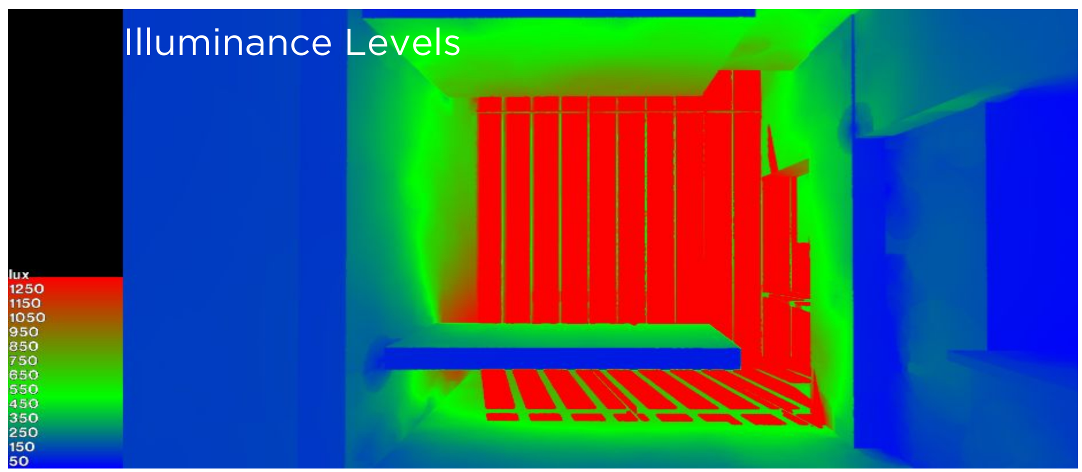


Figure 131: Illuminance Levels throughout the Room- Glass Curtainwall & Vertical Louvers

Solar Screening Comparison –
Useful Daylight Illuminance
Patient Room with Glass Curtain Wall

Variations in useful daylight illumination levels are most evident between the differing solar control methods at the envelope in the family/visitor zone where there are high baseline illuminance levels without the use of these strategies. There was a 33% reduction in illuminance with overhanging baffles to a 40% reduction for vertical louvers and 50% reduction in illuminance for horizontal louvers realized at the envelope.

Light levels at the patient bed are generally well daylit ranging from 522 lx baseline to an average of about 400 lx for the three solar control methods. Light levels at the staff work surface remain inadequate with a baseline of 138 lx and an average of 95 lx among the three solar control methods.

Figure 132: Average Lux Levels of light FALLING ON each surface. South facing room at mid-day.

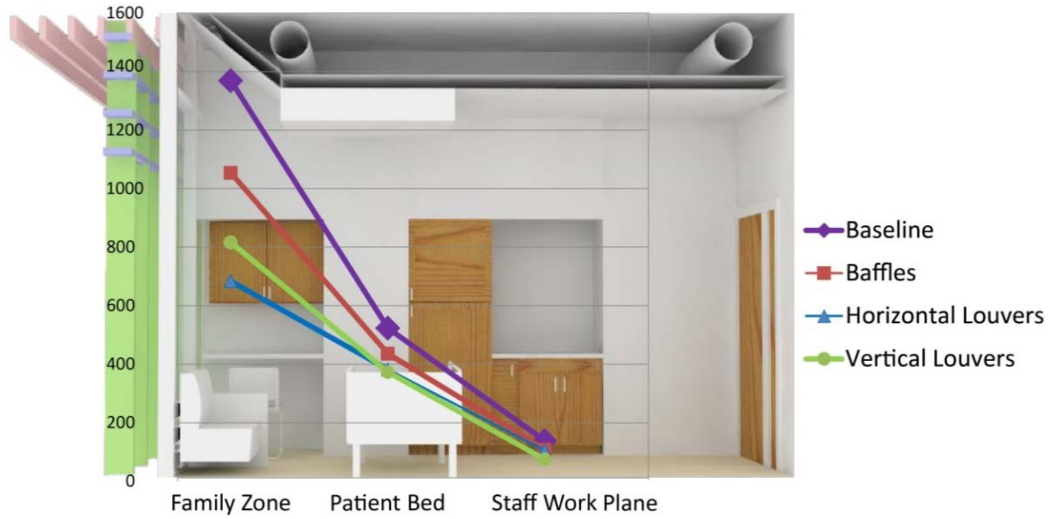


Figure 133: Solar Control Method Comparison- Illuminance – Lux levels throughout the room Patient Room with Glass Curtainwall System

6.4 <u>Solar Screening Comparison – Luminance & Visual Comfort</u>
Patient Room with Storefront System & Overhang with Baffles

When the projecting baffles were used on the 2/3 window wall ratio storefront window system of Patient Room Option B, much of the glare at the envelope was decreased. The placement and projection of the baffles were well suited to redirect the angle of incident solar radiation. This made the projecting baffles effective in reducing variations in luminance levels which can create the potential for glare. This glare was most evident reflecting off of the floor in the family/visitor zone of patient room Option B.
The baffles limited glare at the floor while the work surface remains well lit.

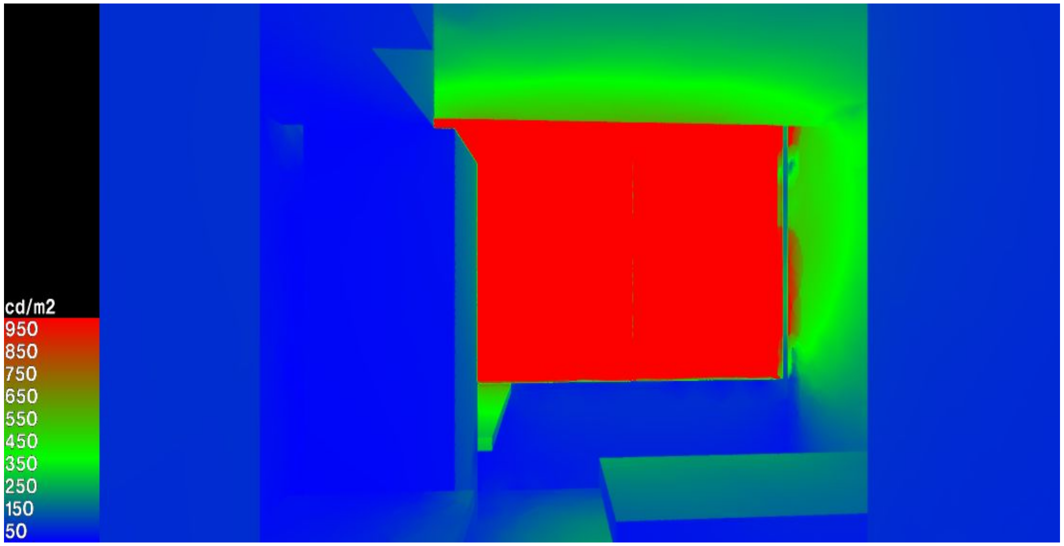


Figure 134: Luminance Levels throughout the Room- Storefront Window System & Overhang Baffles

Solar Screening Comparison – Luminance & Visual Comfort
Patient Room with Storefront System & Horizontal Louvers

The placement and orientation of the horizontal louvers was effective in reducing the potential for visual discomfort from bright reflections or glare that was apparent in patient room Option B. Due to the height, spacing and projection factors of the individual fins, and their angle to sun, the horizontal louvers evenly distribute luminance levels reducing contrasting variations in brightness which create glare. The height that the horizontal louvers are mounted also preserves a view through the storefront window. While the work surface in the family visitor zone remains well lit, luminance levels at the patient bed are low as the height of the louvers reduces daylight penetration.

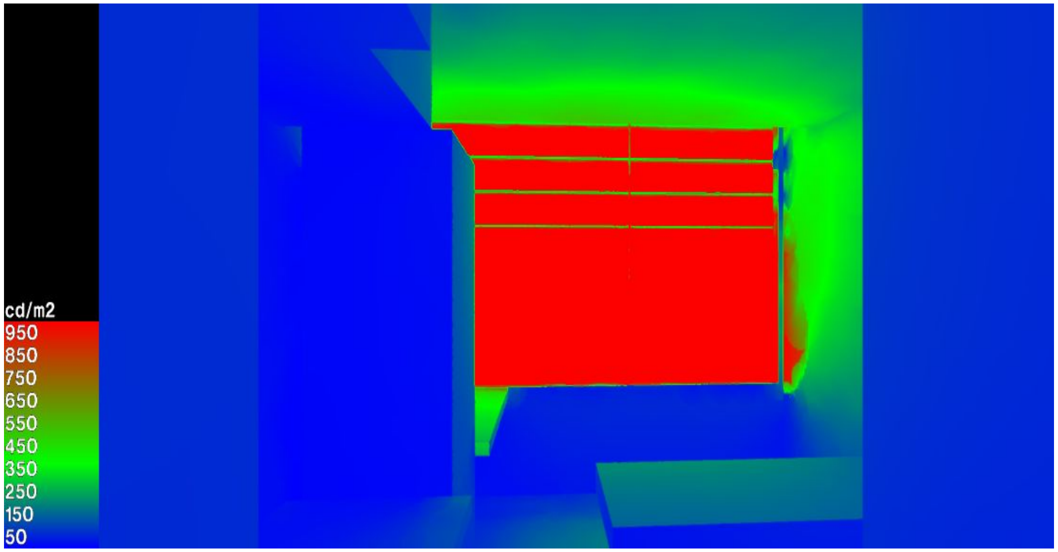


Figure 135: Luminance Levels throughout the Room- Storefront Window System & Horizontal Louvers

Solar Screening Comparison – Luminance & Visual Comfort Patient Room with Storefront System & Vertical Louvers

The vertical louvers were the least successful at affecting lighting conditions in patient room Option B. While the vertical louvers do allow more daylight at the patient bed, this is because they are ineffective at shading the room. This can come at the expense of lighting and thermal conditions near the envelope. The orientation of the vertical louvers does not provide an angle well suited for regulating daylight on the south elevation. Lighting levels were not well distributed, creating variations in luminance levels that would cause glare or visual discomfort. This is evident in the excess glare that is visible on the floor, work surface, and the wall in the family visitor zone.

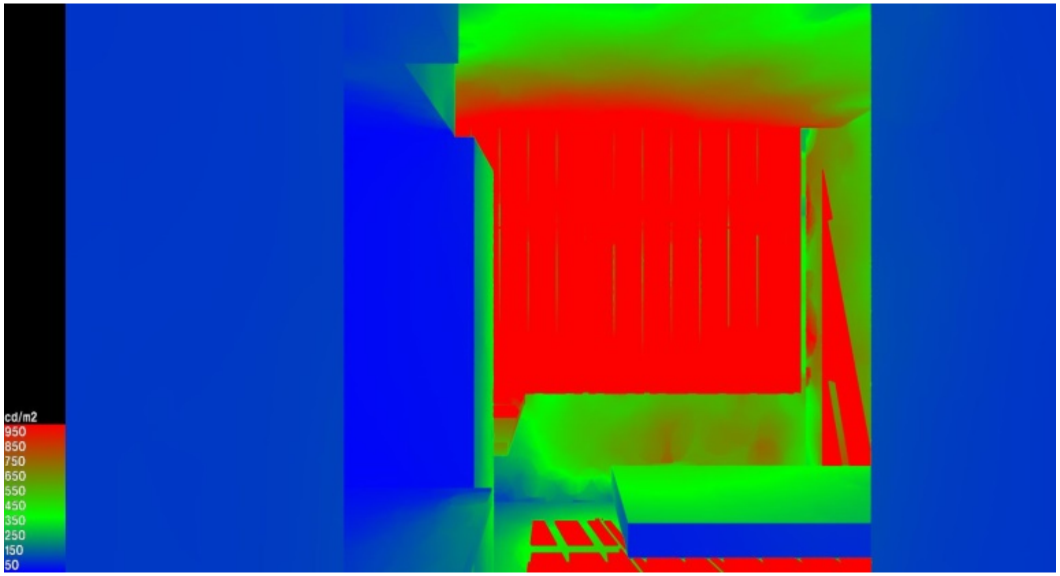


Figure 136: Luminance Levels throughout the Room- Storefront Window System & Vertical Louvers

Solar Screening Comparison – Luminance & Visual Comfort Patient Room with Glass Curtain Wall & Overhang Baffles

The 3/3 window wall ratio of the full height curtainwall allows the greatest quantity of natural daylight. However, this can come at the expense of daylight quality as strong luminance levels or light reflected off of surfaces can create adverse lighting effects like excessive brightness or glare. The height and depth of the overhang baffles did not create a projection factor great enough to shade the window wall ratio of the full height curtainwall. Due to their relative size and position the overhang baffles had little impact to the strong luminance levels provided by the full height curtainwall. This was evident in the visitor zone with luminance levels that create glare at the floor.

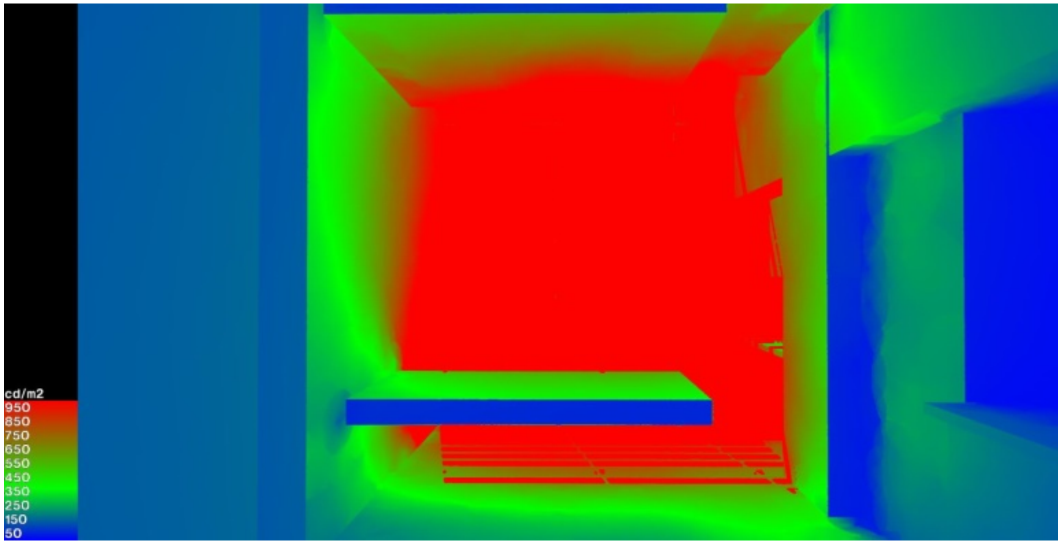


Figure 137: Luminance Levels throughout the Room- Glass Curtainwall & Overhang Baffles

Solar Screening Comparison –
Luminance & Visual Comfort
Patient Room with Glass Curtain Wall
& Horizontal Louvers

The size of glazing area afforded by the full height curtain wall system resulted in excess luminance levels associated with brightness and glare. Due to their sizing and spacing the horizontal louvers provided the most shading of the three approaches. While their effect was still limited, the horizontal louvers had the most impact on luminance levels near the envelope in the family/visitor zone. This is due to their orientation to the angle of incident radiation which was the most effective in reducing luminance levels and potential glare at the family visitor zone.

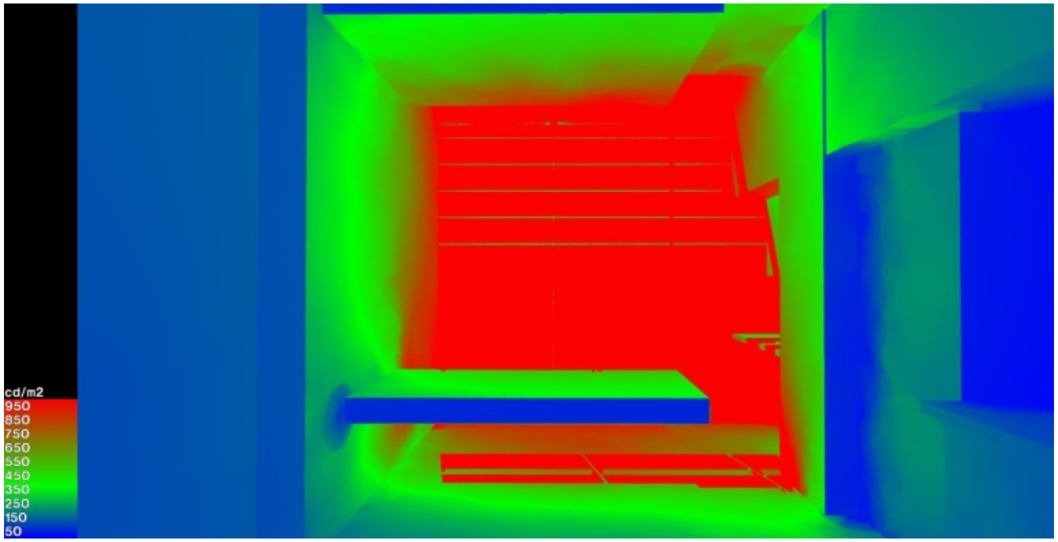


Figure 138: Luminance Levels throughout the Room- Glass Curtainwall & Horizontal Louvers

Solar Screening Comparison –
Luminance & Visual Comfort
Patient Room with Glass Curtain Wall
& Vertical Louvers

The vertical louvers do little to reduce the luminance levels of the patient with the full height glass curtain wall. The vertical louvers allowed the highest luminance levels of the three solar control options. This is due to the orientation of the fins which mounted vertically, are not at an ideal angle to provide shade on a south façade. The vertical orientation does not allow for the surface area of the louver to block the angle of incident solar radiation. This results in non-uniform lighting conditions and variations in luminance levels which creates glare. This is most evident at the floor in the family visitor zone near the envelope.

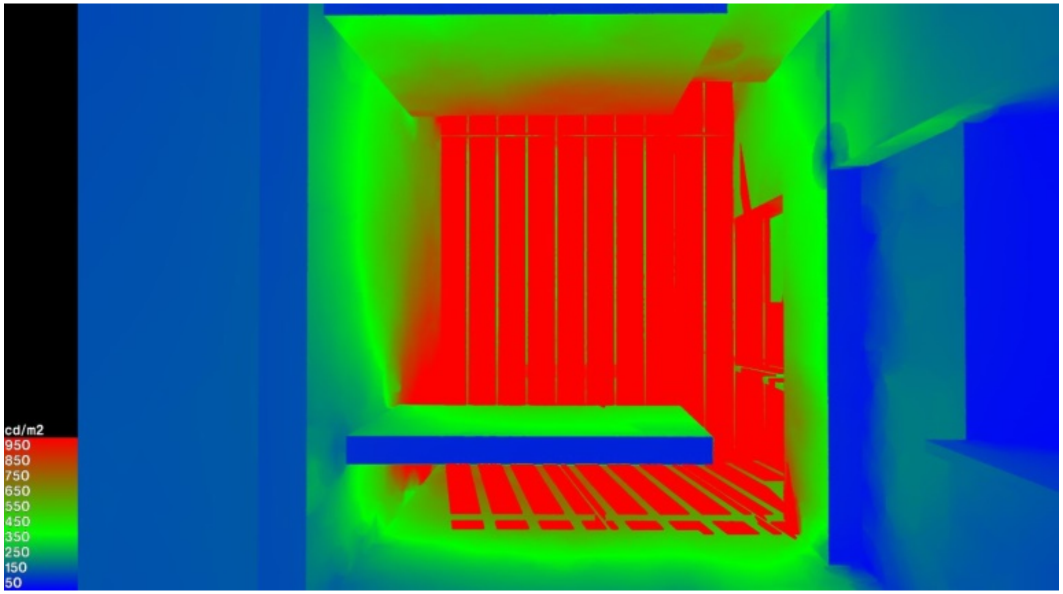


Figure 139: Luminance Levels throughout the Room- Glass Curtainwall & Vertical Louvers

Solar Screening Comparison –
Energy Consumption
Annual Cooling & Heating

In 2003 artificial lighting was responsible for 18% of the average hospital's energy consumption, while HVAC and lighting together represented more than 70% of the total energy consumed in healthcare facilities (U.S. Department of Energy, et al. 2003). This means that approximately 52% of the average U.S. healthcare facilities energy consumption in 2003 was attributable to HVAC and mechanical systems for cooling and heating alone. This figure considers healthcare facilities across all climate zones in the U.S. energy consumption for facilities in more extreme climates like Climate Zones 1 and 2, where the case studies are located and the simulation takes place, can require a greater reliance on HVAC systems in order to meet occupant thermal comfort. The effect of the solar control methods on energy consumption is measured in Btus Consumed Annually

6.5 Solar Screening Comparison – Energy Consumption

Annual Cooling & Heating

Patient Room with Storefront System

Btus Consumed Annually

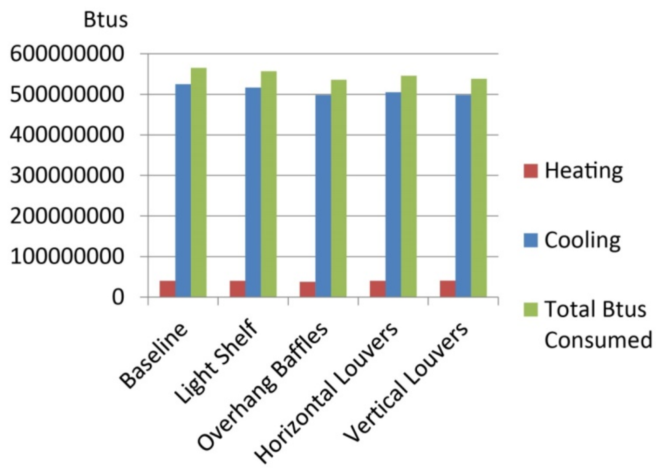


Figure 140: Solar Screening Comparison- Energy Consumption – Annual HVAC Cooling & Heating- Patient Room with Storefront Window System

The HVAC energy consumption of each model can be directly correlated with the inherent variations in solar heat gain that are a result of each design configuration. In this case using the same room configuration and window wall ratio while varying the exterior solar control methods illustrates the effect of each solar control method on HVAC energy consumption. The location of the simulations in a cooling dominated climate is reflected in far higher cooling costs with heating representing a small percentage of annual HVAC energy consumpion. This presents a greater opportunity to lower HVAC energy consumption along with associated costs and environmental impacts by lowering solar heat gain at the envelope. The graph illustrates a measurable impact to HVAC energy consumption, most notably to cooling energy by utilizing various solar control methods to reduce solar heat gain.

The baseline model does not use any solar control methods resulting in the greatest HVAC energy consumption due to higher levels of solar heat gain. The light shelf, while successful as a dayllghting instrument has the least impact of the solar contriol methods as its limited surface area blocks the least incident solar radiation. The greater surface area of the overhanging baffles, horizontal louvers, and vertical louvers have greater impact on HVAC energy consumption as they have the potential to block greater levels of incident solar radiation.

Solar Screening Comparison –
Energy Consumption
Annual Cooling & Heating
Patient Room with Glass Curtain Wall
Btus Consumed Annually

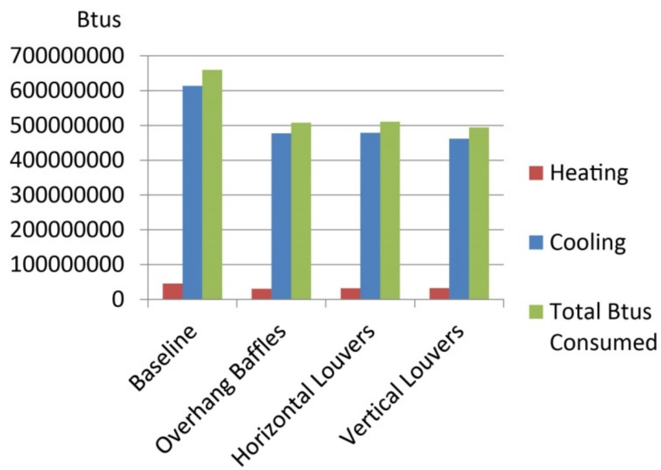


Figure 141: Solar Screening Comparison-
Energy Consumption – Annual HVAC Cooling & Heating-
Patient Room with Glass Curtainwall

Given the greater surface area of glazing that the full height curtain wall provides at the envelope, the resulting increased levels of incident solar radiation create higher temperatures within the room. In cooling dominated climates this creates an increased load on mechanical HVAC systems to maintain occupant thermal comfort. Employing the various solar control methods tested can reduce unwanted solar heat gain and reduce energy consumption by mechanical systems.

The three solar control methods averaged a reduction in HVAC energy consumption of 23%. The vertical louvers performed the best, acheiving a 25% reduction in annual cooling energy consumption mostly attributed to cooling. There was less evident impact in heating energy cost due to the location in a cooling dominated climate. Although an average reduction of 31% was seen in heating cost utilizing these strategies, the heating cost was only responsible for a small fraction of the average overall HVAC energy consumption.

6.6 Solar Screening Comparison – Environmental Impact Annual Carbon Dioxide Emissions

Heating and cooling are one of the greater energy consumers in healthcare facilities due to the constant 24-hour need to provide occupant thermal comfort. This creates an environmental impact in the way of carbon emissions resulting from continuous use of HVAC equipment. Typically greater glazing area creates increased levels of solar heat gain leading to greater reliance on mechanical systems and increased carbon emissions. These environmental impacts can be somewhat mitigated through various solar control strategies to provide better solar access and views while reducing solar heat gain and the reliance on mechanical systems, in turn lowering carbon emissions. Carbon Dioxide Emissions are measured in Lbs. of CO2 Emitted Annually – Mixed Mode System

Solar Screening Comparison – Environmental Impact
Carbon Dioxide Emissions
Patient Room with Storefront System
Lbs. of Co2 Emitted Annually

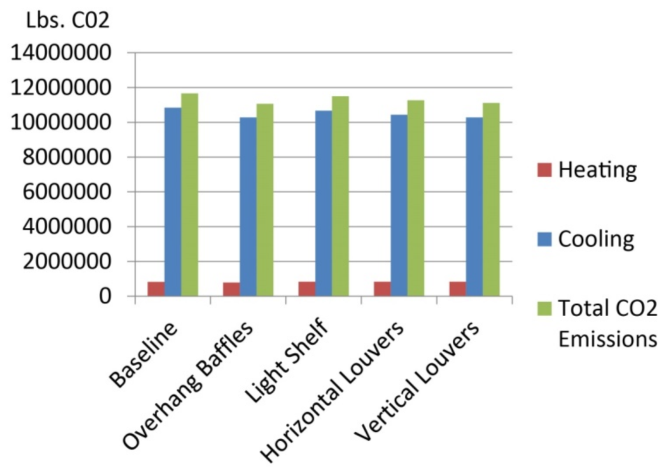


Figure 142: Solar Screening Comparison- Environmental Impact – Annual Carbon Dioxide Emissions- Patient Room with Storefront Window System

The Carbon Dioxide Emissions and resulting Environmental Impact are reflective of the HVAC energy consumption which represents the reliance on mechanical systems to maintain occupant thermal comfort. The differences in the design of the envelope, in this case using the same room configuration and window wall ratio with the use of varying solar control methods shows the impact that these strategies can have on the reliance of mechanical systems. The different strategies also demonstrate varying degrees of impact on the environment through reductions in carbon dioxide emissions.

The baseline model registers the greatest levels of carbon dioxide emissions as it does not use any solar control method at the envelope to aid in reducing unwanted heat gain. This increased heat gain creates an increased reliance on HVAC systems to maintain thermal comfort. The solar control methods with greater surface area provided more protection from incident solar radiation reducing solar heat gain, resulting in less reliance on HVAC systems and lower carbon dioxide emissions.

Solar Screening Comparison –
Environmental Impact
Carbon Dioxide Emissions
Patient Room with Glass Curtain Wall
Lbs. of Co2 Emitted Annually

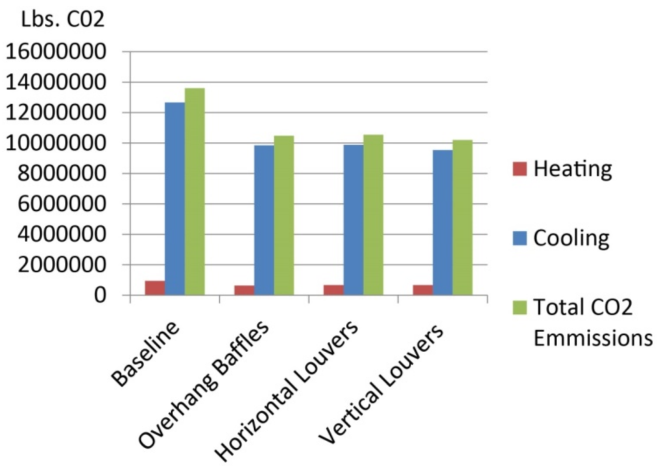


Figure 143: Solar Screening Comparison- Environmental Impact – Annual Carbon Dioxide Emissions- Patient Room with Glass Curtainwall

The environmental impact measured in pounds. of carbon dioxide emitted annually tends to consistently reflect the annual energy consumption from heating and cooling, as reliance on HVAC systems creates carbon dioxide emissions as a direct byproduct of natural resource consumption. The three solar control methods once again averaged a 23% reduction in carbon dioxide emissions with the vertical louvers providing the greatest reduction in carbon dioxide emissions with a reduction of 25 %. These reductions in energy consumption and resulting carbon dioxide emissions take into account the effect of the various solar control methods, specifically on thermal changes effecting HVAC usage. There is still potential for greater energy savings and resulting reduction in environmental impact from limiting the use of electric lighting by using these strategies to increase potential for natural daylighting.

Case Study Comparisons

Solar Screening Options	Glass Curtainwall 3/3 of wall	Storefront Window 2/3 of wall	Single Window 1/3 of wall
	Incident Solar Radiation Watts per Square Meter (w/m2)		
No shading (Baseline)	Greatest Solar Radiation	Moderate Solar Radiation	Least Solar Radiation
	Solar Heat Gain Annual Solar Heat Gain in Watts (Watts/yr)		
No shading (Baseline)	30,000 Watts Max	21,000 Watts Max	10,000 Watts Max
	Daylight Factor Percent Daylight Factor (%df)		
No shading (Baseline)	Family Zone- 15% Patient Bed- 3-7% Staff Work Surface- 1%	Family Zone- 7-11% Patient Bed- 6.5-7% Staff Work Surface- 1%	Family Zone- 4% Patient Bed- 0% Staff Work Surface- 0%
Overhang Baffles	Family Zone- 15% Patient Bed- 4-5% Staff Work Surface- 1%	Family Zone- 14% Patient Bed- 2% Staff Work Surface- 0%	N.A.
Horizontal Louvers	Family Zone- 8% Patient Bed- 3-4% Staff Work Surface- 1%	Family Zone- 2% Patient Bed- 5% Staff Work Surface- 4%	N.A.
Vertical Louvers	Family Zone- 10% Patient Bed- 2-3% Staff Work Surface- 1%	Family Zone- 5-6% Patient Bed- 3% Staff Work Surface- 0%	N.A.
	Illuminance (Useful Daylight) Lux (lx)		
No shading (Baseline)	Family Zone- 1368.95 Patient Bed- 522.92 Staff Work Surface- 138.15	Family Zone- 1076.5 Patient Bed- 485.77 Staff Work Surface- 29.15	Family Zone- 227.85 Patient Bed- 69.57 Staff Work Surface- 9.55
Overhang Baffles	Family Zone- 1053.3 Patient Bed- 435.65 Staff Work Surface- 108.05	Family Zone- 876.65 Patient Bed- 377.27 Staff Work Surface- 22.75	N.A.
Horizontal Louvers	Family Zone- 682.9 Patient Bed- 382.15 Staff Work Surface- 103.85	Family Zone- 602.45 Patient Bed- 344.17 Staff Work Surface- 16.35	N.A.
Vertical Louvers	Family Zone- 815.55 Patient Bed- 372.53 Staff Work Surface- 74.6	Family Zone- 1024.5 Patient Bed- 366.1 Staff Work Surface- 20.35	N.A.

Figure 144: Case Study Comparison – Summary of Findings Table

Solar Screening Options	Glass Curtainwall 3/3 of wall	Storefront Window 2/3 of wall	Single Window 1/3 of wall
	Luminance (Visual Comfort) Candelas per square meter (cd/m2)		
No shading (Baseline)	Family Zone- 5880.8 Patient Bed- 541.01 Staff Work Surface- 145	Family Zone- 5660.93 Patient Bed- 427.2 Staff Work Surface- 195.6	Family Zone- 396.5 Patient Bed- 56.48 Staff Work Surface- 5.7
Overhang Baffles	Family Zone- 4730.1 Patient Bed- 436.03 Staff Work Surface- 113.75	Family Zone- 4713.3 Patient Bed- 351.95 Staff Work Surface- 129.25	N.A.
Horizontal Louvers	Family Zone- 5073.48 Patient Bed- 397.5 Staff Work Surface- 109.35	Family Zone- 3550.96 Patient Bed- 343.37 Staff Work Surface- 122.15	N.A.
Vertical Louvers	Family Zone- 5424.2 Patient Bed- 367.05 Staff Work Surface- 84.5	Family Zone- 3649.56 Patient Bed- 349.9 Staff Work Surface - 120.8	N.A.
	Energy Consumption Btus Consumed Annually for HVAC Cooling & Heating (Btus/yr)		
No shading (Baseline)	659272528	565092036	457593879
Overhang Baffles	507473948	535865216	N.A.
Horizontal Louvers	510747164	545748672	N.A.
Vertical Louvers	494167312	538440144	N.A.
	Environmental Impact Carbon Dioxide Emmissions - Pounds of Co2 Emmitted Annually (Lbs. Co2/yr)		
No shading (Baseline)	13606991	11663158	9444464
Overhang Baffles	10473950	11059923	N.A.
Horizontal Louvers	10541508	11263923	N.A.
Vertical Louvers	10199311	11113076	N.A.

Figure 144 Continued: Case Study Comparison – Summary of Findings Table

7 CONCLUSIONS–

Primary contributions-

The advantages of natural daylighting and views have been thoroughly documented in their impact on occupant outcomes and building performance characteristics. This research has sought to link the built design factors responsible for creating environments that contribute to these occupant and building performance outcomes. Through the simulation and analysis of three typical approaches to glazing design in the patient room, this research has documented various relationships between built features that impact fenestration and glazing design and the metrics that have been shown to affect both occupant and building performance goals.

Main conclusions-

Built design factors like room layout, room adjacency, ceiling, and structural configurations can collectively impact the characteristics of patient room window configuration, driving its design and limiting its ability to affect lighting and thermal conditions within the patient room. The resulting fenestration design can impact these lighting and thermal considerations drastically, and can be quantified using specific performance metrics. This research used simulation and analysis of these various built design factors to measure their effect on lighting, thermal, and energy metrics known to impact occupants and the environment.

The simulations measured lighting characteristics through daylight factors (%df), useful daylighting levels of illuminance (lux), and visual comfort in luminance image (cd/m2). Thermal characteristics were measured with incident solar radiation (w/m2), solar heat gain coefficient (SHGC), and annual solar heat gain (watts/yr). These considerations impacted the resulting energy consumption for annual cooling and heating (btus/yr), leading to environmental impact in the way of carbon dioxide emissions (lbs. co2/yr). These lighting and thermal metrics are not independent of one another and are often interrelated as reflected in the simulation and analysis results. It was found that variations in glazing fenestration design had a direct and significant effect on these lighting, thermal, and energy metrics.

Glazing fenestration design had an impact on lighting thermal and energy metrics. The size and location of glazing area or window wall ratio had a significant impact on the resulting lighting, thermal, and energy results. The size and location of the glazing area is dictated by various other design factors like room layout, adjacency, and ceiling configuration which can be driven by structural and mechanical layouts. Rooms that performed well were those that took into account these design considerations to provide for adequate glazing area contributing to improved lighting conditions, and also utilized solar control strategies to regulate thermal conditions. The resulting lighting and thermal conditions can be tailored through the design and application of these solar control methods.

Lighting-

Rooms with greater glazing area generally provided greater quantity of useful daylight illuminance measured in lux. However, excessive light levels also were shown to create glare, measured in candelas per meter square. This glare was evident in luminance image, a representation of the quality of lighting conditions. The increased levels of glare allowed by greater window wall ratios can lead to visual discomfort. The selection and application of different solar control methods makes it possible to maintain useful daylight levels from a larger glazing area while reducing unwanted glare and the potential for visual discomfort.

Thermal-

While greater glazing area provides more natural light, it also provides greater levels of incident solar radiation, energy that can be released as heat. Typically the greater glazing area or window wall ratio the more potential for increased solar heat gain. In the cooling dominated climate where the simulations were run, both incident solar radiation and solar heat gain were shown to increase relative to increased window wall ratio. The use of solar control methods were shown to help mitigate these increases in solar heat gain coefficient by reducing levels of incident solar radiation that lead to solar heat gain.

Energy-

The increased solar heat gain resulting from greater glazing area also was shown to increase reliance on mechanical HVAC systems for cooling, to maintain occupant thermal comfort. Energy consumption for cooling and heating was measured in btus consumed annually and was shown to increase relative to glazing area or window wall ratio. This increased energy consumption for mechanical systems to combat heat gain also resulted in increased environmental impact from carbon dioxide emissions measured in pounds of carbon dioxide emitted annually. The use of solar control methods that reduce incident solar radiation and solar heat gain help reduce the reliance on mechanical HVAC systems in cooling dominated climates, reducing energy consumption and environmental impact in the form of carbon dioxide emissions.

Next steps-

In order to weigh the effects of the various design approaches evenly, certain variables of the simulation were limited to provide equal conditions in which to gather specific comparable data. This meant that variables like location and climate zone, weather and orientation served as controls. These factors remained the same throughout the various simulations to focus the comparison on the differences between the three design approaches.

This research could be expanded upon by applying it to varying conditions. The simulations were performed in climate zone 1 using the same location in southern Florida. This meant that the three patient room models were subjected to the same environmental conditions. This location was chosen as it is representative of the actual physical location of the three case studies, and because it provides some of the most significant incident solar radiation and temperatures under which to test the effects of the three patient room fenestration configurations. However this means that the results are reflective only of buildings located in climate zone 1 and are not representative of buildings located in other climate zones where differing climatic conditions and considerations occur. Considering that climate zone 1 is the most cooling dominated climate condition, many of the simulation results would have far different outcomes in a heating dominated climate where there are differing thermal considerations. For instance take into account solar heat gain. In a cooling dominated climate like Florida, solar heat gain presents an adverse effect to keeping temperatures within the occupants comfort zone. Solar heat gain in this case presents a challenge to mitigate in order to reduce the added dependence on mechanical systems to cool the space. However, in a heating dominated climate, such as the Northeast solar heat gain can be beneficial to maintaining thermal comfort, passively aiding mechanical systems in raising temperatures up to the desired thermal comfort zone for the majority of the year. The research findings could be expanded upon by performing the same lighting, thermal, and energy simulation and analysis in other climates to take into account the impact that glazing fenestration design has in the climatic conditions of other regions.

Likewise, the simulation and analysis results could be expanded upon further by using more variation in the orientation of the patient room models tested. The simulations were performed with the patient room glazing facing south. This served as a control to test each patient room model in the same orientation. South was used because in the northern hemisphere the southern elevation receives the greatest levels of solar exposure which contributes to both lighting and thermal conditions. While facing the patient room models south provided the most even and effective orientation to test the impact that glazing design can have on lighting and thermal conditions in the northern hemisphere, the data does not provide for the other building elevations with rooms facing other orientations. Performing the same simulations in the other orientations could provide results more representative of patient rooms located throughout an entire hospital.

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02: Patient preferred air temperature

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03: Patient preferred humidity levels

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04: Patient Room Glazing Design Effects

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05: Literature Map

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06: Literature Review

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07: Thermal Imaging of Hospital Façade

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29: Patient Room with Full Height Curtainwall Nemours Children's Hospital –Daylight Hours

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30: Patient Room with Storefront Window System Joe DiMaggio Children's Hospital

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115: Work Plane Illuminance –

Patient Room with Storefront Window System & Horizontal Louvers

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116: Work Plane Illuminance –

Patient Room with Storefront Window System & Horizontal Louvers

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117: Illuminance levels throughout the Room -

Patient Room with Storefront Window System & Horizontal Louvers

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118: Work Plane Illuminance -

Patient Room with Storefront Window System & Vertical Louvers

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119: Work Plane Illuminance -

Patient Room with Storefront Window System & Vertical Louvers

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120: Illuminance Levels throughout the room -

Patient Room with Storefront Window System & Vertical Louvers

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121: Average Illuminance measured in Lux (lx)

Levels of light FALLING ON each surface

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122: Solar Control Method Comparison-

Illuminance Image – Lux levels throughout the room

Patient Room with Storefront Window System

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123: Work Plane Illuminance -

Patient Room with Full Height Glass Curtainwall & Overhang Baffles

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124: Work Plane Illuminance -

Patient Room with Full Height Glass Curtainwall & Overhang Baffles

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125: Illuminance Levels throughout the room –

Patient Room with Full Height Glass Curtainwall & Overhang Baffles

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126: Work Plane Illuminance -

Patient Room with Full Height Glass Curtainwall & Horizontal Louvers

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127: Work Plane Illuminance -

Patient Room with Full Height Glass Curtainwall & Horizontal Louvers

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128: Illuminance Levels throughout the room –

Patient Room with Full Height Glass Curtainwall & Horizontal Louvers

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129: Work Plane Illuminance -

Patient Room with Full Height Glass Curtainwall & Vertical Louvers

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130: Work Plane Illuminance -

Patient Room with Full Height Glass Curtainwall & Vertical Louvers

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131: Illuminance Levels throughout the room –

Patient Room with Full Height Glass Curtainwall & Vertical Louvers

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132: Average Lux Levels of light FALLING ON each surface.

South facing room at mid-day

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