GlassCon GLOBAL
INNOVATION IN GLASS TECHNOLOGY

CONFERENCE PROCEEDINGS

Chicago
Sept. 5-7, 2018

Administered by:
FCA INTERNATIONAL

Comparison of Control Strategies for Dynamic Glazing Based on Occupant Visual Comfort

Jon Prowse
View Dynamic Glass, USA

Jason Zedlitz
View Dynamic Glass, USA

Abstract
Dynamic façades, which can change tint to reduce glare and maximize comfort, are becoming more common in building construction. Controls strategies for these dynamic façades are of crucial importance as dynamic glass is only effective if it is in the right tint state at the right time. Two different control strategies have been analyzed and contrasted using real world data and theoretical modelling, with emphasis on predictive model based controls vs sensor based controls. Sensor based control for dynamic façades uses photo sensors on or near windows to control tint levels of dynamic façades. Model based predictive control uses external inputs such as sun location, occupant location, local weather conditions, and sensor data to predicatively chose a tint state before it is required. These control strategies have been analyzed based on: a) ability to control glare b) natural light levels allowed c) occupant comfort (visual). The output provides clear quantitative evidence of control strategy performance across the relevant metrics to inform decision making for dynamic façades. The study found that on average, model based systems provide better glare control 12% of the time and better daylighting 12% while never operating less effectively on either metric.

Keywords: daylighting - glare – shading, electro- or thermo-chromic glass, means and methods, future trends

1 Introduction

1.1 Overview of Dynamic Façades:

A Dynamic Façade is a façade system that is able to change tint between clear and tinted state to block glare and solar heat gain, while modulating the amount of light in a space. There are many types of Dynamic Façade technologies including electrochromic, thermochromic, photochromic, suspended-particle, micro-blind and polymer-dispersed liquid-crystal. Each of these technologies work differently but all are focused on shifting glass from a clear to tinted state to avoid the use of blinds, decrease glare and increase daylight. By far the most common type of dynamic façade used in architectural glass is electrochromic glass. This glass works by applying an electric charge to a thin coating, moving electrons across several specialized layers in the coating in order to block more light and effectively tint the glass. Electrochromic façades are the focus of this paper from a modelling and performance standpoint but the finding would be similar for other dynamic glass technologies, the main caveat being that not all other technologies are controllable (thermochromics and photochromics for instance can only react directly to temperature or UV levels rather than be controlled by a user).

1.2 Background on Occupant Glare

Since many different measurements are used to establish when there is glare on building occupants and therefore when to go to tinted state, it is important to establish what actually causes glare. Glare is defined as 'visual conditions in which there is excessive contrast or an inappropriate distribution of light sources that disturbs the observer or limits the ability to distinguish details and objects. [1] In other words, when something is too bright compared to other objects, particularly those an individual would like to view, glare can make it very hard to see. This can be demonstrated at night (when outdoor illuminance levels can be as low as 1 or 2 Lux) and a streetlight or a car headlight can cause significant glare. During the daytime, that same car headlight would cause no glare at all. This can also be seen during the day (when Lux levels are much higher at about 400-600 inside and 10,000 or more outside). Since the light level is so much higher during the day, glare can only be caused by something very bright, the sun for instance. There are two main light sources for building occupants, artificial lights that are put in the space and daylight from the sun. There are also other light sources that are more localized to particular occupants like computer screens, overhead projectors and task lighting. Outdoor light can be either direct or indirect. Indirect light, called diffuse light, happens when the light that is coming inside is not from the direct source but indirectly come to the person through light bouncing off other objects. Due to the higher interior brightness during the day, glare is not typically caused by diffuse light but much more commonly caused by direct sun glare. [2]. In this paper, it will be assumed that only direct sun light on an occupant will cause glare. This is a simplification as reflections off neighboring buildings and very strong diffuse light with low internal light levels can also cause glare but for the purpose of this paper, direct sunlight will be an adequate approximation of glare conditions.

1.3 Benefits of Increased Daylight:

Many studies have been done to show the benefits of daylight to occupants. According to a study conducted by Dr. Alan Hedge of Cornell University, a building with more daylight provided by a dynamic façade leads to occupants that are 2% more productive, suffer from 51% less eyestrain, 82% increase in light quality, and 56% less drowsiness. [3]

2 Dynamic Façade Control Strategies

2.1 Sensor Based Controls

Sensor based control is the most basic type of electrochromic façade control. It involves photo sensors which measure irradiance from the sun on the façades to decide whether to go to "tinted" or "clear" state.. This is accomplished using something called "threshold" control. When the irradiance level goes above a certain threshold, the systems decides that the space will experience glare. Typically this value is set for the entire year at one value. Sensor based control also requires that sensors be places on or directly near each window or group of windows.

2.2 Model Based Controls

Model based control uses sensor readings as only one input. Model based control strategies include data on sun position, sun angles, local weather data, occupant location, nearby obstructions, irradiance levels and possibly other metrics to build a model of whether an occupant will experience glare. At its most basic, model based control can tell whether an occupant will experience glare from direct sun. More advanced models can also detect reflections from nearby buildings and anticipate near future glare to go to the right tint predicatively. For the purpose of this paper, basic occupant based position modelling has been assumed; however, further work could include other more advanced modeling methods.

3 Building Details

The building to be analyzed is situated at 1 University Avenue in Toronto, Canada and is an office building. Dynamic façade is used throughout the 17th floor where the study was conducted.

3.1 Site Conditions and Baseline

Analysis will be done on several key locations throughout the 17th floor to show the different control techniques and how they perform under each condition. This study is focused on the southern façade as it presents the most potential for glare. The building shape and location are shown below. It has an orientation with the south orientation at 163 degrees from square to the line of latitude. Please see figure 1 for a google images view of this site. Further research could include façade analysis on other orientations.

Figure 1. Overhead orientation view of One University in Toronto, Canada; south-east orientation is 163 degrees

3.2 Internal Office Space Details

Internally the space is a mix of individual and group work rooms near the façade. The floor plan below shows the layout of the office space along with the specific areas that have been studied. As can be seen, we have chosen office areas near the external façade on the southern facing façade. The rooms being considered are 1738, 1733, 1732, and 1729 as per the figure 2. User locations in each of these areas are indicated by charts in the floor plan.

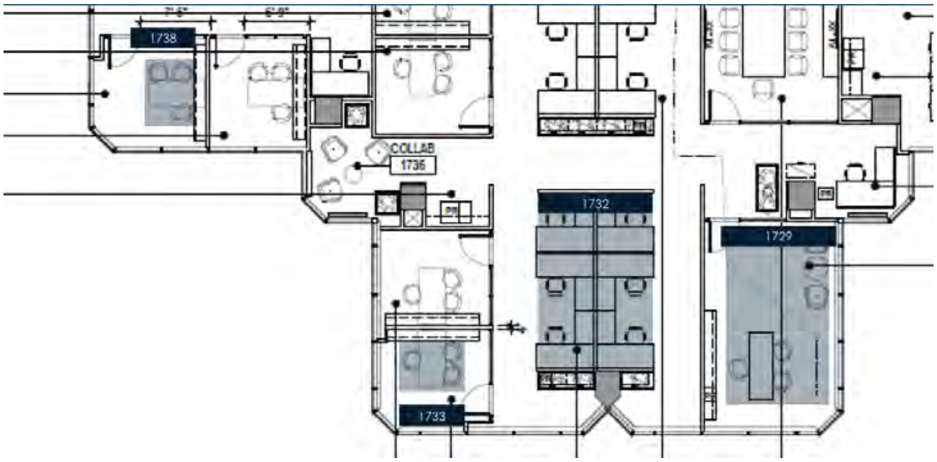

Figure 2. A floorplan view of the 17th floor of One University with studied rooms highlighted.

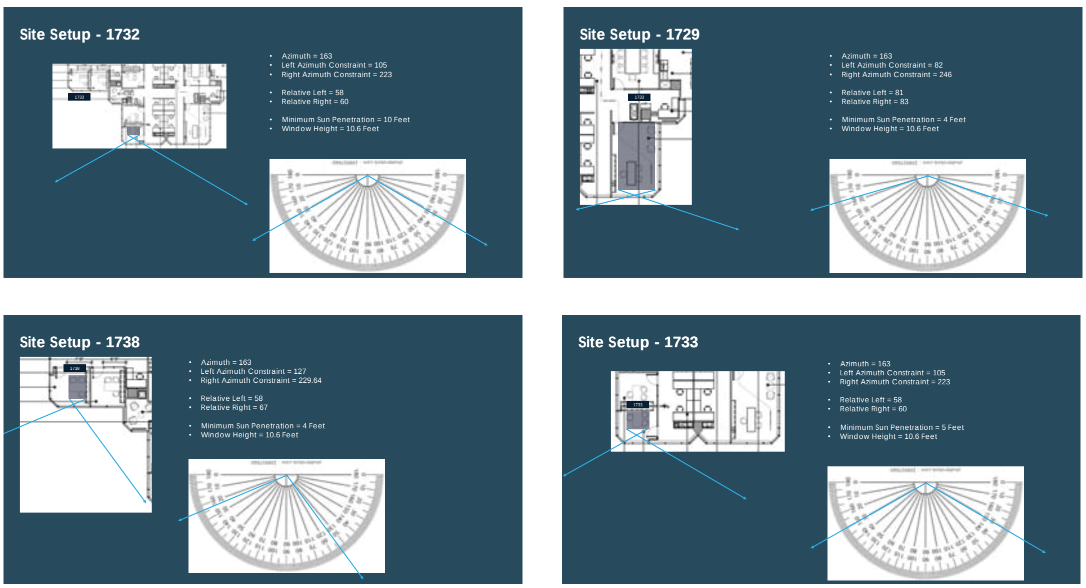

Figure 3. Room orientations.

4 Simulation Comparison of Control Strategies

Using the One University building, and specifically the identified rooms, the team simulated operation of both model based and sensor based controls under clear sky (sunny) conditions throughout the year. The key analysis metric for any given time is whether a model reports “glare present” or “no glare”. In the case of “glare present”, the model will go to a “tinted” state while in the case of “no glare” the model will go to a “clear” state. While many electrochromic glazing technologies have several tint states, for this analysis, it was assumed that the glass will only go between “clear” and ”tinted”. This level of analysis is adequate to answer the main question of this paper: How do the control strategies handle daylight and glare?

4.1 Clear Sky Model Simulation

In order to compare the two control strategies, the team used a clear sky model which simulates sunny conditions throughout the year. This model was chosen as, since this paper is focused on performance for daylighting and glare, clear sky conditions are the most important. This also simplified the analysis. Full year analysis doing actual annual conditions is recommended further work.

4.2 Simulation of Direct Sun on Façades (ie. Façade Exposure)

In order to set a baseline, the team modelled how many hours of each year the sun directly hits the façades of the spaces. Since each façade is south facings, the rooms will have the same façade exposure throughout the year.

Table 1 shows the total hours of direct façade sun exposure throughout the year for each of the room façades. Since these are south facing walls, they have high façade exposure. While façade sun exposure does indicate the presence of sun, it does not necessarily indicate glare on occupants.

Table 1. First total façade exposure hours, second the total sensor model glare hours and then the glare hours for each of the rooms under model based conditions

Month	Façade Exposure	Sensor	Model 1729	Model 1732	Model 1733	Model 1738
January	296	205	296	238	238	227
Feburary	299	200	283	204	223	185
March	315	200	296	93	203	159
April	295	168	257	3	115	115
May	274	117	204	-	16	61
June	241	56	166	-	-	23
July	263	81	189	-	1	45
August	300	145	246	-	86	104
September	302	185	284	50	177	143
October	321	209	301	185	231	186
November	294	192	291	231	231	212
December	287	196	287	237	237	237

4.3 Sensor Based System Operation Simulation

Sensor based system operation is simulated using data from ASHRAE Clear Sky Tau Model [4]. Using these irradiance values, thresholds are applied to sensor readings. Higher sensor readings correspond with tinted glass. Below, in figures 4 and 5, is shown actual ASHRAE output for 2 days to illustrate the varying irradiance levels (measured in watts/m2) in Toronto throughout the year (the summer solstice, winter solstice).

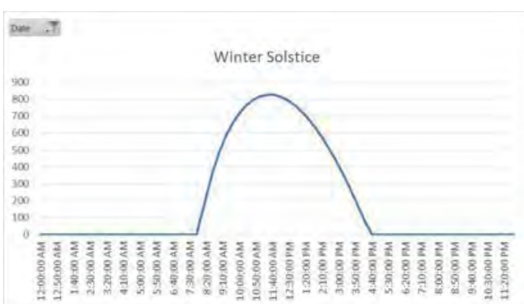

Figure 4. Winter Irradiance ASHRAE values at 1 University southern façade

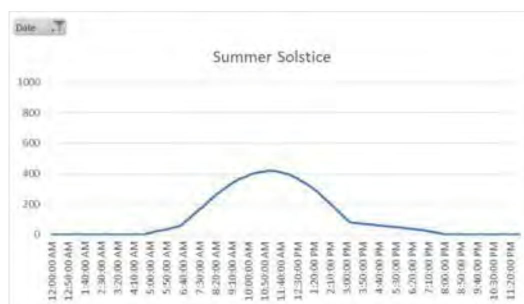

Figure 5. Summer irradiance ASHRAE values at 1 University southern façade

Typical days consist of very low irradiance levels throughout the day followed by peaks in the mid-day. Peaks are actually highest during winter, due to the low sun angle causing more direct sun irradiance on the façade.

Sensors work by setting a threshold irradiance level (measured in Lux or foot candles), and changing tint based on passing the threshold. Each tint state in a sensor based control system corresponds to a certain illuminance range. In order to simplify the analysis and focus on only glare vs non glare conditions, the team has set the irradiance threshold for tinted vs non tinted to be 400 w/m2. This figure was arrived at in order to strike the best balance between daylight and glare and using 300 previous sites gathered data; other threshold choices would skew to too much glare or not enough daylight. Based on this, the total hours (in 10 minute increments) that this irradiance would be above the threshold is shown in Table 5 in Appendix B. The modelling used latitude/longitude and façade orientation and was based off average irradiance levels modelled in ASHRAE Clear Sky [4]. As can be seen, not all hours with façade exposure will have glare conditions with a sensor since at some of these times, light levels are below the threshold.

4.4 Model Based Control Simulation

In order to simulate the glare for the model based approach for these spaces for an entire year, the team used sun position based on the NOAA (National Oceanic and Atmospheric Administration) calculator throughout each hour of the year. It was also necessary to establish critical angles for glare conditions. If the sun is within the left and right angle of the window and also penetrating far enough into the space to hit the user, that is considered a glare condition (ie. the sun is directly on the occupant position). Figure 6 shows the glare angle for one of the rooms in this study (in this case room 1738). As can be seen the glare angle extends to the east and west based on the windows and occupant area. Full room critical angle data can be found in figure 3.

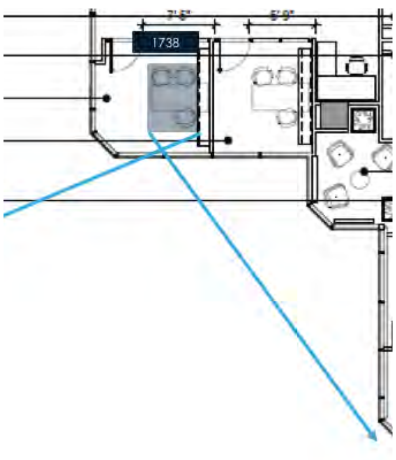

Figure 6. Critical angles for model based control in room 1738

For each room, critical angles were arrived at independently based on:

- Outside obstructions
- Interior occupant location
- Window size and location
- Orientation to sun path

Based on this analysis, the total hours (measured in 10 minutes increments) that each of the areas will experience glare was simulated for the model based control. Table 5 in Appendix B below shows the total number of glare hours for each of the rooms studied. In all none glare cases, the glass would go to clear state. Note that these values are quite different than the values for sensor based systems. This will be discussed below.

4.5 Analysis of Sensor Based Model Failure as compared to model based operation

Note: This comparison assumes proper operation of the model based system (ie. It tints only when direct glare is on occupants); Section 4.6 below tests this assumption.

In order to compare the sensor based and model based control methods, total glare condition hours identified using the model based approach were compared to the number of hours that the sensor based system would operate. Since the model based system is able to identify glare based on occupant position, any deviation of sensor based systems from this will present an inaccuracy in sensor based system. Model and sensor based simulation data is verified against real world measurement in the next section to ensure that model based system does in fact operate to predict glare.

The tables 2 and 3 show the percentage of time when sensors fail in two ways. Table 2 shows the percentage of time that sensors did not detect glare when the occupant was experiencing glare. Table 3 shows the percentage of time the sensors detected glare when an occupant was not experiencing glare. As can be seen, sensor values consistently overestimate the glare potential in summer, when there is sun on the Façade but the sun angle is shallow, and underestimate the glare potential in winter, when sun angles are low so even morning and evening sun can cause glare at low light levels. Section 5.1 has expanded detail on this error.

Table 2. % of total time with sun on façade when sensors did not detect glare when there was glare

Month	1729	1732	1733	1738
January	31%	12%	12%	8%
February	28%	12%	12%	1%
March	30%	6%	6%	0%
April	30%	0%	0%	0%
May	32%	0%	0%	0%
June	45%	0%	0%	0%
July	41%	0%	0%	0%
August	34%	0%	0%	2%
September	33%	3%	3%	1%
October	29%	11%	11%	1%
November	34%	14%	14%	8%
December	32%	14%	14%	14%

Table 3. % of total time with sun on façade when sensors did not detect glare when there was glare

Month	1729	1732	1733	1738
January	0%	1%	1%	0%
February	0%	11%	4%	6%
March	0%	40%	5%	13%
April	0%	56%	18%	18%
May	0%	43%	37%	20%
June	0%	23%	23%	14%
July	0%	31%	30%	14%
August	0%	48%	20%	16%
September	0%	47%	5%	15%
October	0%	18%	4%	8%
November	0%	1%	1%	1%
December	0%	0%	0%	0%

Even if a sensor system were to have seasonal variability, it would not be able to match both façades as changes in orientation, external obstructions and occupant location can lead to very different glare exposures.

Note: This analysis is only accurate for sunny conditions, in cloudy and partly cloudy conditions, glare conditions don't typically occur so neither system will go to its tinted state.

4.6 Comparison of Actual System Operation to Simulation

In order to verify that the teams simulations for sensor based and model based controls are accurate to actual site conditions, the simulations have been compared to actual site data at One University.

4.6.1 Comparison of ASHRAE sensor data to Actual Façade Sensor

Figure 7 shows the ASHRAE sensor compared to actual on site sensors for one day in June. As can be seen, the two sensor values follow each other closely, with values from site varying more often based on cloud cover effects. The peaks of the orange line match the contours of the ASHRAE model. This indicates that the ASHRAE model is a good approximation of on-site conditions. The on-site measurements have been taken with a View Ring Photo Sensor directional photo sensors facing the same direction as façades. [5]

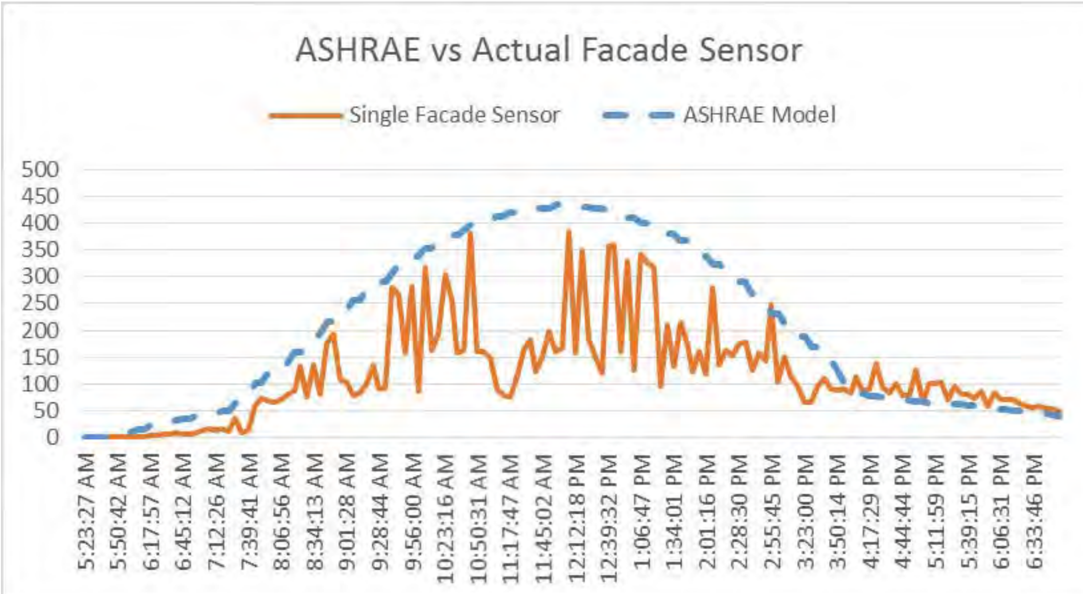

Figure 7. Equinox photo sensor readings at 1 University southern façade

4.6.2 Comparison of Model Based Control Simulation Vs Actual Onsite Model Operation

In order to establish that the model simulation used is accurate to actual site conditions, operation of the model based simulation was compared to actual operation of View Intelligence ® on site for 10 days. It can be seen in table 3 that actual operation vs theoretical simulation are within 9% of each other for all rooms. Deviations are only due to some additional complexity in on site Intelligence model which accounts for reflected glare, nearby building obstructions and pre tinting. With those deviations removed, the simulation and actual Intelligence operation are within 1%. This can be considered an accurate fit and shows adherence of the model based simulation to actual site conditions of a model based system.

Table 4. Comparison of Model Based simulation to View Intelligence ®

	Clear Sky Hours (Intelligence)	Clear Sky Model (Model Based)
1729	70.83	64.5
1732	-	0
1733	-	0
1738	18.25	13

5 Conclusion

As per the analysis above, the key difference between the sensor and model based systems is that the sensor based system can only change tint based on irradiance level whereas model based systems change tint based on presence of direct sun glare on occupants. While radiance level is still an important input to a model based system, it does not accurately predict glare at the correct times. What this means for a typical building (like the one studied) is that sensor based systems will be too dark in the summer and experience glare requiring manual intervention in the winter. This also varies based on many inputs around building geometry. For instance, Room 1729 and Room 1732 had the opposite problems throughout the year even though they have similar orientations due to external obstruction and most importantly differences in occupant location (see Tables 1 and 2 for details). Room 1729 had glare that was not picked up by sensors 33% of the time, while Room 1732 only had that problem 6% of the time. Conversely Room 1729 never had an issue where glare was reported and it was not the case while Room 1732 had that problem 27% of the time.

Throughout the year in a sensor based system, there is too much glare 12% of the time while there is not enough daylight 12% of the time averaged across all room. In every month and every room, the sensor model is either overly dark or allowing too much glare. These numbers are similar because we chose the sensor threshold to balance between the two but changing sensor threshold would increase one and decrease the other. With a model based system, since occupant location is known, glare and daylight can be optimized at all times. Table 5 shows the effect of inaccuracy on the occupant experience. For each room and month it is indicated whether the space has too much glare or is darker than it needs to be with sensor based controls.

Table 5. Months when sensor based systems does not block glare or unnecessarily reduces natural light

Month	1729	1732	1733	1738
January	Glare not blocked	Glare not blocked	Glare not blocked	Glare not blocked
February	Glare not blocked	Glare not blocked	Glare not blocked	Not enough light
March	Glare not blocked	Glare not blocked	Glare not blocked	Not enough light
April	Glare not blocked	Not enough light	Not enough light	Not enough light
May	Glare not blocked	Not enough light	Not enough light	Not enough light
June	Glare not blocked	Not enough light	Not enough light	Not enough light
July	Glare not blocked	Not enough light	Not enough light	Not enough light
August	Glare not blocked	Not enough light	Not enough light	Not enough light
September	Glare not blocked	Not enough light	Not enough light	Not enough light
October	Glare not blocked	Not enough light	Glare not blocked	Not enough light
November	Glare not blocked	Glare not blocked	Glare not blocked	Glare not blocked
December	Glare not blocked	Glare not blocked	Glare not blocked	Glare not blocked

5.1 Sensor Based System Failure Due to Lack of Contextual Knowledge

One of the main reasons sensors tend to fail is that since there is no contextual knowledge outside actual sensor readings, they are forced to take only direct sensor measurements rather than many. The sensor system only measures in one direction because otherwise it might get positive sensor readings when there is no sun on façade at all. Conversely, model based systems are able determine if there is a potential glare condition based on geometric features and then measure light in many directions to determine if it is bright enough. This is especially important during indirect sun angles or morning and evening time periods. Figure 7 below shows sensor values for both a typical façade sensor (used for sensor based control) and a multidirectional rooftop sensor (used for model based control). The blue dotted lines are the range of time on this day that a glare condition potentially exists. Note how the multidirectional sensor is able to pick up high light levels much more effectively and indicate glare that is missed by the façade sensors. In this case the sensor based system will never go to tint regardless of high glare probability.

5.2 Sensor Based System Failure Due to Lack of Occupant Location

The most common type of sensor failure experienced was occupant location based failure. This is when the sensor picks up sun on the façade but in this particular case, there is no sun on any occupant. This can be seen in all rooms and account for a substantial portion of sensor failures.

6 Recommendation for Control System Design

Model based systems have clearly performed better on each metric. Not only does the system block glare more effectively, blocking glare at all times while sensors fail 12% of the time, but it also allows more daylight, sensors allow less daylight 12% of the time. Modelled based systems allow Dynamic Glass to reach a better balance between glare control and daylight, optimizing for both. Model spaced systems will give the occupant a better experience and are recommended for all building types.

References

[1] CIE, CIE 146:2002 CIE equations for disability glare. Color Research & Application, 2002 27(6): p. 457-458

[2] Discomfort Glare and the Lighting of BuildingsP. Petherbridge B.Sc., R. G. Hopkinson, B.Sc.(Eng.) Ph.D., M.I.E.E.

[3] https://www.prnewswire.com/news-releases/study-natural-light-is-the-best-medicine-for-the-office-300590905.html

[4] ASHRAE, 2017. Handbook of Fundamentals, Chapter 14, Pages 10-11

[5] https://viewglass.com/assets/pdfs/photo-sensor-data-sheet.pdf