

Visual comfort and energy benefits of View Smart Windows in workplaces

Executive summary

This white paper presents the results of a 12-month study conducted at the offices of View Inc. in California, to evaluate and compare the visual comfort of standard Low-e glazing with that of View Smart Windows in a workplace setting. Daylight Glare Probability (DGP) and illuminance levels at work-plane level were the metrics used to assess visual comfort. The test setup consisted of two adjacent office rooms with identical floor plans, furniture, HVAC, and windows with south-east exposure. The window of the baseline office (demo room A) was fitted with dual pane low-emissivity (Low-e) glass and motorized shades. The test office (demo room B) was fitted with dual pane View Smart Windows with no shades. High Dynamic Range (HDR) images were captured at fixed time-steps and converted to luminance maps using the PHOTOLUX v3.2 software, to analyze DGP and illuminance levels in both spaces. The analysis showed that View Smart Windows maximizes daylight in the space while keeping the glare probability below perceptible level at all times.

This study is in follow-up of an earlier white paper “Energy benefits of View Smart Windows”¹ that documented the annual energy use savings of View Smart Windows using the same test setup as the one described above. The study revealed that the use of View Smart Windows windows resulted in energy savings of 39 percent over the energy use with Low-e glazing.

Physical setup and methodology

Test site configuration

The testing facility consists of two adjacent south-east (azimuth 155°, measured clockwise from north) facing single-room offices, located on the second floor of a commercial office building in Milpitas, California. The rooms have identical office floor plans, furniture, HVAC systems, and solar radiation exposure.

- Dual pane Low-e glass and manual motorized shades (5% openness factor) were installed in the window of demo room A
- Dual pane View Smart Windows was installed in the window of demo room B.

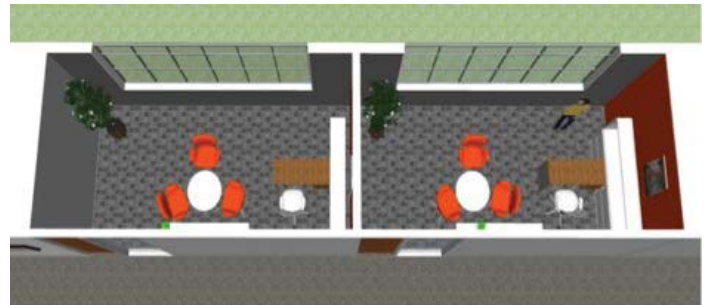


Figure 1. Schematic diagram of demo rooms with south-east facing windows



Figure 2. Demo room A: Low-e glass



Figure 3. Demo room B: View Smart Windows



Figure 4. Demo room B

Baseline commissioning

To ensure that the test rooms were receiving identical solar radiation exposure and environmental performance (HVAC, insulation, and lighting), prior to testing, the windows in both rooms were fitted with the same Low-e glass and monitored for two weeks, with sensors and controls calibrated and tuned to identical parameters. The energy use data showed less than 2 percent difference between the two rooms.

Occupancy

To maintain a controlled environment, both rooms were unoccupied during the duration of the monitoring period.

Lighting Dimmable lighting was installed in both rooms. However, electric lighting was switched off during the testing period to maintain focus on the natural light contribution.

Data collection

High Dynamic Range (HDR) digital images of each room were captured using identically configured cameras with fisheye lenses mounted on tripods at a height of 5 feet from the floor level. The cameras were placed in identical locations directly facing the windows of both rooms.

This setup was opted for in the interest of capturing the maximum range (vision angle, or cone) of views, with balanced shadow and highlight detail of the spaces from floor to ceiling. Windows were presumed to be the primary glare sources. See Appendix A for additional details.

Data processing

PHOTOLUX v3.2 image analysis software was used to produce luminance maps to identify maximum luminance values in each image.

Metrics

Glare metric

Daylight Glare Probability (DGP) based on “IES RP-5-13: Recommended Practice for Daylighting Buildings”² was used for the analysis of glare. Glare was categorized based on DGP values, as shown in Table 1.

Lighting level requirement

An illuminance threshold of 30 footcandles (fc) (323 lux) was assumed to be the lighting level requirement for both rooms. Considering that electric lights were turned off for the duration of the study, the data recorded the extent of times when this lighting requirement was met using transmitted daylight alone.

Imperceptible glare	<0.35
Perceptible glare	0.35 - 0.45
Disturbing glare	0.45 or higher

Table 1: Glare category definition by DGP

Test findings

Spring (March 22 to June 21) analysis

Analysis for a clear day in April shows that there was minimal sun penetration inside these spaces due to high sun angles on the south facade. View Smart Windows remained in its clear states for majority of the daylight hours; only transitioning to its darkest tint for a short period during early morning. Direct glare was not an issue for most of the day and hence, the performance of View Smart Windows was slightly better than the Low-e glass. DGP remained below the disturbing glare threshold of 0.45 in both the rooms as shown in Figure 5.

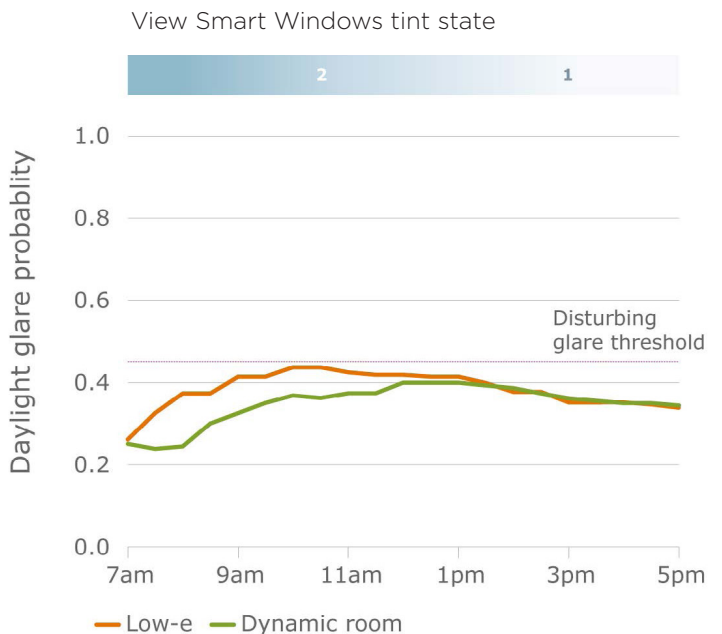


Figure 5: DGP analysis data for April

Summer (June 22 to September 21) analysis

During a clear day in August, direct glare was not a concern from the chosen point of view. Shades were thus assumed to stay open throughout the day (with an assumption that shades will be closed only for glare control). The analysis showed some instances of disturbing glare with Low-e glass in the morning from 9:00am-11:00am due to high contrast between interior and exterior luminance. View Smart Windows was mostly at intermediate states (20 percent and 40 percent visible transmittance) throughout the day to maximize daylight and minimize instances of disturbing glare, as shown in Figure 6.

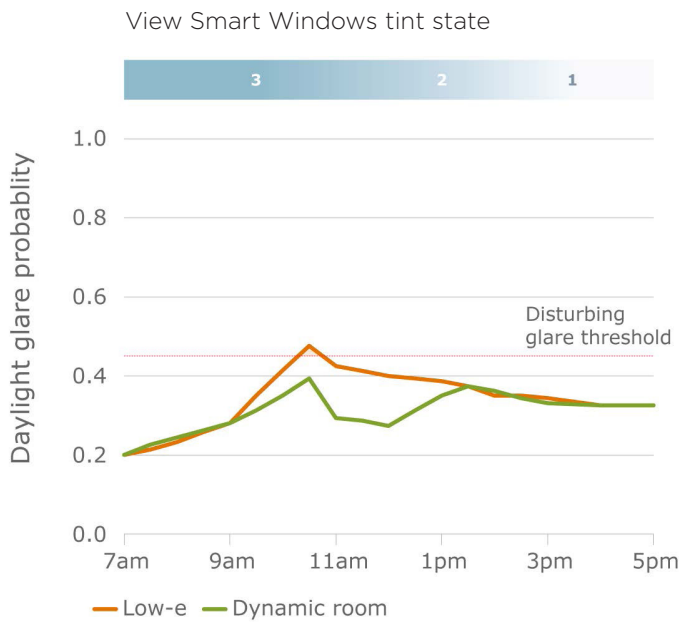


Figure 6: DGP analysis data for August

Fall (September 22 to December 21) analysis

The low solar altitude angles during October caused direct glare situations during most of the day. The space with Low-e glass was above the disturbing glare threshold from 9:00am-2:00pm obstructing occupant’s ability to work comfortably in that space. It was assumed that occupants would pull the shades down in this scenario to mitigate glare.

According to research conducted by the Urban Green Council,³ if shades are deployed for glare control in the morning, there is high likelihood that they will stay closed through the remainder of the day. While this helps in reducing DGP, the shades block useful daylight coming into the space (see Figure 7), and obscures the occupants’ beneficial view of the outside. View Smart Windows provides glare control while maximizing daylight.

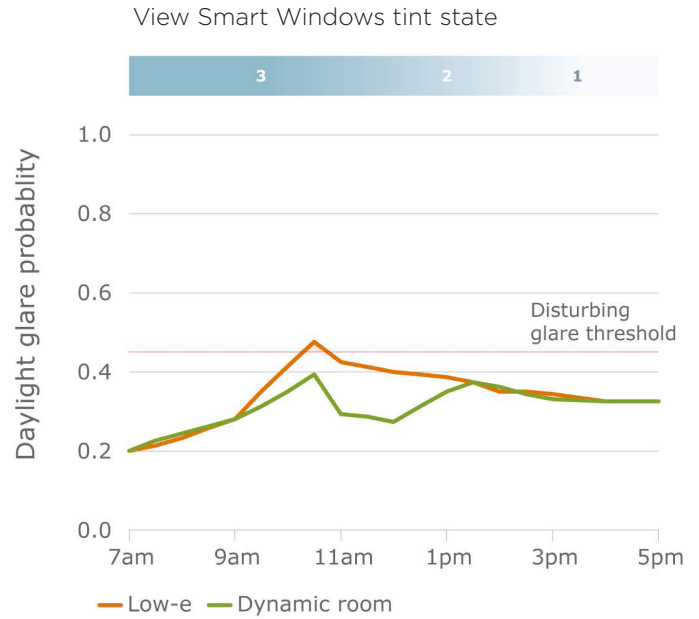


Figure 7: DGP analysis for October

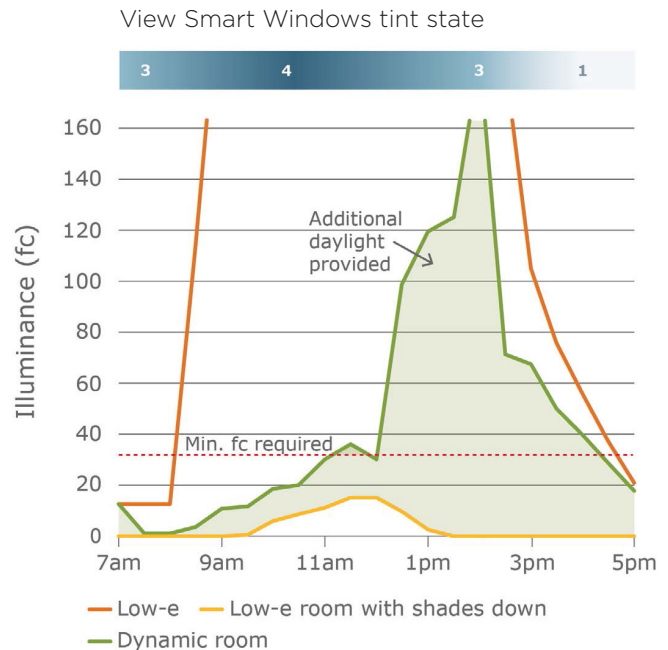


Figure 8: Illuminance levels at work-plane level (October)

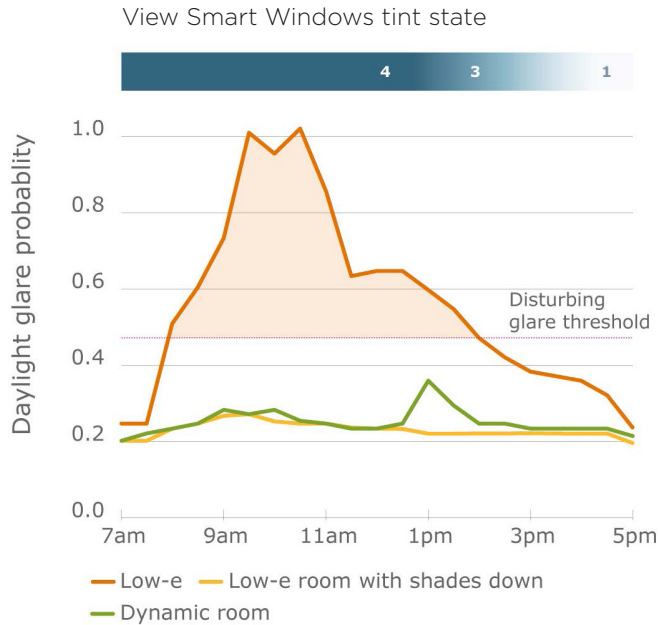


Figure 9: DGP analysis for December

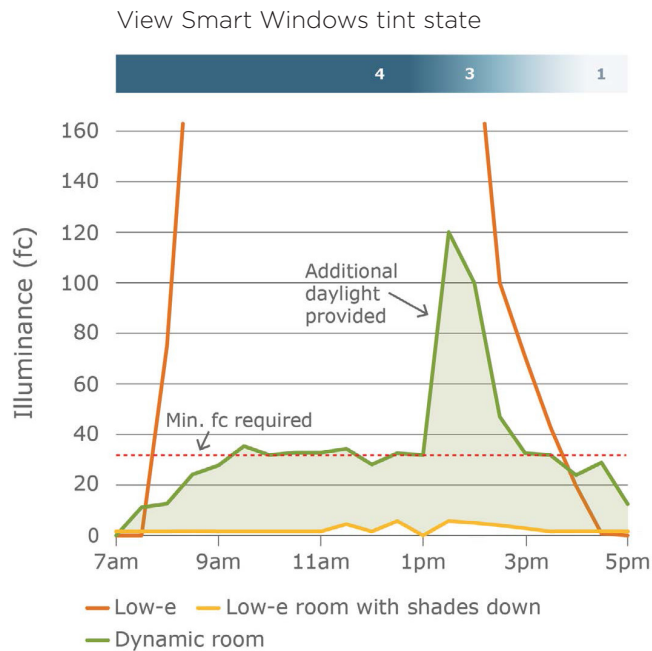


Figure 10: Illuminance levels at work-plane level (December)

Winter (December 22 to March 21) analysis

Solar angles are at their lowest during winter, thus creating the worst-case scenario for direct glare. Analysis for a clear day in December showed that with Low-e glass, DGP was above the disturbing glare threshold between 7:00am-3:00pm. Shades would have been closed throughout the day to mitigate the direct glare blocking both views and daylight coming in the space. View Smart Windows optimizes the tint level thus reducing glare while maximizing daylight and maintaining access to views.

Summary of findings

The results presented in the study encompass one entire year, and hence include all possible combinations of solar azimuth and altitude angles that can impact visual comfort in a space.

The analysis of measured data showed that View Smart Windows provides superior visual comfort through the provision of:

1. Effective glare control
2. Maximum possible daylight after controlling for glare
3. Uninterrupted views of the outside

Under direct-sun conditions, View Smart Windows transitions to its darkest tint (based on intelligent controls), providing comfortable work environment. With visible transmittance being less than 4 percent during direct glare conditions, DGP is kept below 0.35 (imperceptible glare threshold). At all other times, the tint level is optimized to provide maximum daylight while still mitigating glare.

Conclusions

View Smart Windows maximizes daylight in a space while keeping the glare probability below a perceptible level at all times. Its Intelligent control algorithm keeps the glass at its darkest tint during direct glare conditions and optimizes daylight at all other times. With static Low-e windows, shading devices such as blinds or shades are needed to mitigate glare. The downside to shading devices is that natural daylight and access to views are also sacrificed. View Smart Windows provides a greater level of control over glare without the need for blinds.

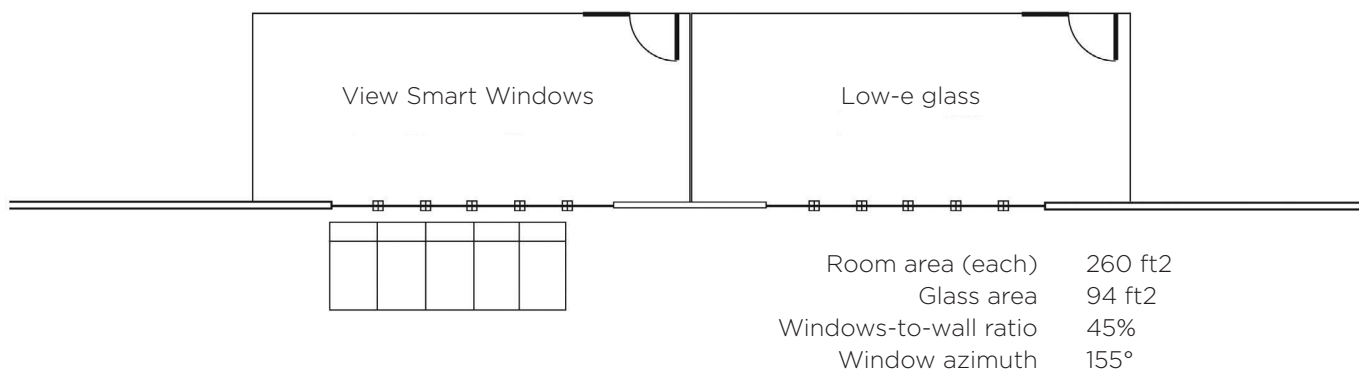
The views and access to natural daylight are maintained, providing all the human benefits the sun brings without any compromises.

Appendix

Tint level	Transmittance (%)	U-value (BTU/h-ft2F)	Solar Heat Gain Coefficient (SHGC)
Tint 1	58%	0.29	0.46
Tint 2	40%	0.29	0.29
Tint 3	20%	0.29	0.16
Tint 4	3%	0.29	0.09

- Performance values apply to a 1” (25mm) IGU with ½” (12.7mm) argon airspace, outboard lite is 6mm and fully tempered with EC coating on surface #2, inboard lite is 6mm clear
- All values calculated with LBNL WINDOW6.3 program and IGDB v.24

Test rooms configuration details



Setup description

The windows in each room were simultaneously exposed to the same exterior and interior conditions with no obstruction to the direct sun.

Data collection details

- Camera make and model: Canon 60D
- Lens make and model: Sigma Fisheye 4.5mm F2.8EX DC
- HDR process: guidelines provided in the PHOTOLUX 3.2 User’s Guide⁴ were followed to collect sets of 7 images which were then processed into single HDR images using Photolux to obtain the luminance maps
- Data was collected twice monthly from April 2013 to April 2014 on days with weather conditions of clear, sunny skies. HDR images were captured simultaneously in both rooms every 30 minutes from 7:00am-6:00pm producing a total of 23 HDR images per day per room, with a total of 1104 images collected during the 12 month testing period.

Metrics and software

The HDR images using fisheye lens were processed in PHOTOLUX 3.2 software, which allows the user to calculate several glare indices based on the luminance distribution in the visual field. The following glare indices can be automatically calculated:

- UGR - CIE Unified Glare Rating
- GI - British glare index
- CGI1 - R. G.Hopkinson's "Cornell Formula," known also as Daylight Glare Index (DGI)
- CGI2 - CIE modification to the Cornell Formula, which uses illuminances rather than luminances
- DGR - Discomfort glare rating, used to calculate VCP, visual comfort probability

Glare matrix and details of calculations

Discomfort glare: light source that are bright enough to be distracting or uncomfortable is defined as the source for discomfort glare. In this analysis, window was considered the primary glare source.

For a light source greater than 0.1 steradian in size (a "large-area" glare source), either CGI2 (CIE Cornell Glare Index) or DGP (CIE Daylight Glare Probability) would be the preferred indices for a glare evaluation. 0.1 steradian is approximately the angle subtended by a 3'x3' window at a distance of 10.'

Daylight Glare Probability (DGP) is well-validated recent addition to the list of glare metrics. It was specifically developed to be easy to implement with digital cameras, and to reflect the common range of visual conditions found in European (similar to American) offices. DGP is the basis for the EVALGLARE tool in Radiance. Hence, DGP was used as glare metric for this analysis.

Based on the PHOTOLUX data we could calculate CIE DGP based on CGI2, by using the Ed value for each image (the amount of illuminance at the lens caused by "direct" glare sources, i.e., all sources above threshold).

Conversion from CGI2 to DGP

PHOTOLUX calculates CGI2 from luminance values in a given scene, but does not calculate DGP. However, CGI2 and DGP are calculated using similar equations (notably the term inside the summation), so DGP for the same scene can be calculated using the CGI2 value for that scene:

$$CGI2 = 8 \log_{10} \left[2 \left(\frac{1 + E_v}{500} \right) \sum_{i=1}^n \frac{L_{si}^2 w_{si}}{P_i^2} \right] \quad (1)$$

$$DGP = 5.78 \times 10^{-5} E_v + 9.18 \times 10^{-5} \log_{10} \left[1 + \sum_{i=1}^n \frac{L_{si}^2 w_{si}}{E_v^{1/2} P_i^2} + 0.16 \right] \quad (2)$$

Where the following data can be obtained from PHOTOLUX:

Ev = Vertical illuminance at the viewing location (lux)

Ed = Direct vertical illuminance at the viewing location (i.e., from glare sources)

Ei = Indirect vertical illuminance at the viewing location (i.e., from non-glare sources)

Ev = Ed + Ei

Citations

1. Online at: http://viewglass.com/pdf/View_Workplace_DemoRoom.pdf
2. Description and purchase information at: <http://www.ies.org/store/product/recommended-practice-for-daylighting-buildings-1305.cfm>
3. Online at: <http://urbangreencouncil.org/seduced-bythe-view>
4. Online at: http://www.photolux-luminance.com/images/stories/photolux/download/Photolux_3_2_Users_guide_Eng.pdf

HDR images of workspace for October

View Smart Windows

Low-e with shades closed

Low-e

Tint 3
7:00am



Tint 4
9:00am



Tint 4
11:00am



Tint 3
1:00pm



Tint 2
2:00pm



Tint 1
5:00pm

