Comparison of Occupant-Centric daylighting levels in windows for affordable housing in Portland, OR.

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ABSTRACT: This paper presents the results conducted from observing shade configurations and daylighting levels within an affordable housing bedroom unit. We conducted mainly qualitative data as the residents of the 82nd and Orchard building declined to participate in our study. Our quantitative data considered shade configuration, collected over a three-day period, and daylight factor using a physical model with photometric sensors. The results were compared to actual resident shade use over the course of the day to determine if a clerestory window outperforms a standard view glazing unit.

KEYWORDS: Daylighting, Window, User-Preference, Daylight-Factor, Bedroom

INTRODUCTION

Daylight is critical to human health and inherently to the non-visual circadian rhythm system. Circadian rhythm is a biological clock and an endogenously generated 24-hour cycle that impacts flora and fauna. Daylight and temperature maintain the natural circadian cycle as external cues to align the body clock (science direct). Light can turn on, off, speed up, or slow down the genes that control the biological clock and circadian rhythm in organisms. When the circadian system becomes irregular, health concerns arise.

Human health is the balance of physical and mental well-being. These two forces are rooted in the body's endocrine and nervous systems. Stimulated by light, these systems react to fluctuating light levels over the day, impacting circadian rhythm (Figueiro). When out of sorts, health concerns such as diabetes, sleep-deprivation, obesity, and depression may arise (Duffy).

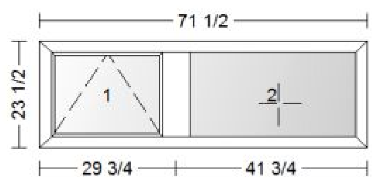
Design work and daylight research primarily focus on the workplace. Analysis of visual task performance and analyzing the needed amount of daylight or electric light can be profitable for companies to improve worker productivity. Less research has been conducted in the home environment, as it is not space where productivity has notable economic value. The home is an exciting area of study because it is where workers start and end their days. Understanding lighting levels in the home is critical to psychological health, and to promoting normal circadian rhythm that impacts alertness, human performance, and safety. A large epidemiological study conducted in Finland found "that health -related quality of life was higher for people reported higher interior light levels" (Figueiro). In affordable housing, the proper amount of interior daylighting is essential, primarily if residents work night and are more susceptible to a disrupted circadian rhythm and onset health concerns (Duffy).

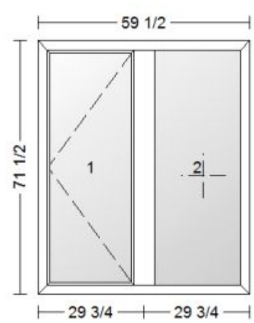
The Equivalent Melanopic Lux (EML) is a measurement of light's effect on the circadian cycle. From the WELL building institute feature 54, the biological effects of light on humans measured in EML is a proposed alternate metric that weights the ipRGCs (the eyes' non-image- forming photoreceptors) instead of the cones, which is the case with traditional lux. Verification, EML is measured on the vertical plane at the eye level of the occupant. We will pay close attention to this during our research and collect light readings on a vertical plane at eye level. The WELL building institute specifies in feature 54 that a bedroom must receive 200 or more equivalent melanotic lux (EML), without the assistance of artificial lighting to support circadian health and meet a minimum threshold for daytime light intensity. The sensor should be placed facing the wall in the center of the room 1.2 m [4 ft] above the finished floor). During the nighttime, lights provide not more than 50 equivalent melanopic lux (WELL).

Similar to EML, occupant-centric daylight factor percentage is the ratio between indoor illuminance and outdoor illuminance, typically measured on a vertical plane at eye level. (100 x indoor/outdoor illuminance) Effective daylighting levels of 100 to 300 lux are essential to maintaining user satisfaction within the home and lead to a significant reduction in electric lighting use. For this study, the occupant-centric daylight factor was measured to calculate an estimated EML for window and shade status comparison. Window areas can benefit energy efficiency by reducing the amount of electric lighting used within a residential unit (Ghisi, 2005, 117). When space fails to provide adequate daylighting levels it can negatively affect resident health. Low levels of daylighting were 1.4 times more likely to report depression, fatigue, and a greater risk of falling (Brown, 2011, 131). Window position and size may impact the performance of the building from an energy efficiency standpoint it also can impact the residence perception of their space (Persson, 2006, 349).

Our research setting was an affordable housing complex on SE 82nd and Orchard St. in Portland, Oregon; designed by SERA Architects. The building form was in the shape of a "T" with the longer side running East-West. The "T" was to the Western edge of the lot running North-South and surrounded by single family residential. A busy road ran along the North and shorter Eastern facade, a playground and jiffy lube to the South. There are two types of bedroom units in the building. One-bedroom type has a clearstory window, and the other a large standard window opening. Both windows are operable and allow for daylighting, ventilation, and views out - although the views are not all favorable. The building is home to residents of diverse backgrounds who prefer a large amount of privacy.

The vertical plane occupant-centric daylight factor readings were determined from a physical model in a controlled lighting environment. We modeled the shade orientations and collected the occupant-centric daylight factor percentage to calculate EML using LiCor photometric sensors placed in the vertical plane at the simulated standing eye height of an occupant within a controlled lighting chamber that allowed readings to be accurate and unobtrusive on the residents. Measuring on a vertical plane simulates the amount of light entering one's eye vs. reflecting off of a work surface. All of the shade model data was collected on the same day with a constant overcast sky condition. Research of the users shade preference was conducted through exterior observation over a two day period to understand a variation in use. Data was collected by visiting the site and counting the shade orientations on each facade at different times of the day. Readings were collected at 9:30am, 11:30am, 2:30pm, and 6:30pm.





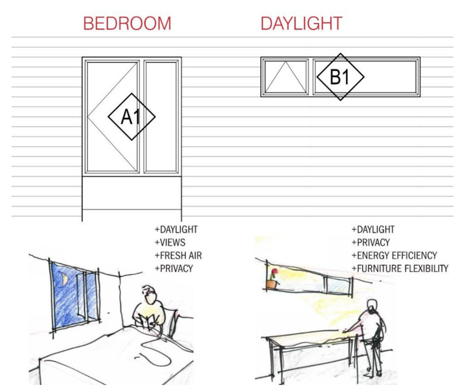


Figure 1: Clearstory window B **Figure 2:** Standard window A **Figure 3:** Diagram by SERA Architects[1]

*(Figure 1 & Figure 2 will be compared in this study although diagram indicates otherwise).

The window-to-wall ratio and daylighting factor are the two most prevalent ways to evaluate window performance. The daylight factor compares the light levels outside the building with levels for the interior. This calculation estimates how much daylight will reach the building occupant. According to the WELL building standard, the window-to-wall ratio for a bedroom must measure between 20% and 40% on external elevations. However, it is also important to take user perception and visual preference into account (U.S.).

82nd and Orchard is a multi-family affordable housing complex in Portland, OR. Privacy is important to the residents and could affect their window preference. By collecting data on the light levels from differing size windows and cataloging the resident's use of shading privacy devices, we hope to identify tradeoffs between daylighting and

[1] SERA

privacy. We hope to aid SERA Architects, an architectural firm in the Portland Metro area conducting multi-family development, in identifying cost-effective and health-promoting window-to-wall ratio design solutions to benefit future affordable housing projects.

Research Questions

1. Would a resident prefer a clearstory window over a standard window unit in their bedroom?
2. Would it be more cost efficient for architects to specify a clearstory window unit in affordable housing bedroom units?
3. Are the daylighting levels vastly different for each type of opening?
4. How does user shade preference affect the comparison of use preference to daylight factor performance for each?
5. Do the residents at Orchards of 82nd receive adequate circadian-effective lighting through current application of daylighting fenestration?

Topic

Compared two window units by evaluating daylight factor percentage and window-to-wall ratios on the Orchards of 82nd affordable housing complex to determine if the daylighting conditions received by the residents met the WELL 62 and 63 recommendations.

Project Scope

The scope of this project evaluated the occupant-centric daylight factor percentage for a bedroom unit space and compared how the daylight levels changed with a shading device (open and closed conditions) and with different fenestrations.

HYPOTHESIS

The clearstory window will meet WELL v2 circadian daylighting standard for occupants at 5’ - 0” from window at center of room with observed window shade operation.” The view window will not meet WELL v2 circadian daylighting standard for occupants at 5’ - 0” from window at center of room with observed window shade operation.

METHOD

Since the living units were all occupied and we could not obtain permissions for a field study, we built a 1” = 1’ - 0” scale model of a standard bedroom space and used Canson paper materials, black foam core and black tape to block out any unwanted light along the seams. Canson paper was used to clad the interior of the model to simulate the same light reflectance values (LRV) as the actual finishes in the bedroom units.

Surface Material	Actual Material	Modeled Paper Type	Light Reflectance Value
Wall + Ceiling	Benjamin Moore, Egg-Shell, White	Canson white 707-190 335	LRV: 88.9
Floor Material	Luxury Vinyl tile, Pancraft, 1800V 6” Highland Forest, Sandy Oak 20230	Canson 707-191 366 sand	LRV: 20
Unit Shades - Blinds	SWF Contract, Customiser 1” Aluminum Blinds, Snowcap White	Canson strathmore pure paper tint 528-16 cream	LRV: 75

Figure 4: LRV Chart

Figure 5: Canson paper clad interior + daylight factor grid on ground plane. Light meter hole.

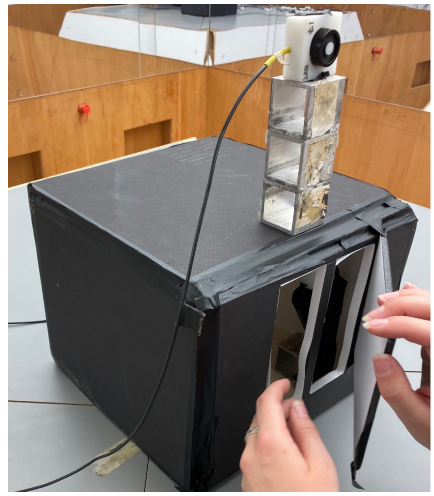


Figure 6: Window 1 orientation and adjustable Shade. Light meter on top of model.

The fourth wall of the model was interchangeable to test the two window configurations. Two walls were built to include a cut out of the same window-to-wall ratios of either the larger window unit or smaller clerestory. Inside the model, we installed a LiCor photometric sensor on that back wall and one that moved along a grid to collect the daylight factor percentage for the bedroom. A third sat on the top of the model to accurately calculate the daylight percentage for the outside to inside of the model. The occupant-centric daylight factor percentage readings were taken fifteen times as the sensor moved across the grid in the “bedroom”. Readings were also collected using shade orientations of: open, mostly open (1/4th down the window), middle, mostly closed (3/4th down the window), and a closed condition. These readings are to be compared to the actual shade use by 82nd and Orchard residents. Shade use data at 82nd and Orchard was collected by visiting the site and recording the shade configurations along each facade of the building at different points of the day.

After the data was collected, it was analyzed to determine whether the clearstory windows were left open more than the standard units, and if so, did they allow for WELL building standard 62.

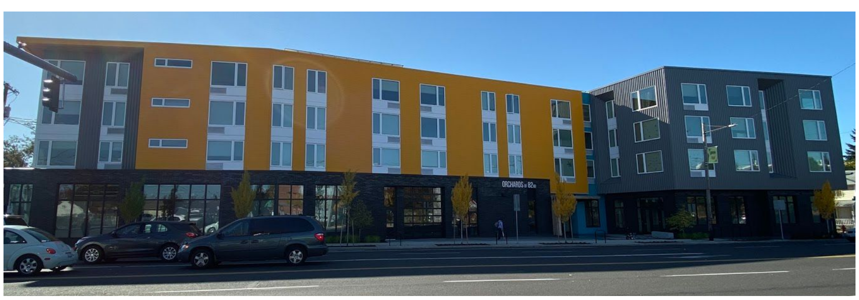


Figure 7: Photo of North facade taken during shade orientation data collection.

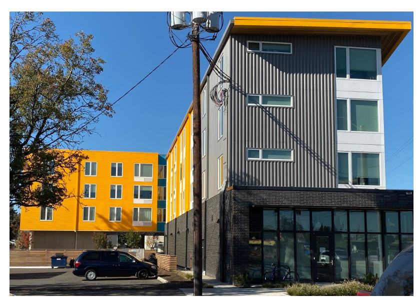


Figure 8: East Facade.

RESULTS

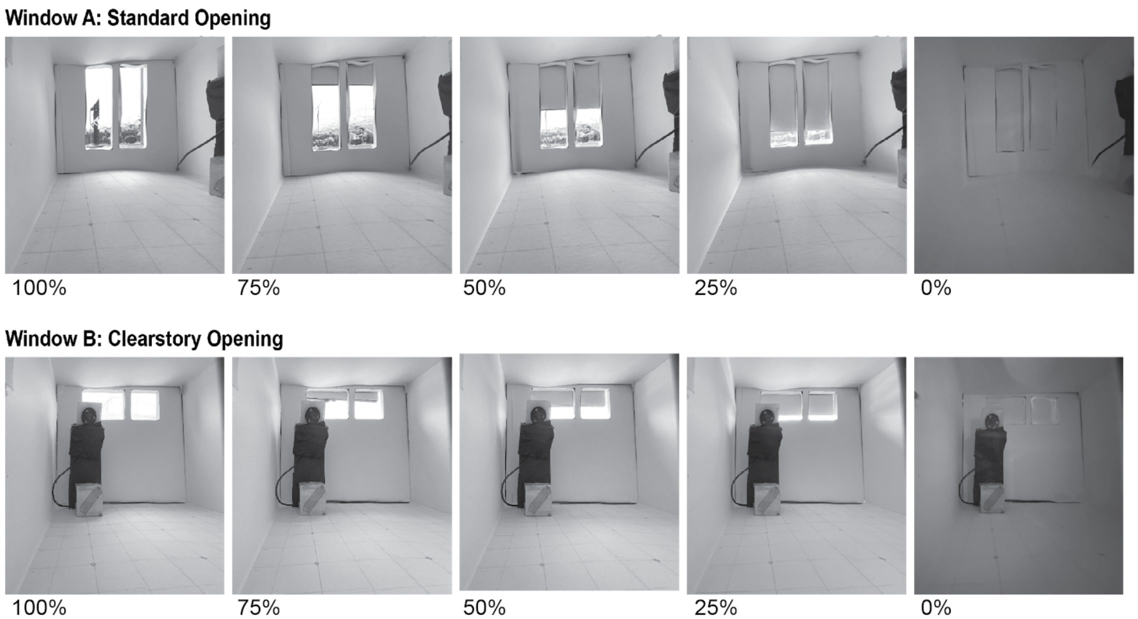


Figure 9: Interior condition of physical daylighting model

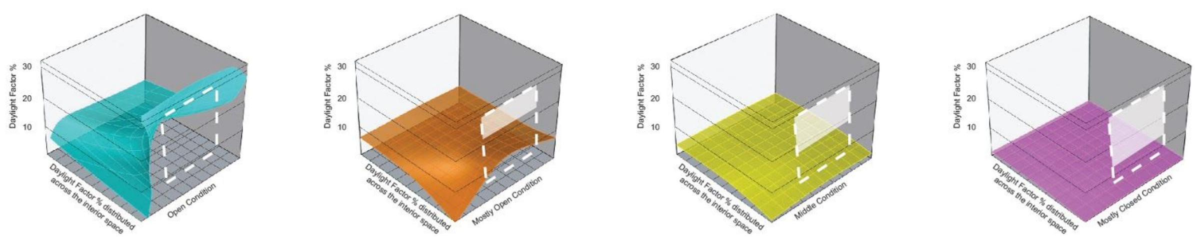


Figure 10: Daylight factor percentage decay across depth of room for Standard opening

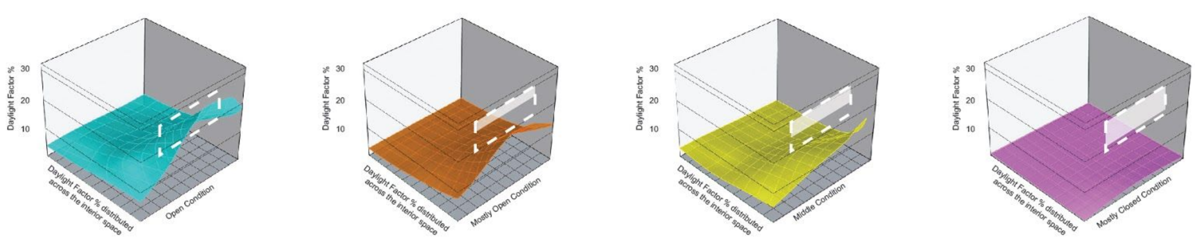


Figure 11: Daylight factor percentage decay across depth of room for Clerestory opening

9:30 AM	Window A - Standard	Window B - Clearstory
11/16/2019		
North	9 closed	1 closed
	5 open	2 open
	1 mostly closed	
South	17 closed	3 closed
	1 middle	
	3 open	
East	8 closed	2 closed
	2 mostly closed	1 mostly open
	1 mostly open	
	1 middle	
West	11 closed	
	1 mostly closed	

11:30 AM	Window A - Standard	Window B - Clearstory
10/24/2019		
North	9 closed	1 closed
	1 open	2 open
	3 mostly open	
	2 middle	
South	9 closed	3 open
	5 middle	
	4 open	
	2 mostly closed	
East	5 closed	1 open
	3 open	2 closed
	2 middle	
	2 mostly closed	
West	5 closed	
	5 mostly closed	
	1 middle	
	1 open	

2:30 PM	Window A - Standard	Window B - Clearstory
11/16/2019		
North	9 closed	1 closed
	4 open	2 open
	1 mostly closed	
	1 middle	
South	14 closed	2 closed
	2 middle	1 open
	4 open	
	1 mostly closed	
East	5 closed	2 closed
	2 mostly open	1 mostly open
	3 middle	
	2 mostly closed	
West	5 closed	
	3 mostly closed	

6:30 PM	Window A - Standard	Window B - Clearstory
11/16/2019		
North	11 closed	1 open
	1 mostly closed	2 closed
	2 middle	
	1 open	
South	16 closed	2 closed
	3 open	1 open
	2 middle	
East	5 closed	1 mostly closed
	2 mostly open	2 closed
	3 middle	
	2 mostly closed	
West	11 closed	
	1 mostly open	

	2 middle				1 open	
	1 open					

Figure 12: Data from shading observation site visit

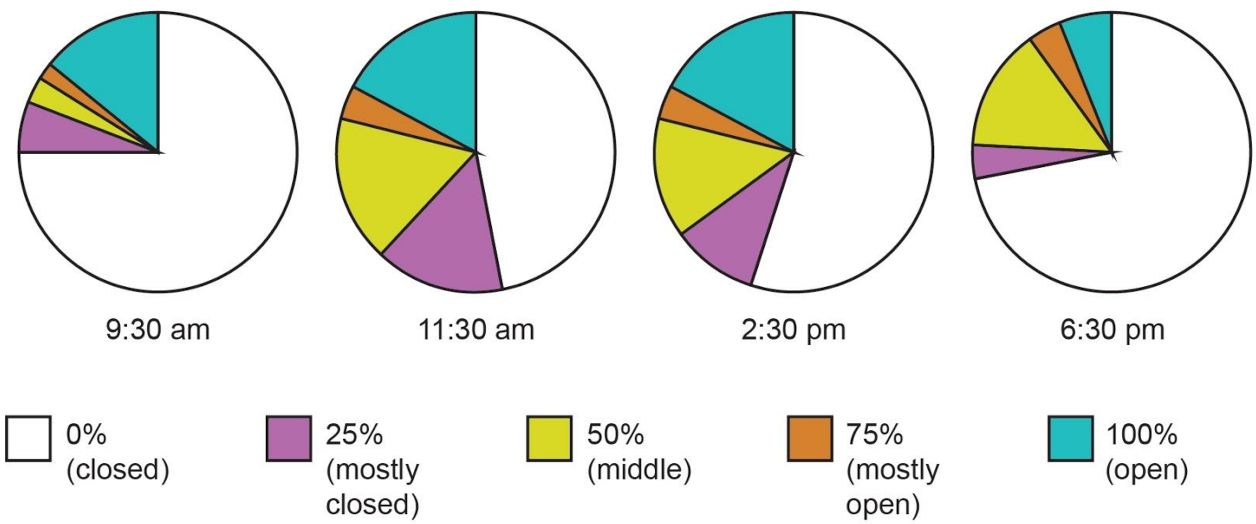


Figure 13: Shading use of Standard opening over the course of a day

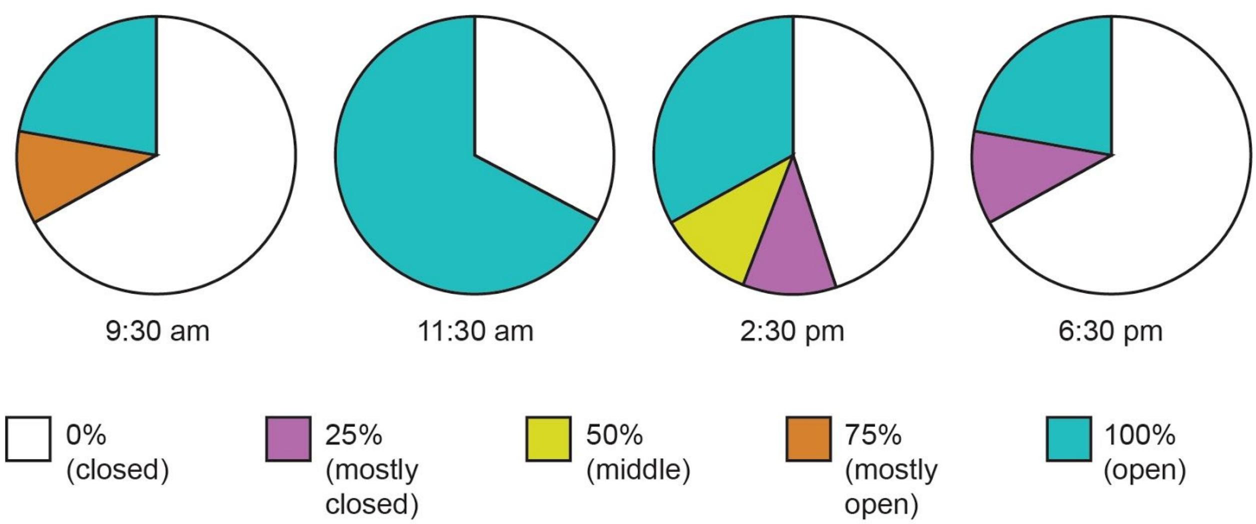


Figure 14: Shading use of Clerestory opening over the course of a day

Date: Sat, 11/16/19	Date: 10/24/19	Date: Sat, 11/16/19	Date: Sat, 11/16/19
Time: 9:30am	**Time: 11:30 am**	**Time: 2:30 pm**	**Time: 6:30 pm**
Temp: 52 degrees	Temp: 57 degrees	Temp: 55 degrees	Temp: 55 degrees
Cloud Cover: Partly Cloudy	Cloud Cover: Clear	Cloud Cover: Cloudy	Cloud Cover: Cloudy
Daylight Factor: 32.3 klx	Daylight Factor: 30.79 klx	Daylight Factor: 8.57 klx	Daylight Factor: 1.9 klx
Percentage Open Unit A: 0.75	Percentage Open Unit A: 0.71	Percentage Open Unit A: 0.51	Percentage Open Unit A: 0.70
Percentage Open Unit B: 0.66	Percentage Open Unit B: 0.43	Percentage Open Unit B: 0.44	Percentage Open Unit B: 0.66
Difference: 9%	28%	7%	4%

Figure 14: Additional data from shading observation site visit

DISCUSSION

The data collected from the physical daylighting model proved that window type A had a higher daylight factor percentage than the clearstory window B. The window-to-wall ratio of window A is 110%. The window-to-wall ratio of window B is 43%. This proves that window A has a larger aperture, thus allowing for more daylight to enter the bedroom space. This was anticipated before the study. WELL building standards state that bedrooms must have a window-to-wall ratio of between 20 and 40% (WELL). What was interesting was comparing physical shade orientation preference of the residents to the physical model results

We hypothesized that the smaller clearstory window aperture provided adequate daylighting to the residents of Orchards of 82nd based on the WELL buildings standards (for feature 62, daylight modeling), with the intent to support circadian and psychological health by setting thresholds for interior sunlight exposure during occupancy. This could be true if window B, the clearstory window could outperform window A if the shade preference of users was to mainly have their bedroom shades down. What we found however was that even with the observations of most of the shades being down, the standard unit A was preferred. This could be due to more standard window units then clearstories, squing the math. Another takeaway for designers is to spec a bottom up interior shade that would allow for a high degree of privacy, while providing adequate daylighting for occupants. Bottom up shades encourage daylight and reduce the need for electric lighting.

CONCLUSION

Based on our findings, we conclude that window A, the standard opening , allows for a greater daylight factor percentage because it is larger than the clearstory unit. When the shades are left open, window A receives about double the amount of daylighting. However, if window A has the blinds drawn even just a little to the mostly open condition and Window B is left open, then Window B will outperform . To our surprise, residents drew the shade a bit or even closed their clearstory windows. The user preference that was observed changed our initial impression. We requested to survey residents on their shade preference, but our efforts were unfortunately declined. This is an area to revisit in the future to determine why we observed what we did. The blinds that were speced by the Architect may allow a small amount of light through when closed. For accuracy, we modeled this aspect as a solid but it would be interesting to see if a different type of interior shade would change the residents preferences.

ACKNOWLEDGEMENTS

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ADDENDUM

		Open		Mostly Open		Middle		Mostly Closed		Closed
Interior Sensor A, 1	8.52516	19.9	5.7834	13.5	3.40578	7.95	1.15668	2.7	0.325584	0.76
Interior Sensor B, 1	9.12492	21.3	6.12612	14.3	3.637116	8.49	1.24236	2.9	0.0162792	0.038
Interior Sensor C, 1	8.48232	19.8	5.95476	13.9	3.508596	8.19	1.24236	2.9	0.0162792	0.038
Interior Sensor A, 2	8.65368	20.2	5.74056	13.4	3.444336	8.04	1.19952	2.8	0.0325584	0.076
Interior Sensor B,2	9.68184	22.6	5.9976	14	3.697092	8.63	1.32804	3.1	0.0162792	0.038
Interior Sensor C,2	9.12492	21.3	5.95476	13.9	3.679956	8.59	1.24236	2.9	0.05355	0.125
Interior Sensor A, 3	8.9964	21	5.5692	13	3.482892	8.13	1.24236	2.9	0.0488376	0.114
Interior Sensor B,3	11.60964	27.1	6.59736	15.4	3.91986	9.15	1.2852	3	0.0325584	0.076
Interior Sensor C,3	10.19592	23.8	6.16896	14.4	3.688524	8.61	1.19952	2.8	0.0646884	0.151
Interior Sensor A, 4	10.23876	23.9	4.66956	10.9	3.024504	7.06	0.94248	2.2	0.0162792	0.038
Interior Sensor B,4	16.75044	39.1	7.41132	17.3	3.924144	9.16	1.19952	2.8	0.0162792	0.038
Interior Sensor C,4	12.25224	28.6	6.04044	14.1	3.247272	7.58	1.071	2.5	0.0818244	0.191
Interior Sensor A, 5	8.1396	19	3.04164	7.1	1.794996	4.19	0.47124	1.1	0.0162792	0.038
Interior Sensor B,5	27.54612	64.3	9.76752	22.8	2.776032	6.48	0.68544	1.6	0.0655452	0.153
Interior Sensor C,5	20.22048	47.2	7.15428	16.7	2.330496	5.44	0.59976	1.4	0.0818244	0.191

Figure 14: Raw data from testing physical model - Window A

		Open		Mostly		Midd		Mostly		Close

				Open		le		Closed		d
Interior Sensor A, 1	3.992688	9.32	2.61324	6.1	2.65608	6.2	0.501228	1.17	0.17136	0.4
Interior Sensor B, 1	4.24116	9.9	2.686068	6.27	2.31336	5.4	0.501228	1.17	0.034272	0.08
Interior Sensor C, 1	3.9627	9.25	2.5704	6	2.05632	4.8	0.3624264	0.846	0.025704	0.06
Interior Sensor A, 2	4.41252	10.3	2.947392	6.88	2.05632	5.3	0.44982	1.05	0.017136	0.04
Interior Sensor B,2	4.9266	11.5	3.17016	7.4	2.22768	5.2	0.445536	1.04	0.034272	0.08
Interior Sensor C,2	4.41252	10.3	2.9988	7	2.18484	5.1	0.419832	0.98	0.051408	0.12
Interior Sensor A, 3	5.65488	13.2	4.11264	9.6	2.87028	6.7	0.466956	1.09	0.051408	0.12
Interior Sensor B,3	6.81156	15.9	4.75524	11.1	3.55572	8.3	0.51408	1.2	0.034272	0.08
Interior Sensor C,3	5.74056	13.4	3.954132	9.23	2.69892	6.3	0.5355	1.25	0.034272	0.08
Interior Sensor A, 4	7.75404	18.1	5.39784	12.6	4.36968	10.2	0.522648	1.22	0.051408	0.12
Interior Sensor B,4	12.38076	28.9	7.96824	18.6	6.98292	16.3	0.775404	1.81	0.034272	0.08
Interior Sensor C,4	9.29628	21.7	5.74056	13.4	4.24116	9.9	0.569772	1.33	0.034272	0.08
Interior Sensor A, 5	8.01108	18.7	7.32564	17.1	5.48352	12.8	0.72828	1.7	0.017136	0.04
Interior Sensor B,5	18.93528	44.2	13.62312	31.8	9.29628	21.7	1.56366	3.65	0.25704	0.6
Interior Sensor C,5	14.90832	34.8	9.98172	23.3	10.02456	23.4	0.895356	2.09	0.025704	0.06

Figure 15: Raw data from testing physical model - Window B