

## A FRAMEWORK TO SIMULATE THE NON-VISUAL EFFECTS OF DAYLIGHT ON THE COGNITIVE HEALTH OF MILD COGNITIVE IMPAIRMENT (MCI) PEOPLE

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### ABSTRACT

Human health and well-being concerns have been recently brought to the forefront of building performance assessment through contemporary practices of sustainability design. Mental health challenges in aging populations require an increased awareness in design practice to improve the lives of individuals that suffer from such experiences, as well as their caretakers. Within the bounds of sustainability, daylighting plays a critical role in human well-being, specifically non-visual effects such as regulating circadian health, which contributes to alertness and sleep cycles of healthy individuals. Interior spatial investigations have been developed through simulation-based workflows, including modeling tools such as Adaptive Lighting for Alertness (ALFA) (Solemma, 2019). However, such tools typically don't address challenges in vulnerable communities, such as people with Mild Cognitive Impairment (MCI). Insufficiency of research that focuses specifically on such MCI and elderly experiences necessitate additional efforts from designers to understand and create built environments that empower their lives. In this paper, a critical review of human cognitive health and its relationship to daylighting is presented. The research establishes the link between simulating the non-visual effects of daylighting using DIVA for Rhino, Climate Studio, and ALFA in relationship to MCI individuals and enhancing their cognitive health in indoor environments. This research aims to demonstrate design solutions that could empower MCI patients by informing the design of spaces that specifically promotes their health and wellbeing. Finally, the paper presents a case study that showcases simulation techniques that focus on daylighting and health modeling for this vulnerable population, with recommendations for future work validation by deploying an ecologically valid experimental design.

### INTRODUCTION

Enhanced sustainable designs that would promote human health and well-being are currently viewed as one of the future requirements of built environment design (Winer, 2019). It is estimated that nearly 15% of the global population suffers from various types of disabilities as reported by the World Health Organization (WHO) (World Health Organization, 2011). Accordingly, this should drive designers and innovators to come up with advanced solutions tackling various disability challenges that might face many individuals.

Among the diverse types of disabilities, MCI has recently been in the spotlight, calling out the attention of many researchers and designers due to its possible progression into Alzheimer's Disease (AD) (Matthews et al., 2008). According to the World Populations Prospects: the 2019 Revision, by the year 2050, 16% of the world population will be at the age above 65 years old meaning that one in six people in the world will be at this age (United Nations, 2019). On the other hand, the Alzheimer's Association estimates that approximately 15 to 20 % of people at age 65 or older have MCI showcasing the importance of understanding the challenges that might face MCI patients (Alzheimers Association, 2018). It has been showcased that elders spend up to 95 % of their time indoors between bedrooms and living rooms (Almeida-Silva, 2014). Consequently, architecture plays a role in providing enhanced indoor experiences that can improve their overall health. Contemporary sustainable designs that are based on building performance assessment tackle various issues to provide integration that can promote such well-being.

Under the umbrella of sustainability, daylighting plays an important role in promoting human health, especially through non-visual effects such as regulating circadian health which plays a critical role in stimulating and regulating alertness and sleep cycles in healthy people (Konis, 2017). Numerous researchers have been

addressing the effects of daylighting on healthy individuals and the common outcomes of its experiences on cognitive performances and mental health. However, they did not sufficiently focus on individuals with disability challenges making it strenuous for designers to use such resources when designing for people with disabilities, such as MCI.

In this paper, a critical review of human cognitive health in relationship to daylighting and its non-visual effects is established. This research aims to provide a better understanding of the existing standard nursing homes that could empower MCI patients by showcasing the essential criteria of space design that specifically promote their health and wellbeing through daylighting design. This was pursued through an experimental design showcasing the suggested design metrics for MCI patients' cognitive well-being as it relates to daylighting, and the possible ways to achieve them through simulation using DIVA, Climate Studio, and ALFA.

## LITERATURE REVIEW

### **Daylighting and Circadian Health**

It has been recognized decades ago that the use of daylight and delivering it within interior spaces is vital for the improvement of the human condition, as well as enhancing lifestyles and working conditions of people (Sharp et al., 2014). Various studies suggest that when daylight exposure is maximized in health care centers and hospitals, patient recovery is accelerated while the length of hospitalization declines (Boubekri, 2004).

The circadian system accounts for the synchronization of daily changes under the effect of the amount of daylight an individual is exposed to. It is responsible for an extensive range of behavioral and physiological functions such as alertness level, change of mood, sleep/wake cycles, and body temperature. Failure to receive the appropriate amount of daylight could affect the 24-h diurnal cycle (Andersen, 2015) (Czeisler and Gooley, 2015). Consequently, one could conclude that people who are exposed to sufficient daylight are expected to have a satisfactory circadian system which allows them to be further active in their day and encounter better sleep cycles and moods throughout their daily lifestyle.

However, in some cases such as with elderly individuals, exposure to daylight becomes less of a vital part of their daily life due to possible physical impairments. Thus, access to daylight loses priority even though it has crucial benefits (Boubekri, 2008).

### **Understanding MCI**

MCI is considered one of the various types of dementia that affects elderly individuals. In 1999, Petersen et al

brought forward the diagnostic criteria for MCI demonstrating that it is the transitional state affiliated with memory impairment that is associated with an increased risk of progression to AD (Petersen et al., 1999). A study stated that people with MCI were about three times higher risk of developing AD when compared to healthy individuals (Bennett et al., 2002). This further highlights the importance of developing enhanced designs that improve the overall health of MCI patients, possibly contributing to preventive methods of progression to AD. MCI can be divided into two subtypes, either an amnesic subtype with memory deficits or a non-amnesic subtype with a cognitive decline other than memory, extending to the impairment of a single domain of function or multiple domains (Mussele et al., 2013). Patients might experience neuropsychiatry symptoms such as depression, anxiety, agitation, irritability and apathy (Rosenberg et al., 2013). This might lead to several complications such as MCI individuals isolating themselves away from people, suffering from insomnia and, losing interest in daily life and activities (Molano and Vaughn, 2014).

### **Effect of Daylight on MCI Individuals**

Typically, dementia, MCI, and common disorders in adults affect those at the age of 65 years or older (McKeel et al., 2007). This results in the change of some functions such as sleep-wake / circadian rhythms affecting overall mood changes and quality of life (Naismith, Lewis, and Rogers, 2011). A previous study showcased a direct relationship between daylight exposure and the correction of circadian rhythms in elderly people. It stated that anxiety and insomnia disorders which are symptoms of MCI could be refined by daily exposure to daylight. The study pointed out that sleepiness, fatigue, and alertness at daytime might be improved if elders were exposed to adequate daylight resulting in improved circadian systems and thus, better sleep-wake cycles (Karami et al., 2016). However, there are currently no minimum requirements regarding exposure to daylight in dementia care environments including MCI individuals. Further research has the potential to prove the importance of daylight not as a factor of safety and visual importance but as a significant factor in the non-visual effects of daylight (Konis, Mack, and Schneider, 2018).

### **Daylight Metrics for MCI and Dementia Patients**

Daylighting has proved its positive effects on human health and well-being along with its significant role in sustainability and less energy consumption (Wong, 2017). As the number of aging communities increase, designing for the elderly and patients suffering from

MCI becomes a prerequisite for the demands of the future. Regarding the previous section of this paper, the effect of daylight on MCI patients on circadian rhythms has demonstrated positive impacts, however, one must fully understand the required daylighting/lighting metrics needed to design for MCI patients and the possible differences that exist when comparing them to healthy individuals.

One of the main issues with MCI individuals is aging eyes which function differently from healthy younger people. The image projected onto the eye reduces in both contrast and illuminance. Thus, people with MCI require increased levels of illuminance, brightness, and contrast within the space they are using to compensate for the retinal dysfunction. On the other hand, discomfort glare which tends to increase with age along with the adaptation time needed from dark-to-light and vice versa needs to be taken into consideration (Torrington, Tregenza, and Noell-Waggoner, 2007). MCI and aging individuals need light exposure within a space to be as much as five times greater than younger people (Brawley, 2001). This includes the increasing of illuminance values and brightness levels.

Additionally, bright light therapy has been suggested by several researchers to study the effect of lighting whether daylight or artificial light on individuals with various types of dementia including the early stages of it as MCI. A study consisted of a 1-week adaptation session, a 1-week pretreatment and a 4-week treatment session with bright light therapy resulted in demonstrating that individuals with early and mild stages of dementia as MCI who are exposed daily to bright light at 3000 lux from 9-11 AM showcase improvement in their circadian systems and cognitive functions (Yamadera et al., 2000).

Another study on the effect of bright light and the use of melatonin as a supplement on cognitive and noncognitive functions with elderly residents of a group care facility examined the effects of up to 3.5 years of a daily supplement of light and/or melatonin and its effect on patients with various types of dementia. Lights were on daily between 9 AM till 6 PM with illuminance values higher than 1000 lux measured before the eyes in the gaze direction. The study resulted in illustrating that the simple increase in illuminance values improved circadian rhythms. Even with the supervised intake of melatonin, it has proven no change in their health without including bright daylight (Riemersma-van Der Lek et al., 2008). Accordingly, the application of 2000-3000 lux source of light could be considered adequate for stimulating circadian rhythms after exposure of 1-2 hours daily (Alparslan, Ozkaraman, Ozbabalik, & Colak, 2019).

However, it is important to acknowledge that research has shown that the human circadian system is mainly sensitive to short-wavelength light and that it has a direct effect on melatonin levels (Thapan et al., 2001). It has been proven that short-wavelengths between 440-nanometer (nm)- and 500nm have the most effect on melatonin suppression by light (Rea et al., 2005). Accordingly, a study investigated the effect of a tailored lighting intervention of low-level “bluish-white” lighting during daytime in 14 nursing home resident rooms for individuals with AD and related dementias suggested that; the use of 300-400 lux of a bluish-white light to have a direct effect on circadian system (Figueiro et al., 2014). Though this study does not use daylight as the main source of light, the results could guide future integration between daylight and artificial light to produce enhanced design metrics and solutions while decreasing the high-intensity requirements needed for illuminance.

### **Lighting Metrics which Simulate Circadian Rhythms**

The circadian system of the human body is kept in sync with the amount and intensity of light exposure. A different type of photoreceptors in the human retina known as Intrinsically Photoreceptive Retinal Ganglion Cells (ipRGCs), has been increasingly acknowledged through the general interest of researchers to study and analyze the non-visual effects of light in human circadian systems (Konis, 2017). These photoreceptors have the highest photosensitivity to light with wavelengths within the range of 447-484nm (Ewing, Haymaker, and Edelstein, 2017). Several researchers have been studying metrics to measure the biological effect of light to quantify it. Accordingly, the Equivalent Melanopic Lux (EML) was proposed by Lucas et al as a measurement of light’s effect on the circadian systems. They provided a toolbox which analyzes the EML for each five photoreceptors in the eye (Cyanopic, Melanopic, Rhodopic, Chloropic, and Erthyropic) for certain spectrums (Lucas et al., 2014) (Lucas et al., 2013).

Despite limited research available concerning the minimum requirements for daylight access in buildings to support circadian entrainment, the International WELL Building Institute has developed a building certification system that provides minimum requirements for circadian lighting design (Konis, 2017). The WELL standards for circadian lighting is divided into four parts; the first part states that workspaces should have around 200 EML or higher to achieve circadian entrainment. On the other hand, part two indicates EML values of 200 during the daytime and 50 during nighttime in all living environments such as bedrooms, bathrooms, or rooms with windows. Thirdly,

an average of 250 EML should be provided in break rooms serving restaurants or hospitals. Lastly, the requirements of EML within learning environments range between 125-150 depending on the age of the users and the function of space (International WELL Building Institute)

Accordingly, researchers have been investigating and working on improving circadian design metrics. However, the gap remains clear with the lack of lighting metrics for circadian entrainment regarding people with certain types of impairment, such as MCI and dementia.

### **Daylight Challenges for MCI Eye**

#### **Complications**

The use of daylighting/artificial lighting has many benefits, however, there could be unintended complications occurring because of high illuminance values. Design parameters such as visual comfort, glare, brightness, contrast, and adaptation from indoor to outdoor or vice versa should be considered when designing indoor spaces for MCI patients.

#### **Glare**

Glare experiences are one of the most unwanted outcomes of natural lighting in indoor spaces. Thus, when designing for MCI patients the avoidance of glare becomes a prerequisite. Direct and indirect glare from windows causes problems amongst MCI and aging individuals creating discomfort and visual dysfunction (Brush, Meehan, and Calkins, 2002). Glare is typically divided into disability glare and discomfort glare whereas; disability glare is the lack of a person's ability to see a certain object in a scene due to glare interfering with visual performance and tasks, on the other hand, discomfort glare is the premature tiring of the eyes due to glare which might not interfere with visual tasks and is often accompanied by discomfort only (Hensen and Lamberts, 2012). As a result of the high illuminance values needed to improve the overall visual performance of MCI patients as mentioned before, balancing and diffusing daylight might become a priority within the space. A study on lighting solutions for contemporary problems of older adults suggested that to avoid glare caused by the high contrast ratio between daylight and dim interior light is to bring daylight within the space from several directions. This could be achieved by adding several windows or skylights allowing the light to balance out within the space avoiding concentration of glare in one direction. However, in some cases, the use of ambient electrical lighting might be needed to improve the overall experience of lighting within the space (Noell-Waggoner, 2004). Glare should be controlled without eliminating the admission of daylight within the space. Façade systems that reduce glare

effects include the addition of blinds and screens that are easily controlled from places near the patient as his/her bed are also crucial when using daylight in facilities and homes of MCI and dementia patients (Van Hoof et al., 2010).

Daylighting is considered a vital parameter when designing for MCI patients. A well- designed system should typically provide the occupants with sufficient daylight to promote their circadian systems, perform their daily tasks, provide glare control, provide a view to the outside world, and generally save energy and control heat (Day et al., 2019). This research aims to provide daylighting design guidelines for spaces that cater to MCI individuals using a simulation- based investigation.

## **METHODOLOGY**

An experiment was designed and conducted using quantitative methods of analysis. The goal is to investigate the performance of a representative nursing and care homes standard design, as recommended by the Neuferts Architects' Data edition book for architectural standards (Neufert, 2012). This edition provided several design standards of a typical bedroom for one or two elderly individuals. However, in this experiment, the typical room with one bed only is investigated. Figures 1 and 2 demonstrate the typical arrangement of furniture and design parameters of the bedroom. The clear height between the floor finish to the ceiling is assumed to be 4 meters and the window dimensions are based on the bedroom depth as mentioned in the standard. Since the room depth is  $\leq 8$  meters, the window size should be 16-20% of the total room area which creates a window of 2.8 meters in width and 2.7 meters in height. The location was assumed to be Atlanta, using Hartsfield International Airport, GA, USA, TMY3 climate file.

### **Methods and Metrics**

Two different daylight design metrics are considered. These metrics are defined by the literature review as mentioned before: Point-in-time illuminance, and Glare. Each metric is assigned thresholds based on the review, and daylighting simulations are conducted at two points in the investigated space. The first point (A) is at the head of the bed and the second point (B) is at the armchair (Figure 1). Simulations are undergone using DIVA for Rhino in Grasshopper (Jakubiec & Reinhart, 2011), and Climate Studio (Solemna, 2020). These simulations are run annually for assumed north and south window orientations.

In this experiment, point-in-time illuminance and glare are analyzed based on the existing literature which states that space with illuminance values varying between 2000-2500 Lux are considered as adequate amount of daylight to entrain circadian rhythms in elders

and MCI individuals (Yamadera et al., 2000) (Riemersma-van Der Lek et al., 2008). The goal is to provide recommended exposure for 1-2 hours per day that entrain circadian rhythms (Alparslan, Ozkaraman, Ozbabalik, & Colak, 2019).

In addition, glare should be non-existent or minimized as much as possible to avoid any visual discomfort. Thus, the ideal state assumed would be a minimization of the Daylight Glare Probability (DGP) metric, which indicates the minimal effect of glare within a space when it is “imperceptible” (Weinold & Christoffersen, 2006).

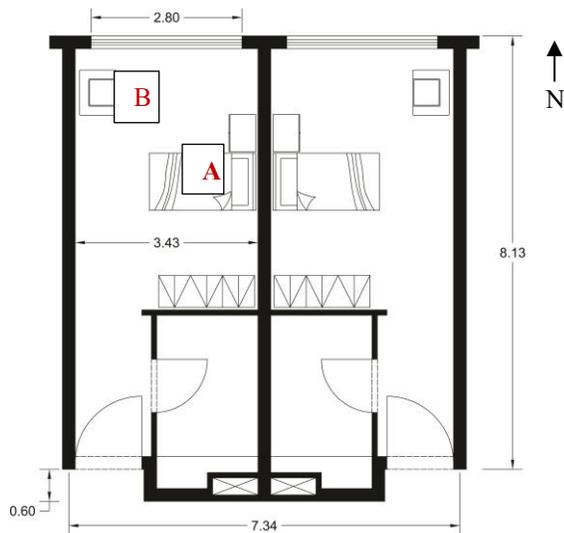


Figure 1. Neufert's Standard One-Bedroom; Nursing and Care Home Design



Figure 2. Neufert's Standard One-Bedroom, Interior View

## RESULTS

The results of this experiment follow the two reviewed metrics: Illuminance, and DGP. Each metric is analyzed to identify the times at which daylight within the space is considered adequate.

### Point-in-Time Illuminance

As shown in Figure 3, with the window facing the south orientation, the number of days in each month that

include 1 hour of illuminance values between 2000-2500 lux is considerably higher than the optimum option which is 2 consecutive hours at both point A and B. Values above or below the proposed threshold are excluded. In addition, Figure 4 shows that the north orientation lacks illuminance values that fall within the proposed threshold. It shows that point B could be the only recommended location for minimal daylight exposure for less than 2 hours.

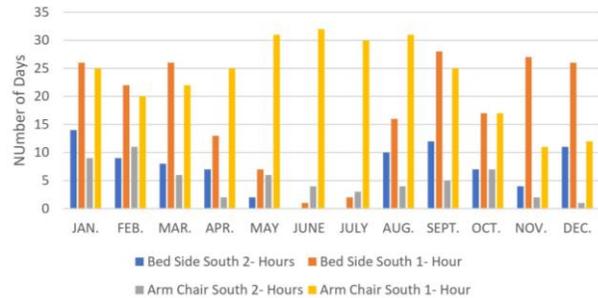


Figure 3. Annual Point in Time Illuminance- Glazing facing South Orientation- Days that achieve 2000-2500 lux for 1-2 consecutive hours



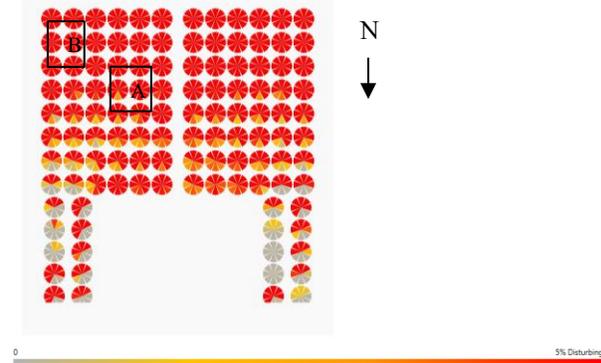
Figure 4. Annual Point in Time Illuminance- Glazing Facing North Orientation- Days that achieve 2000-2500 lux for 1 hour

### Daylight Glare Probability (DGP)

Annual DGP is simulated using Climate Studio to indicate the ranges of glare for both cases of south and north directions at points A and B. As shown in Figure 5, glare is considered an issue when the window is facing the south orientation. The whole room suffers from 73.6% of disturbing glare percentages over the year for more than 5% of time. It is shown in Figures 6, and 7 that point B suffers from intolerable glare most of the time across the year, unlike point A which has perceptible glare percentages during the summer months.

On the other hand, Figure 8 shows the annual DGP of the north orientation, indicating that disturbing glare only occurs 18.2 % of time which allows higher comfort in the space. It is shown in Figures 9, and 10 that Point B suffers from perceptible to intolerable glare during the

summer months, unlike point A which is considerably comfortable throughout the year with minimal glare.



sDG (% views with Disturbing Glare > 5% of Time)

Figure 5. Annual Glare- Glazing Facing South Orientation at points A and B.

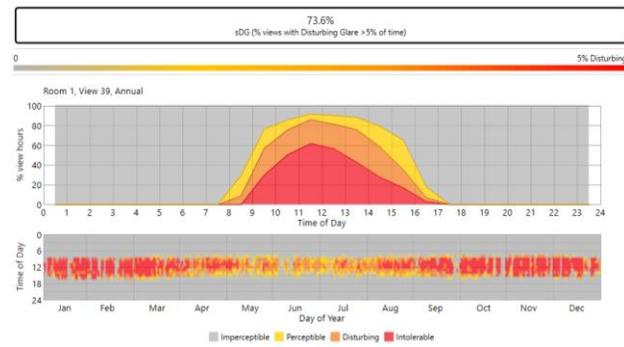


Figure 6. Annual Glare Schedule at Point A- Glazing Facing South Orientation.

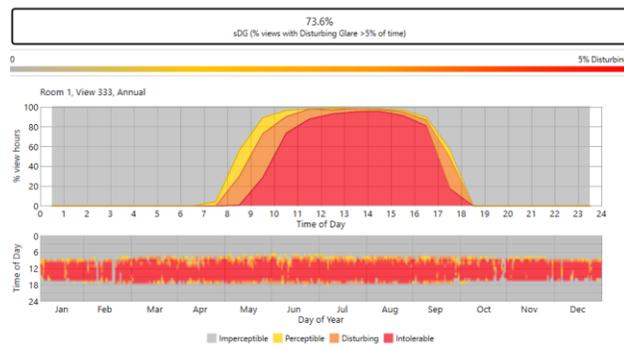
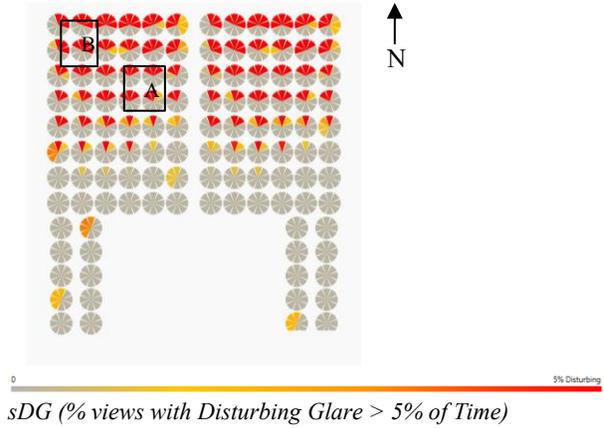


Figure 7. Annual Glare Schedule at Point B- Glazing Facing South Orientation.



sDG (% views with Disturbing Glare > 5% of Time)

Figure 8. Annual Glare- Glazing Facing North Orientation at points A and B

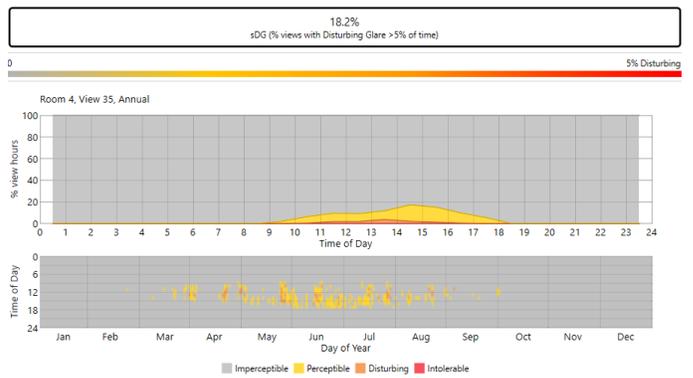


Figure 9. Annual Glare Schedule at Point A- Glazing Facing North Orientation.

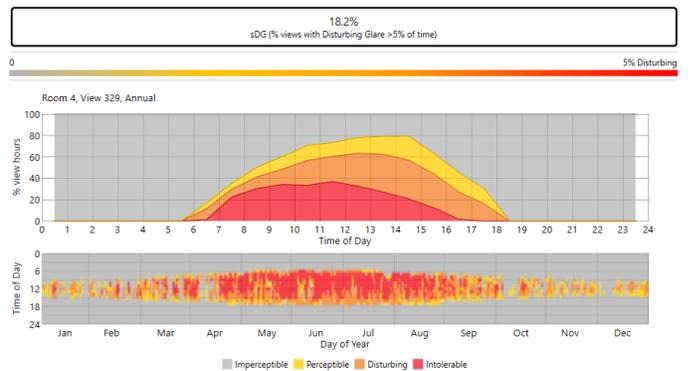


Figure 10. Annual Glare Schedule at Point B- Glazing Facing North Orientation.

## DISCUSSION

This paper presented a brief understanding of the available research regarding lighting metrics needed for circadian entrainment for individuals with MCI. Though

it acts as a piece of the puzzle to complete the needed research in this field, it remains in need of development and advancement to provide a further detailed design framework.

The experiment undergone in this paper provides an initial understanding and analysis of one standard room. Annual point-in-time illuminance is analyzed with windows facing the north and south directions. However, this analysis is limited to two points in the standard room and does not include options for windows facing other orientations.

Though the annual illuminance values occurring at both points A and B demonstrate that a one-hour exposure of adequate daylight would be the proposed option given that two hours exposure might not be available at most times of the year, it could be used in future design recommendations to predict when lighting need to be increased over the year.

However, this experiment does not include the effect of higher or lower illuminance values. Also, it does not include the addition of electrical lighting that could work together with daylighting to compensate for the hours where the daylighting is in-adequate.

In addition, this investigation showcased possible glare issues and challenges. Though the south orientation receives most adequate daylighting illuminance values, it still suffers from high disturbing glare percentages over the year which is not treated in this paper. This is considered an alarming situation which requires specific design measures to be taken into consideration. The recommendation would be to extend the research facing the south along with eliminating glare issues without compromising the daylighting illuminance values reaching the room. The north orientation could be proposed for spaces that do not need to entrain circadian rhythms or that could have an enhanced daylighting experience benefiting from the minimal glare.

This experiment is limited only to the investigation of one architectural standard room. Therefore, to provide a variety of design options and criteria, it is recommended that the experiment expands to include different design standards from various sources other than Neufert's standards along with investigating these standards in different locations across the world which could benefit in providing a larger span of design recommendations and understandings. It is also recommended to expand the investigation to include human behavior which could have a great impact on the space design and furniture layout based on the users.

Generally, this paper along with the experiment included is considered as an initial phase of investigating daylighting criteria needed for nursing and care homes designs for individuals with MCI.

### EML as an Evaluation Metric

Based on the literature review indicating that illuminance values between 2000-2500 lux is considered as an adequate value that entrains circadian rhythms, a follow up experiment is discussed as a trial of the north orientation to test the relevance of EML as a metric. The software ALFA was used to test out the existence of 450-500 EML in the standard room when illuminance values are at 2000-2500 lux. The analyzed time frame is during June, September, and December 21<sup>st</sup> starting from 7 AM till 6 PM.

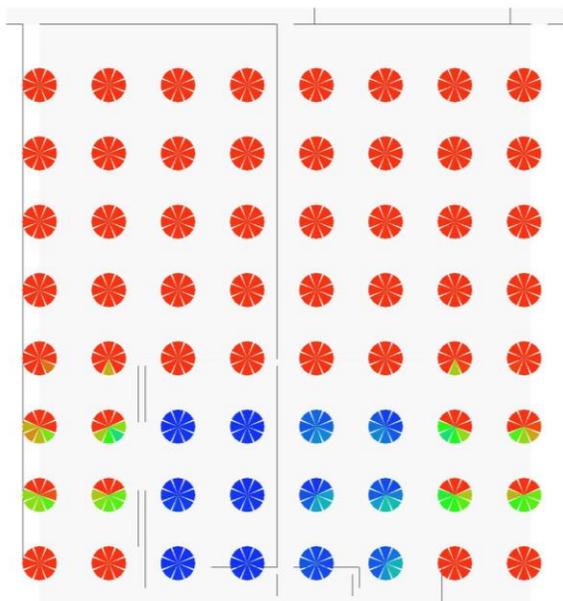
Table 1 shows that both points A and B indicate EML levels above 450 EML at most times of the day in select simulated seasons.

Figure 11 shows an example grid system that was produced by ALFA. This grid divides the required plan/space into points with 360-degree directions. Each point uses the legend to show the values ranging between 0 to 450 EML. Figure 11 is an example of the simulation output for each time of day during two different months.

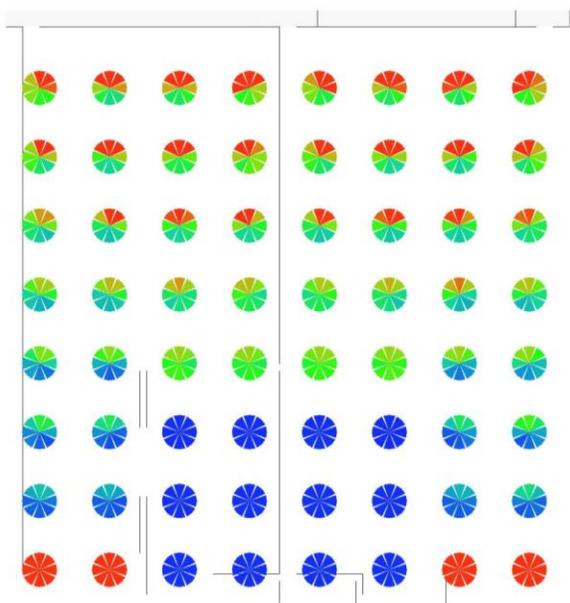
Based on this analysis, the percentage of views above 450 EML within the space is considered adequate at most times of the day on the 21<sup>st</sup> of June, September, and December. Percentage values range from 0 – 75% of views above 450 EML across the whole bedroom and not only at points A and B. This is considered as a positive indication of alertness within this standard bedroom which proposes that the dependence on illuminance values between 2000-2500 lux could be adequate to test the existence of proper EML values within a space. Thus, further testing of the south orientation was un-necessary.

*Table 1. Equivalent Melanopic Lux (EML) – Glazing Facing North Direction- Indicator of Existing Range of EML within 450-500 EML at Points A and B*

	Point A – At Bed			Point B – At Armchair		
	June	Sept.	Dec.	June	Sept.	Dec.
07:00	√	x	x	√	√	x
08:00	√	√	x	√	√	x
09:00	√	√	√	√	√	√
10:00	√	√	√	√	√	√
11:00	√	√	√	√	√	√
12:00	√	√	√	√	√	√
13:00	√	√	√	√	√	√
14:00	√	√	√	√	√	√
15:00	√	√	√	√	√	√
16:00	√	√	√	√	√	√
17:00	√	√	x	√	√	x
18:00	√	x	x	√	x	x



June 21<sup>st</sup> 8 AM



December 21<sup>st</sup> 8 AM



Figure 11. Percentages of Views between 0-450 EML on June and December 21<sup>st</sup> at 8 AM.

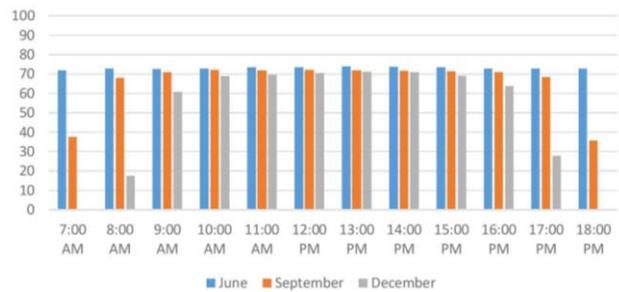


Figure 14. Percentages of Views above 450 EML

## CONCLUSION

The effect of daylighting on health and well-being has been promoted through various research, all in support of its direct effect on circadian systems in human beings affecting sleep, alertness levels, and mood changes. This research focuses on the effect of daylight on people with MCI and the required metrics needed to entrain circadian rhythms. As assumed by the research, these metrics include point-in-time illuminance ranging between 2000-2500 lux, DGP experiences, and EML values at 450 or above.

According to the literature review, it can be inferred that individuals with MCI who are exposed to adequate daylight for a minimum of 2 hours per day should have a functional circadian system that acts towards the improvement of their overall health.

This paper provides general design considerations that should be studied when designing for the elderly given that their eyes function differently from younger individuals.

Though the experiment showcased positive results for a standard nursing home space that demonstrate the experience of adequate daylight values throughout certain times of the day in select simulated seasons, it still needs further development. However, based on the investigation, it is recommended that designing similar nursing home spaces and rooms should avoid orientations that minimize solar access, such as the north direction in a northern hemisphere. This is due to lack of sufficient lighting values that enter and reach the space to entrain circadian rhythms. On the other hand, direct solar exposure is highly recommended for creating well daylight spaces that entrain circadian systems, such as in the south orientation in the northern hemisphere. Especially with designs that eliminate glare experiences. Accordingly, one can induce that each orientation comes with challenges and possibilities. Thus, future investigation should include different locations and orientations of a tested building, along with design for solar control and addition of human behavior as a factor affecting design recommendations.

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