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# The Influence of Light in the Built Environment to Improve Mental Health Outcomes

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THESIS

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**Abstract**

Current mental health statistics for United States active duty and Veteran military members justify research into the causes and remedies for those plagued with negative mental health outcomes. Recent research suggests the built environment might be connected to our mental health. This study investigated this connection with active duty and Veteran populations across the US. A literature review was completed on the factors of light in the built environment that affect mental health outcomes. According to the current academic literature, bright light therapy, daylight, windows, and full-spectrum fluorescent lighting are the light factors that positively influence mental health outcomes. A statistical analysis of surveyed active duty and Veteran populations' mental health symptoms compared to the natural light rating in their residence was completed. This analysis found that the natural light in the residential built environment had a positive mental health impact on the surveyed active duty population. The results of a trend analysis comparing residential natural light, general health, and emotional well-being saw as the self-reported residential natural light rating decreased, the general health and emotional well-being also decreased. Finally, application of the results and the costs and benefits of designing and implementing built environment changes are discussed for positive mental health outcomes for military personnel.

**Acknowledgments**

First and foremost, I would like to thank my wife and my daughter for putting up with the long nights and days of research and writing. I would like to express my sincere appreciation to my faculty advisor, Lt Col Andrew Hoisington, for his direction and support throughout the course of this thesis effort. The insight and experience was certainly appreciated. I would, also, like to thank my sponsor, Dr Lisa Brenner of the Rocky Mountain Veterans Association, for both the support and latitude provided to me in this endeavor. Finally, I would like to thank my committee, Maj Steven Schuldt and Dr John Elshaw for their guidance.

Nathanael T. Kohl

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# THE INFLUENCE OF LIGHT IN THE BUILT ENVIRONMENT TO IMPROVE MENTAL HEALTH OUTCOMES

## I. Introduction

### General Issue

In 2013, the World Health Organization released their Mental Health Action Plan increasing the global emphasis on mental health [1]. Approximately 13.3% of the United States (US) adult population was afflicted with 43.8 million cases of mental illness last year, and nearly 46.4% of the population will experience some mental illness within their lifetime [2]. Mental healthcare is considered a national issue given the above statistics and rates for negative mental health outcomes continue to rise [3]. According to the National Institute of Mental Health, 18 to 25-year-old adults suffer from mental illness at the rate of 25.8% compared to adults aged 26-49 years at a rate of 22.2% and adults aged 50 and older at 13.8%. The cost of care for mental health treatment reached $187 billion in 2013 [4].

Active duty and Veterans are not immune to the negative mental health outcomes and actually have an increased risk. For example, Veterans experience severe depression at a rate 20% higher than the national average [5]. To this date, nearly nine million military Veterans have sought mental health care through the Department of Veterans Administration (VA). The VA treated nearly 1.7 million Veterans for mental health symptoms in 2018 alone [6]. Additionally, nearly 30 percent of active duty military will develop some form of negative mental health outcomes after their time in service [7] and half of those will have inadequate healthcare [8]. Veteran mental health has been

thoroughly publicized through statistic of 22 Veterans a day that commit suicide [9], one and a half times the rate of adult US non-Veterans [10].

One issues that has not been thoroughly studied to date is the connection between the built environment and mental health outcomes. The built environment refers to the human-made environment used by individuals, and ranges from buildings to parks [11] [12]. Americans spend 82% of their time in the built environment [13]–[15]. A disconnect between time in nature and time in the built environment is likely due to urbanization. Fifty-five percent of the world's population lives in urban areas, a 25% increase in the last 70 years. The increase in urbanization results in additional time spent in the built environment and correspondingly less time in nature [16]. Due to the amount of time spent in the built environment, it is possible there might be a role for it to play in mental health. Specifically, one of the aspects of the built environment that may affects mental health outcomes is theorized to be light, both artificial and daylight.

Light in the built environment has been studied for its impact on office and factory workers, students, and hospital patients. Light therapy has been used in hospital and clinical studies to improve mood [17], reduce depression symptoms [18], reset circadian rhythms[19], and even slow the onset of Alzheimer's disease [20]. However, research is lacking on light in the residential built environment and the manner and role it may have in mental health outcomes.

**Problem Statement**

A previous study by engineers and psychologists of the Air Force Institute of Technology and the US Department of Veteran Affairs in Denver, Colorado researched

what aspects of the built environment can affect our health. That study concluded that the factors important to the built environment and mental health were indoor air quality, views of nature, light exposure, and the control of the individual's climate in the built environment [18]. The purpose of this study is to investigate the natural light in the built environment and how it affects the mental health of our Veterans and active duty military members.

**Research Objectives**

The research objectives of this thesis, providing understanding on how light in the built environments of active duty and military Veterans impacts their mental health, are as follows:

1. Identify aspects of light in current academic literature that influence mental health outcomes.
2. Administer the Housing, Occupancy, Materials and Environment (HOME) survey to active duty units across the US Air Force.
3. Analyze both the active duty and Veteran survey results to investigate the significance of light positively affecting mental health outcomes.
4. Recommend to military engineers the aspects of the built environment that can be adjusted to allow more light to enter the facility based on the findings from the previous two objectives.

**Way Ahead**

Due to the research being experimental, the thesis follows the scholarly format. Chapter 2, "Connecting Light in the Built Environment to Mental Health Outcomes, A Review," is a review of current academic literature of factors of light in the built environment that influence the occupant's mental health. This article is intended to discover the factors of light that positively affect mental health, providing a baseline comparison for chapters 3 and 4. Chapter 2 also includes a discussion on current research limitations and more pathways to future research. The target journal is *Journal of the Illuminating Engineering Society*.

Chapter 3, "The Influence of Residential Light on the Mental Health of U.S. Veterans and Department of Defense Personnel," provides details on Veteran and active duty survey results of their homes and any associated mental health symptoms. Self-reported surveys of active duty member's and Veteran's residences and a validated mental health questionnaire were analyzed for the impact of light on mental health outcomes. The HOME survey is a self-reported survey that was used to assess multiple factors of the built environment, but this study focused on response to the light related questions. The Veteran population of 210 and the active duty population of 229 was tested against the 36-Item Short Form Survey (SF-36) general and mental health questionnaire. The target journal for this paper is *Journal of Environmental Psychology*.

Chapter 4, "Shine the Light in the Built Environment to Improve Mental Health," presents to military engineers the lighting design of base housing and dormitory facilities for occupant mental health. The cost and benefit of these design changes is discussed.

These changes include the significant results from Chapter 3 for inclusion in Base Design Guides across the Air Force. Publication intention for this chapter is *The Military Engineer*. Finally, conclusions are presented in Chapter 5.

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# II. Connecting Light in the Built Environment to Mental Health Outcomes, A Review

## Chapter Overview

The purpose of this chapter is to provide a review of the current academic literature that connects light in the built environment to positive mental health outcomes. The target audience for this article is architects, engineers, and social scientists. The article highlights why this research is justified and how the built environment can influence mental health outcomes. The research is organized into the success of bright light therapy on mental health, how daylight affects mental health, and the aspects of artificial light that affect mental health. The article discussed these topics in detail and provides potential improvements that can be made to the built environment for positive mental health outcomes. The research concludes with a discussion of the current research limitations and opportunities for future research. This chapter provides the foundation for all subsequent chapters.

## Publication Intention

Title: Connecting Light in the Built Environment to Mental Health Outcomes, A Review

Publication: *Journal of the Illuminating Engineering Society*

**A Review on Light in the Built Environment and its Influence of Mental Health Outcomes**

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## ABSTRACT

With an increased awareness of public mental health issues, more investigation is warranted in the mechanisms of how the built environment may influence an individual's mental health. Known built environment influencers are connection to nature, natural lighting, ability to control your own climate, and noise parameters. Specifically, light research has shown potential in reducing negative mental health outcomes, and lessons learned in that research may be informative in the built environment. For example, positive influences on mental health outcomes with the use of light has been shown with bright light therapy, bright light in the morning, low light in the evening, and exposure to natural light or daylight. Bright light in the morning and low levels of light in the evening reduces depression symptoms within a week. In contrast, bright light in the evening has an adverse effect on depression through modulation of individual's melatonin levels that alters the natural circadian rhythm affecting mood, sleep, and mental agility. The excretion of melatonin in individuals can be suppressed by light when its intensity exceeds approximately 2500 lux. In addition to the intensity, individuals are affected psychologically by the different spectrums of light. Artificial lighting does not usually

contain the full spectrum (daylight fluorescent) lighting recommended for positive mental health outcomes, although full spectrum fluorescent lights contain the necessary color spectrum for positive mental health outcomes. Due to the rise in urbanization and time in the urban built environment, architects and engineers may need to consider optimizing the built environment to include proper light exposure influencing positive mental health outcomes. Prior to design and modifications, it is recommended that controlled studies are conducted to target specific light parameters and their relation to mental health outcomes,

## INTRODUCTION

Mental health and architecture have received more attention in recent years, as evident by a search of the terms “mental health” and the “built environment” starting in 1997 (Science Direct), and 99% of the articles have been published since 2002 (Scopus). The built environment refers to the human-made environment used by individuals, and ranges from buildings to parks [1], [2]. Pre-2000, research on the built environment focused on the aspect physical health as a response to poor health conditions in the urban built environment [3]–[5]. More recently, researchers have shown the built environment may have positive and negative impacts on the mental health of individuals. Factors important in that research have been hypothesized to be indoor air quality, views of nature, light exposure, and the ability of individuals to control aspects of the built environment [6].

Americans spend approximately 82% of their time in the built environment [7], [8], yet still another 13% increase in urban growth is expected within 30 years [9]. Fifty-

five percent of the world's population live in urban areas, a 25% increase in the last 70 years [10].. The rise in urbanization resulted in more time spent in the built environment and less exposure to nature [11]. It has been found that being confined indoors for extended periods of time leads to negative mental health outcomes [12]. Past research has not thoroughly studied the impacts of the built environment on mental health. According to Health in All Policies (2006), the urban built environment is a significant factor to both physical and mental health. In 2013, the World Health Organization released their Mental Health Action Plan, increasing the global emphasis on mental health, stating that the built environment should be studied for its impact on mental health [13], [14].

Negative mental health outcomes including depression symptoms (such as Seasonal Affective Disorder, major depression, and Bipolar Disorder) which impacts 5-8 % adult Americans each year [15]–[18]. In 2017, 47,173 suicides were reported in the United States and 50% of them were people diagnosed with severe depression [15]. One US population is at a higher risk to negative mental health outcomes, however. Military Veterans suffer negative mental health outcomes at a rate of 20% higher than the national average [19]. Two million veterans received mental health treatment from the U.S. Department of Veterans Affairs from 2006 through 2010 [20], and the built environment may have an impact on assuaging negative mental health outcomes.

Many aspects of the built environment have an unknown impact on the mental health of the occupant. Four of the factors of the built environment that are known influencers of mental health outcomes are a connection to nature, natural lighting, ability to control your own climate, and noise parameters [11]. Edwards and Torcellini (2002)

concluded the design process of the built environment should consider psychological and physiological well-being of the occupants. Designing the built environment is a difficult process because the relationship between the individual and their built environment can change due to the individual's perception of their surroundings [21], [22]. The built environment impacts each occupant differently base on their own preferences.

The built environment provides a space of protection from the elements, yet occupants need to retain some connections to the world outside. Inclusion to the outdoors in the built environment can be achieved with natural light (daylight), windows that allow daylight, and full-spectrum fluorescent lighting. The distribution of daylight can be separated between light required for visual activity and the how the light affects the occupant of the built environment both physically and mentally [23]. When daylight is not available, full-spectrum bright lights have been shown to also have a positive effect on built environment occupants [24]. Daylight and full-spectrum (lighting that covers the full color spectrum) artificial lighting are suggested for rehabilitation and relaxation, reducing stress, and improving mood, thereby mitigating negative mental health symptoms [25].

The purpose of this paper is to review on the effects of light in the built environment with regard to mental health outcomes. Light has been connected to positively affect eating disorders, depression, circadian rhythm, Alzheimer's disease, sensory stimulation, therapeutic design, and therapeutic patient rooms [1], [26]–[33]. For this reason, daylight and full-spectrum fluorescent lighting are linked to rehabilitation and the ease of mental health symptoms [25]. Through each of the lighting features, this paper

seeks to find the effects of light that can be used to treat those affected with mental health issues. This paper will focus on the integration of natural and artificial lighting into the built environment, which has the potential to decrease the rates of depression and suicide [30].

## KNOWN RELATIONSHIPS BETWEEN LIGHT AND MENTAL HEALTH

### Circadian Rhythm

Circadian rhythm, or sleep/wake cycle, is a 24-hour internal regulation of physiological processes that cycles between sleepiness and alertness at regular intervals [34]. External factors influence the circadian rhythm, like light absorbed by the eye that controls the production of the hormone melatonin, influencing both mood and sleep levels [22]. Bright light can suppress nighttime melatonin production, but standard indoor lighting does not have the same impact. In order to suppress nighttime melatonin, light must be above 2500 lux [35] and exposure between 4 and 7 p.m. [36].

A disrupted circadian rhythm occurs from abnormal light exposure, especially with light exposure at the wrong time of day [37]. The disruption of the circadian rhythm for an extended period of time causes further damage to said individual's psyche [38]. Using bright light to keep the individual alert and low light to help the individual get ready for sleep can assist the circadian clock natural rhythm [39]. In contrast, poorly timed light exposure and intensity of light will disrupt the sleep-wake cycle, which happens in some latitudes in the winter [40]. Seasonal Affective Disorder (SAD) where lower light levels in the winter months (or in the extreme locations 24 hours of night/day) cause individuals to have symptoms of depression and a disrupted circadian rhythm [38].

Proper intensity and timing of light can help assuage the symptoms of SAD and reset the circadian rhythm.

The use of properly timed light exposure could prove to be an invaluable therapeutic tool for the improvement of sleep quality and the circadian rhythm [38]. Sleep quality is a complaint in 15-35% of the adult population [41]. Most cases complain that falling asleep or staying asleep are their main challenges [42]–[46]. Sleep quality complaints are particularly relevant to mental health because the lack of sleep causes a reduction in alertness and cause negative moods [47]. Adults complain that the reason they have sleep issues is due to anxiety and stress, although insomnia related to mental health disorders are common [48]. Sleep quality disturbances are also a common issue in depression and Post-Traumatic Stress Disorder (PTSD) [41]. In the early 20$^{th}$ century, the human circadian system was thought to be insensitive to light, with synchronization to the 24-hour day accomplished either through social contacts or the sleep-wake schedule [49].

**BRIGHT LIGHT THERAPY**

The use of bright light therapy has shown positive mental health results [1]. A successful use of light for improving mental health has been documented through bright light and the circadian rhythms within individuals [31], [35], [50]. Additionally, mood can be improved through bright light [51]–[53]. Lewy (1987) observed best results when bright light was administered immediately upon awakening and above 2500 lux [54]. Morning light was more affective at reducing depression levels than evening light, but if the individual was given dosages of bright light both morning and evening, the

depression levels either increased or remained the same compared to before the study[55]. Indeed, evening exposure to bright light only had moderate positive affects to positive mental health outcomes [56], [57]. The bright light exposure in autumn and winter was not as effective as in spring and summer [47]. Buresova et al. (1991) studied the effect of a single exposure to bright light and the individual's circadian rhythm, observing clinical maximum impact early in the morning [59].

Benedetti et al. (2001) found that a bright light therapy session in the morning decreased the length of hospitalization in those suffering from bipolar depression [58]. Using bright daylight has been so successful that hospital environments, as a part of the patient care program, now utilize it to help speed along recovery by improving attitude and sleep/wake cycles [22]. In the mental health wing of an Alberta hospital, Bright morning light reduced the average hospital stay 3.67 days [58]. Bright light increases vitality even in healthy patients [53]. Less time in recovery reduces suffering and fewer drugs administered to the patients [66].

Poor sleep quality can be mitigated through bright light therapy sessions to reset the circadian rhythm [56], [57]. A single pulse of bright light in the early morning advanced the circadian rhythm by one cycle, roughly two hours. A single bright light exposure in the early morning may shift melatonin secretion by as much as 2.6 hours earlier [59]. The circadian pacemaker may be phase-advanced by a single bright light exposure in the morning [62]. Several individuals with SAD were shown to have improvement in their symptoms when they were exposed to bright light from 6 to 9 a.m. [36]. This caused their melatonin levels to rise an hour earlier than the control week [63].

Although short bursts of bright light therapy works to ease SAD symptoms, other forms of light such as daylight and full-spectrum lighting, are better suited for long-term exposure in the built environment [35], [38], [58]. Bright light therapy may be able to affect more than just SAD, studies have shown that it can positively affect Bipolar Disorder as well [64]. Each individual that has successful treatment with the natural process of bright light therapy were able to reduce anti-depressant prescriptions [51], [65]–[67].

## IMPACT OF LIGHT ASPECTS OF HEALTH AND PERFORMANCE

Research on the impact of light in the built environment began nearly 100 years ago [68]–[70]. The first studies were conducted to assess the relationship between light and worker performance [71]. Edwards and Torcellini (2002) investigated daylighting and its effects on the occupants. The study found that inclusion of daylight had positive outcome on the attitudes of the workers. Daylight, that is light in the built environment from the sun, and proximity to windows positively affected individuals [12]. Light in the built environment is a factor on mood and alertness but it has not been thoroughly studied [72]. The amount of light exposure in the day has been correlated to quality of life, social functioning, satisfaction with life, and emotion well-being [73].

One area that has been thoroughly studies with light is its impact on productivity and the psychology of workers [68]–[70]. Employees self-report that the daylight was the most effective in prompting attitude change toward the working environment compared to the artificial lighting [74]. Job satisfaction and intention to quit are lowest

with those that had the greatest amount of daylight passing through their windows. This suggests that windows were not just a preference for their workers but a significant impact on their psychological well-being [75]. Further studies found that by increasing daylight, productivity and morale soared and workplace accidents were reduced. Changes in performance are due to improved color rendering and better safety for workers from the increased intensity of light. These studies gave clear evidence that the amount of daylight has a direct positive influence on performance. However, daylight can reduce productivity and increase employee absenteeism due to the possibility of extremely high lighting levels, excessive glare, and high temperatures [76]. Light can also have negative effects on mental health to include irritability and task performance through glare and thermal discomfort [77].

## DAYLIGHT AND MENTAL HEALTH

Mankind has depended on daylight for illuminance since the beginning of time, but only recently did research begin to notice that the quantity of daylight can affect mental health outcomes [78]–[81] [12]. The quantity of exposure to higher illuminance levels activates photoreceptors in the eyes that control behavior, improve mood, and physiology [62]. Illuminance levels above 1000 - 10000 lux at the eye decreases fatigue improving mood and behavior [47], [84], [90]. Daylight has a color temperature range of 5000 – 10000 K depending on sky conditions, season, and time of day [85]. Smolder et al. (2013) reported participants had higher vitality, improved mood, and improved self-reported sleep quality when they had experienced more daylight. Daylight contains the

entire color spectrum of light, but the blue portion of daylight encompasses 50% of the spectrum, making daylight the preferred light to use to have positive mental health outcomes [86]. Daylight exposure was not significantly affect feelings of tension, positively or negatively [87][12].

Daylighting has also been linked to positively influence eating disorders, depression, circadian rhythm, and stimulating the body for patients for quicker healing in hospital recovery rooms [78], [88], [89]. Daylight lowers stress levels, increases productivity, eliminates noise and flickering from electric light sources, provides the best quality of light available, eases the stress on the eyes, leads to increased information processing and learning ability, enhances the mental capacity of the individual [22], [78], [91], [92]. For example, students with Attention Deficit Disorder were calmer with daylight instead of artificial light, in part due to noise reduction of the fluorescent lights, and in part due to the calmer feel to the classroom [93]. Daylighting in building interiors is currently based on average local availability of real sunshine and its distribution throughout the day [12]. The distribution of light is connected to the mental health of those who are in close proximity to the source of light [76], [93]. Daylighting is the best source of light for mental health and is generally the cheapest source of light [12], [22], [86], [94], [95].

Mehrotra et al. (2015) observed that daylighting in a hospital was vital to the recovery of patients, the comfort of visitors, and the care provided by the hospital staff [26]. Verderber (1983) showed that daylight can reduce the stress of patients, doctors, and nurses [96]. Heart attack patients in a cardiac intensive-care unit, treated either in

sunny or dull rooms, found patients stayed for a shorter time in sunny and brightly lit room versus dull rooms [66]. Federman et al. (2000) observed that patients with the Veterans Health Administration (VA) stayed approximately 12 days less in brighter daylight areas [97]. Sunny hospital rooms in Alberta, Canada were studied to see if they had any influence on the expedition of recovery from severe depression [66]. After the Canada study concluded it was found that daylight contributed to lower recovery time in the hospital. The female patients in daylit rooms left an average of 16% faster, with males leaving even quicker at 32% than those in dull rooms. The resulting data showing the decrease in time suggests that bright daylight can help ease the symptoms of severe depression. There is consistent evidence that shows the technical and architectural aspects of providing daylighting conditions in recovery areas of a healthcare facility are important [26].

**Windows**

The role of windows in the built environment is important the occupant's mental health [75], [98], [99]. Windows are openings for light an elements that influences the indoor environment and mental health [100]. Illumination from windows in the built environment both positive and negative effects on mental health outcomes [101]. Among the architectural or interior design characteristics that the occupants the built environment desire are the proximity of a window and the amount of daylight let in [102]. Windows and daylight are important to the psychological well-being of the office workers [103]. The occupant's desire for natural, rather than artificial light, and the effects of daylight are why windows are important to building occupants [98]. Windows are not an

architectural standard for all buildings, but research has shown that it has an impact on our mental health [26], [75], [78], [103]–[106]. The results of the Leather et al. (1998) study show that even within the environment of offices, workplace conditions influence employees' health and well-being. Daylight can have positive physical health outcomes, such as metabolizing vitamin $D_3$ and is essential to the regulation of calcium to the maintenance of bones and teeth, and most of the vitamin D in the bloodstream comes from the exposure to light [107]–[109].

Built environments that do not contain windows have provided sources of evaluation for the impact of daylighting. For example, factory workers in the first underground factory in Sweden had negative attitudes, complained of headaches, and fatigue [110]. In another windowless building, Pritchard (1964) noted that workers complained of claustrophobia and unhappiness, which caused depression in the workers to increased [22], [71]. Windowless classrooms are a specific built environmental that has been investigated on influence on student's physical and mental outcomes [94].

Four classrooms in one study included normal windows and warm light tubes, skylight and daylight tubes, windowless and warm light tubes, and windowless and daylight tubes [94]. Overall, daylight was found to have an effect on the body growth of children through light perception through the eyes influencing the metabolism of hormones in the brain [111]. In the normal windowed room, the students had the highest amount of natural hormones, such as cortisol, melatonin, and growth hormones, while the students in the windowless room and warm light room had markedly lower levels of the

same hormones. The students showed an increased ability to concentrate year round and were easily cooperative; students in the latter room the showed just the opposite [94].

The correct window design and size is important to the proper amount of daylight in a facility and maintaining contact with the outside world to influence positive mental health outcomes [112], [113]. The amount of light coming through the window, the position of the sun throughout the day, and the intensity of the light are factors that impact the minimum size of a window [114]. The amount of light penetrating the window is only a part of the desire for exposure to daylight [112]. The influence of the light from windows in a room depends on the length of the room and the location of the observer comparison to the window [114]. Window size does have an impact on mental and physical health suggesting that windows are necessary to improve mental and physical health outcomes [76], [115], [116].

Illuminance from daylight varies based on the window location in the facility [117]. The magnitude of the daylight coming through the window can be adjusted using blinds or a glare-reducing tint. The illuminance depends on the available daylight outdoors, external obstructions, glazing transmittance, interior geometry, and internal reflections [118]. The intensity of the light within a few feet of the windows may cause headaches and productivity loss [113]. The direction of light can help visibility within the facility by contrasting different surfaces. Illumination from the side causes more glare than light from directly above [119]. To introduce light from above, skylights can be installed to help the vertical flow of the light. Daylight from a skylight is mostly unobstructed from man-made obstructions, but skylights by themselves are inadequate to

properly illuminate a building [117]. If the skylight is used with a transmitting system using reflection (mirrors) or a hybrid system, the light reaches the far corners of the facility, naturally lighting the space, thus reducing the need for artificial light [120]. The daylight added throughout the facility through windows and skylights makes the workers job less stressful, keeping their mental health outcomes positive [113].

## ARTIFICIAL LIGHT AND MENTAL HEALTH

Artificial lighting supplements daylighting in the built environment [121]. Artificial lighting can be used as a supplement for a naturally lit room, but daylight is desired by the occupants of the built environment [122]. Light from windows generally comes from the side, while light form artificial sources generally come from above. A meta-analysis of literature on the spectral qualities of full-spectrum lamps used in light therapy studies found that there was no difference in lighting between daylight and full-spectrum fluorescent light [24]. The recent development of high-quality and long-life artificial light sources is comparable to the spectral properties of daylight, but is still not the most effective for positive mental health outcomes [117]. Daylight has lowered the depression levels in the severely depressed, but full-spectrum fluorescent lighting has not been tested for nonseasonal depression [66].

The increased use of artificial lighting has resulted in a rise of complaints from the occupants of the built environment [23]. The occupants are not complaining about the artificial lighting, but the emotional or psychological response to the built environment and the lack of natural light [23]. Ne'eman (1974) theorized that buildings need to be

designed to combine artificial and daylighting leading to the integration of both natural and artificial spectrums of light becoming a common process in modern construction. Permanent Supplementary Artificial Lighting of Interiors (PSALI) is an example of a combined design [23].The PSALI is the combination of artificial lighting and daylight to influence the occupants of the built environment. The working-functional lighting is provided by daylight and the artificial lights provide lighting where daylight cannot be used.

**Full Spectrum and Relationship to Health**

The full-spectrum lighting helped to treat sleep disorders and premenstrual dysphoria [123]. Improvements in productivity led to an increased level of mental performance, improved sleep quality, and increased morale among night-shift workers have been attributed to full-spectrum lighting [20]. Full-spectrum fluorescent lighting reduced SAD symptoms in the workers as well [124]. However, even with full-spectrum lighting covering the blue spectrum lighting, it does not fully substitute for daylight [22] [61], [125], [126]. Yet, for certain population groups such as chronically ill, the elderly, shift workers, and those living in extreme polar latitudes, artificial light might be the only available source for light [127]. Individuals reported that with full-spectrum fluorescent lighting, their mood improved and some occupants had fewer binge-eating episodes [128].

McColl and Veitch (2001) reviewed studies from 1941-1999 for evidence that full-spectrum lighting impacts physical and mental health [24]. The study found that full-spectrum lighting caused fewer headaches, reduced the incidents of epileptic seizures,

and reduced stress [129]–[132]. Full-spectrum lighting has been shown to be extremely important in improving an individual's mental health because of its similarity to daylight (see Figure 1 [133]). Positive changes in performance are due to improved color rendering and better safety for workers from the increased intensity of light and positive effects of light on the psychology of the occupants [22].

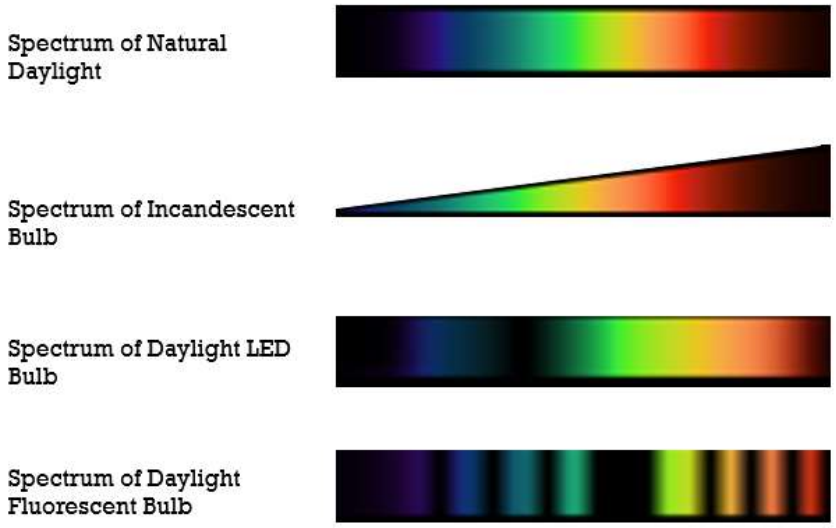


**Figure 1: Different Color Spectrum of Light**

Full-spectrum fluorescent lamps provide similar health-promoting effects in daylighting, productivity and moral soared, workplace accidents decreased, and hospitals saw a rise in patient healing. [134]–[137]. Full-spectrum fluorescent lamps are also stress-reducing. A study found that after 14 days of exposure to full-spectrum fluorescent lamps and 14 days of sunlight, the stress levels were the exact same; but exposure to cool white fluorescent lamps for 14 days after saw a rise in stress levels [111]. Cool white fluorescent lighting, like incandescent lighting, is in the red-yellow portion and provides low levels of light in domiciles [138]. Cool white lighting is found in most facilities, but

full-spectrum fluorescent lighting is not as common [139]. Energy-efficient lighting, such as LEDs, also lacks the blue portion of the spectrum that daylight and full-spectrum fluorescent lighting have [22].

**Brightness**

The brightness of light affects performance, mood, and mental health; if it is too bright, it can negatively affect building occupants [57], [58], [64], [127], [128]. The full-spectrum lamps emit light in all parts of the visual spectrum and has a color correlated temperature (CCT) of 5000k, which is equivalent to soft daylight. The recommended minimum lighting in the built environment for office work, personal computer work, or studying is 500 - 800 lux [95]. Light had an effect on school test scores and accidents decreased by as much as 50% when the lighting was increased from 161 to 1075 lux [71]. Interior lighting above 1500 lux for an exposure period of 12 hours can be harmful to the eye [140].

Being able to turn off the artificial lighting along the exterior walls and closing the window curtain can reduce the intensity of light, but the interior lights need to stay on to even out the distribution of light throughout the room. This can be accomplished with two series of lights in the offices space and a simple on/off switch to save on the cost of a sophisticated automatic dimming switch [113]. With properly installed and maintained daylight systems, designers can install an artificial lighting system that will help decrease the stress levels for office workers, help patients heal at hospitals, improve productivity, and increase safety of workers [22]. For a list of light brightness and its intended uses, please see Table 1.

**Table 1: Light Brightness and its Intended Uses (modified from Westinghouse Lighting** [141]**)**

| Color Temperature | Warm White | Soft White | Neutral | Cool | Soft daylight | Daylight |
|---|---|---|---|---|---|---|
| **Kelvin** | 2700K | 3000k | 3500K | 4100K | 5000K | 6500K |
| **Mood & Effects** | Friendly, Personal, Intimate | Soft, Warm, Pleasing Light | Friendly, Inviting, Non-Threatening | Neat, Clean, Efficient | Bright, Alert | Bright, Cool |
| **Applications** | Homes, Libraries, Restaurants | Homes, Hotel Rooms, Lobbies, Restaurants, Retail Stores | Executive Offices, Public Reception Areas, Supermarkets | Offices, Classrooms, Mass Merchandisers, Showrooms | Graphics Industry, Hospitals | Jewelry Stores, Beauty Salons, Galleries, Museums, Printing |

## RESEARCH LIMITATIONS

Understanding light in the built environment and its impact on the mental health of the occupant is still in its infancy. Research is positive in terms of light and mental health outcomes, but still has several limitations and are not fully understood. For example, more thorough research has been done to assess how light affects the physical and mental health in offices, hospitals, and other large gathering facilities, but the research fails to assess individual's mental health in residences. With the rising number of cases of mental health in our society, a greater effort to research how the built

environment affects the occupants is needed. Specifically, more studies of light in the residences need to be conducted in order to fully understand the complete impact on mental health.

Interior lighting designs have been studied and optimized for illumination and coverage areas, but the research fails to adequately optimize both interior and daylighting together for the treatment of mental health symptoms. The research detailed in this study does provide a starting point to design the built environment for individual houses, dorms, and other lodging facilities. This may be a possible solution to helping the millions of people in the world with from mental health issues. Architects, interior designers, engineers, and lighting designers all together can contribute to the reduction of the employee's psychological discomfort at work [102]. This research will help to understand what changes to the built environment need to be made in order to have positive mental health outcomes.

## CONCLUSION

Integration of natural and artificial light in buildings during daytime hours can be described as the holistic design process for the built environment. The integration process takes the positives and negatives of natural and artificial light into account in order to formulate the optimal design for that specific project [23]. A 1983 study investigated the processes, merits, and deficiencies of both natural and artificial light are considered in order to arrive at the optimal design for a specific project [113]. This optimal solution depends on the type of building, use of the facility, and local environmental factors. The

lighting aspect of the built environment is one factor that should not be overlooked during the design process. The quality of the visual built environment depends on illumination intensity, glare limitation, and reduced heat agitation. If both natural and artificial light are used to assuage the symptoms of depression, fewer patients should need prescription drugs. The studies above have shown that proper use of natural and artificial light in hospitals has helped patients with symptoms of depression leave the hospital sooner. With this indication, and the evidence from the studies conducted in offices, it can be assumed that proper lighting in the homes of the patients will help to either eliminate or shorten the period of admittance in hospitals. This may also play a factor in reducing the suicide rates across the United States and the world. Architects and engineers should use these considerations when designing and constructing housing for their clients. This could reduce the suicide and depression rates around the nation.

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# III. The Influence of Residential Light on the Mental Health of U.S. Veterans and Department of Defense Personnel

## Chapter Overview

The purpose of this chapter is to analyze the data gathered of Veteran and active duty residential built environments and how it is related to a psychometrically sound mental health measure. This data was gathered through partnership with the Rocky Mountain Illness Research, Education and Clinical Center (MIRECC), a survey administered to 210 Veterans and 229 active duty service members. The factors gathered from the surveys were compared to the SF-36 mental health measure. Correlation and ANOVA regression analysis was used to find statistical significance between the natural light rating in their residences and emotional well-being, social function, and general health. From this data gathered, possible design factors are studied in order to affect design changes for possible mental health outcomes.

## Publication Intention

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**The Influence of Residential Light on the Mental Health of U.S. Veterans and Department of Defense Personnel**

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## Abstract

Mental health of Veteran and active duty personnel has become an increasingly important issue in the last two decades. Veterans and active duty service members commit suicide at a rate of 24.8 per 100,000 individuals, nearly twice the civilian rate. Diagnosing mental health symptoms and assisting present and past soldiers has received considerable research, but little is known about the mechanisms of how residential light in the built environment affects mental health. This paper focuses on a joint research project between the Air Force Institute of Technology and the Department of Veteran Affairs to assess the built environment of Veteran's homes and associated mental health outcomes. The aim of this study was to determine: 1) measurements for analyzing the built environment in terms of mental health outcomes, and 2) developed a self-reported

survey to assess Veteran and active duty residential natural light quality. The survey included 210 Veteran and 229 active duty respondents. A literature review suggested that adequate natural light has a positive influence on mental health outcomes and may have the potential to mitigate negative mental health outcomes. Those respondents with lower emotional and social well-being also had lower levels of natural light in the home, indicating that natural light may increase the social and emotional states of the occupant. This analysis found that the natural light in the residential built environment had a positive mental health impact on the surveyed active duty population. The results of a trend analysis comparing residential natural light, general health, and emotional well-being saw as the self-reported residential natural light rating decreased, the general health and emotional well-being also decreased. Further studies between mental health medical specialists and building designers should focus on understanding the aspects of the built environment that can neutralize negative mental health outcomes.

**Introduction**

Military members serve their country and in the line of duty may face certain hardships. When they have completed their time in service, these military members are called Veterans [1]. Due to the unique nature of military service, Veterans can specifically have problems with negative mental health outcomes. For example, symptoms of major depression are 20% higher than the national average [2]. Overall, nearly nine million military Veterans have sought mental health care through the Veterans Administration (VA). In 2018 alone, over 1.7 million Veterans received mental health care. Research spending in the VA is approximately 1.8 billion every year for

mental health [3]. Additionally, thirty percent of active duty military will develop some form of negative mental health outcomes after their time in service [4] and half of those will have inadequate healthcare [5]. Health care providers and engineers are working together to help fill the unknowns for those affected with negative mental health outcomes.

The built environment refers to the human-made environment used by individuals, and ranges from buildings to parks [6] [7]. Americans spend 91% of their time in the built environment [8]–[10],yet still another 18% increase in urban growth is expected within another 30 years [11]. The increase in urbanization results in additional time spent in the built environment and correspondingly less exposure to daylight [12]. Studies concluded that people are deeply interested in nature and maintaining their connection to outside the built environment [13]. According to Health in All Policies (2006), the urban built environment may be a significant factor to both physical and mental health of individuals. In 2013, the World Health Organization released their Mental Health Action Plan increasing the global emphasis on mental health, stating that the built environment must be studied for its impact on mental health [14].

With the rise of urbanization, the mental health rates in US military Veterans, and the evidence that the built environment affects the mental health of the occupants, research into the built environment of Veterans and its effects on their psychological health is justified. Factors important to the built environment and mental health has been hypothesized to items such as indoor air quality, views of nature, light exposure, and the

control of the individual's climate in the built environment [15]. This paper focuses solely on the exposure to daylight.

The benefits of light on physical health and the lighting effects on office workers have been documented for nearly 100 years, but research has been limited on the effects of residential light on mental health [16]–[22]. Researchers found that bright light therapy has positive impacts on mental health in research and clinical applications, and exposure to daylight has been observed to diminish eating disorders, decrease depression, regulate circadian rhythm, mood, perception, and reduce Seasonal Affective Disorder (SAD), a regular occurring depression in the winter when the daylight is at its lowest levels [23]–[26]. Artificial lighting supplements daylighting in the built environment [27]. Artificial light improves sleep quality, increases morale [20], and reduces SAD symptoms [28]. Full-spectrum fluorescent lighting (FSFL) is the aspect of artificial light that closely resembles the color spectrum of daylight. The full-spectrum artificial lighting has been used to treat sleep disorders and premenstrual dysphoria [29]. However, even with full-spectrum lighting having a similar color spectrum, it does not fully substitute for daylight [30]–[33]. The recent development of high-quality and long-life artificial light sources has challenged the superiority of the spectral properties of daylight, but FSFL is not the most affective for positive mental health outcomes [34]. In certain circumstances, a bright light for a short period of time has been effective in clinical research, called bright light therapy. Bright light therapy has been used to reset circadian rhythms, improve mood, increase vitality, mitigate depression, and decrease the amount of time in hospitals by promoting healing [15], [35]–[40].

Smolder et al. (2013) reported participants had higher vitality, improved mood, and improved self-reported sleep quality when they had experienced more daylight. Daylight contains the entire color spectrum of light, but the blue portion of daylight encompasses 50% of the spectrum making daylight the optimal light to use to have positive mental health outcomes [41]. Daylight also affects mood and perception; positive impacts included daylight and window proximity [24]. Daylight can lower stress levels, increase productivity, eliminate noise and flickering from electric light sources, and provide the best quality of light available [24], [30], [42]. Daylight eases the stress on the eyes and can lead to increased information processing and learning ability, enhances the mental capacity of the individual and reduces tension [37]. Daylight also may influence more than mental health of the occupants in the built environment. Light was found to influence physical health through the metabolism of Vitamin D [43]. Vitamin D affects dopamine, noradrenaline and acetylcholine, which are well-known actors in the pathophysiology of mood disorders, attention deficit disorders and Alzheimer's disease. Window illumination may not be the only contributing factor to mental health. Studies have found that our connection to nature and views of nature influence mental health [44], [45], [46].

Among the architectural or interior design characteristics that define the built environment are the proximity of a window and the amount of daylight shining through [19]. The occupants' desire for natural, rather than artificial light, and the effects of daylight are why windows are important to building occupants [20]. Windows are not an architectural standard for all buildings, but research has shown that it has an impact on

our mental health [24], [35], [46]–[50]. Windows have also been found to influence positive mental health outcomes by allowing the occupant to view nature. The connection to nature was found to have a significant influence on the occupants of the built environment [12]. Adding windows into a facility is not easy once the facility is constructed, but windows can easily be added at the design phase. Other research also suggests that daylight is the optimum lighting for positive mental health outcomes.

The present study by engineers and psychologists of the Air Force Institute of Technology and the US Department of Veteran Affairs in Denver, Colorado is researching what aspects of the built environment can affect our health. The purpose of this paper was to investigate connections between the residential built environment of Veterans and active duty personnel and their mental health scores via a validated mental health measure. This is the first known study that focuses on the natural light in the residences of the occupants of the built environment and how light impacts their mental health.

**Methodology**

This study is part of the United States-Veteran Microbiome Project (US-VMP) occurring at the Rocky Mountain Mental Illness Research, Education and Clinical Centers (MIRECC) in Aurora, Colorado [41]. In addition to the US-VMP participants, the present research opened the participant eligibly to active duty military and civilians at Air Force bases across world. Data was collected from the participants through a self-

reported built environment survey of 210 Veterans and 223 active duty military personnel and a basic mental and physical health questionnaire.

Enrollment into the US-VMP began in May 2016, and the first round of surveys was given in March 2018. The Veterans were given a Housing, Occupancy, Materials, and Environment (HOME) survey, the Short Form Health Survey (SF-36), Rocky Mountain MIRECC Demographics Questionnaire. Each questionnaire or survey took 5 – 10 minutes to complete and the factors of interest, functional health and well-being, personal and military characteristics, and built environment factors that influence mental health, respectively [12]. The active duty military personnel and DoD civilians were given the HOME survey and the SF-36. This study focused on the HOME surveys and the SF-36 for equilateral comparison.

*Mental Health Measures*

Each mental health measure was evaluated in a self-reported questionnaire. The Rocky Mountain MIRECC also administered a Demographics Questionnaire to obtain standard demographic and historical information. Each of the questionnaires, summarized below, has a score related to the severity of the symptom that the questionnaire sought to measure.

1) 36-Item Short Form Health Survey (SF-36): a multi-purpose, health survey that provides an 8-scale profile of perceived health and well-being [51].

The SF-36 questionnaire was used to provide an overview of the Veteran and active duty mental health. Analysis of the Veteran survey was completed using the

emotional well-being, social functioning, and general health scores from the SF-36. The active duty survey analysis was completed using the same SF-36 measures. The US average scores for the SF-36 health measure are summarized in Table 1 below. These average scores were compared to the active duty and Veteran reported scores. A score below the mean for that category was considered to be a poor score [42].

Table 1: SF-36 US Average scores

| Health Category | Number of Questions in Category | Mean | Standard Deviation |
|---|---|---|---|
| Physical functioning | 10 | 70.61 | 27.42 |
| Role functioning/physical | 4 | 52.97 | 40.78 |
| Role functioning/emotional | 3 | 65.78 | 40.71 |
| Energy/fatigue | 4 | 52.15 | 22.39 |
| Emotional well-being | 5 | 70.38 | 21.97 |
| Social functioning | 2 | 78.77 | 25.43 |
| Pain | 2 | 70.77 | 25.46 |
| General health | 5 | 56.99 | 21.11 |
| Health change | 1 | 59.14 | 23.12 |

*Built Environment Measure*

Currently, there is not a validated survey for analyzing the impacts of the built environment on the mental health of occupants. The present study helped develop the Housing, Occupancy, Materials, and Environment (HOME) for the active duty

population (see Appendix A.1). Questions in the HOME survey included simple demographics, home characteristics, indoor lighting, windows, and view. The questions that this study evaluated the most involved how well the occupant rated the natural light in their residence. If the person had a natural light rating above 6 on a Likert scale response, then the occupant was considered to have good natural light.

*Statistical Methods*

The statistical analysis to summarize demographic and responses to the questionnaires was performed in SPSS Statistics (IBM, Armonk, New York). Statistical significance was assumed with an alpha value of 0.10. due to the population sizes not meeting the power requirement of 783. Data was converted from Likert scale responses to the quantitative answers necessary for statistical analysis. All "Yes or No" questions were also changed to a numeric scale. Once all of the data was formatted correctly, correlation analysis was completed. HOME survey variables included the participants number of residences in past 10 years, occupants in the home, the square footage, age of the facility, ceiling height, the natural light rating, whether at least half of the windows looked upon a natural setting, and ceiling height. The above variables were compared using the Pearson chi-square and t-test to assess their relational strength. A factorial analysis was completed to determine the intercorrelation between each of the variables. This factor analysis created Pearson correlation coefficients for the variable of natural light.

Mental health measure scores were tested for normal distribution using the Shapiro-Wilk goodness-of-fit test. If the scores were normally distributed, then a one-

tailed t-test was used to compare the means of the active duty and Veteran population's SF-36 test scores. If the scores were not normally distributed, then a Wilcoxon rank-sum test was used, which is a one-way chi-square test to determine the difference between the means of those affected and those unaffected by mental health outcomes. Finally, each of the active duty and Veteran populations were combined to further assess the natural light versus SF-36 scores. An ANOVA regression analysis, Pearson correlation, and Spearman correlation and Chronbach's alpha tests were completed on the combined data as well. The Chronbach's alpha was used to test the reliability of the responses given by the active duty and Veteran populations.

**Results**

*Active duty group Demographics (DoD personnel)*

There were 229 active duty and civilian respondents to the HOME survey. The age range of those who participated was 20-69 years old and an average age of 39.6 with 75.6% of participants below 50. The survey population had 51% of the population with undergraduate or graduate degrees. The relationship responses were reported as 72.1% married, 17.5% single, and 10.5% divorced or other. The survey participants reported that 3.5% had been homeless at one point. The full demographics from the present study are summarized in Table 2 below.

Table 2: Active Duty Survey Demographics

| Variable | N (%) or Mean ± SD |
|---|---|
| Total | 229 |
| Age | 39.6 ± 12.19 (20-69) |
| AGE CATEGORIES | |
| 20-29 | 57 (24.9%) |
| 30-39 | 79 (34.5%) |
| 40-49 | 37 (16.2%) |

| | |
|---|---|
| 50-59 | 42 (18.3%) |
| 60-69 | 14 (6.1%) |
| GENDER | |
| Male | 175 (76.4%) |
| Female | 54 (23.6%) |
| RACE | |
| Caucasian | 179 (78.2%) |
| African American | 16 (7.0%) |
| Multiracial | 10 (4.4%) |
| Other | 24 (10.5%) |
| ETHNICITY | |
| Hispanic | 23 (10.0%) |
| Non-Hispanic | 206 (90.0%) |
| MARITAL STATUS | |
| Married | 165 (72.1%) |
| Single | 40 (17.5%) |
| Cohabitating | 7 (3.1%) |
| Separated/Divorced | 16 (7.0%) |
| Widowed | 1 (0.4%) |
| EDUCATION LEVEL | |
| No High School Degree | 1 (0.4%) |
| High School Degreee | 7 (3.1%) |
| Some College | 46 (20.1%) |
| Associate Degree | 56 (24.5%) |
| Bachelor Degree | 64 (27.9%) |
| Master's Degree | 53 (23.1%) |
| Doctoral Degree | 2 (0.9%) |
| STUDENT STATUS | |
| Not in School | 175 (76.4%) |
| Full-Time | 7 (3.1%) |
| Part-Time | 47 (20.5%) |
| PRIOR HOMELESSNESS | |
| Yes | 8 (3.5%) |
| No | 221 (96.5%) |

*Active Duty Light Results*

A correlation table was developed for the active duty group with natural light and SF-36 data. Natural light was found to be positively correlated with the SF-36 variables, general health (p=0.003), influencing the feeling of "pep" (p=0.000), and making the individual feel full of energy (p=0.003). Natural light was positively correlated to the built environment factors, home size (p=0.000), 50% of windows view greenspace

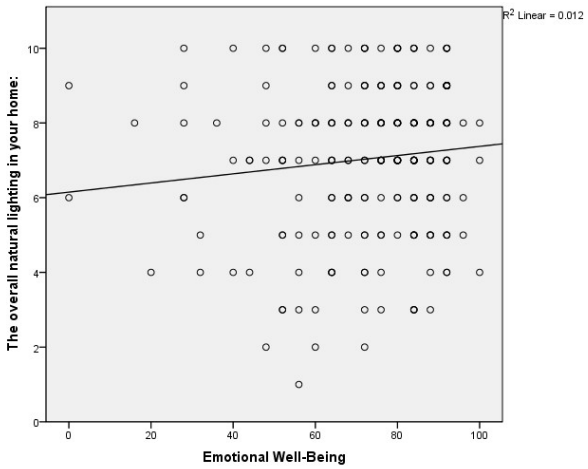
(p=0.000), live near greenspace (p=0.008), nature pictures (p=0.000), if the occupant owns or rents their home (p=0.042) and climate adjustability (p=0.000). Natural light was also negatively correlated with the SF-36 variables with feeling down (p=0.025), feeling worn out (p=0.015), feeling tired (p=0.043), emotional problems interfere with going out (p=0.008), and the built environment measure live near a highway (p=0.005). Each of these correlations make up only a part of the each of the measures in the SF-36, however. The natural light rating was found to be significantly correlated at a 90% confidence interval with the greater overall measures of emotional well-being (p=0.091), general health (p=0.081) and lower pain scores (p=0.010). Because of these significant correlations, further evaluation was completed using ANOVA regression analysis.

Table 3: Active Duty Natural Light and SF-36 ANOVA Results

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| Natural Light vs Emotional Well-Being | The overall natural lighting in your home: | 1.005 | .593 | .111 | 1.697 | .091 |
| Natural Light vs Social Functioning | The overall natural lighting in your home: | 1.018 | .629 | .106 | 1.619 | .107 |
| Natural Light vs General Health | The overall natural lighting in your home: | 1.107 | .631 | .115 | 1.754 | .081 |

In the ANOVA regression analysis, it was observed there is significance between emotional well-being (p=0.091) and general health (p=0.081), with natural light levels. Social functioning of the individuals was found to have no relation to natural light in the regression analysis. The ANOVA results are presented in Table 3 above. To further

analyze the trend of natural light vs emotional well-being and general health, a trend analysis was completed. Figures 1 and 2 below show that as the natural light rating increases the overall health and emotional well-being scores also rises.



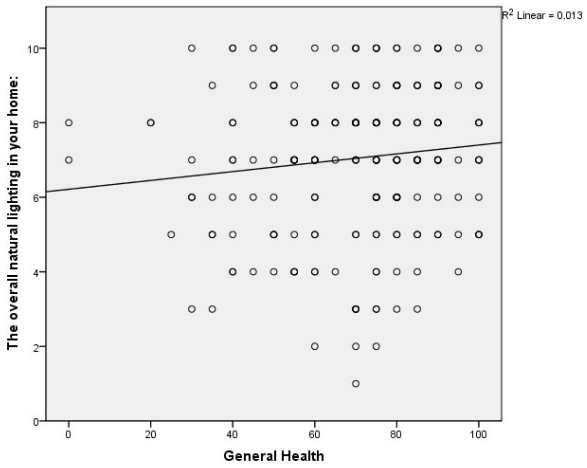




Figure 21: Active Duty Natural Light vs Emotional Well-Being Figure 32: Active duty Natural Light vs General Health

*Veteran group Demographics (Rocky Mountain MIRECC)*

In the Veteran study, there were 210 respondents. Nearly 78% of the participants were male, and 72% were Caucasian. The age range was 22 to 85 years old with an average age of 48.2; a majority of the participants were below 50 years of age. Caucasian and African Americans were the highest participants at 74.3% and 10.5%, respectively. More respondents were married (36.7%) than divorced (17.6%), but 21.9% of respondents failed to give their marital status. The Veteran population was educated with 65.8% earning at least an associate's degree, but this is 10.6% less than the active duty population. Seven of the respondents were currently homeless, and 61.82% reported that they had been homeless at one point in their lives. The seven that reported being

homeless did also submit a HOME survey and were analyzed because their built environment may still influence mental health. The full demographics are summarized in Table 4.

Table 4: Veteran Survey Demographics

| Variable | N (%) or Mean ± SD |
|---|---|
| Total | 210 |
| Age | 48.2 ± 13.6 |
| AGE CATEGORIES | |
| 20-29 | 16 (7.6%) |
| 30-39 | 50 (23.8%) |
| 40-49 | 48 (46.7%) |
| 50-59 | 43 (20.5%) |
| 60-69 | 38 (18.1%) |
| 70+ | 15 (7.1%) |
| GENDER | |
| Male | 163 (77.6%) |
| Female | 46 (21.9%) |
| Transgender | 1 (0.4%) |
| RACE | |
| Caucasian | 156 (74.3%) |
| African American | 22 (10.5%) |
| Multiracial | 16 (7.6%) |
| Other | 15 (7.1%) |
| ETHNICITY | |
| Hispanic | 32 (15.2%) |
| Non-Hispanic | 178 (84.8%) |
| MARITAL STATUS | |
| Married | 77 (36.7%) |
| Single | 30 (14.3%) |
| Cohabitating | 15 (7.1%) |
| Separated/Divorced | 37 (17.6%) |
| Widowed | 5 (2.4%) |
| No Response | 46 (21.9%) |
| SEXUAL ORIENTATION | |
| Heterosexual | 191 (91.0%) |
| Gay/Lesbian/Queer | 15 (7.1%) |
| Bi-sexual | 4 (1.9%) |
| EDUCATION LEVEL | |

| | |
|---|---|
| No High School Degree | 1 (0.04%) |
| High School Degree | 18 (8.6%) |
| Some College | 52 (24.8%) |
| Associate Degree | 25 (11.9%) |
| Bachelor Degree | 77 (36.7%) |
| Master's Degree | 34 (16.2%) |
| Doctoral Degree | 2 (1.0%) |
| EMPLOYMENT STATUS | |
| Employed Full-Time | 41 (19.5%) |
| Employed Part-Time | 19 (9.0%) |
| Unemployed Seeking Job | 31 (14.8%) |
| Unemployed Not Seeking Job | 18 (8.6%) |
| Retired | 55 (26.2%) |
| No Response | 46 (21.9%) |
| STUDENT STATUS | |
| Not in School | 189 (90.0%) |
| Full-Time | 13 (6.2%) |
| Part-Time | 8 (3.8%) |
| CURRENTLY HOMELESS | |
| Yes | 7 (3.3%) |
| No | 203 (96.7%) |
| Number of Times Ever Homeless | 1.88 |

*Veteran Light results*

A correlation analysis for the Veteran data was completed for natural light versus home size, if 50% of windows view greenspace, if the occupant lives near a highway, pictures of nature in the household, how easily the resident can adjust their own climate, emotional well-being, social functioning, the general health of the respondent, and other possible scenarios. The positively significant correlations to natural light in the Veteran built environment survey were home size ($p=0.000$), 50% of windows view greenspace ($p=0.000$, live near greenspace ($p=0.000$), nature pictures ($p=0.017$), if the occupant owns or rents their home ($p=0.053$) and climate adjustability ($p=0.000$). The natural light rating

was negatively correlated to living near a highway (p=0.008). Poor natural lighting, a natural light rating below 6 out of 10 on a Likert scale response, was analyzed for any correlations as well. The correlations found for poor natural lighting were found to be: negatively correlated to home size (p=0.004), 50% of windows view greenspace (p=0.000), live near a highway (p=0.051), live near greenspace (p=0.000), and nature pictures within the home (p=0.013). The significant correlations were used to further evaluate the data using an ANOVA regression.

The regression analysis found that poor natural lighting, had no significant impact on emotional well-being, social functioning, and general health. The overall natural light rating regression analysis found that it was not significantly related to any of the SF-36 scores. (see Appendix A.2 for ANOVA results). This result suggested that self-reported natural light has little direct impact on our general health or on the emotional well-being of our Veteran population.

A trend analysis was completed between the Veteran natural light rating and two SF-36 variables, general health and emotional well-being. A plot was created using the self-reported natural light rating compared to the emotional well-being score (Figure 3) and a second plot was created using the natural light rating and general health. A fit line was added to the plot to discover any trends in the data. Figure 4 shows that those that individuals with lower emotional well-being scores also had a lower self-reported natural light rating. Social function, however, was not affected by natural light and showed no trends in the data. The trend in the data points from the general health of the individual

data (see Figure 4) saw the trend line saying that those with lower general health also had low natural light scores.

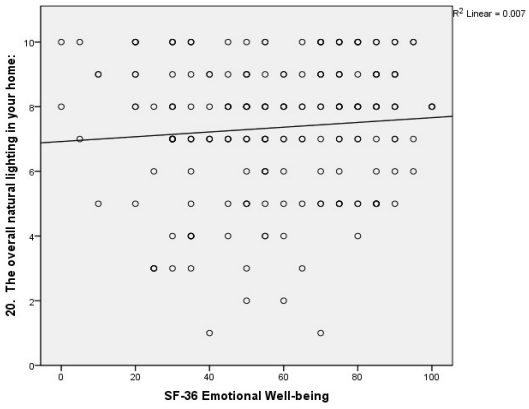



Figure 3: Natural Light Scores vs Emotional Well-Being

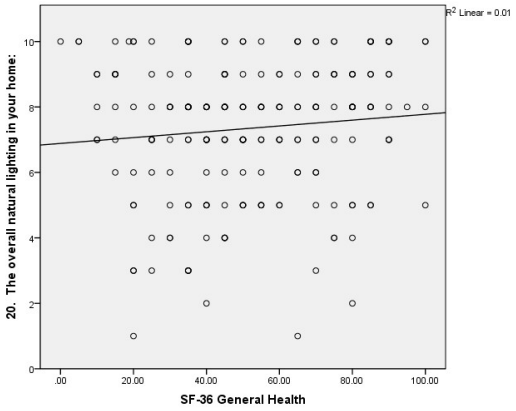



Figure 4: Natural Light Scores vs General Health

*Combined Data Light Results*

The combined population data was analyzed using a Pearson correlation for continuous variables and a Spearman correlation for binary variables. The Pearson correlation table found that natural light did not have a significant correlation to emotional well-being, social functioning, or general health (see Appendix A.4 for Pearson correlation table). The Spearman correlation analysis found that natural light had a significant correlation to general health (p=0.068), but did not have significant relationships to social functioning and emotional well-being (see Appendix A.5 for Spearman correlation table). The ANOVA regression analysis results, however, showed no significant relationship as seen in table 5 below. The combined data Chronbach's alpha test revealed that active duty and Veteran populations answered as expected (see Appendix A.3).

Table 5: Combined Data ANOVA Regression Analysis

| Model | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|
| | B | Std. Error | Beta | | |
| Natural light vs General Health | 0.792 | 0.543 | 0.069 | 1.458 | 0.146 |
| Natural Light vs Social Functioning | 0.280 | 0.630 | 0.021 | 0.444 | 0.657 |
| Natural Light vs Emotional Well-Being | 0.677 | 0.518 | 0.062 | 1.307 | 0.192 |

**Discussion**

To verify the survey participants were a subgroup of the full military population, demographics of the survey participants were compared to a 2017 survey of active duty and DoD personnel and an Air Force magazine article [43], [44]. The 2017 report found that 8.3% of the Air Force is above 41 years of age [44]. The differences in the active duty and Veteran demographics varied depending on the category. The 2017 report was similar to the survey participants in education at high school level or some college and below, but varied when it came to bachelors and graduate level degrees, with only 22.7% having the same degree [48]. The report did not specify active duty homeless rates. These results also matched the 2010 National survey of Veterans, Active Duty Service Members, Demobilized National Guard and Reserve Members, Family Members, and

Surviving Spouses (NSV) [50]. The male and female ratios were similar at 76.4% for the active duty and 77.6% for the Veterans. The race of each population was even similar to both the 2017 survey and the 2010 NSV survey being 78.2% Caucasian, 7.0% African American, 4.4% Multiracial and 10.5% Other; the Veteran population was 74.3% Caucasian, 10.5% African American, 7.6% Multiracial, and 7.1% Other. The educational level of the Veteran population was different from the 2010 NSV with only 10% of the participants reporting a high school diploma or lower. While the above data may be similar, there were some major differences as well.

The active duty and Veteran populations differed in a few key demographics. The active population had a higher married rate of 72.1% compared to 36.7% in the Veteran survey. The divorce rates for the Veteran population were higher than the active duty respondents at 17.6% and 7%, respectively. The divorce rate of the Veteran population could be a factor that influences their mental health. Research suggest that divorced adults are 20% more likely to experience a negative mental health outcome [47]. Other studies have concluded that a mental health disorder will also lead to higher rates of divorce [48], [49]. The differences in statistics of divorce and marriage rates could be a part of the explanation of some of the lower mental health scores in the Veteran population. Another demographic difference is the age of each population; the active duty average age was 39.6 while the Veteran population average age was 48.2, but this is expected due to Veterans having already completed their time in military service. The Veteran population was not as educated as the active duty population with 45.3% not graduating from college with a bachelor's degree compared to 23.6% for the active duty

population. Research suggests that lower educated individuals are 16% more likely to develop a mental illness in their lifetime [50]. Because of these differences in the demographics of the survey populations, the Veteran population was analyzed separately

The descriptive statistics in Table 6 suggest that the active duty population had good natural light in their built environment with an average rating 7.05, based on the arbitrary 6 out of 10 natural light rating given for this survey. The table also suggests that the emotional well-being, social functioning, and overall general health of the survey population are all above the SF-36 cutoff for the US mean scores. The Veteran population had an average self-reported natural light rating of 7.35. This could possibly be explained by the location of the Veterans in Denver, CO. Denver averages 300 days of sunshine every year, possibly leading to higher lighting scores. The SF-36 scores for emotional well-being, social functioning, and general health of the Veteran population were all below the US average scores. The differing demographics and SF-36 scores between the active duty and Veteran populations were the reasons that the populations were analyzed separately.

Table 6: Active Duty Survey Descriptive Statistics

| Variable | Mean ± SD |
|---|---|
| NATURAL LIGHT VS GENERAL HEALTH | |
| Active Duty | 70.11 ± 19.23 |
| Veteran | 51.80 ± 23.64 |
| United States | 56.99 ± 21.11 |
| NATURAL LIGHT VS EMOTIONAL WELL-BEING | |
| Active Duty | 73.32 ± 18.05 |
| Veteran | 57.45 ± 23.36 |
| United States | 70.38 ± 21.97 |
| NATURAL LIGHT VS SOCIAL FUNCTIONING | |
| Active Duty | 75.27 ± 19.14 |
| Veteran | 55.30 ± 30.27 |

| | |
|---|---|
| United States | 78.77 ± 25.43 |
| NATURAL LIGHT RATING | |
| Active Duty | 7.55 ± 1.99 |
| Veteran | 7.35 ± 2.08 |

Both survey population's reported differing built environment statistics including home size, home age, ceiling height and at least half of the windows viewing greenspace. The active population had 1800 square feet (sf) homes, 38.6-year-old homes, 9.5ft ceiling height and, and 41.2% of the homes had at least half of the windows look at greenspace. The Veteran population had 1650 sf home size, 40-year-old homes, 9.6ft ceiling height, and 50.4% of the homes had at least half of the windows viewing greenspace. Research suggests that home size and the age of the home are associated with the quality of the home, which is significantly correlated with mental health outcomes [51]. The Veteran population's smaller home size and older aged homes could be influencing their lower mental health scores. Due to some similarities in the statistics between the Veteran and active duty population, some of the same correlations exist. Both the active duty and Veteran populations did not a significant relationship between natural light and social functioning, but the active duty population had a significant relationship between general health and emotional well-being. Differing built environment factors may be influencing the difference in the mental health scores as well.

The active duty population's ANOVA and correlation results suggest that natural light in the built environment is correlated to positive mental health outcomes. The non-significant result could be from the fact that the active duty survey population is relatively healthy and that the survey is self-reported [46], [49]. The Veteran population

relationships between natural light and general health, emotional well-being and social function was neither significantly correlated or significant according to the ANOVA regression. The non-significant results could be that the Veteran population views their natural light in the built environment more positively, as seen in Table 6. The combined data showing no significant relationship between natural light and the SF-36 measures in the Pearson correlation and the ANOVA regression could be an effect of the Veteran population's data skewing the results. Even with positive results from the active duty portion of the survey, more research needs to be completed to further the validity of the survey.

Once the survey is validated and the results either stay the same improve, or decline with more participants, changes can be made to the built environment of our active duty and Veteran populations. Currently, without conclusive evidence, engineers and architects will view these results with skepticism. Design engineers will not want to implement changes without conclusive results. Some changes can be inexpensive and quickly accomplished, such as keeping the shades open during the day, or the changes can be more challenging, such as redesigning a facility to have more windows to allow more light into the facility. It should be noted, however, that the required intensity of daylight to positively affect mental health outcomes is unknown.

*Limitations*

Although this study was only a preliminary analysis of light and mental health, there are several limitations that should be noted. The first limitation that is highlighted is the sample sizes of the Veteran and active duty populations of the survey. This still does

not give the survey the required statistical power of 783 participants for validating the HOME survey. As more participate in the study, the power of the sample will be rectified and the survey may be validated. The HOME survey was not validated in a previous study [12], but the study did show significant correlations between the built environment and mental health outcomes.

Another limitation is that the populations were analyzed separately, leading to a comparison analysis and not a combined analysis. The active duty personnel overall general health scores were higher (70.11) than the mean for the SF-36 scoring (56.99). The Veteran's overall General Health score of 51.80 suggests that the Veteran population is not as generally healthy as the average American. The Veteran population also had a lower emotional well-being score of 57.45 than the score of the active duty population (73.32) with the mean of emotional well-being being 70.38. These emotional scores suggest again that the Veterans lack overall emotional health, thus suffer from more negative mental health outcomes. The social functioning score for the Veteran population is 55.30; the active duty score is 75.97, and the mean score is 78.77. Both populations have poor social function according to the SF-36 standard, suggesting that both populations may need positive mental health outcomes. Many active duty personnel may not have developed emotional, general health or social issues and are most likely not to report them even if they do have issues. The active duty has a stigma that if they report any negative mental or physical health issues, they may lose their careers.

An additional limitation is that the natural light rating was self-reported. The higher self-reported natural light rating for the Veteran population could be from the

location of the respondents. The Veteran population lived in Denver, CO, which is known to have approximately 300 days of sunshine a year. The active duty survey respondents were from around the country, limiting the ability to know the population's location. Without seeing the residence and having a validated way to measure the natural light in the building, studies have to rely on the self-reported measure. The self-reported overall natural light rating for the active duty population was 7.05 out of 10, while the Veteran natural light rating was 7.35 out of 10. This was unexpected, as we would expect the Veteran population to have a lower light rating based on the SF-36 ratings.

**Conclusions**

The natural light in the built environment appears related to active duty mental health outcomes. As participation in the study continues to grow, built environment factors that influence mental health outcomes should become known. This would increase the understanding of how the built environment can influence mental health outcomes. More standardized, and fewer self-reported, measures of the built environment are needed to accurately assess the factors that can improve mental health outcomes. Further studies could investigate the alterations made by the occupants to discover what the changing built environment does to mental health outcomes. Interdisciplinary studies should be continued to further the understanding of how the built environment influences positive mental health outcomes. The more that social scientists, engineers, and architects understand how the built environment affects mental health outcomes, healthier living environments can be built leading to a population with more positive mental health outcomes.

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# Appendix A

## Appendix A.1 HOME Survey

**Housing, Occupancy, Materials, and Environment Questionnaire**
**Baseline**

1. How many residences have you lived in over the last 10 years? _____

2. How many people currently live in the home with you? _____

3. How large in approximate square feet is the home you live in? _____

4. What year was your home constructed? _____

5. How tall are the ceilings in your home (in feet)? _____

6. Do you or anyone smoke any substance in the home you live in (e-cigarettes included)?

☐Yes ☐ No

7. Do you burn incense or candles in your home daily?

☐Yes ☐ No

8. Do you have any dogs that are regularly in your home?

☐Yes ☐No

9. Have you in the last 5 years done any of the following: replaced more than 50% of the carpet, applied paint to more than 50% of your home, remodeled, or replaced the roofing of your home?

☐Yes ☐ No

10. Do you have the ability to open the windows in your home whenever you would like?

☐Yes ☐ No

11. Do 50% or more of the windows in your home look upon a natural setting (e.g. not man-made structures)?

☐Yes ☐ No

12. Do you live within 1 mile of a highway or interstate?

☐Yes ☐No

13. Do you live within 0.5 miles of open greenspace (park, playground, field, hiking trails, etc.)?

☐Yes ☐No

14. Do you feel you have adequate privacy in your home?

☐Yes ☐No

15. Does your home have a basement?

☐Yes ☐No

16. Has your home ever had water damage?

☐Yes ☐No

17. Do you have any pictures or paintings of nature in your home?

☐Yes ☐No

18. Do you own or rent the home you live in?

☐Rent ☐Own

19. What type of home do you live in?

Detached Single Family:

If yes, what size is the lot upon which your home sit?
<0.25 acres 0.25-0.5 acres 0.5-1.0 acres >1.0 acre
Apartment:
☐Yes ☐No
If yes, what floor do you live on?

Multiple Dwelling Unit (condo, townhouse, etc.)
Other:

If yes, please specify:

**On a scale of 1-10 (1 being poor and 10 being excellent), please rate the following aspects of your home:**

20. The overall natural lighting in your home:
1 2 3 4 5 6 7 8 9 10
21. Your ability to adjust your indoor climate to your liking:
1 2 3 4 5 6 7 8 9 10

Appendix A.2: ANOVA Regression Results

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| Natural Light vs Emotional Well-being | (Constant) | 50.599 | 5.932 | | 8.530 | .000 |
| | 20. The overall natural lighting in your home: | .933 | .777 | .083 | 1.200 | .231 |
| Natural Light vs Social Functioning | (Constant) | 53.356 | 7.712 | | 6.918 | .000 |
| | 20. The overall natural lighting in your home: | .264 | 1.010 | .018 | .262 | .794 |
| Natural light vs General Health | (Constant) | 55.736 | 4.059 | | 13.731 | .000 |
| | 20. The overall natural lighting in your home: | .792 | .543 | .069 | 1.458 | .146 |

A.3: Chronbach's Alpha Table

| | Chronbach's Alpha | Number of Items |
|---|---|---|
| Emotional well-being | 0.868 | 5 |
| Social Functioning | 0.860 | 2 |
| General Health | 0.853 | 5 |

A.4: Combination Data Pearson Correlation

| | | SF-36 Emotional Well-being | SF-36 Social Functioning | SF-36 General Health | 3. How large in approximate square feet is the home you live in? | 2. How many people currently live in the home with you? | 5. How tall are the ceilings in your home (in feet)? | 1a. How many residences have you lived in over the last 10 years? | 20. The overall natural lighting in your home: |
|---|---|---|---|---|---|---|---|---|---|
| SF-36 Emotional Well-being | Pearson Correlation | 1 | .721 | .549 | .050 | .095 | -.005 | -.118 | .062 |
| | Sig. (2-tailed) | | .000 | .000 | .298 | .045 | .911 | .013 | .192 |
| SF-36 Social Functioning | Pearson Correlation | .721 | 1 | .623 | .023 | .092 | .022 | -.058 | .021 |
| | Sig. (2-tailed) | .000 | | .000 | .631 | .053 | .652 | .223 | .657 |
| SF-36 General Health | Pearson Correlation | .549 | .623 | 1 | .009 | .081 | .042 | .093 | .069 |
| | Sig. (2-tailed) | .000 | .000 | | .859 | .088 | .382 | .052 | .146 |
| How large in approximate square feet is the home you live in? | Pearson Correlation | .050 | .023 | .009 | 1 | .215 | .086 | -.143 | .280 |
| | Sig. (2-tailed) | .298 | .631 | .859 | | .000 | .076 | .003 | .000 |
| How many people currently live in the home with you? | Pearson Correlation | .095 | .092 | .081 | .215 | 1 | .001 | -.056 | .068 |
| | Sig. (2-tailed) | .045 | .053 | .088 | .000 | | .985 | .240 | .155 |
| How tall are the ceilings in your home (in feet)? | Pearson Correlation | -.005 | .022 | .042 | .086 | .001 | 1 | .039 | .014 |
| | Sig. (2-tailed) | .911 | .652 | .382 | .076 | .985 | | .422 | .778 |
| How many residences have you lived in over the last 10 years? | Pearson Correlation | -.118 | -.058 | .093 | -.143** | -.056 | .039 | 1 | -.120 |
| | Sig. (2-tailed) | .013 | .223 | .052 | .003 | .240 | .422 | | .011 |
| 20. The overall natural lighting in your home: | Pearson Correlation | .062 | .021 | .069 | .280 | .068 | .014 | -.120 | 1 |
| | Sig. (2-tailed) | .192 | .657 | .146 | .000 | .155 | .778 | .011 | |

A.5: Combination Data for Spearman Correlation

| SF-36 Emotional Well-being | SF-36 Social Functioning | SF-36 General Health | 20. The overall natural lighting in your home: | Dogs? | Smoke? | Candles? | Remodel? | Open Windows | 50% windows | <1 mi hwy | .5 mi park | privacy? | basement | Wtr damage | Nature pics | | own/rent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SF-36 Emotional Well-being | Correlation Coefficient | | 1.000 | .692** | .523** | .067 | -.075 | .168** | .004 | .006 | -.014 | .000 | .050 | -.017 | .063 | .161** | .100* | .140** | .041 |
| | Sig. (2-tailed) | | . | .000 | .000 | .162 | .118 | .000 | .935 | .895 | .762 | .998 | .296 | .719 | .186 | .001 | .036 | .003 | .392 |
| SF-36 Social Functioning | Correlation Coefficient | | .692** | 1.000 | .612** | .048 | -.049 | .104* | .046 | -.059 | .035 | -.014 | -.048 | -.026 | .067 | .138** | .135** | .123** | -.003 |
| | Sig. (2-tailed) | | .000 | . | .000 | .308 | .305 | .029 | .332 | .214 | .463 | .775 | .315 | .592 | .158 | .004 | .004 | .009 | .947 |
| SF-36 General Health | Correlation Coefficient | | .523** | .612** | 1.000 | .087 | -.005 | .218** | .023 | -.054 | .037 | -.036 | .108* | -.015 | -.013 | .141** | .145** | .112* | -.054 |
| | Sig. (2-tailed) | | .000 | .000 | . | .068 | .921 | .000 | .628 | .259 | .437 | .450 | .023 | .753 | .779 | .003 | .002 | .018 | .261 |
| 20. The overall natural lighting in your home: | Correlation Coefficient | | .067 | .048 | .087 | 1.000 | .033 | -.007 | -.035 | .021 | .109* | .270** | .104* | -.184** | .179** | -.141** | .086 | .157** | .204** |
| | Sig. (2-tailed) | | .162 | .308 | .068 | . | .491 | .884 | .467 | .659 | .021 | .000 | .028 | .000 | .000 | .003 | .071 | .001 | .000 |
| Dogs? | Correlation Coefficient | | -.075 | -.049 | -.005 | .033 | 1.000 | -.031 | -.066 | -.037 | .083 | .009 | -.028 | -.028 | .116* | -.142** | .061 | -.092 | -.003 |
| | Sig. (2-tailed) | | .118 | .305 | .921 | .491 | . | .511 | .163 | .442 | .080 | .850 | .559 | .560 | .014 | .003 | .199 | .052 | .951 |
| Smoke? | Correlation Coefficient | | .168** | .104* | .218** | -.007 | -.031 | 1.000 | .132** | .026 | -.030 | -.005 | .110* | -.016 | -.028 | .102* | -.013 | .085 | -.007 |
| | Sig. (2-tailed) | | .000 | .029 | .000 | .884 | .511 | . | .005 | .588 | .529 | .917 | .021 | .730 | .549 | .032 | .787 | .074 | .878 |
| Candles? | Correlation Coefficient | | .004 | .046 | .023 | -.035 | -.066 | .132** | 1.000 | -.023 | -.009 | -.059 | -.029 | .023 | -.026 | -.032 | -.057 | -.108* | .021 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sig. (2-tailed) | .935 | .332 | .628 | .467 | .163 | .005 | . | .628 | .857 | .212 | .536 | .629 | .583 | .496 | .231 | .023 | .654 |
| Remodel? | Correlation Coefficient | .006 | -.059 | -.054 | .021 | -.037 | .026 | -.023 | 1.000 | .033 | .093 | -.001 | -.074 | .066 | -.159** | -.089 | .080 | .366** |
| | Sig. (2-tailed) | .895 | .214 | .259 | .659 | .442 | .588 | .628 | . | .484 | .051 | .988 | .119 | .166 | .001 | .062 | .093 | .000 |
| Open Windows | Correlation Coefficient | -.014 | .035 | .037 | .109* | .083 | -.030 | -.009 | .033 | 1.000 | .081 | -.047 | .003 | .095* | .008 | .062 | .014 | .075 |
| | Sig. (2-tailed) | .762 | .463 | .437 | .021 | .080 | .529 | .857 | .484 | . | .091 | .326 | .946 | .045 | .865 | .190 | .770 | .116 |
| 50% windows | Correlation Coefficient | .000 | -.014 | -.036 | .270** | .009 | -.005 | -.059 | .093 | .081 | 1.000 | .002 | -.142** | .120* | -.104* | .016 | .069 | .221** |
| | Sig. (2-tailed) | .998 | .775 | .450 | .000 | .850 | .917 | .212 | .051 | .091 | . | .972 | .003 | .011 | .029 | .743 | .148 | .000 |
| <1 mi hwy | Correlation Coefficient | .050 | -.048 | .108* | .104* | -.028 | .110* | -.029 | -.001 | -.047 | .002 | 1.000 | .021 | -.024 | .057 | .166** | .042 | .078 |
| | Sig. (2-tailed) | .296 | .315 | .023 | .028 | .559 | .021 | .536 | .988 | .326 | .972 | . | .657 | .619 | .234 | .000 | .372 | .100 |
| .5 mi park | Correlation Coefficient | -.017 | -.026 | -.015 | -.184** | -.028 | -.016 | .023 | -.074 | .003 | -.142** | .021 | 1.000 | .017 | .153** | .002 | -.151** | -.050 |
| | Sig. (2-tailed) | .719 | .592 | .753 | .000 | .560 | .730 | .629 | .119 | .946 | .003 | .657 | . | .721 | .001 | .962 | .001 | .293 |
| privacy? | Correlation Coefficient | .063 | .067 | -.013 | .179** | .116* | -.028 | -.026 | .066 | .095* | .120* | -.024 | .017 | 1.000 | -.089 | .106* | .051 | .180** |
| | Sig. (2-tailed) | .186 | .158 | .779 | .000 | .014 | .549 | .583 | .166 | .045 | .011 | .619 | .721 | . | .061 | .025 | .287 | .000 |
| basement | Correlation Coefficient | .161** | .138** | .141** | -.141** | -.142** | .102* | -.032 | -.159** | .008 | -.104* | .057 | .153** | -.089 | 1.000 | .141** | -.057 | -.341** |
| | Sig. (2-tailed) | .001 | .004 | .003 | .003 | .003 | .032 | .496 | .001 | .865 | .029 | .234 | .001 | .061 | . | .003 | .227 | .000 |
| Wtr damage | Correlation Coefficient | .100* | .135** | .145** | .086 | .061 | -.013 | -.057 | -.089 | .062 | .016 | .166** | .002 | .106* | .141** | 1.000 | -.026 | -.063 |
| | Sig. (2-tailed) | .036 | .004 | .002 | .071 | .199 | .787 | .231 | .062 | .190 | .743 | .000 | .962 | .025 | .003 | . | .583 | .182 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nature pics | Correlation Coefficient | .140** | .123** | .112* | .157** | -.092 | .085 | -.108* | .080 | .014 | .069 | .042 | -.151** | .051 | -.057 | -.026 | 1.000 | .168** |
| | Sig. (2-tailed) | .003 | .009 | .018 | .001 | .052 | .074 | .023 | .093 | .770 | .148 | .372 | .001 | .287 | .227 | .583 | . | .000 |
| own/rent | Correlation Coefficient | .041 | -.003 | -.054 | .204** | -.003 | -.007 | .021 | .366** | .075 | .221** | .078 | -.050 | .180** | -.341** | -.063 | .168** | 1.000 |
| | Sig. (2-tailed) | .392 | .947 | .261 | .000 | .951 | .878 | .654 | .000 | .116 | .000 | .100 | .293 | .000 | .000 | .182 | .000 | . |

# IV. Shining Light in the Built Environment to Improve Mental Health

## Chapter Overview

The purpose of this chapter is to provide military engineers and architects the recommendations to adjust the lighting in the built environment for positive mental health outcomes. This article is backed by research from chapters 2 and 3 while several lighting design factors are discussed. This chapter is intended to bring awareness to the military engineers and architects regarding mental health and the built environment.

## Publication Intention

Title: Shining Light in the Built Environment to Improve Mental Health

Publication Intent: The Military Engineer

## Shine the light in the built environment to improve mental health

**Nathanael Kohl, Capt, USAF; Lisa Brenner, PhD, VA ; Andrew Hoisington Lt Col, USAF**

*Capt Nathanael Kohl is an Air Force Civil Engineering Officer currently pursuing his master's degree in engineering management at the Air Force Institute of Technology (AFIT). Capt Kohl is researching mental health and the built environment through an initiative led by AFIT assistant professor Lt Col Andrew Hoisington.* *This research would not have been possible without the guidance and assistance of Dr. Lisa Brenner and her team at the Department of Veteran Affairs Rocky Mountain Mental Illness Research Education Clinical Center (MIRECC).*

*Summary: Together the Air Force Institute of Technology (AFIT) and the Department of Veteran Affairs Rocky Mountain Mental Illness Research Education Clinical Centers (MIRECC) formed a partnership that is investigating approaches to find built environment adjustments to positively affect mental health outcomes. This article investigates the lighting in the built environment and how it can be used to improve the mental health of our US military members and Veterans.*

Mental Health is one of the many concerns shared between United States (US) active duty and Veteran members. Veterans are experiencing Post Traumatic Stress Disorder (PTSD) and depression at a rate of 20 percent higher than the equivalent civilian population. Although efforts have been made recently, mental health still has a poor stigma for many in the military and is avoided by some people. For active duty, negative mental health outcomes reduce the military warfighting capability and has an economic

burden. Improving a military member's mental health can keep them in the force longer, improve productivity, and enable a more ready force for deployments. Negative mental health outcomes can be treated and even prevented. Together, the Air Force Institute of Technology (AFIT) and the Department of Veteran Affairs Rocky Mountain Mental Illness Research Education Clinical Centers (MIRECC) are in a partnerships to investigate approaches to assist active duty and Veterans mental health.

Engineers may have a role to play in improved mental health of service members through design and renovations in the built environment. The built environment is the physical environment where individuals work and live (Figure 1). Americans spend nearly 82% of their time in the built environment, thus making it a potential rich target for research regarding its impact on mental health. We already know that individuals can be emotionally connected to the built environment, causing feelings of both happiness and sadness. Expanding that basic principal, it is possible that the built environment can influence mental health more broadly. Social scientists and engineers are two professional groups that can study the built environment for factors that may impact mental health outcomes. A promising area thus far has been connecting light in the built environment to mental health outcomes. For example, light in the built environment has been connected to mood, depression, and anxiety. More specifically, bright light therapy (BLT), daylight, and

**Figure 41: The built environment**

artificial light have been proven to positively affect mental health outcomes. Circadian rhythms, mood, and vitality can be improved through BLT. Bright Light Therapy can also mitigate depression, reduce patient recovery time in hospitals by stimulating healing, and decrease symptoms of Alzheimer's Timing of BLT is important; if bright light is applied too late in the day, the positive effects are negated. Bright light is just one example of a built environment factor that has the potential to positively affect mental health outcomes.

The AFIT and MIRECC team are investigating how light may positively influence mental health outcomes in the built environment through an extensive literature review, surveys of active duty and US military Veterans, and analysis of their residential built environment The literature review revealed that individuals subjected to higher levels of natural light (daylight) were more likely to have better physical and mental health. Daylight exposure led to higher vitality, improved mood, lower depression levels, and improved circadian rhythm. The literature also suggested that select artificial lighting, specifically full-spectrum fluorescent lighting (FSFL), has the possibility to improve mental health outcomes. Full-spectrum fluorescent lighting has nearly the same color spectrum as daylight (see Figure 2) with health improvements that include fewer headaches, less incidents of epileptic seizures, and lowers stress levels. Indeed, FSFL mimics that body's natural response to sunlight. For example, one research study found that after 14 days of exposure to FSFL and 14 days of sunlight, the biomarkers of stress were statistically the same.

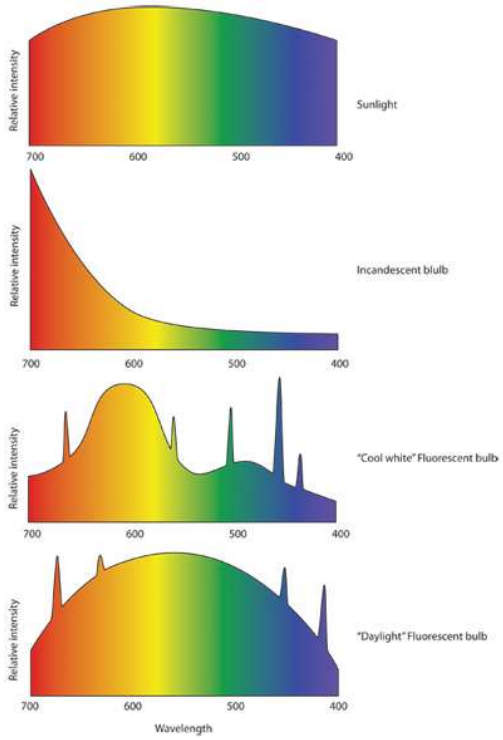


**Figure 2: Different color spectrum of light**

Engineers and architects can make daylight and artificial light modifications to have positive mental health outcomes in the built environment. In order to achieve positive mental health outcomes, light should have intensity equal to 2,500 lux. For comparison, daylight is between 5,000-10,000 lux. At or above 2,500 lux, light can deter seasonal affective disorder (SAD) symptoms, reduce depression, improve mood, improve cognitive ability, and ease other mental health issues. Windows are in nearly every facility, but access to the windows by occupants is important. There might be an opportunity in some facilities to adjust the size of windows or even add additional windows during the design phase of construction to achieve the desired light in some circumstances. The removal of windows to save construction of renovation costs could have unintended consequences for physical and mental health. Artificial lighting supplements daylighting in the built environment; however, it does not fully substitute for daylight. Some changes may require a change in the design stage of construction or may require more strenuous renovation, but these changes may mitigate the rising negative mental health outcomes However, it should be noted that existing building standards do not account for the

required intensity of daylight and artificial light (specifically FSFL) to positively affect mental health outcomes.

It is recognized that the suggested adjustments needed for positive mental health outcomes may be met by skepticism, because this is a new field of study. Without conclusive evidence that light can positively influence mental health outcomes, many engineers and architects will not implement many of the required changes. Another factor of influencing adjustments is the limited budget to renovate existing buildings and construct new facilities. Minor changes, however, can be made with little economic impact. Existing facilities can ensure that windows are not blocked, allowing for the light to flow inside unobstructed. Facilities also can replace some of the current lightbulbs with FSFL with minor economic impact. For example, the energy consumption from the FSFL is nearly the same as the compact fluorescent lamp lighting, thus no upgrades to the facility energy demands are required. Table 1 shows the cost of FSFL compared to light emitting diode (LED) and incandescent. For certain population groups, such as those living in extreme latitudes (such as Alaska), artificial light might be the only available source for light.

Table 1: FSFL vs LED Energy Cost (modified from thesimpledollar.com)

| | FSFL | LED | Incandescent |
|---|---|---|---|
| Total Purchase Price of bulb over 23 years | $6 | $8 | $21 |
| Total Cost of Electricity used (25,000 hours at $0.12 per kWh) | $42 | $30 | $180 |

| | | | |
|---|---|---|---|
| **Total Operational cost over 23 years** | **$48** | **$38** | **$201** |

In a previous AFIT study, Capt Cody Beemer and Lt Col Andrew Hoisington developed a survey to gather information regarding the residences of Veterans involved with MIRECC. This survey, known as the Housing, Occupancy, Materials, and Environment (HOME) survey, gathered information on the Veteran's residences such as age and type of the home, what the views are through the windows, proximity to greenspace and highways, ability to adjust living climate, indoor air quality, and natural lighting. This survey data also included five psychometrically sound measures of mental health to compare against the aspects of the home. The survey was also sent to active duty service members and civilians working for the Air Force. In addition to the questions on the HOME survey, the active duty members also responded to one psychometrically sound measure of mental health. Although still in early design stages, validation of the HOME survey has the potential to allow social scientists and engineers to investigate aspects of the built environment that can positively influence mental health outcomes. To date, there has not yet been a survey that specifically asks questions that are pertinent to the mental health of occupants. Therefore, it is our belief this avenue of research might provide information on where to advocate funding and renovations to improve mental health.

Increasing awareness of mental health and the built environment may help to increase the amount of built environment design changes made in service member's

location. Many adjustments are often low cost if implemented early in the design phase or can be as easy as replacing light bulbs in existing facilities. Negative mental health outcomes are an unwanted problem and increasing the awareness of these issues may lead to more studies on how to improve mental health outcomes. Engineers and architects have a role to play in reducing the negative mental health outcomes associated with the built environment.

# V. Conclusions and Recommendations

## Conclusions of Research

Investigating how light in the built environment influences mental health, my research attempted to understand the following research objectives:

1. Identify aspects of light in current academic literature that influence positive mental health outcomes.
2. Administer the Housing, Occupancy, Materials and Environment (HOME) survey to active duty units across the US Air Force.
3. Analyze both the active duty and Veteran survey results to verify with significance that light positively affects mental health outcomes.
4. Recommend to military engineers the aspects of the built environment that can be adjusted to allow more light to enter the facility based on the findings from the previous two objectives.

To answer the first question, a thorough literature review was completed of the current and historical academic research, summarized in the discussion in the paper, "Connecting Light in the Built Environment to Mental Health Outcomes, A Review." The paper cited 141 references, 102 of which that were peer-reviewed research articles. The literature search stated that daylight and full-spectrum fluorescent lighting has an impact on mental health, which varied between biological and psychological means. The mental health outcomes connected to light in the built environment included improved mood, mitigated depression symptoms, reduced anxiety, lower stress levels, better circadian rhythms, and more. The existing research in the field of light and the built

environment does have limitations. For example, the research focused on hospital studies, clinical studies, and workplace studies on the impacts of light. Indeed, lighting in residences in relation to mental health research was not found and, therefore, represents a possible future research focus. Based on the literature review, there were several recommendations for future research. Mainly, studies need to be completed using standardized methods of measurement, animal models, and interventional studies to validate the connection to mental health. Further investigating light in the built environment may lead to design adjustments to the built environment that have lasting positive mental health outcomes.

The second and third objectives are accomplished in the article, "The Influence of Residential Light on the Mental Health of US Veterans and Department of Defense Personnel." In this article, 210 Veterans and 229 active duty members were surveyed regarding their residential built environment and the SF-36, a psychometrically sound mental health measure of emotional well-being, social functioning, and general health. My study implicated that natural light improves the general health and emotional well-being in the active duty military group. These findings are consistent with academic literature that confirm that light influences both physical and mental health [1], [2]. The positive results for light may be partially affected as natural light enters the home through windows by simulating a connection to nature [3]. Overall, those with lower self-reported natural light ratings had lower emotional well-being and general health SF-36 scores. These results indicated that the natural light rating of active duty and Veteran personnel influences their emotional well-being, thereby impacting their general overall health. The

quality and quantity of natural light entering the home can have a positive influence on our mental health. This opens new possibilities for future research regarding natural light in the residential built environment, but more importantly, a possible intervention strategy for Veteran populations with negative mental health outcomes. However, because this is the first study on residential light, more research needs to be conducted to validate these results.

The third objective was to recommend to military engineers what aspects of the built environment to allow more light to enter the facility. In the article, "Shine the Light in the Built Environment to Improve Mental Health," recommendations to military engineers and architects were provided for lighting changes in the residential built environment of the DoD. The recommended changes were to add more windows to allow more light into the interior of the housing and changing the artificial lighting to full-spectrum fluorescent lighting. Updating the design guidelines for the DoD to include the full-spectrum fluorescent lighting is a relatively inexpensive change. Adding more windows is inexpensive at the design phase of the construction project but would require a large renovation project when the residence is already standing. A cost-benefit analysis of the changes could help identify the most cost-effective changes that influence positive mental health outcomes.

**Significance of Research**

Current Veteran and active duty members mental health outcomes are a concern and ways to improve their mental health must be continued to be investigated. Academic research indicates that light in the built environment impacts mental health in the

workplace, but no literature exists about light impacting the occupants in the residence. Veterans are a high-risk population for negative mental health outcomes; thoroughly understanding how their residence affects their mental health is necessary. This research suggests that using natural light in the residential built environment to influence positive mental health outcomes is possible. Some changes can be made at little effort or cost to the DoD but have lasting impacts of the occupant's mental health. This research will also hopefully provide the VA with a validated process for intervention and treatment of Veterans with mental illness. By introducing some of the discovered adjustments into the homes of the Veterans and active duty members, they may have a healthier environment that leads to improved mental health outcomes. This research does not suggest that this is the cure for mental illness, but rather, another avenue to Veteran and active duty mental health care.

**Recommendations for Future Research**

Time constraints limited this study as the Veteran data can only be collected from those Veterans who are at the Rocky Mountain VA. The Veterans also will be given another round of surveys every six months and data needs to continually be collected for analysis. The ability to back the light adjustments with validated statistical power will allow a psychiatric diagnoses and changes made in the Veteran and active duty residential built environment that lead to positive mental health outcomes. After the changes have been made, the Veteran and active duty homes can be re-evaluated every six months. This will allow for future researchers to do a field study how changing our light in the built environment influences mental health outcomes.

A field study of how changing the built environment study will be able to be conducted through the Veteran study. Making residential changes to the light and monitoring the changing mental health outcomes will bring causation to the research study. When causation is established, changing the survey from self-reported to an experiment-based analysis of the built environment of our Veteran and active duty members. Research should also investigate the effects of light at different latitude and longitudes, different artificial lighting in the home, and different orientations of the home. These steps into future research will allow engineers, architects, and social scientists to make validated changes to the built environment to have positive mental health outcomes of those afflicted with mental illness.

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**14. ABSTRACT**

Current mental health statistics for US active duty and Veteran members justify research into the causes and remedies for those plagued with negative mental health outcomes. Recent research has suggested that the built environment is connected to our mental health. This study investigated this connection with active duty and Veteran populations across the US. A literature review was completed on what factors of light in the built environment affects mental health outcomes. An analysis of active duty and Veteran mental health symptoms and the natural light rating in their residence was completed to understand the design changes that can be implemented to positively mental health outcomes in their built environment. Finally, application of the results, the cost and benefits of designing and implementing built environment changes are discussed for positive mental health outcomes for our military personnel.

**15. SUBJECT TERMS**
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