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A systematic review on the therapeutic lighting design for the elderly

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Abstract

Research suggests that specialized lighting design is essential to cater for the elderly users of a building because of the physiological changes in the eye with increased age. Recent studies have established that lighting in a space impacts on users' physical performance as well as on the mental state. In particular, light therapies have been found to be successful in treating several mood disorders in the elderly. Nevertheless, information relating to the therapeutic performance of lighting is scattered and comparatively less studied in built environment research. This review aims to identify the criteria for the therapeutic lighting design for the elderly and to discuss its applicability on contemporary design practices. Methodologies adopted for this study include a systematic review of literature to synthesize recent research findings and an evaluation of lighting guides published by the regulatory bodies and professional institutions to identify current practice.

The review identified that there are substantial amount of evidence exists, which can be incorporated during elderly lighting design to increase the therapeutic performance of the space. Apart from enabling the users to navigate safely and perform routine tasks, the therapeutic performance of lighting is significant to enhance elderly wellbeing. Depression, delirium, sleep disorder and disorder in the circadian system are common mood disorders among the elderly, which are evidently influenced by the lighting environment. Advancements in lighting technology, in particular in low energy Light Emitting Diode (LED) lighting have led to new approaches to meet detail photometric parameters to construct the desired therapeutic environment. Our understanding of the photo-biological effects of lighting has enhanced, however the evidence is not well integrated with design guidelines. The research reported here has made an attempt to bridge this gap by developing a comprehensive knowledge base of the therapeutic lighting design for the elderly.

Keywords: elderly, lighting, therapeutic design.

1. Introduction

Visual ability declines with increased age due to physiological changes in human body. Decreased visual acuity causes difficulties in different cognitive activities related to vision, however, visual perception of an elderly person depends on the individual's specific circumstances. Reduced contrast sensitivity with depth perception, glare sensitivity, light-dark adaptation and low vision are all primary visual predicaments among elderly (Lord 2006, Boyce 2003, CIE 1997). These create different visual and lighting requirements for older adults compared to younger people. Apart from these, lighting is also significant for Vitamin D synthesis for human wellbeing.

Along with the physical requirements our understanding of the photo-biological effects has enhanced over the recent years. Direct relationship of lighting has been established in reducing different mood and circadian system disorders among the elderly. These theories can enhance the existing lighting design practice by incorporating therapeutic performance into integrated lighting system. Advancements in lighting technology, in particular in low energy Light Emitting Diode (LED) lighting, have extended the opportunity to control photometric parameters to create therapeutic lighting environments. However information regarding therapeutic lighting is scattered and still not discussed in details in guides. To get the full potentials of the generated evidence into practice there is necessity to collate the evidences and investigate their applicability. Another question is that, what are the particular design parameters to consider in designing therapeutic lighting? As lighting design involves specific illumination and luminance objectives to meet, there is a need to understand the full configuration of therapeutic lighting to incorporate into integrated lighting system.

This paper identified key design modifiers of lighting and the visual environment for the elderly, considering the physical and psychological aspects based on existing evidence and their suitability for application. The paper also highlighted the issues require further attention in future lighting guides.

2. Methods

The study was conducted by methodical literature search within electronic and manual resources. Four electronic databases were searched which were containing numerous journals and abstract indices of health, medicine and the built environment. Table 1 shows the searched databases and initial hits. Advanced search were conducted within these databases by the keywords as described in Table 2. Keywords were separated in four word groups and the groups were combined by "And" during the search process.

Table 1: Electronic databases searched and initial hits

Electronic databases searched	*Number of initial hits*	*Refined for abstract review*
Pubmed	*296*	*121*
Sciencedirect	*593*	*183*
Web of science	*545*	*131*
Ovid MEDLINE	*61*	*61*

Apart from the published journal articles and books, lighting guides from the following 4 organizations were evaluated. They were, the Chartered Institution of Building Services Engineers (CIBSE); Commission International de Eclairage or International Commission on Illumination (CIE); British Standards (BS); and Illuminating Engineering Society of North America (IESNA).

Table 2: Searched keywords and associated groups.

Groups	*Keywords*
People	*Elderly OR Senior OR Age* OR Older OR Aging*
Environment	*Light* OR Colour OR Color OR Visual OR Vision OR chromat**
Disease	*Impair* OR mood OR disorder OR depression OR Mental OR Circadian OR Sleep OR Disorder OR Behaviour OR Behavior*
State/Action	*Fall OR Falls OR (Way and Finding) OR Navigation OR Psycholog* OR Balance*

Before starting the systematic search a preliminary study was conducted to gather an overview of the topic covering different visual disease of the elderly, physical demands of light and lighting for adequate visual performance, and impact of lighting in mood disorder treatments. Based on the preliminary study search keywords were identified to proceed for systematic search focused on therapeutic design of elderly lighting. Core topic identified from initial study which were believed to be related with lighting, and health and safety of elderly are, Falls, Circadian system or sleep disorder, Seasonal and non-seasonal affective disorder, and Restless or agitated behaviour. Analysing these topics keywords (Table 2) were identified used to describe the common typologies in academic journals/articles. Again search process was divided into two major steps. First search stage was the combination of keywords from People, Environemnt and Disease groups; and second search stage was constructed by People and State/Action keyword groups.

After gathering the initial hits the selection of articles were screened within the search engine by applying several inclusion and exclusion criteria. The elaborate list of this criteria for each database is not presented here. The key inclusion criteria to limit initial hits were, Subject type: Humans (Male, Female); Language: English; Journals from core clinical areas, nursing journals, vision research and applied ergonomics journals, gerontology and geriatrics archives, psychology and ageing journals, experimental medicine journals, behavioural sciences, etc.

Within these selected articles, further screening were conducted by reviewing of abstracts and finally 74 articles were selected to review thoroughly.

3. Findings from the study

The review identified two major domains of elderly lighting are based on physical and psychophysical impact of lighting. Physical needs are primarily required due to the changes in the visual system in increased age. This domain of elderly lighting is comparatively more studied and discussed elaborately in published books and guides, whereas information regarding the impact of lighting on psychophysical aspects are scattered and discussions in guides are with less details. In this study psychological impacts are discussed in details, also physical lighting design parameters those are associated with elderly health and safety (e.g. falls, way finding) also addressed. A summary of the domains of elderly lighting are described in Figure 1.

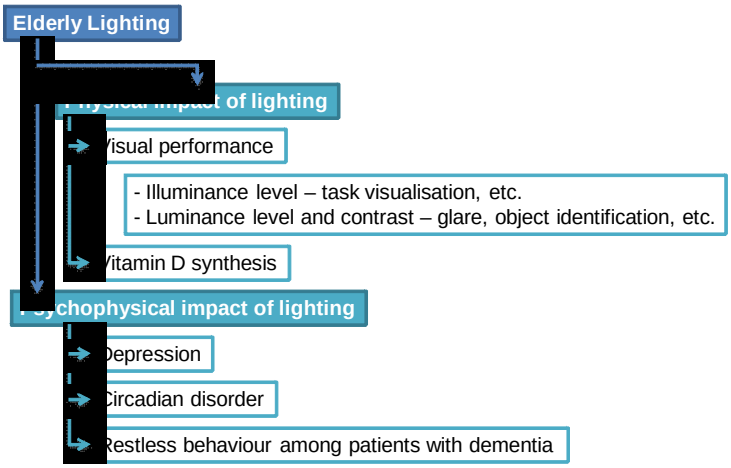


Figure 1: Domains of lighting for the elderly.

3.1 Physical impact of lighting

Ageing brings about physiological changes to the human body, which also affects optical system. With increasing age, the following normal age-related changes occur in the eye (Weale 1963; Boyce 1973), gradual decrease in accommodation; increased absorption of light in the ocular media; increased scatter of light in the ocular media; and decrease in pupil diameter. In addition to these changes, older people are affected by pathological transformations in visual system which causes Age-related Macular Degeneration (AMD), Cataract and Glaucoma. People who suffer from diabetes and hypertension also suffer with Retinopathy (Boyece 2003, Sturnieks 2008). Suffering with one or more of these disease generally cause reduced contrast sensitivity, poor night vision, slowed light-dark adaptation, visual acuity, reduced depth perception and visual field loss, and lead to difficulties in vision related cognition activities (Boyce 2003; CIE 1997, Sturnieks 2008).

Object identification and change detection are the two primary difficulties in vision related cognitive activities among the elderly, which are caused by reduced contrast sensitivity, reduced depth perception and visual field loss (Lord 2006; Nevitt et al. 1989). These disabilities lead to reduced obstacle avoidance ability and balance disorder and cause falls. Studies suggest that lighting can play significant role in reducing falls (Strunkies 2008; Boyece 2003; Lord 2006; Kooijman et al. 2005). Abdelhafiz and Austin (2003) stated poor lighting or inadequate floor finishes as the two main causes of falls; visual impairment is also believed to be associated with accidental falls causing hip fractures. And increasing the visual ability of elderly will contribute in reducing falls and in turn will save medical and care expenses. Luminance contrast is particularly important for older people to identify spatial objects. It allows one to identify the edge of objects, where reduced edge-contrast can lead to predispose oneself over obstacles (Lord 2006). Increasing the illumination level and luminous contrast will increase the visual performance for elderly and enhance navigation through spaces (Rea 1986; Rea and Oullette 1991; Boyce 2003b; Kuyk et al. 1996). Static luminance is preferred by the elderly when identifying objects (Blake et al. 2008, Akita et al. 2004).

Other aspects like change detection and visual search also can impact on navigation ability for the elderly within the built environment. Older adults take longer to detect changes than younger adults (Veiel et al. 2006), particularly they take longer time in final fixation of targets (Ho et al. 2001). Decreased adaptation time is identified as one of the key reason for declined visual search and change detection time, however other than physical aspects psychological behaviour also can be responsible for final fixation of targets. Change detection also requires additional memory to only visual search (Veiel et al. 2006). Maltz and Shinar (1999) noted that older adults are more likely to investigate an area repeatedly and took longer time for fixation in identifying any object due to their cautiousness and a tendency to recheck their decision. Psychological or mental condition tend to have an effect on behaviour within the built environment as well; however, interaction with built environment can be guided by their daily practice. Such as visual environments in their dwelling can be expected to be more static and habituated by daily practice, whereas visual environment of public or other places might have a deeper involvement with their psychological behaviour as well as physical ability. Visual search and change detection certainly can play a role in navigation and way-finding for the elderly. The above findings indicate that rapidly changing elements can affect their reaction ability and in some cases may cause confusion in effective decision making.

3.2 Psychophysical impact of lighting

Apart from the physical needs recent studies developed evidence base on the impact of lighting on mood disorders and psychological behaviours among the elderly. The review identified the major areas, where direct relationship between light and psychological behaviours are established. These finding are focussed on depression, circadian rhythm and restless behaviour among patient with dementia. A summary of these findings are discussed in Table 3 in a structured format and a general discussion has been conducted in next sections.

Table 3: Significant findings of light therapies in mood disorder and circadian system treatments in last ten year period.

Author	*Type of disease*	*Type of therapy*	*Methodology*	*Light output*	*Length of treatment*	*Result*
Lieverse et al. (2008, 2009)	*Non-seasonal major depression for elderly*	*Bright light in elderly subjects*	*Light box with high intensity blue and dim red light*	*Bright light: 10,000 lux at 40 cm distance;* *Dim red light: less than 50 lux*	*One hour each day for three weeks, participants were taking breakfast or do some reading*	*BLT reduces non-seasonal depression among the elderly. Additional lighting can be installed in the homes to treat depressed patients.*
Hoof et al. (2009)	*Behaviour with circadian rhythmicity and nocturnal restlessness for adults with dementia*	*Blue and yellowish high intensity light*	*A room with ceiling mounted luminaires with 6500K and 2700K which provide 1800 lux over table surface*	*1800 lux over table surface*	*Not fixed*	*High intensity bluish light significantly improves restless behaviour and circadian rhythm disorder*
Terman and Terman (2005)	*SAD for all age groups*	*Bright light*	*Light Box*	*10000 lux*	*30 mins*	*Most effective for SAD treatment*
Terman and Terman (1997)	*SAD and sleep awake for age groups*	*Dawn simulation*	*Gradually increases light levels from .001 lux to ~300 lux for 90 mins or over, before actual sunrise during winter*	*0.001 - ~ 300 lux*	*90 mins or over*	*Effective for morning awake and remove morning drowsiness*
Figueiro (2002, 2005)	*Sleep disorder for patients with Alzheimer*	*Exposing to blue LED*	*Blue LED table top luminaires along with regular ceiling fluorescent lamp luminaires*	*30 lux at the cornea from blue or red LED, ambient light around 300 lux on table*	*2 hours, between 6:00 pm-10 pm for 10 days or, 2 hours, 4:30 pm - 6:30 pm*	*Blue light exposure significantly improved sleep disorder*

Gasio et al. (2002)	*Sleep disorder for elderly*	*Dawn-dusk simul-ation (DDS)*	*DDS system with white light, system configured for two dates/latitude . They were, 10th April at 38ºN and 1st of July at 29ºN*	*Minimum light 0.001 lux and maximum light ~210 lux at 30 cm distance from the diffuser*	*Dusk lasted for 44 mins and dawn 34 mins for 38ºN. For 29ºN dusk and dawn both lasted for 30 mins.*	*Circadian timing system remains functionally responsive and induced a small advance in circadian rest in low intensity DDS light. DDS light therapy can contribute to improve sleep quality by increasing 'zeitgeber' strength.*
Kobayashi et al. (2001)	*Sleep disorder for elderly with and without dementia*	*Bright light in light therapy room*	*Bright light exposed in light therapy room*	*~8,000 lux at eye position*	*For one hour during lunchtime from 11:30-12:30*	*Difficulty in falling asleep and drowsiness in morning declined during light exposure in eight patients among ten. The score of drowsiness decreased in afternoon during post light exposure. Clinical ratings of sleep-wakefulness improved for eight patients.*

3.2.1 Depression and lighting

Though the extent is not accurately known, nursing home residents suffer a widespread depression (Abrams et al. 1992). Biderrman et al. (2008) implied that this suffering is usually neglected and can affect the quality of life. Winter depression or Seasonal Affective Disorder (SAD) are very common among the elderly in nursing homes. The English Longitudinal Survey of Ageing (ELSA) measured mental health state by widely used T-12 item General Health Questionnaire (GHQ-12) among elderly in 2002; 20% of men and 28% of women were classified as depressed according to this study (Soule et al. 2005).

Different treatments demonstrate successful use of light therapies in reducing these disorders. Bright light therapy (BLT), light box method, whole-room method, head mounted units and dawn-dusk simulation (DDS) are major methodical ways to reduce mood disorder related to

light treatments (Terman 1997). General recommendations suggest adequate light levels by both daylight and artificial lights encourage in reducing depressions.

3.2.2 Seasonal and non-seasonal affective disorder

For SAD, Treatments of 10000 lux for 30 minutes were found most effective, with remission rate of 75%. Another earlier study showed that comparatively lower 2500 lux for two hours have similar success in remission rates (Terman and Terman 2005). Morning treatments were found to be more effective than midday or evening treatments, however, these studies were not particularly focussed on elderly subjects, but general treatments of depression are expected to be considerable for elderly. The American Psychiatric Association Committee on Research in Psychiatric treatments concluded that bright light and dawn simulation treatments (for non-seasonal depression and SAD) are effective as most antidepressant pharmacotherapy trials (Golden et al. 2005). A recent study by Liverse et al. (2009) identified the success of light therapy (High intensity blue) among the patients with dementia and concluded that lighting system of patients' home can be modified to serve as antidepressants or as stand-alone treatment for the depressed elderly patients.

Light therapy treatments are generally mild and not completely without side effects. Headaches, eye strain, nausea, jumpiness/jitterness etc. are a few side effects observed to be related to the treatments. Except these, the tendency to commit suicide has been found among a few patients after or during light therapies. These entails that a more cautious approach is taken for the implementation of light therapies (Terman and Terman 2005). Additionally, another problem of light therapy is the daily time commitment for patients.

3.2.3 Circadian system and sleep disorder

Dawn simulation was found successful in stimulating circadian system and reduce depression (Golden 2005). It simulates sunrise during winter earlier than actual sunrise by gradually increasing for 90 minutes or over from 0.001 lux (starlight) to around 300 lux ("sunrise under tree cover") while the patient sleeps (Terman and Terman, 2005). Several studies suggest dawn simulation significantly increase awakening performance and reduce drowsiness (Avery et al. 2002, 2004; Golden 2005). Also Kohsaka et al. (2000) identified elderly exposed to bright light for short duration in morning have better wake up and sleep cycle. Terman and Terman (2005) stated that the performance of dawn simulation depended on the appearance of diffuse and broad-field illumination which reaches patient in different postures. Such efficiency is not present in all commercially available devices with small directional light distribution.

Few other studies also showed success in managing circadian rhythmicity. Particularly recent studies demonstrate that exposure to high intensity blue light for a specific time of day increases sleep-wake cycle for older patients. A study by Hoof et al. (2009) among demented elderly, provided exposure to blue light (6500 K CCT) with 1800 lux over table surface installed in dining and visitors area for three weeks time period alternatively with a yellowish light (2700 K CCT) for two weeks. The study measured restless behaviour and circadian rhythmicity among

users and concluded that a high-intensity blue light can contribute in managing restless behaviour and improving circadian rhythmicity among demented older adults. However, Forbes et al. (2009) suggested that the evidence those established relation between lighting and behaviour among patients with dementia are still inconclusive and further research is required.

Studies by Figueiro (2002, 2005) demonstrated, that the use of low intensity blue LEDs for two hours at evening improved sleep efficiency for older people. The patient group sampled for the test were elderly suffered with Azheimer's Disease and the result showed significant improvement in sleep disorder for most of the patients. This study was based on the knowledge that circadian system is sensitive to short-wave length radiation (Brainard et al. 2001). Followed by these findings Figueiro (2008) described a 24 hour lighting system for elderly where exposition to blue LEDs are suggested. For circadian system it is found that narrowband blue light is highly successful. Considering these aspects, a 24-hour lighting system has been designed by Figueiro to provide: high circadian stimulation during the day and low circadian stimulation at night; good visual conditions during waking hours; and nightlights that are safe and minimise sleep disruption. Daylight is given high importance for correct circadian stimulation, and the lighting scheme suggested that "ratio of daytime to nighttime light exposures may be as important as the absolute light levels for circadian entrainment (Figueiro 2008) ." It is also suggested that future lighting systems should consider proper design of light/dark pattern that can improve sleep efficiency for the elderly. The author also suggested that progressive architects can follow these early findings when designing physical spaces for the elderly.

These results show an improvement in recent studies on the impact of light in managing sleep disorder and circadian rhythms. It can be expected in future these findings will be implemented in lighting design for elderly to achieve better circadian rhythm management and sleep-wake cycle.

3.3 Lighting guides and recommendations

Lighting regulations are available in different regions and countries. In North America, the Illuminating Engineering Society (IESNA) publishes lighting regulations. European Standard EN 12464-1 binds standard agencies of 20 European countries including British Standards (BSI) in the United Kingdom. In UK Chartered Institution of Building Services Engineers (CIBSE) publishes lighting design guidelines, which again complies with International Commission on Illumination (CIE) guides. Specific lighting regulation for the elderly and low vision are found from CIE Low Vision (1997) and IESNA Lighting and the Visual Environment for Senior Living (1998). CIBSE and British Standards (BSI 2002) does not provide any separate lighting guide for elderly or low vision. A review on these guides identified that, lighting regulations are generally covered by illumination levels in 'lux' with suggestions of distribution guidelines. Luminance distribution guidelines are specified in descriptions rather than in photometric units. Although discussion on the necessity of natural and bright light is highlighted, specific recommendations are not covered about the amount of daylight an

individual required with therapeutic performance of lighting. A brief review on guidance published by these institutions (CIBSE, CIE and IESNA) on two primary lighting design modifiers, illumination level and luminance distribution are discussed below.

Illumination level is well described in guides. IESNA (1998) and CIE Low vision (1997) prescribed lighting recommendations for separate spaces like bedrooms, living rooms, kitchens, entrance etc. Individual task lighting is given in preference for low vision people for better visual performance. Guidance on luminance distribution is found in qualitative descriptions rather than quantitative measuring units. Among the guides IESNA (1998) describes the derivation of contrast sensitivity of objects through contrast formula considering veiling luminance. This type of mathematical derivations of contrast can be useful in a systematic evaluation of a designed space. However, the guides lack in defining the luminance environment parameters precisely. Luminance and contrast threshold for individuals suffering specific disease are not discussed. CIBSE Lighting Guide 2 (2008) is a specific guide for hospital and healthcare environments, which provides recommendations on maximum luminance of surfaces and light sources from viewing angles for vertical and ceiling surfaces (maximum 1500 cd/m2 for vertical walls). A set of recommendations similar to these might be useful for elderly lighting recommendations but not presented on existing elderly and low vision guides. High contrast is also suggested to ensure readability of signs and bulletin boards; however a suggestion in quantifiable units to define optimal high contrast for specific group of people like elderly or low vision is not discussed in details.

4. Discussion

4.1 Design parameters for therapeutic lighting

Illumination level, spatial distribution of illuminance and luminance, and colour contrasts are established lighting design considerations for the elderly. The impacts of these parameters vary for specific treatments and demand customisation to suit the circumstances. Although the evidence exists in the healing of mood disorders, circadian disorder and restless behaviour, these are not well established in lighting design practice. Bright light therapy and dawn simulation in reducing depression and circadian disorder (Terman & Terman 2005), and blue LED therapy (Figueira 2008) in treating circadian disorder are proven methodologies. Generally mood disorder treatments through lighting are configured by illumination level (lux), chromaticity of light (Correlated Colour Temperature), duration and time of the day. For therapeutic lighting design time and duration are new parameters that added up with physical lighting parameters. A summary of light therapies are given in Table 4.

Table 4: Summary of light therapies in illumination level, light spectrum, duration and time of day (Figuera 2008; Terman & Terman 2005).

Therapy	*Disease*	*Light level (lux)*	*Chroma-ticity*	*Duration*	*Time of day*	*Authors*
Blue LED	*Sleep disorder*	*30*	*Blue*	*2 hours*	*evening*	*Figueiro (2002, 2005)*
Bright light	*SAD*	*2500*	*4000 K*	*2 hours*	*mornin g*	*Terman & Terman (2005)*
Bright light	*SAD*	*10000*	*4000 K*	*30 mins*	*mornin g*	*Terman & Terman (2005)*
Dawn simulation	*SAD and sleep awake*	*0.01-300*	*--*	*90 mins or over*	*mornin g*	*Terman & Terman (1997)*

4.2 Revision of lighting guides

Noell-Waggoner (2006) emphasized on the lack of lighting regulations or standards for nursing homes. Existing recommendations consider required illuminance levels but the effect of photo biological needs are not considered. Studies found that community living dwellers are exposed to higher levels of bright light (necessary for vitamin D synthesis) compared to the residents living in nursing homes. As a result, nursing home residents experience more falls, hip fractures and sleep problems.

Significant evidence is available on the impact of light on circadian rhythm and mood disorder treatments. In the case of depression, different methods already showed success and developed evidence base. Incorporation of these suggestions into built environment has the potential to create a better therapeutic lighting environment for the elderly. The integration of lighting systems with seasonal and environmental response can help in reducing winter or seasonal depression, though methodological research is expected in implementing these findings into lighting system design. Incorporating lighting system for winter depression particularly can be important for high latitude countries where diurnal length is short enough to stimulate disorder. Collaboration among physicians and designers can find a desired solution in designing lighting environment considering these newer theories. Specific guidelines are required to strengthen the knowledge of therapeutic aspects of lighting and its application in real practice.

Review also identified the importance of luminance contrast in lighting design for the elderly. Luminance environment can be critical as contrast or luminance threshold varies widely depending on individual's visual ability and acuity. Such as, an individual suffering from Cataract tend to be more sensitive with higher luminance where increased illuminance level can have adverse effects in visual performance if the distribution is not optimal and surface produce high luminance due to reflections. Similarly different age related diseases demands specific lighting and visual environment to reduce vision related difficulties. A range of luminance and contrast ratio threshold for specific low vision people is desired for quantitative evaluation to define environmental luminance contrast for the disease specific individual.

Contrast and luminance threshold also increase with adaptability and knowingness of activity or space, however for patients with dementia or other disrupted psychologically diseased elderly, contrast threshold might vary widely as they forget the environment or activity. The guides also lack in discussing recent use of LED technology incorporating vertical light sources. Detail luminance distribution design guidelines to optimise vertical lighting design is desired to ensure safety and reduce unexpected discomfort and disability glare from vertical light sources.

5. Conclusions

The review has covered different aspects of elderly lighting from physical and therapeutic aspects. The aim of this review was to identify key design modifiers of lighting and visual environment for the elderly and evaluate their current state of application. The review discussed various lighting design modifiers and highlighted significant parameters in photometric terms to enhance the therapeutic design. Importance of lighting in ensuring safety, navigation and task performance is well established. Along with this the review identified that, recent studies demonstrate ample evidence on therapeutic performance of lighting. However, implementation of these theories into built environment design is not well established. This review also discussed existing lighting regulations and its limitations. To realise the full potential of lighting design in enhancing therapeutic aspects, guidance in quantitative terms is necessary. Therefore, a revision of lighting regulations is suggested.

There is a growing support for evidence-based design in the built environment, in particular in the therapeutic and healing aspects. With regard to therapeutic and healing aspects of elderly lighting, a substantial knowledge base is required to guide design decision-making. Through the state-of-the-art review, this study has developed an evidence base to support therapeutic design of elderly lighting.

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