An Ergonomic Criteria for Domestic Lighting Design and Evaluation

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Abstract:

Statement of the problem: lighting design relies on natural and artificial light sources to provide visual comfort in comfortable spaces. However, there is limited knowledge about ergonomic lighting design in interior spaces. Multiple and homogeneous lighting design approaches can create uncomfortable and un-holistic environments. A comprehensive and harmonious lighting design approach with specific design criteria is needed. **Objectives:** The aim of this paper is to provide designers and non-specialists awareness of the design and judgment and lighting conditions. The ultimate goal has been to develop guidelines for ergonomic criteria for the proposal, design, and evaluation of lighting conditions in domestic spaces. It also targets the establishment of an ergonomic evaluation criterion for domestic lighting based on the functions of home activities. And to validate the established criterion through case analysis of residential units, taking into consideration the levels of visual comfort and accessibility. **Significance:** The study suggests operational definitions, measurable variables, and manipulation strategies for light installations, allowing luminaires and controls to be adjusted based on current conditions. Strategies should be designed to analyze lighting designs and identify dysfunction. The study also guides a gradual transition from a lighting design with performance defects to evaluations without defects, considering the systematic impact of light variation strategies, avoiding blind or intuitive implementation. **Method:** This study has established a controlled criteria and evaluating lighting quality in family rooms, bedrooms, kitchens, and computer workstations in home environments through an inductive approach. Using an analytical descriptive approach, the study outlined lighting systems, fixture selections, light sources, dimming automation, task/ambient lighting ratios, luminance levels, lamp distribution patterns, and existing installations in domestic activity areas that don't meet the developed design criterion. **Results:** The study examined the design of interior and exterior residential lighting, focusing on artificial light distribution, lamps, luminaires, surface and ceiling lighting, and their visual impact. It also explored how activities influence lighting design and evaluated visual comfort methods. The study developed an ergonomic evaluation criterion for domestic lighting, including base formulas and numerical values, to analyze domestic lighting accessibility. The study will validate the proposed criterion through case studies of residential units, considering visual and theoretical analysis, and the influenced home activity type.

Keywords:

Ergonomic Criteria, Domestic Lighting, Design Evaluation, Lighting Fixtures, Illumination, Visual Perception, Visual Comfort

Paper received July 09, 2022, Accepted September 28, 2022, Published on line November 1, 2022

1. Introduction

The interior lighting design depends on natural and artificial light sources to support the visual comfort needed in comfortable spaces. Nevertheless, there is limited knowledge about lighting design in the interior space to support the visual needs ergonomically. Lighting design approaches are multiple and homogeneous for individual spaces which can lead to both a visually uncomfortable and unholistic environment. Hence, there should be a comprehensive and harmonious lighting design approach with specific design criteria concerning support of visual needs ergonomically (McKee & Hedge, 2022).

Light is electromagnetic radiation perceived by the eye and interpreted by the brain. The eye is a sense organ with a lens, retina, and optic nerve. The structure and function of the human eye influence the choice and characteristics of light sources, luminaires, and lighting systems, as well as different lighting strategies. It can be divided into scotopic, mesopic, and photopic vision based on illumination level. Concerning the automatic and voluntary functions of light, vision can be divided into ecological, comprehension, and proprioceptive vision (Boyce, 2022).

Man's advancement in science and technology has resulted in lives becoming more comfortable. It has also expanded day-to-day problems threatening the reliable conduct of everyday life. Light is essential for the accomplishment of routine activities. Among the comfortable illumination systems in

Citation: Ahmed Moustafa (2022), An Ergonomic Criteria for Domestic Lighting Design and Evaluation, International Design Journal, Vol. 12 No. 6, (November 2022), pp 377-402

development, domestic lighting is thought to be important due to a greater per capita use of domestic lamps. According to Pode, (2020) Domestic lighting not only increases the comfort of everyday life but also affects the reliability of accomplishing domestic activities and the practicality of spaces. However, this skilled domain of man-machine systems has been mostly ignored in development, design, and evaluation standards.

Domestic lighting is essential for comfort and visual performance in living, working, and relaxing areas. It should satisfy visual tasks, make objects more visible, and prevent glare discomfort. Office environments should be designed to avoid visual stress and fatigue, while domestic lighting should make workers feel relaxed and convenient. Fulfilling this study's objective will result in an intelligent house with appropriate satisfaction levels. The study of user interior perception, which describes the feeling of an interior environment created by users themselves, is becoming increasingly important. It encompasses the atmosphere, image, action, behavior, intention, and judgment that characterize the feeling of space within a building. (Gerhardsson & Laike, 2021).

1.1. Statement of the problem:

lighting design relies on natural and artificial light sources to provide visual comfort in comfortable spaces. However, there is limited knowledge about ergonomic lighting design in interior spaces, especially the domestic environment. Multiple and homogeneous lighting design approaches can create uncomfortable and un-holistic environments. A comprehensive and harmonious lighting design approach with specific design criteria is needed.

1.2. Research Objectives

The aim of this paper is to provide designers and non-specialists insight into the complex connection between human judgment and lighting conditions. Ultimately, the goal is to develop guidelines for ergonomic criteria for the proposal, design, and evaluation of lighting conditions in domestic spaces. Objectives can be classified into general and specific objectives:

General objectives:

1. To establish an ergonomic evaluation criterion for domestic lighting based on the functions of home activities.
2. To validate the established criterion through case analysis of residential units, taking into consideration the levels of visual comfort and accessibility.

Specific objectives:

1. To review the design considerations of interior and exterior residential lighting, with a focus on artificial light distribution, lamps and luminaires, surface and ceiling lighting, and their visual impact. Additionally, to understand how activities positively or negatively influence lighting design.
2. To review individual and joint desktop evaluation methods for visual comfort, and to summarize the visual comfort indices A, D, Lm, and Lb. Additionally, to understand how lighting conditions affect viewing tasks.
3. To experimentally develop an ergonomic evaluation criterion for domestic lighting, including a set of base formulas and numerical values, to be used in the ergonomic analysis of domestic lighting accessibility. This includes:
   - Setting up a range of practical home activities to be used in the analysis.
   - Conducting a detailed study of individual lighting accessibility, considering the level of luminance, contrast, glare, and flooding area.
   - Establishing resultant ergonomic indices of the assessment criterion and numerical values for error level and range of individual indices. This will be done through case studies of residential units, incorporating the effects of visual and theoretical analysis, as well as the influenced home activity type, to validate the proposed criterion.

1.3. Significance:

The significance of this investigation lies in:

1) The study proposes operational definitions, measurable variables, and manipulation strategies for light installations where luminaires and/or automatic and/or manual controls could be modified according to the current conditions and requirements. However, strategies should be designed to form a set of alternative conditions to help better analyze the lighting designs and clearly show suspects of dysfunction.
2) It helps form a gradual transition from a given lighting design that has revealed some defects in performance to the evaluation of other designs without defects. The important point here is to account for the systematic impact of light variation strategies, avoiding making them blindly or, if possible, intuitively.

1.4. Methodology

The research used a combination of qualitative and quantitative methods to address a research problem. For creating an ergonomic lighting design criterion for domestic activities and evaluating the existing lighting systems and designs a criterion was developed using an inductive approach. An analytical descriptive approach was utilized for developing the lighting criterion, the lighting quality of the family room, bedroom, kitchen, and computer workstations in living setting using the methods introduced by Fusaro & Kang, (2021). Same approach was used for outlining lighting systems, fixture selections, light sources, dimming automation, task/ambient lighting ratios, luminance levels, lamp distribution patterns, and existing lighting installations in domestic activity areas that don't meet the developed design criterion. As was suggested by Durmus et al., (2020).

This study investigates the behavioral ergonomics of lighting designs for domestic activities, evaluating ergonomic design criteria and evaluating existing designs for standard activity areas.. (Osibona et al.2021).

A variety of understanding levels on applied lighting systems for domestic activities that affect occupancy behavior were elicited through the selection of three coupled questionnaires. The findings revealed that behavioral discrepancies exist between the stated dimensions of lighting design that are well-understood and issues that are lesser-known dimensions of incumbent behavior towards lighting designs that ought to be understood and considered to develop setup and re-evaluate urban and rural lighting design installations (Heydarian et al.2020). This research focuses on the behavioral ergonomics of lighting designs for domestic activities to develop an ergonomic lighting design criterion for domestic activities, evaluate the existing lighting systems and designs in terms of the developed criteria, state the defects or non-compliance issues of the evaluated design criteria on those designs that do not meet the developed criteria, suggest rectifications or point out the need for further expert assessments for those defects or non-compliance issues, and generate a general understanding of lighting systems or designs in the residential quarters.

An ergonomic lighting criteria database was created and used as a case study to analyze the impact of lighting designs. Expert designers were interviewed to estimate design creation and awareness of benefits. Data from interviews was categorized and framed to identify missing links between the system and suggestions.

The research process involved five independent steps to answer subquestions. Each step built upon previous results, such as case studies based on the design criteria database and lighting designs. Descriptive analysis and expert interviews were used to gain insight into design creation in the DR. The results are complementary, providing a comprehensive answer to the initial research problem.

The research process involves making difficult decisions about the research avenues and paths, balancing ambition and feasibility. Factors such as time frame, tools, resources, constraints, and sustainable alternatives contribute to the process. However, decisions regarding limitations and choices are often overlooked. Aesthetics are often overlooked in data analysis and qualitative methods, despite the research's ambition and expertise.

1.5. Data Collection Methods

The research used a mixed-method approach, involving advanced multi-sensory analysis and human subject studies to evaluate lighting conditions in domestic environments. The study involved full-scale measurements of illuminance, CCT, light source spectra, and other parameters, along with analyses of psychological effects like illuminance adaptation, mood, comfort, preference, and emotional responses. Quantitative data analysis included lighting design provisions, salience measures, and vision parameters. Qualitative explorations were obtained through focus group interviews. The research also assessed the potential of advanced low-cost sensing technologies in lighting design. The study provided empirical knowledge on emotional responses to lighting design opportunities and focused on specific effects of visual-spatial, color-temporal, and spectral composition parameters in domestic environments (de et al.2021).

2. Theoretical Framework

The provision of sufficient artificial lighting in homes and the workplace is fundamental for visual effectiveness and comfort during daytime and evening hours. However, many houses and apartments lack proper illumination. Inherently, inadequate lighting leads to safety and health problems. Vision safety is critically dependent on ambient lighting since the risk of accidents is a function of the luminance vision of the environment. Domestic lighting must meet the different requirements for rooms with various purposes. Those for apartments and houses are specified in the Austrian norm ON 92 1003. Regulations for residential buildings are similar in neighbouring countries. While the designing of commercial lighting installations has been subject to norms for over three decades, residential lighting has been largely neglected until today. The impact of lighting conditions on people has become of interest for many fields, from eye physiology via lighting and architecture to psychology and brain research (Ticleanu, 2021). However, the integration of these disciplines and the resulting diverse theories have little impact on immediate lighting design. Existing tools, like lighting simulation programs, render sufficient support for nearly all aspects of lighting design, except for the very complex human side. Understanding of human perception and behavior under lighting stimuli is generally known at a basic level but the limitations and use of parameters are misty and subjective (Cuttle, 2022).

Research on space perception focuses on lighting stimuli like brightness, color, and texture, neglecting hygienic aspects like discomfort glare and daylight proportions. This results in lighting being a design and aesthetic concern rather than a fundamental precondition for space perception, leading to unmeasurability, insecurity, and complexity. (Casciani, 2020). The residential environment strongly relates to individual comfort perception and domestic activities. Hence, an adequate and widely applicable model for the indoor domestic environment is necessary. For evaluating lighting conditions in rooms with different shapes, proportions, and furnishings under various distributed daylight and electrical lighting, a large number of lighting conditions have to be calculated. Still, little is known about the computational effort.

2.1. Ergonomics in Domestic Lighting Design

Ergonomics is a field of research that studies the relationship between humans and their technological environment, with one of its goals being to improve design and utilization processes by considering the physical, perceptual, and cognitive characteristics of individuals. Ergonomics is not only concerned with the use of new technologies but also with examining the feasibility and effects of pre-existing technologies, such as lighting systems (Wolska et al., 2020).

In new building constructions or renovations, the adoption of new lighting technologies is often an important focus; this creates the opportunity to examine the impact of the (new) lighting system and its design on human behavior and performance. In private dwellings, housing arrangements are sometimes renovated entirely with support from an architect, in which case the lighting system will also be subject to review (Altomonte et al.2020). More often, however, new technologies, including new lighting systems, are purchased and utilized by the residents without the intervention of an architect. This thesis deals with the latter situation. It investigates how ergonomics can be used for domestic lighting design in one-family houses with an already existing exterior design. The main focus is on exploring how a feasible lighting design and check can be developed that meets ergonomic criteria or guidelines with as little effort as possible (Soheilian et al., 2021).

Particular emphasis is placed on the desired appearance of the indoor and outdoor environment when employing the lighting system, such as lighting patterns on walls and ceilings, glare effects, and light colors. To obtain the desired ergonomic appearance, a design support is developed that can be employed without the need for complex calculations and with the aid of pre-designed examples (Kong et al., 2022). McKee & Hedge, (2022)claim that the methods for designing and checking should meet the criteria mainly based on the school of visual ergonomics (where ergonomics focuses mainly on visual effects). Furthermore, the extent to which the proposals can be applied to systematic design methods is investigated. Ultimately, evaluation experiments reveal the extent to which indoor ergonomics are compensated for by outdoor ergonomics (of the exterior illumination).

Lighting is a vital component of design and architecture, having profound effects on human perception and activities. Selecting suitable lighting fixtures based on photometric data and space dimension alone is not sufficient for domestic lighting design and evaluation. The psychological and physiological responses of humans to lighting must be taken into consideration as well. Human-centered lighting design, which emphasizes and prioritizes human characteristics and activities, should be pursued to bridge the gap between lighting design and human factors (Pourfathollah et al.2022). Human characteristics like ethnicity, age, gender, culture, personality, lifestyle, and activities influence lighting choices in various spaces like hospitals, offices, schools, homes, and theaters. Standardized technical requirements for lighting design are crucial, but designers also need criteria to evaluate acceptability and effectiveness. Safety and comfort in domestic spaces significantly impact health, welfare, and quality of life (Houser et al.2021). For domestic lighting design and assessment, the characteristics of domestic space, lighting components, response factors, and evaluation tools based on human concepts should be defined and established. In recent times, lighting has been recognized as an integral part of architectural and interior design, making the development of reliable and transparent domestic lighting design essential (Konstantzos et al.2020).

2.2. Personal Variations and Sensitivity to Lighting

Lighting as a factor in environmental experience is often considered the same for all persons and all categories of lighting. However, this is a false assumption. Individual differences and sensitivities are now known to vary by order of magnitude. Differences in hair color, some eye colors, skin pigments, and generally, some differences in the physical constitution make a profound change in sensitivity, even because of the color of the clothing, which is seldom considered. The influence of sensitivity is very pronounced in such a matter as domestic lighting that touches so intimately with the personal life of people (Chellappa, 2021).

To address the specific needs in residential lighting, wild and narrow-spectrum fluorescent lamps should be substituted with incandescent lamps. The light-source luminance should increase with the increase of the light-source color temperature to reduce the disability glare in central vision and periphery vision. When there are more than 10 light sources in the field of view, a sitting position must be taken to perceive the effects of direct glare, which can be successfully simulated by the block fuzzy set approach.

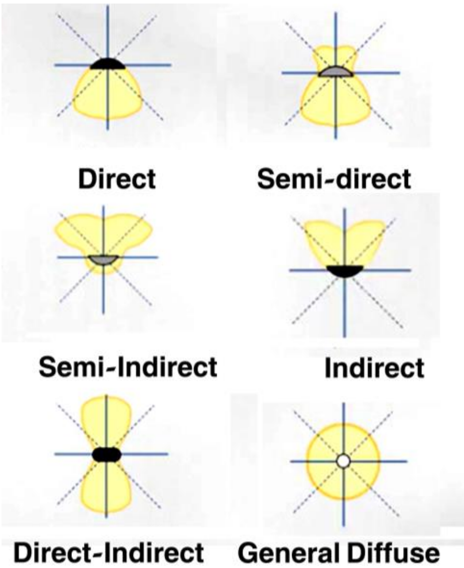

Figure (1) Lighting Distribution types

It has often been stated that artificial light has an imperfect culture, but it is not true. Natural light is often not understood and has not settled a cultured state so far. Several successful attempts to establish the most favorable artificial lighting conditions have been made, but despite the perfectness of the light itself, those conditions may not give the expected improvement in standpoint for different persons. Most likely because of an unrecognized earth or passion of the persons considered (Houser et al.2021).

To demonstrate the above-mentioned sensations of lighting and their variations, a definite house and its household have been worked out, and a study was made upon the household with a side view towards their domestic illumination. The house is a flat screen type with its upstairs rooms directly converted lighting-wise from the upstairs flat, and basement rooms designed as normally illumined judging by outside earth conditions (Zeng et al., 2021). The five realistic persons investigated, differ profoundly in their sense of time and space, emotionality and logic, firmness and timidity, the outside world and personal experience adaptability completely give up the same domestic lighting by the same lighting system. A thorough analysis of the investigated persons has been made and emphasized by creating vivid portraits of them for keeping a personal view concerning their lighting experience in mind (Sholanke et al.2021).

2.3. Age-Related Changes in Visual Perception

As a consequence of the change of the primary characteristics of the senses, it is important to investigate the conditions in which the integration of lighting into furniture - or equipment to be used on it - is provided. Lighting is supported by understanding in accordance with light sources that are used. Neon and incandescent lamps, fluorescent and HID lamps, gas-discharge lamps... The operator perceives objects located in the working area, the light that reflects from them and acts on the eye. Illuminations are the total luminous fluxes of the eye's surface, used to estimate large and small objects of work. The level of illumination must meet DEM stands' lighting conditions. Daytime lighting assessment is easy with theoretical studies, while artificial lighting facilities assessment is more complex and determined experimentally.

Previous research reveals that the eye's response to a visual stimulus depends on its contrast to the background. The dark signal difference remains constant for red and green targets of the same lightness. A range shift of the red stimulus from a smaller dark background significantly decreases distinction conditions. This information is crucial in finding optimal workplace coziness. The biggest discomfort glare is usually produced by light sources with the highest luminance values. Minimizing the luminance of direct visible light sources, shielding them from the workplace visual field, or disposing of sources with smaller radiant brightness is essential. (Yoshimoto et al.2020). Research also suggests that the age range spectral selection of light and illumination is influenced by age limits. The exponential spectral balance hypothesis is proposed and tested using laboratory observations of 330 college students.

2.4. Disease-Related Factors Affecting Lighting

Complications in the elderly can result from neurological diseases, arthritis, eye structures changing, or focusing problems, affecting their ability to process light information. Common issues include cataracts, diabetic retinopathy, Parkinson's disease, retina detachment, brain injury, dementia, and macular degeneration, leading to blindness or chronic dark adaptation, reducing light access to the central nervous system. (Al-Namaeh2021). These diseases can cause distorted perception of lightness, brightness, and the quality of sources, affecting one or several visual parameters than what is defined by "normal" performance in the C.I.E standards. Orthoscopy, a precondition of uniform soft lighting, cannot be achieved under these circumstances. Comparing sensitivity graphs of the eye with the feasible output of lamps yields the importance of understanding the special illumination needs of people with these complications and related perception problems. Domestic lighting designers evaluate designing results based on standard lightness, color, or direction of sources, similar to a good lighting designer's domestic lighting conditions. Understanding the possessors and potential environmental settings helps outline planning rules adjusted to their ill-state, separating adjusted requirements from good lighting designer capability and designer tasks. (Livingston, 2021).

2.5. Cognitive Functions Impact on Lighting Preferences

Cognitive functions, including perception, attention, memory, and reasoning, are essential for daily life and significantly influence the development of mood and affect. Several studies have explored the relationship between light conditions and cognitive performance. Young adults showed improved spelling test performance under blue light compared to red light. In a review of 17 studies, participants were found to perform better under bright lighting conditions. Academic performance in school children was positively associated with daylight exposure.

A study on university students revealed that cognitive functions can influence lighting preferences, modulating mood and affecting groups with the same cognitive traits. The results suggest that variations in lighting conditions can affect mood and affect individuals with the same cognitive traits, leading to alterations in mood under the same lighting conditions. This highlights the importance of considering individual cognitive differences in lighting preferences. (Yang & Jeon, 2020).

Cognitive functions like emotion regulation, attention focus, and cognitive flexibility are interconnected. High emotion regulation and attention focus are linked to low cognitive flexibility. Cognitive control involves controlling emotions to achieve goals, which can involve strategies like inhibiting reactions or shifting attention focus. This ability to switch attention focus is opposite to maintaining focus on one task (Grol & De Raedt).

2.6. Ergonomics and Visual Comfort

As a domain of inquiry linking work with the worker, ergonomics has become recognized as a mechanism for improving applied human performance. There is a growing assertion that ergonomics provides appropriate guidelines for evaluating design quality in general and industrial design in particular, but evidence of such application has been scant. While the effectiveness of lighting design in mitigating a performance decrement has received some consideration, only recently has a heightened awareness emerged concerning the role of visual ergonomics in practical lighting design (Karwowski and Zhang2021). The emergence of new technology, alternative sources, and novel luminaires has made the control of light more possible than before, and researchers have investigated the effects of providing glare-free lighting on visual comfort. This aspect of ergonomics, however, is seldom integrated into the design and evaluation procedure (Salvendy & Karwowski, 2021).

Visual comfort and glare should be defined using ergonomic/design quality index. Lighting experiments were conducted in simulated offices to measure glare ratings and performance. Seven different lighting designs were tested. Illuminance levels and control methods were investigated to achieve comfort without compromising adaptability. Effective glare control was found through direct/indirect luminaires. It was indicated that performance could be maintained at a particular aural illuminance between 210 - 395 lux, while visual comfort was ensured. Two equations were proposed for quantifying glare and design quality index respectively. These application cases presented various user criteria for evaluating the quality of light. Seven case studies were conducted to demonstrate these criteria in practice (Soler & Voss, 2021).

The ergonomic lighting design quality index and visual comfort glare quality index are presented as a comprehensive evaluation tool for lighting design. They can be used alongside conventional measures for a more accurate evaluation. An open, standardized database on lighting and design can help designers and researchers compare and enhance their designs. (Tabadkani et al., 2021).

2.7. Circadian Rhythms

Circadian rhythms are biological processes that follow a 24-hour cycle, affecting sleep-wake cycles, hormone release, body temperature, and other bodily functions. All living things have circadian rhythms, which determine their natural sleeping and feeding patterns (Leung & Martinez, 2020). Light is the most well-known influence on circadian rhythms, as it stimulates nerve cells to convert light into a chemical language that tells the suprachiasmatic nucleus (SCN), the brain's master clock, that it is daytime. This signals the entire body that it is daytime, affecting hormones, body temperature, and other functions that help with the morning routine. (Tonsfeldt et al., 2022).

At night, proteins accumulate and slow down daytime protein production, leading to a nightly routine. Eating at night activates sugar and lipid metabolization processes, deactivating daytime processes and activating nighttime ones. Missing eye light signals can cause confusion, obesity, and diabetes. Conversely, if food is consumed without light gathering and activation, metabolization is poor (de et al.2021).

4. Domestic Lighting Design Principles

If a home residents inform that they are unable to see clearly at there activity place. In that case, the situation may be resolved by making adjustments to the task itself or by enhancing the worker's visual abilities (e.g., by prescription correct work glasses). If corrective action is not done, localized eye discomfort may manifest as weariness, soreness, pain, burning, pulling, tearing, etc. Together, these symptoms constitute a disease known as asthenopia, or, to put it bluntly, eye strain. There are many different things that might induce this syndrome, but "bad" lighting, "bad" eyesight, and "bad" job are the main culprits. Therefore, the selection and design of domestic lighting systems in buildings involve close consideration of tasks to be performed within them, whether they be day-to-day activities such as cooking, cleaning, working at home, reading, watching television, or occasional activities such as entertaining guests or as a household celebration. The following guidelines are recommended for a better visual working environment at home:

- Domestic lighting primarily involves artificial lighting (Carlucci et al.2020). It is essential, therefore, to understand the nature of residential buildings and the contexts within which domestic lighting is designed and assessed.
- The effects of lighting (daylight and artificial) on users' health and well-being with special reference to vision, emotions, and behavior is a major issue and should be given substantial consideration (Ticleanu, 2021).
- Lighting design should satisfy functional and aesthetic needs while enhancing usability, safety, and security. Design and arrangement of light sources, luminaires, and luminance distribution must take into account the task, surrounding surfaces, users, and environment, including artworks and other objects (Konstantzos et al.2020).
- Each task requires a design luminance, but lighting must also accommodate a variety of tasks performed within the space under consideration. The difficulty of the task, how it is performed, and the quality of the light sources involved influence the amount of required light. Aesthetics and decor must be compatible with other whole-space design considerations such as color, room finish, and furnishings.
- Lighting design should involve understanding physical and biological processes, translating them into luminance and illuminance distributions.
- A user centered approach should be utilized as traditional lighting design relies on a designer, but a user-centered approach acknowledges designers as co-developers and stakeholders in the lighting environment.
- House occupants or home users are active participants, adapting and changing their environment in response to their experiences. Complex solutions are often found in architectural designs or artistic expressions (Münch et al.2020).

4.1. Functionality and Aesthetics

Thinking about lighting, one pays attention not only to the light source but also to several related properties, like how much illumination or how even is the lighting in a room. Such properties directly touch the functionality aspects of lighting.

Functionality in lighting aspects is not only about how well involved a cooking process or product reading is in relation to diversification of luminance and reflection in view angles. However, it raises the issue of lighting in relation to the temperature of light concerning the activity, as well as questions concerning the storage of goods, coloring of products, security aspects, and so on. It might be necessary to look into how advancements in the development of lighting systems affect the functionality of lighting (Aslanoğlu et al.2021).

Similarly to issues of functionality, several properties begs inquiries, but on a more scarce basis, like how pleasing a lighting atmosphere is about the diversity and distribution of luminance. Such properties directly touch the aspects of aesthetics of lighting. However, it is not only about how the simple use of luminance can influence tastefulness, but it also brings about questions like how different respects of largeness, reflection, or color can affect aesthetic qualities. A set of lighting properties like color, uniformity, and intensity, as well as corresponding lighting varieties concerning these properties like white, blueish, homogeneous lighting, diffused, direct lighting, high-contrast, and low-contrast lighting, might be considered concern variables of lighting. Unfortunately, mostly through unstructured language, fixation of some lighting properties to aesthetic and functionality aspects of lighting has been done (D'Alessandro et al.2021).

4.2. A User-Centered Design Approach

The requirements of users and the welfare of people are becoming more and more apparent to designers of home lighting systems. A concentrated effort is being made to consider human factors, or the requirements of the people who will be residing in spaces with lighting design, as well as investigating the ways in which lighting may contribute to the creation of "feel good" settings that promote performance, safety, well-being, comfort, and health. The subsequent design tenets center on satisfying user requirements and experience levels in residential settings (Harputlugil & de Wilde, 2021).

To evaluate the ergonomic performance of lighting design, the following components need to be identified, considered, and quantitatively described, if at all possible. The User Environment Specification is one of the inputs; it is often produced by the designer following user and stakeholder consultations over the overall design. (Grandbaek & Bødker, 2020). This information ought to contain:

- User Identification

Identification of the users including their ages, general health and physical, sensory, and cognitive ability. Also, whether or not there are any specific user requirements that the lighting design should address.

- Activity Specification

Specification of the activities and tasks that need to be undertaken by the users within the space including whether they are primary, secondary, or incidental. Also, whether there are any specific requirements for the activities that should be addressed in the lighting design.

- Temporal Specification

Specification of timing, duration, and frequency of use of the spaces and activities under consideration.

- Environmental Specification

Specification of design conditions including dimensions, finishes, colors, layout, and equipment, together with any other design inputs that will not change.

- Other Design Inputs

Specification of other systems, design inputs, or constraints that will impact on the lighting design including safety/security, acoustics, thermal, aesthetic, and architectural considerations, building ordinance codes, and planning restrictions.

The Designer will then apply Ergonomic Design Guidelines relevant to the User Environment inputs to the proposed lighting design solution/s including:

- Element Identification

Design, layout, and location of luminaires, controls, and displays associated with the lighting environment, including entry/exit lighting, task lighting, lighting for orientation/safety/other environmental cues, and integration of the lighting design into the architectural details.

- User Profile Development and Simulation

Creation of a user profile with the physical, sensory, and cognitive characteristics of the average user population—including the extremes of the user spectrum—that will be compared to the inputs from the lighting environment for analysis and simulation. To find potential ergonomic problems with the surroundings, a profile should also be created for non-typical users, such as elderly or disabled people (Altomonte et al. 2020).

- Potential User Interaction

Analysis of the way(s) that potential users will performance priorities and consider Lighting Design Effectiveness in regard to task performance, luminance levels/gradients and spectral distributions, comfort, aesthetics, distractions, glare, flicker, effects on health/well-being/fatigue, effects on security (and fear of crime), and feasibility of control and reconfiguration.

4.3. Design of lighting systems

This section presents a design methodology for lighting systems that reach the satisfactory levels set by medical and psychological lighting requirements. Traditional lighting design (TLD) systems mainly focus on luminance or illuminance. Since these luminance/illuminance-controlled designs can yield unsatisfactory parameters at night, multiple TLD solutions might be necessary for a 24-hour cycle. To avoid such high design costs, this section proposes the analysis, screening, and design of lighting systems based on personal envelopes (Karlen & Spangler, 2023).

The person envelope concept is a method that considers the impact of multiple light sources on human perception, considering parameters like sky model modulation, artificial light source density, and room shape and surface reflectance. It aims to find an LS parameterization near a target bright cloudy sky tone envelope, focusing on systems with available artificial light sources and daylighting components (Livingston, 2021).

The study defines environmental scenes and shading positions at sunrise/sunset, with sampling time intervals for daytime and nighttime. It efficiently uses direct luminance, distinct sources transmissivities, and luminance peripheral angles for paired arrangements of LSs. A screening methodology is suggested for complex arrangements, assuming ideal LSs in a cluster. Alternative lighting systems are found by calculating person envelopes of candidate daylighting systems and quotidian sky conditions, allowing for evaluation of competing lighting designs by establishing separate catalogues (Aguilar-Carrasco et al.2021).

4.4. Basic Principles of Lighting Design

Lighting not only illuminates different environments but also creates diversified atmospheres and moods. Therefore, lighting design must pursue various aesthetic principles. At the same time, lighting that is blatantly excessive, poorly directed, or improperly composed may cause glare, shadows, poor visibility, or other visual discomfort. Illuminating spaces and objects should always consider basic principles in lighting design. These are proportion, balance, composition, direction of light, orientation, identity, and detail (Winchip, 2022)

Proportion refers to the relative size or arrangement of light compared to shadow. It is often suggested to light spatial features that are 1.5-2 times higher than the adjacent field. Excessively bright areas often ruin the proportion. Overall distributed lighting creates an equal sense of depth. Landscape lighting should match the surrounding brightness for better integration (Wu et al., 2022).

Balance refers to the spatial arrangement of light spots compared to surrounding shade. It is relative to space, design, vision pathways, lighting characteristics, observer positions, and viewing angles. Multi-light sources create a dynamic balance. Ambient, task, and accent lighting create the background, focal illumination, and atmospheric lighting, respectively. Rotating a light source, enlarging light spots, augmenting up-light ratio, or emphasizing low angles of illumination may create a dynamic effect of balance (Dou et al.2021). Composition refers to the arrangement, organization, and utilization of light by considering sizes, shapes, patterns, and distribution compared to surrounding shadows. Composition builds centre and focus, group and hierarchy, path and closure, rhythm and frame, links and coherence, scale and proportion, symmetry and asymmetry, and movement in space. Transitions in lighting temperatures and brightness create easy progression while abrupt changes may create tension. Stepping transitions sound like "up lighting" or "down lighting," while subtle variations sound like downtown or uptown.

The direction of light refers to angles of illumination in terms of horizontal and vertical direction. The interrelation between luminous and shadow determines the visibility of texture, form, and surface. The depth of texture depends on the ratio of angles between luminous and shadow. An angle of 30 degrees creates a shadow where smooth texture brightens evenly while coarse texture touches bright here and dark there. High angles create slight variations while low angles expose variations or obliterate shadows (Petrou & Kamata, 2021). Orientation refers to the strategy of light in space relative to the surroundings; awareness of surroundings, distance and way-finding relative positions, identification and accentuation, composition and integration with nature. Landscape lights may prevent confusion in direction with well-illuminated paths, approaches, and spaces, creating an atmospheric effect. Identity, uniqueness, enhancement, branding, characteristic, and style are all important aspects of design. Lights can dramatize, highlight, or conceal, while brightness intensification creates an appealing view. Transparency is the interplay between internal and external spaces, and detail depends on scale, illumination, and surroundings. Unrecognized detail lighting creates an ambiance, while intimacy and emotion details express characters and personalities. The essence of character is reflected in bright shapes and sizes against the surrounding darkness (Sova, 2021).

4.5. Importance of Establishing Design Criteria

In the field of lighting design, it is crucial to define criteria for the meaningfulness and viability of new techniques or technologies. This should consider both the audibility of the achievement and its acceptability to professional practitioners. Many lighting designers are not formally trained in illuminance properties, making it necessary to work in a field lacking depth of understanding. Focusing on graphic presentation of relevant illuminance properties is essential. Lighting designers must adapt to the increasing number of new luminaires, including economical throwaways, artistic compositions, and anti-luminaires, to ensure quality lighting. They must also be prepared for the threat of price-driven artificial sun paint jobs and the potential for poor luminaire and building design due to overlooked years of physiology and exaggerated photometric technology (Nichols, 2021).

The lighting question often overlooks the need to intelligently balance luminaire characteristics with interior needs, task boundaries, and architectural geometry. Lighting technology in design and evaluation is crucial, but oversight and realization of potential are often overlooked. Good lighting media can cause chaos and dull attention distribution. Expanding to adjacent disciplines can help improve graphic harmonizing considerations (Turekulova et al., 2020).

4.6. Key Design Considerations

The domestic environment has distinct lighting needs that differ from those of public spaces. These needs are influenced by circadian cycles, ages, different types of domestic activities, social interactions, and seasonal variations. Since there is no clear-cut division between night and day at home, the design necessities also depend on the distinction between types and levels of accessibility of specific domestic spaces. Daily or habitual activities might be performed in certain, usually well-illuminated parts of the domestic environment. On the other hand, transitional and social activities might require low illumination levels and involve designated or hidden spaces. Over a longer period, the domestic environment's lighting modality may shift because of more applicable or poorly fulfilled user needs or external conditions (seasons, changes in working hours, etc.) (Institution of Lighting Professionals 2019).

The study analyzes lighting judgment factors in domestic environments to identify and address lighting-related problems. Factors include individual appearance, age, eye health, domestic activities, time of day, perceptual features, and formally premediated light sources. The deliberative explanatory part examines related lighting design requirements and their differences based on the domestic environment. Collected needs are categorized based on lighting judgment factors, identifying those that meet premeditated or transformed needs. The study identifies gaps in standard lighting design assessment approaches that may require changes. Finally, challenges to the presence of each lighting judgment factor in the existing supplementary needs, lighting context demands, and lighting conditions in case of formal noncompliance with any need, monitoring malfunctions, and sudden changes are discussed. The approach proposed can be applied to other environments, thus enhancing the knowledge of ergonomic lighting design and assessment in general (Konstantzos et al.2020).

4.7. Psychological impact of lighting

The desire for an adequate (or appropriate) response to light sensitivities has existed since the origins of mankind. Initially, just as there was documented attention paid to the amount and placement of furniture in homes, attention was devoted to the amount and placement of light. However, little was known, except by guesswork, about the types, colors, and intensities of all variable factors of lighting. Thus, a quasi-naturopathic approach to lighting persistently prevailed until recently (Boyce, 2022).

Following the formulation of accepted knowledge in behavioral sciences laboratories, attention shifted to the ornamental, decorative, or aesthetic effects of light on objects, surfaces, and shadows. Contemporary lighting displays sensitivity to specific light needs of that which must have been seen and felt by most observers beforehand. Vermeer’s paintings depict an awareness of the softness of light qualities illuminating mankind. The game of chess was visually understood better in candlelit chess halls (Carrubba 2022).

Thus, an apology is presented for the attempts here to state the need for adequate lighting sensibility somewhat in a looking-glass manner, pretending a response would yield a living thing, while asking the living thing to stretch sensibilities toward lighting systems or devices. With a major intention to draw more or less adequate profiles of lighting sensibility. The word "sensitivity" is, however, used rather than "sensibility." Sensitivity commonly expresses the relation between stimulation and response of living systems, while sensibility is an attributed quality of perception-rich living systems.

Lighting designs often seek stimuli with no prior or parallel responses or predictions of absent or below expectations. The grade of the expected organism also matters within different organism levels, indicating behavioral precision. Lighting displays often seek stimuli of parallel delight or amazement absent in ongoing behavior, which could be modelled. However, these models are not yet tested in design experiments. (Houser & Esposito, 2021).

Domestic lighting is crucial in guiding human behavior and influencing mood. It can be modulated continuously, unlike the clutter of hardware used in design. Fixation times are derived from eye tracking data or glances to areas of interest. Design rules and recommendations are essential for creating spaces that frame intended behavior. Individual adjustments can influence the suitability of a space for an activity. The type of disturbance plays a pivotal role in the design. Interiors are fitted with light fixtures that transition from warm to cold color temperatures, mimicking the natural dynamic behavior of sunlight. The goal is to illuminate spaces with ambient light color temperature matching seasonal changes, creating an alert and productive atmosphere. Tests in a mock-up office and a large field study have shown that light variation positively affects behavior and performance.. (Osibona et al.2021).

4.8. Environmental Considerations in Lighting Design

Good lighting alone cannot compensate for poor architectural or furnishings design nor overcome the destitute mood engendered by desolate surroundings. Designers can individualize their issue appreciation by commenting on a perceived need or demand for lighting in contributed environments, distinguishing between the purposes of different environments, and expressing expected social and environmental conditions which may be pursued by lighting. Good lighting designs must be compatible with environmental, social, economic, managerial, and other relevant limitations. Each lighting proposal must be evaluated with respect to these limitations, exploring affordable compromises when necessary. Lighting schemes must also be compatible with societal, cultural, and legal patterns. Inappropriate uses of lighting may lead to disfigurement of natural environments, physical and psychological discomfort, frustration, or accidents (Kwong, 2020).

The anticipated effects of light on people must be expressed as reliable attributes of the luminous atmosphere. Modern designs must be modified to address the problem of illuminating perception, where directorial regulation of lighting variables is insufficient. Knowledge of lighting aesthetics and cognition must be expressed in terms of luminance to be postulated, examined, and compared with anticipated or actual luminance. Applicable viewing and managerial recommendations must be assessed for suitability and effectiveness in controlling the postulated emergency of designed luminous phenomena while limiting or excluding undesired lighting effects.

5. Lighting Technology

Lighting technology advances have significantly influenced residential lighting. The earliest lamps had low efficiency and unfavorable light distribution characteristics. Changes in lamp technology mainly increased light output per watt, minimizing energy loss as heat. This development subsequently enabled the introduction of compact fluorescent lamps (CFLs) and other new light sources. Integrated circuit technology advances also greatly impacted control devices for lighting systems. Early systems used mechanical time switches, increasing in complexity and size to provide a good function design for household use. Control devices are now available in simple, low-cost alternatives and more complicated, programmable alternatives (Wagiman et al.2020).

The development of residential lighting technologies has influenced people's visual well-being and efficiency for a long time. The development of lamp designs improved light output efficiency. Development in lamp and luminaire technology has influenced lighting character and quality, affecting the person's perception of the environment's brightness and discomfort glare. The use of new light sources and luminaires has provided more possibilities for light distribution and effects. However, the advantages of new developments depend on where a new lighting system is installed (Kusuma et al., 2020). For example, when lamps with a good color rendering index (Ra) replace those with a lower Ra, it undoubtedly improves the situation. Still, a flickable lamp replacement with that equal Ra may cause visual discomfort. Everyone recognizes that lighting systems can work positively and negatively on visual effects. Because lighting systems have a significant effect on a person, lighting systems should be designed considering the current technology and its understanding of visual perception factors. Together, lamps and luminaires create a lighting character, but this interplay is easily underestimated. The same luminaire character play quite differently in light with other visual properties. The aim is to produce an ergonomic lighting quality based on high (Dang et al., 2020).

5.1. Considering Natural and Artificial Light Sources

This segment centers on natural and artificial lighting systems. First of all, natural light sources will be studied, including the sun, sky, and daylight. Natural lighting evaluation and guidelines for the use of natural light in building design, such as apertures and light wells, are also discussed. Continuation focuses on artificial light sources and their potential as lighting systems for buildings. An overview of various artificial light sources capable of such function is first provided and subsequently discusses technical and aesthetic criteria for the selection of artificial lighting systems (Michael et al.2020). Finally, the integration of natural and artificial light sources is elaborated through examination of examples of bi-light lighting systems, and subsequent discussions of criteria for harmony and aesthetically appealing lighting design; examples of well-integrated lighting mixes; and guidelines for the integration of natural and artificial light sources in building design are provided (Livingston, 2021).

Sources of Light

The mesopic vision of the eye is neither photopic nor scotopic vision. The human eye sensitivity curve at mesopic levels can be accurately simulated by the widely used CIE 1964 10° Supplementary Color Matching Functions.

1. **Natural light sources** include the Sun, stars, moon, certain natural phenomena, and bioluminescent organisms.
2. **Artificial light sources** are used for residential lighting, namely.
   - **Incandescent sources,** light bulbs, and fires.
   - **luminescent sources,** Electric bulbs and fluorescent.
   - **Mercury vapour sources.**
   - **and high-intensity discharge.**
3. **LED light** sources are energy-efficient options that have gained popularity in modern lighting.

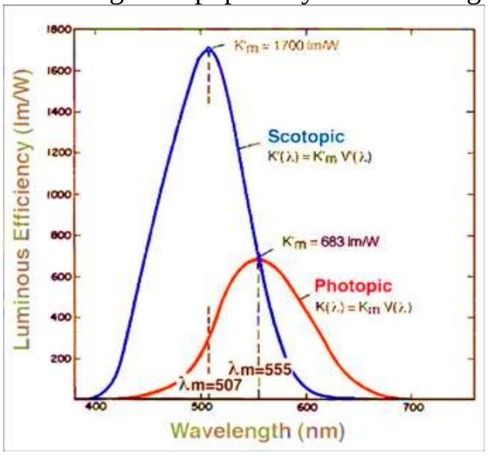

Figure (2) Lighting Efficiency [Source]

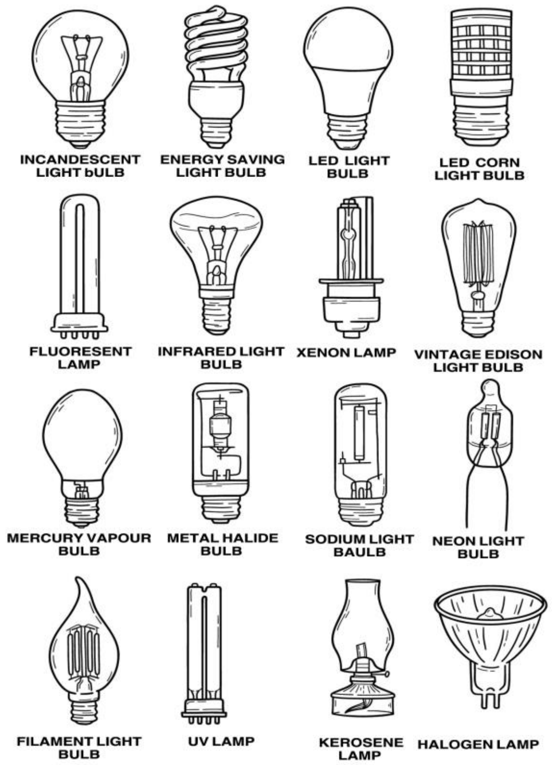

Figure (3) Types of Light Bulbs and Lamps

Most lighting systems consist of natural and artificial light sources, both of which need to be studied, evaluated, and selected according to the needs of the particular situation. First of all, light sources that are under nature's control will be considered, either as potential illuminations for buildings or as outer light source inputs for some of the artificial lighting systems. Natural light sources include the sun, the sky, and daylight. Along with the examination of these light sources, the methods of evaluating natural lighting systems will also be examined (Tabadkani et al., 2021). As far as the use of natural light in building design is concerned, daylight, apertures, and light wells; the daylighting design of atria are further cases of lighting systems using apertures; and the heating/cooling effects of the use of natural light on buildings are secondary, sternly controlled and even desirable phenomena, will be considered altogether (Piraei et al., 2022).

Artificial light sources will be studied, either as potential lighting systems for buildings or as outer light sources for some of the natural lighting systems. An overview is provided of artificial light sources, including atmospheric constructions, either as natural light systems or as sky light for artificial luminaries with artificial, illuminating spheres: Use of light tubes connected to artificial illuminator units but ended with an aperture serving as light wells for daylight. An overview of design criteria for the selection of light sources concludes the examination of each category of light sources. Would the resulting illuminations harmonize, conflict, or compete with each other in a designed space? Would the harmony of the total lighting design exceed sum of its parts and hold unexpected aesthetic achievements? These are some of the questions with respect to bi-light lighting design. Examples of bi-light lighting systems with deliberately selected natural and artificial light sources to create aesthetically appealing synergetic effects are examined (Livingston, 2021).

5.2. Lighting and the building regulations

The fourth and final level of compliance with ergonomics within buildings is to satisfy the requirements of local statutory building regulations. These codes follow the hierarchy of national... regional/local. The local regulations have adopted national codes or standards in order to ensure a common approach to life-safety and associated issues. These codes or standards can take one of two pro-formas, either a performance or prescriptive approach. Performance codes set out broad performance objectives or goals to be achieved within the building over the desired lifespan; however, they give no details of how to achieve this. Prescriptive codes lay down specific rules and regulations, which when followed will satisfy the intent of the code, even though these may not be fully agreed on as achieving the goal of the code (Economidou et al.2020).

Most countries favor the prescriptive approach as they argue that the codes have been long drawn up by knowledgeable experts, designers should therefore use them; on-the-spot local officers can use them for monitoring and policing the compliance with the codes, which is difficult to do for performance-based codes. Many designers disagree with this because the prescriptive approach is seen as being inflexible and not allowing designs to be tailored to suit the unique features of every building (Gentile, 2022). The prescriptive approach has led to some tall buildings being built with huge 'vertical ducts' each of which contains several escape stairs from the various floors. These massive wastes of useful space are a necessity because many local codes stipulate that the escape stairs must have a protected distance from the main core area containing lifts and air conditioning ducts - completely disregarding the fact that modern detection and control equipment may render such a division unnecessary. Some local authorities have placed unreasonable restrictions on the proportion of glass that can be used in a building façade for fear of glare and overheating, completely disregarding the fact that sunlight can be attenuated with blinds or external shading devices (Yue, 2020).

An acceptable solution is in response to each of three areas, compact fluorescent lighting, thermal controls and marr beams and the Auditorium and

Group Study Rooms. The testing to Ionized gas discharge lamps, cooling and glare are covered in Appendix A. The need for other codes, other than the building regulations, and to what extent they are followed is discussed. Colouring effectiveness, MR 16, domestic lighting and marine turtles and other controls are not covered. These should be considered separately from the Main Report. The Codes and controls intend to satisfy the three aims of technical, health and safety issues, good design and efficiency.

Finally, compliance with the lighting building regulations. It is of interest that the lighting regulations within the Building Regulations appear twice. Regulations L.1 and L.2 cover dwellings, flats and unconventional accommodation, while F.1 and F.2 cover residential, schooling, and building regulations. The need for Codes and other controls, and what other controls there are, are also covered. Address cares with Euro codes the foresight of UK's past codes (Capehart & Brambley, 2021).

5.3. Energy Efficiency

Energy efficiency is one of the most important issues concerning the design of lighting. It is concerned with how to provide the needed pleasant, safe and good vision without waste facility.

a) **Lighting Technology.**
   The advantages of both the conventional and the new technologies. Globally, mercury vapour lamps combine a long life with high efficiency and are being used as the basic means of artificial lighting. Still, incandescent lights were widely used too; nevertheless, they are being gradually replaced with fluorescent lights. (Scartezzini, 2020)

b) **Economics of Lighting.**
   A model is presented to study the economics of several ways of affording illumination. It differs from other models in that it takes the life cycle of the facility into account. It shows that even when the investment is significant, the total cost is almost always computed with the yearly expenses. (Wu et al.2022)

c) **Environmental Impact of Lighting.**
   The impact is here defined in a broader way than in general use, and lighting is concerned not only with aesthetics but also with the effect of increasing the apparent daylight. The actions taken to mitigate outside impacts are reviewed, and the possible impacts inside habitations are denied. The involvement of these, as well as the mitigation actions taken, is reviewed.

d) **The Economical Site of Domestic Lighting.**
   With the work of two Ph.D. students, a model considered a starting point to explore the possible advances in ergonomics was improved, and a model concerning domestic lighting was developed and programmed.

e) **Ergonomic Rating of the Lighting.**
   The degree of satisfaction regarding some elementary aspects of lighting in sites that work with computers was evaluated, focusing on offices, classrooms, homes, and sites attended by handicapped people. Issues such as glare, brightness display, the comfort of the users, safety, and health were considered.

5.4. Sustainability

Domestic lighting is crucial for daily activities and can have complex effects on individuals. To design and evaluate lighting, both qualitative and quantitative factors must be considered. An ergonomic criteria set based on literature reviews, interviews, and Q-methodology is proposed for domestic lighting design and evaluation. Architectural design aims to meet various demands from individuals, groups, buildings, and the environment, including lighting, thermal, and acoustics. Current lighting design methods are limited to specific parameters, neglecting individual differences. A systematic and holistic design process is needed to address complex needs by variables and co-structure. Sustainability, which includes understanding, social, economic, and environmental aspects, is essential for domestic environmental factors like lighting. Sensitivity to illumination and color rendering may vary due to chromatic adaptation. An illuminance range of 174-348 lux and CCT range of 3534-5905 K can be recommended for each group. (Brown et al.2022).

5.5. Types of Lighting Fixtures

The lighting fixtures for general lighting should provide adequate brightness over the areas to be illuminated. The distribution of brightness of the fixture should be such that glare and shadows on the work surface are minimized, and the overall brightness distribution of the room is conducive to easy visual adaptation. All fixtures should be easy to maintain and operate without glare caused by adjustment of lamps, diffusers, etc.

Fixtures should be free from shadows and be of a size, shape, and color that will coordinate aesthetically with the surrounding elements of the interior. Additional criteria should also be established for supplementary lighting, in the same way as for general lighting (Ticleanu, 2021).

Indirect lighting is usually provided by fixtures that distribute all the light produced by lamps toward the ceiling. The ceiling should be designed to reflect and diffuse most of the light scattered from it to the working planes, while preserving an even distribution and a desirable ceiling brightness. The low effectiveness of indirect lighting fixtures near the ceiling plane can be compensated for by the use of higher output fixtures or reflectors having less downward radiation. Among the indirect lighting fixtures, ellipsoidal reflectors with limited downward emission will result in the most directional light distribution.

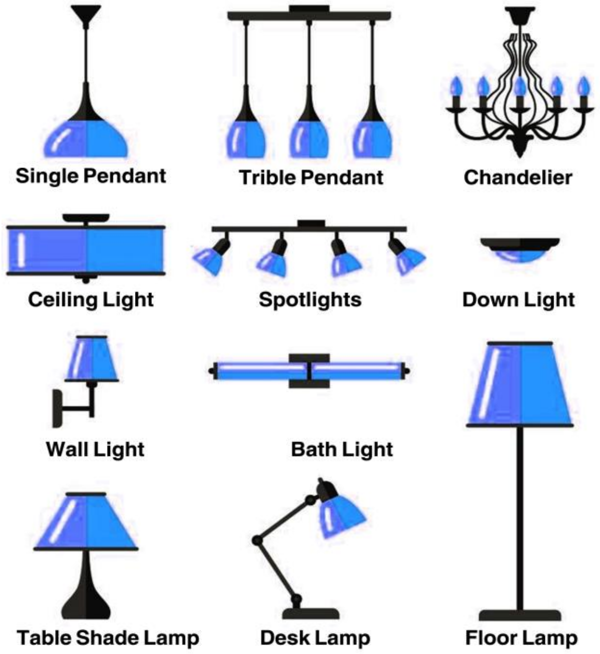

Figure (4) Domestic Lighting Fixtures

A good model to determine the effectiveness of this type of fixture has already been presented. The indirect lighting fixtures of any geometry producing large solid angles of downward radiation will produce more uniformly illuminated ceilings and also reduce the number of glare sources in the room. Another solution providing good uniformity of room illumination and lower ceiling brightness may be the use of a combination of indirect and semi-indirect lighting. A parabolic or K-bronze reflector bowl which controls the lumens ejected from the fixture is frequently used in indirect lighting. This allows high-intensity lamps to be concealed by housing (Siniscalco, 2021).

The position and inclination of lighting fixtures can greatly affect the glare produced. This should be considered in each fixture type. Continuous rows of lighting fixtures should also be avoided when using high brightness decorative lamps or reflector lamps. Ceiling fixtures should not be placed higher than necessary, in order to reduce the brightness contrast between the ceiling and the fixtures. The design of rooms with exposed ducts or beams in conjunction with lighting fixtures should be carried out with particular care. For surface-mounted fixtures, drafts caused by ventilation ducts or emotional drafts from window areas should be avoided. In the case of recessed fixtures, care should be taken to ensure that beams or catch boxes do not obstruct the exit angle of the luminaires and create serious glare (Konstantzos et al.2020).

5.6. Incandescent vs. LED vs. CFL

Domestic lighting utilizes artificial light sources to assist illumination either naturally or artificially. Lighting sources can be classified into various categories depending on different parameters such as their principle of working, energy consumption, thermal performance, luminous output efficiency, and so on. This project discusses a comparison of major categories of domestic lighting systems such as incandescent bulbs, compact fluorescent lamps (CFL), and light-emitting diodes (LED) (Sholanke et al.2021).

Incandescent bulbs display the most crucial and simple type of electric illumination. Electrical energy flows through a thin filament of tungsten metal contained in a glass bulb. The glass bulb is usually pumped to vacuum or filled with inert gas to delay the filament's oxidation during operation; otherwise, it burns brightly for a short time. Tungsten has a high temperature melting point, which is utilized to glow at temperatures up to 3000 degrees Celsius. At these temperatures, the filament glows a yellowish white, and after that temperature, it glows a bluish white producing an unpleasant light to the vision. The light produced in incandescent bulbs is non-directional and thus needs the application of reflectors to direct the light. The incandescent light bulb yields a luminous output efficiency of 5% to 7% of the consumed electrical energy at standard temperature (Pode, 2020).

A compact fluorescent lamp (CFL) is a commercial type of fluorescent lighting that uses low-pressure discharge in mercury vapor enclosed in a coil glass tube. The inner surface is coated with phosphor materials like LTP244A or 8A phosphate to convert ultraviolet radiations into visible radiations. The lamp's ballast supports electrical energy used for starting and maintaining the discharge. CFLs have various control systems and require a time of 1 to 2 minutes to glow sufficiently bright. They have a low input luminous output efficiency of 37% to 75% depending on the operating time. Light-emitting diodes (LEDs) are semiconductor devices with light-emitting properties. The intensity and wavelength of light from LEDs depend on the band gap energy of semiconductor materials used to fabricate the diode. White LEDs are fabricated from blue LED coated with yellow phosphor materials, producing a combination of blue and yellow light in the white spectral. White LEDs operating under commercial spectrum use InGaN for blue LED and YAG for yellow phosphor conversion, resulting in a luminous output efficiency of 80% and a lifespan of over 100,000 hours. (Van et al.2021).

5.7. LED Technology

As a relatively new lighting technology, LEDs should be treated with care during their gradual introduction in professional lighting applications.

LEDs can be simply classified as low powered LEDs and High powered LEDs, Low Powered LEDs are used for indication, such as an exit sign, a green power button on a computer or red blinking light on a kitchen device. High Powered LEDs are used for general lighting. Energy Star qualified LED lighting use multiple high powered LEDs inside a fixture to produce white light.

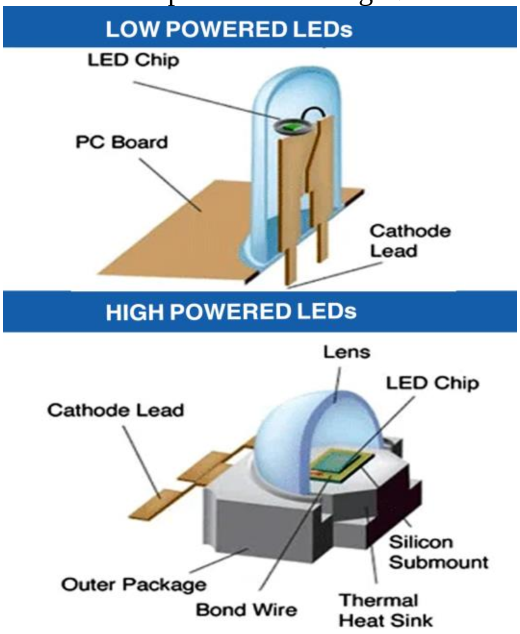

Figure (5) High and low powered LEDs

Conversely, some lighting technologies should be eliminated without delay. Highly inefficient light sources producing low-quality lighting must be replaced as a priority. Non-dimming fluorescent lighting, for example, emits high levels of flickering light to be switched off at the end of the day (Winchip, 2022). While currently available low-glare high-lumen packages could improve indoor lighting considerably, there is still a large choice regarding lamps and luminaire design principles. Based on recent trends, however, one can predict the widespread adoption of a few LED technologies such as direct view LED lighting, RGB color tiles, and high-lumen point LEDs (Behar-Cohen F, et al. 2011) .

The following explores the pros and cons of direct view LED lighting and RGB colour tiles. Lighting systems based on high-lumen point LEDs are also described more briefly. The position of high-lumen point LEDs in the development of indoor lighting is discussed more broadly, covering current controllable higher-level LED technologies.

LED-based controllable lighting is expected to see significant changes in system performance with the arrival of new LED generation fixtures that produce high levels of ambience illumination at low glare. Large companies have reached a level of reliability, allowing gradual introduction into professional lighting technology. These fixtures consist of tightly individual LEDs mounted in a flat panel with a transparent plastic surface, casting evenly distributed sidelight onto a prismatic luminance diffuser, creating a low luminance ceiling effect while maintaining light mosaic tiling on vertical surfaces.

The intensity of the input color difference LED panel can be relative multi-channel dimmed with a pre-programmed control system, allowing modulating the ambience by adjusting the light colors or by switching on the sun with pre-programmed locations for each position depending on the sun's path. The light mosaic technology, perception of colors and ceiling luminance should gradually invade or replace most current lighting luminaires and change luminance-matching luminaires in office working environments. Lighting research laboratories outside research institutions should lead its gradual introduction.

6. Smart Lighting Systems

Emergent smart technologies are creating new possibilities for the design and evaluation of domestic lighting. Communicative lighting systems might be designed with a myriad of sensor-based physical parameters, dynamic set-points, and dynamic temporal spectra, hence offering the chance to investigate their ergonomic potential. This section gives an overview of the counseling research on such proposed smart systems. More particularly, the concept of smart, sensor-driven, and closed-loop lighting systems responsive to user behavior and preferences is explained in relation to ambiance modulation. The state-of-the-art is examined through a case study on an award-winning, market-ready application of input-lighting systems and a recent experimental setup at the workplace, contrasting a switch-controlled to a pre-programmed M/A/CRH scenario. Reflections are offered on the successful modeling instrumentarium, but also on unexplored avenues in joint tuning of physiological and behavioral correlatives and the tension between bought unexposed settings and ill-designed product use (Leelaarporn et al.2021).

In order to make real-time adaptations of the light exposure in a responsive manner and according to users' needs, facility management has to abandon traditional rigid approaches (use of static on/off and switch-controlled systems only) in designing for domestic lighting. On the opposite, the implementation of smart, sensor-driven system solutions has been proposed. Recent advancements in state-of-the-art lighting design and technology have increased the feasibility of smart, closed-loop lighting systems which are able to monitor user behavior in practice and responsively adapt the light exposure accordingly. These types of control systems allow light-initiated processes, but also offer the chance to have a positive impact on user behavior and/or modulate preferences. Responding to a growing awareness of light's role beyond its visual function, i.e. its potential to influence the human condition by positive stimulation of mood and well-being, these proposed smart systems should primarily beneficially modulate the lighting ambiance, and thereby the user's visual, ecological, and arithmetic characteristics (Aussat et al., 2022).

6.1. Pros and Cons of Different Lighting Technologies

A typical domestic lighting installation has several areas or rooms, as well as some wall-mounted or ceiling-mounted fixtures. For concepts of traditional, low-energy, and advanced lighting technologies (e.g., lamps, fixtures, or luminaires) and control strategies or systems, an inventory of all lamps and fixtures, including their locations, power ratings, luminous flux, spectral power distribution (SPD) curves, and control methods, needs to be prepared. Main electrical and lighting-related data, such as power, illuminance, and glare, should be noted for each lighting area. This is within the designer's domain. Very few natural lighting attributes are considered in this domain. The extent to which design and evaluation are restricted to lamp and fixture selections is assumed as the designer's capability. The shading technologies and materials of windows, skylights, and proper obstructions, if any, are also assumed to be within the designer's responsibility. Any adjustable shading device is treated as a part of the existing daylighting system and therefore does not belong to the designer's tasks. (Cheng et al., 2020)

Lighting technologies refer to lamps, luminaires, and lighting control systems. A lamp produces light and can be either an incandescent, fluorescent, low-pressure sodium, high-pressure sodium, metal halide, induction, light-emitting diode (LED), or organic LED. In W/m2, luminous power conversion efficiency is an important criterion of lamp technologies. A luminaire or fixture is an assembly of a lamp and the components that aerially distribute the flux emitted from the lamp(s). Luminaires are usually categorized according to their installation styles and how lamps and luminous flux are treated, such as direct, indirect, semi-direct, or semi-indirect. A lighting control system may include dimmer switches, timers, sensors, and programmable or panel-control systems. Brick of lighting technologies refer to traditional, low-energy, and advanced technologies. In addition to available watts per fixture, luminaires that can provide luminous efficacy by angle distribution tables are preferred (Michael et al.2020).

High-energy consumption can lead to the use of high-wattage or incandescent lamps, medium-energy fluorescent lamps, high-pressure sodium, and metal halide lamps. High initial cost luminaires should be chosen based on aesthetics or space design requirements. Energy-saving lighting technologies should be preferred after considering efficacy and initial cost. Available lighting systems verify energy consumption and daylight availability. High-efficiency occupancy sensors, dimmable ballasts, and switches are power-saving after nine seconds but should be chosen cautiously for open spaces like auditoriums. Lumens with good luminous power conversion efficiency and comfortable lighting are preferred.

A phosphor lamp or fluorescent lamp with its spectral distribution combined with an illumination-induced nighttime outlook may promote better sleep quality. In a system of a lighting control strategy, daylighting distribution and window treatment should also be included in the system boundary. Skylights and clerestories should only be treated as the basic existing system if light shelves cannot be introduced. Lighting technology disaggregation usually includes lighting-related settings in the basic building model (Boyce, 2022).

6.2. Quality of Light and Color Rendering

Artificial lighting, like daylight, is composed of visible light radiation with different spectral distributions. Natural daylight, on average, reflects the spectral distribution of the solid body black body radiator close to the temperature of 5500K. The most important property of artificial lighting systems is its distribution, and this property varies with the type of light source used in the lighting system, such as incandescent lamps, fluorescent lamps, halogen lamps, and HPS lamps. The quality of light is usually assessed visually based on testing the general appearance of a uniformly lit white surface illuminated by the light sources and how the white surface captures its own color under the light. The modern evaluation of the lighting system's quality follows a new paradigm based on the understanding of the human neuro-visual system and the distance between the luminous power distributions of the lighting systems and standard light sources defined by the CIE. A widespread measure of color rendering is the color rendering index (CRI), which is defined for general use light sources. It analyzes the effect of the light sources on the colors of eight specific color samples (the CIE color samples), which after being illuminated by the light sources will have new colors characterized by the Cartesian coordinates of a new color point in the colorimetric diagram. A local color rendering index "RA" is defined as a quality factor based on the general color rendering index "R1" that assesses the color samples, in which the greater the distance "da" the lower the value of "RA" that follows 0, 33, 53, 58, 64, 74, 83. It tries to describe the rendering effect of artificially illuminated daylighting or free-running daylit spaces (Huang et al.2020).

A quality assurance method including ray tracing lighting simulations and automatic quality metric calculations in post-processing shades of the information, where after rendering the images the quality factors of the simulation are automatically evaluated, replicable, and scored into metrics as QA check, could characterize the image quality. Those metrics are luminance uniformity, the number of samples per unit area, photometric sampling frequency, spectral fidelity of the lights, spectral rendering of the materials, and shading fidelity of the materials. All these quality metrics could be scored into a continuous decimal scale from zero to one hundred and presented as well-known numerical metrics (Bellazzi et al.2022).

6.3. Lighting control systems

This section focuses on creating ergonomic criteria for evaluating the design of domestic lighting control systems. The purpose of lighting control systems and the types of control tasks are described. Control demand is based on the adequacy of illuminance levels, so an ergonomics criterion is provided for evaluating the performance of the illuminance control system. The performance of the architectural lighting system can fluctuate with time. The fluctuations of the performance, in particular the illuminance levels, should be detected by a control system, which should execute control actions, e.g., to dim or to turn off the lighting equipment. The parts and properties of a control system are described and ergonomics criteria for evaluating setup properties are provided (Konstantzos et al.2020). There are five setups for control systems:

(1) control based on subjective judgment by the user (e.g. manual on/off control),
(2) control based on illumination levels measured at the workplace with unidirectional sensors (e.g. integrated-on-off control systems),
(3) systems measuring illumination levels at the workplace with bi-directional sensors (e.g. rules for dimming luminaires with various downlight distributions),
(4) measuring illumination levels outside with environmental sensors (e.g. control of blinds), and
(5) systems taking into account statistical predictions of illuminance levels. Setup properties for control systems based on sensor networks are considered.

This section provides ergonomics criteria for evaluating properties regarding frequency and time delays in feedback loops. The illuminance must be controlled after detecting the cause/possibility of variation of performance; so there are constraints regarding sensing, computing and executing time delays. The vibrations of performance due to the control actions should be treated, so there are also criteria regarding maximum time delay. The comfort of control actions is associated with the maximum change of control actions per unit of time and maximum change of controlled variables per unit of time. The comfort of control actions can be affected by circumstances, so different comfort criteria should be applied depending on the context of tasks (Gao et al., 2020).

6.4. Manual vs. Automated Controls

Light is a unique stimuli that can improve discomfort and productivity, necessitating a two-fold evaluation of lighting performance. Increased environmental lighting levels can lead to production losses due to circadian factors. To address this, lighting design parameters should focus on comfort, circadian, and health care in the emission performance of a space. Lighting control involves limiting its application within acceptable discomfort and irritation ranges, minimizing sensory adaptation. Manual control strategies can be ineffective, and occupant discretion is crucial. The adaptability of the space should also be considered, as the home environment varies with lifestyle changes. Simulation modeling efforts should be carefully considered, considering the target demands of the project. Manual and automated controls can match occupant preferences and scene execution, but they complicate the evaluation of lighting performance and modeling optical contributions of smart luminaries. A better presentation of manual and automated controls is to discuss them sequentially, assessing sensory effect on simple luminaire arrangement on homogeneous surfaces. This allows for deeper understanding of either side in accordance with the systematic provision of the models designed (Pode, 2020).

6.5. User-Friendly Manual Controls

User-friendly manual controls: Manual controls should be easily accessible and user-friendly. There should be a refined set of controls for adjusting lighting, rather than a multitude of controls for programming sophisticated lighting modes. Where adjustment is necessary, manual controls should be easy to locate and identify in the home setting. Controls should adjust the most commonly used functions and quantities. It may not be necessary to adjust control settings in all lighting situations. Lighting design should therefore consider the likelihood of users adjusting control settings, together with how this may vary for different lighting situations. User-friendly manual controls must consider the nature of the manual controls passed on to the user. Controls should allow the light distribution, luminance, illuminance, and/or color properties of the lighting installation to be easily adjusted by users. Control settings should then be records of the most recently selected control settings, which can be recalled at any point later (Ding et al., 2020).

6.6. Smart and Integrated Lighting Automation

According to CEN 12464-1, the recommended illuminance levels for various rooms are as follows: in offices or meeting rooms, it should be 500 lux; in corridors and access zones - 100-200 lux; in restaurants for eating tables - 300-500 lux; in restaurants for food preparation areas - 750-1500 lux; in kitchens - 500-750 lux; in warehouses for storage zones - 200-300 lux; and in areas for loading and unloading - 500-750 lux. The level of illuminance expected in Serbia, considering SSL's engineering practice, is at a minimum of two levels. However, with the current lighting technology, the luminance level can be higher, which is not in accordance with the recommended levels for domestic and office interior rooms (Boyce 2022).

The indoor layout for office and domestic rooms is similar. Windows are positioned on the walls facing the street, and they are either elongated or vertical. On the wall opposite the window's wall, there are doors that lead to the hall corridor for both rooms. The second door for the office leads to communication with the outside, e.g., to another building. Obstructing structures in the room planning are radiators and air conditioning apparatus in the right corner.

A smart lighting system was tested in a domestic room at illuminance levels of 700, 500, and 300 lux. In the office room, the illuminance levels tested were 500, 300, 150, and 50 lux, along with the incorporated optical movement sensor. The influence of stroboscopic effect in the outside, mainly with LED lighting appliances, in respect to the higher frequency of their flickering compared to fluorescent appliances, is not within the scope and area of validation. The value of illuminance has been calculated for all simulation cases for each of the five movement sensors. This list of rooms and calculated illuminance levels should be presented briefly at points 1-4 and 6, which model the reviewed lighting appliances with respect to the indoor zone illumination and glare or brightness modeling (Sun, 2021).

A smart lighting demo installation was built according to the previous testing conditions after simulating the five best movement sensors for the selected room types, considering auxiliary conditions and minimum SIS safety classification for each sensor state. The vision perceptible effect glare, future detection of a bright cup turning against the black background, will be high, resulting in discomfort glare from the direction of the red zone. It was observed that there is glare in the shed optical appearance, which is in the light zone. The brightness and glare curves have the course of full brightness, with the maximum brightness being more than ten times greater than the design luminous intensity distribution curve, as well as a glare index well above the acceptable limit of seventy-six. The night vision hazard (NVHZD) and outside daylight vision hazard (DDNHZD) are twenty-two. The complete smart lighting demo installation model that was created is shown in the basic view, with a lighting appliance with a built-in movement sensor placed in the upper left corner.

6.7. Enhancing Energy Efficiency via Intelligent Control

The digital revolution has led to a surge in the development of outdoor and indoor lighting control systems, which are becoming increasingly popular due to their economic feasibility. Current domestic lighting control options include light switching, dimming, and color temperature adjustments, which can be operated manually or automatically. Automation control systems can regulate luminance through actions that influence the overall system's state, light color, and spectrum. Control targets must be defined during the project phase to establish a goal. Daylight performance is a primary interest in domestic settings, as window position and shape dictate solar movement during the day. Control objectives should specify a target indoor daylight sharing coefficient or fixed illuminance level, considering recommended luminance ratios. Target illuminance levels can be constant or variable during daily changes in daylight provision, and control luminance ratios should be known alongside electric lighting illuminance. Sensor types should be adapted to the selected control strategy and objectives, considering their type, installed location, and technology. (Yu et al., 2020).

6.8. Integration with Smart Home Technology

The perception and evaluation of lighting systems are influenced by various factors, including surface luminance distribution, lamp selection, and luminaire placement. To achieve balance and illumination, advanced lighting analysis techniques and tools are needed. Research into techniques and tools capable of quantifying and simulating combined aspects can improve the final perception and effectiveness assessment of lighting systems. (Giovannini et al.2020).

Intelligent lighting control is a crucial aspect of home technology, improving the quality of life by ensuring responsive engagement in areas like bathrooms, nurseries, kitchens, stairs, and corridors. Automatic control of lamps and outdoor lighting facilitates seamless home arrival, while monitoring sunlight intensity and automating curtains opening and closing create habitable spatial zones. Ambient lamp brightness levels, temperature, and tonality can be adjusted to maintain cognitive perception of daylight. Combining control with natural elements like indoor plants, biotopes, or fish tanks enhances comfort and creates a more enjoyable habitat (Alhalaby, 2022).

The integration of lighting control into home systems is gaining interest from both consumers and industry members. This includes factors like food and air quality, planting, cleansing, and lifestyle architecture. Lighting design is influenced by light exposure patterns, personal preferences, and usage patterns of lighting types and dimmer levels. This approach can provide insights into the benefits of incorporating holistic aspects in lighting design, both for daylighting and artificial lighting. This perspective is assessed through larger facades on the use of potential lighting types and strategies in different environments.

6.9. Technological Innovations in Domestic Lighting

The focus on task, ambient, and accent lighting in domestic environments has increased due to technological advancements and changing living practices. This shift requires a reevaluation of existing criteria, which traditionally focus on vision issues like glare and shadows. Rapid innovations in daylighting strategies, electrical lighting equipment, and control strategies have led to a need for improved glare thresholds. The increasing use of visual and auditory media in intimate family settings has diversified visual tasks and viewing distances, complicating ambient lighting design. Modern designer lamps and decorative lighting blur aesthetics, requiring color appearance evaluation and caution regarding direct view of bulb beads or luminaires (Sovacool & Del Rio, 2020).

7. Evaluation Criteria

Lighting design must observe some evaluation criteria in order to achieve the optimal quality of the lighting in a building. The process of evaluation generally involves some measures of objects or events of humans. In domestic lighting, as well as house design, there is a kind of balance between light sources on the external macro level and the viewers' ability to see. The phenomena noticed on both sides should match one another to provide comfort to the eyes. Hence, the following masking with such evenings as discomfort glare is avoided. In most of the cases, the parameters of the light sources are fixed. Thus, research for evaluating the lighting design is focused rather on the observer's eye sensitivity or viewing zone as a dominant than on the sources.

The thesis study examines vision, perception, and action as fundamental human attributes. Vision measures the ability of the eyes to see, evaluated through physical light properties like illuminance, luminous flux, luminance, and photometry. Perception describes how well the brain interprets visual information, influenced by behavioral factors. Action motivates movement and performance, focusing on vision and perception attributes of viewing domestic lighting (Boyce 2022).

The optimal domestic lighting in a house is determined by lighting comfort and light intensity criteria. Lighting comfort assesses discomfort glare and light intensity determines the ideal night condition for enhancing beauty. The glare index is proposed as an evaluation criterion for outdoor lighting design, along with three indices to evaluate the glare effect from the luminance contour. Conventional numerical glare estimations are also discussed, with new indices considering light attributes in the neighborhood and view depth of lighting exposure. Light intensity is defined as the result of emotional feelings based on light intensity and viewing domestic luminance, comparing blocks or units in drawings. The relative light intensity satisfies the equality of viewing condition and viewing luminance (Pracki & Skarżyński, 2020).

7.1. Visual Comfort

Visual comfort in a room is significantly impacted by ambient light illumination. A high reflectance ratio on a ceiling can cause brightness differences that exceed the installed lumens, making it uncomfortable to view from the normal eye level. To reduce discomfort, it is suggested that no glare should be found, if necessary, and preliminary computer simulations of brightness distributions on the ceiling and walls. Excessive luminance or brightness differences (glare) are more annoying than insufficient brightness, and the distribution of ambient light significantly affects the eye's discomfort. Ambient light intensities are acceptable when viewing bright picture screens, but softening or outperforming the brightness of light sources should reduce glare. In office rooms, attention must be paid to glare, both constantly and hemispherical. Glare is the annoyance caused by excessive brightness of a light source or multiple sources in the field of vision. A target brightness condition between ceiling and wall luminance is essential for achieving visually tolerable comfort (Tabadkani et al., 2021).

7.2. Task Performance

Lighting conditions should be evaluated in relation to the visual task performed or the light objects visualized. General evaluation numbers are meaningful only if the conditions under evaluation are for the same tasks and objects as the lighting design or recommended for the evaluation. In particular, luminance and glare conditions should be examined in relation to the objects of interest, even if they are not the ones most crucial for comfort. The size and luminance of task (as well as similar surrounding surfaces, if possible) determine the brightness ratio with respect to surrounding background areas, which, together with the viewing angles, determines the glare evaluation. Illuminance, exposure/size, brightness ratio, and glare can be determined for the most important task/(distractions) but should be interpreted in relation to that task (if known, its position in the space, and extension) and the visual conditions of interest to the evaluated space (Giovannini et al.2020).

A local glare source is usually less objectionable for relatively big tasks than for relatively small ones, as it is perceived with angles diverging more from the task-related viewing angles. As previously mentioned, the size of task is crucial with respect to uniformity, as, on the average, it varies with the square of luminance. Thus, with respect to uniformity (or its alternative micro-pressure in pure gains) lighting conditions should be simultaneously evaluated for the same comparatively small task sizes on the same bigger tasks, preferably even both considering glare perception (not ceiling luminance but fewer/less bright luminaries visible). Trail lighting effect in tunnels on vehicle glare, detailing lighting function in conference units, distractions in meeting rooms with monitors lit against daylight, or tram station outside illuminance on sidewalk contrast with train tunnel inside, however, task brightness should be taken into consideration mainly in such cases (Konstantzos et al.2020).

8. Case Studies

This section aims to demonstrate the feasibility of the ergonomic criteria for domestic lighting design and evaluation by presenting three types of case studies. In each type of case studies three or more lighting design variants for the same room layout and use functions are analyzed. From the sensory, physiological, and psychological aspect, the variant with the most acceptable qualitative parameters is assessed to comply with guidelines from Ghita et al., (2022).

8.1. Comparison of Different Lighting Designs

Lighting design plays a critical role in the comfort and well-being of individuals. This section presents a comparison of ten different lighting designs that were evaluated through 3 case study. The analyses focused on glare control, uniformity, colour temperature, and room brightness. All case study lighting fixtures were designed and prototyped by students of the “Prodcut Design I Course” in BUC during the first semester of the academic year 2021/2022.

The first case study examined a standard lighting design installed on a nightstand in a bed room. This design was challenged for glare control. Unfortunately, high glare levels were noted in this setting because of other sources of downlights installed in the ceilings. Another important point was poor light distribution with high variations of illuminance at the bed area. This lighting design illuminated the bed with only 27.2% uniformity, and at several points there were PE light levels below the recommended illuminance. Finally, looking at color temperature, there were areas illuminated by light sources with high color temperature near windows.

Figure (6) Case study 1 , designs 1 (left) to 3(right)

Figure (7) Case study 1 , designs 4 (left) to 6(right)

The second case study presented 3 slightly improved bed side lighting design for the open-plan office. This lighting design was proposed to solve some of the challenges of the standard lighting design. The new proposed design includes bedside lamps with built-in glare control, and an asymmetric reflectance configuration for the ceiling. This lighting design also proposed to fulfill recommendations for color temperature and avoid high color temperature lighting sources being near workstations. This improved lighting design was tested to note whether it solved the problems of the evaluated standard lighting design in the first case study. Overall, this was a marginally more successful design with good glare ratings below appropriate thresholds. Finally, with consideration of daylight, this lighting design on average illuminated the bed area with uniformity of 64.0% .

The third case study four drastically better designs for nightstand lamps for bedside lighting. All of the issues with the standard and marginally improved lighting designs were addressed by the new bedside lamp design. The newly suggested design calls for an asymmetric reflectance configuration for the ceiling and bedside lamps with integrated, adjustable glare control. The goal of this new lighting design was to avoid placing high-color lighting sources close to bed and to comply with color temperature requirements. To find out if it addressed the issues with the assessed standard lighting design in the prior case studies, this enhanced lighting design was put to the test.

With good glare ratings below suitable levels, this design was overall somewhat more effective. Lastly, taking into account daylight, this lighting scheme uniformly lit the bed area by 87.0% on average..

Figure (8) Case study 3 Designs 7(left) to 10 (right)

8.2. User Feedback and Satisfaction

A questionnaire was conducted in order to evaluate user feedback and satisfaction with the lighting solutions that were developed. The characteristics of visual comfort, mood or atmosphere, and the overall sense of the lighting environment were all covered in this questionnaire, which contained both closed-ended and open-ended items. The same people who assessed the lighting treatments based on the evaluation criteria also served as participants. The participants were asked to offer their thoughts on each of the lighting units after they were each displayed separately. Among the queries were:

1. Which of the lighting solution options do you think is the most aesthetically pleasing? Why?
2. Which of the lighting solution options do you think is the least aesthetically pleasing? Why?
3. Which lighting scheme is most appropriate for the bed room?
4. In your opinion, what kind of ambiance or mood does each lighting intervention create?
5. Provide your thoughts and overall impression on each lighting design as a whole.

Each of the three cases was assessed independently. In accordance with the questions on the questionnaire, the comments were examined. The results pertaining to mood or ambiance, overall impression, and lighting design preference questions were presented after the findings addressing visual comfort. The conclusions were exemplified by quoting the participant comments..

Addressing the visual comfort question, it was found that most of the comments regarding this aspect were related to the prototype lighting solutions (1 to 10). Two of the prototype lighting designs (7 and 8) were considered the most visually comfortable. The uniformly lit space provided by design 6 was mentioned also in almost every comment made regarding the high comfort choice. The designs 4,5,9 and 10 were noted to light up the whole space bed room and its corners evenly. This evenly illuminated space prevents dark areas, which creates visual comfort. As another reason for the high comfort choice, it was stated that the indirect light of the designs 4 and 5 softens the contrast of the lighted surfaces relative to the background and prevent glare.

9. Future Trends and Innovations

As new technologies evolve, lighting design is embracing the new opportunities that arise from the integration of these technologies. Digitalization and automation are facilitating user-centered lighting designs that meet the changing needs and lifestyles of their users. These technologies enable strong engagement of lighting systems' end-users, through their role as co-designers. Therefore, lighting designs are anticipated that are tailored to their end-users, energy-efficient, low-carbon, versatile, and easy to modify after implementation (Cuttle, 2022).. This section discusses future trends and innovations in the field of domestic lighting design. Some light and high-tech sensors and interconnected lighting solutions are becoming increasingly "intelligent" or "smart." By enabling the collection and exchange of data, these new types of lighting products can respond to their users' behaviors and preferences, as well as automatically adjust their operations to maximize energy efficiency. User-centric lighting designs are expected to embrace these innovations while ensuring that end-users' privacy and well-being are not compromised. Thanks to improved knowledge of light and its effects, light as a multi-purpose tool - addressing humans' visual, biological and emotional dimensions simultaneously - is enabling lighting designs that promote better places and enhance users' experience within them (Korneeva et al., 2021).

The urgent need to mitigate climate change and the global challenges that arise from it are prompting a profound socioeconomic transition towards a greener, lower carbon, circular, and resource-efficient economy. As part of this transition, sectors like domestic lighting design step up their efforts to boost energy efficiency, conserve resources, extend service life, and adopt cleaner production methods. New lighting products are expected to use less energy in their operation, maintenance, and material flows. In addition, lighting designs are anticipated that promote less energy and resource-intensive ways of living, working, and moving, in line with the constant re-evaluation of practices required in a low-carbon society (Pode, 2020).

New sensors, devices, and manufacturing technologies offer enhanced flexibility for the design and production of adaptable lighting solutions. These novel lighting products can automatically adjust their performance in response to their changing social, physical, or environmental context, and/or their users' varying preferences. Such adjustability gives lighting solutions more versatile or multifunctional capabilities, allowing them to address more demands and be used for a wider range of applications. User-centric lighting designs are foreseen that maximize the adaptability of installed lighting products and systems, enabling end-users to actively shape their performance characteristics throughout their entire service life (Pode, 2020).

9.1. Smart Lighting Technologies

The integration of smart lighting systems in building design is crucial due to the rapid urbanization and modernization of cities worldwide. With an estimated 85% of the world's population living in cities by 2050, smart lighting technologies aim to improve infrastructure efficiency and service quality. These technologies address issues such as urban pollution, energy wastage, and high costs of lighting systems. They also help analyze traffic violations, control traffic, enforce guidelines on smart street lights, and monitor traffic. The integration of AI in lighting systems improves performance and capabilities by integrating statistical data analysis. Intelligent lighting systems use daylight harvesting, photo control, active daylighting control, and combined technology to regulate lighting systems, architecture, luminaires, and combined units. These systems ensure adequate lighting levels, address urban infrastructure development, energy saving, enhanced mobility, improved livability, safety, and security (Casciani 2020).

9.2. Sustainability in Lighting Design

Sustainability in lighting design is crucial for architects, designers, and end users as it significantly impacts energy usage and greenhouse gas emissions. Sustainable design solutions for new buildings, retrofits, and upgrades to lighting systems are discussed. Electronic technologies like microprocessors, microcontrollers, LCDs, LEDs, and fluorescent tubes offer opportunities to address energy use and environmental concerns. However, the quality and distribution of light sources significantly impact the efficiency of lighting systems. Proper lighting placement and distribution can reduce lighting levels and energy consumption for light fixtures. (Zhan et al.2021).

Sustainable lighting design resources have been developed to educate architects and engineers on new practices. These resources include education modules, technical reports, illustrative examples, and project case studies. They include sustainability-oriented calculations and metrics to position new practices in a familiar design framework. These resources address daylighting and electric lighting, providing recommendations and metrics for passive solar design and electric lighting power density requirements. They also offer detailed metrics for electric lighting design geometry, controls, and technologies.

10. Implications for Design Practice

The study reveals that subjective assessments of lighting conditions vary between illuminated items, illuminated wall surfaces, and indirect ambient lighting in residential areas. These conditions were evaluated in high-efficiency energy-saving lighting technology-equipped homes. The study also assessed luminance and illuminance levels according to international lighting criteria. The findings suggest that indirect ambient lighting, illuminated items, and illuminated wall surfaces are alternative solutions for energy-efficient domestic areas. These design approaches help avoid direct glare and create uniform and pleasant room light effects. The study emphasizes the importance of people-centered information in building and town planning. Definitions of wall surfaces and ambient light effects are also sought, with the aim of achieving visual uniformity. The effects comparison study was limited to bedroom areas where lighting units are frequently used..

10. Conclusion

This research offers a comprehensive overview of domestic lighting design and evaluation, focusing on three design projects for domestic environments. It collects ergonomic criteria for within-room arrangement of picture and luminaire pairs and overall illumination impression, which are the main design objectives and support the evaluation and decision-making process.

The search for appropriate light levels to achieve optimal conditions for well-being, comfort, and domestic activity should be framed with possible variations of lighting due to control strategies and luminaire arrangement. This set of conditions is where daylight can be gradually adjusted by may be digital shading systems, where the daylight penetration is planned taking into consideration the size, position, and geometry of interior structures as well as latitudes and exposure, rivals artificial lighting scenarios where dimming systems help achieve the best effects. These chosen variables should also be tested with regard to variations in preference and performance due to the considered domestic activities such as general observation, reading, preparing meals, washing up, and ironing. These activities have some general characteristics influencing the choice of adaptations that could roughly be described as duration, size, position, sprightliness, and complexity that should be considered while seeking the best fit between human performance and daylighting strategy

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