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LIGHT AS A FACTOR IN HEALTH AND QUALITY OF LIFE – INTEGRATION OF NATURAL LIGHT AND HUMAN CENTRIC LIGHTING IN ARCHITECTURAL DESIGN OF INTERIORS IN RESIDENTIAL BUILDINGS

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Abstract:
The article analyses the role of light in residential interior design from historical, technological, and contemporary perspectives, with particular emphasis on the integration of natural and artificial light within the framework of Human Centric Lighting (HCL). It presents the evolution of approaches to light – from ancient principles of building orientation, through nineteenth-century hygienic reforms and modernist postulates, to contemporary technical regulations and lighting quality standards. The development of artificial lighting is discussed, from incandescent and fluorescent lamps to modern LED systems, highlighting their impact on visual comfort, human psychology, and health. A central focus is given to the HCL concept, which involves adjusting lighting parameters to the circadian rhythm and integrating daylight with artificial light to support users' health and well-being. Based on this framework, a set of design guidelines for residential environments is formulated, covering urban, architectural, and technological aspects. The article emphasises the importance of dynamic lighting scenarios, personalised solutions, and protection against blue light exposure at night. It argues that the integration of natural light and HCL represents one of the key directions in twenty-first-century residential design, in which light serves not only a functional role but also biological, psychological, and aesthetic purposes.

Keywords: Human Centric Lighting; LED light; well-being; mental health; healthy lifestyle

INTRODUCTION

Since ancient times, light has played a fundamental role in the design of living spaces. Its importance encompasses both functional aspects – ensuring visibility and comfort of use – as well as symbolic, aesthetic and psychological dimensions. Even ancient architects were aware of the significance of the orientation of buildings in relation to the cardinal directions on the living conditions of their inhabitants. In the Middle Ages, access to lighting determined social prestige, and in the 19th century, it became a pillar of hygiene reforms aimed at improving the quality of life in overcrowded cities. In the 20th century, electrification changed the way people functioned, making them independent of the cycle of day and night.

Nowadays, increasing building density and urbanisation processes are limiting access to daylight. On the other hand, the dynamic development of LED technology and digital control systems is opening up new possibilities for shaping the lighting environment. The Human Centric Lighting (HCL) concept is in line with these trends, treating light as a factor that supports biological rhythms, mental health and comfort of life. The purpose of this article is to formulate a set of guidelines for creating lighting environments in the architectural design of residential interiors, taking into account the integration of natural light and the principles of Human Centric Lighting.

Despite the growing importance of light in shaping the quality of the living environment and the rapid development of lighting technologies aligned with the Human Centric Lighting concept, design practice still lacks consistent methods for integrating these solutions

into the architectural structure of interiors. In particular, there remains insufficient understanding of how the parameters of biologically effective lighting can be linked to the process of shaping space, its structural elements, and finishing details. The research problem addressed in this article therefore concerns determining how the principles of Human Centric Lighting can be translated into the practice of architectural interior design in residential buildings, so that light serves not only a technical function, but also spatial and biological ones.

1. DAYLIGHT IN RESIDENTIAL ARCHITECTURE

The history of architecture clearly confirms the importance of bringing daylight into residential interiors. Already in ancient times, architectural solutions ensuring access to sunlight were used – atriums, peristyles, courtyards. Vitruvius recommended positioning rooms according to their function and the directions of the world in order to make proper use of solar radiation. In the Middle Ages and the modern era, access to light was not only a practical but also a prestigious element of everyday life.

Urban transformations since the 16th century have led to the gradual conversion of low-rise residential buildings into multi-storey tenement houses, built on a medieval street grid. [T.Tołwiński, 1939, p. 351]. Dynamic urbanisation and population influx resulted in the creation of cramped neighbourhoods and reduced access to light. The industrial revolution in the 19th century exacerbated these phenomena. In the immediate vicinity of industrial plants, densely built-up districts of high-density tenement houses were created, often completely deprived of sunlight, with narrow and damp streets, cramped flats and outbuildings conducive to disease and a deterioration in the quality of life of the inhabitants. [T. Tołwiński, 1939, p. 2]. The turning point came with the hygiene reforms of the 19th century, inspired, among other things, by Edwin Chadwick's report (1842) published in Great Britain, where daylight and ventilation were recognised as the foundation of public health, hygiene and disease prevention. The announced urban planning regulations were intended to ensure that residents had minimum access to sunlight, thereby improving their living conditions.

The beginning of the 20th century brought about a two-pronged development in the approach to light: on the one hand, the growing electrification gradually popularised access to artificial light, while on the other hand, avant-garde architects associated with the CIAM movement formulated the postulates of 'sun, space and greenery' as the basic conditions for healthy living. CIAM congresses emphasised the health, disinfecting and aesthetic values of sunlight (Frankfurt 1929) as well as the need for appropriate orientation of buildings in relation to the cardinal directions and maintaining distances between buildings [Brussels 1930; Mumford, 2000, p. 54]. Of particular importance was the Athens Charter (1933), which formulated urban planning and architectural guidelines in the spirit of rationalisation and ensuring access to light for all residents.

After World War II, the issue of ensuring adequate access to daylight was included in the technical and construction regulations of many countries. For example, in Poland, a minimum amount of sunlight for residential rooms was introduced – 3 hours[1] on the day of the equinox. In the United Kingdom, BRE guidelines have been in place since the 1960s. (Site Layout Planning for Daylight and Sunlight), In Scandinavian countries, particular importance was attached to maximising light access during the short winter days. In the second half of the 20th century, with widespread electrification, artificial lighting became the norm, significantly increasing the comfort of living and the flexibility of living space design. At the same time, however, this led to a decline in the importance of natural light as a basic design criterion – it began to be seen as an added value rather than a prerequisite for the health and well-being of residents.

2. THE DEVELOPMENT OF ARTIFICIAL LIGHTING

The development of artificial lighting has completely changed the way humans function, extending the hours of activity and making social and economic life independent of the cyclical changes of day and night. However, from the very beginning, the use of artificial light has been fraught with imperfections, which over time have taken various forms – from light quality, through health concerns, to aesthetic and psychological issues.

For most of the 20th century, tungsten bulbs were the primary source of lighting in homes. They emitted light with a full, continuous spectrum, very similar to natural sunlight in the afternoon. As an incandescent source, similar to fire and sunlight, it reproduced colours very well (CRI = 100), and its warm colour (approximately 2700 K) was perceived as friendly and comfortable. However, its disadvantage was

[1] The author analysed the history and chronology of regulations concerning supplementary lighting in her publication: *Wczoraj, dziś i jutro w promieniach słonecznych (?)* (M. Bartnicka 2010).

low energy efficiency and short lifespan. Both of these factors led to the phasing out of incandescent bulbs. Fluorescent bulbs, introduced in the 1930s as a more economical alternative, had limitations related to their spectrum (low colour rendering index), the presence of mercury and aesthetic issues. Ultimately, they did not gain full acceptance in residential spaces.

The development of LEDs was a breakthrough. Initially used only in signalling, they began to be used in general lighting in the 1990s. Users' adaptation to LED technology was gradual and involved many challenges. The first generations of light-emitting diodes were criticised for their cool, unnatural light colour, which did not contribute to creating a warm and comfortable home atmosphere. It was only with the introduction of solutions that allowed for a warmer colour temperature *(warm white)* that the perception of these light sources changed. With the development of technology, manufacturers began to offer high-quality digitally controlled LEDs with adjustable light intensity and colour temperature *(tunable white)*. Today, LEDs are the primary source of light in homes and public buildings. Nevertheless, certain problems are emerging in their use – uneven quality of products available on the market, flicker in cheap fixtures and an excess of blue light that is very dangerous to health and can negatively affect, among other things, the human circadian rhythm.

3. THE EFFECT OF LIGHT ON HUMANS

Light, both natural and artificial, plays a fundamental role in regulating biological, psychological and social processes. Its importance goes far beyond its purely functional role – it determines the quality of life and how space is perceived. In particular, daylight is a fundamental regulator of biological rhythms, supports mental health and ensures the highest quality of visual comfort.

There are two pathways for light reception in the human eye. The first is responsible for image formation and visual perception, and the second is responsible for the body's non-visual response to light [2]. Exposure to daylight, especially in the morning, stabilises the circadian rhythm, accelerates the decline in melatonin and supports cortisol secretion, which improves concentration and cognitive performance [C. Cajochen, 2007]. Natural light also influences serotonin production, which translates into improved mood, emotional stability and mental resilience [G.W. Lambert et al., 2002]. Research indicates that people who use spaces well lit by natural light report higher satisfaction, better work organisation and greater motivation to engage in cognitive activities [J.A. Veitch & A.D. Galasiu, 2012].

The development of artificial lighting has completely changed the conditions in which humans function, extending their active hours and making them independent of the natural cycle of day and night. From a civilisational perspective, this has been a huge step forward, but in biological terms it also has had negative consequences. Artificial light, especially light rich in blue radiation, leads to the inhibition of evening melatonin synthesis and a shift in the circadian rhythm. This can result in sleep disorders and a decrease in the quality of night-time regeneration. In the long term, it can lead to hormonal imbalances, metabolic disorders, immune system dysfunction, and increased susceptibility to lifestyle diseases [K. Skwarło-Sońta, 2014]. Lack of access to sunlight or exposure to lighting with inappropriate parameters is associated with reduced serotonin levels, which can lead to fatigue, decreased concentration, low mood, and in extreme cases, depressive disorders, including seasonal winter depression SAD *(Seasonal Affective Disorder)* [S.N. Young, 2007; P.J. Cowen, M. Browning, 2015].

In terms of visual comfort, daylight is an unrivalled benchmark – its full spectrum of radiation ensures accurate colour reproduction, natural shading and dynamic changes in light intensity and colour over time, which prevents monotony, supports visual adaptation and reduces eye fatigue [L. Edwards, P. Torcellini, 2002]. Artificial light, unlike daylight, has a discontinuous spectrum, which leads to colour distortion and reduced visual comfort. The colour rendering index (CRI), which measures the quality of colour reproduction, has long been a significant limitation in the quality of artificial lighting. Both fluorescent lamps and first-generation LEDs reproduced colours as 'faded' and their constant, unchanging luminous flux parameters contributed to eye fatigue [M.S. Rea, 2000]. Artificial light, although increasingly sophisticated, still requires conscious design to minimise problems such as glare, lack of luminance variation and visual monotony.

[2] This process is associated with the presence of relatively recently discovered light-sensitive retinal ganglion cells of the type ipRGC *(Intrinsically Photosensitive Retinal Ganglion Cells)*, containing melanopsin. These cells send signals to the suprachiasmatic nuclei (SCN) of the hypothalamus, which acts as the 'central biological clock', and then to the pineal gland, which controls the secretion of melatonin [D.M. Berson et al. 2002; S. Hattar et al. 2002]. Melatonin, known as the 'darkness hormone', informs the body about the onset and duration of night, acting as a biological 'clock and calendar' [R.J. Reiter 1993; K. Skwarło-Sońta 2014a].

4. HUMAN CENTRIC LIGHTING – DEFINITION AND OBJECTIVES

The concept of Human Centric Lighting (HCL) emerged at the beginning of the 21st century in response to growing interest in the impact of light on health and well-being. It involves supplementing seasonally variable or insufficient daylight with artificial light that supports human biological and mental functions. Unlike traditional lighting principles, which focus mainly on illuminance values and ergonomics, HCL treats light as a tool that supports the health, circadian rhythm and psychophysical wellbeing of users. HCL is defined as a way of designing lighting systems that adapt the intensity, colour and dynamics of light to the natural circadian cycles of humans. The basic aims of HCL are:

- Circadian rhythm support – adjusting light parameters to the time of day.
- Improved mental wellbeing – impact on mood, stress reduction and improved cognitive abilities.
- Integration of natural and artificial light – compensating for daylight deficiencies with dynamic systems that simulate the variability of sunlight.

In practice, this means using cool, blue-rich light with higher intensity in the morning and afternoon, which supports the secretion of cortisol and serotonin, while inhibiting melatonin, promoting activity and concentration [M.S. Jalali et al. 2024]. In the evening, warmer and less intense lighting is used, which helps to calm the body and prepare it for sleep [P. Varma et al. 2024].

HCL solutions use tunable white LED luminaires and digital control systems that allow lighting scenarios to be programmed in sync with the daily cycle. Such luminaires are installed both in suspended ceilings as panels or downlights, and in the form of tabletop desk lamps or free-standing lamps. In simpler versions, the user operates a remote control or mobile application, while professional solutions use advanced central controllers and light intensity and presence sensors that automatically adjust lighting parameters to the amount of daylight, the number of people in the room or the type of activities performed. In practice, HCL solutions are particularly important in homes, where people spend most of their time, including when working remotely. Users of spaces equipped with HCL systems report improved sleep quality, better concentration and a greater sense of comfort during the day.

5. DESIGN GUIDELINES

The urban layout and architecture of residential spaces should ensure the best possible conditions for sunlight exposure, at least temporarily. This is not always the case. Many contemporary architectural solutions significantly reduce full access to natural light, especially sunlight. Therefore, it is appropriate to use available lighting technologies designed to compensate for deficiencies and variability in daylight. Electric lighting should not only compensate for daylight deficiencies, but also enhance its positive biological effects [M.S. Jalali et al. 2024], thereby contributing to the comfort of users and the well-being of residents [P.R. Boyce 2014]. It is also extremely important to ensure visual comfort and proper perception of space through the appropriate placement of light sources, uniform luminance distribution and avoidance of glare.

A review of best design practices and research findings on the lighting environment indicates that both proper planning for daylight access and the implementation of dynamic lighting systems can significantly impact users' visual comfort, health, and well-being [P.R. Boyce 2014; K.W. Houser & T. Esposito 2021].

Based on the analysed research, case studies and contemporary recommendations, a set of design guidelines can be formulated to support the health, visual comfort and well-being of residents. These measures are multifaceted and should include solutions in the following areas:

- Urban planning: ensuring the required amount of sunlight in flats through lighting analyses carried out at the residential development planning stage and by maintaining appropriate distances between buildings and the right proportions of development [P. Littlefair, 2011]. This is the most difficult point to implement, as it can be observed that residential developments, especially in city centres, are becoming increasingly dense and developers are focused on the most intensive use of space possible, with sunlight not being a priority [M. Bartnicka 2010]. Furthermore, due to regulations requiring lifts in every multi-family building, corridor layouts are increasingly being used, resulting in one-sided apartment buildings with a specific orientation towards the north and, consequently, varying access to sunlight.
- Architectural solutions supporting sunlight inflow: use of large glazing, skylights, shelves and blinds directing the light stream, as well as light-coloured finishing materials. Designing room layouts to promote even light distribution. It should be emphasised that even advanced light-space solutions will not be effective if a favourable orientation towards the cardinal directions is not ensured.

- Implementation of HCL: these systems should not be viewed as a substitute for natural light, but rather as a factor that enhances its impact on the user of the space; therefore, the integration of daylight and artificial light is recommended [R.J Lucas et al. 2014, K.W. Houser & T. Esposito 2021] and maintaining their dynamic nature over time [C. Cajochen 2007]. To achieve this goal, an appropriate lighting system must be designed, consisting of various types of luminaires equipped with light sources capable of emitting light with different CCT colour temperatures and variable brightness in order to improve the quality of life of residents in accordance with the circadian cycle. Such lighting should be activated automatically (intelligent control based on DALI, KNX, ZigBee) or individually.
- Dynamic lighting scenarios: to enhance the synergy between daylight and artificial lighting, use cool (5000–6500K) bright light in the morning and during the day and warm (2700–3000K) relaxing light in the evening, conducive to calming down and preparing for sleep [K.W. Houser, T. Esposito 2021]. It is worth taking this into account in the functional layout of interiors, so that kitchens and work spaces (home office, remote work) are well lit during the day, and bedrooms are protected from excess light in the evening and at night.
- Protection against blue light: exposure to short-wave blue light should be limited in the evening and at night, and night [K. Skwarło-Sońta 2014a], lighting should be designed with low intensity and warm colour [P. Varma et al. 2024]. In this case, the recommendation promoted by the medical community – to eliminate the use of displays (laptops, smartphones) at least one hour before bedtime – also plays an important role. It is also important that, in principle, no displays, including televisions, should be used in complete darkness; the light from the screens should be supplemented with additional light.
- Visual comfort: luminaires with appropriate shades should be used to eliminate glare and ensure uniform luminance and soft light-shadow transitions without excessive brightness contrasts, so as not to cause eye strain [P.R. Boyce 2014].
- Flexibility and customisation: good lighting design allows for the creation of different lighting scenarios for different activities (working, reading, relaxing) and user groups (children, seniors).
- Light as an aesthetic element: in all solutions, it should be remembered that the lighting used is not only a source of adequate vision, but also a medium that creates the atmosphere and character of the interior.

6. DISCUSSION

Contemporary lighting design in residential settings goes beyond the traditional view of lighting fixtures as mere interior decor. The development of LED technology and Human Centric Lighting (HCL) systems is leading to a redefinition of the role of light as an integral component of interior architecture. In this context, lighting fixtures, linear systems, and modular solutions become elements that help shape the space, its perception, and its functionality.

The use of technologically advanced lighting systems requires their early integration into the design process. Lighting that complies with HCL principles cannot be treated as a secondary stage, implemented after the spatial layout has been finalized. The parameters of biologically effective light—such as variations in illuminance, color temperature, and light distribution—determine architectural solutions, particularly regarding the design of interior partitions, ceiling systems, and finishing details. Suspended and integrated ceiling systems are a key area of integration, enabling the implementation of linear luminaires with variable color temperature and indirect lighting systems, including soft reflected light. These solutions allow for uniform luminance distribution, reduced glare, and dynamic modeling of the lighting atmosphere depending on the time of day. Similarly, light walls, niches, and profiles built into architectural partitions enable the creation of layered lighting in a space, which aligns with recommendations from research on visual comfort and circadian rhythms.

The integration of HCL systems also influences decisions regarding interior layout and technical infrastructure. It becomes necessary to consider installation space, service accessibility, component modularity, and compatibility with building management systems (BMS). In design practice, this means close collaboration between the interior architect, lighting designer, and technology suppliers as early as the conceptual phase.

From the perspective of residential interior design methodology, this means that traditional design methods must be expanded to include the specifications of lighting systems offered by manufacturers and technology providers. Taking into account luminaire parameters, control scenarios, and installation requirements at an early stage of the design process allows

for consistency between the spatial concept and the lighting environment. This integration is a prerequisite for the effective implementation of Human Centric Lighting principles in residential architecture.

The implementation of lighting systems based on the Human Centric Lighting concept should not be limited to selecting fixtures with specific technical specifications. From the perspective of interior architectural design, the way in which dynamic light helps create the atmosphere of a space and influences the perception of its character is of key importance.

Lighting designed in accordance with HCL principles can be used as a design tool to shape the atmosphere of an interior based on the room's function and the users' circadian rhythm. In residential spaces, it is particularly important to design a multi-layered lighting environment that includes:

- general lighting, which enhances the overall perception of space,
- task lighting, designed to support specific activities and tailored to users' needs,
- ambient lighting, which creates a sense of comfort and security.

Dynamic changes in color temperature and light intensity can interact with the interior's color scheme and geometry, enhancing its character—from stimulating and energizing in the morning zones to calming and restorative in the afternoon and evening zones.

The use of HCL systems also influences the design of the relationship between light and spatial structure, enabling:

- emphasizing the rhythm of partitions,
- creating a sense of depth in the interior,
- defining functional zones without the use of physical partitions.

In this context, light becomes a medium for experiencing space, helping to shape its atmosphere and influencing the quality of life for its users not only through biological parameters but also through the sensory perception of the space.

CONCLUSIONS

For centuries, lighting has been an integral part of residential space design. Today, its importance is taking on a new dimension. Limited access to daylight in dense urban areas requires conscious integration with artificial lighting systems. The development of LED technology and the Human Centric Lighting concept allows for the creation of a living environment that supports health, biological rhythms, visual comfort and aesthetics. Light is therefore becoming not only a technical element, but also a medium that supports quality of life. The integration of natural and artificial light, based on HCL guidelines, is a key direction in contemporary residential interior design. It is an approach that combines tradition with modernity and responds to the needs of a healthy, sustainable living environment in the 21st century.

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