Renewable Energy 73 (2015) 109–114

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Chronobiological aspects of green buildings daylighting

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ARTICLE INFO

Article history:
Received 8 February 2014
Accepted 5 June 2014
Available online 22 June 2014

Keywords:
Daylighting
Spectral filters
Indoor environment
Chronobiology
Health

ABSTRACT

Daylight is the primary stimulus for synchronizing the human circadian photobiological system. Deficiency of daylight or its spectral anomaly in indoor environments is related to several health problems such hormonal unbalance, sleep disorder, depression and so on. In the light of new knowledge about the non-visual influence of light on humans, it is necessary to re-evaluate a number of the requirements and criteria of designing healthy indoor environment. This article has two main purposes. First, the author presents and summarizes a conceptual framework of chronobiological aspects of daylighting in built environment. Second, presentations of principles of circadian photometry based on an action spectrum of suppression of melatonin secretion in human organism and relevant consequences for creation of architectural environment, mainly fenestration systems.

1. Introduction

In modern buildings and urban environment people has been disconnected more and more from nature, in particular from enough daylight intensity in interior spaces. It is well known that in developed countries a large fraction of population spend 80–90% of their lifetime indoors. This fact strengthens arguments for assurance of diffuse daylight and direct sunlight in occupied interior spaces. Although dynamic artificial lighting design aspires to mimic color of daylight and changes intensities of illuminance during course of a day it can't compensate natural optical stimuli.

Over the past 30 years, the biomedical literature has shown that natural light helps to maintain a good health and can cure some of the medical ailments. In the last decade, there has also been a gradual increase in awareness of the non-visual effects of daylight (or more generally light) received by the eye. Discovery of a novel photoreceptor in the retina [1–3] led to a series of studies of human body respond to optical radiation [for example [4–9]]. Many of the published scientific papers confirm that optical radiation influence nearly all human behavioral and physiological parameters, both directly and indirectly. These parameters are linked to the biological rhythms. Biological rhythms in living organisms examine chronobiology. Biological rhythms are solar- and lunar-related. In this article we present the implications from chronobiology for daylighting design, which are mainly based on circadian rhythms (near 24-h light–dark cycle) whose are related to melatonin secretion ("the sleep hormone").

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http://dx.doi.org/10.1016/j.renene.2014.06.008
0960-1481/

2. Chronobiology in daylighting of buildings

We all can be considered "outdoor animals". Our body has been adapted to the circadian and circannual patterns of daylight for a million years. In modern societies, people spend most of their time indoors (at work and at home), but their gene code is still defined for outdoor life. Disturbances of the circadian rhythms have been revealed to also be correlated with disturbances in circadian physiology, neurobehavioral performance, some cardiovascular problems, immune dysfunction, depression, digestion, alertness and wellbeing. Therefore, a more intense future integration of chronobiological aspects in architecture and lighting design is warranted to help alleviate these problems in different populations and age groups. Surveys consistently show that people prefer daylight over artificial light, a desire for windows and good-quality view is well-established, and daylight as a primary source of light is believed to be also more healthful. These consequences are valid particularly for temperate and higher latitudes. A daylit spaces experience continuously changing natural illumination conditions over the day and from season to season. This sequence of conditions is unique to every design and every climate, location, site, and building. Architectural solutions of buildings should respect cyclical nature of light, the specific spectrum of daylight and the intensity of light that people are exposed to. Daylight apertures must be assessed with typical sky conditions at the site. The glazing material should distort the daylight spectrum only minimally. The quality and timing of daylight should be controlled to ensure the physical and mental wellbeing of building occupants.

Chronobiologically effective indoor daylight defines mainly:

- intensity of eye illuminance,
- color spectrum of the light,
- direction of the light,
- dynamism of daylight.

High light levels stimulate our circadian cycles mainly through activating serotonin (an antidepressant) and suppressing melatonin. Typical artificial illuminance levels on working horizontal plane in a room (about 500 lx) are not enough effective on light-induced melatonin suppression. Illuminance on eye of an indoor occupant by proper designed side daylighting system is often higher than 2000 lx.

Natural changes in daylight spectrum balance the body's circadian rhythms. The color temperature of the sky varies mostly between 6000 (overcast sky) and 10,000 (light blue sky) Kelvin. The color temperature of dark blue sky can be more than 20,000 K. The circadian effective is mainly blue light spectrum. There is a different spectrum of daylight at dawn (6–9 AM), in the late afternoon (4–9 PM) and in the evening. Generally, in the morning the blue light region of daylight is reach and in the late afternoon blue light is preferentially scattered out and orange and red color parts of daylight spectrum rise up. These natural changes in visible light spectra modify the hormonal and resultant physiological response in humans. Physiological changes due to non-visual light exposure depend on the timing and spectrum of light. For instance, circadian blue light exposure in the morning is healthy and in the evening may be disruptive to human health.

Direction of daylight varies permanently. The third type of photoreceptor in the retina (ganglion cells) is located predominantly in nasal and lower part of the human eye. From this point of view light-colored finish upper part of a room support distribution of indirect daylight on the circadian most sensitively parts of eye.

Dynamic daylight climate produce dynamic interior illumination, which continually differ in photopic and circadian light. Indoor habitable spaces should not be separated from dynamics of outdoor environment. Dynamics of external light climate is connected to several other climatic parameters that influence human productivity, health and wellbeing. Daylight must be also controlled for glare, discomfort, and temperature effects according to the needs and preferences of occupants.

New findings in non-visual aspects of light on humans provide the basis for major changes not only in lighting strategies, but also in architectural and urban concepts. The integrated approach is recommended which addresses the critical interactions between the site planning and the building design (building and rooms orientations, architectural openings, shading and screening systems, etc.), building interior and all light sources such as daylight (skylight and/or sunlight and reflected daylight) and artificial light.

The design team is responsible for addressing human and the technical issues on the project. Design decisions can improve or degrade the health potential of an indoor space. One of the crucial human issues is adequate level of natural light in living and working indoor environment.

The principles of building environment for photopic and also circadian lighting design (see Fig. 1) can contribute to creative and healthy architectural design. Adequate circadian light can enhance the therapeutic aspects of indoor environment.

Regretfully, not all daylighting practices have followed the chronobiological fundamentals of daylighting.

3. Photopic and circadian light

Light is currently defined as optical radiation entering the standardized human eye that provides visual sensation according to the well-known human photopic curve $V(\lambda)$, see Fig. 2. Almost all standards, measuring devices, lighting technologies, and applications have been based on that photopic curve, which represent photopic light. Typical daylight spectrum of overcast sky (represented by CIE illuminant D65) corresponds well with human circadian response, see Fig. 3.

Light has also many non-visual aspects. Much of our knowledge about light input to the circadian system comes from studies of acute melatonin suppression during night-time exposures. Action spectra $C(\lambda)$ for melatonin regulation in humans according [2,3] is in Fig. 2. Melatonin is the most popular marker of circadian rhythms. Even from the Fig. 2 it is noticeable that photopic and circadian systems do not operate in absolute isolation, but are mingled at some level. Action spectra of photopic and circadian light differ in spectral sensitivity, quantity, timing, duration, spatial distribution, and adaptation. The circadian activation needs much more light than vision. Time of a day is unimportant to vision. However, time of a day is quite important to circadian rhythms. Visual responses are very quickly. The circadian system operates much slower. The effects depend on the infusion of the hormone melatonin into the blood stream. Bright light results in faster

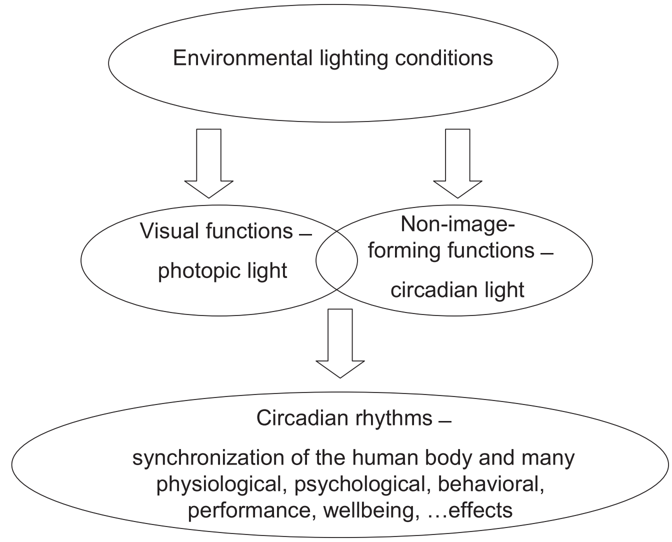

Fig. 1. Photopic light and circadian light as the components of light environment.

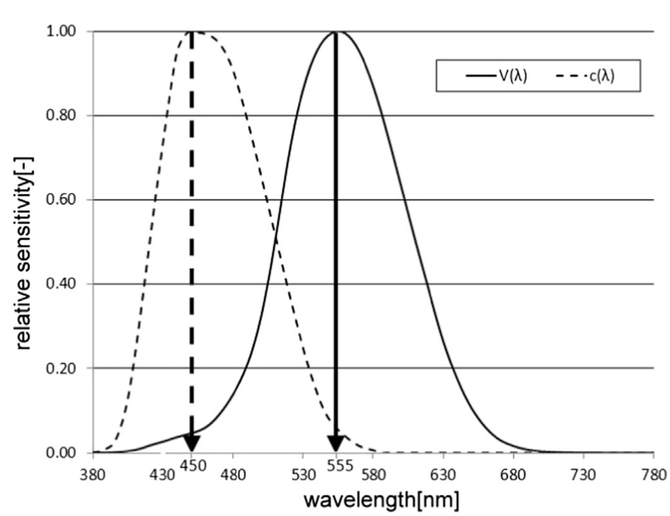

Fig. 2. Human action spectra of circadian ($C(\lambda)$) and photopic ($V(\lambda)$) light.