TECHNICAL REPORT

ISO/TR 9241-610

First edition
2022-10

Ergonomics of human-system interaction —

Part 610: Impact of light and lighting on users of interactive systems

Ergonomie de l'intéraction homme-système —

Partie 610: Impact de la lumière et de l'éclairage sur les utilisateurs de systèmes interactifs

Reference number
ISO/TR 9241-610:2022(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

A list of all parts in the ISO 9241 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

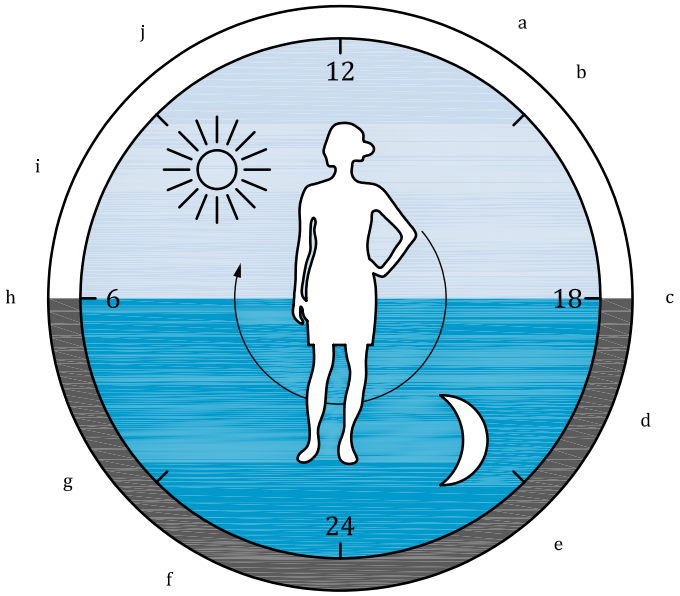
ISO 9241-6 was developed to give guidance on the work environment, including lighting to support vision. Since the discovery of a third sensor in the human eye, ample research has demonstrated that ocular light exposure, besides supporting visual perception, influences many aspects of human physiology and behaviour, including circadian rhythms, alertness and sleep, mood, neuroendocrine and cognitive function.

Users of interactive systems that mostly incorporate at least one visual display are likely to be affected both by the light generated by their work equipment and by lighting as an environmental factor. New scientific evidence establishes the fact that light exposure by the work equipment can reach levels of the same magnitude as ambient lighting[1].

Lighting has been defined as the use of light for making things visible since the International Lighting Vocabulary of the CIE was published in 1938.[2] In the 4th edition published in 1987, its definition was "application of light to scene, objects or their surroundings so that they may be seen".[3] The role of lighting has been thoroughly reconsidered in the light of the scientific evidence in the last two decades so that the internationally acknowledged definition was changed in the last version.[4] The definition now reads "application of light to a scene, objects, or their surroundings" (E-ilv 17-29-001).

"… so that they may be seen" has been dropped because of the new, additional role of light. It is required by scientists as well as practitioners that the design of lighting be performed in consideration of health effects. Currently, "Light and Health" has become a slogan pointing to the new goal. This can be characterized as considering and supporting human circadian rhythms governed by the circadian clock. Although such rhythms have been studied for decades, the discovery of molecular mechanisms controlling them was awarded the Nobel Prize for Medicine in 2017. The illustration by the Nobel Prize Committee can also serve as a short description for this document: "This clock [circadian] helps to regulate sleep patterns, feeding behaviour, hormone release, blood pressure and body temperature.

A large proportion of our genes are regulated by the clock." (Figure 1)[5].



a Best coordination.
b Fastest reaction times.
c Highest body temperature.
d Highest blood pressure.
e Melatonin secretion.
f Deep sleep.
g Lowest body temperature.
h Cortisol release.
i Fastest increase in blood pressure.
j High alertness.

SOURCE The Nobel Committee for Physiology or Medicine. 'The 2017 Nobel Prize in Physiology or Medicine' press release[5]. Reproduced with permission of the copyright holder.

Figure 1 — The circadian clock (also known as the circadian oscillator) and its impacts on our physiology

It should be noted that the first Nobel Prize in Medicine was awarded in 1903 to Niels Ryberg Finsen for his contribution to the treatment of diseases with optical radiation.

The new role of light has been considered not only by scientists but also by various institutions that deal with ergonomics, work organization, safety and health. Due to a high variety of sources that can be of relevance, this document has been prepared on the basis of documents representing the published outcome of expert evaluations of literature with a good general agreement, although published with a time difference of more than a decade. This document has been prepared after studying References [1] and [6] to [11] and the literature reviewed by their respective authors.

Ergonomics of human-system interaction —

Part 610:
Impact of light and lighting on users of interactive systems

1 Scope

This document provides users of interactive systems with a summary of the existing knowledge about ergonomics considerations for the influence of artificial (electric) and natural lighting of environments on humans other than on vision, with a focus on non-image-forming effects.

The document can furthermore be used as guidance on the specification of use environments in consideration of non-visual effects of lighting, also called non-image-forming (NIF) functions.

Therapeutic use of light and optical radiation is not part of this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
correlated colour temperature
CCT
temperature of a black body (Planckian) radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions

[SOURCE: IEV 723-08-34]

3.2
chronobiology
field of biology pertaining to periodic rhythms that occur in living organisms in response to external stimuli such as photoperiod

3.3
chronotype
phase relationship of the circadian clocks to the zeitgeber

Note 1 to entry: A person's chronotype is the propensity for the individual to sleep at a particular time during a 24-h period.

3.4
circadian
biological process that displays an endogenous, entrainable oscillation of about 24 hours

3.6
circannual
biological process that displays oscillation of about a solar year

3.7
colour rendering
<of a light source> effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant

[SOURCE: E-ilv 17-22-107,[4] modified — Notes to entry removed.]

3.8
colour rendering index
CRI
R
measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation

[SOURCE: E-ilv 17-22-109,[4] modified — Notes to entry removed.]

3.9
cone
photoreceptor in the retina containing light-sensitive pigments capable of initiating the process of photopic vision

[SOURCE: E-ilv 17-22-002,[4] modified — Notes to entry removed.]

3.10
daylight
part of global solar radiation capable of causing a visual sensation

Note 1 to entry: This definition is used for the purposes of lighting engineering. In physics, daylight is solar radiation in the range of optical radiation.

[SOURCE: E-ilv 17-29-105,[4] modified — Notes to entry replaced.]

3.11
daylight factor
D
quotient of the illuminance at a point on a given plane due to the light received directly and indirectly from a sky of assumed or known luminance distribution and the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky, where the contribution of direct sunlight to both illuminances is excluded

[SOURCE: E-ilv 17-29-121,[4] modified — Notes to entry removed.]

3.12
intrinsically photosensitive retinal ganglion cell
iPRGC
cells in the human retina that are intrinsically photosensitive due to the presence of melanopsin, a light-sensitive protein

3.13
light at night
LAN
exposure to artificial light during the dark hours of the day

3.14
light
<physics> radiation within the spectral range of optical radiation

Note 1 to entry: This definition also covers the use of the term in most disciplines, e.g. medicine, chemistry, biology.

3.15
light
<lighting engineering> radiation within the spectral range of visible radiation

Note 1 to entry: Visible radiation is optical radiation capable of causing a visual sensation directly (see E-ilv 17-21-003[4]).

3.16
luminous colour
colour perceived to belong to an area that appears to be emitting light as a primary light source or that appears to be specularly reflecting such light

[SOURCE: E-ilv 17-22-045,[4] modified — Notes to entry removed.]

3.17
luminous intensity
I_v, I
density of luminous flux with respect to solid angle in a specified direction

$$I_v = \frac{d\Phi_v}{d\Omega}$$

where

Φ_v is the luminous flux emitted in a specified direction;

Ω is the solid angle containing that direction.

Note 1 to entry: Luminous intensity is measured by candela, which is one of the seven SI base units.

[SOURCE: E-ilv 17-21-045,[4] modified — Notes to entry revised.]

3.18
melatonin
hormone that is produced by the pineal gland

3.19
optical radiation
electromagnetic radiation at wavelengths between the region of transition to X-rays ($\lambda \approx 1$ nm) and the region of transition to radio waves ($\lambda \approx 1$ mm)

Note 1 to entry: The lower end of the range begins in some regulations and standards at 100 nm. The difference is irrelevant for this document because both $\lambda \approx 1$ nm and $\lambda \approx 100$ nm are in the range of UV-C radiation.

[SOURCE: E-ilv 17-21-002,[4] modified — Notes to entry revised.]

3.20
photopic
relating to or denoting vision in daylight or other bright light, believed to involve chiefly the cones of the retina

3.21
rod
photoreceptor in the retina containing a light-sensitive pigment capable of initiating the process of scotopic vision

[SOURCE: E-ilv 17-22-003,[4] modified — Notes to entry removed.]

3.22
spectrum
display or specification of the monochromatic components of the radiation considered

[SOURCE: E-ilv 17-21-015,[4] modified — Notes to entry removed.]

3.23
use environment
generic term for the physical environment where light and optical radiation is present or intentionally used

Note 1 to entry: In industrial areas, use environment is called work environment. Since the physical environment outside the working space is also effective for the items under consideration, the term use environment has been introduced for the purposes of the ISO 9241 series.

3.24
zeitgeber
environmental cue, such as a change in light or temperature, that entrains or synchronizes an organism's biological rhythms, usually naturally occurring and serving to entrain to the Earth's 24-h light/dark and 12-month cycles

Note 1 to entry: From the German "zeit" (time) and "geber" (giver).

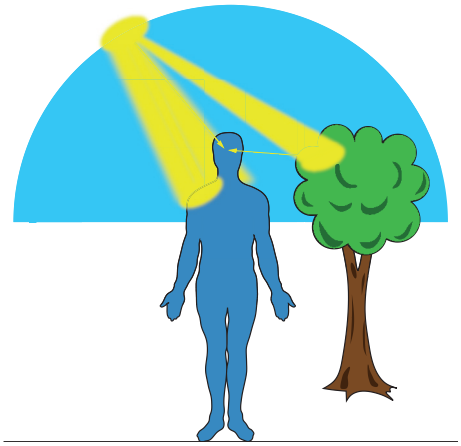
4 Light and lighting — more than just vision

4.1 How radiation impacts the human body

Radiation, in general, can generate effects in any material if absorbed by it. Radiation or parts of it reflected or transmitted do not cause any effect, for example a transparent material does not warm up independently from the level of energy passing through. Cells, tissues and organisms can be affected by two different categories of radiation, ionising and non-ionising. The distinction is based on the energy level of the radiated particles. Light, IR, UV and radio waves belong to non-ionising radiation.

NOTE Extraterrestrial UV radiation capable of ionising does not penetrate the atmosphere, whereas electric sources emitting similar wavelengths are only used for special purposes and are, therefore, not relevant for this document.

The relevant parts of the spectrum for this document are light (see Figure 3, Figure 4), (non-ionising) UV and IR. They can cause a variety of responses after entering the body through three pathways (Figure 2).[12]



Source Çakir, G. *Tageslichtnutzung und Sonnenschutzmaßnahmen an Büroarbeitsplätzen*.[13] Reproduced with permission of the copyright holder.

Figure 2 — Pathways for the solar radiation

A plethora of biological effects are caused by optical radiation hitting the skin and the eyes. Depending on the wavelength, energy can penetrate the skin to a different depth. While vision for which light is responsible is considered in most publications, generating vitamin D is of vital interest for human health, not only for the bones but also for the communication between cells (see also 4.5).

4.2 The role of light for life

Light[1)] is part of the radiant energy that fills the universe. Almost all life on Earth has evolved accompanied by light. No wonder that most living species have developed biological processes as a response to the natural light, the availability of which is governed by the rotation of the Earth and its motion around the sun.

Thus, light is central to the biological history of the world, both as a fuel for photosynthesis and as an environmental signal. As a fuel for photosynthesis light produces all green life from sea level up to the highest places where plants can survive, but also all tropical coral reefs deep down to where sunlight carries sufficient energy. As a signaller, light carries much of the information that enables life to adapt to its environment, and improved ability to receive that information is responsible for numerous evolutionary adaptations.

The importance of visible-light signalling for humans is demonstrated, for example, by the exquisiteness of the eye as an optical instrument; the large fraction (half) of the human brain devoted to visual signal processing; and our extreme dependence on visual technologies[14]. In fact, the human eye is not a sensor that conveys information from the environment to the brain like the ear; it is part of the brain.

At a very early stage of human history, artificial lighting was developed as one of the first human technologies. It expands the productive day into non-daylight hours and during the day it expands the productive space into the non-daylight areas of enclosed spaces. Bringing daylight into built space was one of the main objectives of architecture for thousands of years. Doing so, daylight was manipulated in different ways even when the “built” environment was a cave.

For the longest part of history, workrooms were built such that artificial lighting served as an auxiliary means to the main source, daylight. The availability of fluorescent light changed the architecture of buildings thoroughly, and it was believed that industrial work could be performed even completely without daylight. But the current notion is that “since the introduction of electric lighting, there has been inadequate light during the day inside buildings for a robust resetting of the human endogenous circadian rhythmicity, and too much light at night for a true dark to be detected; this results in circadian disruption and alters sleep/wake cycle, core body temperature, hormone regulation and release, and

1) Light in this sense is optical radiation.

patterns of gene expression throughout the body." [15] Although in the first half of the 20th century the light inside buildings was less adequate than now, fewer people spent fewer hours in such environments.

With electric lighting becoming ubiquitous, the daily pattern of the light/dark cycle which existed even in artificially lit interiors to a certain extent has disappeared or can be shifted to other parts of the 24-h day depending on working hours or personal preferences. However, it is well-known that the light/dark cycle incident on the retina regulates the timing of the human circadian system. Disruption of a regular, 24-h pattern of light and dark can significantly affect our health and well-being[16].

4.3 Non-visual effects of radiation

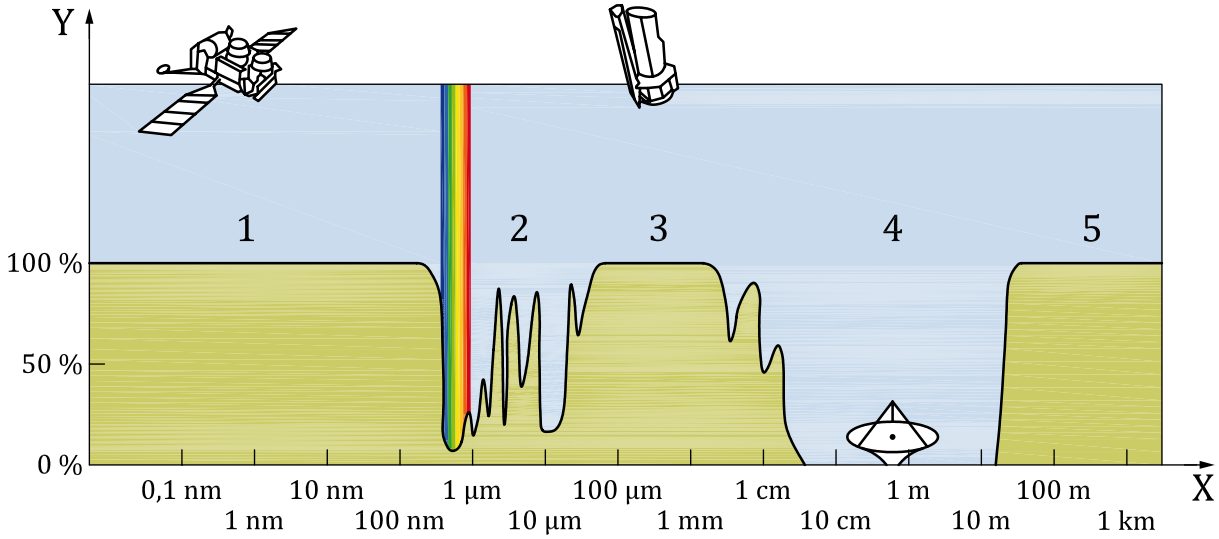
The solar energy received on the surface of the Earth is part of the radiant energy after being filtered by the atmosphere. The overall range of wavelengths measurable on Earth extends over a range of wavelengths from 10^{-16} m to 10^{5} m (electromagnetic spectrum). Only a limited range of wavelengths of radiation from 380 nm to 780 nm is considered light by definition in lighting engineering because these enable the eye to form images by exciting visual sensation, a process called vision. In contrast to these, some other effects of radiant energy are called "non-visual".

NOTE There is some confusion in the naming of effects caused by optical radiation other than vision. Since the 1920s, when disciplines dealing with the impact of "light" on humans became separated, various effects that did definitely not relate to vision were attributed to photobiology. Thus, some researchers used the phrase "biological effects" until it was acknowledged that also vision is biological. Before the discovery of the ipRGC in 2002, NIF effects of light were called "light effects"[17]. The term NIF effect (non-image-forming effect) was coined by Küller in 1983 to cover effects other than vision. But it is still possible to find expressions like "non-image-forming (NIF) biological effects of light" in scientific publications.

In many publications, effects mediated by melanopsin-containing or intrinsic photosensitive retinal ganglion cells in the eye are considered "non-visual". But the subject matter of Reference [7], "the eye-mediated non-image-forming effects of light", suggests that the "ability of optical radiation to stimulate each of the five photoreceptor types that can contribute to retina-mediated non-visual effects of light in humans". If only light in the definition of CIE can stimulate the photoreceptors in the eye to name "optical radiation" instead is at least confusing.

The effects considered in Reference [7] are limited to circadian effects without circannual effects. The question is whether circannual effects are not eye-mediated. Are they not non-visual? Currently, there is not even an agreement on how to spell non-visual.

To avoid further confusion, the word "non-visual" is used as an alternative to "NIF" following the rationale of Reference [18]. If circadian effects in the sense of eye-mediated events are addressed, this will be indicated.



Key

1 gamma rays, X-rays and ultraviolet light blocked by the upper atmosphere (best observed from space)

2 visible light observable from Earth, with some atmospheric distortion

3 most of the infrared spectrum absorbed by atmospheric gases (best observed from space)

4 radio waves observable from Earth

5 long-wavelength radio waves blocked

NOTE The original legend of the figure uses the term transmittance instead of absorption.

SOURCE NASA[19], open source.

Figure 3 — Rough plot of Earth's atmospheric absorption (or opacity) to various wavelengths of electromagnetic radiation, including visible light

Optical radiation generally refers to all radiation that can be measured using certain techniques and equipment (mirrors, lenses, filters, diffraction gratings, prisms). Thus visible, ultraviolet (UV), and infrared (IR) radiation are collectively considered optical radiation. All parts of the optical radiation are relevant for non-visual effects, including light. (Figure 4, from Reference [8]).