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ELEMENTS OF THE DAILY AND ARTIFICIAL LIGHTING IN AN INTERIOR

ABSTRACT *The daily and artificial lighting in the interior are the key elements shaping the visual environment and health aspects. The paper reviews of selected principles and technology of daylight and artificial light. Successively discusses the following topics: natural and artificial light sources and control them, day-lighting strategies, supplementing daylight with artificial light, energy efficiency requirements under the applicable standards in the European Union, and health factors in lighting and daylight in the house of senior. In the end, the rules of management daylight.*

Keywords: *daylight and artificial light, health factors in lighting, daylight strategy.*

1. INTRODUCTION

The natural and artificial lighting have many interconnections which are important for energy efficiency and health demands [1], [13]. The paper presents sources and control of natural and artificial light and daylight strategies [2].

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Special attention is paid for supplementation of daylight by artificial light. Energy efficiency of daylight requirements are explained on basis European Standards [12], [13]. The health factor in lighting is important in all buildings however it is especially critical in senior housing where residents may have restricted mobility. The end of paper gives some notions on managing daylight in a building.

2. SOURCES OF LIGHT

Illumination is produced naturally, by the sun, and artificially, by oil and gas flames and electric light sources. The development and growth in use of artificial sources of light over the last century has fundamentally changed the pattern of life for millions of people on Earth.

2.1. Natural light

Natural light is light received on Earth from the Sun, either directly or after reflection from the Moon. The prime characteristic of natural light is its variability [3], [9]. Natural light varies in magnitude, spectral content , and distribution with different meteorological conditions, at different times of day and year, at different latitudes. Moonlight is of little interest as a source of illumination but daylight is used, and strongly desired, for the lighting of buildings. Daylight has two components: sunlight, where the source is the sun, and skylight, where the source is the sky. Sunlight is light received at the Earth’s surface, directly from the sun. Sunlight produces strong, sharp-edged shadows. Skylight is light from the sun received at the Earth’s surface after scattering in the atmosphere. It is this scattered light that gives the sky its blue appearance, as compared to the blackness of space. Skylight produces only weak, diffuse shadows. Balance between sunlight and skylight is determined by nature of the atmosphere and the distance which the light passes through it. The greater the amount of water vapor and the longer the distance, higher is the proportion of skylight. The illuminances on the Earth’s surface produced by daylight can cover a large range, from 150 000 lx on a sunny summer’s day to 1 000 lx on a heavily overcast day in winter [2]. Several models exist for predicting daylight incident on a plane, at different locations, for different atmospheric conditions. These models can be used to predict the contribution of daylight to the lighting of interiors. Figure 1 shows a spectral distribution of daylight. It is clear that daylight contain significant amounts of ultraviolet and infrared radiation and that, over the visible wavelengths, daylight is a continuous spectrum.

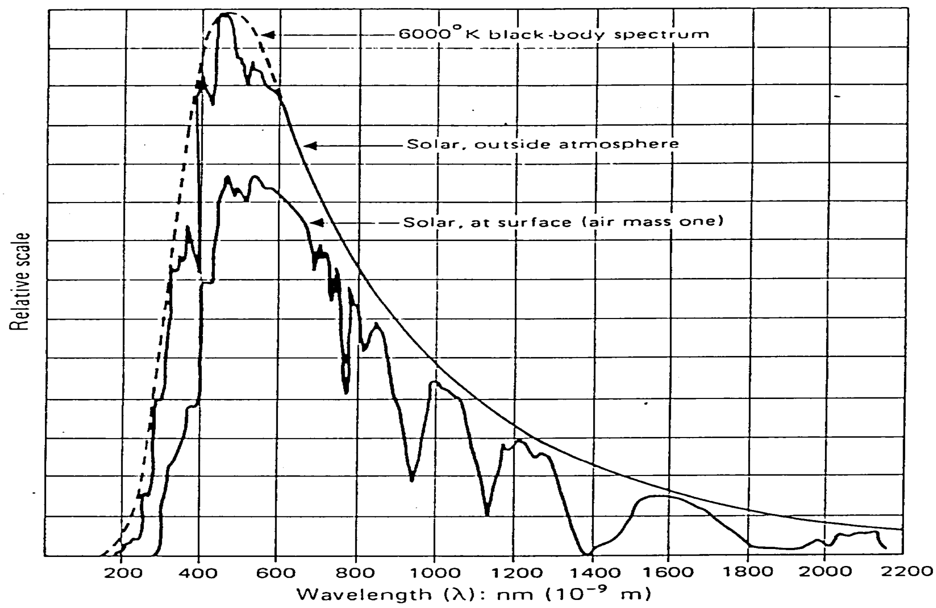

Fig. 1. The spectrum of natural light (Lighting Research Center,www.lrc.rpi.edu)

The correlated color temperature of daylight can range from 4000 K for an over cast day to 20 000K for clear blue sky (Fig. 2).

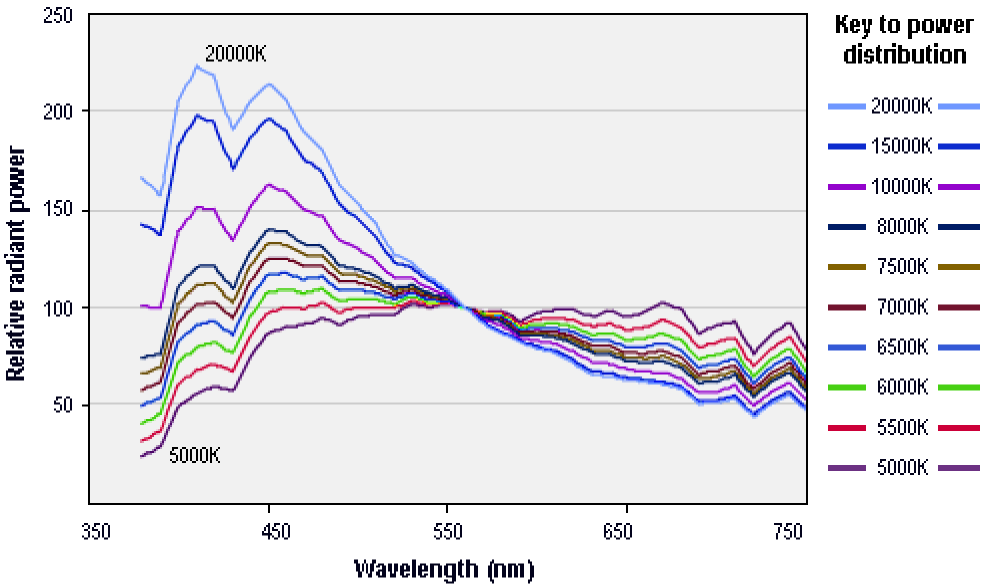

Fig. 2. The correlated color temperature of daylight (Lighting Research Center,www.lrc.rpi.edu)

In addition to the amount of daylight and its spectral power distribution, daylight varies in a luminance distribution over the sky. Models of the luminance for a completely overcast sky and an element of clear sky were elaborated. In practice, the luminance distribution of the sky varies between these two models depending on the degree of cloud cover. Daylight availability data are available for different climate types and there are average models, the average being taken over the complete year. These databases can be used to estimate the cost benefits of using a lighting control system linked to daylight as well as the impact of daylight on the annual energy consumption of a building. A simple worst-case approach is still sometimes used, namely to assume a CIE (Commission Internationale De L'eclairage) standard overcast sky producing an illuminance on the ground of 5000 lx. For sunlight, there are standard sky path diagrams to predict the position of a patch of skylight in a building for any specific window or skylight size, form, and orientation.

2.2. Artificial light

The first form of artificial lighting used by humans was firelight ,created by the combustion of wood. Developments in basic technology lead to the creation of the oil lamp, the candle and, ultimately, the gas lamp, all of which depend on combustion of fuel. Oil lamps, candles, and gas lamps are sometimes used today, either through necessity or for the atmosphere they evoke. The lighting industry makes several thousand different types of electric lamps. Those used for providing general illumination can be divided into two classes; incandescent lamps and discharge lamps. Incandescent lamps produce light by heating a tungsten filament to incandescence. Discharge lamps produce light by an electric discharge in gas. Incandescent lamps operate directly from the electricity supply. Discharge lamps require control gear between the lamp and the electricity supply, because different electrical conditions are required to initiate the discharge and to sustain it. Now, we have the light emitting diode (LED), a semiconductor that emits light when a current is passed through it. The spectral emission depends on materials used to form the semiconductor and we can see development of these new sources for general lighting.

3. CONTROL OF LIGHT

Being able to produce light is only part of what is necessary to produce illumination. The other part is to control the distribution and intensity of light from the light sources.

3.1. Control of natural light

For daylight, this is done by means of window or skylight shape, placement, and glass transmittance properties. The control of daylight admitted through a window or skylight is achieved by mechanical structures, such as light shelve, or by adjustable blinds. Whenever the sun, or a very bright sky, is likely to be directly visible through a window, some form of will be required. Blinds can take various forms ; horizontal, venetian, vertical, and roller being the most common. Blinds can also be manually operated or motorized, either under manual control or under photocell control. Probably the most important feature to consider when selecting a blind is the extent to which it preserves a view of outside. Roller blinds which can be drawn down to a position where the sun and/or sky is hidden but the lower part of the window is still open are an attractive option. Roller blinds made of a mesh material can preserve a view through the whole window while reducing the luminance of the view out. Such blinds are an attractive potion where the problem is an over-bright sky will be of limited value when a direct view of sun is the problem . The same applies to low transmission glass.

3.2. Control of artificial light

For electric light sources, it is done by placing the light source in a luminaire. The luminaire provides electrical and mechanical support for the light source and controls the light distribution. The light distribution is controlled by using reflection, refraction, or diffusion, individually or in combination. One factor in choice of which method of light control to adopt in a luminaire is the balance desired between the reduction in the luminance of the light source and the precision required in light distribution. Highly specular reflectors can provide precise control of light distribution, but do little to reduce the maximum luminance of the luminaire. Conversely, diffusers make precise control of light distribution impossible but do reduce the maximum luminance of the luminaire. Refractors are an intermediate case. The light distribution provided by a specific luminaire is quantified by the luminous intensity distribution. All reputable luminaire manufactures provide luminous intensity distributions for their luminaries. Control of light output is provided by switching or dimming systems. Switching systems can vary from the conventional manual switch to sophisticated daylight control systems which switch lamps near to windows off when there is sufficient daylight. Time switches are used to switch off all or parts of a lighting installation at the end of the working day. Occupancy sensors are used to switch off lighting when nobody is in space. Such switching systems can reduce electricity waste bat they will be irritating if they switch off lighting when light is required and they may shorten lamp life if switching occurs frequently. The factors to be considered when selecting a switching system are whether to relay on manual or an automatic system, and if it is automatic, how to match the switching to the activities in the space. If your interest is primary in reducing electricity consumption, a good principle is to use automatic switch off and manual switch on. This principle uses human inertia for the benefit of reducing energy consumption. If you wish to relay on voluntary manual switching of lighting , care should be taken to make lighting being switched visible from the control panel and to label the switches so that the operator knows which lamps are being switched. As for dimming systems , these all reduce light output and energy consumption but a different system is required for each lamp type, and some lamp types cannot be dimmed. The factors to consider when evaluating a dimming system are, whether the light source can be dimmed, the range over which dimming can be achieved without flicker or the lamp extinguishing, the extent to which the color properties of the lamp change as the light output is reduced and any effect dimming has on lamp life and energy consumption. Sophisticated lighting control systems are available for some light sources which allow the user to have a number of preset scenes. These systems use dimming and switching to alter the lighting of a space. They are commonly used in rooms with multiple functions, such as conference rooms.

4. DAYLIGHTING STRATEGIES

Daylighting strategies may be divided into two groups. The first includes sidelighting systems, where light is brought from the sides of a building into the interior space. A window is the simplest example of that strategy. The second group includes toplighting systems, where light is brought from the top a building and distributed into the interior. A skylight is the simplest example of such a system. A successful daylighting strategy is one that maximizes the daylight levels inside the building but optimizes the quality of the luminous environment for the occupants. Daylighting design is not only about maximizing light levels. Excessive sunlight in an interior can be extremely uncomfortable for its occupants. The key word in dayligting design is control, not only of light levels but also of the direction and the distribution of light.

4.1. Sidelighting systems

Most sidelighting systems are designed to overcome the problem of uneven distribution of natural light resulting from the use of traditional side windows. Effective sidelighting systems operate by reducing excessive daylight levels near the windows and increasing them in areas away from the windows, thus giving rise to a more balanced daylight distribution throughout the room. Adding devices to the window glazing such as lightshelves , prism, mirrored louvers and aidolic zenital collector system (Fig. 3) offers a viable sidelighting strategy because of the ability of these devices to deflect light further away from the window wall and towards the back of the room.

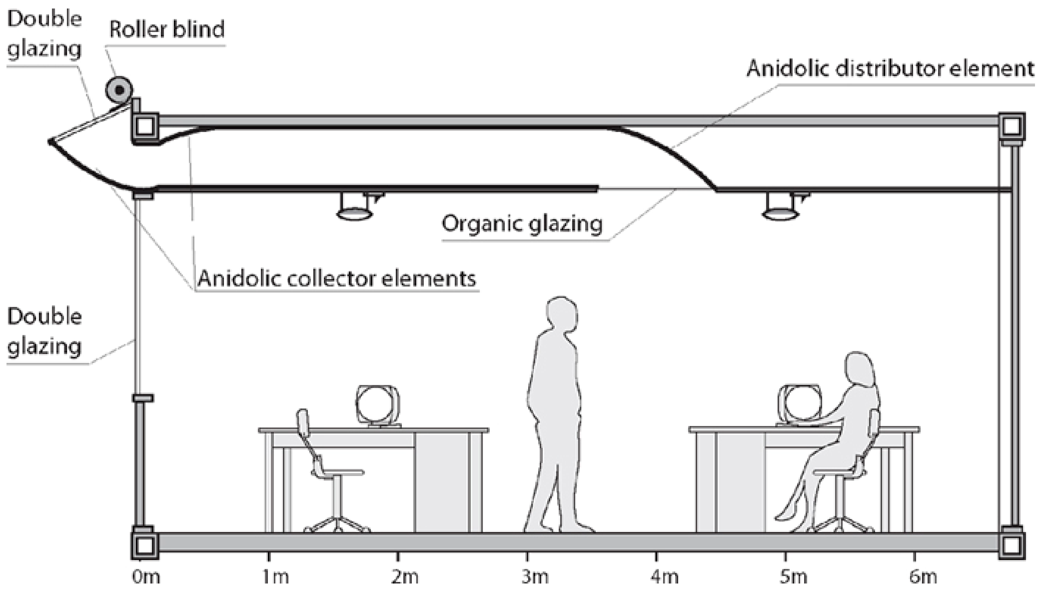

Fig. 3. The elements of anidolic zenithal collector system (SPIE Newsroom, 13 August 2009, http:spie.org/documents/Newsroom/Imported/1773/1743_ 6097_0_ 2009-08-05.pdf., SPIE is International Society for Optical Engineering)

4.2. Toplighting systems

Typical toplighting systems are: a skylight, roof monitor, sawtooth and light pipe system. A skylight system is one of the simplest toplighting strategies. It usually provides a horizontal or slanted opening in the roof of a building and is designed to capture sunlight when the sun is high in the sun and diffuse light from the zenithal area of the sky vault, and introduce it into portion of the room under the skylight. This daylighting approach can be used only for the top floor of a multi-story building or for single-story buildings. Several skylights uniformity distributed across the ceiling lead to a uniform distribution of daylight. Roof monitors and sawtooth systems are toplighting strategies that differ primary in their shapes. Under these systems, light is captured through vertical or sloped openings in the roof. These openings can be designed to capture sunlight at

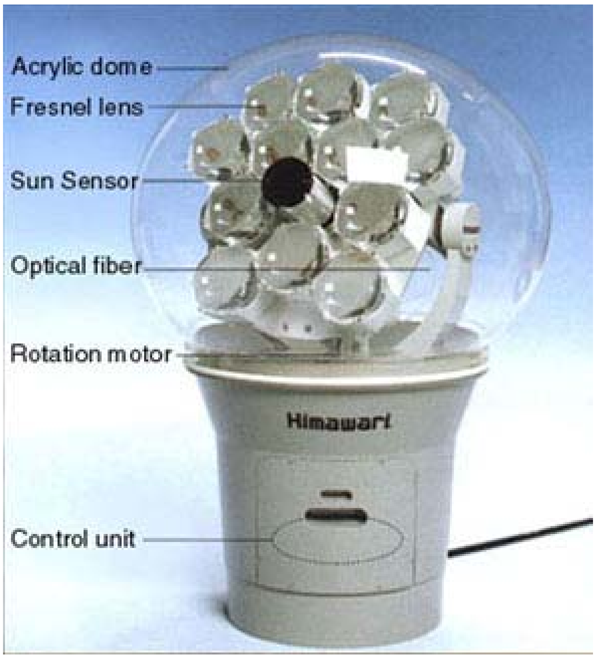

Fig. 4. The elements of the light pipe system from Himawari (www.himawari-net.co.jp)

certain times of the day or of the year, depending on the requirements of the building. Roof monitors can be single-sided or two-sided. Single-sided roof monitors and sawtooth systems provide a directional effect inside the room, especially if the elements are spaced far apart. Two-sided roof monitors provide a more uniform distribution of daylight and less directionality, particularly under overcast sky conditions. A light pipe system is a toplighting strategy designed to bring daylight into the lower floors of a multi-story building. This apparatus can be relatively simple or sophisticated and elaborate. The typical components of a light pipe system are a solar collector that gathers sunlight, a concentrator that focused solar energy onto a smaller area, a transport system, and a distribution system. Figure 4 shows the some elements of the light pipe system from Himawari.

5. SUPPLEMENTATION OF DAYLIGHT BY ARTIFICIAL LIGHT

It is generally accepted that some natural light is desirable for the lighting of building interiors (Fig. 5), [4] and (Fig. 6). However, increase in the minimum illumination which is considered appropriate for various tasks have directed attention to the possible use of artificial light as a permanent supplement to daylight. As a result of studies certain principles for the design of permanent supplementation of daylight by artificial light can be stated. The following requirements should be met:

- the design of the windows and of the supplementary lighting should be treated as a whole,
- the combined illumination should nowhere be less than the level judged appropriate for any specific visual task in the room,

- there should be an acceptable balance of brightness between the parts of the room lit mainly by daylight and those parts lit mainly by artificial light,
- there should be sufficient illumination to prevent excessively dark shadows,
- during the hours of daylight, the daylight should always appear to be dominant.

The amount of artificial necessary to give an ideal balance of brightness between those areas lit by daylight and those served by artificial light is in proportion to amount of exterior daylight. It is also dependent on distribution of daylight in the room and on the amount of unobstructed sky that can be seen. The relief of monotony given by variations in daylight is of value, and it is unwise to lose this quality by swamping the daylight with artificial light. With normal room decorations 400 lx seems to provide a satisfactory balance for a range of sky luminance of 1300-7000 cd/m^2. Another factor which is important is the spectral quality of the light used to supplement daylight, although it is not essential for the supplementary light to match exactly the color of natural daylight. The natural light itself varies very much in its spectral content quality through the day. One advantage of supplementary artificial light is that it allows more freedom in the design of windows and relieves the designer of the necessity to provide high daylight factors at the back of the room. Nevertheless, the design of the windows requires careful consideration to reduce the area of the sky visible to the eye from inside the room, to limit the brightness of surfaces and provide good distribution of daylight without necessarily providing maximum penetration to the back of the room. A minor, but not negligible factor is the effect of the supplementary lighting on dull days. Again limited experience suggests that when the average brightness of the sky falls below 1000 cd/m^2 the need is likely to be felt to switch on the normal night-time lighting. This leads to the problem of reconciling the requirements for supplementing the daylight and requirements for artificial lighting at night-time. There are two possibilities:

- an independent system, which may give lighting of an entirely different character, or
- some modification of the supplementary system.

Which of the two methods is most appropriate in given circumstances will depend to some extent on the distribution direction, and color of the light from the supplementary system. If, for instance , the supplementary artificial light is designed to implement in character and direction that given by a large side window, it may not provide the more uniform lighting often desirable after dark.

Whichever scheme is adopted, it is important to avoid sudden changes from a high level of supplementary light to a relatively low level of normal artificial light. While night-time lighting may be accepted as after dark, they would be considered inadequate if experienced immediately after the brighter supplementary light.

Fig. 5. Supplementary daylighting by artificial lighting at the visual task (Energy efficient lighting in offices, Commission of the European Communities, 1992)

Fig. 6. The dome of a daylight on the German Parliament (www. German Parliament)

6. ENERGY EFFICENCY REQUIREMENTS

Lighting should be designed to meet the lighting requirements of a particular task or space in an energy efficient manner. It is important not to compromise the visual aspects of a lighting installation simply to reduce energy consumption. Light levels as set in European Standard (12464- 1: 2004) are minimum average illuminance values and need to be maintained. Energy savings can be made by harvesting daylight, responding to occupancy patterns, improving maintenance characteristic of the installation, and making full use of controls. The amount of daylight varies throughout the day depending on climate conditions. In addition, in interiors with side windows the available daylight decreases rapidly with the distance from the window. Supplementary lighting may be needed to ensure the required illuminance levels at the work station are achieved and to balance the luminance distribution within the room. Automatic or manual switching and/or dimming can be used to ensure appropriate integration between artificial lighting and daylight. A procedure for the estimation of energy requirements of a lighting installation is given in EN 15193. It gives a methodology for the calculation of a lighting energy numeric indicator (LENI), representing the energy performance of lighting of buildings. This indicator may be used for single rooms on a comparative basis only as the benchmark values given in the EN 15193 are drawn up for a complete building.

7. HEALTH FACTORS IN LIGHTING

The natural and artificial light is important to people's health and wellbeing. Light affects the mood, emotion and mental alertness of people. It can also support and adjust the circadian rhythms and influence people's physiological and psychological state [1], (Fig.7).

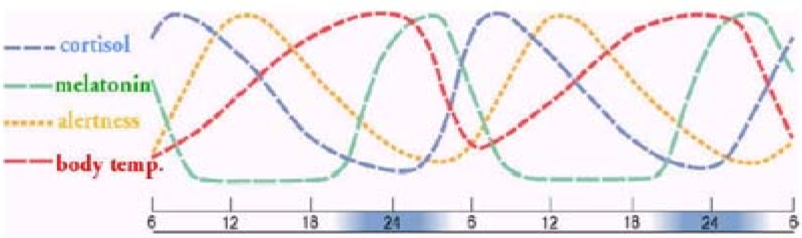

Fig. 7. Double plot (2x24 hours) of typical daily rhythms of body temperature, melatonin, cortisol and alertness in humans for a natural 24-hour light/dark cycle

Up to date research indicates that these phenomena, in addition to the criteria defined in EN 12464-1, can be provided by the so-called “non-image forming” illuminaces and color appearance of light. Varying lighting conditions in time by higher illuminance, luminance distribution and wider range of color temperature then specified in this European Standard with daylight and/or dedicated artificial lighting solutions can stimulate people and enhance their wellbeing. The recommended bands of variation are under consideration. The lack of sunlight can even be toxic because it leads to deficiency of vitamin D in our bodies. Buildings should be designed to maximize our exposure to sunlight in order to facilitate the cutaneous photosynthesis that supplies most or all of our vitamin D needs. Vitamin D is vital to our lives and is the first defense against such ailments as cancer, osteoporosis, diabetes, multiple sclerosis, and other immune system diseases. We need only 15 to 35 minutes a day of outdoor exposure to sunlight three or four times per week to generate an adequate amount of vitamin D, which is estimated to be between 120 and 150 nanomoles per litre of blood. Many of us, however, do not receive adequate exposure to sunlight because of climate, working conditions, health problems, or age. Some of us are bedridden or old and not very mobile, thereby limiting our exposure to sunlight. Because glass filters out about 95% of the UV-B radiation, the length of exposure to sunlight indoors must be nine or ten times longer than the recommended outdoor exposure. Buildings that house the elderly have even higher requirements for sunlight because aged skin diminishes the cutaneous photosynthesis of vitamin D. Many of us spend most of the daytime hours at work and may be unable to come into contact with daylight outside our work schedules. As a result buildings should be designed to admit light levels that will enable us to maintain a well-balanced circadian rhythm. High daylight levels optimize the secretion of serotonin and keep us alert. In addition to vitamin D, a well-balanced circadian rhythm that includes adequate amounts of serotonin during the day and melatonin at night appears to boost our immune systems and allows our natural defense mechanisms to fend off many ailments including cancer, diabetes, and multiple sclerosis. Because we spend the majority of our lifetime indoors, buildings should be considered as healing places in addition to their traditional role as shelter. Building that don’t admit sunlight provoke disease, either directly or indirectly. Daylight is one of the most effective antidepressants available. Research has shown that light levels above 2500 lx can offset Seasonal Affective Disorder (SAD); however illuminance levels of 10 000 lux have been shown to be four times more efficient. These illuminances levels are significantly higher than those generally recommended for most visual task. Needless to say, we cannot rely on electric lighting systems to supply such high illuminance levels, helps to alleviate 80% of SAD disorders. The spectral quality of light also plays a significant role in the fight against SAD and nonseasonal depression, and in the production of vitamin D through the skin. High illuminance combined with the full spectrum quality of daylight make daylighting the most economical and perhaps the only plausible solution. Designers may not be able to meet this need for exposure to sunlight everywhere in a building. They can ,however, incorporate, solariums, balconies, atria, and terraces where building occupants can have access to unfiltered sunlight.

8. DAYLIGHTING FOR SENIOR HOUSING

Although daylight is important in all buildings, it is especially critical in senior housing where residents may have restricted mobility and needs for higher light levels than the general population. Designed well daylight serves as a welcome visitor, connecting residents with the outside world while bringing energy savings and improving light levels, visibility and safety [11]. Furthermore, the daylight spectrum offers intrinsic health benefits. Daylight has advantages for senior housing that involve several quality-of-life and life safety issues:

- **helps improve visibility:** research shows that the eye ages, it can require substantially higher light levels to achieve the same visual acuity. The low lighting power density(LPD) goals set by energy conservation approaches challenge the lighting designer to achieve good lighting for the senior environment within an energy-efficient LPD allowance. Well-designed daylighting scheme increases light levels during daytime hours while reducing the electric lighting load, providing improved visibility with substantial energy savings,
- **provides high color rendering:** the spectral power distributions of daylight varies throughout the day , but it emits radiant power across the entire visible spectrum, making it a very good source for rendering colors,
- **provides exterior views:** views to the exterior (especially to the horizon) connect occupants with nature and outside activities and help to reduce the isolation that seniors often experience. Exterior views provide a dynamic environment for residents with limited mobility, connecting them with changing sun patterns through the day, variations in the weather and seasons, and the comings and goings of other people. This reinforcement of time of day and orientation in time and space is important. In addition, exterior views lengthen the eye's focal distance, allowing eye muscles to relax and reducing stress. Research has demonstrated that the benefits of views are exhibited both psychologically and physiologically. In the hospital environment, views of nature have been correlated with

reductions in pain medication and recovery times. Staff will benefit from daylight and views in other ways. Several research projects have linked higher productivity and work satisfaction when staff has access to daylight and views,

- **transitions reduce adaptation discomfort:** on sunny days, exterior spaces are several orders of magnitude brighter than the interior. Although all people experience difficulties with vision as their eyes adapt from the bright exterior to the less bright interior, older eyes take much longer to adapt to the changes in light levels. Providing graduated levels of daylight across transition spaces is a natural way to minimize this adaptation discomfort. Proper daylighting of transition spaces can create a gradual reduction in the exterior light level across the entry sequence. A well-design entry sequence may involve moving from direct sunlight to a partially covered exterior walkway, then through a fully covered entryway, arriving at an interior space with windows or skylights,
- **maintenance of circadian rhythm**: within the typical lighting environment, light levels provided by electrical lighting are not sufficient to activate the circadian system, and most lamp sources do not have the spectral power distribution that effectively addresses circadian needs. Sections of the home can be designed to deliver the higher levels of daylight that may serve to enhance these processes and increase the health of residents who have limited access to the outdoors. Such areas may include spaces where residents will spend a major portion of their day.
- **energy conservation:** good daylighting design when properly integrated with electric light, can save energy especially if the interior space is properly ventilated. In fact, a “double” energy savings may occur in summer because the space needs less energy to power electric lamps, and less energy is needed for air conditioning to remove the lamp heat.

However, daylighting also brings with it some issues for lighting design in senior housing. The aging eye is more sensitive to glare and older people may experience more thermal discomfort around poorly insulated window assemblies. Careful attention must be paid to daylighting details to provide bright, cheerful interiors without the negative effects of glare, confusing shadows and thermal discomfort.

9. NOTIONS ON MANAGING DAYLIGHT

Daylight should be used wherever possible because it is free and delivers good color rendition [11]. Daylight can be delivered to spaces by using:

windows, roof windows, light pipes, doors that transmit light and glass blocks. The sun can provide very strong light. Whilst the quality of this is pleasing and improves mood, the light can be too strong and may need to be carefully managed with: light-diffusing blinds, curtains, special glass, external shading devices (in lower latitudes).On the other hand there may not be sufficient daylight. The day effect is higher where: more sky can be seen from the window(e.g. the room is higher in a building; there are fewer external obstruction like trees), window area is bigger, the light transmission through the window is enhanced, the room surfaces reflect more, the room is smaller in proportion to the windows. Another important factor is the orientation of the window(s). South-facing rooms receive 50% more light than north-facing rooms. The quality of daylight can vary within a building, e.g. a ground floor north-facing room might receive less daylight than a first floor south-facing one. If artificial lighting is not being used during the hours of daylight, the average daylight factor should be at least 5%. If electric lighting is being used during the hours of daylight, the average daylight factor should be at least 2%.

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OŚWIETLENIE DZIENNE i SZTUCZNE WE WNĘTRZU

Zbigniew TURLEJ

STRESZCZENIE *Oświetlenie dzienne i sztuczne we wnętrzu są podstawowymi elementami kształtującymi środowisko wizualne i prozdrowotne. W referacie dokonano przeglądu wybranych zasad i technologii oświetlenia dziennego i sztucznego. Kolejno omówiono następujące zagadnienia: naturalne i sztuczne źródła światła oraz sterowanie nimi, strategie oświetlenia dziennego, uzupełnianie światła dziennego światłem sztucznym, wymagania dotyczące efektywności energetycznej na podstawie obowiązujących standardów w Unii Europejskiej, czynniki zdrowotne w oświetleniu oraz oświetlenie dzienne w domu seniora. W końcu przedstawiono zasady zarządzania światłem dziennym.*

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