THE CHANGING PERSPECTIVE OF DAYLIGHT DESIGN TO FACE THE CHALLENGE OF CLIMATE CHANGE

Md. Ashikur Rahman JOARDER M. Arch[1]
Andrew PRICE Ph.D[2]
Monjur MOURSHED Ph.D[3]

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Abstract

From the history of human civilization and development of architecture, it is evident that for most of the periods daylight was the leading choice of people and researchers for building illumination, except for a very short period of 50 years (1920 - 1970) in-between. The argument for daylighting has changed in different era, from the one and only source of light to energy efficient source, from healthy source of light to, again unique source of light to stop generation of fossil fuel GHG-emitting energy. The vast campaign for daylight building was started to save energy, but later it was proven that sometimes daylight itself causes extreme cooling load to the building more than the savings from artificial light. Therefore, improper and outthought addition of daylight may cause harm rather than targeted benefit. Now, the uppermost argument and interest for daylighting is its encouraging acceptability to occupants' health, comfort, performance and satisfaction. Due to the accelerated climate change in future, failure to protect the buildings from UVR from sunlight, can go the other way and could be a threat on human health and wellbeing. This paper presents, how the design philosophy of daylight has changed/ updated with time. The purpose of this paper is, learning from past, highlight the added agendas of climate change for daylight designers and researchers, so that each and every solution and decision of daylight design will not only meet the current requirements and strategy but also fit in future episode.

1. Introduction

Daylight is one of the free gifts of nature. Due to its availability, most of the time it is overlooked and become underutilized in building service design, though the strategy for proper and 100% utilization of daylight in buildings is still an evolving topic of research. In a sense, daylight in buildings is not always free, because conventional window costs more than a blank wall, and linear buildings (to keep the depth of building within reach of daylight) are more expensive to construct compared to the compact one, let alone the sophisticated and high performance facades (e.g., intelligent skins, active facade systems, double-skin facades, etc.) to accommodate proper daylight into buildings (ERG, 1994). It is also recognised that all the effects of daylight may not be beneficial for the users (Ahmed & Joarder 2007). Research is going on to make daylight more useful source of energy and comfort, and less harmful for buildings' inhabitants.

The research on daylight was started to find out and manipulate physical/ objective characters of daylight e.g., depth of daylight in buildings without additional support and how it can be increased passively, the nature and availability of daylight on different geographical locations, the changing quantity and quality of daylight with orientation, time of day and seasons, how could daylight be made comfortable for users by ensuring radiation and glare free light etc. and have reached to a concrete knowledge for referencing. However, the subjective character of daylight such as, impact of daylight on health, performance and activity is not fully resolved, moreover has controversy result in findings, and equally debated by the researchers (Loftness et al., 2006). Rapidly accelerating climate change (global warming) and increase of UVR (Ultraviolet Radiation) levels in atmosphere strike the researchers' concern in this subjective health issue of daylighting. Similar to all other fields, in the arena of daylight building design the climate change issue is triggering the designers to consider its impact in the design badly. Before focusing on the climate change issue, it is important to know the past and present issues of daylighting design to understand the changing/

[1] Assistant Professor, Dept. of Architecture, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh & Researcher, HaCIRIC, Department of Civil and Building Engineering, Loughborough University, UK, M.A.R.Joarder@lboro.ac.uk

[2] Professor, HaCIRIC, Department of Civil and Building Engineering, Loughborough University, UK, A.D.F.Price@lboro.ac.uk

[3] Lecturer, HaCIRIC, Department of Civil and Building Engineering, Loughborough University, UK, M.M.Mourshed@lboro.ac.uk

updating philosophy of daylighting design. This paper consists of major three parts. The first part briefly describes the changing agendas of daylighting design from past to present. The second part shows the consequences of climate change on human health due to increasing amount of UV radiation in sunlight and highlights the added agendas of climate change. The last part briefly describes the precautions with available technology to protect individuals from UVR when insides the buildings.

2. Changing Agendas for Daylighting Design

The notion of building architecture developed with the introduction of window and daylight in building design (Joarder, 2007). From ancient time, the designers have used daylight into the buildings to give an architectural statement. However, strong argument for daylight inclusion in building design is often associated with health and energy benefits. Before 1940s, daylight was the primary light source for buildings and artificial lights supplemented the natural light. In a short span of 20 years, electric light satisfied most of the lighting requirements of occupants (Edwards & Torcellini, 2002). The arrival of fluorescent light and cheap energy allowed deep-planed, fully air-conditioned and mechanically ventilated buildings with sealed windows in expensive, dense, noisy and polluted urban sites. Daylight, in this stage, was no longer a critical design element and external walls usually have less windows, even no windows or, in case of curtain walls, all windows. Nevertheless, this phase was short-lived. Two factors that encouraged the return to natural light and ventilation in buildings were 1970s energy crises together with realization of the damage to the biosphere by greenhouse gas (GHG) emissions (ERG, 1994). Actually, this was the driving force for daylight building design.

At the beginning, the focus of daylighting design was to reduce the use of electric lighting for energy and environmental benefits. Almost as a side issue, in the late ‘70s and early ‘80s human health and performance benefits of existing daylit buildings come to the focus (Ternoey, 1999). The health and performance of people in buildings become the major issue with the realization that the cost of people (performance and/ or productivity) in buildings is often 75 to 100 times greater than the cost of utility bills. This health and performance benefits became the major thrust of 1990’s daylighting research and experimentation (Ternoey, 1999).

A growing number of references suggest a strong correlation between daylight and performance. Daylit buildings can increase human performance because people enjoy such spaces and will stay a little longer and/or return more frequently to work, study, or shop. The presence of windows in the workplace and access to daylight has linked with increased satisfaction with the work environment (Zullo, 2007). The Centre for Building Performance and Diagnostics (CBPD) has identified twelve international case studies that indicate that improved lighting design increases individual productivity between 0.7-23% while reducing annual energy loads by 27-88% (Loftness et al., 2006). Electric lighting energy use can be reduced by 25-50% with advanced light sources, design strategies and controls, and by 75% with the addition of daylighting (Clanton et al., 2004). In daylit schools, student have higher standard test scores, noticeably less disciplinary problems and absenteeism (Hathaway et al., 1992), even in elementary daylit school children grew on average 2 cm per year taller than ordinary schools. The book collections in daylit libraries are used up to 50% more than in traditional library designs. Retail sales increases of 8-12% were recorded in daylit areas (Ternoey, 1999). The health benefits of natural light/windows in hospital patient recovery rooms have been a given fact for half a century. There is strong evidence that daylight can be extremely beneficial to patients (Joarder et al., 2009a) as well as staff in healthcare settings. Adequate lighting conditions are essential for performance of visual tasks by staff in hospitals, and poor lighting conditions can result in errors (Joseph, 2006).

As a result, in the early stage, many first-time daylight designers, in their over-excitement, tried to achieve a large amount of foot-candles into a room that sometimes creates glare into the space with excess solar heat gains (which increases space cooling loads) and wipe out all savings from electric lighting (Ternoey, 1999). Therefore, with the increase of glazed areas risk of glare, overheating, high cooling loads and thermal discomfort increased (USGBC, 2008). As a result, environmental, economic and human performance, all issues came forward in the daylight research. Energy and environmental concerns made daylighting a rediscovered aspect of building lighting design. Now a day, benefits of daylight extend beyond architecture and energy and psychological and physiological aspects of natural light become as significant as the energy savings (Edwards & Torcellini, 2002)

3. The Current Agendas for Daylight Design

The agendas of daylighting design have changed with time according to peoples need and more knowledge about the objective and subjective nature of lighting. The performance of daylight in a building primarily depends on a combination of building latitude, orientation, form, geometry and environmental factors that block and reflect daylight, e.g. density of built environment, presence of obstructions and trees etc (Joarder et al., 2009b). The admittance of daylight in a particular room depends on the size and placement of apertures, details of glazing and shading devices. However, the design optimized for cloudy conditions needs control to face the bright sunny days. With appropriate architectural detailing, materials and devices, proper control can be achieved. In terms of energy benefit fully integrated daylighting and electric lighting solutions are needed that will minimize energy use and power demand. The physiological, emotional and aesthetic aspects of daylight come in design to optimize occupants’ health, comfort, performance and satisfaction. Appropriate daylighting strategies must consider the issues which were fixed during design time such as building type, climate of the region etc., and at the same time which may vary after occupancy such as change in task, change of climate with time of day, month, year even after 50 years (GBC, 2004).

U.S. Green Building Council Research Committee (2008) in their report on “A National Green Building Research Agenda” described a number of subjects as priority topic for lighting research. As a summary of the topics, they mentioned that the design of daylighting is critical at the point on how artificial lighting systems can be integrated with daylighting effectively to reduce consumption of non-renewable energy, at the same time satisfy occupants’ needs, visual comfort, health and wellbeing.

4. The impact of Climate Change on sunlight and health

Rapidly accelerating climate change, which is caused by GHG emissions, is now fuelling dangerous regional and global environmental events (Architecture 2030, 2008). Greenhouse gas-related climate change may cause both stratospheric ozone depletion and decrease of cloud cover (HPA, 2002). As a result more UVR from sun will reach to the earth surfaces that can damage biological organisms and is partially absorbed by different natural elements (Gibson, 2008). Figure 1 shows different element in the environment, which are responsible for reducing UVR exposure, such as, ozone layer (f_O), clouds (f_C), shade trees (f_t), etc.

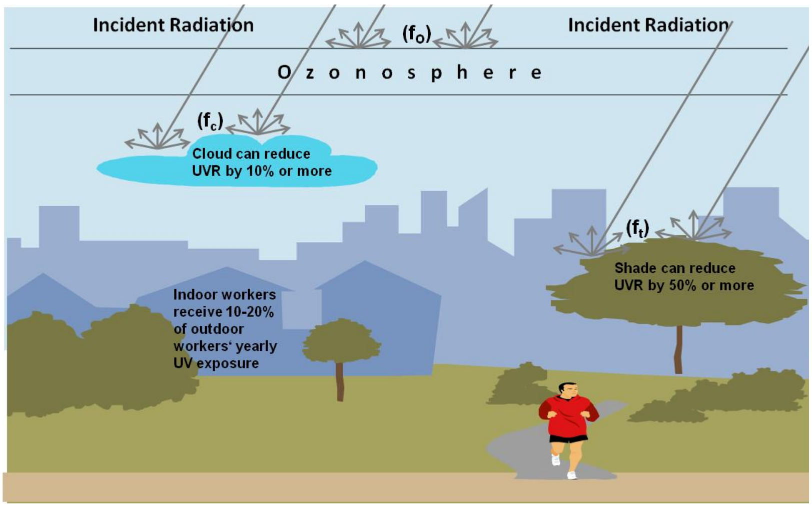

Figure 1 Natural element that affects the transmission of solar radiation to the earth’s surface (adapted from: Gibson, 2008; CCV, 2004)

In addition, climate change will bring warmer and drier summers that will increase the duration as well as levels of sunlight (Kovats, 2008). The decrease of cloud cover is proportional to the increase of UVR levels in environment. For example, if the cloud cover decreases by 4%, the ambient UVR levels can be expected to be increased by ~2% (Diffey et al., 1994). Longer summers and permanent changes in cloud cover may lead to changes in the pattern of daylight inclusion into the building, which is related to personal UVR exposure. As a result, exposure of sunlight to individuals in future will cause receipt of more UVB radiation (wavelengths between 280 - 315 nm) from sun (Figure 2) compared to present and people will be affected by threats associated with such exposures. Actually, the health effects of solar UV radiation on population majorly depend on three factors (CIESINTG, 2008; HPA, 2002). They are:

a) The UV flux in the environment

b) Patterns of behaviour which bring about exposure to UV in the environment and

c) Any deliberate actions taken by the population to mitigate the effects of such exposure.

The last one is very important for daylight designer; the actions to mitigate the effects of UV exposure. Because, individuals’ exposure to UV is not always proportional with the ambient UV levels of the area and depends more on individuals’ patterns of behaviour such as, more outdoor activity, lighter clothing and greater exposure to the sun (HPA, 2008). A little understanding e.g., wearing of a wide-brimmed hat, staying in the shade, avoidance of the sun, the use of suncream is beneficial (ONS, 1997). Therefore, changes towards a more cautious pattern of behavior and living style could mitigate the effects of increases of UVR levels in the environment. Daylight designer and researchers should think of this one deeply.

Assessments of the health risks due to the increases in UV levels require information on the relationship between UV doses and different health end-points. There is a considerable body of research on the effects of health exposure to ultraviolet radiation (Longstreth et. al., 1998; de Gruijl, 1997). However, this is sufficient only to allow a quantitative risk assessment to a few health effects and for others there are important gaps in knowledge (HPA, 2008). The increased level of sunlight has both positive and negative impacts. One of the clearest beneficial effects of daylight on skin with exposure to UV-B radiation is the production of vitamin D (DE, 1996), which is important for skeletal health and calcium metabolism (Kovats, 2008). Deficiencies of vitamin D can increase the risks of rickets in childhood and of osteomalacia and fractures in adults, particularly among the elderly people (Edwards et al., 2002; Liberman, 1991). Among the negative impacts: there is a possibility that UV-B exposure can cause suppression of the immune response to animal and human body (Kovats, 2008; Longstreth, et al., 1998). Figure 2 shows the classification of UVR and the summary of the findings about major negative health effects of exposure to ultraviolet radiation.

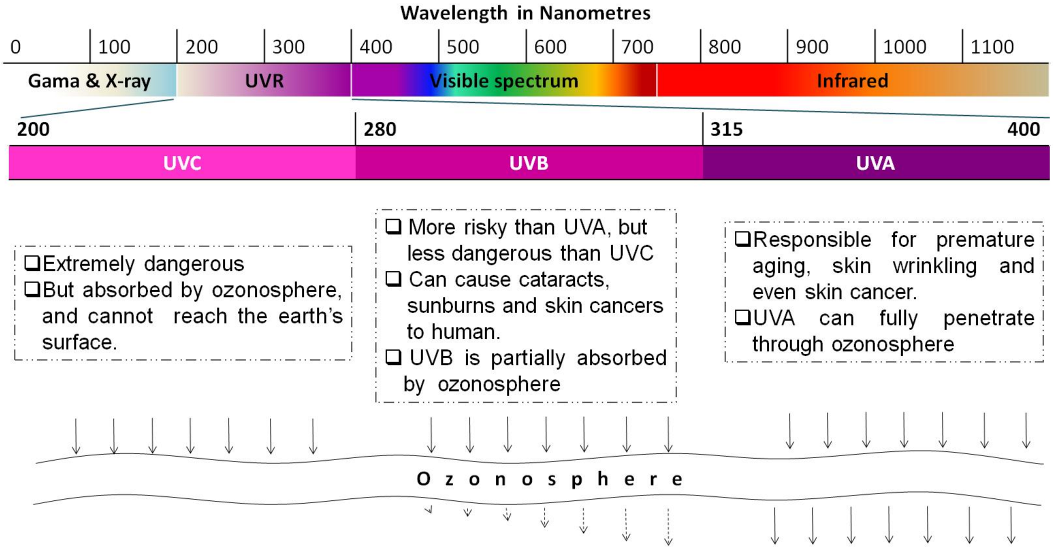

Figure 2 Distribution of UVR and summary of the findings about major negative health effects of exposure to ultraviolet radiation (adapted from: Gibson, 2008; MacDonald et al., 2006).

5. The Added Agendas for Daylight Design due to Climate Change

The overwhelming majority of the world's climate scientists agree that climate change is already with us (UKCIP, 2008) and is one of the largest threats for both the global economy and the local community. Therefore, climate change introduces several new issues to the knowledge gaps of daylighting research.

Assessments on existing buildings show that many buildings are at the risk of being uninhabitable in future without additional energy-intensive cooling devices. This can be expected to have significant impacts on the building industry. Therefore, refurbishment is necessary for the existing buildings to meet the challenge of climate change. At the same time, it is necessary to keep in mind that during new construction the design must satisfy the demand to cope with climate change.

Rules and regulations have been developed for planners to consider climate change at various stages of design when developing spatial plans in EU (Under the EU Strategic Environmental Assessment) and UK (under the Sustainability Appraisal process). Two issues have been highlighted, the first one is the design's impact on future GHG emissions and the second one is the impact of climate change on the design (GBC, 2004).

Therefore, it is important to consider two added issues for further lighting design. Firstly, lighting design in buildings should reduce the risk of climate change. Environmentally sustainable future for all requires about an 80% reduction in primary energy use and fossil fuel air emissions within the next 40 to 60 years in developed nations (Ternoey, 1999). Therefore, there is no way but to use maximum daylight in all buildings irrespective of cost and complicacy. On the other hand, due to rapid climate change and energy shortage it will not be possible to use fossil fuel GHG-emitting energy in future. Therefore, it is necessary to reduce the use of artificial lighting to reduce the production of GHG for electricity. This can be done by introducing Building Management Systems and Intelligent Buildings in the control system. Control can be time based to provide light only when required, e.g. automatic switch on/ off according to a preset schedule based on light use. The other option is control by optimiser parameter to provide light according to the need of user. For example, passive infra-red (PIR) occupancy sensor can be used to identify the presence of occupants and switch on/ off accordingly, or light monitoring by photocell to switch or dim artificial light in presence of daylight to maximise use of daylight (Chapman, 2004). Daylight can be used to reduce the pressure on electrical energy for lighting as well as GHG production, at the same time daylight itself can be a source of electrical energy production without emitting GHG, e.g. use of photovoltatics (PV) can generate electricity from solar energy. PV can generate electricity on cloudy days with the help of only daylight, as direct sunlight is not necessary to run PV.

The second issue for daylight researchers is quite complicated to find out how adequate daylight can be maintained for inhabitants of a building without the adverse consequences of exposure to damaging UVR from sunlight. A number of studies have done on the role of UVR in maintaining vitamin D levels and the clinical importance of vitamin D (ICNIRP, 2006; Holick, 2004). More research is needed to investigate the associations and define the optimum level of vitamin D for individuals. Researchers are trying to estimate the amount of sun exposure people actually need. However, the research results are inconsistent and it is too early to say how much vitamin D people need and how levels can best be increased (Kovats, 2008). As an initial step, it is necessary to protect the interiors from UVR with available technology and techniques.

At first, it is important to know the sources of UVR exposure when a person is inside a building and engaged in indoor activities. Individuals inside a building can receive UVR from three significant sources; directly from the sun, reflected from the environment and scattered from the open sky/ cloud (Figure 3). Therefore, it is evident that, if a person is not directly under sun and stay far from windows, still there are possibility to gain substantial UVR from reflected surroundings and open sky (Figure 4). The fact is, UVR cannot be seen or even felt but it can cause damage to individuals' biological organs (Figure 2). Brief descriptions of available techniques are mentioned here to protect individuals from UVR when inside a building.

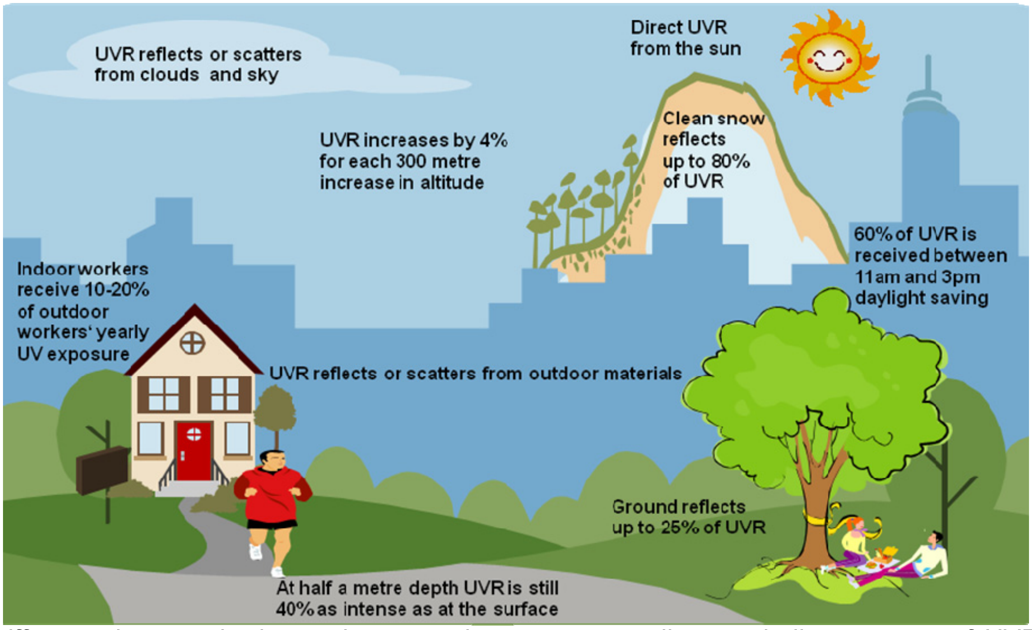

Figure 3 Different elements in the environment that can act as direct or indirect source of UVR exposure (adapted from: CCV, 2004).

5.1 Window Protection

In a residential building, the risk of UVR exposure on occupiers is little through openings, as occupiers spent little time near windows. However, in an office building, or school where the same person seats near window everyday when the UVR is high in the environment (Figure 5), or in a hospital building where patients' stay long time continuously near windows, the person is more in threat to UVR exposure. Tinting windows is a solution to screening out UVR (Figure 4). It is possible to protect interior, from as much as 99.9% of UV rays by tinting glasses. How much tinting is required can be weighed according to the potential risk of users. According to Australian Radiation Protection and Nuclear Safety Agency (ARPANSA, 2008), the rating for ultraviolet protection factor (UPF) is 10 for house window glass (10% of solar UVR will pass through and the glass will absorbs the 90% UVR) and this glass will create only moderate protection against solar UVR. UPF of 50+ is recommended for office building glass, means less than 1% of UVR will pass through and 99% will be absorbed. This glass provides excellent UVR protection. So, according to the function of building, specific type of glass should be used. Appropriate type of glass can also reduce the energy cost of the building by coordinating lighting and heating requirements.

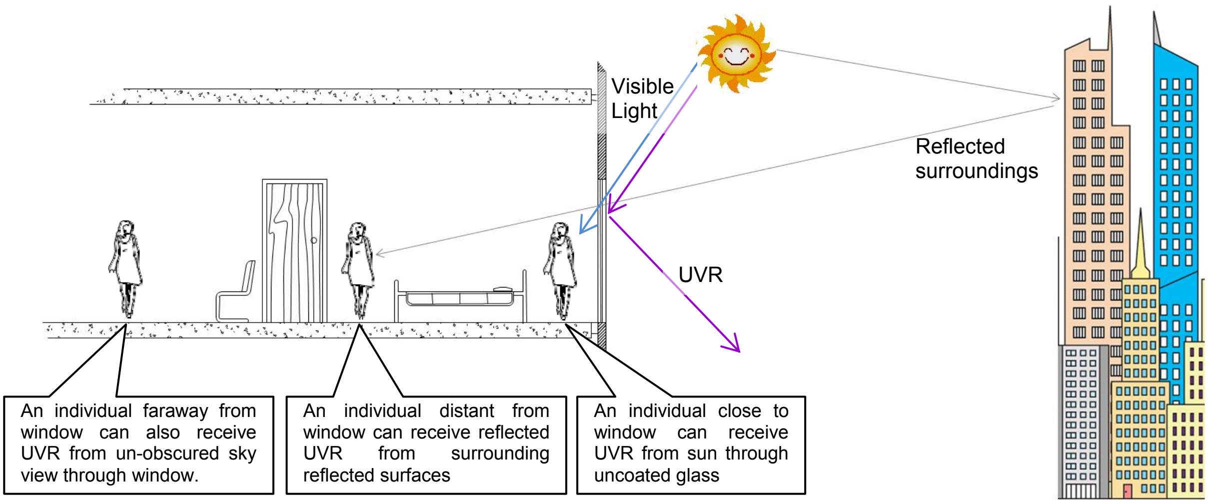

Figure 4 Individuals inside a building can receive UVR at different distances from windows. However, tinted glass can be used to allow visible light to pass but screen out UVR.

5.2 Design building shades considering the period of UV index

The threat of UVR is primarily related with sun elevation, which is fixed with time of day in a particular date of the year and less on the temperature of the day. Therefore, a sunny day at 4:00 PM is safe rather than a cloudy day at 12:00 PM with respect to potential risk of UVR exposure. Therefore, it is necessary to know the critical hours when the UV index is maximum. Figure 5 shows the SunSmart UV alert for Australia which was reported in daily newspapers. Critical hours of UV exposure depend on the geographical location (altitude and latitude) of the place. For example, a country located in the southern hemisphere is closer to the sun in summer due to the earth's oval shaped orbit than similar latitudes in the northern hemisphere. Usually, peak hours for UVR threat are between 10:00 AM and 4:00 PM when the sun's rays are most intense. So, architectural shading systems, e.g. overhangs, fins, light shelves, shade screens, venetian blinds, vertical blinds, miniature louvers, and roller shades (Figure 5) etc. need to be designed to protect the interior during UV peak times with compliance with local climate. Shading devices can be positioned outside the glazing, between the glazings, or at the interior surface. The systems can be static or operable, controlled either by occupants or with motorized, automated controls with respect to time (Joarder, 2007).

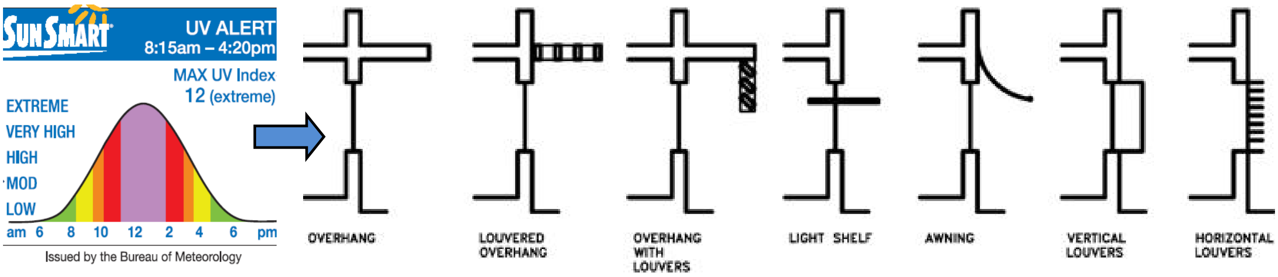

Figure 5 The SunSmart UV alert for critical hours of UV for Australia, reported in daily newspapers (adapted from: CCV, 2009) and various types of shading devices that can be effective for different geographical locations to protect interior when the outdoor UVR level is high. (Source: AGS, 2000)

5.3 Protection from reflected surroundings

In urban areas, many vertical and horizontal surfaces can act as a reflector for UVR when, a person is under shade (Figure 4). UVR can be reflected off ground, hills (snows) and buildings (Figure 3). Reflective surfaces for example, concrete, metal, snow and water can bounce off a considerable amount of UVR. Therefore, reflective surfaces such as, white painted facades, light coloured concrete, polished aluminium, reflecting glasses and other types of metallic surfaces should be avoided as exterior building material. These surfaces can reduce the effect of other protective measures. However, in a built urban environment it is difficult to control the character of neighbour buildings. As an alternative, UVR protection can be done by movable and temporary shade structures for openings made of tinted films, clothes or plastic roofing materials. Permanent protection of openings can be done by introducing verandas and proper window shades (Figure 5).

5.4 Protection by plantation surrounding the buildings

The most natural way to protect individuals and buildings from damaging UVR is to plant shade trees surround the buildings. Visible and UV radiation reflects from leaves of trees (Figure 6). Though a single leave allows some of the sun's radiation to pass through, when it is a tree crowns sun's rays needs to encounter many leaves to get through the crown to the ground and have little chance to reach to the ground (Figure 6). Therefore, the presence of a tree can reduce the amount of UVR exposure to the surrounding structure. Table 1 summarises the result of an experimental study where the amount of radiation was measured in six different spaces by special sensor equipment (pyranometer sensor). Comparing the reduction level of radiation (visible and UVB) in sunny and shady areas, it was found that the reduction in UVB radiation was less in sunny and shady areas than the reduction in visible radiation for two areas. The reason behind this is UVB radiation is scattered across the sky and when individuals stand close to a tree even direct under sun, tree blocks part of the sky as well as some UVB radiation (Figure 6) (Heisler, et al., 2000). Similarly, when an individual is inside a room, far from window, he is still exposed to some part of sky (Figure 4) but trees surrounding the building can block/ reduce the exposure (Figure 6).

Table 1 Average percent reduction in the sun's visible radiation and invisible UVB radiation below a street tree canopy (Source: MacDonald et al., 2006).

Area Under Tree Canopy	Percent Reduction in UVB Radiation	Percent Reduction in Visible Radiation
Sunlit Area–With Leaves	39	3
Shady Area–With Leaves	63	84
Sunlit Area–No Leaves	40	6
Shady Area–No Leaves	56	73
Sunlit Area and Building–No Leaves	59	5
Shady Area and Building–No Leaves	70	47

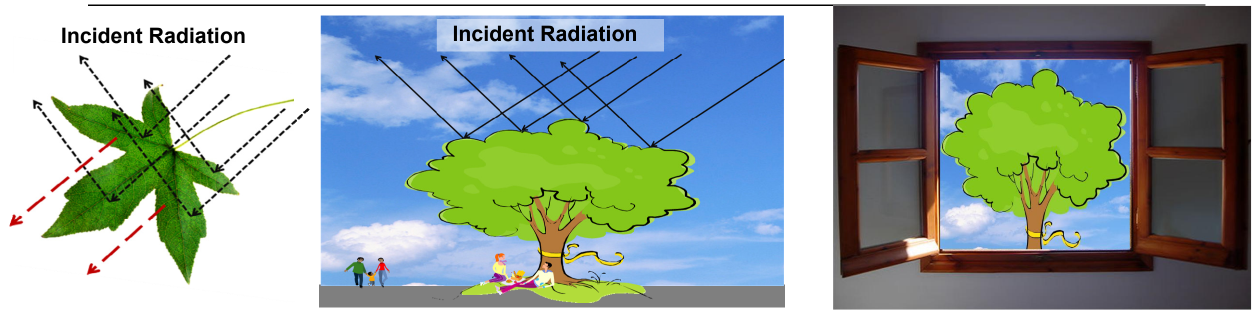

Figure 6 An individual who is not directly under tree or even indoor, still got protection from UVR, as tree blocks scattered UVB radiation across the sky (adapted from: MacDonald et al., 2006).

6. Conclusions

People's preference for daylight is beyond all logic of energy and comfort estimation. By birth human are not evolved to become indoor animals. Individuals are always physically and psychologically desired to be connected with the rhythms and changes of the outdoor world. It is well known from research that when people have to interact with nature, they are tolerable to a wider range of environmental conditions. Natural ventilation, views and daylight give to the occupant a sensation that he is in closer contact with nature and for that reason, he is more tolerable to a wider range of conditions (Gallou, 2005).

This very much positive favour for daylight may cause severe harm to people in future due to climate change. On the other hand, with lots of health benefits, as a source to stop generation of fossil fuel GHG-emitting energy there is no alternative of daylight and should not be ignored in building architecture. Though experimental studies have evidences on the impact of UVB on animal model (suppression of the immune response, cancer cell development, cataract etc.), the knowledge on the impact of daylight on human is still developing. Some protection measure has been described in this paper with available technology. More evidence-based research is necessary on effective and safe daylight design. Designers, architects and planners should take climate change as potency for daylight building design rather than a constraint and take the opportunities to design and refurbish buildings that will be perfect for future climates.

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