CH_2 - Lighting and Physiology

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ABSTRACT

This paper explains the designed performances of the new CH_2 building in Melbourne, Australia. CH_2 is an environmentally significant project that involves biomimicry of natural systems to produce indoor conditions that are conducive to user comfort, health and productivity. This paper focuses on lighting and physiology and examines the solutions chosen for artificial and natural lighting and the likely effects these will have on building occupants. The purpose of the paper is to critically comment on the adopted strategy and, cognisance of contemporary thinking in lighting design, to judge the effectiveness of this aspect of the project with a view to later verification and post-occupancy review. The paper concludes that CH_2 is an exemplar of lighting innovation that provides valuable lessons to designers of office buildings, particularly in the Melbourne CBD.

Keywords: lighting design, expected performance, human physiology, productivity.

INTRODUCTION

The lighting of a workplace can positively influence the health of office personnel, improve efficiency, reduce unnecessary sick leave and result in greater benefits for enhanced productivity. In particular, natural light, with its variations and its spectral composition, together with the provision for external views, is of great importance for the well-being and mental health of the individual, reducing suppressed feelings of panic, anxiety, disorientation and melancholy. The careful management of natural and artificial lighting, including the use of shading devices, can also bring tangible energy savings, preserving the natural colours of the surrounding environment while preventing glare and minimizing heat gains (Wigginton, 1996).

A good lighting strategy should maximize the potential of architectural form while taking advantage of technologies to further refine solutions (Guzowski, 2000). The goals of a lighting strategy can be defined from a great variety of points of view that may consider *ecological issues* (energetic and natural resource depletion, environmental impact), *tasks and activities* (lighting needs in both qualitative and quantitative terms), *systems integration* (lighting, HVAC), *human experience* (visual and thermal comfort, health, orientation in space and time, connections to the outdoor), *aesthetic considerations* (form, dimension and articulation of spaces, materials), as well as other concerns. Logically, it may not be possible or even necessary to address each of those objectives simultaneously; yet, analyzing their potential can clarify design intentions, determine priorities, and reveal possible trade-offs and/or contradictions (Guzowski, 2000).

Light (in all its forms) is not only a resource and a vital sustenance, but also a force that can create meaningful architectural experiences; the moods and the quality of an architectural space can broadly vary with its lighting conditions, transforming a sometimes dark, somble, and oppressive place into a captivating, enthralling, and polychromatic one. In addition, scientific research has recently proven that a close relationship exists between lighting conditions, health, well-being, and our perception of the environment. Daylight, for example, represents one of the most important means of maintaining our biological rhythm and connection to rhythms of nature, and a realistic way of marking important daily moments (van den Beld, 2001). Actually, ocular light stimuli from the retina results in signals being sent to the various glands, involving the whole of the *physical* (energetic exchanges), *physiological* (transformation of energetic fluxes into nervous stimuli) and *psychological* (brain interpretations of those stimuli) aspects that together create the "process of perception" informing us about the characteristics of our surrounding environment (Fonseca et al., 2002).

Regardless of this awareness, nowadays a great part of our social life is temporally organized in relation to a rather "mechanical time", which is basically independent to the rhythms of our body's impulses and needs. In other words, we are increasingly deviating from the organic and functional recurrence dictated by the natural colour, angle and intensity of daylight, and replacing it with an artificial timetable which is, on the contrary, imposed by the schedule, the calendar and the clock.

This paper aims to give a contribution towards the reassembling of the paradox of opening to the natural forces and protecting from its extremes, promoting at the same time a new design attitude that modulates the relationship between the needs of the users and concerns about sustainability (Selkowitz and Lee, 1998).

As a reference case of international best practice, the lighting strategies of the newly developed CH_2 building in Melbourne will be analyzed, and its contribution to sustainable design discussed.

LIGHT AND PHYSIOLOGY

The use of daylight as the primary light source in buildings is a fundamental part of the so-called ESD framework, assumed to minimize energy consumption. However, the diffusion of shared spaces which inhibit a direct control by every user, the inherent limits of automatic lighting control systems and the reductions in terms of energy consumption of modern electric lighting systems, have made it difficult to justify the cost of extensive daylighting on the simple basis of potential energy savings. Rather, to substantiate the use of daylight in built spaces, it is necessary to demonstrate that such use may foster beneficial effects - such as financial gain from performance improvements - in other areas that have an important impact for the organisation owning or occupying the building (Boyce et al., 2003).

For their own well-being, people need appropriate visual contact with the external world and with the cycle of day and night, seasons, weather and the environment. Mankind has worked outdoors for time immemorial; however, once man predominantly began to live and work indoors, he has been forced to accept light levels that are only a fraction of what he had previously enjoyed (Caminada, 2001). Most people nowadays spend more than 90% of their time indoors, often in offices, and in all cases the lighting is still based upon the requirement that, whatever the time of day or night and regardless of the physiological needs of the human body, the task should be accomplished efficiently, safely and with a certain degree of visual comfort. The question is to establish how serious are the consequences of working and living more and more indoors with much less light and with little or no variation than outdoors, and how can a 'healthy' design of the lighting environment compensate for this (van den Beld, 2001).

Medical science and research has recently discovered that almost all human physiological and psychological processes are based on rhythms directly linked to the natural daily (*circadian*) and seasonal (*annual*) cycles of light. In particular, the human brain contains an internal "biological" clock, daily synchronized to the periodicity of nature through the medium of ocular light received by the eye. Day/night light patterns regulate many body processes such as body temperature, heart rate, mood, fatigue, and thus alertness, performance and productivity. Sufficient light received during the natural light period (daytime) synchronizes the biological clock, stimulates circulation, increases the production of vitamin D, regulates protein metabolism and the levels of various hormones; in other words, light provides the direct stimuli needed for the human body to function and feel well and healthy (Boyce et al., 2003).

Research shows that lack of exposure to sufficient light during the day may foster negative effects on various physiological aspects of the human body; this is more evident in particular during the 'dark' winter season or in regions characterized by cold and sombre climates, where there is less light and days are short. Some three per cent of the population in those regions suffers from winter depression (SAD, *Seasonal Affective Disorder*), and the so-called "winter blues" is common. Intensive bright light through the eye can mitigate these feelings and is also the first line of treatment for SAD (van den Beld, 2001).

Concerning "healthy lighting" in working environments, a number of interesting figures can be pointed out. In the first instance, although we are used to significant variations in the level and duration of daylight, office lighting practice seems to totally ignore this. If we consider a daytime office worker, any light deficiency may result in a de-synchronisation of his biological clock, with the result that the body and mind would prefer to rest but they still need to remain active. The results are lower performances, decreased alertness, diminished sleep quality and, in the longer term, counter effects on well-being and health (Van den Beld, 2001). Secondly, just as the spectral composition of daylight shows large variations during the day ("cold" light in the morning and "warm" light at sunset), so people prefer and respond positively to variations in the correlated colour temperature (CCT) of an artificially lit environment (Boyce, and Cuttle,1990).

These recent discoveries on the effects of light on well-being and human health lead to new design objectives for lighting solutions. In addition to the well-known visual comfort criteria (task illuminance and minimization of bright reflections and glare) and direct stimulation of the brain, additional non-visual issues for health and well-being are being formulated in the scientific literature (e.g. Brainard and Glickman, 2003). The combination of medical and scientific research actually suggests the hypothesis that "healthy" lighting for daytime indoor activity is influenced by many more factors than what is suggested in most lighting standards and regulations. There should preferably be a combination of natural and artificial sources, the electric light alone serving to take over when natural daylight falls in the winter period or in the later part of the working day.

MEETING THE LIGHTING REQUIREMENTS

A significant percentage of people perform daily activities that can be described as office tasks, the term comprising a number of frequently varying functions, involving files processing, communication with other people, thinking, organizing and so forth (Kramer, 2002). Each activity demands a different relationship with the spaces that surround the specific workstation and has to meet very complex requirements, including a number of basic human needs that necessarily have to be taken into account in the design of office spaces. Those human needs reflect people's desire for a specific orientation in space and time (*genius loci*) – including aspects that relate to human biorhythm, but also to society and culture – privacy and communication, information and familiarity, as well as variation and surprise. Lighting, both natural and artificial, through the choice of form, colour, material and details, plays a key role in creating a mood and atmosphere that meets occupant's expectations (related to the functionality, aesthetics and ergonomics of the rooms and their furnishings) and demands (privacy, concentration, appreciation of details, etc.), facilitating perception and expressing a message on its own (Kramer, 2001).

Daylight is often associated with a view, telling about the time of day, the season, the weather; its variations in intensity and colour are extremely stimulating for the brain and for the visual apparatus (Zonneveldt, 2001). Views through windows can introduce variety and sensory stimulation that is otherwise missing in totally enclosed environments and give a contribution in terms of the well-being of occupants, improving their sense of orientation and feeling of spaciousness (Carmody et al., 2004). Moreover, since various screen-based tasks require a limited eye movement or change of focus that can be very fatiguing, views can reduce muscle strain by allowing the eyes to shift focus from the near field surrounding the work area to distant objects (Guzowski, 2000).

There is absolutely no doubt that occupants, given a choice, would prefer to live and work by daylight and to enjoy a view to the outside; small and artificially lit spaces are usually disliked, even though they are sometimes accepted due to contingent factors (working groups, stringent visual tasks, etc.). Nevertheless, daylight may also imply major drawbacks; direct sunlight, bright clouds and reflective surfaces can cause glare, contrast and serious visual disadvantages (AS 1680.2.2-1994). Glare, in particular, is a source of visual discomfort due to the contrast determined by the luminance from a bright source (direct or reflected) relative to the average luminance in the field of view of the observer; the ratio at which this contrast becomes a source of uneasiness depends on the specific function being performed in the space. Glare can generally be categorized into two different types: "disability" glare and "discomfort" glare, the former preventing the viewer from performing the visual task and the latter still causing a decrease in visual comfort (Carmody et al., 2004).

In a work environment, a general approach to lighting should try to achieve a balanced combination of daylight and artificial light, mixed to produce sufficient and suitable lighting on the task. Good integration between the two makes it possible to gradually dim the amount of electric light when daylight availability can positively contribute to the visual task without being excessively intrusive or implying major counter effects. It is important that each individual occupant should be able to control his luminous environment to suit his or her own preference. However, since no two people are the same, nor do they perform the same task all day long, daylight and lighting controls should be as versatile and flexible as possible (Selkowitz, 2001). In terms of activities and performance in working spaces, old cathode screens are in general more susceptible to visual problems because of their typical curved surface; newer display technologies such as liquid-crystal screens with anti-reflection coatings can be even viewed under some direct light conditions.

The design of a lighting system should allow for meeting the various requirements of the visual task, allowing user flexibility and personal over-ride to adjust (at least partially) the lighting according to individual wishes and needs. Privacy and personal desires, in particular, require that a room (or a specific area) should be optically sufficiently shielded from other workstations, and that this could be fitted out in a personalized way, thus fulfilling the requirements of people in terms of job, activity and character (Kramer, 2001).

According to the different tasks performed in a space, several adjustable lighting systems should be preferred to evenly distributed ceiling luminaries in order to suit occupant's needs, while, in terms of light distribution, a combination of diffuse and direct light – with directional lighting and some diffuse light needed to avoid dark areas with dense shadows – can provide recognition of three dimensional objects and give "life" to the indoor environment (AS 1680.1-1990).

In a daylit space, it is obvious that users located in a position close to windows will mainly use daylight as their primary light source. At Melbourne's latitude, daylighting can provide adequate ambient light for most operating hours even in the winter season; however, when supplementary light is needed, user-controllable task lights should ensure that task illumination requirements are met at all locations. As a general rule, ambient illumination levels should be designed to be significantly less than task requirements (AS 1680.1-1990); if computers are present, ambient lighting should not exceed 300 lux, in which case user-controlled task lighting should be available as a supplement.

A rule of thumb for spaces that host video display terminals is to provide as little light as possible on computer screens (150-300 lux) for diffuse surround lighting, and up to 500 lux on adjacent task space. However, if glare from windows is expected, interior environment luminance should be kept high in order to balance window brightness and to decrease the risk of visual contrast. To ensure adequate illumination, fixtures and lighting circuits should preferably be grouped by areas of similar daylight availability (e.g. in rows parallel to window walls) in order to allow the possibility for control to be added as retrofit.

The choice of the most appropriate colour temperature for a light source is largely determined by the function of the room, thus involving psychological aspects such as the impression of warmth, relation, clarity and other considerations. For best colour temperature pairing with daylight, a generally-accepted choice consists in the installation of fluorescent lamps with a minimum colour temperature of 4000 K. However, when there is significant night-time use of the building, lamps with a CCT less than 4000 K may be required (AS 1680.1-1990).

In order to save energy and ensure at any time an optimum light distribution, a control system able to dim light and/or turn them off when there is adequate daylight may enhance best achievements and result in minimal complaints (O'Connor et al., 1997).

CH_2 DESIGN FEATURES, EXPECTED PERFORMANCES AND OPERATION

The daylight strategy

The CH_2 building has been designed to be a world leader in ecologically sustainable design and commercial 'green' building technologies: 'a landmark building that will provide a healthy, stimulating workplace' reflecting much of the planet's ecology. Most of the principles followed in the building are not totally new; however, never before in Australia have they been integrated and pursued in such a comprehensive and interrelated way in a multi-storey office building.

The simple rectilinear form has been dictated by the boundaries of the site, yet the long axis oriented towards north and south maximizes solar access and daylight availability while minimizing unwanted solar heat gain from eastern and western orientations (see Figure 1).

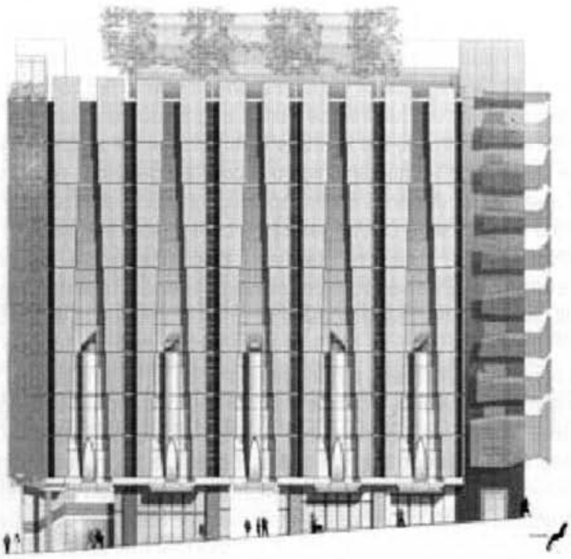

Figure 1: CH_2 Elevations

The building has been designed foremost to be comfortable and healthy for its users, whose physiology and experiential feelings have been regarded as key factors in every single decision. For example, to improve occupant comfort, perception of the space and control over the luminous environment, windows have been considered as a shared communal device, which can be opened or closed and eventually manually-shaded upon necessity (AEC, 2003a).

Amongst other features, how to get natural light into the building (considering the location of the site) has represented a major issue of investigation; nevertheless, also the major counter effects of exposing the façades to an excessive amount of sunlight have been pointed out since the beginning of the design process. To avoid harmful consequences, on the northern and southern façade the windows progressively narrow higher up the building, owing to the obvious fact that more daylight is needed at the lower levels. While optimizing the access to the available natural light levels, this strategy fosters other advantages such as the reduction of the total amount of glass used and the attenuation of energy losses and glare risks.

The glazing has been selected to achieve a visible light transmittance greater than 50% combined with a solar transmittance smaller than 35%. This choice allows for relatively high daylight levels and, above all, reduces solar heat gains, an issue of significant importance in a climate such as Melbourne, both during mid-seasons and summer. Internal and external visible light reflectance are respectively <15% and <20% while the colour of the glass is absolutely neutral for better internal and external colour rendering. To neutralise harmful low afternoon sun on the western façade, recycled timber louvre screens run across the entire elevation. Movement of the louvres is controlled by a computer that dictates the tilt angle and position to ensure optimum shading while still allowing filtered daylight and views.

Working within the constrained nature of the site and the strict requirements of an open plan office setting has presented many challenges to the design team in terms of daylight accessibility and distribution, especially in order to achieve high indoor environmental quality and energy savings. Overshadowing by the surrounding buildings has been a matter of major concern affecting lower floors in particular; no more than a quarter of the building total floor area will actually achieve a daylight factor greater than 2% as measured at the working plane. The solution to this issue has turned out to be a unique system of light distribution that also synergizes with the cooling and ventilation strategy. A barrel vault concrete ceiling, running like waves in north and south directions enables light to penetrate deep into the space, while light shelves (made of 50 per cent perforated steel internally and movable fabric externally), situated 2.2m above the floor level on the northern elevation, enhance daylight penetration and increase reflection onto and off the vaulted roof. As Fontoynont (1999) suggests, this strategy can result in a more uniform and indirect daylight distribution, while also providing significant artificial light reductions.

Glare control and vertical gardens

Shading devices to control sun intrusiveness and reduce luminous discomfort will be used on north, east and west façades of the CH_2 building; those devices will consist of vertical gardens, perforated metal light shelves and vertically-shading/pivoting timber louvres. In order to assess the potential for discomfort glare, a series of studies and simulations have been conducted using advanced software tools such as Radiance (AEC, 2003b, c, d, e).

The preliminary studies indicate that glare at the south façade of CH_2 due to luminous reflection off the north-facing elevation of the adjacent Victoria Hotel presents a significant *uncomfortable* glare source, which may affect the narrower field of vision (90°) as well as the peripheral one. In particular, this glare source will be predominant during the middle of the day in mid-seasons and summer (it is also predicted that some *intolerable* glare, at certain view angles, may occur); the south façade of CH_2 has actually been designed with no fixed or movable shading devices to mask the glazing. Glare is expected to be worse for the upper levels than for the lower ones because of a greater penetration of reflected daylight; nevertheless, the choice of decreasing the size of the glazed surface with the height of the building represents a favourable design strategy also in response to visual problems. Indoor glare at the south façade is predicted to be acceptable (DGI<19) during the early morning and the late afternoon in all seasons (AEC, 2003e).

Indoor glare experienced facing the north façade of CH_2 can be said to be relatively low and generally in the *acceptable* range; the occurrence of discomfort glare may be more severe at the periphery compared with the focus of the viewer's field of vision and more significant in the winter and mid-season afternoons because of low sun conditions. However, it is probable that once workspace partitions, task lighting, accent lighting and workstations are in place, the amount of potential periphery visual discomfort can be limited (AS 1680.2.2-1994).

To further decrease the risk of *intolerable* glare at the north façade of CH_2, steel trellises and balconies, supporting a series of vertical gardens that run the full height of the building alongside the windows, filter light entering the office spaces and form a 'green' microclimate. The three-to-four metre vines will be grown from purpose designed boxes situated to the east and west of each balcony on every storey stretch from the ground to the roof. Further means of reducing glare on the north façade are provided by the light shelves that will block high-angle sun penetration, internal upward rolling retractable blinds located at the level of the light shelves and manually-adjustable vertically sliding timber screens at the window line. Combining the use of these devices is expected to guarantee the necessary protection from light intrusiveness while always maintaining an unrestricted view at eye level.

The expected extensive use of PCs and the awareness that the curved surface typical of CRT monitors can significantly increase the level of glare and veiling reflection. Brighter flat TFT screens have been chosen to enhance visual comfort, while taking less room and contributing to a reduction in internally generated heat loads.

Artificial lighting strategy

The CH_2 building is characterised by a deep open plan (see Figure 2), which, in general, is not considered to be a best practice form for sustainability or daylighting. A consequence of this design is that natural lighting is not an option for a significant part of the internal floor plate and thus has been complemented by an artificial system. This system has been designed as a two-component scheme: a low-energy background lighting system (provided as part of the base building design) and a separate individual task lighting (part of the fit-out) that will provide users more control over their luminous environment. Ecological, economical and psychological issues (as well as cultural considerations) have been factored into the lighting system design to achieve the proposed objectives and to provide an optimum level of lighting for movement, security and occupant activities. A number of artificial lighting options have been simulated in order to obtain the minimum required ambient lighting level on the floor as uniformly as possible, while minimizing any potential glare impacts from the internal lighting and outdoor light levels (AEC, 2003c, d).

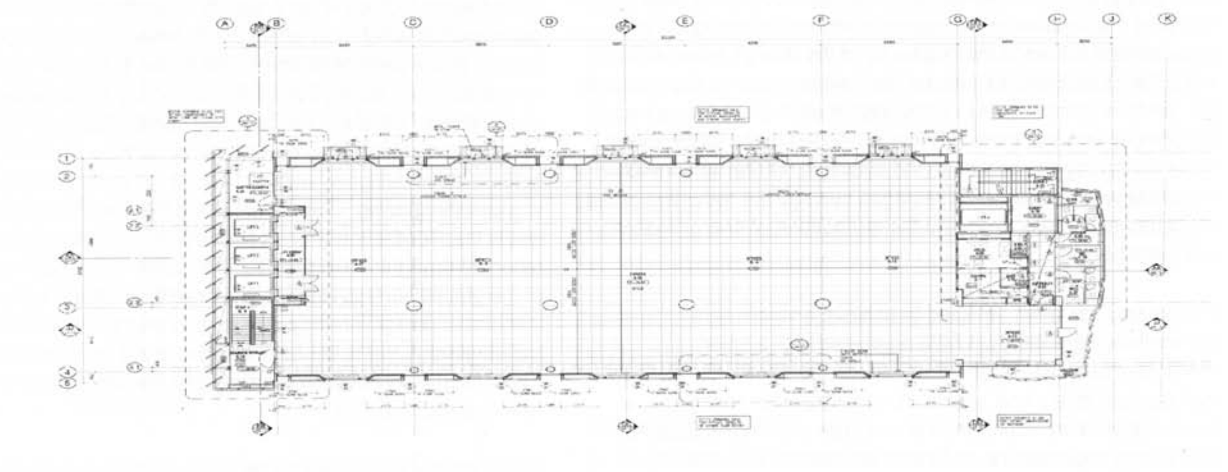

Figure 2: Typical Floor Plan

The background ambient lighting, supplied by T5 fluorescent lamps, will provide a low illuminance in the spaces (160 lux ambient lighting; 70% wattage emitted to the office space, 30% emitted to the ceiling), while the individually-controlled lamps at workstations will provide 320 lux on each desk. An illuminance no greater than 400 lux will be provided anywhere on the office floor with a colour rendering index CRI>85%. In order to achieve an optimal distribution of light, materials and finishes have been chosen with an overall reflectance of 30% for the carpet, 50% for the walls, and 70-80% for the ceiling and the desktops (as per AS 1680.1-1990).

The adopted artificial system includes sensors that continuously monitor the amount of direct and diffuse daylight coming in the building and reflected off the light shelves, and accordingly dim the artificial light levels supplied, thus creating a mix of filtered natural and artificial illumination. The lighting system flexibly provides a number of separated switched zones per office floor that are no greater than 100 m^2, which means that every single luminaire can be programmed to separately address the specific needs of a zone and to suit future fit-out requirements of the space. The deliberate use of workstation task lighting will create the illusion of "campfires" of activity that is both warm and inviting.

From an energy savings point of view, the fluorescent T5 fittings incorporating high frequency dimmable electronic ballasts and the individual task lighting (10W compact fluorescent) for workstations will allow a significant reduction in energy consumption. T5 lamps have a potential for optical efficiency compared to conventional T8s due to their smaller diameter, even though they have the disadvantage of higher surface brightness (thus being a potential source of glare).

In terms of control strategies, during office hours (from 8am to 6pm) lighting levels will be set to achieve an ambient level of 160 lux, with the daylight sensors detecting the availability and distribution of daylight and accordingly controlling the dimmable electronic ballasts. When daylight can provide more than 160 lux, the ambient lights will be switched off; after office hours, the daylight sensors will be inactive. To optimize the use of electric artificial lighting, each workstation will be provided with a local dimmer switch integrated as an icon on the PC screen, which will provide three different lighting control options: *high, medium and light*. The latter option will cause a slider to appear with a "save" button enabling the users to set the preferred task light level in the area of their workstation. Task lighting will be provided in locations where a total lighting of 320 lux is not achievable.

Potential implementation and future opportunities

There could have been a number of opportunities available for CH_2 to harvest natural light and direct it for use within the building. Meticulous investigation has been undertaken by the design team in the attempt to improve the daylight factor, especially at the lower levels, where daylight distribution systems such as *light pipes, fibre optics, prismatic shafts or heliobus systems* were investigated for their feasibility for channelling sunlight from the roof and distributing it to internal spaces (AEC, 2003a). However, those alternative strategies were found to have major drawbacks especially on practical issues (i.e. the openness of the space arrangement and costs) (AEC, 2003b).

In order to implement the adopted design, one of the main problems that emerged from the lighting strategy discussed earlier and the analysis of the lighting patterns down the façades of the building is the poor availability of natural daylight especially at the lower floors during the winter season. As pointed out, the low winter sun, together with the overshadowing off the adjacent buildings, dramatically reduces the availability of natural light in working spaces, a concern that is relevant in terms of energy savings but also from a physiological and psychological point of view.

As a daylight device, the light shelf is actually proven to be particularly useful under direct high-sun conditions, while its effectiveness in terms of daylight distribution is drastically reduced once the available radiation diffusely comes from the sky vault. Conversely, light shelves are far more efficient in rejecting sunlight than displacing diffuse light deep into the interior, especially when their reflectivity indices may be influenced by inconsistent maintenance (Fontoynont, 1999).

Potential improvements to the proposed design could have occurred by putting in place light re-directing devices on the northern façade (mounted in the clerestory area) to complement the effectiveness of the light shelf; examples of those devices can be found in *louvres, highly reflective movable blinds, prismatic panels and laser-cut panels* (Beltran et al., 1996). In general, if installed in the clerestory area – and thus in a position not influencing the perception of the external environment and with the advantage of a light shelf to reduce the risk of glare – these advanced daylight systems have been shown to effectively improve the daylight availability and distribution, and in addition can enhance the satisfaction and productivity of workers and result in significant cost and energy savings (Lee et al., 2002). However, louvres, reflective blinds, prismatic panels and laser-cut panels maximize their light-distribution potential under direct light conditions, a situation that is unlikely to occur at CH_2 especially during winter months (Lee and Selkowitz, 1998). Careful consideration leads then to the conclusion that none of these potential improvements would have given a substantial gain to the natural lighting performance of the adopted design to warrant their addition.

In order to maximize daylight penetration and optimize its distribution, an alternative solution could have included the installation of an *anidolic ceiling*, a non-imaging system that uses the optical properties of compound parabolic concentrators coupled to a specular light duct to collect diffuse daylight from the sky (IEA Task 21, 2000). Yet, in the CH_2 building, the use of such a system would have required adequate suspended ceiling space to exploit its potential to the full, a requirement in contradiction with the multiple functions of the vaulted ceiling design. Another potential solution could have been represented by the use of a similar technology: *anidolic solar blinds* to be placed in the clerestory area on top of the light shelves. Those blinds consist of a grid of hollow reflective elements, each of which is composed of two three-dimensional compound parabolic concentrators. The optics of the portions of the blind that emit light are designed to direct diffuse daylight into the upper quadrant of the room towards the ceiling; the device is, however, still in its prototype stage (IEA Task 21, 2000).

All things considered, the poor availability of daylight at lower levels in winter may not be counteracted without major practical (or visual) drawbacks. Therefore, in order to contribute to the physiological and psychological well-being of occupants via a proper entrainment of their circadian rhythms, it should be recommended to locate in those spaces employees whose work is generally done in teams so that they can gain from the interactions with colleagues the necessary environmental stimulation that cannot be provided by the dynamic pattern of natural illumination (Boyce et al., 2003). Moreover, since the choice of adopting extensive low ambient lighting (160 lux) can imply some negative consequences on the daily metabolism of occupants (people would probably need much higher light levels than that offered by the artificial system or even by daylight a short distance away from the window), the use of luminaries producing a very blue light spectrum (460 nm) can be suggested, for example by adopting blue LEDs.

Concerning the south façade, as reported earlier, one of the major issues with regard to visual comfort in the CH_2 building is due to the presence of glare reflected off the Victoria Hotel Building north façade, which creates high visual contrast in the field of view of the occupant, potentially decreasing the quality of his luminous environment. Of the various implementations investigated by the lighting consultants, the best option seems to be the use of artificial lighting to illuminate the internal wall adjacent the windows in order to decrease the contrast effect between the high luminance of the windows and the comparatively dark internal environment and wall finishes. Even though the economic and environmental cost of providing such additional lighting may not be compensated by a relatively marginal improvement in luminous comfort, the thorough application of this strategy can result in significant energy savings as it reduces the tendency of people to constantly keep blinds down and thus lose all the benefits of available natural light (AEC, 2003e).

An alternative solution could be the installation of vertical gardens on the south façade as well, maybe using plants that do not need a continuous direct illumination, or adjustable downward roller blinds that could block discomfort glare but still admit a reasonable quantity of diffuse light. In this case, the use of a roller blind rather than a venetian device would be surely accepted by occupants since the glare problems will probably be fairly constant during the time of their presence (being due to reflected brightness rather than direct exposure), while the continuous availability of a view out would not be a concern because of the proximity of the adjacent building. Finally, a further simple (but not necessarily less effective) potential response could be the installation of flexible visual tasks, as for example by mounting flat TFT computer screens on movable arms that could be adjusted directly by the users according to the characteristics of their luminous environment and their individual preferences.

CONCLUSION

The lighting strategy developed for the CH_2 building represents an outstanding example of international best practice; in particular, in how it manages to integrate innovative solutions with a number of functions and requirements of the building – that deal also with the physiological and psychological needs of workers – the adopted design exceeds the commonly-accepted standards for a so-called sustainable building.

There are many lessons to be learnt from CH_2; amongst them the need to foresee and control, starting from the conception and design stage, future development of neighbouring buildings in order to eventually predispose the necessary strategies to counteract the effects on solar access and its consequences on luminous environments (overshadowing, reflections, indirect glare, brightness of external surfaces, etc.). This is essentially a problem beyond the grasp of the design team.

As the CH_2 building demonstrates, to be truly "sustainable" buildings have to be designed and operated as "living" and complex systems rather than as passive collections of distinct parts, in order to guarantee to all its occupants optimal comfort conditions, both in perceptive and energetic terms, while also creating a pleasant place to live and work (Selkowitz, 1999).

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