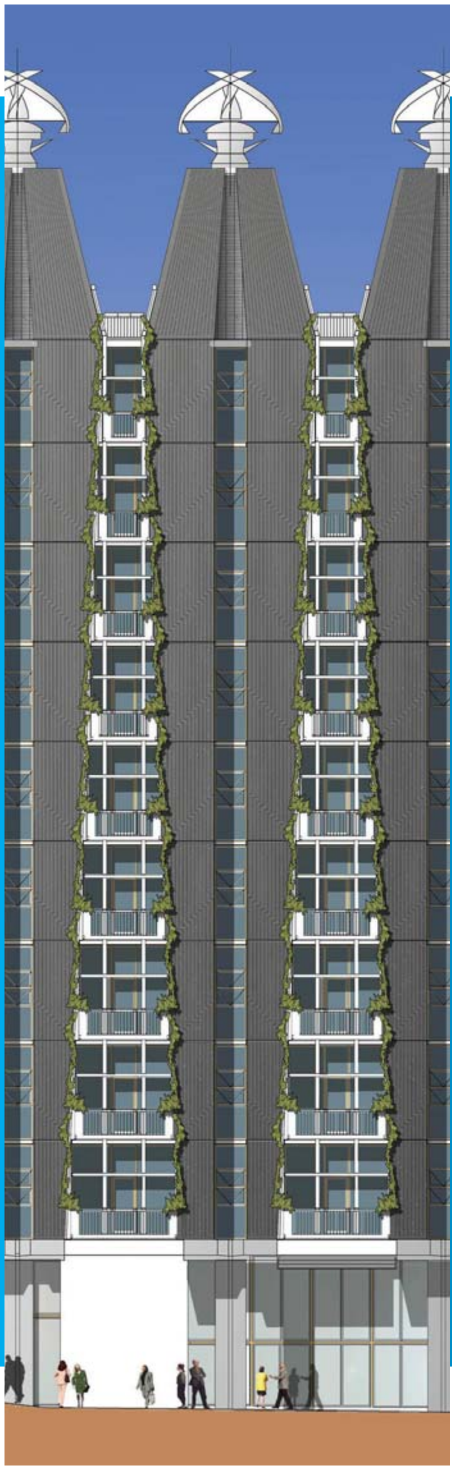
Technical Research Paper 03

Lighting and Physiology



Contents

Disclaimer

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An Australian Government Initiative
AusIndustry

6 star rating
green star Office Design v1
This rating represents World Leadership

Preface

Council House 2 (CH_2) is a visionary new building that is changing forever the way Australia – indeed the world – approaches ecologically sustainable design.

With its Six Star Design Rating granted by the Green Building Council of Australia, CH_2 is one of the cleanest and greenest buildings on earth.

This paper, one in a series of 10 technical papers, investigates the design and systems of CH_2 prior to occupancy and availability of operational performance data. The papers have been written by independent authors from Australian universities, as part of the CH_2 Study and Outreach Program – a coordinated effort to consolidate the various opportunities for study, research, documentation and promotion generated by CH_2.

The aim of the CH_2 Study and Outreach Program is to raise awareness of sustainable design and technology throughout the commercial property sector and related industries.

While the pre-occupancy research papers are a valuable resource, they do have some limitations. For instance, these studies have been written before operational experience. This means the authors' views are based on existing knowledge, which can be difficult to apply when significant innovation exists.

Many of the innovations in CH_2 have been subject to limited, if any, rigorous or directly relevant research in the academic field, which is reflected in the lack of literature cited for systems such as the shower towers and phase change materials used in the cooling system.

Another major limitation is the exclusion, by academics generally, of industry experience of new technologies. The extensive knowledge gained by industry is often not well documented and can be difficult to access through traditional academic channels.

One example, where industry expertise exists, is the use of phase change materials for reducing peak cooling loads and energy use in commercial and institutional settings, such as offices, hospitals, prisons and factories.

In addition, to enable the authors to complete their task, they have based their study on CH_2 project reports prior to the design being finalised. This means some of the descriptions of systems and findings in the papers are to some extent out dated. In particular, findings related to the wind turbines and the heating, cooling and ventilation systems have changed somewhat as a result of final design decisions.

To reduce the impact of these limitations for readers, the Council has provided additional comment as footnotes in some papers.

It is important to inform readers the target audience for these papers is professionals and academics involved in the research, design, engineering, construction and delivery of high performance buildings. This helps to explain the technical detail, length and complexity of the studies.

Although these papers may be of interest to a range of audiences it's important that readers, who possess a limited knowledge of the subjects covered, obtain further information to ensure they understand the context, relevance and limitations of what they are reading.

For more information or to make comment and provide feedback, readers are invited to contact the Council. The details are available at the end of this document.

We hope you enjoy reading these technical studies and find they are a useful resource for progressing your own organisation's adoption of sustainable building principles and encouraging the development of a more sustainable built environment.

Foreword

In 2000 the City of Melbourne made the decision to embark on a revolutionary new project called Council House 2 (CH_2). The decision was due to a pressing need for office space for its administration and the desire to breathe life into an under-used section of the city.

The project gave the Council the opportunity to exercise its environmental credentials by creating a building that was at once innovative, technologically advanced, environmentally sustainable and financially responsible.

This approach allowed the Council to insulate itself against exposure to rising energy and water prices, the diminishing availability of resources and the uncertain long-term availability, while providing a healthy workplace attracting the best workforce in a labour-constrained market.

CH_2 has been designed to reflect the planet's ecology, which is an immensely complex system of interrelated components.

From the revolutionary cooling storage system in the basement to vertical gardens and wind turbines on the roof, the building has sustainable technologies integrated throughout its 10 storeys.

Although the majority of the technologies and principles adopted in the building are not new, never before in Australia have they been used in an office building in such a comprehensive and interrelated fashion.

This includes innovations such as: using thermal mass for improving comfort; phase change material to reduce peak energy demands and energy use; generating electricity onsite from natural gas; and using waste heat for cooling and heating.

Through CH_2, the Council plans to trigger a lifestyle and workstyle revolution. The building will be used as a living, breathing example, demonstrating the potential for sustainable design principles and technologies to transform the way industries approach the design, construction and philosophy of our built environment.

As with many revolutions, there are sceptics. The Council's response has been to patiently press ahead with the construction of CH_2 while actively and energetically encouraging lively debate.

Some of the papers in this pre-occupancy study and outreach series make compelling points in favour of the case for sustainable development. Others reflect a more subtle or sometimes overt scepticism that may be encountered throughout the community.

The City of Melbourne welcomes all of this debate but in the long term intends to demonstrate the effective performance of CH_2 and prove the doubters wrong. Collectively, the studies demonstrate the enormous value to be gained by researching the case for sustainable development and the scope for much more study and documentation in this field in the future.

The City of Melbourne wants CH_2 to be copied, improved on and enthusiastically taken up throughout Melbourne and far beyond.

Technical Research Paper 03
Lighting and Physiology

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Abstract

This study is one of a series outlining the major design elements of the new Council House 2 (CH_2) building in Melbourne, Australia. CH_2 is an environmentally significant project that involves a design approach inspired by the mimicry of natural systems to produce comfortable, healthy and productive indoor conditions, an approach termed biomimicry: to mimic nature or living systems. This study focuses on lighting and physiology and examines the artificial and natural lighting options used in CH_2 and the likely effects these will have on building occupants. The purpose of the study is to critically comment on the adopted strategy, and mindful 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 study concludes that CH_2 is a prime example of lighting innovation that provides valuable lessons to designers of office buildings, particularly in a CBD environment.

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

Introduction – Scope of this Study

The lighting of a workplace can positively influence the health of office personnel, improve efficiency, reduce unnecessary sick leave and result in greater productivity[1]. In particular, natural light, with its variations and spectral composition, together with the provision for external views, is of great importance for personal well-being and mental health, 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 outside environment, while preventing glare and minimizing heat gains[2].

A transparent façade should always be designed to fulfil the needs of the users and the requirements of the building, and find a balance between needs of transmission and requirements of protection. For buildings with high percentage of glass, it is even more important to find the right balance between opening to the environment and protecting from its extremes[3].

Selecting façade and lighting solutions for comfort and energy efficiency can be a very complex problem. There are many design and context variables that interact with each other, making selection and optimisation more difficult.

As Guzowski explains, a good lighting strategy should maximise the potential of architectural form while taking advantage of technologies to further refine solutions[4]. The goals of a lighting strategy can be defined from a wide variety of perspectives such as *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, connection to the beat of outside life), *aesthetic considerations* (form, dimension and articulation of spaces, materials), as well as other concerns. For this reason it is not always possible or even necessary to address these objectives simultaneously; yet, analysing their potential can clarify design intentions, determine priorities, and reveal possible contradictions[5]. For example, lighting is often designed to remain fairly constant during day and night in working environments, not considering that occupant needs can vary in terms of preferences and associated differences in clothing, metabolic levels and the nature of visual tasks occurring in a given working environment[6].

1 Health, defined by the World Health Organisation as a state of complete physical, mental and social well being (and thus not merely the absence of disease and infirmity), is important to people and a fundamental prerequisite for productivity.
2 Wigginton M., *Glass in Architecture*, Phaidon Press, London, 1996.
3 From an historic point of view, the importance of daylight has always been reflected in legislation. Starting from the first century A.D. and until the fall of Rome, roman laws established solar rights; British legislation (dating 1189) guaranteed that if a window had at least twenty years of uninterrupted access to daylight, that access should become permanent; planning principles adopted in Boston and New York at the beginning of the 20th century banned the dark street canyons emerging in urban centres; nowadays, in Japan, building codes dictate that apartments have at least four hours direct access to sunlight per day; German codes state that every workstation in a new commercial building must be directly naturally lit direct with a distance no more than 7.5 meters from the window. Carmody J., Selkowitz S., Lee E., Arasteh D., Willmert T., *Window Systems for High-Performance Buildings*, W.W. Norton &Company, New York, 2004.
4 Guzowski M., *Daylighting for sustainable design*, Mc Graw-Hill, 2000.
5 Ibidem.
6 Selkowitz S.E., Lee E.S., "Advanced Fenestration Systems for Improved Daylight Performance", in *Daylighting '98 Conference Proceedings*, Ottawa, 1998.

This study aims to show how the paradox of opening to natural forces and protecting from its extremes can be resolved, and to promote a new design attitude that modulates the relationship between users' needs and sustainability. As a reference case of international best practice, the lighting strategies of the newly developed Council House 2 (CH_2) building in Melbourne will be analysed, and its contribution to sustainable design discussed.

Light And Physiology

The use of daylight as a light source in buildings is important to achieve ecological sustainable development (ESD) objectives, being assumed to minimise resource consumption, waste generation and improve human well-being. However, the widespread use of shared spaces that inhibit direct lighting control by every user, the inherent limits of automatic lighting control systems and the reductions in terms of energy consumption of modern electric lighting have made it difficult to justify the cost of extensive natural day lighting design solutions on the basis of economic paybacks from potential energy savings. To substantiate the use of daylight in buildings it is necessary to demonstrate beneficial effects in other areas that have, potentially, a more significant impact on occupants, tenants and owners of buildings[10].

Light (in all its forms) is not only a resource and a vital sustenance, but can also create meaningful architectural experiences. The mood and quality of an architectural space can vary greatly depending on its lighting and colour conditions, transforming a sometimes dark, sober and oppressive place into a captivating, enthralling and stimulating 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 is a key way of marking important daily events (dawn, morning, noon, afternoon, sunset and evening)[11].

When light passes through the eye, the signals are carried not only to the visual areas of the brain but also to areas responsible for emotion and hormonal regulation. Ocular light stimuli from the retina result in signals being sent to 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).

The combination of these activities create the 'process of perception' informing us about the characteristics of the surrounding environment[12].

Regardless of this awareness, a great part of our social interaction is temporally organised in relation to a rather 'mechanical time', which is largely independent of 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 imposed by work schedules, the calendar and the clock. As Van den Beld suggests, the species *Homo sapiens* appeared on Earth around 250,000 years ago and evolved under the daily 24-hour light-dark cycle. To a large extent life has been regulated by a natural wake/sleep rhythm: active, mostly outside during the day, and resting at night[13]. During the last couple of centuries, this natural pattern has changed rapidly, initially due to the industrial revolution, and then to some technological innovations (such as electric light) that are now moving us towards a global 24-hour society. Most people nowadays spend more than 90% of their time indoors, often in offices, and in all cases the lighting is based on 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 degree of visual comfort[14].

Medical 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 has been discovered to contain an internal 'biological' clock, daily synchronised 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, productivity, etc. Sufficient light received during the natural light period (daytime) synchronises the 'biological clock' contained in the human brain, stimulating circulation, increasing the production of vitamin D, enhancing the uptake of calcium in the intestine, regulating protein metabolism, controlling the levels of serotonin, dopamine (pleasure hormones), melatonin (sleep hormone) and cortisol. In other words, light provides the direct stimuli needed for the human body to function and feel well and healthy[17].

7 Van den Beld G., "Light and Health", in *International Lighting Review*, Philips Lighting, n. 1/2001.
8 Fonseca I.C.L., et al., "Quality of light and its impact on man's health, mood and behaviour", in *Proceedings of the PLEA 2002 Conference*, Toulouse, July 2002.
9 Selkowitz S.E., Lee E.S., "Advanced Fenestration Systems for Improved Daylight Performance", in *Daylighting '98 Conference Proceedings*, Ottawa, 1998.
10 Boyce P., Hunter C., Howlett O., "The benefits of daylight through windows", Lighting Research Center, 2003.
11 Van den Beld G., "Light and Health", in *International Lighting Review*, Philips Lighting, n. 1/2001.
12 Fonseca I.C.L., et al., "Quality of light and its impact on man's health, mood and behaviour", in *Proceedings of the PLEA 2002 Conference*, Toulouse, July 2002.
13 Van den Beld G., "Light and Health", in *International Lighting Review*, Philips Lighting, n. 01/2001.
14 Caminada J.F., "From surfaces to spaces", in *International Lighting Review*, Philips Lighting, n. 01/2001.
15 Van den Beld G., "Light and Health", in *International Lighting Review*, Philips Lighting, n. 01/2001.
16 Caminada J.F., "From surfaces to spaces", in *International Lighting Review*, Philips Lighting, n. 01/2001.
17 Birren F., "Light, colour and environment – Revised edition", Van Nostrand Reinhold Co., New York, 1982.

Exposure to daylight is usually the major factor for setting the human circadian rhythm, since it usually produces a high illuminance at the eye with a spectrum that perfectly matches the specific sensitivity of the circadian system, and peaks at about 465nm[19]. Sufficient retinal illumination to entrain the circadian system can be provided by artificial lighting alone, even though this solution is less likely to obtain the same results as natural daylight[20]. If we consider a daytime office worker, daylight deficiency may result in a de-synchronisation of his or her biological clock. As such the body and mind may prefer to rest but are required to remain active. The effects of this de-synchronisation are lower performance, a decrease in alertness, diminished sleep quality and, in the longer term, impacts on well-being and health[21].

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 characterised by cold and sombre climate, where there is less light and days are short. About three per cent of the population in those regions suffer from winter depression (SAD, *Seasonal Affective Disorder*), and the so-called 'winter blues' are common. Intensive bright light through the eye can mitigate those feelings and is the first line of treatment for SAD[21].

The combination of medical and scientific research leads to 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. This 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.

Daylight Quality vs Indoor Light

It is now important to establish how serious the consequences of working and living indoors at 'unnatural' times are and whether a 'healthy' lighting system can be designed to compensate for this. A number of interesting facts and figures are relevant to this issue, and are discussed below.

For example, although human beings are accustomed to significant variations in the level and duration of daylight, office lighting practice seems to ignore this fact. Natural outdoor illumination varies from over 100,000 lux on a sunny day to a few thousand lux on a dark, overcast winter day, and for periods of between two and almost 16 hours per day. External lighting levels are therefore, on average, at least 800 lux higher than the accepted horizontal illumination in working spaces (300-600 lux).

Secondly, just as the spectral composition of daylight shows large variations during the day ('cold' light in the morning and 'warm' light at sunset), people prefer variations in the correlated colour temperature (CCT)[22] of artificial light. In particular, according to the Curve of Amenity (*Kruithof Diagram*), the higher the overall lighting level, the higher its colour temperature should be[23]. Most current lighting systems are only adjustable in output levels and not in terms of colour temperature, as a result they can rarely add significant meaning to the variability of a workplace, often creating simple, repetitive and arbitrary indoor lighting environment configuration[24].

Thirdly, daylight is highly dynamic in its intensity and direction, and research shows people would prefer to be aware of these changes and desire continuous contact with the world outside.

Another important issue is the influence of colour on physiology, an issue that may involve subjective as well as objective responses[25]. There are reliable and measurable physiological reactions to colour in addition to those generally associated with vision. These reactions maybe revealed by objective measurements such as *galvanic skin response, electroencephalograms, heart rate, respiration rate, oximetry, eye blink frequency* and *blood pressure*.

18 Birren F., "Light, colour and environment – Revised edition", Van Nostrand Reinhold Co., New York, 1982.
19 The receptors for the biological systems are yet not well known, but there are indications that the green/blue part of the light spectrum is more effective in achieving the biological effects, calling for the fact that it is the morning light – which in nature has a higher colour temperature – that plays an important role in synchronising the daily setting of the internal biological clock with the outside world.
20 Boyce P., Hunter C., Howlett O., "The benefits of daylight through windows", Lighting Research Center, 2003.
21 Van den Beld G., "Light and Health", in *International Lighting Review*, Philips Lighting, n. 01/2001.
22 All the light sources are characterised by two colour properties related to the spectral composition of their emission: the *apparent colour and the colour rendering*, the latter being referred to as the effect that the light has on the colours of the surfaces. The apparent colour of light sources is usually defined in terms of their correlated colour temperature or CCT (expressed in Kelvin). The higher the value of the CCT, the cooler the appearance of the light source; as an example, the flame of a candle, with its reddish-yellow colour, has a CCT of about 1900 K, an ordinary incandescent lamps is characterised by a colour temperature of 2800 K, while the cold bluish-white sky daylight ranges over 6500 K. Each type of lamp has a specific CCT, but for practical reasons the CIE (International Commission on Illumination) has defined three different classes of colour temperatures: 1 (colour appearance "warm", CCT < 3300 K), 2 (colour appearance "intermediate", 3300 < CCT < 5300 K), 3 (colour appearance "cold", CCT > 5300 K). From Australian Standard AS 1680.1-1990, *Interior Lighting – Part 1: General principles and recommendations*.
23 Conversely, high colour temperatures under low luminance tend to make the ambient seem cold and dark, while low colour temperatures under high lighting level tend to make the ambient seem rather artificial. Fonseca I.C.L., et al., "Quality of light and its impact on man's health, mood and behaviour", in *Proceedings of the PLEA 2002 Conference*, Toulouse, July 2002.
24 Boyce P., Hunter C., Howlett O., "The benefits of daylight through windows", Lighting Research Center, 2003.
25 Boyce P.R., Cuttle C., "Effect of Correlated Colour Temperature on the Perception of Interiors and Colour Discrimination Performance", in *Lighting Research and Technology*, 1990.

Whether the association between colour and one or more of the above physiological index is direct (i.e. colour causes the physiological response to be elicited without mediation by a cognitive intermediary response) or indirect (i.e. exposed to a colour the observer makes certain associations), is yet to be clearly defined[26].

Comfort, Satisfaction and Productivity Implications

The above considerations lead to the conclusion that the way in which lighting conditions influence the comfort and performance of individuals involves not only the visual (amount, spectrum and distribution of the light) and the circadian system, but also the perceptual system, which takes over once the retinal image has been processed. Poor lighting conditions are generally considered uncomfortable and can lead to distraction from the task or fatigue due to the presence of glare or flicker. However, perception is much more sophisticated than simply producing a sense of visual discomfort because of the influence of these conditions on an observer's mood and behaviour[27].

The knowledge gained from these recent discoveries on the effects of light on well-being and human health lead to new demands for lighting design solutions. In addition to the well-known visual comfort criteria and direct stimulation of the brain, additional non-visual issues for health and well-being are being formulated in the scientific literature[28].

The combination of medical and scientific research leads to the hypothesis that 'healthy' lighting for daytime indoor activity is influenced by many more factors than those in most lighting standards and regulations. This research indicates that there should preferably be a combination of natural and artificial lighting sources in office environments, with the electric light taking over when natural daylight is reduced in winter or later in the working day.

Dark or windowless spaces are generally disliked by occupants, particularly when rooms are small and there is a lack of external stimulation. However, given the general preference for daylight, and considering the number of factors involved and the fact that people will give up daylight if it is associated with glare, contrast, reflection, solar heat gain or a perceived loss of privacy, it is hard to demonstrate that the presence of windows alone can improve an occupant's productivity[29].

Meeting the Lighting Requirements

The Daylight Design Challenge

Many people perform daily activities that are best described as office tasks such as files processing, communication with other people, thinking, organising and other related tasks[30]. Each activity involves a different relationship with the spaces that surrounding a 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 needs reflect people's desire for a specific orientation in space and time (*genius loci*) – including aspects related to physiological biorhythm, but also to society and culture, privacy and communication, information and familiarity, variation and surprise. Lighting, both natural and artificial, through the choice of form, colour, material and details, plays a key role in creating an atmosphere that meets occupant's expectations (functionality, aesthetics, ergonomics, of the rooms and their furnishings) and demands (privacy, concentration, appreciation of details, etc.). Lighting can also facilitate perception and create a mood or ambiance of its own.

During the day, the presence of daylight should render spaces lively, activating and motivating in line with the human biorhythm. In addition, daylight is often associated with a view, which provides information about the time of day, the season and the weather. Views and variations in intensity and colour are extremely stimulating for the brain and the visual apparatus, contributing to a person's well-being and improving their sense of orientation and feeling of spaciousness[31]. In addition, 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 towards distant objects[32].

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 external factors (working groups, stringent visual tasks, etc.) Nevertheless, daylight can have major drawbacks on visual comfort such as direct sunlight, bright clouds and reflective surfaces that create glare and contrast[33]. Luminance ratios in the field of vision should always be contained within certain limits: too large, and it is difficult for the eyes to adapt; too small, and there are difficulties in estimating depth and distance.

26 Kaiser P.K., "Physiological Response to Color: A Critical Review", in *COLOR research and application*, Volume 9, Number 1, Spring 1994.
27 As an example, lighting that provides poor task visibility and fails to meet occupant's expectations would not only decrease the visibility of the task, but may develop frustration and alter the worker's productivity once he becomes aware of the poor level of comfort of his visual environment.
28 Brainard G., Glickman G., "The biological potency of light in humans: significance to health and behaviour", in *Proceedings of the 25th CIE Session*, San Diego, 2003.
29 Numerous surveys on occupants of windowless spaces demonstrate that the more the room is small in dimensions and gives little opportunity to relief and external stimuli, the more the occupants become dissatisfied with their jobs and with their physical environment; in a small office, more than in a space where many activities go on and there is chance of interacting with people, a window may be the only source of environmental stimulation. On the contrary, other surveys clearly show that daylight and a view out may not be strictly essential in case the space is endowed with a good electric lighting and plenty of stimulation, as it is often the case in meeting rooms and common areas. Boyce P., Hunter C., Howlett O., "The benefits of daylight through windows", Lighting Research Center, 2003.
30 Kramer H., "Mastering Office Lighting", in *International Lighting Review*, Philips Lighting, n. 01/2001.
31 Zonneveldt L., "The Daylight Challenge", in *International Lighting Review*, Philips Lighting, n. 01/2001.
32 Guzowski M., *Daylighting for sustainable design*, Mc Graw-Hill, 2000.
33 As a general rule, in windowless areas features such as photomurals, travel poster or wall hangings can serve as satisfactory visual rest centres when located at a distance significantly greater than the screen reading distance. Australian Standard AS 1680.2.2-1994, *Interior Lighting-Part. 2.2: Office and screen-based tasks*.

Since people are also phototropic (attracted to light), and areas of high luminance in the background of the visual task should be avoided. As the eye attempts to even out the contrast between the two differently illuminated surfaces, the muscles of the eye have to work harder and more frequently resulting in tired eyes and an increased level of stress. As such, the task should always be the area of major visual attention, and brighter than its surroundings, to enhance comfort and minimise glare[35].

Glare in particular is a potential source of visual discomfort due to the illuminance from a bright source (direct or reflected) relative to the average illuminance in the field of view of the observer. The ratio at which this contrast becomes a source of discomfort depends on the specific function being performed. Sources of glare in a workplace can be the sky vault and the sun and/or its reflections on external surfaces or lighting installations. Glare can be categorised in two different ways: 'disability' glare and 'discomfort' glare, the former preventing the viewer from performing the visual task and the latter causing a decrease in visual comfort (and hence productivity)[36]. In addition to these two categories, there is also 'direct' and 'indirect' glare; direct glare is caused when a person views a source of illumination, indirect glare results from light being reflected off surfaces. It is important to note that some studies show that occupants are more tolerant of glare if the light source is accompanied by a view and that lighting fluctuations coming from a natural source are generally quite well accepted, while people tend to find changes in the artificial lighting environment rather disturbing[37].

In relation to glare and reflections on computer screens, direct illumination can decrease visibility by reducing contrast or washing out the screen image[40]. In general, old cathode screens are more susceptible to those problems, while newer display technologies, such as liquid-crystal flat screens with anti-reflection coatings, can be viewed under some direct sun conditions.

Predicting Glare and Controlling Natural Light

The degree of glare in an interior space can be predicted by the determination of a *Daylight Glare Index* (DGI) at a specified location and orientation within the space. This index is based on a subjective response to brightness within a person's field of view, with higher values indicating a greater probability of discomfort glare and vice-versa. The least perceptible difference of glare index which can be visually appreciated is one unit, while the least difference which makes a significant change in the perception of discomfort glare is three units. Each step in the scale of the DGI (13, 16, 19, 22, 25, 28) represents one significant change in glare effect. A DGI of 10 is the threshold for *just perceptible glare* and a glare index of 16 is the threshold where glare is *just acceptable*. For a normal range of tasks in an office environment, the typical maximum glare index is assumed to be 19[41].

To control the intensity of light sources entering a work space and to guarantee a comfortable luminous environment, a good daylight solution should generally be composed of more than a simple window or skylight. Depending on climate, building orientation and environment, additional elements or adaptations may be needed to increase visual comfort.

Daylight systems range from simple static elements (such as louvers or fixed overhangs) to adaptable dynamic elements (such as blinds or movable lamellae), and/or combinations of these. Good solutions start from exploring simple techniques and adding advanced elements, if required. The performance of complex systems such as highly reflective surfaces is very dependant on maintenance and durability of components. Dust, condensation or surface deterioration can also reduce the optical efficiency of these systems, sometimes by more than 50 per cent[42]. Simple daylight systems to reduce glare include a light shelf that can be used to deliver daylight at greater depths into the room by reflecting light on the ceiling and reducing glare in areas close to the perimeter without significantly reducing light levels near the window[43].

34 As a general rule, in windowless areas features such as photomurals, travel poster or wall hangings can serve as satisfactory visual rest centres when located at a distance significantly greater than the screen reading distance. Australian Standard AS 1680.2.2-1994, *Interior Lighting-Part. 2.2: Office and screen-based tasks*.
35 Australian Standard AS 1680.1-1990, *Interior Lighting – Part 1: General principles and recommendations*.
36 Disability glare is generally caused by direct sunlight on viewing task or adjacent surfaces and may make important details invisible; alternatively, if the source of high luminance is viewed directly, noticeable after-images may be created. Discomfort glare is likely to be due to the location and intensity of the light sources in the field of view; a high source luminance, large source area, low background luminance and a position close to the line of sight, all increase discomfort glare. Carmody J., Selkowitz S., Lee E., Arasteh D., Willmert T., *Window Systems for High-Performance Buildings*, W.W. Norton &Company, New York, 2004
37 Lee E.S., Selkowitz S.E, "Integrated Envelope and Lighting Systems for Commercial Buildings: a Retrospective", in *Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings*, Asilomar, June 1998.
38 Disability glare is generally caused by direct sunlight on viewing task or adjacent surfaces and may make important details invisible; alternatively, if the source of high luminance is viewed directly, noticeable after-images may be created. Discomfort glare is likely to be due to the location and intensity of the light sources in the field of view; a high source luminance, large source area, low background luminance and a position close to the line of sight, all increase discomfort glare. Carmody J., Selkowitz S., Lee E., Arasteh D., Willmert T., *Window Systems for High-Performance Buildings*, W.W. Norton &Company, New York, 2004
39 Lee E.S., Selkowitz S.E, "Integrated Envelope and Lighting Systems for Commercial Buildings: a Retrospective", in *Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings*, Asilomar, June 1998.
40 A typical maximum luminance value for a computer screen lies in the range of 80 to 120 cd/m2. Fontoynont M., (edited by), *Daylight performance of buildings*, James & James, 1999.
41 Australian Standard AS 1680.1-1990, Interior Lighting – Part 1: General principles and recommendations.
42 Fontoynont M., (edited by), Daylight performance of buildings, James & James, 1999.
43 Light shelves can improve illuminance distribution in the rooms and may double as shading device, if thoroughly designed to block direct sun at specific moments of the year. Light shelves are best used on north (equator-facing) orientations and maximise their performances in a predominantly clear sky climate. The top of the shelf should preferably be matte white or diffusely specular, and not visible from any point in the room, while the ceiling should be smooth and light-coloured. Beltran L.O., Lee E.S., Selkowitz S.E., "The Design and Evaluation of Three Advanced Daylighting Systems: Light Shelves, Light pipes and Skylights", in *Proceedings of the Solar '94 Golden Opportunities for Solar Prosperity Conference*, San Jose', 1994.

Additional elements comprising a daylight system include indoor or outdoor solar blinds, which are used to help control the intrusiveness of solar energy, in terms of its light and heat components. In office environments, blinds are mostly either horizontal or vertical and should preferably be composed of light, diffusive materials. The individual strips making up the blinds should be as narrow as possible, for the wider the strips, the larger the undesirable light-dark patterns. Slim, light-coloured, horizontal blinds offer the best control of brightness and light distribution[44]. It is important that individual employees are able to close or open blinds to suit their preference. 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[45]. If manually-controlled interior shading is the only option, many occupants will keep the device closed meaning the window is no longer transparent. For efficient use of daylight and to allow continuous adjustments, automatically-operated movable devices are preferable, although the initial cost and maintenance could be slightly higher than with fixed devices[46].

Glazing and Colour Affects

Glazing type should be selected according to daylight effectiveness, occupant comfort and energy efficiency, while still meeting architectural objectives. Glass for windows should be evaluated according to the specific optical and thermal characteristics of the glazing. In particular, glazing colour affects colour appearance and colour rendering of interior finishes and tasks in day lit areas[50].

In relation to interior finishes, light-coloured surfaces reflect more daylight than dark hues. Specular surfaces, such as glazed tiles or mirrored glazing, can create glare if viewed directly from a task position, while diffuse ground-reflected daylight can increase daylight availability. Deep reveals, ceiling baffles, exterior fins and shelves – if they are light in colour – may help keep daylight more even[51].

As a person's mood can be significantly affected by his or surroundings, colour monotony should generally be avoided as much as colour fatigue. Whilst the colour palette on interior surfaces should preferably be simple, attractive visual centres (such as colourful hangings, paintings, posters) are desirable in order to produce a visually pleasant environment. Plants and individually coloured screens play the same role, while a view outside always enhances visual rest and connection with the outdoors[52].

Design for Natural and Artificial Light

In a work environment, a combination of daylight and artificial light is preferable, combined to produce sufficient and suitable lighting for tasks throughout the room, day and night. Good integration between these two sources of light makes it possible to gradually dim the amount of electric light when available daylight is sufficient for the task.

The design of an office lighting system should also allow for the various requirements of its occupants, allowing users flexibility and personal over-ride to adjust (at least partially) the luminous environment according to their individual needs. Privacy and personal needs, in particular, require that each area be separate from other workstations in terms of the luminous environment, and can be fitted out in a personalised way. Depending on the different tasks and activities performed in a space, several adjustable lighting systems are preferable to evenly distributed ceiling lights. 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 assist in the perception of three dimensional objects and give 'life' to an environment[53].

In an office, daylight can provide adequate ambient light for most working hours, and when supplementary light is needed, user-controlled task lights can ensure work requirements are met. As mentioned previously, ambient illumination should be significantly lower than task requirements. Likewise, different artificial light is required during the day than at night, when, as a general rule, light should be calming and restful, in accordance with the human biorhythm.

In a day lit space, it is obvious that people close to windows will often use natural light as their primary illumination source. For other locations, direct/indirect lighting should be designed to pair with daylight distribution. 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 wall), in order to allow the possibility for control to be added as retrofit.

44 Zonneveldt L., "The Daylight Challenge", in *International Lighting Review*, Philips Lighting, n. 01/2001.
45 For example, the lighting needs of a young worker with normal eyesight will be very different from the needs of an older occupant with vision deficiencies, while, on the other hand, the lighting required to proofread handwritten paper forms will be different from those needed to work at a PC screen. Selkowitz S.E., "Integrating Advanced Façade into High Performance Buildings", in *Proceedings of the 7th International Glass Processing Days*, Tampere, 2001.
46 Lee E.S., et. al., "Active Load Management with Advanced Window Wall Systems: Research and Industry Perspectives", in *Proceedings from the ACEEE 2002 Summer Study on Energy Efficiency in Buildings*, Asilomar, August 2002.
47 Zonneveldt L., "The Daylight Challenge", in *International Lighting Review,* Philips Lighting, n. 01/2001.
48 For example, the lighting needs of a young worker with normal eyesight will be very different from the needs of an older occupant with vision deficiencies, while, on the other hand, the lighting required to proofread handwritten paper forms will be different from those needed to work at a PC screen. Selkowitz S.E., "Integrating Advanced Façade into High Performance Buildings", in *Proceedings of the 7th International Glass Processing Days*, Tampere, 2001.
49 Lee E.S., et. al., "Active Load Management with Advanced Window Wall Systems: Research and Industry Perspectives", in *Proceedings from the ACEEE 2002 Summer Study on Energy Efficiency in Buildings*, Asilomar, August 2002.
50 The colour rendering properties of a light source depend mainly upon its spectral energy distribution. In particular, the desired colour appearance of a surface will be matched only if the light source contains in the necessary proportion all the spectral components. In particular, the CIE Colour Rendering Index expresses, on a scale to 100, the degree to which the appearance of any of the fourteen specific colours conforms to that of the same colour illuminated by a reference light source of similar CCT. Where work involves an accurate colour judgement, light sources with high CIE colour rendering indices (>80) are strictly required. Australian Standard AS 1680.1-1990, *Interior Lighting – Part 1: General principles and recommendations*.
51 O'Connor J., Lee E., Rubinstein F., Selkowitz S., *Tips for Daylighting with Windows – The Integrated Approach*, LBNL, California, 1997.
52 Australian Standard AS 1680.1-1990, Interior Lighting – Part 1: General principles and recommendations.
53 Ibidem.

If computers are present, ambient lighting should not exceed 300 lux, in which case user-controlled task lighting is available as a supplement. A rule of thumb for spaces that host Video Display Terminals (VDTs) provides as little light as possible on computer screens (150-300 lux) for surround lighting, and up to 500 lux on adjacent task space. However, if glare from windows is expected, interior luminance should be kept high to balance window brightness and decrease the risk of visual contrast. High-reflectance, light-coloured walls and partitions are preferable[54].

The choice of the most appropriate 'colour temperature' for a light source is largely determined by the function of the room, involving psychological aspects such as the impression of warmth, relation, clarity and other considerations[55]. For best colour temperature pairing with daylight, a generally well-accepted choice is to install fluorescent lamps[56] with a minimum colour temperature of 4000 K. However, when there is significant night-time use of the building, lamps with a CCT lower than 4000 K may be required[57].

In order to save energy and ensure optimum light distribution at all times, a control system that can adjust the lights and/or turn them off when there is adequate daylight may reduce consumption and result in minimal complaints. Typical artificial lighting control systems for commercial buildings include a photosensor strategically located either under the luminaire close to the external opening or on the ceiling. Their sensitivity to light may vary sensibly within the cone of view according to the specific need[58]. Sensors 'measure' light by looking at a wide area of the room floor and work surfaces, and send signals to the control system to dim or switch the lights according to daylight availability and link to a host of other inputs (e.g. lumen maintenance, tuning, occupancy sensors, weekend/holiday/ night time schedules, etc.)[59].

Dimming control is generally twice as expensive as switching because it is the best strategy for implementing energy savings and the most acceptable to occupants since observable changes in the artificial light levels can be made less disturbing. Dimming is not a cost-effective strategy in non day lit areas unless coupled with scheduling controls. In relation to lighting control systems, dimming electronic ballast are fast becoming cost-effective to operate fluorescent lamps in rapid-start mode (i.e. the fluorescent lamp cathodes are supplied with power at all times during operation)[60].

International Best Practice – BRE Fire Research Station

The principles of best practice discussed so far have been applied on a number of buildings around the world. Some of these include the new headquarters of the British Research Establishment[61] (BRE) Fire Research Station, built in Garston (UK) by Feilden Clegg Architects in 1996; a landmark-building intended to be a replicable example of cutting-edge environmental design that shares a number of elements in common with the Council House 2 building in Melbourne[62].

The design of the BRE Fire Station was based on a new performance specification, *Energy Efficient Office of the Future*, founded on environmentally friendly principles with energy performances corresponding to an 'Excellent' Building Research Establishment's Environmental Assessment Method (BREEAM) rating. In the case of the CH_2 building, all consultants were involved from the earliest stage of design, and were joined by the main contractor during the documentation and specification stage.

The BRE Fire Station is an L-shaped block with a three storey office wing (30m by 13.5m), fronting a landscaped area. The relatively shallow office plan, with highly glazed façades, exploits natural daylight and is well suited to cross ventilation via Building Management System controlled windows at high level and manually operable windows at lower levels. Daylight is maximised with large areas of glazing on the north and south façades, providing daylight factors of over two per cent across the floorplate. Penetration is assisted by 3.7m ceiling heights, which are also painted white.

As in CH_2, a wave form floor slab design incorporates ventilation routes that pass over the ceiling of cellular spaces; the high points of the wave have corresponding high level windows allowing daylight to penetrate deep into the plan. Fully glazed façades, in combination with high ceilings and a relatively shallow plan depth, minimise the need for artificial lighting and the consequent electrical energy load is significantly reduced when compared to a conventional office building. However, the need to control glare and solar gain is more important.

54 Desirable reflectance for room surface are: ceilings>80%; walls>50-70%; floors>20-40%; furniture>25-45%.
55 Australian Standard AS 1680.1-1990, Interior Lighting – Part 1: General principles and recommendations.
56 A fluorescent lamp consists of a tubular electric lamp that is coated on its inner surface with a phosphor and that contains mercury vapour whose bombardment by electrons from the cathode provides ultraviolet light which causes the phosphor to emit visible light either of a selected colour or closely approximating to daylight. The 3rd generation T5 lamp, with a diameter of 16 mm, is available with outputs of 14W, 21W, 28W and 35W. Wu Kwok-tin M., *T5 lamps and luminaries, The 3rd generation in office lighting*, web source.
57 Other general rules suggest, for room lit to an illuminance of 240 lx or less, to prefer a warm or intermediate colour, while lamps of different colour should not be used indiscriminately in the same room unless a specific effect is desired.
58 Ehrlich C., Papamichael K., Lai J., Revzan K., "Simulating the Operation of Photosensor-based Lighting Controls", in *Proceedings of the 7th Building Simulation Conference*, Rio de Janeiro, 2001.
59 Lee E.S., Di Bartolomeo D.L., Selkowitz S.E., "The Effect of Venetian Blinds on Daylight Photoelectric Control Performance", in *Journal of the Illuminating Engineering Society*.
60 Fluorescent light is the preferred source of choice for both dimming and switching applications, because it can be efficiently dimmed over a wide range without changes in colour, and can be turned on and off virtually instantaneously. On the other hand, most HID sources (metal halide, high pressure sodium and mercury vapour) are not appropriate for dimming applications because they suffer colour shifts as they dim, and have a more limited dimming range.
61 Wigginton M., Harris J., *Intelligent Skins*, Architectural Press, Oxford, 2002.
62 See following paragraph "CH2 Design Features, Expected Performances and Implementations".

At the BRE Fire Station, these factors are controlled by BMS-controlled external motorised glass louvres. The louvres are extremely slim when rotated to their horizontal position (10mm) but, being wide (400mm), are set well apart (1.2m) so that an excellent view is maintained when they are not angled to provide shading. It is also possible to rotate the blades beyond the horizontal so they can act as adjustable light shelves to reflect direct sunlight onto the ceiling and deeper into the plan. The louvres are controlled by the BMS with the specific purpose of managing solar gain. Occupants can over-ride the automatic setting to reduce glare if they wish, however the system is reset to an optimum position at the end of the day. In terms of artificial lighting, internal sensors measure light levels and movement, dimming high-efficiency T5 fluorescent lamps (from 100 to 0 per cent) when there is sufficient daylight, or switching them off if a room is unoccupied. The sensors have an infra-red receiver, which allows users to over-ride the automatic control by means of a remote control unit. The lamps provide general lighting at around 300 lux, which is supplemented by task lighting when required, and have an uplighting component to guarantee a balanced visual environment. Each of the lamps can be controlled separately by the BMS to allow different light output levels across the floor plan and to make maximum advantage of daylight for the buildings lighting requirements.

International Best Practice – Other Notable Daylight Examples

In addition to the BRE edifice, there are a number of other buildings where natural light is carefully exploited via the use of advanced solutions and devices. One of these buildings is the Parliamentary Office (Portcullis House) in Westminster, London, designed in 1998 by Michael Hopkins & Partners. In this building solar shading is controlled by adjustable louver blinds built into the cavity between a double skin façade, and by light shelves positioned above the bays. These shelves shade the area immediately next to the window and reflect incoming light deeper into the rooms[63].

Light shelves to enhance solar penetration and provide sun shading are also used in the EOS Building in Lausanne, designed by Richeret and Rocha Architects, in the form of 0.8m outside-tilted anodised aluminium blades located at the height of 2m above the floor surface, a choice which offers a reasonable compromise between reflective properties and durability[64]. Deep 0.9m aluminium light shelves, mounted on the inside of two south-facing window strips (northern hemisphere), are also used in the Tax Office Extension building in Enschede (The Netherlands), a project partly founded by the European Commission THERMIE Program and designed by a team from the Dutch Government Building Agency[65].

Rather than using a reflective device to direct natural light towards the interior, the newly refurbished SUVA Company building in Basel, by Herzog & De Meuron architects, exploits a glazed façade divided at each floor into three horizontal bands of motorised top-hinged windows, designed to perform different functions. In particular, the upper 'daylighting' band consists of insulated prismatic glass automatically manoeuvred to follow the solar path. From the inside, they are essentially translucent, thereby inhibiting glare from the sky vault. In response to lighting levels detected by an internal photosensor, they can be adjusted perpendicular to the solar altitude to refract light directly inside[67].

Energy saving targets aside, in relation to the application of advanced lighting control systems, the design of the ABN AMRO Head Offices in Amsterdam (NL)[68], is able to satisfy two other very important requirements: firstly, that the occupants are continuously able to control their thermal and luminous environment; and secondly, that the technical installations can accommodate any changes to the layout of office space. To satisfy these requirements, the extremely flexible LONWorks platform – a widely adoptedopen-bus system used to build automated control applications – has been employed in conjunction with an HELIO lighting control system. With this equipment, the occupant can simply use a remote-control unit to select his or her personal preferences for lighting, temperature, setting of the sun-blinds and even the do-not-disturb sign over the office door. The HELIO sensor passes this information on to the LON that accordingly instructs all the individual building systems. Another important aspect critical to the performance of the ABN AMRO building and the productivity of the organisation is related to the fact that the company experiences frequent organisational changes, requiring constant adaptation of the office layout. With traditional vertical cabling methods, this would involve considerable time and money because internal walls would need to be moved and cabling re-routed. Thanks to the LONWork system, all modifications to the technical control network can be done using computer software rather than having to make changes to the physical layout because all comfort system connections are softwired.

In addition, the lighting installation at ABN AMRO is particularly energy efficient and offers optimal lighting control. The luminaries employ T5 tubular fluorescent lamps, specially designed with mirror optics to produce more uniform distribution of direct and the indirect light, and therefore increase user comfort when working on computers. The luminaries also ensure constant lighting levels on desktops due to a built-in light sensor, achieving a significant saving in energy.

63 Compagno A., *Intelligent Glass Façades – Material, Practice, Design*, Artemis Verlags – AG, Basel, 1995.
64 Fontoynont M. (edited by), *Daylight performance of buildings*, James & James, 1999.
65 Wigginton M., Harris J., *Intelligent Skins*, Architectural Press, Oxford, 2002.
66 Wigginton M., Harris J., *Intelligent Skins*, Architectural Press, Oxford, 2002.
67 Ibidem
68 Philips Lighting, "Fingertip comfort" – Automated control systems for ABN Ambro", in *International Lighting Review*, n. 01/2001.

CH_2 Design Features, Expected Performance and Operation

The Daylight Strategy

The CH_2 building has been designed as a world leader in ecologically sustainable design and commercial green building technologies. The initial Melbourne City Council brief called for 'a landmark building that (would) provide a healthy, stimulating workplace'. Most of the principles followed in CH_2 are not completely new, yet never before in Australia have they been integrated and pursued in such a comprehensive and inter-related way in a multi-storey office building.

The building was designed foremost to be comfortable and healthy for its occupants, whose physiology and experiential feelings have been regarded as key-factors in every single decision as it is recognised that an occupant's positive response to the indoor environment can contribute noticeably to their performance and hence the overall productivity of the organisation. The challenge of getting natural light into the building given its location and overshadowing by surrounding buildings was an issue. The simple rectilinear form has been dictated by the boundaries of the site, with the largest length oriented along the east and west axis to maximises northern solar access and daylight while minimising unwanted solar heat gain being absorbed by the buildings east and west façades. Nevertheless, the major drawbacks of exposing the façades to excessive sunlight have been pointed out, since the beginning, by the project team and their implications have been discussed earlier in this study.

One strategy to reduce these unwanted consequences, for the northern and southern façade, was to progressively widen the lower windows of the building, as more daylight is needed at lower levels due to reduced natural light availability in surrounding narrow city lanes. While optimising access to available natural light at different levels this strategy has other advantages, such as reducing the total amount of glass used and minimising energy losses, heat gain and glare risks. The narrowing window design strategy also combined synergistically with the variable size requirements of the ventilation air supply and exhaust ducts that are integrated into the north and south façade between the window panels. Progressively increasing the size of the windows at lower levels matched a reduction in the width (volume) of the ventilation ducts sizing requirements at lower levels. This nice match of design requirements occurs because the volume of air to be transported via the façade ducts through the roof top intakes and outlets is reduced with every air take off at each lower floor, decreasing progressively from the tenth level down to the first.

The glazing has been selected to achieve a visible light transmittance greater than 50 per cent, combined with a solar transmittance smaller than 35 per cent. 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[69]. Internal and external visible light reflectance are respectively <15 and <20 per cent, 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 powered by photovoltaic panels located on the roof and 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. The solution is a unique system of day light distribution that also synergise 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[70]. As Fontoynont suggests, this strategy results in a more uniform and indirect daylight distribution, while providing significant artificial light reductions[71].

Despite this extremely effective strategy, it must be pointed out that no more than a quarter of the total floor area will achieve a daylight factor[72] greater than 2 per cent due to the overshadowing from the surrounding buildings. Conversely, a detailed study has been simulated on each façade at different times of the day and the year (solstices and equinox) in order to define the areas of the façades which may require additional shading or may not receive enough natural light[73].

Based on the result of those simulations, some assumptions can be made. The eastern façade will be characterised in winter by a direct illumination occurring mainly on the upper floors during the last hours of the morning and the first few hours of the afternoon. In mid seasons (spring and fall), the façade will be directly lit on the top two floors between 11 and 12am, before the sun moves northerly. During summer the balconies at all levels will increasingly receive direct light from 6.45am to 9am, while after 9am, the façade will be totally lit until 11.45am. In the afternoon, the façade will be entirely in shadow.

69 DGU 6-19-6mm, clear Low-E glass solarplus.
70 In the case of CH2, the light shelf is designed as a horizontal combined (internal and external) device, a solution that, in general, is able to provide the best compromise between shading requirements and daylight distribution. IEA SHC Task 21, *Daylight in Buildings – A source book on daylighting systems and components*, LBNL, 2000.
71 Fontoynont M. (edited by), *Daylight performance of buildings*, James & James, 1999.
72 Defined as the ratio of the illuminance at a particular point within an enclosure to the simultaneous unobstructed outdoor horizontal illuminance under a standard (CIE) overcast sky.
73 Advanced Environmental Concepts, "Overshadowing & Shading Images of MCC", Melbourne City Council, March 2003.

Direct solar illumination will not be a concern for visual comfort since during the early hours of summer the building is expected to be only sparsely occupied, while the risk of solar overheating from early morning sun will be significantly less than for western orientation due to lower air temperatures. In addition, it is highly probable that direct light on the balconies during the morning could present opportunities for workers to relax and take a short break, which is important physiologically and psychologically.

With regard to the north façade, in winter, the eastern part of the elevation will be almost totally directly lit from 7.15am to 9am. However, even in this case, glare should not present a major risk of discomfort since during those hours the building is still unlikely to be heavily occupied, while direct solar penetration could provide some passive solar heating, particularly appreciated during clear, cold winter mornings. Top floors of the western part of the façade will be directly lit from 11am till 12.45pm and this direct illumination will cause glare due to a relatively low-angle winter sun unless shaded accordingly. The major concern for the north façade during winter seems to be overshadowing of a neighbouring building during morning hours, which could generate low levels of natural illumination in the office spaces (particularly at lower floors), and consequently greater energy consumption for artificial lighting. The top three floors and western part of the north façade will be increasingly directly lit during the afternoon. At this time of the day the relatively low north-western sun will probably increase daylight penetration in the office space, and a light shelf mounted on top of the windows will act as a shading device rather than a tool to redistribute light. However, on a clear and sunny winter day, the high luminance off the glazed surfaces and the light shelf may require a thorough masking by blinds mounted in the clerestory area, and in the later hours of the afternoon, by proposed vertically-shading timber louvers or evergreen vines.

In mid-seasons, the eastern part of the north façade receives direct sunlight from 6.30am to 9am. Again, this is not a concern in terms of quality of daylight since the building will not be heavily occupied at that time of the day. At 9am, almost the entire façade will be in shadow except for a small portion of the western part on the top two floors. Throughout the morning almost half of the façade will be lit by a comfortable high sun. At 3pm, three quarters of the façade will be day lit, and this portion will increase gradually until 5.30pm. During the last hours of the afternoon, there may be the risk of glare from a low western sun, although the presence of evergreen vines, together with blinds that have been designed to rise up from the floor to counter act NW sun in late afternoon, will reduce the risk of visual discomfort.

During summer, the northern façade will be increasingly lit by direct sunlight from 6.45am. From 9am to 10.45am there may be some glare due to the relatively low-angle eastern sun, even though this discomfort could be alleviated by the vines and may not be disturbing due to the positive physiological and psychological effects of morning light[74].

After 10.15am, some shadowing off the facing building may occur on the lower and central area of the façade, and this pattern of shadow will cover almost all of the eastern part of the northern façade until 2.30pm. From 2.30pm to 5pm, the façade will be entirely directly lit and good daylight penetration will be assured by the light shelf that maximizes its effectiveness when the sun is high on the horizon. In addition, the the presence of the balconies and the light shelf may provide sufficient means of masking direct glare along the perimeter. Some risks of glare may occur in the later part of the afternoon, from 5.15pm to 6.45pm, when the building will not be heavily occupied.

In terms of the west façade, the patterns of shadow are more straightforward due to the absence of major obstructions projecting shade over the building. In winter, the western façade is directly lit from 2pm until sunset (5.30pm), while, in summer, the façade receives direct illumination from 1pm. The risk of glare and overheating are significant but the presence of the intelligently-controlled timber louvers (whose control is based upon a six-hour open and close cycle) can minimise those drawbacks while simultaneously providing a dynamically changing pattern to the façade.

Finally, the southern façade during winter will receive diffuse light during the morning, with some direct illumination on the upper eastern part of the elevation between 8am and 10am (due to the slight easterly inclination of the site). This low-angle sun could potentially cause glare, however low winter temperatures justify the absence of devices or strategies to block this sun penetration since some passive solar heating may be provided. Again, the presence of warm sunlight during the morning, even when it comes with slight visual discomfort, is likely to be tolerated from the occupants because of its physical, physiological and psychological benefits. During the rest of the day, the façade will be in shadow, although the upper floors will receive some indirect glare reflected off the adjacent Victoria Hotel.

During summer months, the façade will receive direct light in the first hours of the day but glare will not be an issue since direct illumination will occur when the building is largely unoccupied. However, there is the risk of excessive solar heating in the early morning that could counteract the night-time ventilation strategy adopted during summer nights. During the rest of the day, the façade will receive reflected diffuse light off the fronting building and will receive direct illumination on the upper levels after 5.15pm, when the building will not be extensively occupied.

In mid-seasons, the patterns of light and shadow will follow the same schedule, with less risk of glare and solar heating in the early mornings and late afternoons because of the (respectively) more easterly and westerly position of the sun at sunrise and sunset.

74 See footnote n.13.

Glare Control and Vertical Gardens

Shading devices to control sun intrusiveness and reduce visual discomfort will be used on north, east and west façades of the CH_2 building. These devices will consist of vertical gardens, perforated metal light shelves and vertically-shading/pivoting timber louvres.

In order to assess the potential for glare at CH_2, a series of studies and simulations have been conducted using the *Daylight Glare Index* to measure visual comfort. In terms of glare control, the adopted lighting strategy and design aims to avoid instances of *intolerable glare* (25<DGI<28), and minimise the potential occurrence of *uncomfortable glare* (DGI<25) in office areas.

The preliminary studies, the results of which are described in a series of reports by Advanced Environmental Concepts (AEC), indicate that reflections off the Victoria Hotel may represent a significant *uncomfortable* visual source of glare, affecting the narrower field of vision (90°) as well as the peripheral one, particularly during the middle of the day in mid-seasons and summer. In addition, some *intolerable* glare at certain view angles may also occur. With these issues in mind, it must be pointed out that the south façade has been designed with no fixed or movable shading devices to mask the glazing, however, columns of plant leafs in the window mullions have been experimented with by the design team. This practical experiment seems to show that the presence of the leaves helps break up the sharp edges of high contrast, which helps the eyes to adjust. Specifically, glare is expected to be worse at the upper levels than at the lower ones due to a greater penetration of reflected daylight.

However, the choice of decreasing the size of the glazed surface with the height of the building represents a favourable strategy in relation to glare problems. Based on these simulations, glare off the south façade is supposed to be *acceptable* (DGI<19) during the early morning and late afternoon in all seasons[75]. On the north façade, glare is likely to be relatively low and generally in the *acceptable* range although 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 western sun.

However, it is probable that once partitions, task lighting, accent lighting and workstations are in place their presence will limit the amount of potential periphery glare, as suggested in the Australian Standard 1680.2.2-1994[77].

To decrease the risk of *intolerable glare* on the north façade, steel trellises and balconies, supporting a series of vertical gardens that run the full height of the building alongside the windows, will filter light entering office spaces and form a 'green' microclimate. The 3-4m vines will be grown in specially designed boxes situated to the east and west of each balcony on every storey via stainless steel mesh stretching from the ground to the roof[78]. As already pointed out, the presence of the vines will clearly increase visual comfort for users, both in terms of glare reduction and the positive physiological effect of having a 'green' visual outlook. Further shading on the north façade will be provided by balconies and the light shelves that will block high-angle sun penetration during summer, while redistributing incoming radiation deeper in the space. At the same time, the internal upward rolling retractable blinds[79] located at the level of the light shelf and the manually-adjustable vertically sliding timber screen at the window line will guarantee the required protection from horizontal light intrusiveness during winter months and in the late hours of the afternoon, while maintaining an unrestricted view at eye-level[80].

Finally, since curved surfaces typical of CRT monitors and reflective glass screens can increase the level of glare and veiling reflection, brighter flat TFT screens have been chosen for CH_2 to enhance visual comfort, maximise the use of space and reduce internal heat loads.

Artificial Lighting Strategy

The CH_2 building is characterised by a deep open plan. A consequence of this building type, forced by the limitations of the small CBD site 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 is designed as a two-component scheme: a low-energy background lighting component (provided as part of the base building design) and a separate individual task lighting component (part of the fit-out), giving users more control over their luminous environment.

75 Advanced Environmental Concepts, "Glare Study", Melbourne City Council, August 2003.
76 Advanced Environmental Concepts, "Glare Study", Melbourne City Council, August 2003.
77 Concerning the design of furniture and screen-based workstations, the AS standard 1680.2.2-1994, *Interior Lighting-Part. 2.2: Office and screen-based tasks*, recommends that "the use of workstations which are partially surrounded by medium-height partition screens requires special attention by the lighting designer (directions and orientations of SBE screens, shadows, reduction of illuminance, etc.). However, such partition screens can have a beneficial effect on reducing discomfort glare and, possibly, veiling reflections. Workstations areas are therefore most suited to local lighting systems in conjunction with a relatively low level of general lighting (as environmental lighting) for the circulation spaces and non-critical task areas."
78 The boxes will be filled with a particularly soil additive, Fytogen Flakes, that acts like large water crystals, storing a reasonable amount of water and air to be released upon need. Part of the water recycled from the sewer mining plant will be used to water those "vertical gardens". Within each planter box, a sub-irrigation system will be installed, able to function as a toilet cistern; when the crystals dry out and the available water is used up, the device refills the planter box until required. This system, together with the crystals, provides the ideal wet-and-dry cycle, without any water wastage or need for manual watering. See Melbourne City Council documentation.
79 Remotely-operable upside down blind, 80% selected fabric, connected to timer for daily return.
80 In this regard, approximately 75% of the office floor plate will be less than 8 meters from the façade guaranteeing to all the occupants a direct access to external views.

Ecological, economical and psychological issues (as well as culture considerations) have been factored into the light system design to achieve the proposed objectives and to provide an optimum level of lighting for movement, security, and occupant activities. A number of different artificial lighting solutions have been simulated to obtain the minimum required ambient lighting level on the floor (160 lux) as uniformly as possible, while limiting any potential glare impacts from the light fittings[81].

The background ambient lighting supplied by T5 fluorescent lamps provides a low illuminance (160 lux ambient lighting; 70 per cent wattage emitted to the office space, 30 per cent emitted to the ceiling), while the individually controlled lamps at workstations provide up to 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 per cent. To achieve an optimal distribution of light, materials and finishes have been chosen with an overall reflectance of 30 per cent for the carpet, 50 per cent for the walls, and 70-80 per cent for the ceiling and desktops. All of these choices are in accordance with the parameters suggested in Australian Standard 1680.1-1990[82].

The adopted artificial lighting system includes sensors that continuously monitor the amount of direct and diffuse daylight entering 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 artificial lighting system flexibly provides a number of separated switched zones per office floor that are no greater than 100m^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 chosen fluorescent T5 fittings incorporating high frequency dimmable electronic ballasts and individual task lighting (10W compact fluorescent) for workstations will offer a significant reduction in energy consumption[83] with T5 lamps widely accepted as far more efficient and longer lasting than conventional T8 lamps[84]. T5 lamps actually benefit is its optical efficiency when compared to conventional T8s due to their smaller diameter, even though they have the disadvantage of higher surface brightness, which can be a potential source of glare, however this has been accounted for in the design of CH_2 and has been discussed earlier. The savings for this configuration has been calculated to be equivalent to a reduction of around 65% when compared to the energy consumed by the current Council house building lighting system. Overall the lighting energy load, as a proportion of the buildings total base load, is estimated to be 1.37 per cent.

In terms of control strategies, one security light will be located at each lift/lobby area and switched on from 12pm to 6am. In all the other areas light fittings will be switched off during that period of time. One push button control panel will be located at each end of the office area in front of the lifts with three different operational modes: *normal* (8am to 6pm, providing an ambient lighting level of 160 lux), *security* (6pm to 8am, two security light fittings will be switched on) and *cleaner* (6am to 8am, providing an ambient lighting of 160 lux for two hours). The presence of different lighting strategies according to the functions taking place in the building will assure optimum energy management.

From 6am to 8am, all the office lighting will be switched on, but dimmed to achieve an internal lighting level of 80 lux. From 8am to 6pm, during office hours, lighting levels will be automatically set to achieve an ambient level of 160 lux, with the photosensors detecting the availability and distribution of daylight and accordingly controlling the dimmable electronic ballasts. When daylight provides more than 160 lux, all the lights will be switched off. After office hours, the daylight sensors will be inactive.

To optimise 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 user 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. Local light fittings will automatically be set at 160 lux of ambient lighting once the computer screen has been turned off. An employee who works after 6pm can use his PC control (or the push button control panel) to indicate longer working hours and adjust the lighting level as required[86].

Potential Implementation and Opportunities

There were a number of opportunities, requiring more complex technologies than windows and light-shelves, available for CH_2 to harvest additional natural light and direct it for use within the building. Meticulous investigation was undertaken by the design team in an attempt to improve the daylight factor of the building, especially at lower floor levels, where daylight distribution systems such as a *light pipe, fibre optics, prismatic shafts*, or an *heliobus* system were investigated for their feasibility for channelling sunlight from the roof and redistributing it to internal spaces. However, these alternative strategies were found to have major drawbacks especially in terms of practical issues (i.e. the openness of the space arrangement and costs)[87].

81 Actually, glare requires more careful control in an environment where the ambient lighting level is intentionally kept relatively low. From Advanced Environmental Concepts, "Artificial Lighting Study", June 2003, and Advanced Environmental Concepts, "Lighting Simulation Report", Melbourne City Council, July 2003.
82 As per AS 1680.1-1990, Clauses 3.3.4., 3.3.5 and 6.2.
83 Lighting power density has been estimated of being less than 2.5 Watts/m2 per 100 lux on façade area.
84 Wu Kwok-tin M., T5 lamps and luminaries, The 3rd generation in office lighting, web source.
85 Wu Kwok-tin M., T5 lamps and luminaries, The 3rd generation in office lighting, web source.
86 From Advanced Environmental Concept Lighting reports.
87 Advanced Environmental Concept, "Natural Light Opportunities", Melbourne City Council, June 2003.

One of the main problems in implementing the adopted design, 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 daylight especially at the lower floors during winter. In this case, the low sun together with the overshadowing from adjacent buildings, dramatically reduces the availability of natural light, a concern that is relevant both 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 dramatically reduced when 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[88].

Potential improvements, although requiring additional costs, to the proposed design could have occurred by putting in place light re-directing devices on the northern façade (mounted in the clerestory area) that could have complemented the effectiveness of the light shelf; examples of those devices can be found in *louvers, highly reflective movable blinds, prismatic panels, laser-cut panels*, and *anidolic ceilings*[89]. However, after careful consideration, none of these improvements were thought to provide significant benefits to the adopted design.

Louvres and *venetian blinds* are 'classic' daylighting systems that can be applied to redirect external daylight deeper into the rooms. These systems are generally composed of evenly-spaced, horizontal, vertical or sloping slats, and highly sophisticated shapes and surface finishes. Fixed systems are usually designed for solar shading, while movable devices can operate optimally according to outdoor conditions. Louvers are generally made of galvanized steel, anodized or painted aluminium or plastic (PVC) for improved durability and reduced maintenance, while venetian blinds are usually composed of small or medium-sized PVC or painted aluminium slats that are either flat or curved. Slat size varies with the location of the blind (exterior, interior or between the glass panes in a DGU unit). Some light-directing devices include perforations and concave curvature in order to reflect the maximum possible amount of light to the ceiling while having a very low brightness at angles below the horizontal[90].

Movable blinds can be operated either manually or automatically, the latter option are preferable for energy efficiency and to optimize the penetration of visible light according to daily and seasonal variations in solar positions. However, with automated systems, an over-ride capability via a remote-control device would almost always be required by tenants to increase satisfaction. Manually-operated systems, on the other hand, are usually less-energy efficient because occupants do not generally continuously optimise their position[91].

As a range of studies suggest[92], if adopted in clerestory areas that do not influence the perception of the external environment, highly-reflective, automatically adjusted Venetian blinds can improve daylight availability and distribution, enhancing the satisfaction and productivity of workers and result in significant cost and energy savings[93].

Another element that could have been installed in the clerestory area of CH_2 is a device called a *prismatic* or *laser-cut panel* to enhance the penetration of diffuse skylight deeper in the floorplate.

A *prismatic panel* is generally composed of a thin, planar, saw tooth device consisting of an array of clear acrylic (PMMA) prisms with one surface of each prism forming a plane; some panels may be partially coated with an aluminium film with high specular reflectance[94]. The system can be designed to reflect light coming from a certain angle while transmitting light coming from others. Refraction and total internal reflection (according to the critical angle of the panel) can be used to change the direction of the light beams, depending on the angle of incidence and the index of refraction of the material used.

A *laser-cut panel* is a daylight-redirecting system composed of a thin clear acrylic material divided by laser cut into an array of rectangular elements; the surface of each laser cut becomes a small internal mirror that deflects light passing through the panel. A laser-cut device strongly deflects light coming from higher elevations (>30°), while transmitting light at a near-normal incidence with little disturbance, thus maintaining external view. Light is deflected in each element of the panel by refraction, then by total internal reflection, and then by refraction again. In general, the panels are cut at an angle perpendicular to the external surfaces, but it is possible to make the cuts at a different angle for added control over the direction of the deflected light[95].

88 Comparing a light shelf solution to a standard window, with an overcast sky, daylight decreases at perimeter but is sustained at the core of the floorplate; with a clear sky and low direct sun (winter), there may be an enhancement of the internal illuminance over the entire room depth; with a clear sky and high sun (summer), there is an enhancement of the internal illuminance but only close to the perimeter for the case of a conventional light shelf. Fontoynont M. (edited by), *Daylight performance of buildings*, James & James, 1999.
89 Beltran L.O., Lee E.S., Selkowitz S.E., "Advanced Optical Daylighting Systems: Light Shelves and Light Pipes", in *Proceedings of the 1996 IESNA Annual Conference, Cleveland*, 1996.
90 IEA SHC Task 21, Daylight in Buildings – A source book on daylighting systems and components, LBNL, 2000.
91 Lee E.S., et. al., "Active Load Management with Advanced Window Wall Systems: Research and Industry Perspectives", in *Proceedings from the ACEEE 2002 Summer Study on Energy Efficiency in Buildings*, Asilomar, Agosto 2002.
92 Lee E.S., Di Bartolomeo D.L., Vine E.L, Selkowitz S.E., "Integrated Performance of an Automated Venetian Blind/Electric Lighting System in a Full-Scale Private Office", in *Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings* VII, Florida, December 1998.
93 Lee E.S., et. al., "Active Load Management with Advanced Window Wall Systems: Research and Industry Perspectives", in *Proceedings from the ACEEE 2002 Summer Study on Energy Efficiency in Buildings*, Asilomar, August 2002.
94 IEA SHC Task 21, Daylight in Buildings – A source book on daylighting systems and components, LBNL, 2000.
95 Ibidem.

Although these devices can provide some benefits to a lighting strategy, it should be pointed out that light shelves, louvers, reflective blinds, prismatic and laser-cut panels perform at their optimum under direct light conditions, a situation unlikely to occur at CH_2, especially during winter months. The CH_2 design team have considered this in their simulations of direct sunlight over the whole year and found that the installation of light shelves are justified on the basis that they also perform the function of shades to reduce heat gain and glare caused by direct sunlight penetration. The light shelves duel function, shading and light reflection, which may only address problems of heat gain or glare for one hour a day by operating as a shade, it will significantly reduce the likelihood of occupants drawing a blind, which is then likely to remain closed for the remainder of the day and lead to a large proportion of the days natural light gain potential being lost.

Other technical solutions for exploiting the diffuse light coming from the sky vault, include *light-guiding shade* or an *anidolic system* located in the clerestory area.

A *light-guiding shade* is composed of a diffusing glass aperture and two reflectors designed to redirect intercepted diffuse light within a specified angular range. In general, highly reflective material such as bright-finish aluminium can be used for the device's inner surfaces. All daylight that enters the light-guiding shade is directed over the ceiling, which means the shade becomes a source of diffuse light completely free of glare when viewed by occupants. As a consequence, the light-guiding shade could have been considered as an alternative solution to the light-shelf, since it is a fixed device installed over the upper third of the window, totally shading the glazed surface from direct sun penetration.

Finally, an *anidolic ceiling* consists of daylight-collecting, non-imaging optics coupled to a specular light duct which transports the light to the back of a room. The system exploits the optical properties of compound parabolic concentrators made of anodized aluminium surfaces and placed on both ends of a light duct to collect diffuse light from the upper area of the sky vault. In particular, on the outside of the building, an anidolic optical concentrator captures and concentrates diffuse light and efficiently introduces those rays into the light duct, where, at its aperture in the back of the room, a parabolic reflector distributes the light, avoiding reflections[96]. In CH_2, the use of such a system would have required adequate suspended ceiling space to exploit its potential to the full. It would also have been inappropriate if coupled with the vaulted roof, which plays an important role in terms of ventilation. However, a potential solution using similar technology may exist, such as *anidolic solar blinds* placed in the clerestory areas on top of the light shelves. These blinds (at present in the prototype stage) consist of a grid of hollow reflective elements, each of which is composed of two three-dimensional compound parabolic concentrators.

The portions of the blind that emit light are designed to direct daylight into the upper quadrant of the room towards the ceiling[97].

Considering all of the above, since the poor availability of daylight at lower levels in winter may not be counteracted without major practical (or visual) drawbacks, it may be advisable to locate employees whose work is generally done in a team in those areas. Through interaction with their colleagues these employees should get the necessary environmental stimulation they require that cannot be provided by the dynamic pattern of natural illumination[98].

Concerning the south façade, as reported earlier, one of the major issues with regard to visual comfort is due to the presence of glare reflected off the Victoria Hotel Building to the south, which creates high visual contrast in the field of view of the occupant, and thus with out accent lighting has the potential to significantly decreases the quality of the luminous environment. Of the various implementations investigated by the consultants Advanced Environmental Concepts (AEC), 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 internal wall finishes. Even though the additional economic and environmental cost of providing such additional lighting may not be compensated by a relatively marginal improvement in luminous comfort it is well worth countering glare in this way as it can often save energy overall by reducing the tendency of people to draw blinds and thus losing all the benefits of available natural light.

An alternative solution could be the installation of vertical gardens on the south façade, possibly using plants that do not need 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 most likely be accepted by occupants since glare problems would probably be fairly constant at certain times of the day. Likewise the continuous availability of a view would not be a major concern due to the proximity of adjacent buildings and a roller blind would also increase the sense of privacy. A further, simple (but not necessarily less effective), potential response could be the installation of flexible visual tasks, as for example by mounting the 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.

It is worth noting that this southern façade glare issue has been exceptionally difficult to respond to within the limitations of the buildings design. Also, similar glare conditions are currently experienced by staff occupying the City of Melbourne's existing adjacent office building.

96 Ibidem.
97 Ibidem.
98 See footnote n. 18.

Proper resolution of this issue indicates that a response at the urban design level is required, where urban design requirements have the potential to make consideration for the reflective properties of the facades of buildings and their potential negative impact in the urban environment, such as creating glare issues for adjacent buildings. For example, one design response would be to change the existing yellow colour of the adjacent Victoria Hotel building to a darker less highly light reflective finish or to suspend planter boxes on this light rich northern façade to support the growth of plants that naturally have low reflective properties.

In terms of future opportunities, the use of advanced chromogenic glazing technologies such as *gasochromic* or *electrochromic* devices, if thoroughly implemented with lighting control strategy, may be able to reduce indirect glare off the adjacent reflective façade, while keeping visual link with the external environment, a key-issue that is fundamental both ergonomically and physio-psychologically[99]. An important feature of such devices as part of a lighting strategy is the possibility of being linked to an automated control system so as to provide the desired interior illuminance over a wide range of exterior lighting conditions[100]. Those technologies, while already available on the market, have not yet been applied to large multi-storey buildings, even though they show enormous potential in terms of energy saving and occupant comfort[101,102].

Conclusion

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

There are many lessons to be learnt from CH_2. Some of these include the need to foresee and control future development of neighbouring buildings in order to develop strategies to counteract the effects on solar access and its consequences on luminous environments (overshadowing, reflections, indirect glare, 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 a passive collection of distinct parts. This is the only way to guarantee optimum comfort for all occupants, both in perceptive and energetic terms, while also creating a pleasant place to live and work[103].

99 Electrochromic and gasochromic glazing are multilayer thin-films glazing units that can be controlled via a low voltage signal or the inflation of a gas mixture to switch reversibly and continuously from a clear, high-transmission state, to a dark low-transmission colour to control solar heat gain, light levels and glare. Altomonte S., "The Architectural Integration of Switchable Devices in Daylight Control Strategies", in *Proceedings of the 2003 CISBAT Conference*, Lausanne, 2003.
100 Selkowitz S.E., Lee E.S., "Advanced Fenestration Systems for Improved Daylight Performance", in *Daylighting '98 Conference Proceedings*, Ottawa, 1998.
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