ENERGY EFFICIENT PROTOTYPE CLASSROOM DESIGN FOR SYDNEY, AUSTRALIA

by

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This report has been approved on the date shown below:

Fred S. Matter — 15 Dec. 98

Fred S. Matter, Professor — Date

Director of Graduate Program

Dedication

To my Family, who have been through so much, these are the good times,

To my committee, Fred Matter, Susan Moody and Larry Medlin, thank you for your support,

To all the faculty, staff and students at the U of A, College of Architecture, thank you for making these three years memorable,

And especially to my friends....

Introduction

Few dispute the effects of mankind's dependence on energy derived from fossil fuels.

As we consume these non-renewable energy sources we are wrecking havoc on the environment in which we live. The combustion of fossil fuels generates by-products that are grouped under the label of "greenhouse gases". These gases are now being produced at such a rate they are affecting the air we breathe and the atmosphere that protects our fragile planet.

The effects of these gases are manifold: they deplete the ozone layer whilst producing a global warming situation, as the sun's energy is trapped within the earth's atmosphere. The ozone layer protects the earth from galactic radiation and it's depletion leaves the earth vulnerable. Global warming increases the incidence of drought, reduces the earth's ability to produce food and melts the polar ice caps.

Australia is particularly vulnerable to these effects. As a country blessed with abundant natural resources and large reserves of coal, oil and natural gas, it is heavily dependent upon these resources for the generation of energy.Although other ecological problems are assailing the planet, greenhouse gas emission is possibly the most potentially devastating for Australia.

Australia is the driest continent in the world with two thirds of the country classified as arid or semi-arid. Drought is the most prevalent natural disaster, and although the land area of Australia is equivalent to that of the continental United States of America, it is at present only able to sustain a population equivalent to approximately 7%. Most of the 18 million people who live in Australia do so within the fertile coastal band.

The environmental picture is bleak: a hole has formed in the ozone layer off the south coast of Australia; 1998 was declared the hottest year on record; the polar ice caps are retreating at an increasing rate; and droughts and bush fires are increasing in frequency and duration.

In response to this perceived disaster, Australia has led the world in alternate energy source research. Study into the use of solar energy, in particular, has been intense over the last thirty to forty years, with much of this research focused on developing energy efficient housing. Housing has been considered the most important target for energy reduction due to its prevalence as a building type and due to the wishes of many individuals who want to make a difference.

The scale of most housing is conducive to energy efficient techniques. Generally, the building type is small in scale and low rise, and is usually occupied by a family, comprising a small group of related individuals. There is also a direct connection between energy usage and the financial cost of the energy used, so even if ecological concerns are not paramount, cost savings are a strong inducement to reduce energy usage.

Energy efficiency has not been as rigorously or as thoroughly studied in other building types, although this is changing. There is a growing base of information concerning the translation of results developed in housing into other building types.

Schools are a case in point. A school classroom is comparable in scale to most residential developments, being small in scale, compartmentalized, often detached and low rise. However, it does not have a comparable function or occupancy.

A classroom functions as a place where children can be educated, where they will learn to read, write and explore their world. It is vital that this space is one in which they feel comfortable, safe and happy. The occupancy of an average classroom is a teacher and thirty to thirty five students. This can be a disparate group, coming from a wide range of backgrounds.

In translating the advances made in energy efficient residential design to a classroom situation, attention needs to be given to the differences in function and occupancy.

The effects of even small reductions in energy use at an individual classroom level can be dramatic when considered at a national level. This is a situation where the adage "every little bit counts" is most applicable.

Schools are significant consumers of energy. They operate almost year round and are occupied for a large part of the day. A breakdown of the sources of energy usage point to lighting, at 50%, and heating and cooling, at 30%, as being the biggest energy consumers. This report focuses on methods of reducing the consumption of energy produced through the combustion of non-renewable resources.

The logical premise for this report was provided by the bioclimatic equation as proposed by Szokolay[1] and applied to the situation in Sydney, that:

Given Conditions - Comfort Conditions = Required Controls

The bioclimatic equation presents the relationship between the existing climate, the human occupants of a space and the strategies that can be deployed to offset any incompatibilities in this situation.

The first variable in the bioclimatic equation is the Given Condition. This encompasses conditions, both cultural and physical, that influence the building being studied.

Culturally, Sydney is the biggest city in Australia, with a population of 4 million people. It is located on the South East coast of the continent in the state of New South Wales. It is a metropolitan city with a diverse population encompassing many different cultures. From its beginnings as a British penal colony in 1788 it has flourished into an international city.

Climatically, Sydney is positioned within the temperate coastal zone protected to the West by the Blue Mountains, a section of the Great Diving Range, and to the East by the Pacific Ocean. Overall, the climate is not a severe one, although it does, at times, rate outside the human thermal comfort range.

The second variable in the equation is the Comfort Condition. This variable needs to be defined for both the visual and thermal environment.

The comfort conditions within a classroom do not vary widely from those that exist within a house, or any other occupied space. The human body, although resilient, does not have a large tolerance for climatic variation and in order for the body to perform at its most efficient, these conditions narrow even further. This applies to both the visual and the thermal environment.

The product of the equation are the Required Controls, and it is in relation to these controls that energy efficient strategies are developed.

This report presents some possible strategies to employ in the fight to at least slow down our societies head long plunge into environmental annihilation.

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[1] Szokolay, p329.

The Australian Education System

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Australia has had an organized "western" education system from the time of white settlement, 210 years ago. From its beginning, as a means of instilling morality into the young members of a penal colony, it has progressed to a system providing a bewildering array of educational opportunities for all children between the ages of 4 and 16. The system consists of a hierarchy of school levels; young children aged 4 to 8 attend Infants School, those aged 8 to 12 attend Primary School, and those aged 12 to 16 attend High School. Further education is available on an elective basis until the age of 18, when entrance into a University or other tertiary institution is often undertaken.

A wide range of schools are available. State (Public) schools are available at all levels, as are private schools, run by denominational and secular agencies, the majority of these are operated by the Catholic Church. All schools are eligible to receive state funding but must be registered in order to do so. Eligibility for registration depends on the school fulfilling State designed syllabus requirements.

This chapter provides an historical perspective of education in Australia. It also looks in some detail at the substantial reforms to education methods which have influenced the physical layout and design of classrooms.

History of Education in Australia

When education was first established in colonial Australia, a system referred to as the Traditional Individual method was used. All the students attending a school shared a classroom, often a room in the school master's house. The children were expected to study silently at their desks, except for the three or four periods in the day when they would be called to the teacher's desk for individual attention. Due to its intensive one-on-one nature this system could only operate while schools were small.

The next system of organized classroom instruction was the Lancastrian Monitorial System. This was first introduced in Sydney in 1811, having been developed by Joseph Lancaster, a Quaker, in 1798. Students still shared a single classroom or hall, but sat in rows of about ten according to their academic level. A monitor was appointed to each row. A single school master was responsible for explaining the learning process to the monitors, who then explained it to the students. This system allowed schools to become considerably larger. At this time teaching aids, in the form of maps and wall charts, began to appear, and the reward and punishment system became formalized.

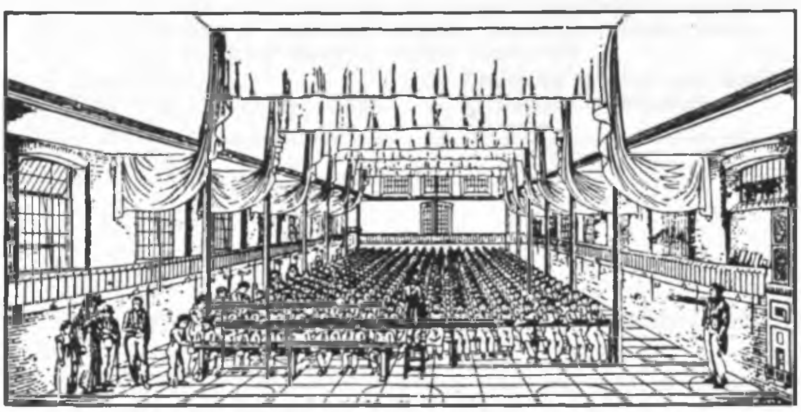
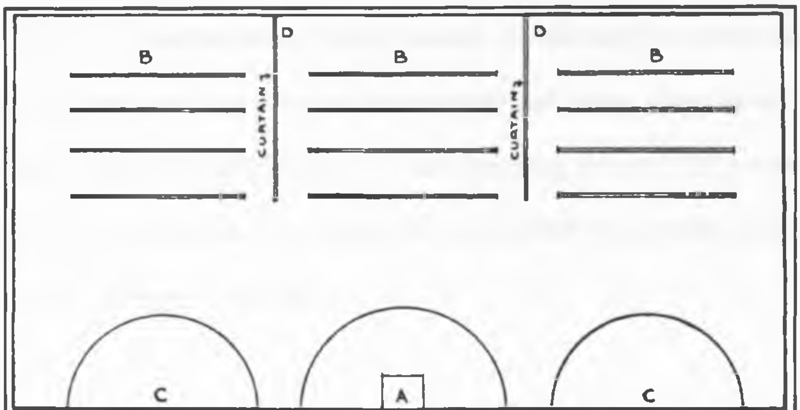


Figure 2.1: Lancastrian Monitorial System[1]

In 1797, a rival monitorial system was developed by Dr. Andrew Bell, an Anglican clergyman, and this eventually appeared in Sydney schools in 1820. Based on the Anglican Church catechism, less emphasis was placed on reward and punishment, with promotion to a higher grade being considered ample reward. The number of students per monitor was also increased to twenty five.

In 1851, 'Pupil-Teacher' classes became popular. This system utilized apprentice, or pupil, teachers in the classroom. All classes took place in one large classroom sub-divided into smaller sections and students were divided into classes according to academic level. The school master worked with one class at a time, while the remaining classes were attended to by a pupil-teacher, who was supervised by the school master at all times.



Sketch of schoolroom illustrating tripartite monitorial system in use in the denominational schools about 1850.

A. Teacher's desk.
B. Desks and Forms for three divisions.
C. Drafts for hearing oral work by teachers or monitors.
D. Curtains.

Figure 2.2: Pupil-Teacher class layout[2]

All of these systems were evident in New South Wales schools during the years to 1906, when a new 'Probationary Student' system, with its more formalized approach to teacher training was introduced. The Probationary Student system was in use in New South Wales from 1906 to 1913. The basic procedure was similar to that of the pupil-teacher system, but had more formal state intervention. Trainee, or probationary, teachers had to pass an examination to gain entrance to the newly established Teaching Colleges, and the examination could be attempted only after two years of experience had been gained.

Changes to this system occurred in 1913, when the education system adopted the ideas and methodologies of J. F. Herbart. Under his system individual teachers conducted separate classes, and were required to receive training at a Teaching College prior to becoming responsible for a class.

During the early 1970's a new system of "open education" gained support in some Australian States. There initially was some confusion about the true meaning of 'open', with some exponents believing it meant an 'open-minded' approach to education, while others believed it referred to an 'open school', involving the community at large. The third expression of this concept was the development of 'open classrooms', where multiple classes were taught in a single space. Team teaching became the norm in such situations, classrooms were often clustered together and different projects were undertaken by individuals or groups of students.

The system currently used in New South Wales schools is a combination of the above. Some topics and subjects are taught by an individual teacher in a single, separate classroom, while others are team taught in joint classrooms, using a more classic 'open' method.

Current Educational Theories

Australian education has been influenced by many factors, including the need to balance the educational aims of individuals with those of society; the curriculum required to supply a liberal education and that desired for a vocational education; and the formal and informal pedagogical methods of teaching.

Bassett et al[3] used a classification system proposed by Kneller to organize current theories on education. The terms perennialism, essentialism, progressivism, reconstructionism and existentialism are used to differentiate between educational aims.

Perennialism emphasizes traditional intellectual values considered to have a universal and permanent character. The major disciplines are considered the most important and a knowledge of them is the basis for a liberal education.

Essentialism considers as essential knowledge pertaining to an individuals ability to cope with his/her duties as a citizen. The method of teaching specific subjects derives from the logic inherent in the subject, rather than from a study of the psychological needs of children.

Reconstructionism is socially oriented, and views education as having a role in bringing about social change. Supporters of this theory are wary of education becoming simply indoctrination.

Progressivism, which has its roots in Europe, places its focus on the student, and stresses the need to deal with each student as an individual. Problem solving and interest in the subject are seen as essential ingredients for learning, the key concept being that education is the continual reconstruction of experience. This theory has its greatest following in the United States.

By contrast, existentialism, which also focuses on the individual, is largely a European theory which seeks to counter the utilitarian nature of our age. Knowledge is considered to have a definable nature, needing to be experienced directly in order to be learnt. This theory is often encountered in fields outside education, such as literature and religion. Current Australian theory is an eclectic mix of all the above doctrines, as no one theory can encompass all the facets of education.

Current Influences on Education

When considering current influences on education it is necessary to consider the influence of society itself. These influences can be divided into three categories: political; economic; and sociological.

Politically, society has a need to raise children to be responsible adults with an understanding of, and the skills necessary to partake in, a democratic society. Political intervention and influence in education is two pronged in Australia, because of the federal system of government. In New South Wales, the Federal (Commonwealth) Government, and the New South Wales (State) Government both have jurisdiction.

Traditionally education is a state responsibility, but in an attempt to equalize the systems operating nation wide, the Federal Government has become more involved, particularly in the tertiary area.

Economically, Australia is a prosperous country, and there is a belief that the country can offer a high level of education to the nations children. Consequently free, compulsory education is provided to all children to the age of 16.

Australia's prosperity has resulted in a trend towards vocationalism, and students are expected eventually to be able to take their place in the work force, as productive members of society. A growing shift in Australia's employment pattern over the last fifty years has seen a progression beyond rural production to industrial production as the primary source of national income, and then to the post industrial phase, where workers are required to be able to interact with consumers in a service situation.

Sociological patterns and needs are probably the most changeable and far reaching influences on education. As a colonized nation, Australia is a country of immigrants. Historically, most immigrants to Australia were European. However, the ethnic background of immigrants has changed in recent years, and now the majority are Asian. In 1947, a mere 2% of children attending school were born in a non-English speaking country. By 1971 this figure was 11%. It is now estimated that one child in seven comes from a home where English is not spoken as the primary language[4].

Equality of opportunity is one of the most dearly held maxims within Australian society, and one of the hardest needs to satisfy. Efforts to equalize educational opportunities run into the reality of the isolation of country students, the disparity between the States with regards to funding, and the disparity between State and Non-State schools with regards to the quality of the education being provided.

The other significant sociological influence is that of the family. More and more families are unwilling or unable to provide the support the educational system needs, as families become more fragmented children must learn to deal with different types of home life. It is becoming essential for schools to respond to the changes occurring within the day-to-day life of the students.

Evolution of the Modern Classroom

Space usage in modern primary school classrooms is radically different from that seen in the traditional classrooms discussed earlier. In the traditional classroom "instruction"[5] was emphasized. The teacher stood at the front of the room and student's desks were arranged facing the teacher. Aisles between the desks allowed for student access, but more importantly facilitated the teacher's supervisory role[6]. There was little contact with the outside world, as it was considered irrelevant to formalized education.

The modern classroom has evolved from this rigid model, due to the changing role of the teacher, a more active role required of students and a departure from a rigid curriculum[7].

The classroom environment is now significantly more flexible with moveable tables and chairs, and although the teacher has a desk, sometimes all the students will be taught as a group or children will be working individually or in small groups on selected activities.

Floor space has been cleared and now provides space for group activities. Equipment is stored in specialized alcoves. Connections to the outside world are encouraged and children will often leave the classroom to access shared school facilities, such as art rooms, and to interact with the wider community.

The ultimate expression of this modern classroom is the 'Open School', where the entire school is a large interconnected space. A more conservative system involves individual classrooms that have the ability to become larger communal spaces, depending on the needs of the subjects being studied. Where once classrooms formed a series of anonymous doors along a corridor, emphasis is now placed on integrating all classrooms into a wider school community.

Space usage in a modern primary school is a result of a series of decisions, both philosophical and pragmatic in nature. Initially the decision must be made as to the educational philosophy of the school. This directly influences the styles of teaching that will be supported. The pragmatic decisions that flow from this revolve around issues of curriculum (see Appendix A), school and class organization and class timetabling (see Appendix B). All these issues will influence each other and affect how a class will be conducted and how it will interact with the space in which it exists.

The more pragmatic issues of space usage relate initially to the physical facilities that are available. Many schools are housed in buildings that were originally designed at a time when educational methods were very different to what they are today. These physical restrictions are often difficult to overcome and can have a significant influence on space usage. Within these limits though, variation is possible.

Endnotes

[1] Barcan, p17.
[2] Barcan, p109.
[3] Bassett
[4] Bassett, p9.
[5] Bassett, p207.
[6] Bassett, p207.
[7] Bassett, p208.

ENVIRONMENTAL DATA AND CLASSIFICATION

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This chapter addresses the first component of the bioclimatic design equation.

In order to undertake a bioclimatic analysis of a given location, existing climatic conditions need to be determined. Once these have been established, they can be analyzed to formulate an overview of the action needed to be taken to achieve thermal and visual comfort. The data that follows includes the lighting variables of cloudiness, occurrence of sky type, and illuminance levels, and the thermal climatic variables of air temperature, precipitation, humidity, wind and insolation.

Lighting Data

Cloudiness and Sky Type

The figure below (Fig. 3.01) graphs the cloudiness of Sydney skies. The mean monthly cloud cover values, taken twice daily, provide an indication of the amount of cloud cover present in the sky. These values are measured in eighths, or octas, of the total sky vault. It is apparent that Sydney experiences partly cloudy skies year round with, on average, about half of the sky vault being covered. There is some seasonal variance, with maximum cloud coverage being apparent in early autumn (March and April) and minimum cloud coverage occurring in late winter (August).

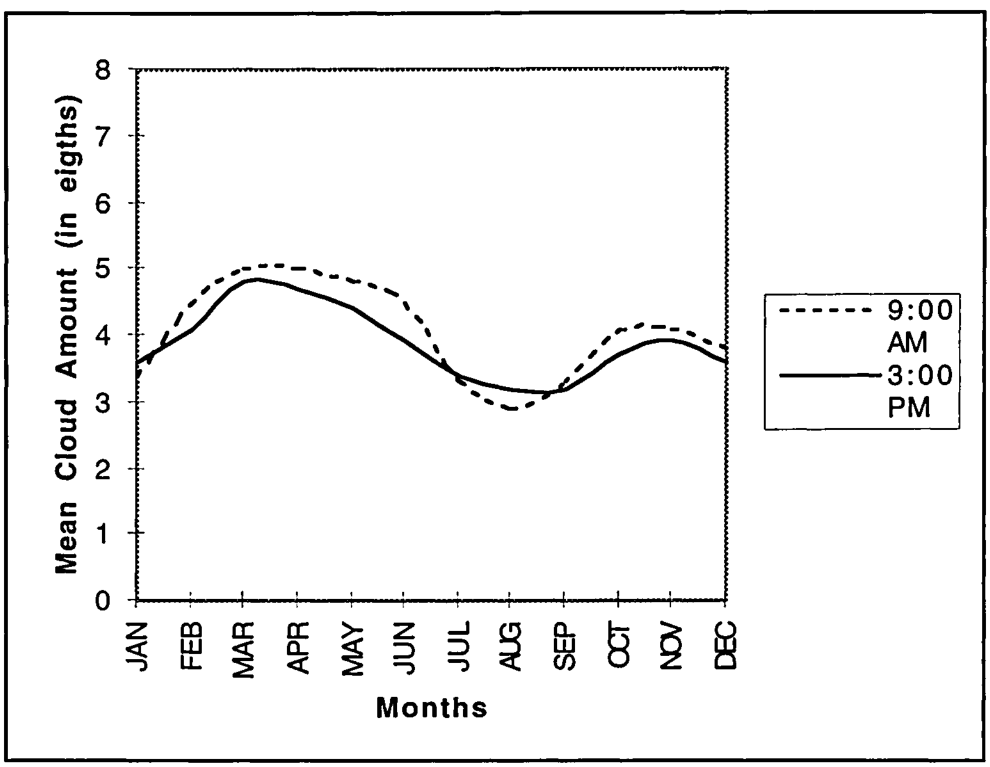

Figure 3.01: Cloudiness of Sydney skies[1]

The bar chart below (Fig. 3.02) displays the frequency of occurrence of specific sky types. This data relates directly to the preceding cloud cover data, but provides a more accurate indication of the mean percentage of the month that the sky will be clear, the percentage it will be partly cloudy, and the percentage it will be overcast, or cloudy. There is not a lot of annual variation in sky conditions. Clear skies occur roughly 10-15% of the month, although this jumps to 25-30% in late winter (July, August). Cloudy skies occur for about 10-20% of the month, year round.

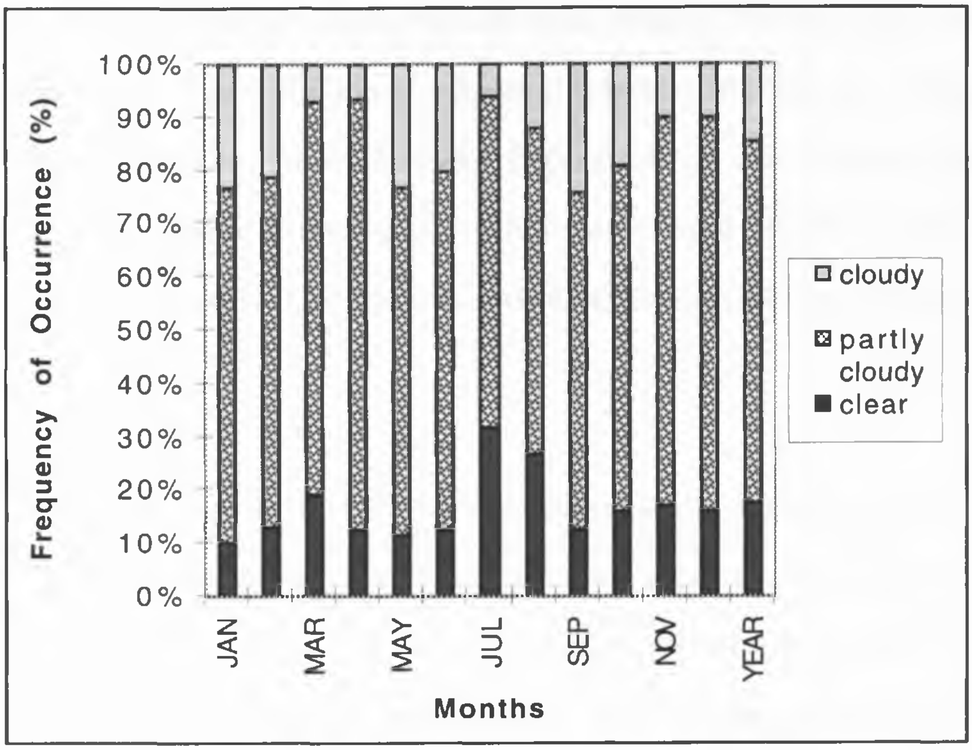

Figure 3.02: Occurrence of specific sky types[2]

Illuminance Levels

The following figures indicate the horizontal illuminance levels experienced in Sydney. Illuminance is the density of luminous flux incident on a surface[3]. This data is presented in two forms. The first set of figures show daily values. The next set show annual values as a percentage of the working year.

The first set (Fig. 3.03, 3.04, 3.05) display the illuminance levels under the three sky types (clear, partly cloudy and cloudy) for specific dates during the year. Figure 3.03 is the Spring Solstice, March 21st, Figure 3.04 is the Winter Equinox, June 21st, and Figure 3.05 is the Summer Equinox, December 21st. These three figures, when considered together, give a comprehensive indication of the conditions experienced throughout the year.

The second set (Fig. 3.06, 3.07) plot horizontal illuminance levels as a percentage of the working year. These values are used in daylighting design as they allow a value to be derived that will supply a specified illuminance level for a specified percentage of the working year. For the purpose of these charts the work day was taken as 9:00 am to 17:00 pm. Figure 3.06 displays the annual average, while Figure 3.07 shows the data according to sky type.

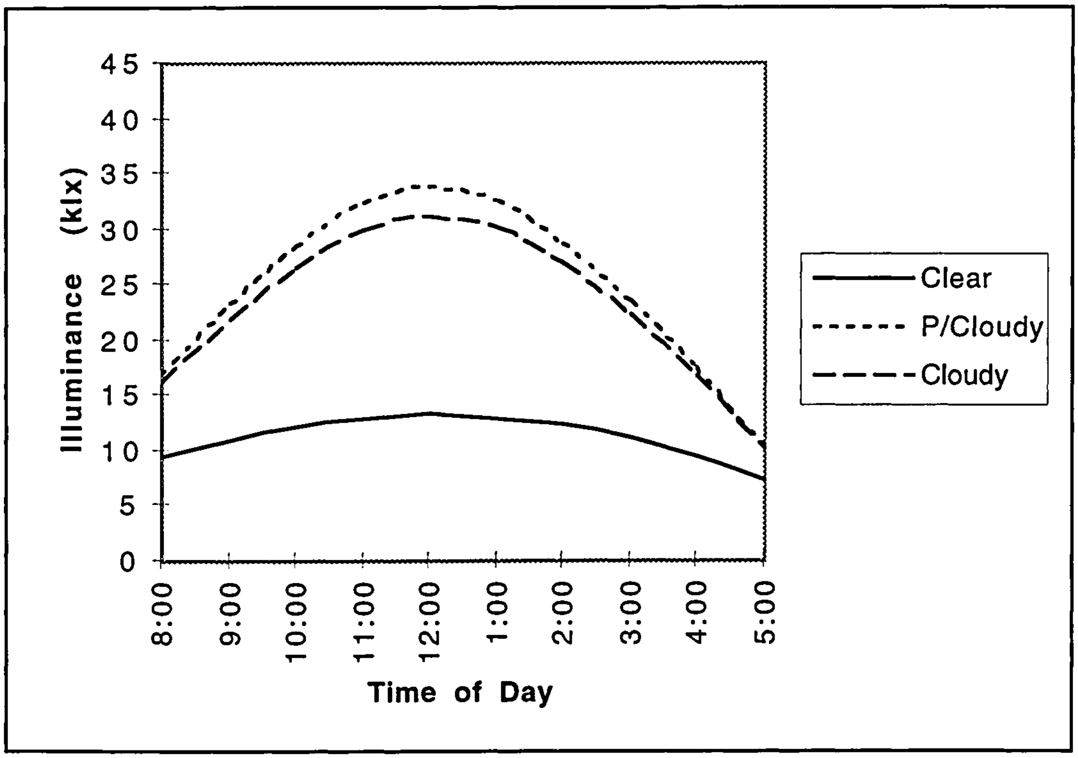

Figure 3.03: Illumination levels : March 21st[4]

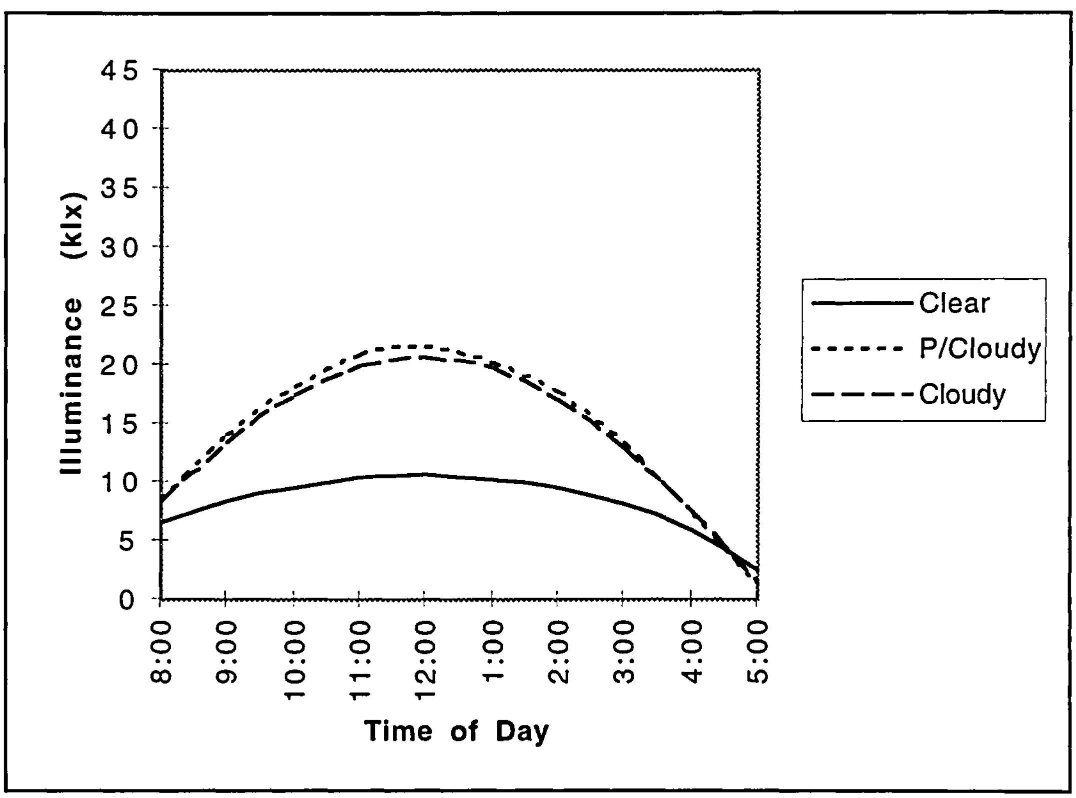

Figure 3.04: Illuminance levels : June 21st[5]

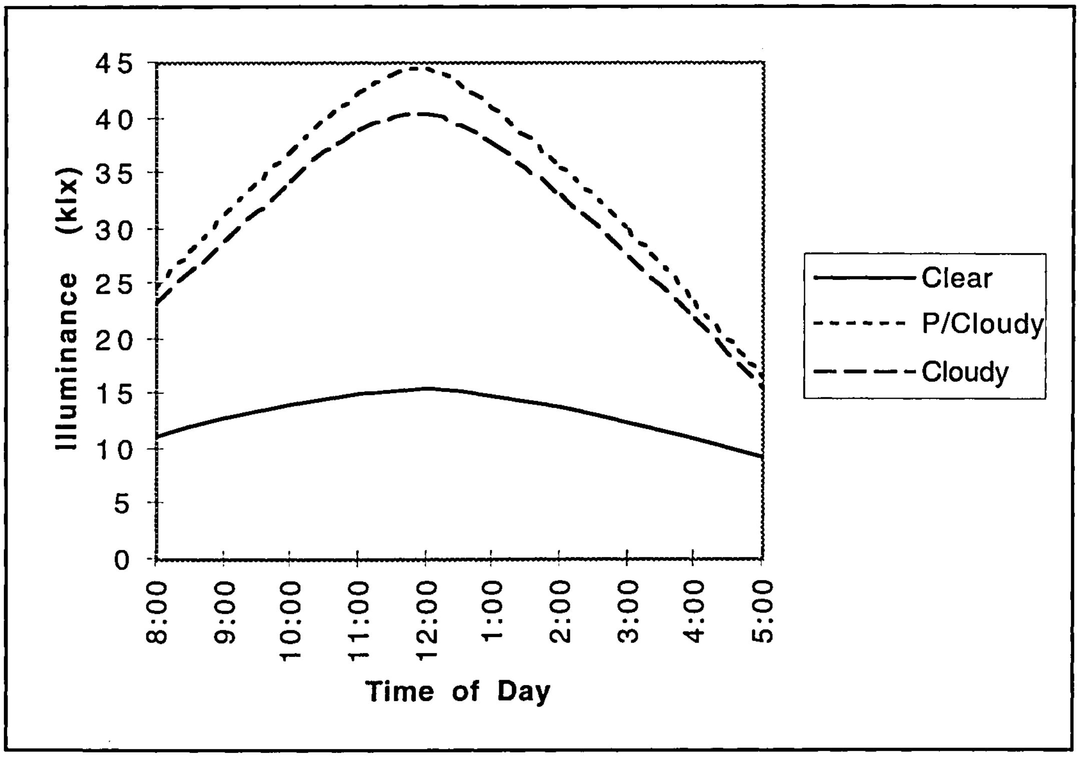

Figure 3.05: Illuminance levels: December 21st[6]

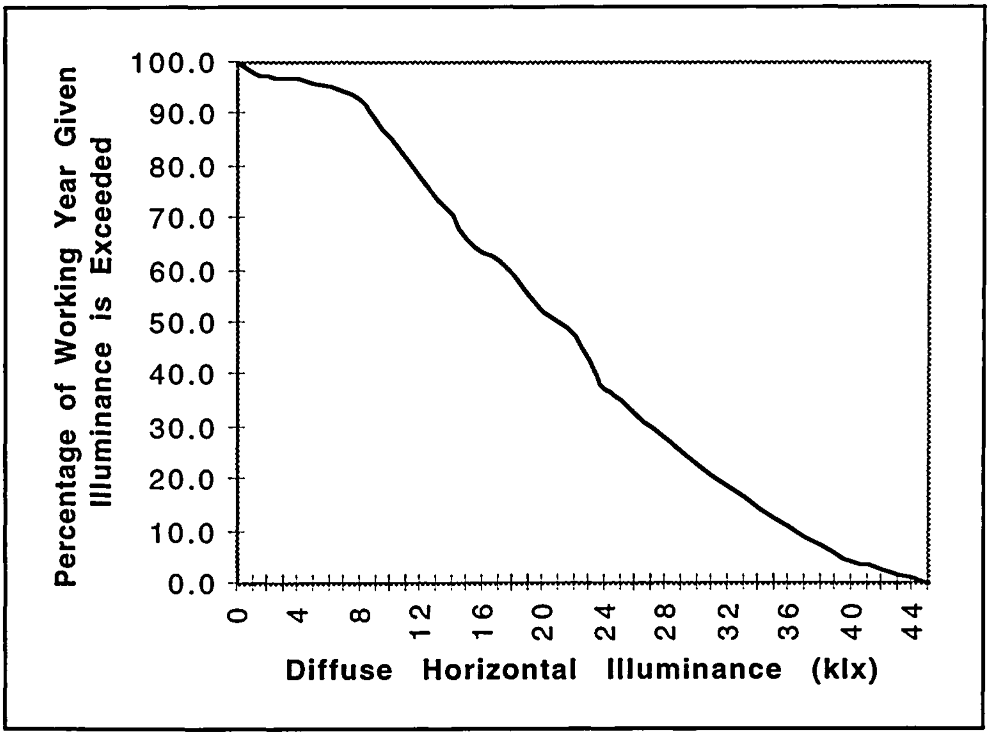

Figure 3.06: Horizontal illuminance levels: % of work year[8]

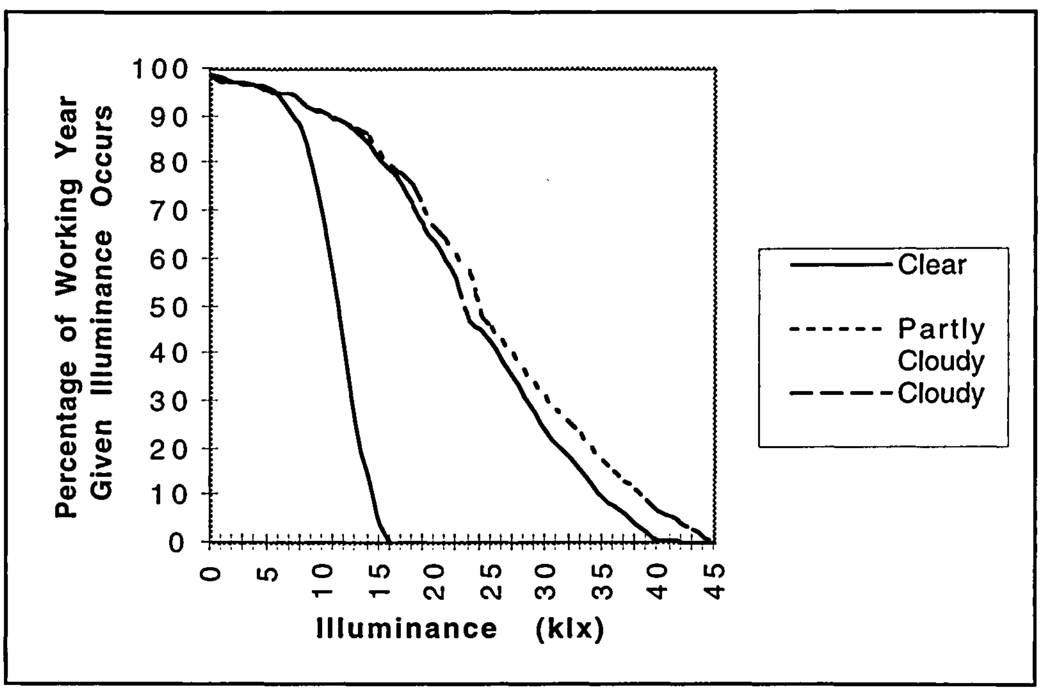

Figure 3.07: Horizontal illuminance levels: according to sky type[7]

Luminous Environment Classification

The sky as a light source is infinitely variable, as evidenced by the data presented. In order to investigate daylighting strategies it is necessary to decide upon a design sky, which will specify luminance distribution, and a luminance level to be used for calculations. The values chosen need to fulfill two criteria: the sky type needs to occur often enough at the site location to be a valid choice; and the luminance level needs to result in a relatively low level of indoor illumination, usually the code minimum. The reason for these restrictions is so that the daylighting values calculated from this design sky are exceeded for the greater part of the time[9].

The design sky chosen for Sydney is a International Commission on Illumination (CIE) overcast sky. This condition occurs often enough to be valid and is the most adverse of the conditions that prevail at this location[10]. The data presented in relation to sky type (Fig. 3.02) indicates that a partly cloudy sky would be a more obvious choice but a standard for this type of sky has not been established[11], so the standard CIE overcast sky is used.

The distribution pattern for an overcast sky was established by the CIE in 1955. It was defined as a sky where all points have a luminance equal to:

$1/3\ L_{90}\ (1 + 2 \sin x)$ where L_{90} = zenith luminance.

In reality the value used for L_{90} is the illuminance produced by the sky on a horizontal plane exposed to the whole of the sky and x = angle of altitude.

Even though an overcast sky condition has been selected for design purposes, other possible situations should be considered. Two other conditions that are likely are a clear sky with less than 30% cloud cover and a cloudy sky with between 30% and 80% cloud cover. The distribution pattern of these skies will differ from that of the overcast sky.

The luminance value for Sydney is set at 8500 lux[12]. The Experimental Building Station[13] (EBS) follows Dresler and Brentwood in setting a lux value that results in daylighting being sufficient to provide the required lighting levels, unaided, for 90% of the working year. This correlates with the data presented relating to illumination levels as a percentage of the working year (Fig. 3.06).

For daylighting calculations the effect of the sun is disregarded, this is due to the fact that as a light source the sun has serious drawbacks. The variability of direction and the intensity of the resulting light, which results in sharp shadows and high contrast, is detrimental to most visual tasks. Generally sunlight should never fall upon a task plane and windows should not be sunlit.

Thermal Data

Air Temperature

The figure below (Fig. 3.08) shows the maximum, minimum and mean monthly temperatures experienced in Sydney. Maximum summer temperatures usually exceed 25°C. Corresponding minimum temperatures average about 18°C. In winter the maximum temperatures reach approximately 17.5°C, with minimums dropping to approximately 9°C. The diurnal (daily) swing is on average about 10°C, with the annual swing also being about 10°C. The extremes experienced can result in temperatures of over 35°C during summer, and just above 0°C in winter. The coastal location of Sydney has a moderating effect on its temperatures.

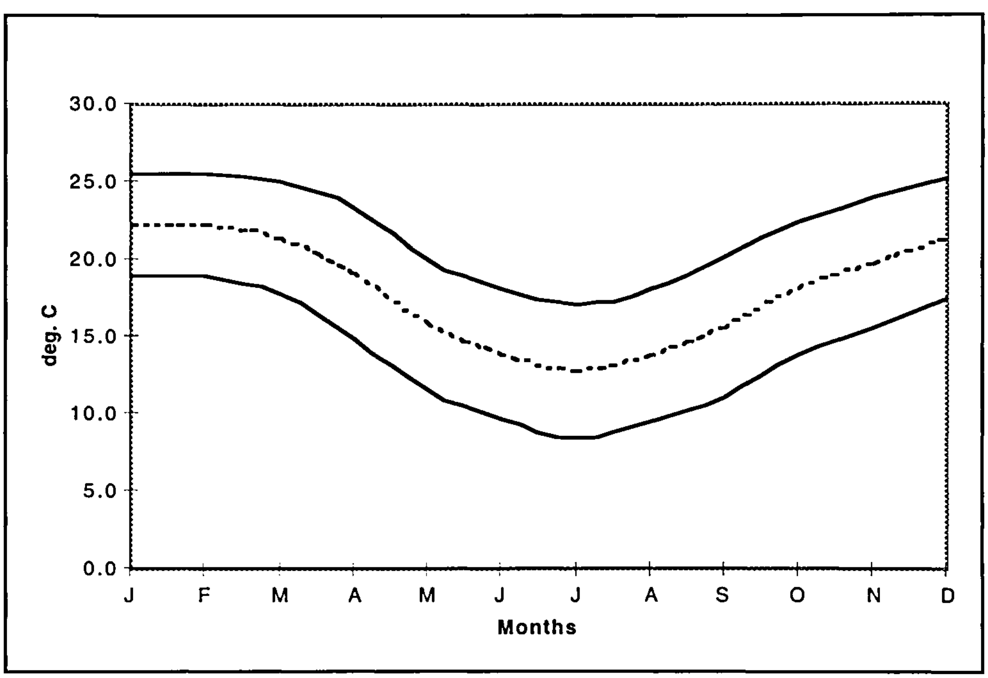

Figure 3.08: Air Temperatures[14]

Precipitation

The chart below (Fig. 3.09) displays the average monthly precipitation received in Sydney. Rainfall occurs year round, with a 60 mm difference between the maximum and minimum monthly values. The highest rainfall is recorded during the autumn months of March, April and May, with the lowest values being recorded during the spring months of August, September and October. There is a significant difference in the nature of the rainfall received during the year, summer rain is accompanied by fierce storms generated by high temperatures and is torrential. In winter the rain is gentler but prolonged.

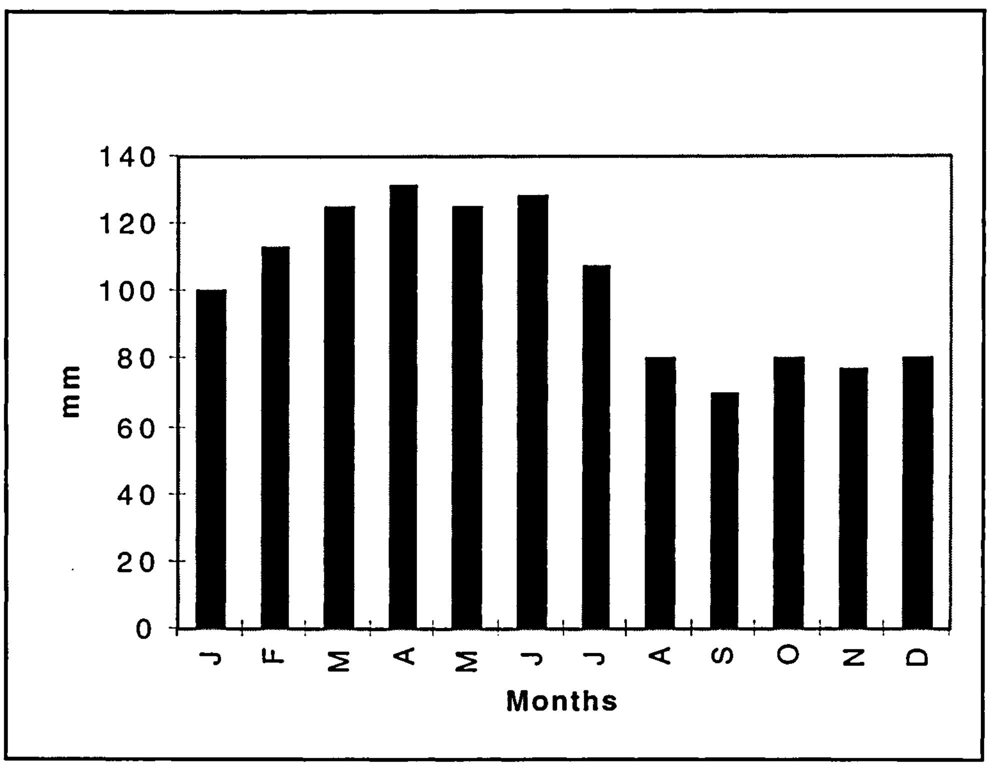

Figure 3.09: Rainfall[15]

Humidity

The figure below (Fig. 3.10) charts the average morning and evening humidity levels for Sydney, on a monthly basis. As indicated, morning humidity levels are higher than evening levels, on average by 5% in summer, and up to 15% in winter. The humidity level does not range widely throughout the year. There is no distinct season of extremely high humidity, nor is there a season of very low humidity, this is due partly to Sydney's coastal location.

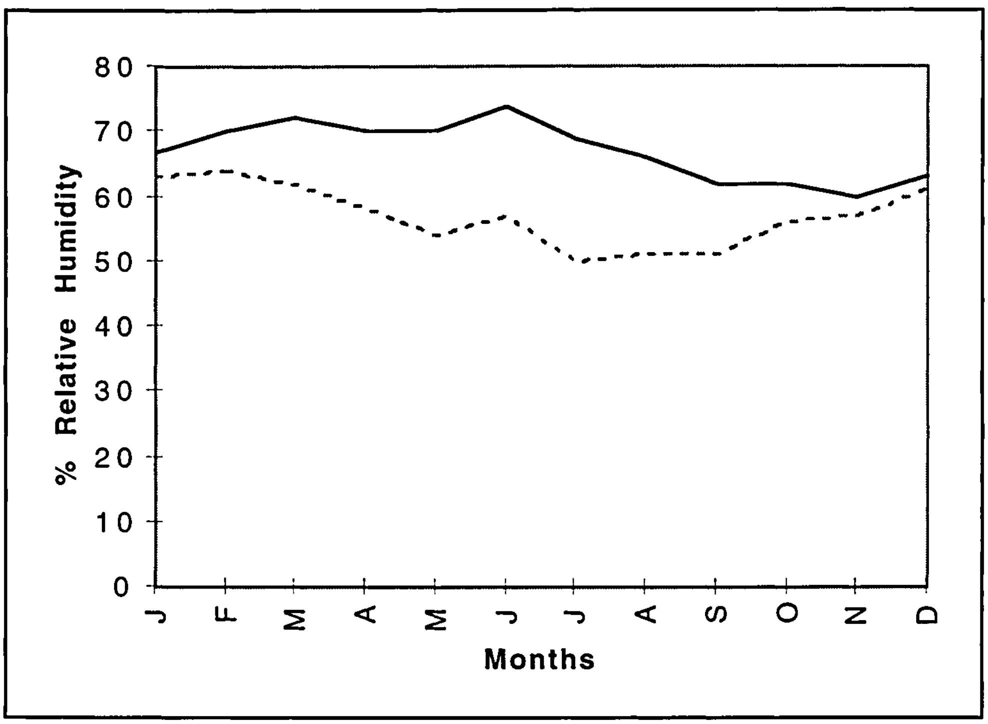

Figure 3.10: Humidity[16]

Wind

The wind roses below (Fig. 3.11) indicate the strength, direction and frequency of winds in Sydney. In summer the predominant winds are from the East. These are sea breezes and are most welcome when they occur on the afternoon of a particularly hot day. The worst winds during this season are the "Westerlies", coming off the overheated inland, they are scorching hot and exacerbate already hot conditions. In winter the predominant wind direction is from the West, these are still reasonably warm, even at this time, and moderate the cooler temperatures of this season.

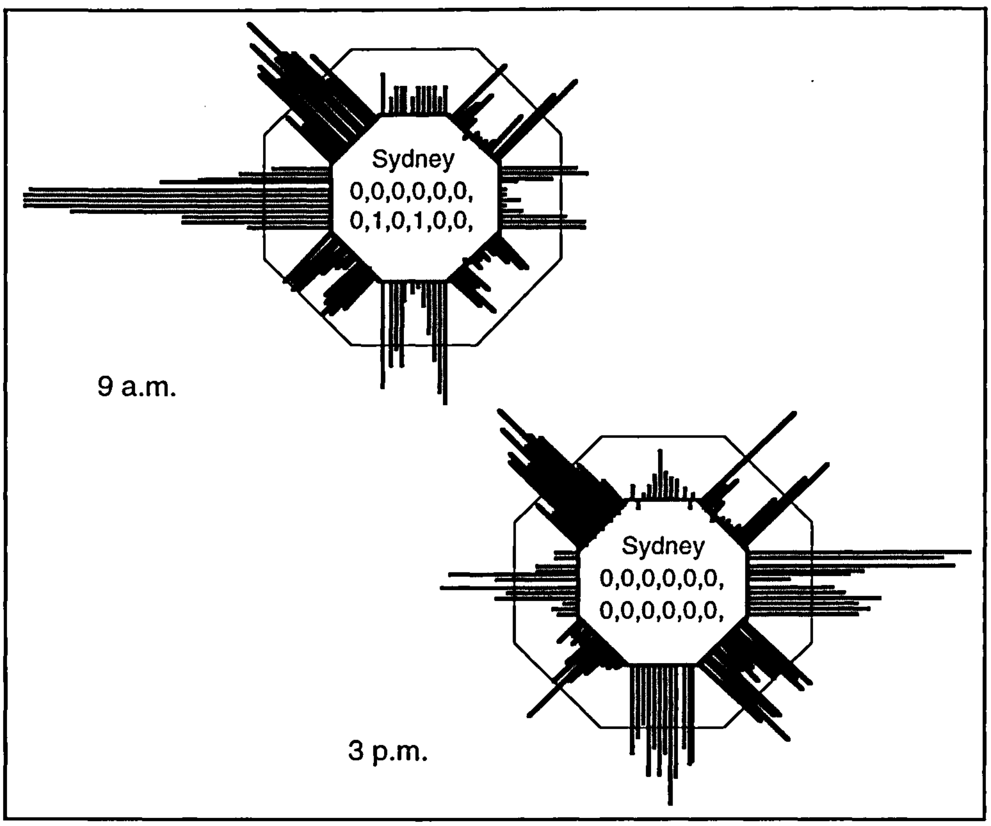

Figure 3.11: Wind Roses[17]

Insolation

The chart below (Fig. 3.12) displays the insolation that falls on both a horizontal surface and a vertical surface facing North. These values represent the total solar radiation striking a surface. This radiation is comprised of three components: direct radiation from the sun; diffuse radiation from the sky; and reflected radiation from the ground and surrounding buildings[18].

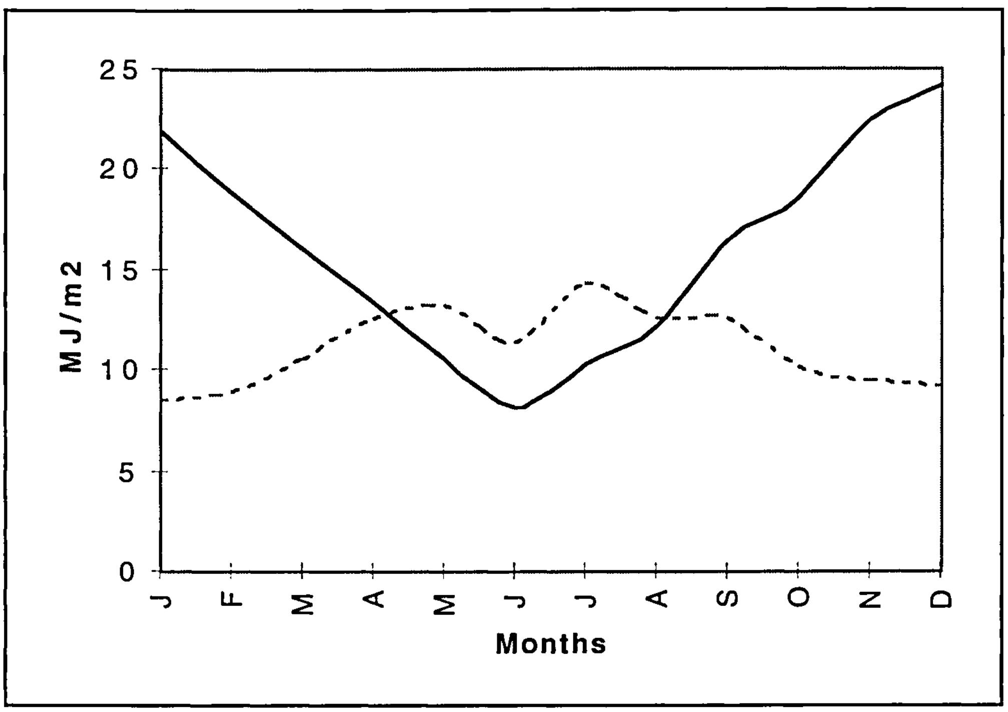

Figure 3.12: Insolation[19]

Climatic Classification

Climatic classification allows climates to be grouped according to specific variables. Numerous systems of classification have been developed in an attempt to categorize "the almost unlimited combinations of climatic factors acting on an almost infinite variety of topography"[20]. Trewartha believes this is done so as to create order from "bewildering multiplicity"[21]. Having labeled specific climate types, it is possible to generate commonalties.

An early system of classification divided the world into five zones. The first zone was the Tropical Zone, bounded by the Tropic of Cancer (23.5 ° North), and the Tropic of Capricorn (23.5° South), these boundaries are the seasonal limit of the sun's vertical rays. The next two zones, labeled Temperate, occur between the tropics and the Arctic and Antarctic Circles (66.5° North and South), these boundaries define the limits of the sun's tangential rays. The final two zones are the Polar Zones, covering the remaining earth surface[22]. These categories are defined by genetic boundaries. They are based on solar illumination, which is a cause of climate. Precipitation was not a governing variable and this results in a system that is too generalized.

Climates can be categorized by genetic or causative factors and by empirical or observable effect. Neither approach when used exclusively can give an accurate and complete view of the variety possible[23]. Trewartha puts forward the belief that a system that combines the two approaches would be the most accurate and useful. However, he also states that the empirical should always dominate, for the genetic approach can only supply generalized patterns[24] . There have been a number of classification systems developed that attempt to combine genetic and empirical approaches.

The most widely accepted of these systems was developed by Köppen and has undergone substantial development since it first appeared in 1901. It is fundamentally an empirical classification, because the climatic types and governing boundaries are generated by observed features of temperature and precipitation and are not constrained in order to fit within a genetic pattern. However, many of the types do coincide with certain broad-scale features of atmospheric circulation, which is a genetic determinant[25].

Trewartha has further refined this system[26]. Temperature and precipitation are the two primary climatic variables, with five of the six climatic groups being defined thermally, and the sixth being defined by aridity. These groups are:

Based on temperature criteria:

A. **Tropical**

C. **Subtropical**

D. **Temperate**

E. **Boreal**

F. **Polar**

Based on precipitation criteria:

B. **Dry**

Within these primary groups there are a series of sub groups, which usually provide further divisions based on distribution of rainfall[27].

The climatic symbols used in the Trewartha climatic classification system are listed in the Appendix (Appendix C). These symbols are defined by specific physical conditions. Included in this appendix are the conditions governing the boundaries between the zones.

A comparison has been created to classify the climate of Sydney into a specific zone, this comparison is tabulated in the Appendix (Appendix D).

Sydney, is placed in zone Cf(a), according to Trewartha's system, this indicates it is within the subtropical humid zone, it experiences no distinct dry season and has hot summers.

Having defined a climatic classification it is possible to investigate the broad effects of climate on building design.

There will be microclimatic variations applicable to specific sites. The factors that will result in variation include the topography, the surface (ground) condition and the surrounding three dimensional objects. These issues need to be considered site by site, as every situation will be different.

Endnotes

[1] Ruck, 1985, p20.
[2] Ruck, 1985, p20.
[3] Ander, p222.
[4] Ruck, 1985, p37.
[5] Ruck, 1985, p37.
[6] Ruck, 1985, p37.
[7] Ruck, 1985, p42.
[8] Ruck, 1985, p10.
[9] Paix, p4.
[10] Paix, p4.
[11] Ruck, 1985, p19.
[12] Paix, p5.
[13] Paix, p5.
[14] DA•SketchPAD2.0, www.arch.utas.edu.au
[15] DA•SketchPAD2.0, www.arch.utas.edu.au
[16] DA•SketchPAD2.0, www.arch.utas.edu.au
[17] Szokolay, 1987, p19.
[18] Givoni, 1976, p38-39
[19] DA•SketchPAD2.0, www.arch.utas.edu.au
[20] Miller, p78.
[21] Trewartha, p238.
[22] Trewartha, p238.
[23] Trewartha, p242.
[24] Trewartha, p242.
[25] Trewartha, p245.
[26] Trewartha, p250-251.
[27] Trewartha, p250.

Visual Environmental Requirements

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The visual environment differs from the thermal in that vision is more than a physiological response to stimuli. Vision occurs when the brain interprets images the eye is viewing. In the thermal environment the body reacts as an organic organism, the brain does not instruct the body to feel hot or cold, it is a physical manifestation of surrounding conditions. In the visual environment, the external environment is filtered, the brain compensates for, and adjusts, what the eyes see.

Objectives of a lighting system

The objectives of a lighting system must be primarily to provide for the safety of the occupants of the space, and to "facilitate the performance of visual tasks"[1], and "aid the creation of an appropriate visual environment"[2].

In determining what constitutes comfort conditions in relation to the visual environment, it is necessary to consider the three interrelated components of the observer, the task and the lit space. The observer is who sees, the task is what is seen, and the lit space supports the seeing. Comfort when applied to the visual environment can more correctly be considered the minimizing of discomfort. To provide an optimum situation in which to perform visual tasks, it is necessary to eliminate or at least minimize circumstances that can distract from the primary visual task.

The Observer

How the eye sees

The mechanism of sight is a complex one, involving both the eyes and the brain. Lechner uses the analogy of the "video camera of a robot"[3] to explain the way in which the eye sees and the brain interprets visual stimuli.

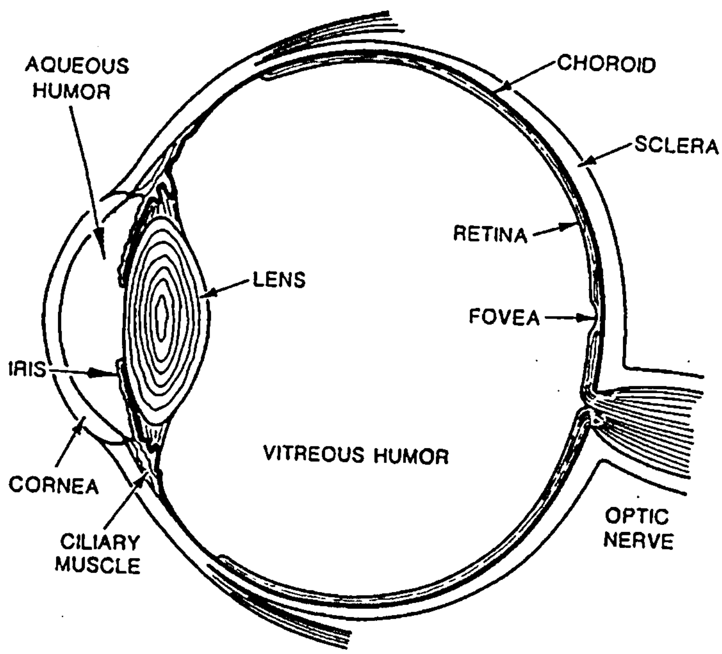

Figure 4.01: Cutaway view of the human eye[4]

In order to see, light must pass through the lens of the eye and strike the light sensitive retina at the back of the eye. Mechanisms exist within the eye to control how much light enters the eye and the focusing of this light on the retina. The pupil acts as an aperture control, with the iris contracting and expanding depending upon the prevailing lighting conditions. In very bright light the pupil contracts, limiting light access, whilst in dark conditions the pupil expands, maximizing light infiltration. Focusing of light on the retina occurs by way of manipulation of the shape of the lens, due to muscle contraction. The retina is the light sensitive section of the eye that generates electrical signals that are then transmitted to the brain for analysis.

Two types of nerve endings generate signals to the brain, namely rods and cones. Rods are highly sensitive to the quantity of light present, and are utilized in low light situations. They do not perceive color. Cones are the corollary, they operate most effectively at normal light levels, and they see color. The differences in these receptors accounts for the difference in nighttime, or scotopic, vision and daytime, or photopic, vision.

A further adaptation of the eye occurs due to the brain increasing and decreasing the quantity of photo chemicals in the eye. With increased quantities of chemical the eye becomes super sensitized to light and as the light levels increase the quantity of chemical is reduced, resulting in de-sensitizing of the eye. Maximum quantities of the chemical can be realized over the space of thirty minutes after entering a dark environment, the reversal of this procedure requires about three minutes[5]. These changes occur in addition to the physical changes occurring related to the size of the pupil. All of this explains the ability of the eye to adapt to a wide range of brightness.

The other physical component of vision is the brain. Once the eye has received the light, and transformed it into electrical signals, the brain then analyses these signals and perceives what is being seen. Lechner extends his analogy of a robot, to include the concepts of "the hardware (eye and brain) and the software (associations, memory and intelligence)"[6].

Visual perception is the result of the brain analyzing what the eye sees. Perception involves many complex interrelated concepts, but it fundamentally involves how the brain processes information. Issues involved include the ability of an observer to focus on an object, and isolate it from others, the ability to perceive a series of strokes of a pen on paper as words, the ability to block out light color shifts, and the ability to perceive color and so on. This is an area of study in and of itself, and beyond the range of this report.

The issue of importance in relation to the development of a suitable visual environment relates to maximizing the eyes ability to receive information correctly. Information needs to be relayed to the brain without conflicting images, or messages.

The Task

Tasks performed in a Classroom

With current trends in education, school classrooms are expected to cater for an ever increasing variety of tasks, often being undertaken simultaneously. Whereas historically all the children in one class would be undertaking one task at one time, be it reading, writing or doing arithmetic problems, now children are likely to be involved in a myriad of tasks. Some will be working at desks doing traditional tasks, others will be working on computers, whilst others might be involved in activities such as painting and pottery.

The traditional visual tasks usually undertaken in a classroom have evolved as well. Information is now provided in numerous ways, be it the teacher writing on the chalkboard or the whiteboard, or students using newspapers, magazines, and computer printouts. The use of multimedia has increased in classrooms, computers are increasingly prevalent, as are televisions, videos, and projectors.

The lighting provided in today's classroom needs to satisfy the visual requirements of all these possible situations, and others that might arise in the future.

Luminance of the task

Visibility relates to the ability of the observer to see a task. It is "the measure of the ease, speed and accuracy with which the task may be seen"[7]. The visibility of a task depends on a multitude of factors, including the luminance of the task, the contrast range of the task and the adaptation requirements placed on the eye of the observer. The luminance of the task refers to the brightness of the surface and is a product of the illuminance striking that surface and the reflectance of the surface. Contrast is the relationship between the luminance of a task and its background. A certain level of contrast is necessary for the eye to differentiate the task, but too great a range can result in a reduced ability to discern detail. Adaptation luminance is related to the physical ability of the eye to adapt to changes in light levels and has been discussed above.

The Lit Space

The three main issues to be considered under the aspect of the lit space, are illumination levels, spacial brightness ratios, and glare.

Illumination Level

Lighting guidelines have been developed that provide recommended illuminance levels for various tasks. These values are based on studies of the amount of light required to perform specific tasks[8]. Some of these guidelines have been adopted as legal standards for the provision of light in buildings. This is the case in Australia, where AS 1680.1-1990[9] Interior Lighting Part 1: General Principles and Recommendations, covers all aspects of lighting design including; task visibility, directional effects of lighting, surfaces, light sources, lighting systems, and lighting design procedures. Subsequent parts of this standard address lighting level requirements. These standards consider lighting design to be more than just the provision of a certain lux level on a horizontal plane, requirements exist concerning glare, unwanted reflectance and other quality issues.

The standard, AS1680.2.3, sets the illuminance level for a general use classroom at 240 lux, and the value for a reading room classroom at 320 lux. These values are referred to as a maintenance illuminance level, and although the issue of the maintenance of lamps, luminaires and room surfaces is more directly related to electric lighting systems, daylighting systems also suffer a loss of illumination level due to accumulated dirt on glazing and room surfaces. A maintenance illumination level is the "value of average illumination below which it is necessary to take remedial action in terms of maintaining the lighting system"[10].

In the United States of America, the IES (Illuminating Engineering Society of North America) Lighting Handbooks are the most influential lighting guidelines. The IES Lighting Handbook uses a different procedure to determine required illuminance levels[11]. Initially an illumination category is selected from tables, based on the task being performed. These categories provide a range of illuminance levels, the final level is decided upon after a series of weighting factors are calculated. These factors include the age of the viewer, the speed and accuracy requirements of the task, and the reflectance of the task background. An example of this procedure, as applied to a classroom, is presented in the figure below (Fig. 4.02). The resulting recommended illuminance level is in the range of 300 to 750 lux, depending on the specific task being performed. In proposing a procedure that utilizes a range of illumination levels, the IES has sought to allow lighting designers a level of flexibility and latitude in their final choice of lighting levels.

Illuminance Selection Procedure *IES (p 2-4)*

Step 1:

Define Visual Task

- reading
- writing
- drawing, etc.

Step 2:

Select Illuminance Category *IES Fig. 2-1 (p 2-5)*

Educational Facilities
Classrooms - General see Reading
Reading

Illuminance Category D and E

Step 3:

Determine Illuminance Range

D	Performance of visual tasks of high contrast or large size	200	300	500
E	Performance of visual tasks of medium contrast or small size	500	750	1000

Step 4:

Establish Illuminance Target Value

Weighting Factors *IES Fig. 2-3b (p 2-21)*

task background reflectance	30 - 70 %	0
age of occupants	under 40	-1
importance of speed / accuracy	important	0
	Total	-1

If weighting factor total equals -1,0,+1
use middle illuminance values

Recommended Illuminance value is 300 - 750 lux.

Figure 4.02: IES Recommended Illuminance Level[12]

The difference to be noted between the two documents is the variation in the lighting level recommendations. The U. S. standard levels are significantly higher than the European and Australian levels, and have always been so[13].

In order to achieve the illumination levels discussed above attention needs to be given to the reflectance's of the primary surfaces of the room. The aim is to reduce the brightness of the brightest surfaces of the room, whilst brightening the darkest ones. Castaldi[14] and others have suggested the following reflectance values: floors should be as light as possible and practical, with a reflectance in the order of 30 - 50%; walls should have a reflectance of between 40-60%; ceilings need to diffuse as much light as possible, and therefore need a reflectance of 70-90%; chalkboards, or the now more common whiteboards, need to be as light as possible and furniture and fittings need to have a reflectance of about 40%. The figure below is a graphic representation of these values (Fig 4.03).

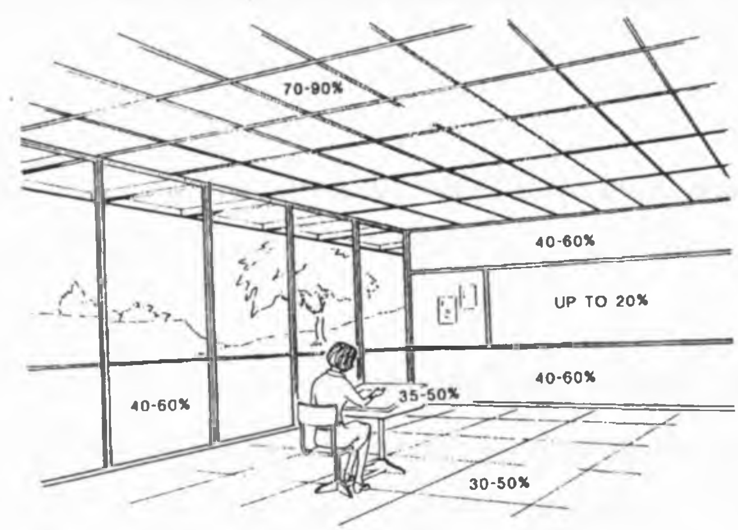

Figure 4.03: Recommended surface reflectances[15]

Spacial Brightness Ratios

It is important to consider the balance of brightness that may be present within the field of view of an observer when they are engaged in a visual task. Ratios are calculated in relation to the brightness of the task when compared to the brightness of its surroundings. Guidelines have been developed that minimize eye fatigue and maximize the observers ability to undertake the visual task. These guidelines include:

- limiting the brightest surface to a value no more than ten times that of the poorest lit task
- not letting any surface be of a brightness less than a third of the brightness of the poorest lit task
- the brightness of any surface immediately adjacent to the task should not exceed the brightness of the task, ideally adjacent surfaces should be about a third the brightness of the task
- and minimizing the difference in brightness of adjoining surfaces[16].

Glare

Glare is defined as "[a]ny brightness within the field of vision which causes discomfort, annoyance or interference with vision"[17].

The standard, AS1680.1-1990, sets a maximum glare index for specific spaces that a lighting system must satisfy. For school classrooms the maximum glare index is 19[18]. This value is in the middle of the range of values, that rise in value from 13, for extremely exacting visual tasks, to 28, which is the value applied to rough or intermittent tasks requiring little glare control.

Glare can occur in a number of forms. Direct glare occurs where there is a light source in the observers field of view, specular glare results when there is a specular reflection in the observers field of view, and contrast glare is created when an extremely bright object is seen against a dark background.

The most obvious sources of direct glare are windows. A number of strategies are possible to reduce the possibility of glare occurring. These include the use of tinted low transmission glazing, providing light colored surfaces adjacent to the window, providing additional lighting directed to the surfaces adjacent to the window, and the use of adjustable louvers[19]. When dealing with glare from electric lighting the standard specifies two alternative methods to evaluate it, one being the luminaire selection system, the other being the glare evaluation system[20]. The most obvious solution is to either remove all light sources from the field of vision of an observer, or provide shielding so that the source is not directly visible.

Specular glare can be controlled by careful attention to the use of finishes on room surfaces. Highly reflective surfaces will give rise to specular reflections, diffuse surfaces will not. Choice of a diffuse lighting system, where light is diffused off the ceiling is another option. Care also needs to be given to the choice of materials for the task, reflective glossy papers can result in veiling reflections.

Veiling reflectance is a form of specular glare that occurs on the surface of the task, rather than within the observers field of vision. They occur when light sources reflect off the task, into the eyes of the observer, effectively obscuring the task. To avoid veiling reflectance the material being used for the task should not be glossy, and light sources should be avoided in positions where they might bounce light into the viewers eyes. Light crossing from the side of the task avoids this problem.

The issue of contrast glare can be addressed by attending to the juxtaposition of elements. Very bright areas should not be placed adjacent to dimmer areas. The use of narrow beam, direct light sources should be avoided.

Due to the varied nature of the activities that can occur in a primary school classroom it is necessary to create a lighting system that will provide adequate light levels for all occasions. The solution is to use a combination of ambient lighting, to provide an overall level of light, and task lighting, to supply supplementary lighting as required. The ambient lighting level will be the illuminance level as set by code, the task lighting will be in addition to this. The provision of light and therefore the layout of the lighting system should not dictate the way a classroom is used. Desks are rarely placed in a formal arrangement, more often they are moved around as required, therefore there is a need for the ambient lighting system to provide a uniform light distribution over most of the classroom floor area. Supplementary lighting is needed where the ambient light level is inadequate, this is likely to occur at the perimeter of the room, as it is here that many teachers establish alcoves dedicated to certain activities, such as reading and computer usage. In order to eliminate visual discomfort a ratio of 0.8 must be maintained between the maximum and minimum illuminance levels in the space[21].

Conclusions

The above has been an overview of the requirements of a suitable visual environment. The lighting provided in a classroom needs to be more than merely functional, in fact to design such a system,

> "is to ignore the fact that
>
> > ...poor lighting can impair vision , cause general body fatigue, and increase body tension. Too long concentration on close tasks, without the exercise of distant viewing, causes eye fatigue and strain. A tired, tense student cannot respond alertly to the learning activities and the schoolroom "[22].

Primary school children can spend up to six hours a day, five days a week for nine months of the year in a classroom, the visual environment created in the space they occupy is obviously going to influence their well-being. A visual environment needs to be created that is stimulating, and supportive of the educational agenda.

Endnotes

[1] AS 1680.1 - 1990, p10.
[2] AS 1680.1 - 1990, p10.
[3] Lechner, p257.
[4] Kaufman, 1984 V1, p3.2.
[5] Szokolay, 1980, p88.
[6] Lechner, p258.
[7] AS 1680.1 - 1990, p12.
[8] Robbins, p26.
[9] AS 1680.1 - 1990.
[10] AS 1680.1 - 1990, p9.
[11] Kaufman, 1987 V2, p2.3.
[12] Kaufman, 1987 V2, p2.4.
[13] Robbins, p27.
[14] Castaldi, p282.
[15] Kaufman, 1981 V1, p6.4.
[16] Castaldi, p281.
[17] Sleeman, p146.
[18] AS 1680.1 - 1990, p37.
[19] AS 1680.1 - 1990 p36.
[20] AS 1680.1 - 1990, p36.
[21] AS 1680.1 - 1990, p17.
[22] O'Connor, p182.

THERMAL ENVIRONMENTAL REQUIREMENTS

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This chapter will discuss the environmental requirements that are necessary to achieve a comfortable indoor thermal environment.

The thermal conditions that occur within a space elicit a biological reaction from the occupants of that space. The human body can only survive within a limited range of conditions and can only function at its most efficient within an even more specific range. For children to perform at their peak potential, conditions within the classroom will ideally fall within this zone of optimal performance.

Objectives of a conditioning system

An optimal thermal environment is achieved when the human body is able to function efficiently. This occurs when the point is reached at which minimal expenditure of energy is required for the body to adjust to its environment. In relation to schools and the provision of an optimal learning environment, this point can also be defined as the one which is conducive to "alert, attentive and motivated"[1] students.

The provision of systems, either active or passive, that are designed to moderate the thermal environment must in no way "impede the functional or humanistic needs of the students and teachers"[2] that inhabit the space.

The primary function of a classroom space is to support the learning experience.

The objectives of a classroom thermal control system must be to provide a thermal environment conducive to learning. In order to evaluate the effectiveness of such a system it is necessary to consider three aspects, the occupant of the space, the interaction of the thermal variables, and the space itself.

Due to the fact that "comfort is determined primarily by the rate of exchange of heat between an individual and his environment"[3], the occupants of a space will be the major determinants of thermal comfort. Thermal regulation of the body's temperature is a response to external stimuli. It is not a reasoned response, but an organic one.

There are multiple variables that interact to achieve resultant thermal conditions. The most obvious of these are air temperature, humidity and ventilation. Mean radiant temperature is less obvious but equally crucial. A number of methods have been developed whereby the interaction of these variables can be considered and charted. Extensive research has been undertaken throughout the world to establish thermal comfort indices.

All energy transfer is governed by the laws of thermodynamics.

> " The first law of thermodynamics is the principle of energy. Energy cannot be created or destroyed but only converted from one form to another".[4]

> " The second law of thermodynamics ... states that heat (or energy) transfer can take place spontaneously in one direction only : from a hotter to a cooler body or, generally, from a higher grade to a lower grade state".[5]

These laws operate so as to maintain a state of thermal neutrality, be it within a building in relation to conditions outside, or a human body in relation to its external environment.

There are three methods of heat transfer; conduction, convection and radiation. Conduction is "the spreading of molecular movement throughout an object or objects in direct contact"[6]. Convection "is the form of heat transfer from the surface of a solid body to a fluid, i.e., a liquid or gaseous medium"[7]. Radiation is the emission from a surface of energy in the form of infra-red wavelengths.

The Occupant

Human Response

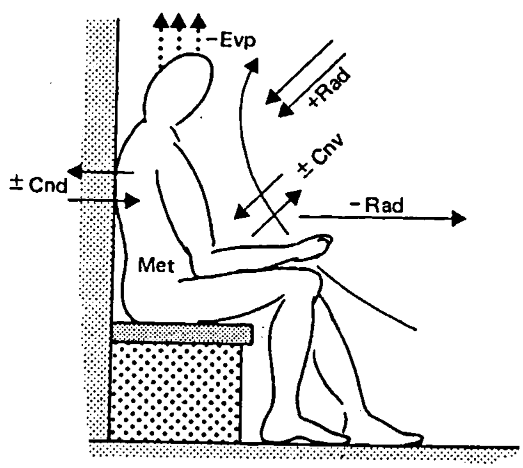

Figure 5.01: Thermal Balance of the Human Body[8]

The human body acts like other objects do in relation to heat transfer and the maintenance of thermal equilibrium. Thermal balance exists if the following equation holds true:

$$MET - EVP \pm CND \pm CNV \pm RAD = 0$$

"MET" refers to metabolism, or "the biological processes within the body that lead to the production of heat"[9]. This occurs either as basal metabolism, which is the constant digestion of food into energy, or muscular metabolism, whereby the use of muscle produces heat as a byproduct of work.

"EVP" refers to evaporation. This is the process whereby heat is lost from the body by the application of heat to transform a liquid into a gaseous form. Sweating is an example of this, as is breathing.

"CND" refers to conduction. This is either a heat gain or a heat loss process, as energy is transferred from a warm object to a cooler one by direct contact. Heat gain will occur if the body is in contact with a surface that is warmer and heat will be lost if the body is in contact with a surface that is cooler.

"CNV" refers to convection. In this process heat is gained or lost to a surrounding fluid which is usually air. As for conduction, this process occurs according to the second law of thermodynamics.

"RAD" refers to radiation. This process occurs when an object radiates infra-red energy, which strikes another object. Whether this results in a heat gain or loss will depend on the relative temperatures of the objects and their proximity. The human body acts as an object in relation to radiation.

In normal circumstances, a sedentary person in a comfortable climate will lose heat from the body in three ways. Approximately 45% will be lost through radiation, 30% will be lost through convection and 25% through evaporation.[10]

In order to sustain life the human core body temperature must remain within a very narrow range. This must occur regardless of the fluctuations in external environmental conditions.

The skin is the organ that is directly responsible for modulating the body's temperature. The ideal skin temperature is a matter of personal preference but is usually in the range of 31 to 34°C, and "skin temperature can be maintained only if a balance exists between heat input to the skin and the heat loss, or output"[11]

A core body temperature of 37°C is normal. A number of causes can result in a change in body temperature, including a change in the external temperature, or in the metabolic rate of heat production. If heat is not dissipated sufficiently, the skin reacts by dilating the blood vessels close to the skin surface, increasing heat transfer to this surface and thereby enhancing radiant and convective heat dissipation. If this proves insufficient and the body temperature continues to rise, sweating will occur with its associated evaporative cooling effect. Hyperthermia results if these measures continue to be insufficient to restore heat balance and heat stroke can occur as the body temperature reaches 40°C. If it reaches 42°C death is inevitable.[12]

The opposite scenario involves a "heat dissipation rate [that] exceeds the heat production rate"[13]. The skin now reacts via vasoconstriction in order to slow the transfer of heat to the surface of the skin, whilst lowering skin temperature. Radiant and convective heat dissipation is now diminished. The insulation action of the skin tissue is enhanced but frost bite can occur at the extremities due to a lack of blood flow. If this proves ineffective shivering occurs, which produces a muscular metabolic reaction with associated heat production. If these measures fail to bring the body back to a state of thermal balance hypothermia can occur. Death is inevitable if the body temperature drops to between 25°C to 30°C.

One succinct definition of thermal comfort as it relates to human body core temperature is provided by Szokolay.

> "The limits of existence can be defined in terms of deep-body temperature as lying between 35 and 40°C, the normal being about 37°C. The skin temperature must always be less than the deep-body temperature, as heat is to flow in that direction. The temperature of the environment in turn must be below the skin temperature, if heat is to be dissipated. The range of environmental temperatures that will allow sufficient, but not excessive heat dissipation, and will

therefor be judged as "comfortable", is referred to as the *comfort zone* "[14]

Even though there are definable physical limits to the definition of thermal comfort, in reality the perception of comfort occurs at an individual level. Individual characteristics affecting thermal comfort include the activities being undertaken, the quantity and nature of the clothing being worn, and the acclimatization of the body[15]. The ability of an individual to influence all but the last of these characteristics makes exact determination of an ideal indoor climate impossible. The environmental factors can be manipulated towards optimal conditions suited to the majority of the occupants, but rarely will it be possible to suit everyone.

Determination of optimal thermal conditions will also be influenced by cultural habits. The ways in which the space is used, the climate to which the occupants are acclimatized and the attitude of society towards the thermal environment will all be factors. In general, the use of air conditioning and central heating is uncommon in Sydney, therefore societal habits are adapted to this.

Thermal comfort zones have been developed through the use of empirical experiments, some of the most extensive of which were conducted by Fanger[16]. In these studies the initial experiment used American college students as subjects. Subsequent tests to validate these findings were performed using both Danish college students and elderly persons as subjects. Statistical data from these studies proved that adults tend to react similarly to the thermal environment, regardless of age or nationality[17]. When considering the applicability of these findings to an environment where the occupants will be almost exclusively children, Fanger concedes that "[f]urther work is needed on children"[18]

The Building Bioclimatic Chart

One of the earliest attempts to formalize the idea of thermal comfort as it relates to environmental variables was put forward by Olgyay in his book *Design with Climate*[19]. The culmination of this process resulted in a "bioclimatic chart", which indicated a comfort zone and, for conditions outside this zone, proposed necessary adjustments that could be undertaken. The comfort zone is determined by the interaction of dry bulb temperature and relative humidity. There is an assumption that there is no air movement and no radiant heat gain or loss. The strategies for the adjustment of non comfort zone conditions focus on either the addition of sunshine (radiant heat) or wind (air movement). Therefore this chart allows simultaneous consideration of the four primary thermal variables.

Givoni highlighted problems of the Olgyay model, claiming that it was "limited in its applicability"[20], due to the fact that "the analysis of physiological requirements is based on the outdoor climate and not on that expected within the building in question"[21]. He asserts that "the relation of indoor to outdoor conditions varies widely with different characteristics of the building construction and design"[22].

The alternate method proposed by Givoni is based on the Index of Thermal Stress, which is "a biophysical model describing the mechanisms of heat exchange between the body and the environment, from which the total thermal stress on the body (metabolic and environmental) can be computed"[23]. An analysis of the climate is undertaken initially, followed by the development of a Building Bioclimatic Chart. This chart allows the designer to observe the simultaneous effect of multiple variables. The Building Bioclimatic Chart is plotted on a psychrometric chart.

The psychrometric chart is a chart used to diagram the interrelated variables affecting thermal conditions. The six psychrometric variables are:-

DBT - dry bulb temperature is an indicator of sensible heat, or the heat content of perfectly dry air.

WBT - wet bulb temperature is an indicator of the total heat content (or enthalpy) of the air, that is, of its combined sensible and latent heats.

AH - absolute humidity is defined as the weight of water vapor contained in a unit volume of air.

RH - relative humidity is defined as the (dimensionless) ratio of the amount of moisture contained in the air under specified conditions to the amount of moisture contained in the air at saturation at the same (dry bulb) temperature.

H - enthalpy is the sum of sensible and latent heat content of a particular atmosphere relative to that of the 0°C air.

sv - specific volume is the reciprocal of density.

In order to utilize this chart as a Building Bioclimatic Chart it is necessary to locate the comfort zone as determined for the particular climate under study. Szokolay outlines a method to achieve this (see Appendix E). The figure below (Fig. 5.02) is the Building Bioclimatic Chart for Sydney.

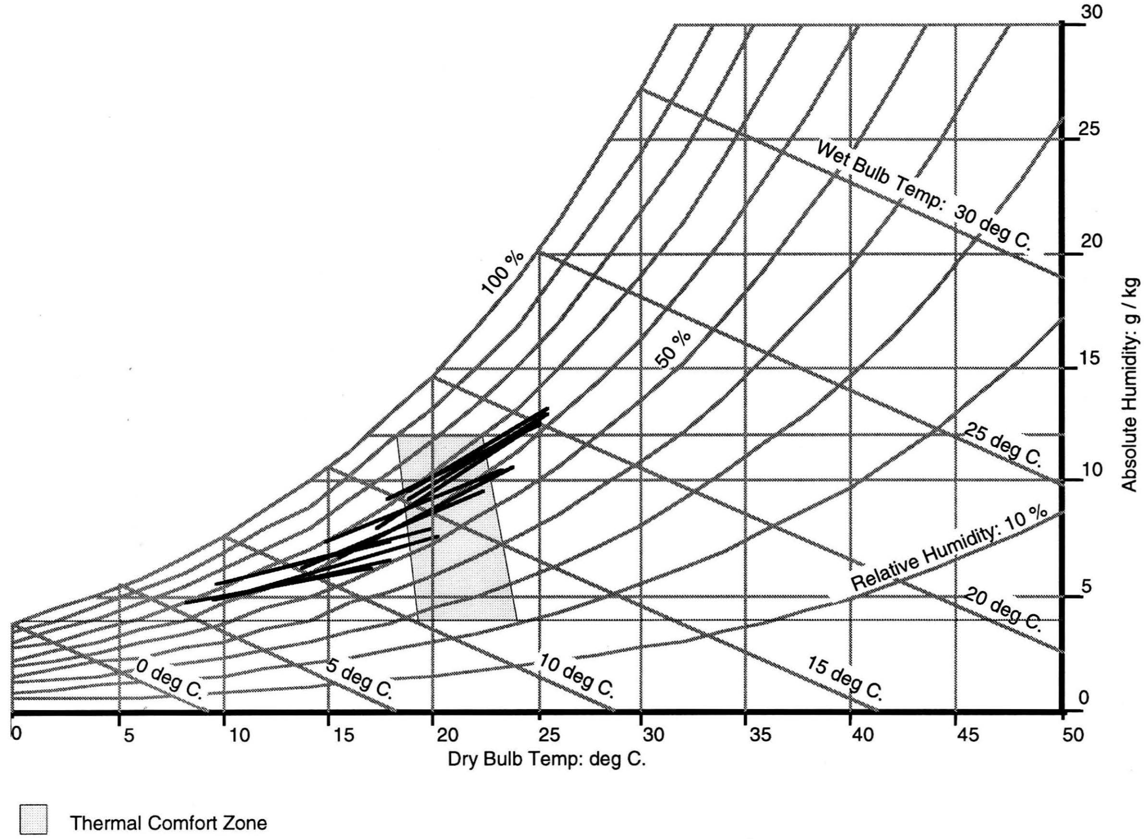

Figure 5.02: Building Bioclimatic Chart for Sydney, Australia

Additional calculations to position strategy zones are necessary to complete the Building Bioclimatic Chart (see Appendix E). These zones quantify the effects of various strategies, namely passive solar heating, mass effect, mass effect with night ventilation and the effect of increased air movement. The figure below (Fig. 5.03) outlines these zones.

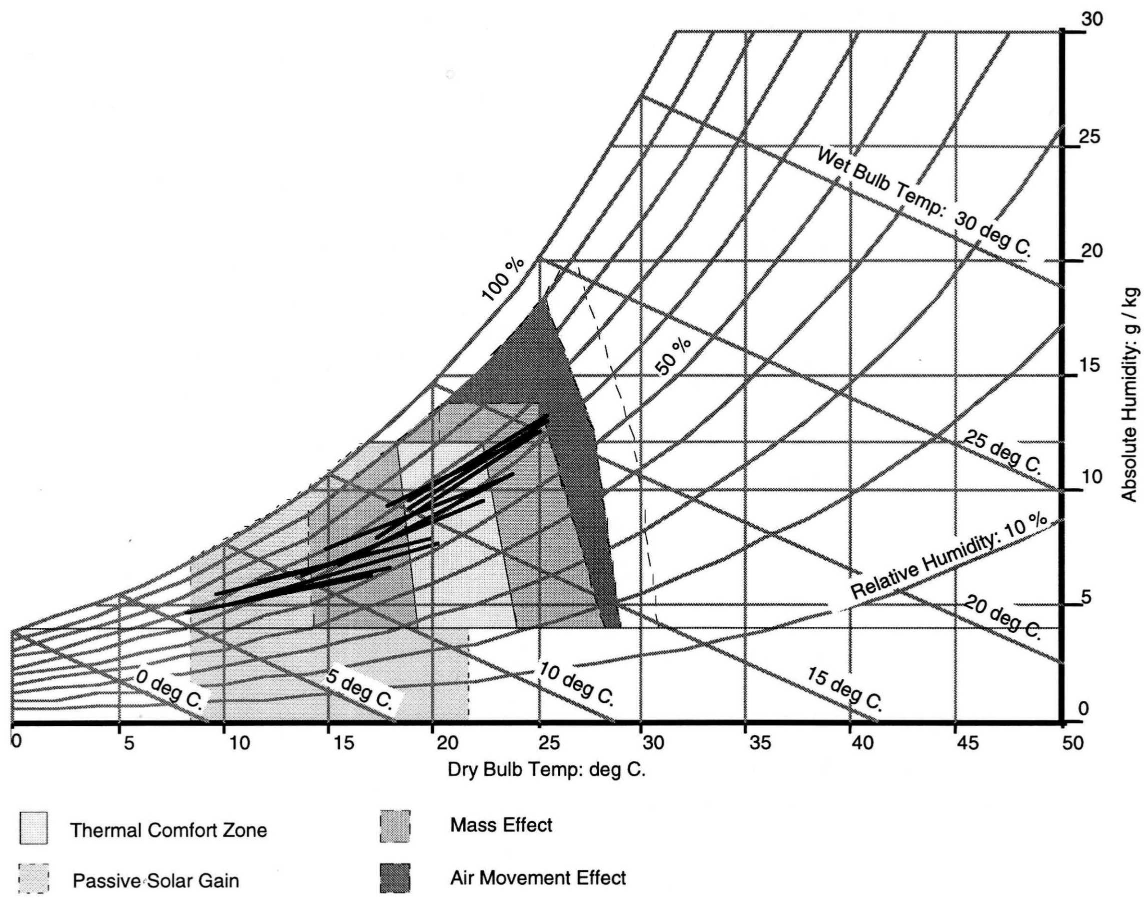

Figure 5.03: Building Bioclimatic Chart, with control zones

The advantages of an integrative system over single figure indices are manifold. The thermal environment is the result of the interaction of multiple variables, so a prediction method that considers these interrelated issues will prove more accurate and more flexible than a system that cannot integrate these variables simultaneously.

The Building Bioclimatic Chart considers the environmental variables but is unable to factor in the individual factors of activity level, clothing and metabolic rate. For this reason there will always be a leeway needed to accommodate the individual preferences of as many occupants as possible.

The Thermally Conditioned Space

It has been determined that "physical stamina and mental activity are at their best within a given range of climatic conditions"[24].

When considering the thermally conditioned space in terms of definable variables the four primary ones are air temperature, humidity, air movement and radiation. Each of these can be quantified and their effect measured therefore, they can be manipulated so as to offset unfavorable climatic conditions, through the use of strategic design.

Air Temperature

The temperature of the air has the most direct effect on human comfort. Air is the medium with which the skin is in direct contact, albeit there is often an insulating layer of clothes present.

The air temperature needs to be at a level where it will support the human heat balance equation. The two heat control processes effected by air temperature are convection and evaporation and in a sedentary person these can provide up to 55% of the body's heat loss. As skin temperature is usually between 31° and 34°C, the air temperature needs to be at a level which allows the body to dissipate heat if it needs to, via blood vessel dilation (convection) and sweating (evaporation).

Testa recommends a classroom air temperature of 18° to 22°C[25]. These temperatures are a little lower than those indicated by the Building Bioclimatic Chart, which are within the range of 18.5° to 22.5°C, depending on the associated humidity.

Effective temperature (ET) is another measure often applied to air temperature. ET is defined as "the temperature of a still, saturated atmosphere, which - in the absence of radiation - would produce the same effect as the atmosphere in question"[26]. This index considers the factors of dry bulb temperature, wet bulb temperature and air velocity. Corrected effective temperature (CET) includes the effect of radiation by exchanging the global temperature for dry bulb temperature in the calculations.

The recommended air temperature needs to be maintained in the zone of space occupied. Variations in temperature can occur due to the effect of convection, whereby hot air will rise and cooler air will settle, but this variation needs to be limited to a less than 3° temperature shift, otherwise there will be a big difference between the temperatures of the head and feet and resulting discomfort.

Humidity

Humidity has a direct effect on the evaporation rate the body can achieve. As a measure of the amount of water vapor contained in the air, when humidity is high the air has a reduced ability to absorb more water, thus evaporation is reduced.

Testa recommends maintaining relative humidity within the range of 50%-60%, the Building Bioclimatic Chart comfort zone covers a range of relative humidity from 20-90%.

Extremes of humidity are problematic. This is particularly the case with high humidity in excess of 90%, due to the fact that evaporation all but ceases when the air is saturated as it can no longer absorb additional water.

The body uses evaporation as a major heat regulation process. It is also an efficient method of heat regulation at the building scale, evaporative coolers rely on this process to perform their cooling function.

Dehumidification is not possible without the intervention of chemical desiccants or mechanical equipment, so excessive humidity is one climatic condition that cannot be ameliorated by the design of the building.

Low humidity tends to offset the effects of high temperatures. The body can increase sweat production, with a commensurate increase in evaporation to moderate the effects of heat.

Air Movement

The rate of air movement in a space effects the convection and evaporation processes. Comfortable rates of air movement are often determined by factors other than thermal comfort and limits are usually based on the need to reduce the incidence of the movement of paper.

Another issue that can affect the selection of a suitable rate of air movement is that of the need for air within a space to be circulated and infused with fresh air so as to dilute odors that will occur as a result of sweating and exhalation. During respiration the human body generates carbon dioxide, which is then exhaled. This then must be replaced with oxygen or the air will rapidly become unbreathable.

Castaldi recommends 10-15 ft^3 of fresh air per student per minute[27], which for a class of thirty students, equates to 300-450 ft^3 or 8.5-12.75 m^3 per minute. This is primarily required for odor removal, and fresh air supply, rather than for thermal reasons. Testa has a suggested rate of air movement of less than 1 m per second[28] as an air speed faster than this can blow papers around and will generally cause a disturbance within the class.

Radiation

Radiation, or the release of infra-red energy by an object or surface, is the hardest of all variables to calculate and regulate. Mean radiant temperature (MRT) is "the area-weighted mean temperature of all surrounding surfaces"[29] and provides the most commonly used index of radiation. This temperature is measured using a globe thermometer that reads globe temperature (GT). This is equal to MRT when there is no air movement. The relationship of GT to DBT indicates whether radiation is producing a heat gain or a heat loss in relation to the thermometer. A heat gain will result in a GT higher than the DBT, whilst a heat loss will produce a GT lower than the DBT[30].

Radiation is directional, it is emitted or absorbed into a surface, the rate at which the surface radiates or absorbs energy being dependent on the surface material as well as on the presence of energy sources. External envelope surfaces are exposed to solar radiation which in turn is absorbed into the material and possibly re-radiated either externally or internally.

The choice of direction is determined by the laws of thermodynamics as previously described. If the surface is cooler than the space and the objects within it, energy will be absorbed. If the reverse occurs energy will be released.

Radiation heat loss in a sedentary person equates to 45% of heat loss, a significant part of the body's heat regulatory processes. For this to occur surrounding surfaces need to be cooler than the body.

The directional nature of radiation can result in unequal exposure if one or more surfaces are significantly hotter or colder than others. The most common example of this is cold windows, where glass provides little insulation value and the glazed surface becomes very cold and can absorb heat from anyone standing nearby.

Close proximity to a hot surface can deceive the body's heat sensors into triggering a heat response although the body, as a whole, is not experiencing heat overload. The opposite reaction can be triggered by proximity to a cold surface whereby the body reacts with cold responses even if the body is in fact at balance.

It has not been definitively determined if asymmetrical radiation has a deleterious effect on the body's thermal comfort[31]. Some studies have shown that test subjects do experience discomfort when exposed to short term asymmetrical radiation. Other studies, especially those involving prolonged exposure, showed little evidence of discomfort. Overall, disparate radiation levels from the surfaces associated with a single space should be avoided, but minor variations are unlikely to cause significant thermal comfort concerns.

Use of Space

The biggest effect that the use of space in a classroom can have on the indoor thermal environment is the variety of activities that can occur. Children can be engaged in quiet activities like reading, or they can be involved in more active activities such as dance and drama.

The number of children in a classroom can vary during the day, as can the number of children involved in particular activities. Control of the thermal environment must therefore reside in the classroom itself so that the teacher can adjust the conditions as the situation changes. Control does not necessarily imply an active system. Passive systems to maintain thermal comfort can be manipulated as easily.

Conclusions

O'Connor, paraphrasing Ackerman, succinctly states the reason for the necessity of a thermally balanced classroom, when he writes that:

> "An overheated child is prone to have lapses in concentration on academic matters and to relax and daydream. There is some indication that students may experience a 2% reduction in learning ability for every degree that the room temperature rises above the optimum"[32].

An underheated child would no doubt suffer as great a drop in performance as one who is overheated, so it is important to maintain a steady, optimal thermal environment in the classroom in order to maximize the learning environment.

Endnotes

[1] O'Connor, p194.
[2] O'Connor, p197.
[3] Castaldi, p266.
[4] Szokolay, 1980, p254.
[5] Szokolay, 1980, p254.
[6] Szokolay, 1980, p255.
[7] Szokolay, 1980, p256.
[8] Szokolay, 1980, p270.
[9] Szokolay, 1980, p270.
[10] Ballinger, 1997, p35.
[11] Szokolay, 1980, p270.
[12] Szokolay, 1980, p271.
[13] Szokolay, 1980, p271.
[14] Szokolay, 1980, p272.
[15] Konya, p26.
[16] Fanger
[17] Fanger, p86.
[18] Fanger, p86.
[19] Olgyay
[20] Givoni, 1976, p310.
[21] Givoni, 1976, p311.
[22] Givoni, 1976, p311.
[23] Givoni, 1976. p90.
[24] Olgyay, p14.
[25] Testa, p39.
[26] Szokolay, 1980, p276.
[27] Castaldi, p21.
[28] Testa, p27.
[29] Szokolay, 1980, p259.
[30] Szokolay, 1980, p259.
[31] Fanger, p96.
[32] O'Connor, p195.

BASECASE DESIGN

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The basecase selected for this study is one of the Component Design Range (CDR) of classrooms designed by the New South Wales Department of Public Works and Services. This home base block was chosen because it was a self contained group of classrooms that could be analyzed as a single entity.

The home base block consists of two home base classrooms and a shared withdrawal space. Each classroom has separate, attached, auxiliary spaces including a general storage area, a personal effects storage area and a practical activities area. The classrooms are separated by an operable wall which can be retracted when required to create a single space.

The total area of this home base block is approximately 200 m^2. The areas of each distinct part are as follows:-

home base classroom	57 m^2
practical activities area	21 m^2
withdrawal area	12 m^2
storage area	8 m^2
personal effects storage	4 m^2

Prototype Design

Part of the Schools Facilities Standard is reproduced here, and provides the educational specifications of the Primary School Facilities Standard as related to a Learning Unit, which is composed of the learning space and associated spaces

The following provides a general overview of the Learning Unit, the activities that will occur in each of the associated spaces, the spaces and requirements for each area, and the relationships that need to be created between spaces.

Overall the Learning Unit caters for a wide range of experiences and activities appropriate to the student' stage of development. Students will be working in many different media, often simultaneously. A variety of relationships between teachers and students, both formal and informal, will occur. Groups will range from individuals to a whole class or grade.

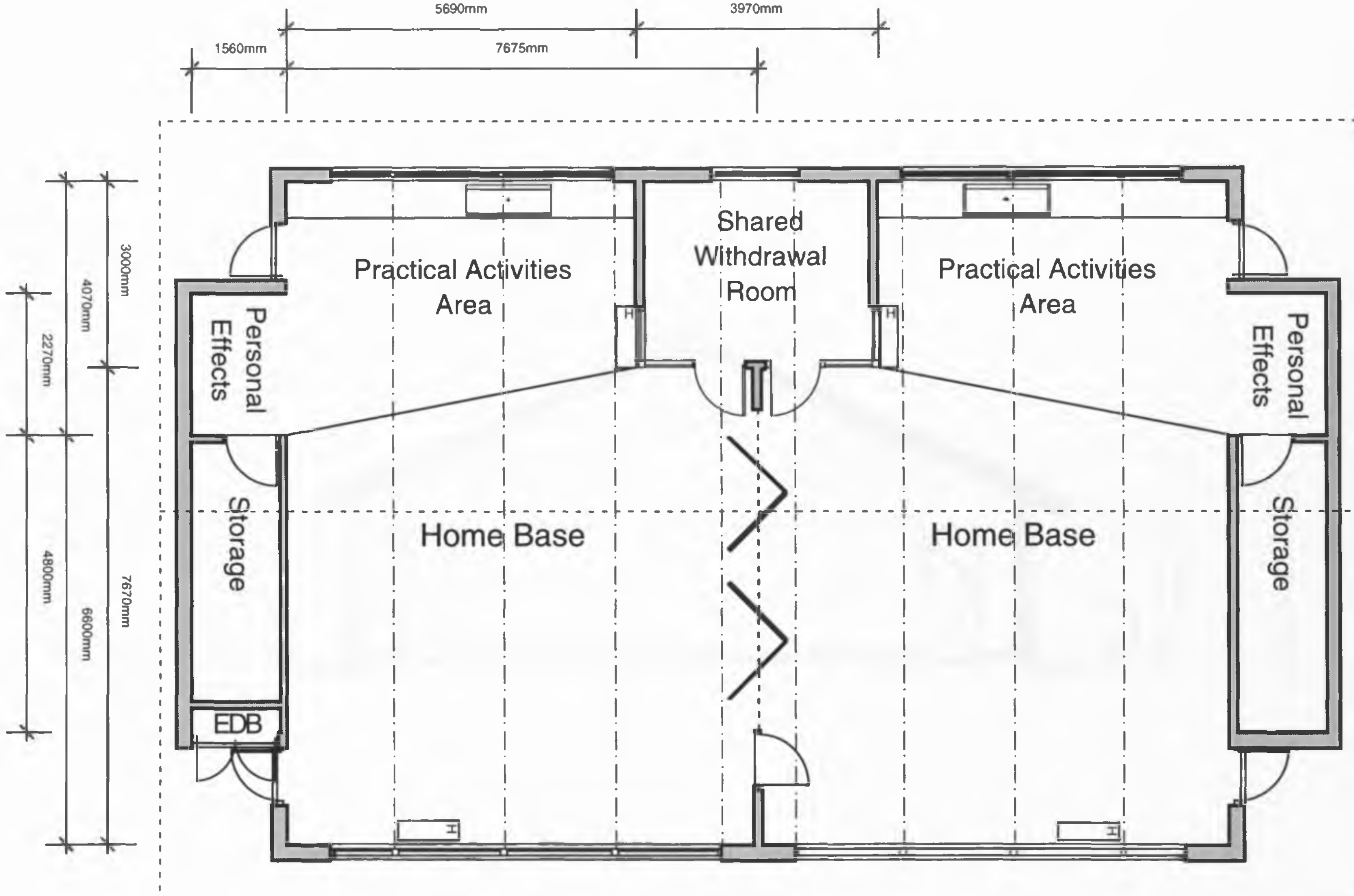
Normally, the number of classes grouped would be sufficient to allow a full Grade to work as a unit. Experience has shown that pupil numbers have created variations to the accepted standard of two (or three) classes per grade. There may be four Yr. 3 classes and only two Yr. 4s, yet both grades need to be able to work together. To cater for these variations, Home Bases should be clustered in groups.

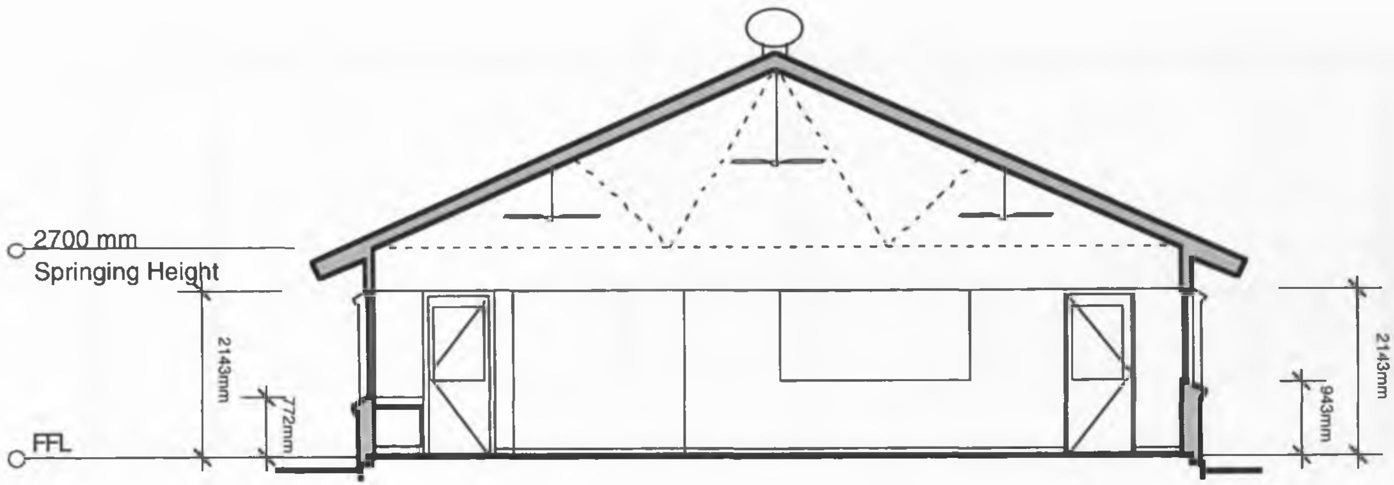
The activities that will occur in these spaces suggest the need for a variety of spaces and a maximum of flexibility. The design should, as far as possible, be responsive to change and not restrict the needs of future users.

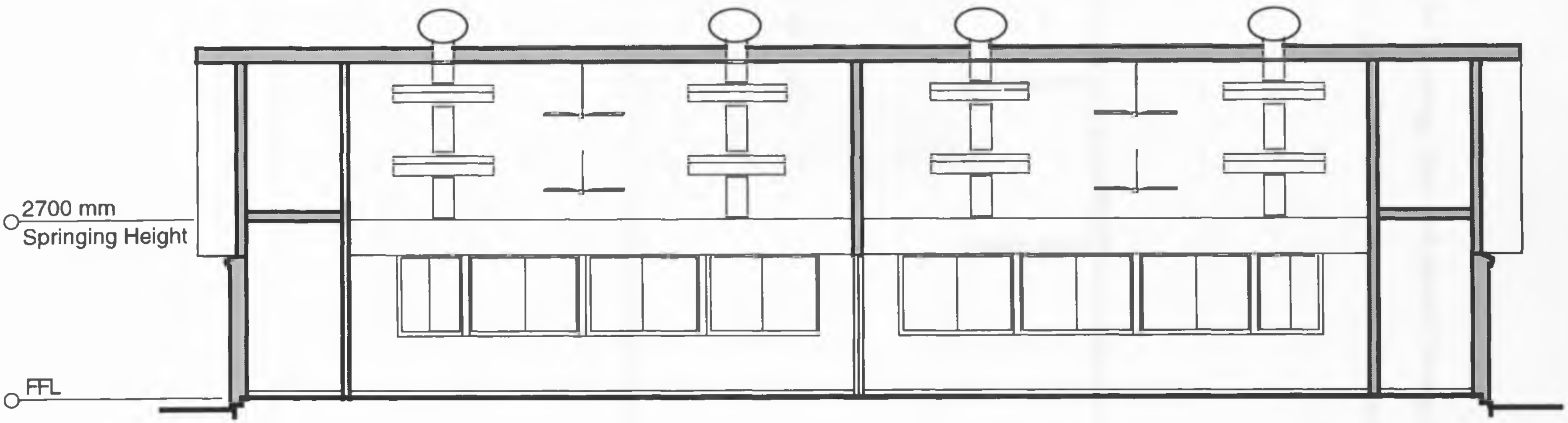
General considerations to be addressed include the need for comfortable conditions for class groups in clustered spaces.

Display of student's work and other material is very important as it encourages the users to personalize the Learning Unit. Display surfaces, both hanging and pinned on walls and ceiling, should be provided wherever possible.

Following pages:


5690mm
3970mm
1560mm
7675mm
3000mm
4070mm
2270mm
4800mm
6600mm
7670mm
Practical Activities Area
Shared Withdrawal Room
Practical Activities Area
Personal Effects
Personal Effects
Storage
Storage
Home Base
Home Base
EDB


2700 mm
Springing Height
2143mm
772mm
FFL
2143mm
943mm


2700 mm
Springing Height
FFL

Home Base

General

The Home Base is the core of the Learning Unit and should be regarded as its most vital element. It must accommodate a class of 30-35 students and their teacher, and provide an identity for the group.

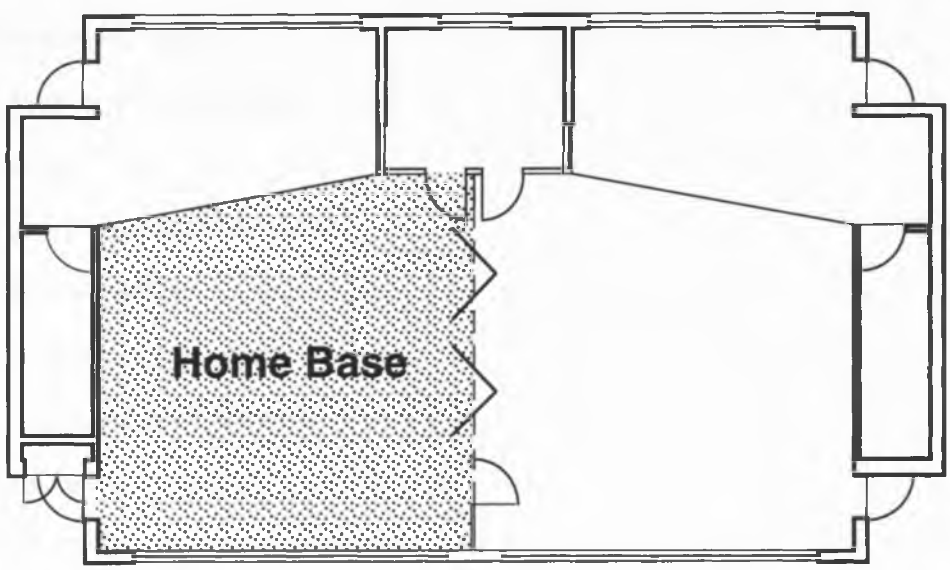


Figure 6.4: Home Base

Activities

Organization may be formal or informal, with students sitting at desks facing a chalkboard, or engaged in group or individual work spread throughout the room. Basic skills are developing through opportunities for students to communicate, to investigate and to express and at the same time to acquire knowledge, understandings, attitudes and values.

Some of the activities that will occur in this space are:-

- Speaking and listening
- Observing and investigating
- Discussions
- Choral and instrumental music
- Poetry, story telling
- Drama, mime, plays, dance
- Incidental art / craft activities
- Free play with structured materials, toys
- Using A / V and computer resources

Spaces / Requirements

- Approximately square shaped room is preferable to allow for both formal and informal teaching approaches.
- A centrally located chalkboard or whiteboard positioned away from glare sources so that all parts of the room have good visibility.
- Display is particularly important in the Home Base and maximum provision should be made. Brown out is required for daytime A. V. work. Special consideration is needed where sky lights are proposed.

- Acoustic absorption in the form of a soft floor finish to overcome noise from movement is encouraged for informal teaching. This can also serve as an additional learning surface where students can sit or sprawl when reading or listening.
- Acoustic separation between Home Bases is necessary to permit independent operation of individual classes.

Relationships

Wide openings are required between the adjoining Home Bases of each Learning Unit to give free movement and allow for supervision when classes combine and cooperate for various activities. In a three Home Base cluster such openings are required between one pair only. Where clusters of four are used, consider this as two pairs of two.

Practical Activities Area

General

An area is required for practical activities which can be an extension of the Home Base.

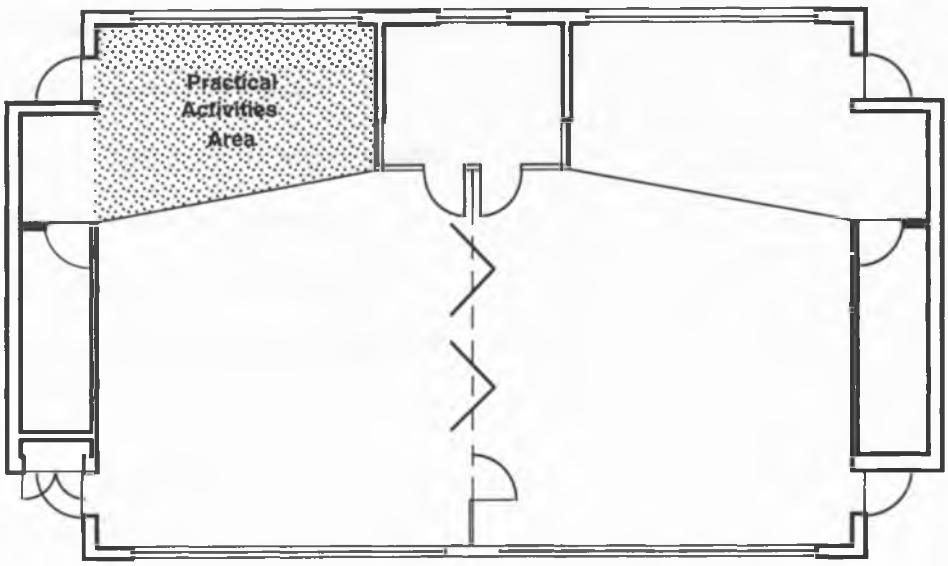


Figure 6.5: Practical Activities Area

Activities

This space provides an area where wet or messy activities can be undertaken by individuals or small groups. A whole class group may be extended into the Home Base or the covered outdoor learning area.

Activities may include:-

- Use of hand tools such as saws, hammers
- Printing with screen or block
- Modeling in clay, plaster, papier-mâché
- Keeping birds, animals, insects
- Making props, costumes for plays
- Preparing, cooking and eating food

Spaces / Requirements

Activities require:-

- Water and drainage, and washing facilities
- Power
- Work benches
- Specialized equipment such as portable oven and boiling hot plate
- Easily cleaned surfaces
- Floor that is non-slip when wet

Relationships

A Practical Activities Area should be provided and considered as an extension of the Home Base. Where used, clusters of two or four Home Bases could have a shared Practical Area. Each Home Base should have wide access to a Practical Activities Area for easy communication and supervision. Many of the activities could well be carried on out of doors. Direct access to the Covered Outdoor Learning Area from the Practical Area provides potential for group or individual withdrawal, as well as direct contact with the external environment.

Withdrawal Room

General

An area is required for small groups of students to occupy, away from the general student space.

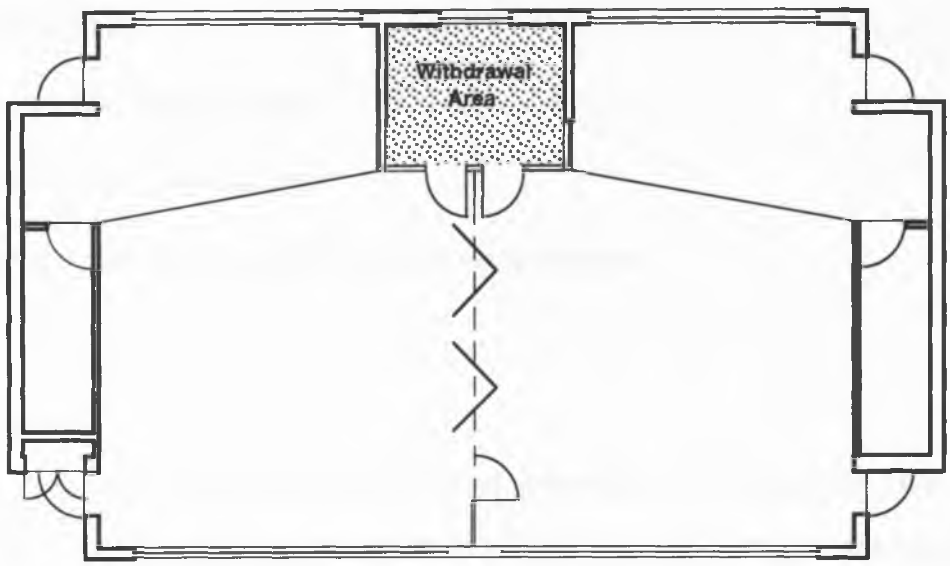


Figure 6.6: Withdrawal Room

Activities

This space will be used by small groups for a variety of activities. The noisy activities may include discussions, poetry or drama readings, story telling and record or music playing. The quiet activities may include individual study and reading.

Spaces / Requirements

- Maximum free floor area and a minimum of furniture
- Soft floor finish
- Power outlets, MATV outlet
- Brown-out from external light
- Adequate ventilation to cater for groups using the space

Relationships

A Withdrawal Area is required to separate small groups from the class in the Home Base. This allows them to carry out activities which may be noise producing or which may require a quiet area. The Withdrawal Area could be a room shared by 2 Home Bases, but acoustically separable from them, or an alcove extension of the Home Base. Supervision of activities in the Withdrawal Area should be possible from the Home Base.

Storage

General

A space for general purpose storage.

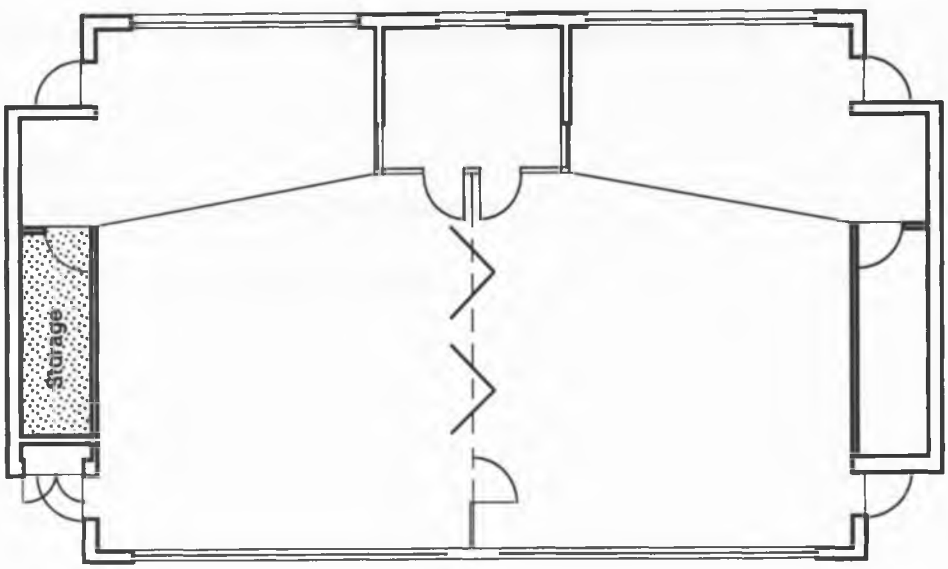


Figure 6.7: Storage

Activities

This is to provide storage for materials and equipment used by teachers and pupils of one Home Base and, in particular, allows the teacher to store items of personal equipment.

Spaces / Requirements

Maximum use of the space and easy movement of mobile equipment should be aimed for, e.g., by outward opening door. Some adjustable shelving is required.

Relationships

- Direct access from Home Base is required.
- Easy access to Practical Activities Area.

Personal Effects Storage

General

This space is for the storage of student's personal effects.

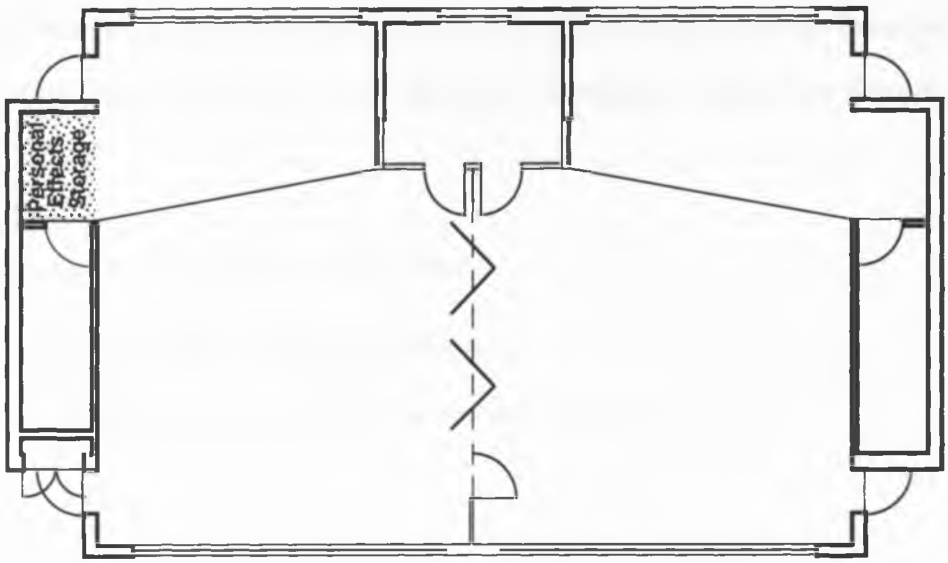


Figure 6.8: Personal Effects Storage

Activities

Storage is required for pupil belongings, in particular, bags and coats.

Spaces / Requirements

Teachers will need to be able to supervise these facilities from the Home Base to ensure security and assistance especially for younger children. Bags will require shelving for 30 children. Coats will require hooks and can be located externally, near the Practical Activities Area entry. If internal a "wet" floor will be required to allow for dripping.

Relationships

- Extension of the Practical Activities Area
- Close to Home Base for direct supervision.

Separation of bags and coats is required to reduce congestion.

Analysis of Prototype

The classroom and practical activities areas form a single open plan space that share a cathedral ceiling. A bulkhead brings the ceiling height to 2700mm in the storage areas.

The materials used to construct this block are standardized. The floor is a slab on ground. Carpet is used in the classroom spaces, withdrawal space and storage areas, while vinyl is used in the practical activities areas.

The walls are brick veneer to a height of 2700mm, with a single external layer of face brick and a steel stud internal load bearing layer. Above 2700mm, the walls are stud framed and clad with a vertical metal deck. Insulation is added to these sections of the wall. The internal wall finishes vary between a plasterboard lining and pinboard material.

The roof is metal deck with a plasterboard internal lining. Roof insulation is double layered, with a 50mm thermal insulation layer laid directly below the metal deck and a 75mm thermal insulation layer being laid directly above the plasterboard ceiling lining. The space between these layers is vented using openings provided at the eaves and ventilators at the ridge line.

Each classroom has windows to the south. The practical activities areas and the withdrawal space having windows to the north, There are no windows in the east and west walls, apart from small glazed panels inset into the access doors in these facades. All windows have a common head height of 2143mm. Sill heights vary, with windows located in the north facade having a sill height of 772mm, whilst the windows in the south facade have a sill height of 943mm. All windows are operable horizontal sliding units, with the openable area being equal to half the total window area. These windows are shaded for part of the year by a 900mm overhang created by the roof eaves.

Provisions have been made for daylighting in this design. In addition to the substantial north and south facing windows, skylights have been inserted into the gable roof. These take the form of strip roof lights, created by replacing half a sheet of roof metal deck with a corrugated reinforced polyester translucent roof sheeting. This allows a clear span of 190mm of light access. Directly below this is a polycarbonate structured clear sheet, and in the ceiling plane, a 400mm wide clear prismatic diffuser allows the light to enter into the space and prevents direct sunlight access. These roof lights are possible because of the use of a cathedral ceiling and exposed roof trusses.

Fluorescent lights are installed to augment the daylighting strategies and to provide illumination in non-daylit spaces such as the storage areas. These fittings are fixed to the underside of the ceiling and integrate well with the position of the roof lights.

A number of thermal strategies have been employed. The large equatorial facing (north) windows act as solar collectors, providing heating. The concrete slab has the potential to act as mass storage, but this is not realized as the slab is covered in part by carpet and in part by vinyl, both of which serve to insulate the slab. Gas fired heaters are provided in the space, to offset cold conditions.

The cathedral ceiling has a cooling effect as it allows the warmer air to rise into this volume, away from the lower occupied space. The roof ventilators remove this heated air, whilst also ventilating the roof space. Air is drawn into the roof space at the eaves and vented at the ridge, adding to the already well insulated roof. A total of six ceiling fans are provided to allow for increased air movement if conditions become too warm. The windows are shaded for part of the year and have internal venetian blinds which can be angled to offset solar penetration. No shading is provided for the roof lights, but the use of multiple layers of polycarbonate acts to insulate these openings. Although the outer skin of this building is brick, a massive material, due to the insulating action of the steel stud inner layer, it does not act as a mass storage material.

Visual Strategies

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The preceding chapters discussed the given and required comfort conditions for the visual environment as it relates to a school situation. This chapter addresses the product of the bioclimatic equation and outlines strategies to achieve the required control.

Required Controls

Control of the external climate in the context of the visual environment is one of exclusion. In order to create a suitable interior visual environment, the vast quantities of light provided by the sun and the sky need to be tempered.

Sydney has an average horizontal illuminance level of 8500 lux, infinitely higher than the 320 lux maximum required illumination level. The need for control arises because most buildings are constructed primarily of materials that are opaque to natural light. Light is easily excluded from the inside of a building and when transparent openings are provided, light is no longer distributed uniformly within the space. The fact that many apertures are placed in a vertical position adds to the unevenness of light penetration.

Seasonal climatic changes, such as overly cloudy days will also affect the quantity and quality of the available light.

Building Occupancy

Natural light is available only when the sun is in the sky. School classrooms are often occupied from 7:00 a.m. to 10:00 p.m., so for at least part of the day, natural light will not be available.

As indicated earlier, classrooms are used year round, apart from a six week summer vacation that occurs from mid December through to the end of January and other shorter holidays.

Lighting Approaches

Two approaches exist for internal illumination. The first disregards all natural light and only utilizes electric or artificial light. The second uses natural light when it is available and when it is insufficient to meet the visual needs of the space, provides artificial light as a secondary system.

The selected horizontal illumination level occurs for at least 90% of the working year, therefore, for at least 10% of the year natural light will not be enough to provide the required level of internal illumination. If illumination is required at night, electrical lighting is the only available source.

Electric lighting

Electric lighting utilizes electricity as its source of energy. Electricity is forced through a filament that becomes super hot and discharges energy as light and heat.

Electric lighting is flexible, versatile and, baring power blackouts, reliable. It is also the biggest consumer of electricity in most buildings.

Light Sources

An electrical lighting system is comprised of the lamp, the luminaire and the luminaire layout. The lamp is the light source, the luminaire controls the distribution of light and the layout influences the distribution of light throughout the space.

Lamp Type

The table below (Fig. 7.01) sets out the variety of lamps available and presents information about each type. The criteria for selecting a lamp include efficacy, flexibility, lamp life, cost and color rendition.

Lamp Group	Incandescent	Fluorescent	Metal Halide	High-pressure Sodium
Advantages	Excellent optical control (e.g. very narrow beams of light are possible) Very good color rendition (especially the warm colors and skin tones) Very low initial cost (especially useful when many low-wattage lamps are used) Flexible (easily dimmed or replaced with another lamp of a different wattage)	Very good for diffused, wide are, low brightness lighting Good color rendition (varies greatly with lamp type) Very good efficacy Long lamp life	Good optical control Excellent color rendition (especially of blue, green and yellow) High efficacy Long lamp life	Good optical control Very high efficacy Very long lamp life
Disadvantages	Very low efficacy (high energy costs Very low lamp life (high maintenance costs) Adds high heat load to buildings	Little optical control possible (no beams) Large and bulky (except new compact types) Sensitive to temperature and therefore not used much outdoors	5 to 10 minute delay in start or restart Fairly expensive	Color rendition is only fair (mostly orange and yellow) About 5 minute delay in start and restart
Applications	For spot, accent, highlighting and sparkle (residential, restaurants, lounges, museums)	For diffused even lighting of a large area (offices, schools, residential, industrial)	For diffused lighting or wide beams (offices, stores, schools, industrial, outdoors)	For diffused lighting and wide beams where color is not important (outdoor, industrial, interior and exterior floodlighting)
Efficacy (lumens/Watt)	10 - 25	40 -90	80 - 120	80 - 140
Life (hours)	750 - 2500	8 000 - 20 000	9 000 - 20 000	20 000 - 24 000

Figure 7.01: Comparison of Lamp Types

Efficacy is an indication of the amount of light a lamp will provide in relation to the energy it consumes. Incandescent lamps have a very low efficacy, converting only 7% of the energy they consume into light. Fluorescent lamps are more efficient, converting 22% of electricity into light[1]. The release of heat accounts for the remaining electrical usage, affecting the thermal conditions within the space.

Flexibility refers to the ease with which the lighting system can be altered. Dimming systems are advantageous in a situation where lighting conditions may need to be changed regularly. Fluorescent lamps are expensive to dim but can be set so that a form of dimming can be achieved by separately controlling various tubes within the luminaire. Start up time is also a consideration. Both metal halide and sodium vapor lamps require substantial start up time, or time until they reach a suitable level of light production. This can be particularly problematic in emergency situations so instant start up lamps are often installed as a back up system.

Lamp life reflects the length of time the lamp will be functional. This is an issue if lamp replacement is difficult or if maintenance is irregular.

Cost usually refers to the initial cost of the lamp but can also refer to the life cost of running it. The issue of cost is linked to lamp life as the more costly lamps usually have a longer life and are therefore replaced less frequently.

Color rendition relates to the energy wave lengths that the lamp produces. No lamp replicates daylight, although some come close to it. Most lamps have a concentration of a particular color and this can result in inaccurate color recognition. Incandescent lamps tend to be warm, producing increased yellow and red light, whilst fluorescent lamps tend to be cooler, producing blue and green light. Color balanced, or corrected, fluorescent tubes can come closest to transmitting daylight patterns of color.

Fluorescent lamps are usually chosen for general lighting in schools. They produce good diffuse light over large areas and have a long lamp life, a high efficacy rating and good color rendition. Most fluorescent luminaires group a number of tubes together and can be designed so that individual tubes can be turned on and off independently, producing inexpensive dimming.

Luminaires

The luminaire is the part of the system that holds the lamp and is responsible for controlling the distribution of light. A luminaire is a combination of various materials which, depending on their placement, will control the distribution of light. These materials can be reflective, transparent, translucent or opaque.

The figure following (Fig. 7.02) indicates the six primary types of luminaire, based on the percentage of light distributed in specific directions, namely upwards towards the ceiling, or downwards towards the workplane.

The distribution of light from the luminaire will influence the overall effect of the lighting scheme. The more light that is directed up onto the ceiling, the more diffuse the overall effect.

Efficiency of light distribution relies on the choice of luminaire and the reflectance of the surfaces of the room. If all light is directed to the ceiling the only light available for task performance is reflected and diffuse light, whereas if all light is directed downwards to the work surface the ceiling is not utilized to enhance light distribution.

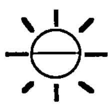
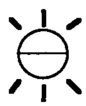
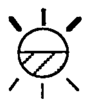
Symbol	Type	% of light upwards	% of light downwards	Explanation
	*Direct*	0 - 10	90 - 100	Direct: direct lighting fixtures send most of the light down to the workplane. Since little light is absorbed by the ceiling or walls, this is an efficient way to achieve high illumination on the workplane. Direct glare and veiling reflections are often a problem, however. Also shadows on the task are a problem, when the fixture-to-fixture spacing is too large.
	*Semi-direct*	10 - 40	60 - 90	Semi-direct: Semi-direct fixtures are very similar to direct luminaires except that a small amount of light is sent up to reflect off the ceiling. Since this creates some diffused light as well as a brighter ceiling, both shadows and the apparent brightness of the fixtures are reduced. Veiling reflections can still be a problem, however.
	*General Diffuse*	40 - 60	40 - 60	General diffuse: This type of fixture distributes the light more or less equally in all directions. The horizontal component can cause severe direct glare unless the diffusing element is large and a low-wattage lamp is used.
	*Direct-indirect*	40 - 60	40 - 60	Direct-indirect: This luminaire distributes the light about equally up and down. Since there is little light in the horizontal direction, direct glare is not a severe problem. The large indirect component also minimizes shadows and veiling reflections.
	*Semi-indirect*	60 - 90	10 - 40	Semi-indirect: This fixture type reflects much of the light off the ceiling and thus yields high-quality lighting. The efficiency is reduced, however, especially if the ceiling and walls are not of a high reflectance white.
	*Indirect*	90 - 100	0 - 10	Indirect: Almost all of the light is directed up to the ceiling in this fixture type. Therefore, ceiling and wall reflectance factors must be as high as possible. The very diffused lighting eliminates almost all direct glare, veiling reflections, and shadows. The resultant condition is often called ambient lighting.

Figure 7.02: Comparison of Luminaire Types

A direct-indirect or general diffuse system is most suited to a classroom application. It allows light to be fairly equally distributed both upwards and downwards. Modeling of objects is enhanced by shadowing, but the presence of the reflected component softens the shadows so that they are not distracting. The use of diffusers and louvers in the base of the luminaire will prevent glare caused by exposed light sources.

Luminaire Layout

The layout of luminaires within the room determines the distribution of light throughout the space and is based on the light level requirements. Some layouts provide a uniform level of light throughout the space, whilst others mirror the needs of specific tasks. A layout should not produce a dull, uniform light level that resembles an overcast sky as this can be psychologically disturbing to the occupants. However, it must also avoid creating overly bright or overly dim areas, unless this contrast is desired.

Lighting Strategies

Electric lighting design requires all the aforementioned issues to be resolved in such a way that the resultant system provides the required light levels and desired light distribution.

Szokolay proposes the total flux concept for lighting system calculations, whereby the quantity of flux installed (Φi) is greater than the flux received (Φr) by a ratio referred to as the utilization factor (UF).

This relationship allows the amount of lighting that needs to be installed to achieve a desired flux level on the workplane to be determined. Utilization factors are usually supplied by the manufacturers, as an indication of the effectiveness of their product. The utilization factor is dependent on five factors: the properties of the luminaire, and whether it is open or closed; the DLOR, which relates to the amount of light emitted upwards and therefore partially absorbed by the ceiling and walls; the reflectance of the ceiling and walls; the proportions of the room, which define the amount of light striking the walls in relation to the percentage that directly reaches the workplane; and the direct ratio, which is a measure of the percentage of the light emitted by the luminaire that directly reaches the workplane[2].

Various calculation methods can be used to determine the number of lamps to satisfy the lighting requirements. Due to the interconnected nature of a lighting design system there is no single solution to the many issues that need to be addressed and it is necessary to define the requirements that the system must fulfill and prioritize the secondary issues. The figure below (Fig. 7.03) tabulates these calculations for the basecase.

Lumen Method			
length of room	11	m	
width of room	7.75	m	
Area	85.25	m2	
Height of room	2.7	m	
H of workplane	0.7	m	
Hm	2	m	
R.I.= l x w	2.27		
(l+w)Hm			
E	320	lux	
Flux rec.	=A x E		
	27280	lm	
Conversion factors			
UF	0.43		recessed modular
			diffuser (DLOR=50%)
MF	0.8		
Flux initial	=Flux rec./ UF x MF		
	79302	lm	
Lamp chosen	1.5m/65W		
	4400	W	output
	68	lm/W	
	0.75		conv for natural tube
	3300	W	revised output
Number of lamps	24		required

Figure 7.03: Lumen Method calculations

The glare index must then be calculated to reduce the probability of the luminaire resulting in unacceptable glare situation. Calculations must fall within the limits set by lighting standards. The figure below (Fig. 7.04) presents the calculations for the basecase.

Glare index		
Assumptions		
floor is light		
ceiling	70%	
walls	50%	
luminaire	BZ 3	tubular
	4600	cm2
	0%	DLOR
	54%	ULOR
	3300	output
Height	2.7	
eye level	1.2	
H	1.5	m
Room sizes	11	m
	7	H
	7.75	m
	5	H
Initial glare		
index	crosswise	endwise
	13.4	15.5
Corrections	crosswise	endwise
initial	13.4	15.5
reflectances	4	4
luminous area	-7	-7
downward flux	1.8	1.8
height	-0.8	-0.8
total	11.4	13.5
Allowable	19	
glare index		

Figure 7.04: Glare Index calculations

Daylighting

The use of daylighting as a lighting system in classrooms has been controversial. Historically, classrooms were almost exclusively daylit. During the 1960s, research was conducted into the benefit or otherwise of windowless classrooms. The result was that,

> "while windows (or windowlessness) seem to have no impact upon students' academic performance, strong economic arguments favor windowless schools, and some equally strong psychological arguments oppose them"[3].

Daylight provides a dynamic light source, due to the changing nature of the color, contrast and light levels it provides[4].

Energy efficiency provides one of the strongest arguments in favor of daylighting schools. The figure below (Fig. 7.05) indicates a breakdown of the energy usage in an average school. Electric lighting comprises approximately half of the electricity consumed, therefor any reduction in the use of electric lighting will result in energy savings.

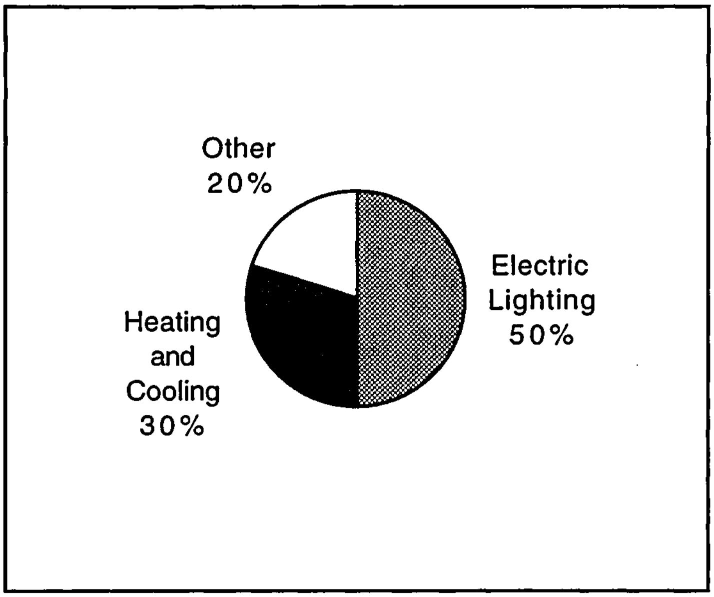


Figure 7.05: Energy Usage in schools

Daylighting Sources

The sun is the source of all daylight. It radiates a constant stream of energy towards the earth, some of which arrives at the earth's surface in wavelengths within the visible band. Light from the sun can be divided into two forms: sunlight which is received directly from the sun and daylight which is received from the sky vault via reflection.

Sunlight is problematic as a light source because of the constantly changing position of the sun and the intensity of its illumination value. Daylight is therefore the light most utilized in the lighting of buildings.

Sky conditions will affect the quantity and quality of available daylight. On days when the sky is clear sunlight is the primary light source, with less light being received from the clear blue sky vault. When conditions are cloudy or overcast, the entire sky vault acts as a diffuser and daylight is the primary light source. Partly cloudy days are an amalgam of these two conditions, giving rise to an extremely variable situation.

Three types of daylighting are received by a building: direct light, diffuse light and reflected light. Direct light is light that comes from the sun or the sky, with no interference. Diffuse light is light that has been scattered by interaction with moisture in the form of clouds or other contaminants in the atmosphere. Reflected light is light that has been reflected off another surface, be it the ground or other surrounding surfaces. These distinct types of light interact with the building in different ways and can be controlled using specific techniques. The figure below (Fig. 7.06) illustrates these daylight types.

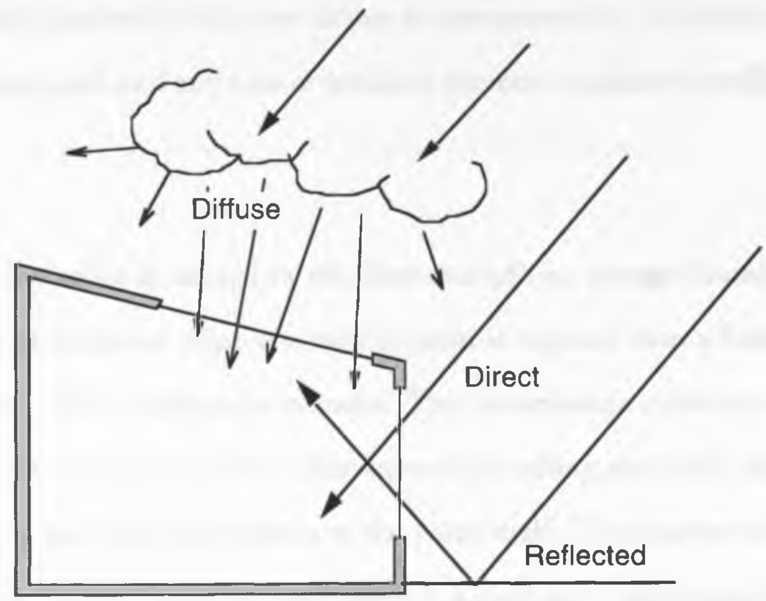


Figure 7.06: Types of Daylight

Calculation Methods

There are two approaches towards quantitatively examining daylighting. The first involves using "luminous quantities"[5] whereby a set of outdoor conditions is assumed from which internal values can be calculated. The second involves using "relative values"[6], often referred to as the "daylight factor method" involving the calculation of the ratio of illumination of a point internally to that of a point externally. This ratio will not alter regardless of the variation in external conditions.

There are numerous methods of calculating the quantity of light that will reach a given point. Some of these methods are mathematical, others are physical.

The total flux or lumen method is similar to the method used for electric lighting design. It involves establishing an illuminance on the window surface (Ew) then multiplying this value by the area of the window (Aw) to give the total lumens entering the window (Φt).

This is then multiplied with reduction factors to compensate for the effect of maintenance, the type of glazing used and any bars or mullions present, to achieve an effective flux value (Φe).

If this effective flux value is divided by the floor area (*A*), an average illumination value is obtained. If the illumination value at a specific point is required then a further factor, the Utilization Factor (UF), needs to be included. This incorporates correction values for the size and proportion of the room, the reflectance of the ceiling and walls, the type of fenestration being used and the position of the point itself. The accuracy of this method is not high, with best results being achieved when it is used with toplighting systems, where certain spacing-to-height ratios are not exceeded.

The split flux method is a more accurate method. It considers the three separate components of daylight: the sky component (*SC*), which is the light received from the portion of the sky visible from the window, the external reflected component (*ERC*), which is the light entering the window after being bounced off the ground or other external surface and the internal reflected component (*IRC*), which is that part of the light which arrives at a point after having been reflected off internal surfaces.

This method is complex, but its results are accurate for both toplighting and sidelighting. Each component is calculated independently using tools developed for the purpose, the most widely utilized of these being the Building Research Station (BRS) protractors, which are used in conjunction with scaled plans and sections of the building to calculate the sky component and external reflected component.

Daylighting Systems

The most important issues to address when designing a daylighting system are the resultant penetration and distribution of light within the daylit space.

Robbins[7] has categorized daylighting systems according to a series of proportional relationships as a way of evaluating and comparing the characteristics of different systems.

The initial category of relationships are spatial, whereby the impact of daylighting on the space of a building is considered in relation to the volume and size of the space.

The ratio of envelope to floor area:

$a = e / f$ e = envelope area

f = floor area

The ratio of volume to floor area:

$b = v / f$ v = volume

f = floor area

When considering the usual ratio outcome for a daylit building (Fig. 7.07) the issue of initial cost becomes apparent. Increased surface area in a design usually translates to higher construction costs[8]. Daylit buildings usually have higher ratios than non-daylit buildings, but there is some overlap in the figures, designers should aim to place their buildings in this range.

	a	*b*
Daylighted	0.80 - 2.25	11.0 - 22.0
Nondaylighted	0.3 - 2.00	9.0 - 14.0

Figure 7.07: Proportional relationship ratios

The second category focuses on the lighting performance of specific apertures.

The third category are the spatial / aperture relationships that encompass the association between the aperture and the space it is daylighting. These ratios will be examined in conjunction with specific daylighting systems.

These relationships attempt to classify the penetration and distribution of light within the space. Penetration of light refers to the possible lux levels that could be expected to occur at specific points within the room, and is defined "as the distance into the room that daylight reaches along the task plane at a predetermined level of illuminance"[9]. Light distribution is designated by the extent of its latitudinal or longitudinal spread. Latitudinal spread is defined as "the distance along which a predetermined level of illumination extends perpendicular to the plane of the aperture along the work plane"[10]. Longitudinal spread relates to the "distribution of daylight along the length of the aperture"[11].

The results of these findings are usually displayed using sections and floor plans of the space being studied.

The single most significant factor affecting daylighting results is the sky condition. An overcast sky will produce deeper penetration but softer shadows, whereas a clear sky will not provide as deep a penetration but the shadows are sharper and more defined. Glare is a problem irrespective of sky condition because of the high contrast between the aperture and surrounding surfaces.

When using a section chart, results are graphed as a curve indicating illuminance level against distance from aperture. When reading these charts three components are important: the slope of the curve, the presence of any knees in the curve and the rate of change of slope in the curve. The general shape of a curve will not alter, except due to differing sky conditions, irrespective of the absolute illuminance present. Knees in the curve are used as an indicator of a significant change in slope, while the rate of change in the slope is indicative of changes in the illumination levels.

Daylighting systems fall into two categories, sidelighting and toplighting. Both systems have positive and negative characteristics, making them suitable for different applications.

Sidelighting

Sidelighting occurs in two forms, windows or view apertures, and clerestories or non-view apertures. Positive characteristics of a sidelighting scheme include the strong directionality of the light provided and the ability of the scheme to provide lighting on a two dimensional horizontal surface[12]. The negative characteristics relate to the problems of glare created by having a light source that can be in the field of vision of the observer.

Windows

Two sets of proportional relationships govern both forms of sidelighting; penetration ratios and spread ratios. Penetration ratios include the space height to sill height (H) ratio, and the ceiling height to aperture height (V) ratio. The spread ratio is the ratio of aperture length to aperture height (M). These variables are graphically represented in the figure below (Fig. 7.08).

H = f/h

V = H/h

M = l/h

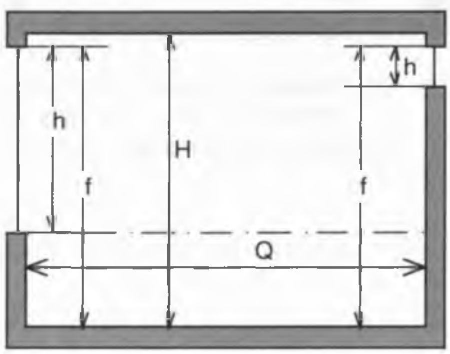


Figure 7.08: Ratio variables - Window

The variables that can be adjusted include *H*, which is altered by adjusting the height of the aperture sill, *V* which is altered by manipulating the height of the top plate of the aperture, and *M* which is affected by changes to the width of the aperture.

Ching defines a window as,

> "An opening in the wall of a building for admitting light and air, usually fitted with a frame in which are set operable sashes containing panes of glass"[13].

The figure below (Fig 7.09) displays the classic light penetration achieved by a window aperture. The light level is highest directly adjacent to the opening, dropping off sharply towards the opposing wall. This variability of lighting is the biggest counter indication to the use of windows as the only source for daylighting.

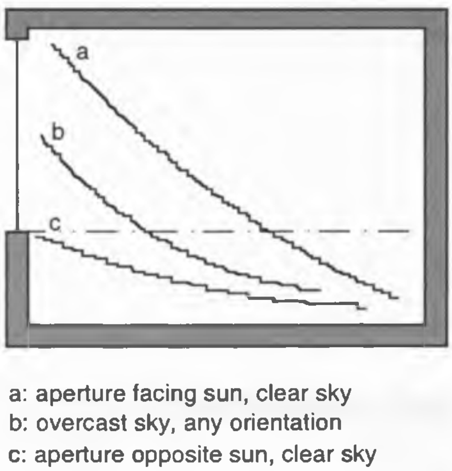


Figure 7.09: Penetration curve - Window

Clerestories

A clerestory is defined as,

> "A portion of an interior rising above adjacent rooftops and having windows admitting daylight to the interior"[14].

Robbins refers to windows as view apertures and clerestories as non-view apertures, set into the wall of a building. Clerestories are further defined as being "any window whose sill height is greater than eye height"[15], the top plate also has to be at or below ceiling height, otherwise the aperture is considered a roof light.

When considering clerestories there is the additional ratio of height of the aperture to the distance to the opposing wall (Q). The figure below (Fig. 7.10) indicates the variables used in the ratios.

H = f/h

V = H/h

M = l/h

Q = Q/f

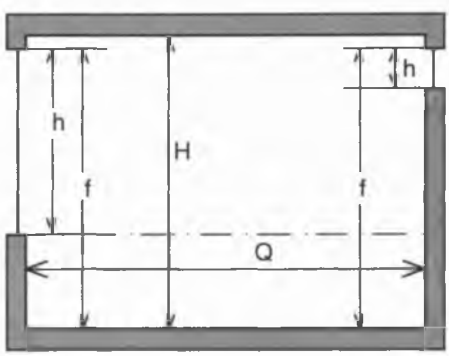


Figure 7.10: Ratio variables - Clerestory

In comparison to windows, clerestories provide superior vertical surface illumination because they avoid the problem of overshadowing by elements in front of the surface being lit. The resultant lighting curve is slightly different as well, with the point of maximum illumination occurring away from the wall surface adjacent to the aperture. The figure below (Fig. 7.11) graphs the basic clerestory lighting pattern. By varying the *Q* ratio, the point of maximum illumination can be positioned by the lighting designer.

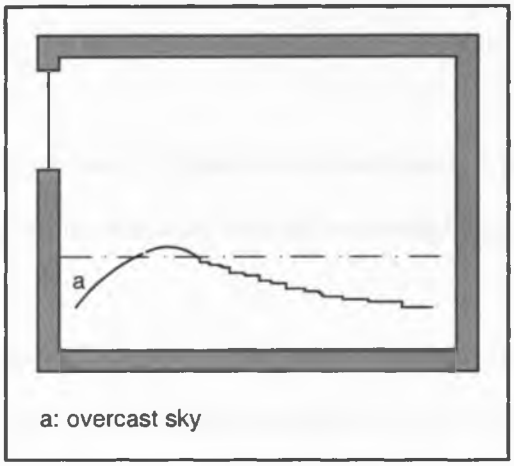


Figure 7.11: Penetration curve - Clerestory

Toplighting

Toplighting can take a number of forms, including horizontal apertures or skylights, angled apertures, sawtooth and monitor systems.

The positive characteristics of toplighting schemes include the evenness of light penetration and the size of the area that can be lit. The negative characteristic is the obvious inability of a toplighting scheme to light buildings beyond a single story, the exception to this being beam lighting systems.

Penetration and spread are used to describe the distribution pattern produced by toplighting schemes in much the same way as for sidelighting schemes.

The proportional ratios, of ceiling height to aperture height (H) and aperture length to aperture height (M) apply to all toplighting schemes, with additional ratios applicable to specific types of toplighting.

$$H = f/h$$

$$M = l/h$$

When designing toplighting schemes there is an assumption that sunlight is excluded, so all light is provided by daylight, therefore there will be differences due to sky conditions.

Horizontal Apertures

Horizontal apertures, or skylights, are apertures in the flat roof of a space. An additional ratio applicable to this scheme is the ratio of height of the aperture above the floor to the width of the aperture (N). In all horizontal aperture calculations the thickness of the roof is assumed to be minimal. When this is not the case the aperture becomes a light well and exhibits different distribution patterns. The ratio for this situation relates the depth of the aperture to the height of the aperture above the floor (*O*). The fig below (Fig 7.12) illustrates the ratio variables.

N = H/w

O = H/O

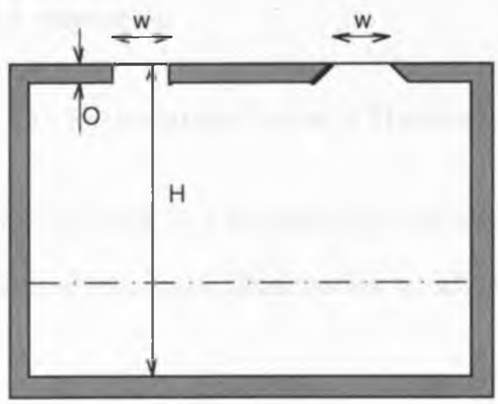
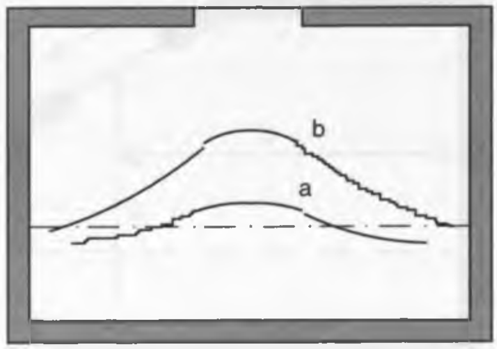


Figure 7.12: Ratio variables - Horizontal aperture

The standard pattern of a single skylight under an overcast sky, shows a peak maximum illumination level directly below the opening with light levels falling off sharply to either side. Factors affecting this pattern include the installation of multiple skylights, which will provide a more even level of illumination. Varying *M* will affect the longitudinal spread of light, whilst altering *N* will result in a reduced maximum illumination level and a flattened slope to the lighting level curve. Altering *O* has significant effects on both the maximum illumination attained and the spread of light within the space. The figure below (Fig. 7.13) illustrates the basic curve for a single skylight.



a: clear sky
b: overcast sky

Figure 7.13: Penetration curve - Horizontal aperture

The differences of pattern displayed by a horizontal aperture under a clear sky concentrate on the position of the point of maximum illumination which will move depending on the position of the sun.

Angled Apertures

Angled apertures are skylights set in an angled roof. The ratio of the distance from the floor to the midheight of the aperture to the width of the aperture (G) and the ratio of the distance from the opposing wall to the middepth of the aperture, to the distance from the floor to the midheight of the aperture (Q) are specific to this system. The figure below (Fig. 7.14) indicates the relevant ratios.

G = G/w

Q = Q/G

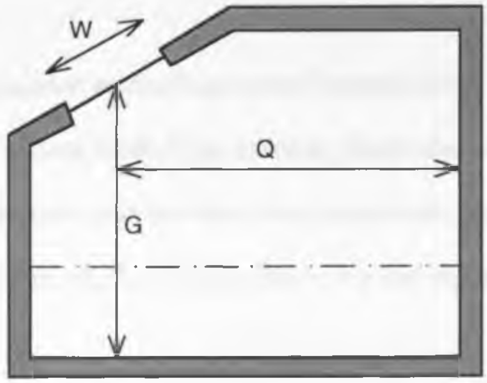


Figure 7.14: Ratio variables - Angled aperture

The most distinct feature of the penetration pattern for this scheme is that the light levels either side of the point of maximum illumination are not equal. This pattern can be used to create two distinct areas within a space, with differing lighting characteristics. The figure below (Fig. 7.15) illustrates this light pattern.

Differing sky conditions produce minimal variation in the lighting curves produced by this system, although the point of maximum illumination may move with the position of the sun in clear sky conditions.

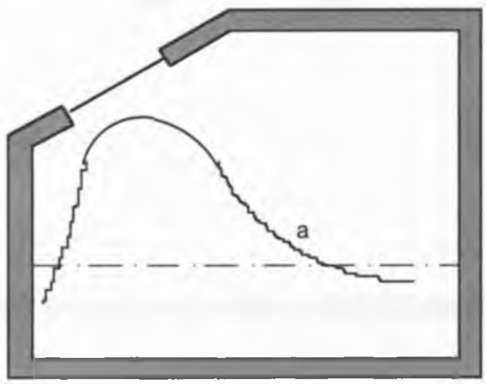


Figure 7.15: Penetration curve - Angled aperture

Sawtooth Apertures

Sawtooth apertures are usually vertical apertures located above the ceiling line, coupled with an adjacent angled ceiling with light entering from one direction only. Variations exist utilizing angled apertures and bi-directional apertures, the later being referred to as butterfly roofs. The location of this system above the ceiling line differentiates it from clerestories.

Additional ratios for a sawtooth system are the ratio of the floor to ceiling height to the length of the sloped surface of the aperture (*S*), and the ratio of the length of the sloped surface of the aperture to the distance between the apertures (*W*). The figure below (Fig. 7.16) indicates the ratio variables.

S = S/f

W = S/W

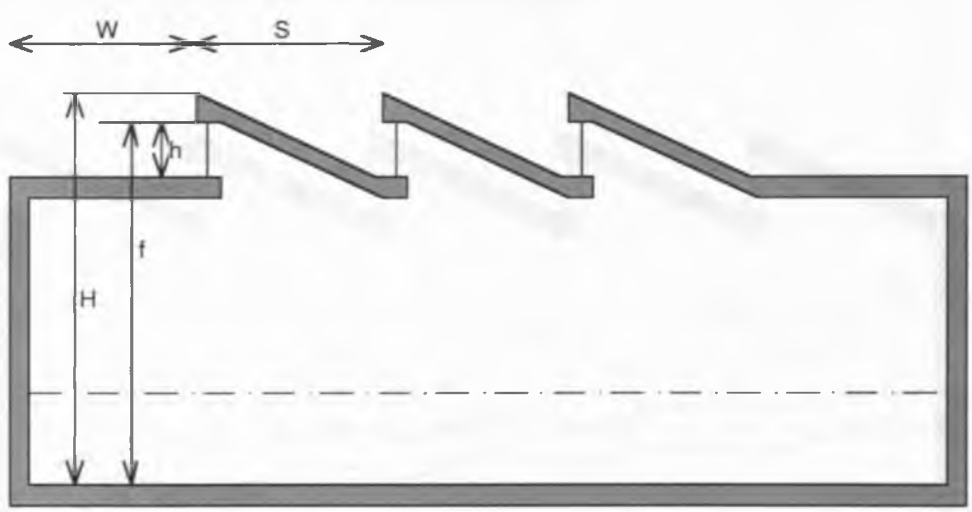
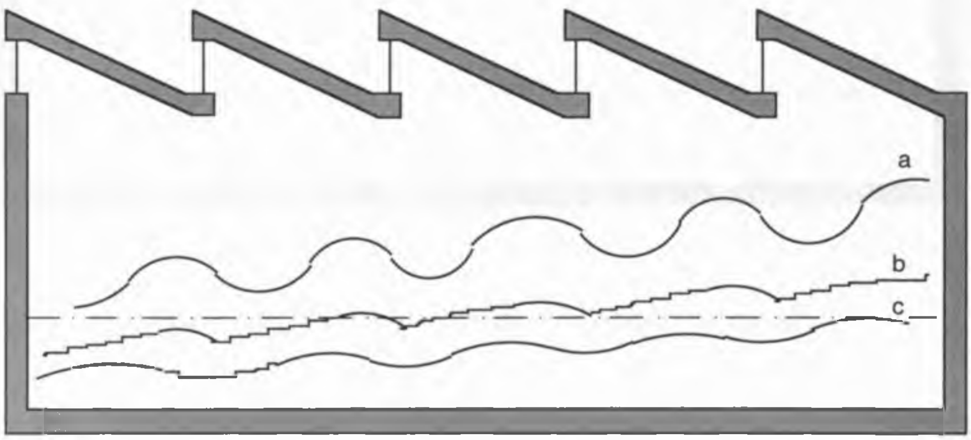


Figure 7.16: Ratio variables - Sawtooth system

Sawtooth apertures are usually used in series, the pattern displayed by a single aperture is different to that displayed by a series of three or more. A minimum of three apertures are needed to establish what is considered the typical sawtooth lighting curve. The figure below (Fig. 7.17) illustrates this basic curve for differing sky conditions and building orientations.

Vertical apertures located above the ceiling line are exposed to different sky luminance values than those located below the ceiling line and are more readily affected by differences in sky conditions. Different sky conditions and different orientations will therefore alter the pattern of light penetration and distribution.

Varying the distance between the apertures (*W*) increases the difference between the maximum and minimum values of illumination. If the angle of the glazing is altered, the pattern begins to resemble that of a series of angled apertures. Butterfly roofs display patterns closely resembling that of a monitor system.



a: clear sky, aperture facing sun
b: overcast sky
c: clear sky, aperture opposite sun

Figure 7.17: Penetration curve - Sawtooth system

Monitor Apertures

The monitor system differs from the sawtooth system in that paired bilateral apertures are provided, which by definition, open to opposing parts of the sky vault.

The same ratios apply to a monitor system as to a sawtooth system but with the complication of the additional aperture. The effect of bilateral light access is most pronounced when considered under clear sky conditions. The figure below (Fig. 7.18) indicates the ratio variables applicable to a monitor system.

S = S/f

W = S/W

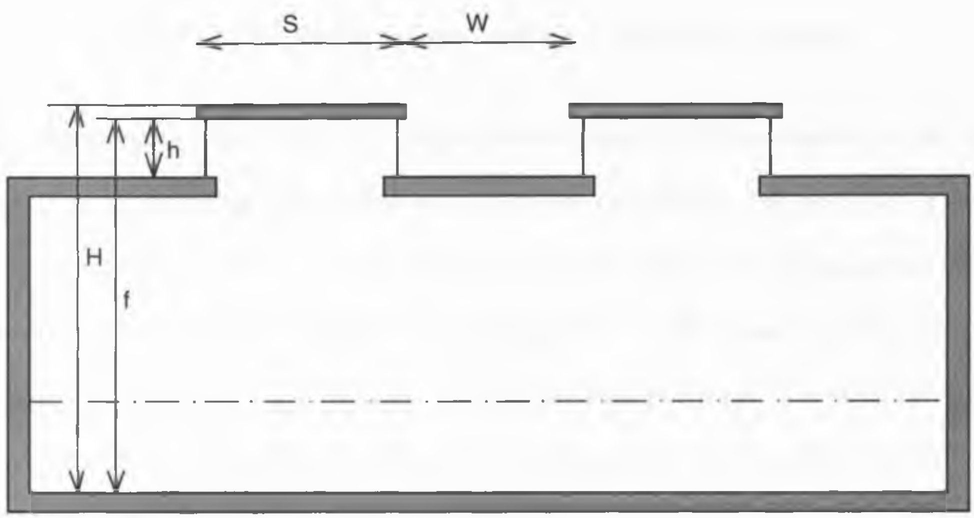
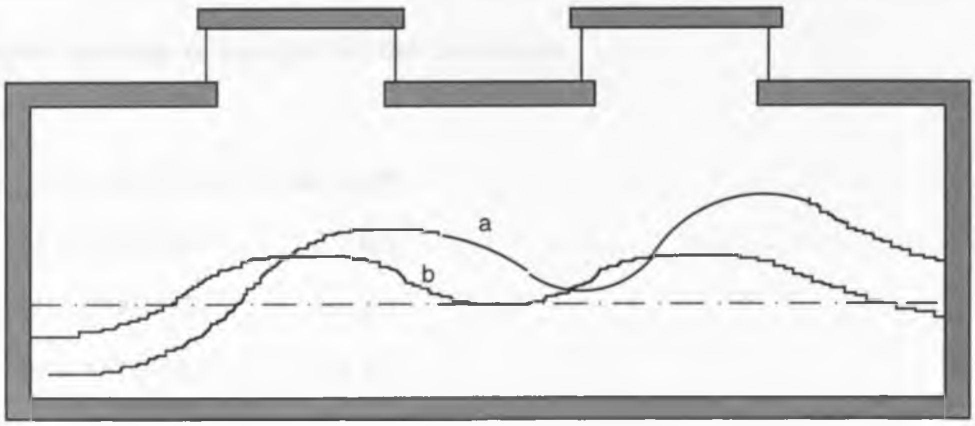


Figure 7.18: Ratio variables - Monitor system

A series of apertures are needed to establish a typical monitor pattern and differences are apparent at the edges of the series. The standard monitor lighting curve displays points of maximum illumination directly below the raised portion of the monitor. Illumination levels are equal on either side of this point under overcast skies, and unequal under clear skies due to the influence of the sun. The figure below (Fig 7.19) indicates the basic curve for these two sky conditions.



a: clear sky, apertures facing and opposite sun
b: overcast sky

Figure 7.19: Penetration curves - Monitor system

If M is manipulated the maximum and minimum levels of illumination can be altered with the curve becoming flatter, and with clear sky conditions, the position of maximum illumination can be moved. Varying the H ratio shifts the points of maximum illumination and stretches out daylight distribution. Altering the S or W ratio has the most significant impact on the position of the points of maximum and minimum illumination. Orientation affects which parts of the sky the apertures are exposed to and therefore exerts considerable influence on daylighting distribution.

Daylighting Strategies

Existing Daylighting Systems

The basecase has large windows located in the north and south facades which provide a substantial quantity of daylight for the classrooms.

The ratios for the North windows are:

H = 2143/1371 = 1.6:1

V = 2700/1371 = 2:1

M = 4570/1371 = 3.3:1

These ratios will vary from the basic ratios in that the altered H value, due to the raised sill, will drop the maximum illumination point slightly. The change in the V value will also create a drop in maximum illumination, as will the reduction in the M value. This window has a higher sill and a lower head and is not as wide as the standard one.

The resultant light penetration and distribution will be less than that apparent in the standard curve but will follow a similar pattern with the point of maximum illumination occurring adjacent to the wall and falling off as it enters the room.

The ratios for the South windows are:

H = 2143/1200 = 1.8:1

V = 2700/1200 = 2.3:1

M = 4570/1200 = 5.3:1

These ratios show variations similar to those of the north facade windows, despite the windows being significantly wider with a higher sill.

The rooflights in the basecase are angled apertures. They run parallel to the slope of the roof and therefore face both North and South. These apertures focus daylight into the center of the space and are advantageous in balancing out the light entering through the windows.

The figure below (Fig. 7.20) plots the lighting curves for the basecase. One curve has been charted using points in the center of the space, the other shows the lighting curve against the west wall.

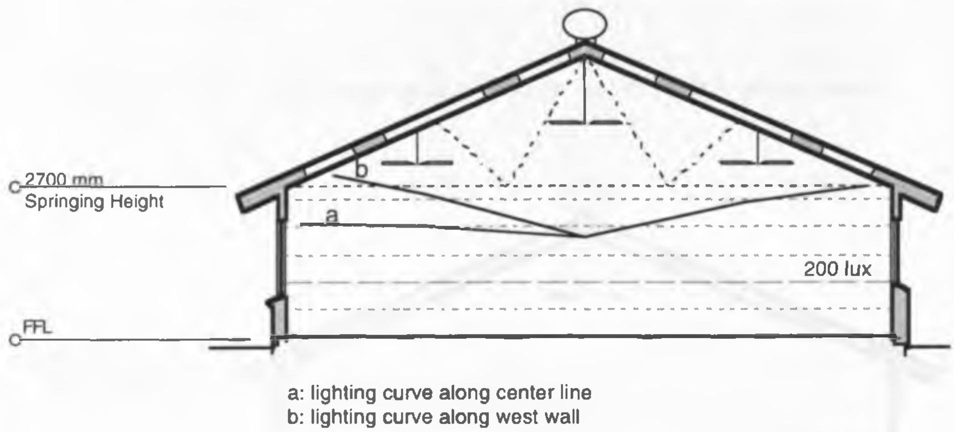


Figure 7.20: Lighting curves - Basecase (with windows)

The photograph below (Fig. 7.21) provides an indication of the light distribution within the space. Light is obviously concentrated at the windows, although the light level is relatively uniform throughout the space.

Figure 7.21: Photograph of Base case (with windows)

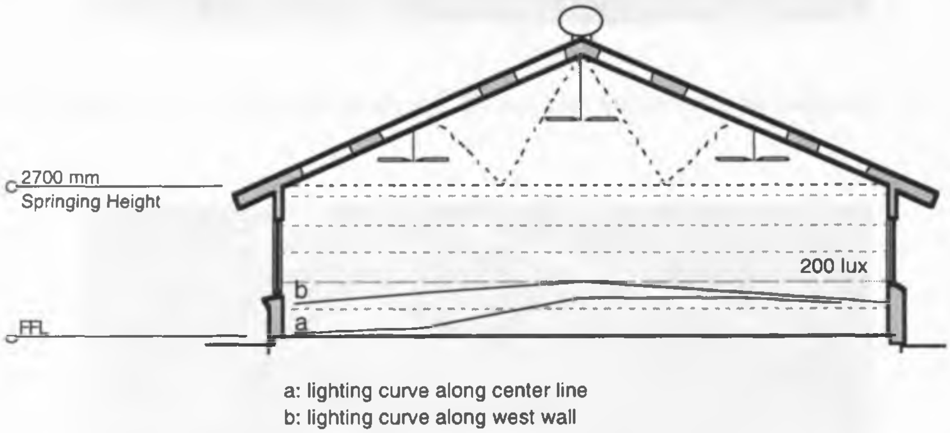


Figure 7.22: Lighting curves - Basecase (without windows)

The basecase rooflights are not particularly effective on their own. When simulations were run without the windows, the resultant light curves where significantly flatter, with the point of maximum illumination occurring in the center of the room, the point where the light from opposing skylights will merge. The figure above (Fig. 7.22) displays these findings.

The photographs in the following figures (Fig. 7.23, 7.24) show the basecase without windows. The truncation of the rooflights is clearly visible in the second of these images (Fig. 7.24).

Figure 7.23: Photograph of Basecase (without windows)

Figure 7.24: Photograph of Basecase (without windows)

Proposed Daylighting Systems

The base case as designed has extensive sidelighting systems in place. The toplighting system is minimal and does not fully utilize the potential of a single story building for daylight penetration, so a series of toplighting strategies were investigated.

Investigation Procedure

The investigation of possible daylight strategies was undertaken using a combination of photometric and photographic methods, utilizing a "mirror-box" artificial sky, to provide an accurate and consistent light source that can closely match a designated sky type.

The "mirror-box" type artificial sky is a rectangular light tight box with interior walls clad with mirrors, the ceiling is composed of fluorescent lamps and a diffuser panel to provide diffuse light. The multiple inter-reflectance generated by the mirrors created a simulation of an overcast diffuse sky, with a luminance distribution similar to that of the CIE overcast sky.

To produce useable results the variables within the scale model that effect light penetration and distribution need to be accurately rendered. Interior surfaces need to be of a reflectance similar to that of the actual space and apertures need to be sized and placed correctly. Depending on the type of research being conducted, interior fixtures and furnishings can be included but are not essential to overall general readings.

When a scale model is placed in the "mirror-box", photometric and photographic results can be generated for analysis.

Photometric Analysis

The design of daylighting systems requires an analysis of both the quantity and quality of the light that penetrates into, and is distributed within, the space.

Photometric analysis provides information related to the quantity of light available at specific points within the space. Light sensors are used to measure the light levels achieved by the various systems being studied. The figure below (Fig. 7.25) indicates the location of the sensors within the study model.

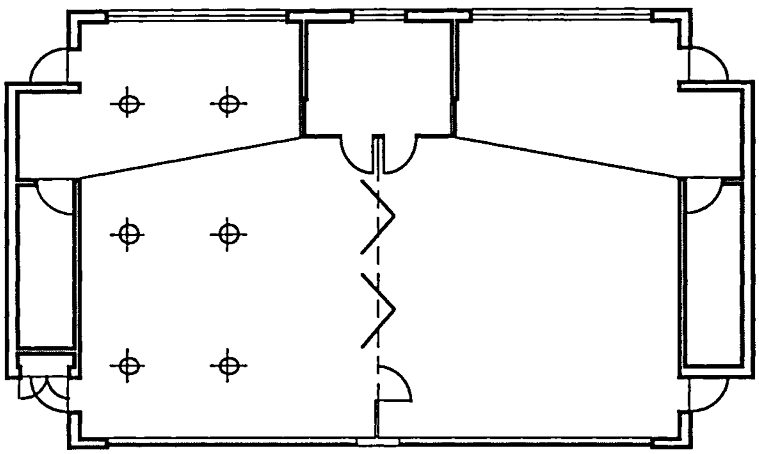


Figure 7.25: Location of light sensors

From these sensor readings graphs can be generated that indicate the distribution of light within the space and the variation in light levels across the space. The quantity of light can be measured as an illuminance level or as a factor of available exterior daylight.

Photographic Analysis

The quality of light within a space is as important as the quantity of light. The way in which light interacts with the physical design elements of the room will influence the success of a daylighting system.

Photographic analysis involves photographing the interior of the scale model in such a way that the space can be conceived of as if it was being viewed at full scale. The photographs reproduced in this paper were taken using a 28mm lens, set so that eye level was consistent with the scale model. These images graphically indicate the nature of the light within the test space.

Sawtooth System

The first system to be examined was a sawtooth layout, utilizing a series of four rooflights equally spaced across the depth of the room, with the glazed areas oriented north. The figure below (Fig. 7.26) indicates the ratio variables for this strategy.

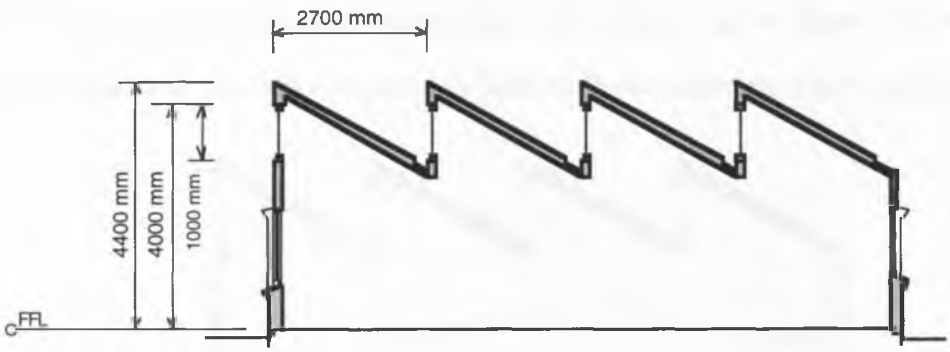


Figure 7.26: Ratio variables - Sawtooth

The spatial ratios are as follows:

H = 4400/1000 = 4.4:1

M = = ∞ :1

S = 2700/3700 = 0.7:1

W= 2500/0

The figure below (Fig. 7.27) indicate the resultant curves generated by this system, when it was simulated with the sidelight windows. The additional light is most obviously of advantage against the north wall.

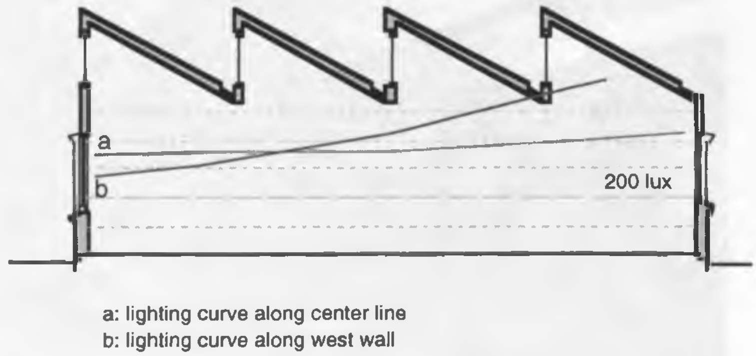


Figure 7.27: Lighting curves - Sawtooth (with windows)

The lighting values for the sawtooth system alone are presented in the figure below (Fig. 7.28) this demonstrates the classic increase in lighting levels under successive apertures.

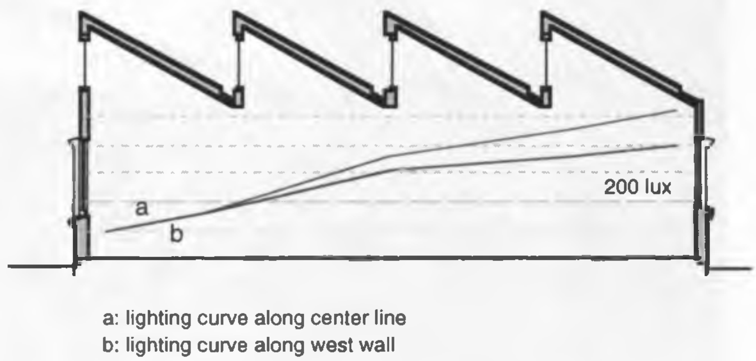


Figure 7.28: Lighting curves - Sawtooth (without windows)

The photographs below (Fig. 7.29, 7.30) demonstrate the advantages and disadvantages of this system. Light is fairly uniformly distributed within the space and the ceiling is well illuminated. The apertures have been continued to the external walls and therefore these walls are receiving high levels of light, although there is some shadowing related to the rhythm of the apertures. The north wall is also markedly darker (Fig. 7.29) despite the presence of windows.

Figure 7.29: Photograph of Sawtooth strategy

Figure 7.30: Photograph of Sawtooth strategy

One of the problems associated with this system is glare, as evidenced in the photographs, where very large, very bright areas are within the viewers field of vision. This situation can be tempered by using tinted glazing materials or other shading apparatus. These measures would need to be installed in order to facilitate the "brown out" of the classroom for audio visual displays.

Monitor System

This strategy consisted of four monitors that were evenly spaced across the depth of the room. The glazed apertures were oriented to face north and south. The findings indicate the results achieved by an overcast sky simulation, so orientation was less of a factor than it would be in a clear sky situation. The figure below (Fig. 31) indicates the ratio variables for this strategy.

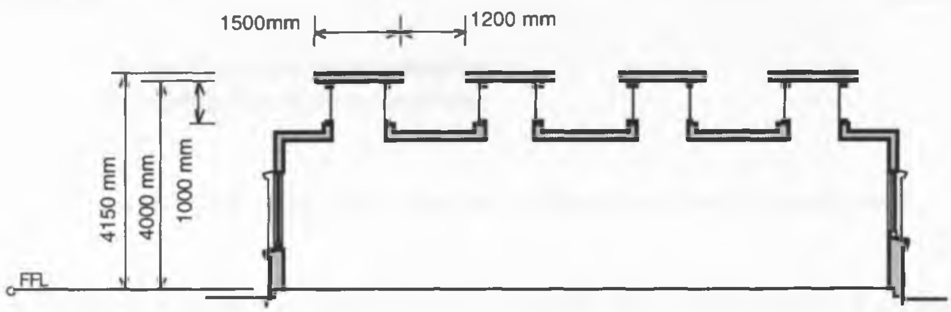


Figure 7.31: Ratio variables - Monitor

The ratios used were:

H = 4150/1000 = 4.1 :1

M = = ∞ : 1

S = 4150/1500 = 2.8 : 1

W = 1500/1200 = 1.2 : 1

The figure below (Fig. 7.32) graphs the results obtained for this monitor system, in conjunction with the windows. The light curves display the more uniformity of light levels obtainable with this type of system. The monitors in this case have a small *S* ratio and this increases the light level as a higher proportion of glazing is included over a given floor area.

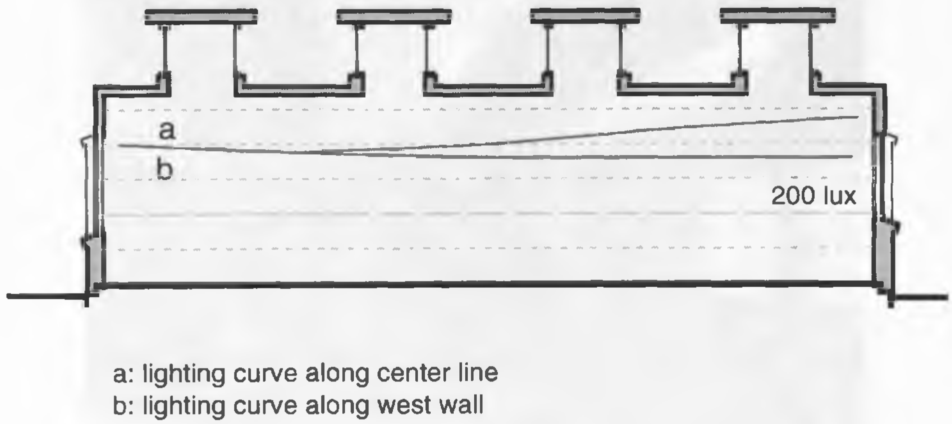


Figure 7.32: Lighting curves - Monitor (with windows)

When this system was simulated without the windows, the results showed a distinct point of maximum illumination. The figure below (Fig. 7.33) graphs these results.

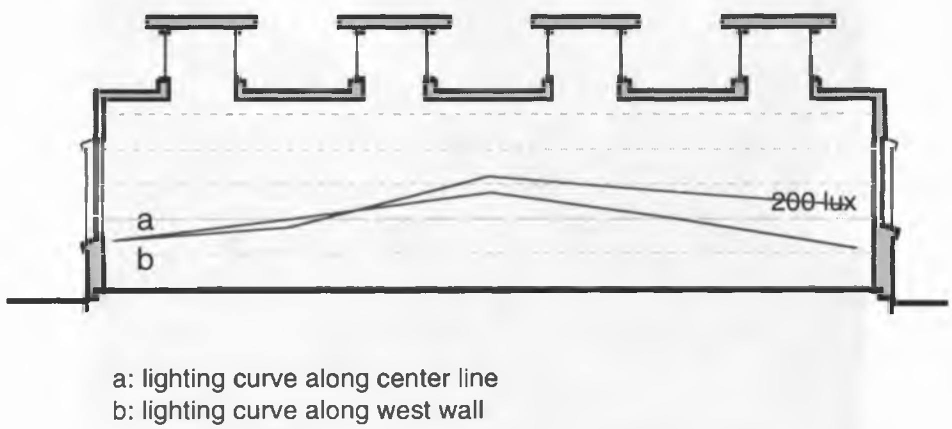


Figure 7.33: Lighting curves - Monitor (without windows)

The photographs below (Fig. 7.34, 7.35) indicate the uniformity of light distribution within the space and the equivalent light levels of the walls, some shadowing is seen on the walls perpendicular to the monitors. There is also evidence of glare, although measures similar to those outlined for the sawtooth system would greatly alleviate these problems.

Figure 7.34: Photograph of Monitor strategy

Figure 7.35: Photograph of Monitor strategy

Endnotes

[1] Lechner, p283.
[2] Szokolay, p156.
[3] Robbins, p10.
[4] Robbins, p4.
[5] Szokolay, p103.
[6] Szokolay, p103.
[7] Robbins
[8] Robbins, p65.
[9] Robbins, p66.
[10] Robbins, p66.
[11] Robbins, p66.
[12] Robbins, p66.
[13] Ching, p271.
[14] Ching, p274.
[15] Robbins, p80.

THERMAL STRATEGIES

Table of Contents

Table of Figures

Preceding chapters have presented information pertaining to the two primary variables in the bioclimatic equation. This chapter will resolve this equation as it relates to the thermal environment; identify the conditions that require control and present strategies that can accomplish this.

Required Controls

In order to identify climatic conditions requiring control a Building Bioclimatic Chart was created for the climate being considered. The chart below (Fig. 8.01) plots the monthly climatic conditions as a series of lines, with the comfort zone as indicated.
(see Appendix E)

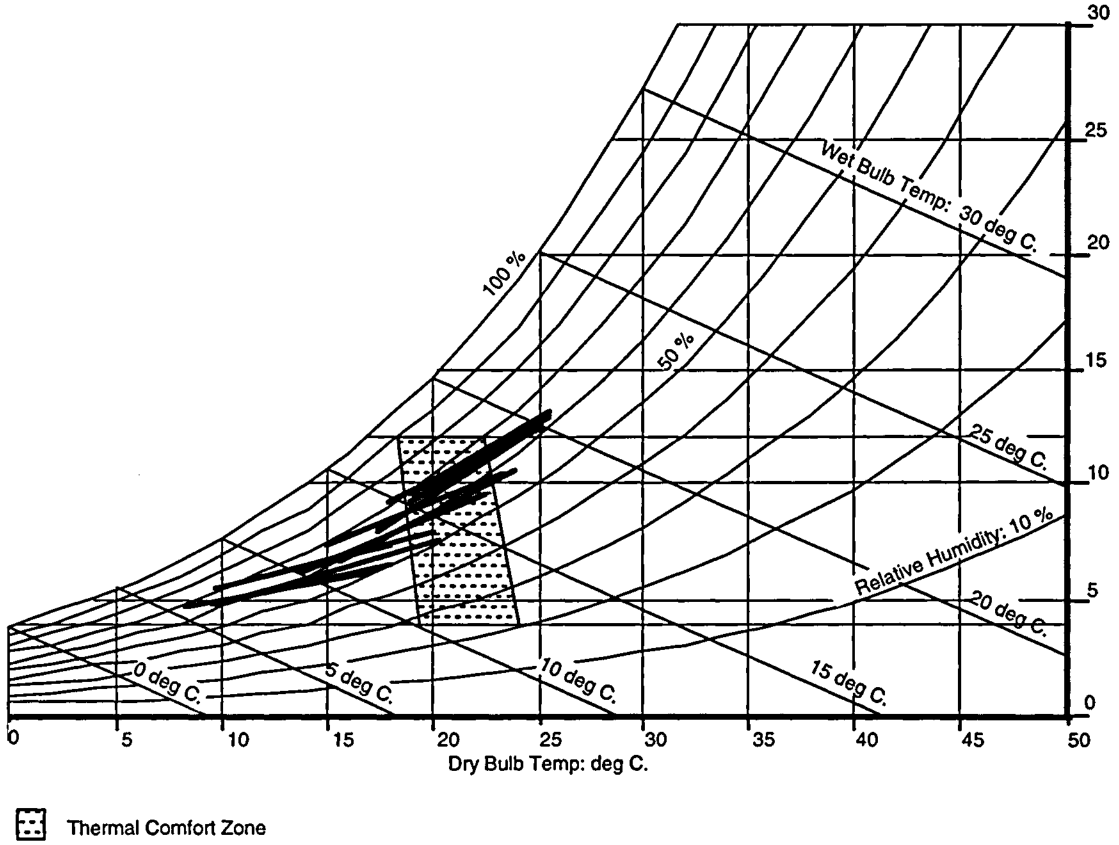


Figure 8.01: Building Bioclimatic Chart[1]

Analysis of this chart indicates that although Sydney experiences a temperate climate, for at least some part of the day, during all months of the year, conditions are such that they occur outside the thermal comfort zone. During the summer months of December, January and February, the maximum conditions experienced are above the upper limit of the comfort zone, whilst the minimum conditions are at the lower end of the zone. During the winter months of June, July and August, both maximum and minimum conditions are below those of the comfort zone. The figure below (Fig. 8.02) tabulates the monthly conditions in relation to the need for heating and cooling. Overall, heating is the most important thermal requirement.

Month	Max. Temp *Strategy Required:*	Min. Temp *Strategy Required:*
January	Cooling	Comfortable
February	Cooling	Comfortable
March	Cooling	Heating
April	Cooling	Heating
May	Comfortable	Heating
June	Heating	Heating
July	Heating	Heating
August	Heating	Heating
September	Comfortable	Heating
October	Comfortable	Heating
November	Cooling	Heating
December	Cooling	Heating

Figure 8.02: Indication of Monthly Thermal Comfort

These charts are generated from monthly mean climatic data and not from the extremes that can occur, which by definition would be further removed from the zone of thermal comfort.

Building Occupancy

The range of temperature and humidity plotted on the Building Bioclimatic Chart gives an accurate indication of the climatic conditions, but other variables need to be considered in order to form a comprehensive overview of the climate as it relates to a specific building. These variables relate to the occupancy of the building, when the building is occupied, and who the occupants are.

School classrooms are usually occupied by a teacher and students between the hours of 8:00 a.m. and 4:00 p.m. Before class the teacher may be the only occupant and after class some classrooms may be used for after-school care, community classes or meetings. Therefore, the room might be occupied from 7:00 a.m. till 10:00 p.m., but rarely overnight.

Thermal comfort need only be achieved within the classroom space whist it is occupied. A cooling down of the room overnight is not a problem as long as it can be warmed up in time for the beginning of the school day.

Occupancy of school classrooms is not consistent throughout the year. In New South Wales schools close for a summer recess from the middle of December until the end of January. Other two week breaks occur throughout the remainder of the year but these have little effect on the thermal control of the building as they are not of a long enough duration.

Having determined what controls are necessary throughout the year it is now possible to look at the methods available to provide them. Controls can be divided into two primary types: active controls, utilizing Heating, Ventilation, Air Conditioning (HVAC) systems, and passive controls, utilizing non mechanical systems. This paper concentrates on the use of passive systems, but will provide a brief overview of active controls will be presented.

Building Thermal Balance

To determine the thermal balance of a building three primary heat flow rates must be calculated: heat gain or loss, the cooling or heating load and the heat extraction or addition rate[2].

Heat gain is "the rate at which heat enters or is generated within a space at a given instant"[3], and can be "classified by the manner in which it enters the space"[4], such as:

- "Solar radiation through fenestration.
- Heat conduction through the envelope.
- Heat generated within the space by people, lights, electrical equipment or appliances, or any other electrical, mechanical , or thermal processes within the space.
- The exchange of cool indoor air for warmer outside air by infiltration and/or ventilation."[5]

Heat loss is "the rate at which heat flows out of a space to the surrounding environment"[6]. This flow can be classified as:

- "Heat conduction through the envelope.
- The exchange of warm indoor air for cold outside air by infiltration or ventilation."[7]

Active Thermal Controls

Active thermal controls involve the mechanical addition or subtraction of heat from a space in order to offset heat gains and losses and maintain interior conditions at a comfortable level.

Design Temperatures

Prior to embarking upon heating and cooling load calculations it is necessary to determine certain parameters. Design temperatures must be determined for both indoor and outdoor conditions. The indoor design temperature is set by the thermal comfort zone, whilst the outdoor design temperatures are set by climatic conditions.

The winter indoor design temperature was selected at 22°C, whilst the outdoor design temperature was selected at 5.6°C, representing the lowest temperature experienced for 97.5% of the time during the months of June, July and August.

The summer indoor design temperature was set at 23°C, and is at the lower end of the comfortable range due to the nature of the occupancy of the space (i.e. approximately 30 active children in each class). The outdoor design temperature is based on peak summer conditions and represents "the hottest temperature, the highest likely coincident solar heat gain, maximum occupancy, and the highest simultaneous equipment on line"[8]. The temperature selected was 28.9°C and is the 2.5% Design Dry Bulb (DDB), so only 75 hours of this three month period will exceed this situation.

Required Heating Capacity

Calculation of a heating load provides a figure that represents the amount of energy that will need to be added to a building to offset the heat losses. The components of a building heat load include:

- "Transmission heat loss through:-
    - Fenestration.
    - Opaque walls.
    - The roof.
    - The floor, below grade walls, slab edge, etc.
- Outside air heat losses:-
    - Due to infiltration and/or ventilation."[9]

When calculating the heating load all the above factors need to be considered. Transmission heat loss is calculated for all exterior surfaces using the formula:

Load = net area x U-factor x ΔT

Outside air load is calculated using the formula:

Load = L/s x O.A. factor x ΔT

Total heat loss is the addition of all these calculations. (see Appendix F)

Heat loss for the basecase was calculated at 377.5 kW. This is a peak heating load and indicates the maximum heating that will be required in the building during the year. This figure can be translated to a rate of fuel consumption if additional factors such as year round climatic conditions and fuel efficiency are considered.

Required Cooling Capacity

The procedure for calculating cooling loads is similar to that for heating loads, but is more complex. The peak cooling load condition does not correlate to the incident of highest heat gain because some of the gain is absorbed by materials present in the space and will not be released until a later time. The components of a building cooling load include:

- "Solar heat through fenestration.
- Transmission heat gain through:-
    - Fenestration.
    - Opaque walls.
    - The roof.
- Internal heat gain from:-
    - People.
    - Lights.
    - Electrical appliances and equipment.
- Outside air heat gain:-
    - Due to the exchange of cool indoor air for hot outside air by infiltration and/or ventilation."[10]

In calculating cooling loads, both latent and sensible heat gains are considered.

Solar gains are calculated using heat gain factors and shading coefficients.

Transmission gain is calculated using the formula:

Load = net area x U-factor x ΔT

Internal heat gain is calculated from a survey of occupants and equipment.

Heat gain from outside air is determined by the formula:

Load = L/s X O.A. factor x ΔT

Total cooling load is an addition of these calculations. (see Appendix F)

The cooling load for the basecase was calculated at 463.5 kW. This is a peak cooling load and indicates the maximum cooling that will be required in the building during the year. As with the heating load, this figure can be translated into a rate of fuel consumption when additional factors such as year round climatic conditions and fuel efficiency are considered.

Active Strategies

In choosing an HVAC system the basic elements must first be decided upon. These include:

- "Equipment to generate heat or cooling.
- A means of distributing heat, cooling, and/or filtered ventilation air where needed.
- Devices that deliver the heat, cooling, and/or fresh air into the space."[11]

The diagram below indicates these HVAC elements (Fig. 8.03).

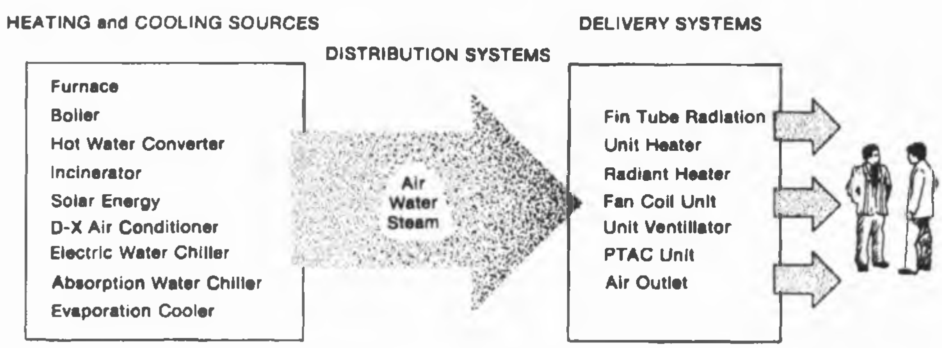


Figure 8.03: HVAC Elements[12]

A series of interconnected issues will determine which system is selected. These issues include: initial and life cycle costs; suitability for the intended occupancy; floor space required for equipment; maintenance requirements and equipment reliability, and simplicity of controls[13].

Passive Thermal Controls

Passive control systems do not rely on mechanical equipment but rather utilize the fabric of the building itself and its surroundings to control and enhance the thermal environment within the building.

The building is looked upon as a "combined solar collector and storage unit"[14]. It can be conceived as being composed of the following elements: solar collectors or glazed apertures that are exposed to the sun; a means of storing the heat that is collected; and an insulated outer skin to restrict the flow of energy[15]. Depending on the control required, different permutations of these elements will produce the desired effect.

In order to evaluate the strategies presented, computer simulation was performed using the Calpas[16] program. A basecase was developed that represented the home base block as it is currently designed, and then each strategy was simulated independently to observe its impact upon energy usage. The results have been used to compare the effectiveness of one strategy in relation to another, rather than for quantitative calculation of energy usage.

A preliminary analysis of the Building Bioclimatic Chart provided an initial indication of the controls that would be required to provide thermal comfort within a building located in Sydney. A more detailed analysis can be undertaken if the Building Bioclimatic Chart is enhanced with the inclusion of potential control zones. These zones, shown on the chart below (Fig 8.04) indicate the passive strategies that will be most effective in combating the extremes of climate that occur. From this chart it is possible to deduce for each month a set of strategies that can passively counter the existing climatic conditions. A tabulated form of these findings is presented below (Fig. 8.05).

Requirements for passive heating occur for a substantial part of the year. The period from May to October experiences under heating for at least part of the day, with conditions dropping into the solar input and winter mass effect control zones. Passive cooling is also required during the year, with the period from October to April experiencing overheating for part of the day. During these months conditions rise into the summer mass effect and increased ventilation control zones.

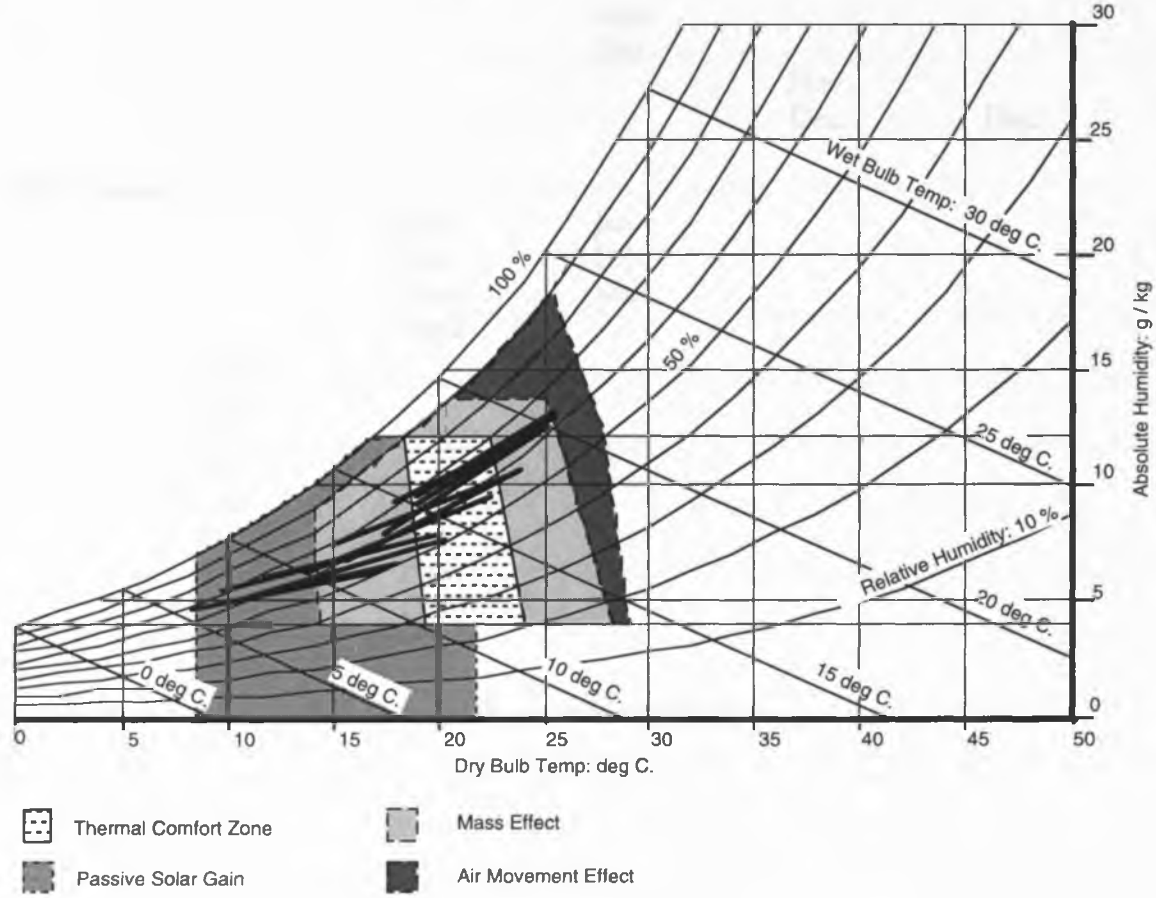


Figure 8.04: Building Bioclimatic Chart (with Control zones)

Thermal Strategy	Solar Input Indicated *Heating*	Mass Effect Indicated *Heating*	Thermal Comfort	Mass Effect Indicated *Cooling*	Ventilation Indicated *Cooling*
Max. Temps					
				Jan.	Jan.
				Feb.	Feb.
				Mar.	
				April	
			May		
		June			
		July			
		Aug.			
			Sept.		
			Oct.		
				Nov.	
				Dec.	Dec.
Min. Temps					
		Jan.	Jan		
		Feb.	Feb.		
		Mar.	Mar.		
		April			
	May				
	June				
	July				
	Aug.				
	Sept.				
	Oct.				
		Nov.			
		Dec.			

Figure 8.05: Monthly Strategy Recommendations

Passive Solar

Passive methods of heating a space utilize the solar energy of the sun. This energy is allowed to penetrate the building envelope and heat the interior. Strategies fall into three distinct forms: direct gain, thermal storage walls and sunspaces[17]. The primary differences in these systems lie in the relationship between the aperture and the mass associated with it.

Passive solar systems require some combination of the following elements;

- equatorial facing glazed apertures
- mass material for energy storage.

Within these elements there exists endless variations but the basic concept does not change. An aperture is required to allow solar energy to penetrate into the building. This aperture is usually glazed so as to take advantage of the imperviousness of glass to short wave radiation. Solar energy, which is long wave radiation, is transmitted through the glass. It interacts with materials within the space and is re-radiated as short wave radiation which cannot exit through the glass, so is effectively trapped within the building, providing heat. Mass acts as a collector, by absorbing some of this heat and storing it until the laws of thermodynamics dictate that the reverse will occur, whereupon the mass radiates the heat into the space. The inclusion of mass in passive solar systems serves to even out solar gain.

Direct gain systems rely on solar energy directly entering the space and warming it. Mass is not an integral part of this system, although it does enhance its efficiency. Variations to this system involve a choice of glazing, size and orientation of apertures, and shading and insulation of the glass.

Thermal storage wall systems require mass to be located directly adjacent to the glazing. Solar energy passes through the glass and strikes the mass, which absorbs the heat. The heat delivery to the space is therefore delayed. The apertures used in this system cannot function as view apertures, because of the adjacent mass blocking it. This system is not efficient at providing heating during the day, so is often combined with a direct gain system.

The last type of passive solar systems are sunspaces. These developed from the concept of greenhouses and are an extension of the thermal storage wall system. In this system the mass wall is pulled away from the glazed aperture resulting in the formation of a room. Variations in this system arise from the way in which the sunspace is connected to the space and the way heat is transferred from the sunspace to the space.

Passive solar systems rely on maximizing solar energy collection. Strategies to improve their efficiency include, maximizing equatorial facing windows (north windows in the Southern Hemisphere), installing roof lights and shaping and orienting the building as a whole so as to increase its exposure to the winter sun. Other strategies to increase the amount of solar energy entering the space include, enhancing the reflectance of surrounding ground surfaces and using reflectors to bounce heat into the space.

These systems have an inherent problem because of the low insulation value of glass. While glazed apertures allow solar energy to enter the building during the day, at night they are the biggest source of heat loss through the envelope of the building. Strategies to offset this problem include minimizing glazing in all the walls that do not receive constant winter sun, namely the east, south and west walls. Apertures in these walls do not receive enough sun during the day to counter the loss of heat at night. Another strategy is to utilize some method of insulating the glass. This can take numerous forms but basically involves using another material to cover the glazing at night to allay heat loss.

In choosing strategies suitable for improving the basecase consideration was given to its current design and its intended function.

The basecase currently has large amounts of glazing on the north facade so increasing this area was not practical. The option of incorporating roof lights was addressed in relation to the provision of daylighting. The orientation of the basecase is hypothetical and currently the long elevation of the building faces north, which is ideal. Therefore the strategy that was investigated concentrated on increasing the solar heat being bounced into the building by increasing the reflectance of surrounding ground surfaces. Changes were not significant with only a 5% drop in heating load. However, the cooling load was significantly increased, illustrating that in trying to solve one issue another can be exacerbated..

Strategies designed to reduce heat loss through glazing were more effective. The removal of south facing windows dramatically reduced both heating (12%) and cooling loads (1. However, such a dramatic design change would seriously compromise daylighting and psychological comfort within the classrooms. The simulated installation of night insulation was effective at reducing cooling loads but had no effect on heating loads.

Passive solar input is primarily a heating strategy and when climatic conditions cause overheating of the space, the heat intake must be controlled by blocking or reflecting solar access to both the opaque and transparent components of the external envelope. The walls will transmit heat to the interior at a rate which is dependent on the material and the presence or absence of insulation materials. The windows provide the biggest source of solar energy input. This can be used to advantage when heating is required, but is deleterious when cooling needs are paramount.

Shading is the most commonly utilized cooling strategy and needs to be provided for all solar gain windows and can be used for walls as well. The design of shading for windows depends on the solar path, the times that solar input is undesirable and the window size and orientation.

The graph below shows the solar path for Sydney (Fig. 8.06). From this diagram it is possible to calculate the position of the sun in relation to both azimuth and altitude, at any time of the day, for a representational day of each month of the year.

In order to calculate when solar input is undesirable the hourly temperatures are tabulated for a representational day for each month of the year (Fig. 8.07). Any time of the day during which the temperature rises above 21°C, overheating can occur. When these times are transposed onto the solar path an area corresponding to the times that it would be desirable to exclude solar input from the building is shown (Fig. 8.08). Design of a shading device involves devising a combination of vertical and horizontal fins in a configuration that allows solar energy to enter the apertures when heating is required, but be blocked when overheating is likely to occur.

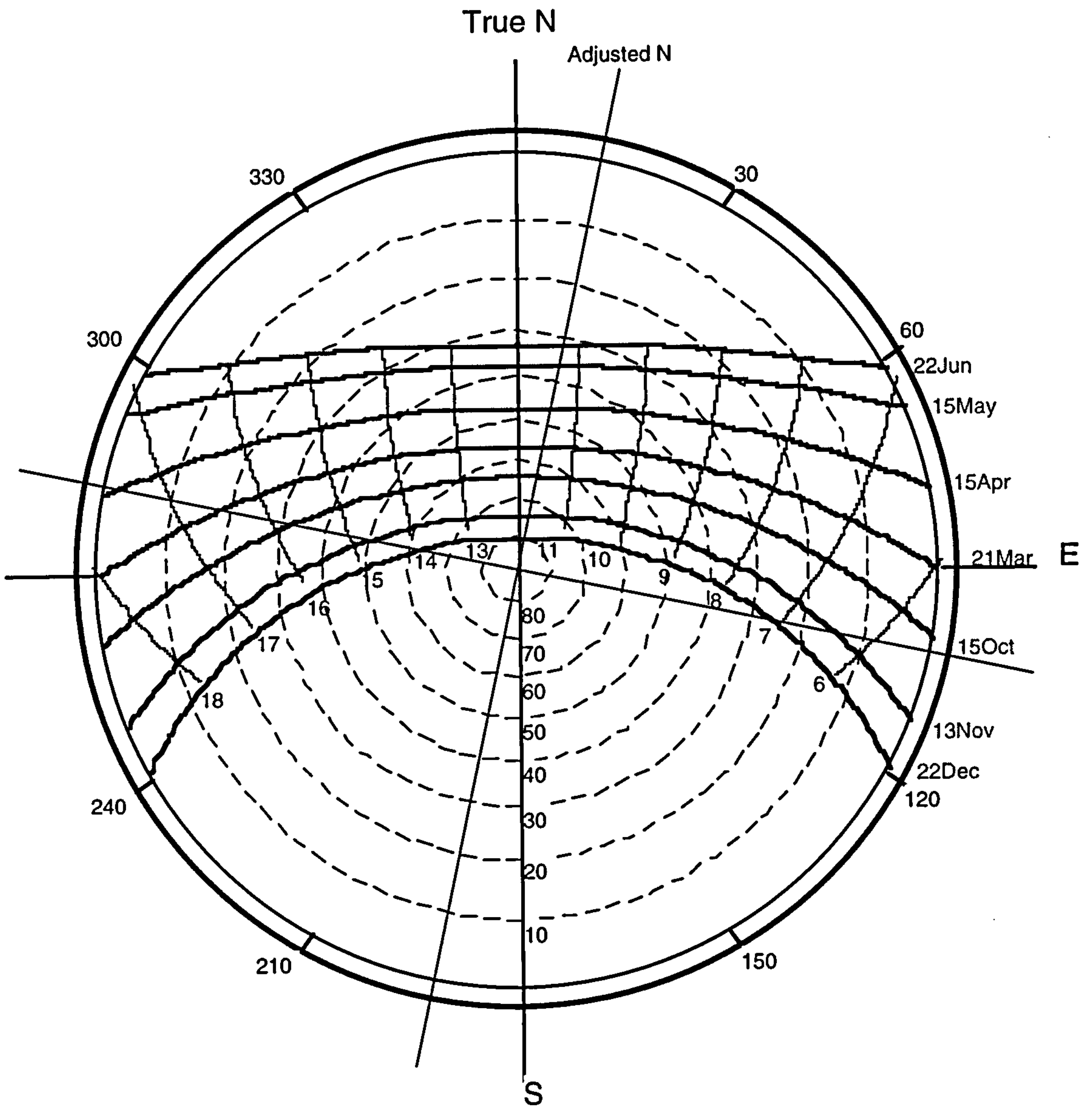


Figure 8.06: Solar Path for Sydney, Australia.[18]

Month	From:	To:
January	9:00 am	10:00 pm
February	9:00 am	10:00 pm
March	9:30 am	7:45 pm
April	11:00 am	5:45 pm
May	N/A	N/A
June	N/A	N/A
July	N/A	N/A
August	N/A	N/A
September	N/A	N/A
October	11:30 am	5:00 pm
November	10:15 am	6:15 pm
December	9:30 am	7:45 pm

Figure 8.07: Monthly overheated period

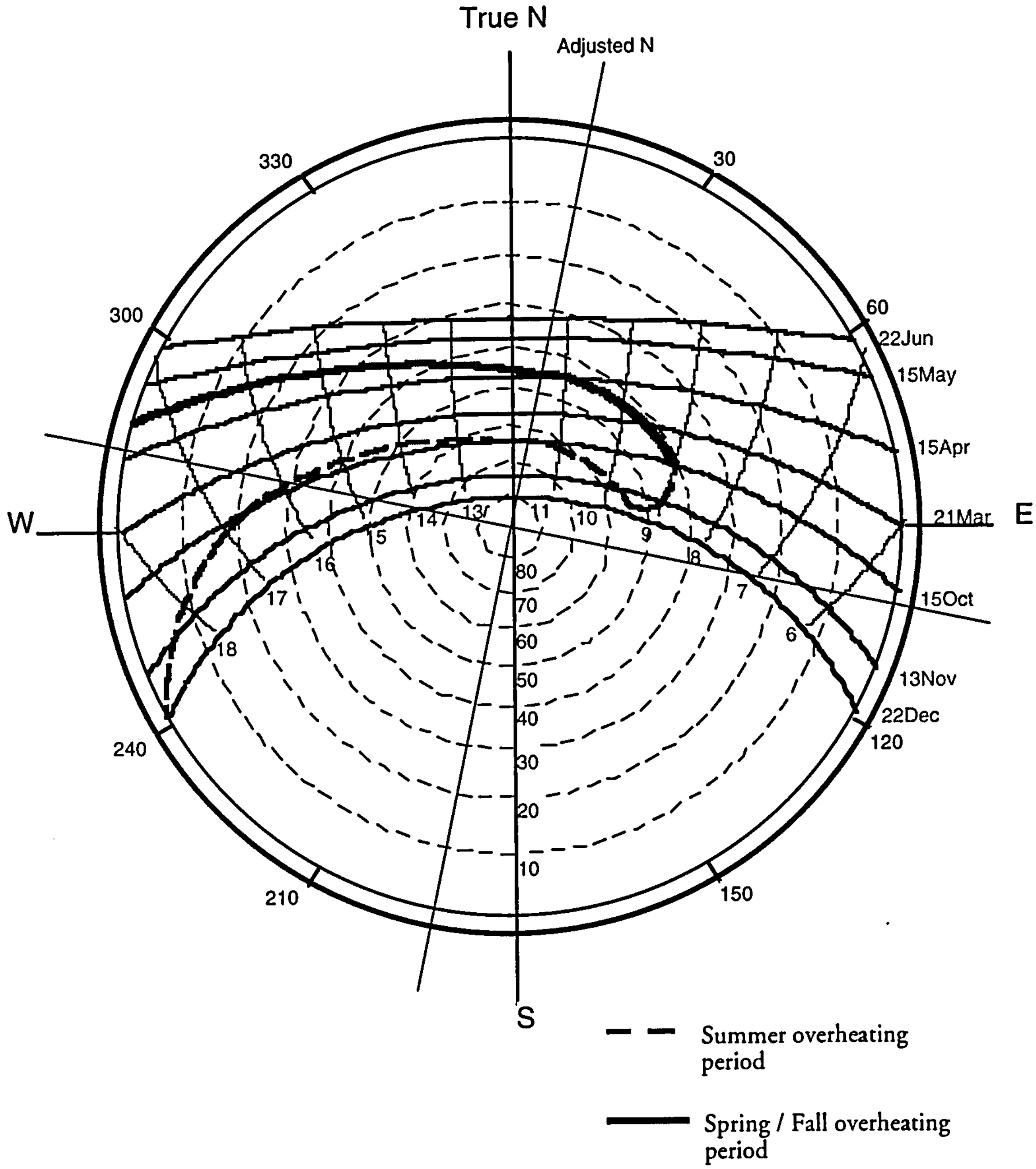


Figure 8.08: Solar path indicating overheated period

Mass Effect

Another issue related to passive solar heating systems involves the provision of mass. Thermal storage walls and sunspaces rely on the provision of mass in order to perform their functions. Direct gain systems function more efficiently when mass is present, although it is not an integral part of the system.

Mass functions as both a heat storage material and as a buffer between the outside and inside environments. High capacitance materials are used as mass because they have an ability to readily absorb heat, materials such as concrete, brick and earth fall into this category.

Massive materials need to be exposed to the space in order to act as a heat sink or storage. Solar energy entering the space will heat the air and any mass material it strikes. Material not directly exposed to sunlight will be heated indirectly as the colder material absorbs energy from the warmer air. The mass does not relinquish this stored heat until the air temperature drops to a point where it is cooler than the material. This delay of heat release is useful in flattening out day to night variations in the temperature experienced within the space.

Massive materials in external walls can act as a buffer between the external and internal environments. The same processes that make massive materials useful for heat storage can also be utilized to delay heat transfer from the outside to the inside of the building. This delay is referred to as time lag its length is dependent on the material itself and its thickness. Solar energy striking the external skin of the material slowly heats it up and this heat is then transmitted through the material to the inside surface via conduction. The time lag for this can be as much as ten or twelve hours, therefore heat will be entering the building when the space is no longer receiving solar input and is beginning to cool down.

The use of mass as a cooling strategy relies on the same principles. Mass located with a direct connection to the internal space will absorb heat present in the space, negating the need for it to be cooled by alternative means. Mass located in the external walls will delay the transmission of heat from the outside to the inside space. The use of mass does not exclude heat from the space but rather, delays its release, providing an advantage in a temperate climate where nights can be cooler. In a school the lag in heat transmission during hot days is ideal, as the room will be unoccupied when the energy is radiated into the space.

The basecase as currently designed contains no mass. The concrete floor, often used as a convenient heat sink, is thermally insulated by carpet and vinyl tiles laid over it. The external walls of brick veneer play a slight role in providing time lag delay of heat transmission, but do not function as a heat sink material. No other mass materials are used in the construction.

The strategies simulated related primarily to the choice of materials for major external surfaces. These were limited to conventional materials that could easily be incorporated into the existing design.

Slab on ground concrete slabs function well thermally as heat sinks, so strategies were concentrated on the covering materials. When the basecase was simulated with an exposed slab there was a significant decrease in heating and cooling loads of about 35% each, indicating the benefit of providing thermal mass. Exposed concrete slabs are not a viable option though for a classroom space. Other options that were simulated included a tiled floor, which showed an improvement of about 35% in both heating and cooling, because tiles are thermally conductive and act as mass. A combination of carpet in the classrooms and tiles in the practical activities areas was simulated but showed little significant savings in cooling and a significant increase in heating loads, due to the small percentage of tile in relation to the area of carpet. Some compromise between tiling and carpeting would seem the most appropriate solution, ideally most of the classroom space would be tiled, with carpet used in areas where the children are likely to be using the floor.

Wall materials are more easily manipulated. Currently the basecase external walls are brick veneer consisting of a brick outer skin and a timber or steel framed inner skin. The strategies simulated concentrated on increasing the mass effect of these walls. One strategy reversed the brick veneer, thereby relocating the brick skin to the inside and the timber framed skin to the outside, putting the massive material in contact with the interior. The framed layer also serves to insulate the mass from the outside temperatures so that heat is not radiated externally or absorbed. This strategy resulted in significant cooling load reductions of about 30%. Heating loads were also reduced by approximately 20%.

The second strategy that was simulated was a double brick construction, separated by an air cavity. This system exposes the mass material to both the internal and external environments. The results showed an increase in cooling load when compared to the previous strategy due to the loss of the mass insulation, but heating loads maintained a 20% reduction.

Two other strategies involved replacement of the exterior brick skin with skins of different materials. When concrete block was simulated it resulted in an increased heating and cooling load. Hebel block was more successful with a 10% reduction in cooling load and a 15% reduction in heating load. Hebel block is an autoclaved aerated concrete block which provided substantially more insulation value than brick, so this wall configuration is super insulated rather than thermally massive.

A single strategy simulated in relation to the roof material involved replacing the existing metal roof deck with a tile roof. This increased the cooling load by 5% whilst having almost no impact on the heating load. This is believed to be due to the difference in reflectivity between a light colored metal deck and a dark terra-cotta colored tile.

Air Movement

Ventilation is the introduction of outside air into an enclosed space or the movement of air within the space. The introduction of outside air is essential in order to maintain the quality of the air inside the building. Air quality is a health issue and relates to the supply of oxygen, the removal of exhaled carbon dioxide and other contaminants and the dilution of odors. The effect of outside air on the thermal balance of the interior is dependent on the quantity of air and the relative difference in internal and external temperature and humidity levels.

Rates of ventilation are specified by legislation and are set at a level whereby a sufficient quantity of fresh air is constantly being brought into the space to replenish the internal air. Three issues arise in relation to air quality: oxygen supply, contaminant removal and odor dissipation. The supply of oxygen is fundamental as it is the gas that humans extract from the air when they breathe and is necessary for human life. Human exhalation produces various byproducts, the primary one being carbon dioxide which in large quantities is lethal to humans. Materials used in all forms of construction also produce byproducts that are dangerous at high levels of concentration. These contaminants therefore need to be removed from the air supply. Humans also produce odors from biological processes such as sweating, which need to be diluted.

The thermal balance of the building can be greatly affected by ventilation, depending on the variation existing between indoor and outdoor climates. When this variation is extreme, incoming air needs to be conditioned. Energy that has been spent on conditioning air that is being expelled will be lost. Infiltration, which will be explained in detail later, is particularly problematic in this respect as its uncontrolled rates of exchange increase as temperatures become more divergent.

Ventilation occurs in three forms, all of which can be present in a single space, forced ventilation, natural ventilation and infiltration[19].

Forced ventilation involves the mechanical movement of air and allows the highest level of control over the quality and quantity of air that is introduced and circulated around the building. This form of air handling is often mandatory in buildings where large quantities of outside air need to be introduced to maintain internal air quality. Forced ventilation is related to the use of a HVAC system and is beyond the scope of this report.

Natural ventilation involves the movement of air through openings designed in the building's envelope. It is powered by wind and variations in temperature. The flow of air within the building depends on the size and location of inlets and outlets and the layout of partitions within the space.

Natural ventilation is used primarily as a cooling strategy. Ventilation can have a cooling effect within a space through two processes, comfort ventilation and convective ventilation. Comfort ventilation uses air moving across the skin to directly cool the body through enhanced evaporation. Convective ventilation uses cooler night air to cool down the internal space, preparatory to the hotter times during the day.

Natural ventilation requires the provision of designed openings in the building's envelope. The size and position of these openings will influence the effectiveness of ventilation generation. Three types of natural ventilation can be incorporated into a building design. Cross ventilation is the most common form and utilizes window and door openings placed in the walls of the building. Depending on wind direction, air will move into the building through openings in one wall and will travel across the space to exit the building through openings in another wall. Air circulation within the space is affected by space divisions and partitions. Optimal cross ventilation will be achieved when inlet openings are present in a windward wall and outlet openings are located in the leeward wall. Optimal conditions are not always possible and some cross ventilation will occur even if both the inlet and outlet are located in the same wall.

Stack ventilation occurs when cooler outside air enters the space preferably through low level inlets. This air is heated within the space, it then rises and is allowed to exit through high level outlets causing more inlet air to be drawn into the space. The stack effect is reliant on a difference in the height of the positioning of the outlet in relation to the inlet. Maximum effect is achieved with maximum height differential. The effect can be induced using double hung windows but to achieve a significant effect, outlets are often positioned in the roof, which also allows the use of roof ventilators to enhance the exhausting of the heated air. A reversal of the stack effect is the mechanism that produces the cool air distributed by a cool tower.

A ventilated envelope is the third form of natural ventilation. This utilizes the stack effect mechanism, but instead of air being drawn into the space, it is drawn into the envelope itself. A double layer form of construction is used and ventilation is induced between these layers. This reduces the build up of heat across the envelope by venting some of it to the outside.

The basecase utilizes all three forms of natural ventilation. Large sliding windows are situated in the northern and southern facades to allow half the overall glazed area to be opened and used as ventilation inlet and outlets when required. Apart from the withdrawal space, the home base block is open plan, therefore cross ventilation is further enhanced by the lack of partitions and divisions within the space. Stack effect ventilation is induced by the addition of outlets situated in the ridge of the roof and aided by a cathedral ceiling and roof ventilators positioned externally. The roof itself is a ventilated envelope, with air being drawn up the slope of the roof from ventilation inlets at the eaves to the ventilators at the ridge. Internal ventilation is addressed by the installation of ceiling fans that can be used to increase the rate of air movement when conditions are hot.

No additional ventilation strategies were simulated as the existing design has extensive systems already in place.

Infiltration involves air movement through undesigned openings in the envelope. Usually the term infiltration refers to outside air infiltrating into the space, while exfiltration is used to specify air that is moving through the envelope from the inside to the outside. This movement is driven by wind and temperature variations and will often provide the main source of outside air in envelope-dominated buildings. Infiltration due to its uncontrolled nature has the most unpredictable influence on thermal conditions. The transferal of air via infiltration and exfiltration occurs when climatic conditions are unfavorable for thermal comfort.

The laws of thermodynamics partially regulate infiltration flow rates. During winter months air will flow from the heated interior to the cooler exterior, whilst in summer this flow will reverse with heated exterior air flowing into the cooler interior. Both these situations are deleterious to regulating the thermal state of the building. For this reason infiltration and exfiltration need to be minimized as much as possible. Newer construction techniques have resulted in increasingly air tight buildings, but a complete seal is almost impossible to achieve and would be undesirable in buildings not utilizing a HVAC system. Air exchange needs to occur at a sufficient rate to maintain a supply of fresh air. A compromise is required between the rate of infiltration sufficient to maintain air quality and a rate that does not adversely affect thermal comfort.

Endnotes

[1] DA•SketchPAD2.0, www.arch.utas.edu.au
[2] Bradshaw, p93.
[3] Bradshaw, p94.
[4] Bradshaw, p94.
[5] Bradshaw, p94.
[6] Bradshaw, p94.
[7] Bradshaw, p94.
[8] Bradshaw, p100.
[9] Bradshaw, p95.
[10] Bradshaw, p136.
[11] Bradshaw, p136.
[12] Bradshaw, p137.
[13] Bradshaw, p136.
[14] Ballinger, 1997, p79.
[15] Ballinger, 1997, p79.
[16] Calpas, Berkeley Solar Group.
[17] Lechner, p110.
[18] DA•SketchPAD2.0, www.arch.utas.edu.au
[19] ASHRAE, p23.1.

CONCLUSIONS

An analysis of energy usage within schools shows that there is a heavy reliance on it to provide light and heat within the classroom.

This report has sought to analyze this usage and propose strategies for saving energy in the visual and thermal environments.

In undertaking this study an attempt has been made to gain insight into facets of architecture that affect energy usage in a classroom utilizing the bioclimatic equation, as presented by Szokolay, that:

Given Conditions - Comfort Conditions = Required Controls

This equation was applied to an existing classroom prototype in Sydney, Australia.

A brief description is given of the education system in Australia over the past 210 years.

A detailed analysis of the climatic conditions experienced in Sydney, Australia shows that Sydney has a temperate climate but can experience hot summers and mild winters.

Heating is the predominant climatic modifier required, but not to any great extent. Sydney does not experience sub-zero temperatures because of its coastal location.

An overview is given of the conditions within the visual and thermal environments that are most conducive to a learning situation.

The conditions required for a comfortable visual environment within a classroom include sufficient illumination, an exclusion of glare and the establishment of a space in which children can easily view their work, regardless of the task or where it is occurring. The variability of tasks occurring within a classroom poses the greatest challenge to correctly defining the requirements of a lighting system.

The establishment of thermal environmental criteria is in many ways easier, because the body reacts biologically to the thermal conditions within a space. The definition of thermal comfort has tantalized and captured the imagination and curiosity of biological designers for the last four decades and beyond, with extensive research being conducted into it. As a result tools, such as the Building Bioclimatic Chart, have been developed to simplify the quantitative presentation of required thermal comfort conditions. Research has focused on the thermal comfort of adults with little research being conducted exclusively with children. Children constitute the majority of occupants in a classroom and although it is unlikely that they will react in a markedly different manner to adults, further research is indicated.

Defining the required visual and thermal conditions provides a benchmark against which the basecase and subsequent strategies can be tested. The basecase used for this report was a prototype classroom block designed by the Schools Division of the New South Wales Department of Public Works. It constitutes a Learning Unit, comprised of two homebase classrooms, a shared withdrawal space and associated auxiliary spaces. Each classrooms has its own practical activities area and storage areas. An initial analysis of the basecase was undertaken in relation to both the visual and thermal environments.

Required Controls are the product of the bioclimatic equation. Once the given conditions and the comfort conditions have been established, the difference between the two constitutes the conditions that require some form of control.

The visual and the thermal environments can be controlled by active or passive means. In order to provide a visual environment that satisfies the requirements of a classroom, it is necessary to employ an active system in the form of electric lighting or a passive system in which naturally occurring daylight is filtered through and controlled by the building envelope. A third alternative involves a hybrid of the two systems. In the study the last option was found to provide the best compromise for the efficient use of energy and the provision of a good visual environment.

A basic electric lighting system required twenty four 65W fluorescent tubes to light the basecase space to an illuminance of 320 lux. The correct choice of a luminaire will ensure that there is no glare associated with these lamps.

Toplighting systems were the most beneficial strategies to investigate because they take advantage of the fact that the space is single story and because they are not detrimentally impacted by changes in location of the prototype.

Of the series of systems tested, a monitor type provided the best light distribution throughout the space. This system was also able to provide the maximum required illumination value of 320 lux for at least 90% of the work year. A secondary electric lighting system would provide light in the event that the natural light is insufficient, which can occur on very cloudy days and when the classroom is used at night. A considerable saving is achieved when the electric lighting system is only used for approximately 10% of the work year. Systems are available that integrate an electric system with a daylighting one, controlling the amount of electric light dependent on the quantity of daylight available, this integration would require further research

When considering the thermal environment the same division exists between active and passive systems. An active system uses electricity to power the method of adding or subtracting heat from the space. Passive systems rely on the design of the building envelope to control heat gain and promote heat loss when appropriate.

Heating is the primary control required in Sydney. When designing an HVAC system a series of calculations must be undertaken to ascertain required heating and cooling capacity. These capacities are based on the assumption of design temperatures which the system is then sized to accommodate.

The required heating and cooling capacity calculations consider the thermal balance of the building. The requirement for heating arises from the tendency of the building to lose heat through transmission and convection. The requirement for cooling arises from solar gain, transmission gain, natural gain and convection gains. The cooling capacity calculations are more complex than the heat capacity calculations because the materials of the building can absorb and store heat. Consideration needs to be made for the nature of these materials.

Passive thermal systems utilize the fabric of the building itself to control and enhance the thermal environment within the building. In order to increase heating, passive solar strategies were investigated. While daylighting strategies resulted in increased areas of glazing mass proved the most important in relation to energy savings. This was because the basecase did not contain any mass materials in a position to provide storage.

The various strategies proposed resulted in energy savings of up to 35%, in both heating and cooling loads. Ventilation was well designed for in the basecase, with provisions for both natural cross ventilation and stack ventilation, therefore no further strategies were investigated.

The homebase used as the basecase prototype for this report was designed to be energy efficient. Efforts were made to maximize the passive systems that were integrated into the external envelope and priority was given to maximizing the comfort of the occupants of this space.

The optimized case incorporated the monitor system as previously described and an increase in thermal mass, via the use of tiles, along with the use of Hebel block in place of the external brick skin. When simulated, these strategies resulted in good daylight illumination levels and distribution, as well as a 20% decrease in heating load and a 15% decrease in cooling load. These savings were achieved whilst improving the comfort of the people inhabiting the space.

In investigating the basecase, this study has sought to gain an understanding of the systems employed and to propose other systems that could be integrated to improve the basecase.

Appendices

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Appendix A: Curriculum

The curriculum is the single biggest influence on the way a school organizes itself. The New South Wales (NSW) Board of Studies, which is a statutory State Government body, is responsible for overseeing the education of the State's children and does this through the development of a state-wide curriculum.

In order to facilitate the formulation of this curriculum, a series of guiding principles have been established, these are:

- Children learn best when they see purpose in their learning and know the outcomes they are working to achieve.
- Learning experiences should be responsive to children's individual needs.
- Children's learning experiences should assist them to learn more.
- Children's learning is enhanced when they see connections among their learning experiences and relate them to their everyday experience.
- Children learn best when they are happy to learn.
- Children's achievements should be effectively and appropriately recognized.
- Children learn best when concepts of justice and equity govern the learning environment.

The Board's stated aim is to provide all children with the "knowledge, skills and understandings necessary for a satisfying and productive life".

In developing this set of principles, the NSW Board of Studies is attempting to rationalize current educational theory as it relates to primary age children. There is a strong focus on the needs of children as individuals, as "they are encouraged to participate in planning their learning and thus move towards increasing control over, and responsibility for, their own learning"[1], but this is offset by a societal need, for "their learning [to enable] them to participate in and contribute more effectively in their world"[2]and "the development of positive values and attitudes"[3] is encouraged.

From these guiding principles, six Key Learning Areas (KLA's) have been identified. These provide a broad grouping of the subjects that children are expected to learn during their formal education, and constitute what is termed a "well balanced"[4] curriculum.

These are:

- English
- Mathematics
- Science and Technology
- Personal Development, Health and Physical Education
- Human Society and Its Environment
- Creative and Practical Arts

For each year they are at primary school, students must gain learning experiences in all these areas.

The Board, in developing primary syllabuses and curriculum support materials, has sought to "ensure a K-12 learning continuum that is of the highest standard and supports best teaching and learning practices"[5].

Syllabuses have been produced in relation to each of these KLA's, detailing aims, objectives, content and outcomes.

The aims of the syllabus details the benefits the student will gain from undertaking the study. The objectives provide a more specific statement of intent. Teachers are provided with direction on the teaching and learning process. The objectives also provide a broad outline of the knowledge, skills and understandings which are considered fundamental to a mastery of the subject. The substance of the subject is referred to in the Content, which includes topics, areas of study, key questions, practices, skills and processes which may be laid out for the teacher. An Outcome Statement in the syllabus specifies the intended teaching results and provides a clear indication of the knowledge, skills and understandings that most students are expected to have gained.

Following is a synopsis of each of the six Key Learning Areas, including the aims of the subject, and the strands included within the subject.

English K-6

"The aim of English K-6 is to develop students' ability in using language effectively and critically, and to encourage positive attitudes towards learning English."[6]

Language, which in this case is English, is considered central to a child's "intellectual, social and emotional development"[7].

The subject is divided into three strands, comprising:

- Talking and Listening
- Reading
- Writing.

Mathematics K-6

"The aims of Mathematics K-6 are to:

- develop in students favorable attitudes towards, and stimulate interest in, mathematics;
- develop in students a sound understanding of mathematical concepts, processes and strategies and the capacity to use these in solving problems;
- develop in students the ability to recognize the mathematics in everyday situations;
- develop in students the ability to apply their mathematics to analyze situations and solve real-life problems;
- develop in students appropriate language for the effective communication of mathematical ideas and experiences;
- develop in students an appreciation of the applications to mathematics of technology, including calculators and computers;
- encourage students to use mathematics creatively in expressing new ideas and discoveries and to recognize the mathematical elements in other creative pursuits;
- challenge students to achieve at a level of accuracy and excellence appropriate to their particular stage of development."[8]

There are four strands to this subject: the content strands:

- Space
- Measurement
- Number

and the process strand:

- Working Mathematically.[9]

Science and Technology K-6

"The aim of Science and Technology K-6 is to develop in students competence, confidence and responsibility in their interaction with science and technology, leading to:

- an enriched view of themselves, society, the environment and the future, and
- an enthusiasm for further learning of science and technology."[10]

This subject concentrates on the process of investigating, the process of designing and making, and the use of technology.[11]

This subject is divided into six strands:

- Built Environment
- Information and Communication
- Living Things
- Physical Phenomena
- Products and Services
- The Earth and Its Surroundings.[12]

Personal Development, Health and Physical Education K-6

"The aim of Personal Development, Health and Physical Education K-6 is to develop in each student the knowledge, skills and understandings needed to understand, value and lead healthy and fulfilling lives. In doing so, the syllabus will form the basis for students to adopt a responsible and productive role in society.

This aim will be achieved by developing in each student:

- self-esteem, social responsibility and well-being:
- movement skills and personal fitness:
- the ability to make informed health and lifestyle decisions."[13]

This subject is divided into eight content strands:

- Growth and Development
- Interpersonal Relationships
- Personal Health Choices
- Safe Living
- Fitness and Lifestyle
- Games and Sports Skills
- Gymnastics (Movement Exploration)
- Dance

Human Society and Its Environment K-6

"The aim of Human Society and Its Environment K-6 is to develop in students the values and attitudes, knowledge, skills and understandings that:

- enhance their sense of personal, community, national and global identity; and
- enable students to participate effectively in maintaining and improving the quality of their society and environment."[14]

This is the subject where it is expected that children will learn to analyze, synthesis and apply knowledge. It seeks to teach children to think critically, make decisions and solve problems.[15]

This subject is divided into four strands:

- Change and Continuity
- Cultures
- Environments
- Social Systems and Structures.[16]

Languages other than English are included as a subset of this subject.

Creative Arts K-6

"The aim of Creative Arts K-6 is to develop in all students a lifelong commitment to participate in each of the art forms of Visual Arts, Music, Drama and Dance; value the personal and shared meanings gained from experiencing the arts; and appreciate the role of the Visual Arts, Music, Drama and Dance in re-affirming, building, and challenging society and culture."[17]

There are four strands within this subject:

- Visual Arts
- Music
- Drama and Dance

Appendix B: School and Class Organization

Another of the decisions in determining the use of physical space in a school is the method of grouping students into classes. Schools usually settle on one of the five standard systems, or a variation thereof, depending on the size of the school, the number of students in each age or grade level, the preference and experience of the teaching staff, and the physical facilities available.

The five systems most commonly used include;

- vertical or multi-aged grouping
- ability grouping by subject
- ability grouping
- parallel grouping
- stratified grouping

Vertical grouping involves placing students of varying ages and school levels into one class. This is believed to most closely mirror a family situation, with older and younger students working together.

When the ability grouping by subject system is used, children are placed in a class group for the study of a specific subject, according to ability in that subject. The group they are placed in for English, may not be the same as the one they are placed in for Mathematics.

A more general version of this process is ability grouping, where children are "streamed" according to ability, but only one grouping is used for all subjects. This method results in "A" and "B" classes, which have been shown to be detrimental to some children's self-esteem. It is sometimes referred to as a 'homologous' system, because all children of like ability are grouped together.

In contrast is a parallel group structure. The students in each grade are divided into classes in such a way that ability is evenly distributed. This results in a "heterogeneous" grouping with children of widely differing ability being grouped together. This type of class is difficult to teach because of the wide range of ability present in the class.

Stratified grouping is a hybrid of the preceding two systems, which aims to limit the extremes present in a parallel class, while incorporating more diversity than is present in an ability grouped class. In this system children are ranked according to ability and then divided into groups, the size of which is dependent on the overall size of the grade. These groups are then distributed to teachers in such a way as to achieve diversity. A grade of 60 students would be ranked by ability into six groups of ten. Groups one, three and five would be assigned to one teacher, and groups two, four and six to another. The range of ability present in each class is reduced but diversity is still present. Similarly there is no obvious top or bottom class, and teachers do not have to cope with the special needs of the top and bottom ten students simultaneously.

The size of classes in New South Wales primary schools is set at a maximum of thirty five students. The actual number in any class is a product of school enrollment. In the public system, teachers are allocated according to number of students, therefore classes can become large before additional teachers are available. Funding will also have an effect on class size.

Class Timetabling

The method of timetabling used to organize the school day is related to the school and class organization system in use. The three patterns most commonly adopted are:

- the traditional system,
- the integrated day,
- the mastery concept.

The traditional system uses "fixed allocation of time for particular subjects"[18]. The integrated day treats time "as a fixed medium or context for free-ranging activity by pupils"[19], while the mastery concept views time "as a major variable in learning, and different times are allowed to different students to achieve mastery in the same tasks"[20].

Appendix C: Definitions of Climatic Symbols and Boundaries[21]

Climatic Symbols

A = killing frost absent: in marine areas, cold month over 18.3°C

r=(rainy) 10 - 12 months wet: 0 - 2 months dry.

w= winter (low-sun period) dry; more than 2 months dry.

s= summer (high-sun period) dry; rare in A climates.

B = evaporation exceeds precipitation.

Boundary,

$$R = 1/2\,T - 1/4\,PW$$

where;

R = rainfall, in.

T = temperature, °F.

PW = % annual rainfall in winter half year.

Desert / Steppe boundary is;

$$R = \frac{1/2\,T - 1/4\,PW}{2}$$

W= desert or arid.

S= steppe or semiarid.

h= hot; 8 months or more with average temperature over 10°C.

k= cold; fewer than 8 months average temperature above 10°C.

s= summer dry.

w= winter dry.

C = 8 to 12 months over 10°C; coolest month below 18.3°C.

a= hot summer; warmest months over 22.2°C.

b= cool summer; warmest month below 22.2°C.

f= no dry season; difference between driest and wettest month less than required for s and w; driest month of summer more than 3 cm.

s= summer dry; at least three times as much rain in winter half year as in summer half year; driest summer month less than 3 cm.; annual total under 88.9cm.

w= winter dry; at least ten times as much rain in summer half year as in winter half year.

D = 4 to 7 months inclusive over 10°C.

o= oceanic or marine; cold month over 0°C [to 2°C in some locations inland].

c= continental; cold month under 0°C [to 2°C in some locations inland].

a= same as in C.

b= same as in C.

f= same as in C.

s= same as in C.

w= same as in C.

E = 1 to 3 months inclusive over 10°C.

F = all months below 10°C.

t= tundra; warmest month between 0°C and 10°C.

I= icecap; all months below 0°C.

Climatic Boundaries

A / C boundary = equatorial limits of freeze; in marine locations the isotherm of 18°C for the coolest month.

C / D boundary = 8 months 10°C.

D / E boundary = 4 months 10°C.

E / F boundary = 10°C for warmest month.

t / i boundary in F climates = 0°C for warmest month

B / A, B / C, B / D, B / E boundary = evaporation equals precipitation.

BS / BW boundary = one half the above boundary.

h / k boundary in dry climates = same as C / D.

Do / Dc boundary = 0°C [to 2°C] for coolest month.

Appendix D: Climatic Classification of Sydney, Australia

Trewartha Classification		Sydney Data
C =	8 to 12 months over 10°C	all months, Jan to Dec, mean temperature above 10°C
	coolest month below 18.3°C	coolest month, July, mean temperature 12.8°C
f =	no dry season	lowest monthly precipitation, Sept, 70mm highest monthly precipitation, April, 131 mm 61mm difference
	driest month of Summer more than 3cm of rain	driest month of Summer, Dec, 80mm (8 cm)
a =	hot Summer, warmest months over 22.2°C	warmest months, Jan and Feb, mean temperature over 22.2°C, Oct to April, maximum temperature over 22.2°C

Appendix E: Building Bioclimatic Chart Calculations

Thermal Comfort Calculation Procedure[22]

The comfort zone can be plotted on the psychrometric chart using the following procedure:

1. find the annual mean temperature, Tav
2. find the thermal neutrality, Tn

   Tn = 17.6 + 0.31 x Tav (such that 18.5 < Tn < 28.5°C)

3. plot this Tn on the chart, on the 50% RH (relative humidity) curve
4. mark the lower and upper limits on the 50% RH curve

   Lower = Tn - 2°

   Upper = Tn + 2°

5. draw the corresponding SET lines, as the side boundaries

   SET slope = 0.025 x (DBT -14) for each g/kg of vertical distance

6. mark the upper AH (absolute humidity) boundary at the 12 g/kg level and the lower boundary at the 4 g/kg level.

This comfort zone will be valid for lightly clothed people at sedentary work. For heavier physical activities the Tn should be adjusted:

for light work (210W): - 2 K

for medium work (300W): - 4.5 K

for heavy work(400W): - 7 K

Thermal Comfort Calculations for Sydney

1. Annual Mean temperature (Tav)

Max. Temperature (12 months)	= 22.025
Min. Temperature (12 months)	= 13.97
Tav	= 18°C

2. Thermal neutrality (Tn)

Tn	= 17.6 + 0.31 x Tav
Tn	= 17.6 + 0.31 x 18
	= 23.18 °C
	≈ 23.2 °C
Tn (adjusted for light work)	= 21.2 °C

4. Upper and Lower temperature limits

Lower	= Tn - 2
Lower	= 21.2 - 2
	= 19.2 °C
Upper	= Tn + 2
Upper	= 21.2 + 2
	= 23.2 °C

5. SET slope calculations

SET	= 0.025 x (DBT -14)
SET (Lower)	= 0.025 x (19.2 - 14)
	= 0.13 K/ (g/kg)
SET (Upper)	= 0.025 x (23.2 - 14)
	= 0.23 K/ (g/kg)

Control Zone Calculations

Passive solar heating

daily useful solar gain = daily heat loss

Dv x A x eff = q x (Tn - To) x 24

A = area of solar window

eff = efficiency of the passive solar system

q = specific heat loss rate of the building

Tn = neutrality temperature

To = outdoor temperature limit

July (coldest month)

A = 20%

eff = 0.5

q = 115 W/K

Tn = 21.2 °C

Dv x 20 x 0.5 = 115 x (21.2 - To) x 24

To = 21.2 - 0.0036 x Dv

Dv = 3972

To = 21.2 - 0.0036 x 3972

= 6.9 °C

Mass effect

Summer (February hottest month)

(Tmax - Tmin of hottest month)

pt 5s: 12 g/kg AH level at a DBT of:

$T5s = T2 + 0.5 \times (Tmax - Tmin)$

$T5s = 22.5 + 0.5 \times (25.5 - 18.9)$

$= 25.8\ °C$

pt 6s: 4 g/kg AH level at a DBT of:

$T6s = T5s + 0.2 \times (T5s - 14)$

$T6s = 25.8 + 0.2 \times (25.8 - 14)$

$= 28.2\ °C$

pt 7s: 14 g/kg AH level at a DBT of:

$T7s = T5s - 0.05 \times (T5s - 14)$

$T7s = 25.8 - 0.05 \times (25.8 - 14)$

$= 25.2\ °C$

Winter (July coldest month)

(Tmax - Tmin of coldest month)

pt 5w: 12 g/kg AH level at a DBT of:

$T5w = T1 - 0.5 \times (Tmax - Tmin)$

$T5w = 18.7 - 0.5 \times (17.1 - 8.4)$

$= 14.4\ °C$

pt 6w: 4 g/kg AH level at a DBT of:

$T6w = T5w - 0.2 \times (T5w - 14)$

$T6w = 14.4 - 0.2 \times (14.4 - 14)$

$= 14.3 °C$

Air movement effect

Temperature depression (dT) = 6 x v - v^2

for 1 m/s velocity dT = 5 K

pt 8 dT = 5 K

T8 = T2 + dT

T8 = 22.5 + 5

= 27.5 °C

pt 9: 4 g/kg AH level at a DBT of:

T9 = T8 + 0.1 x (T8 -14)

T9 = 27.5 + 0.1 x (27.5 - 14)

= 28.9 °C

pt 10: at a DBT equal to T1, on the 90% RH curve

SET = 0.025 x (T8 -14) per unit AH

SET = 0.025 x (27.5 - 14)

= 0.34 K/ g/kg

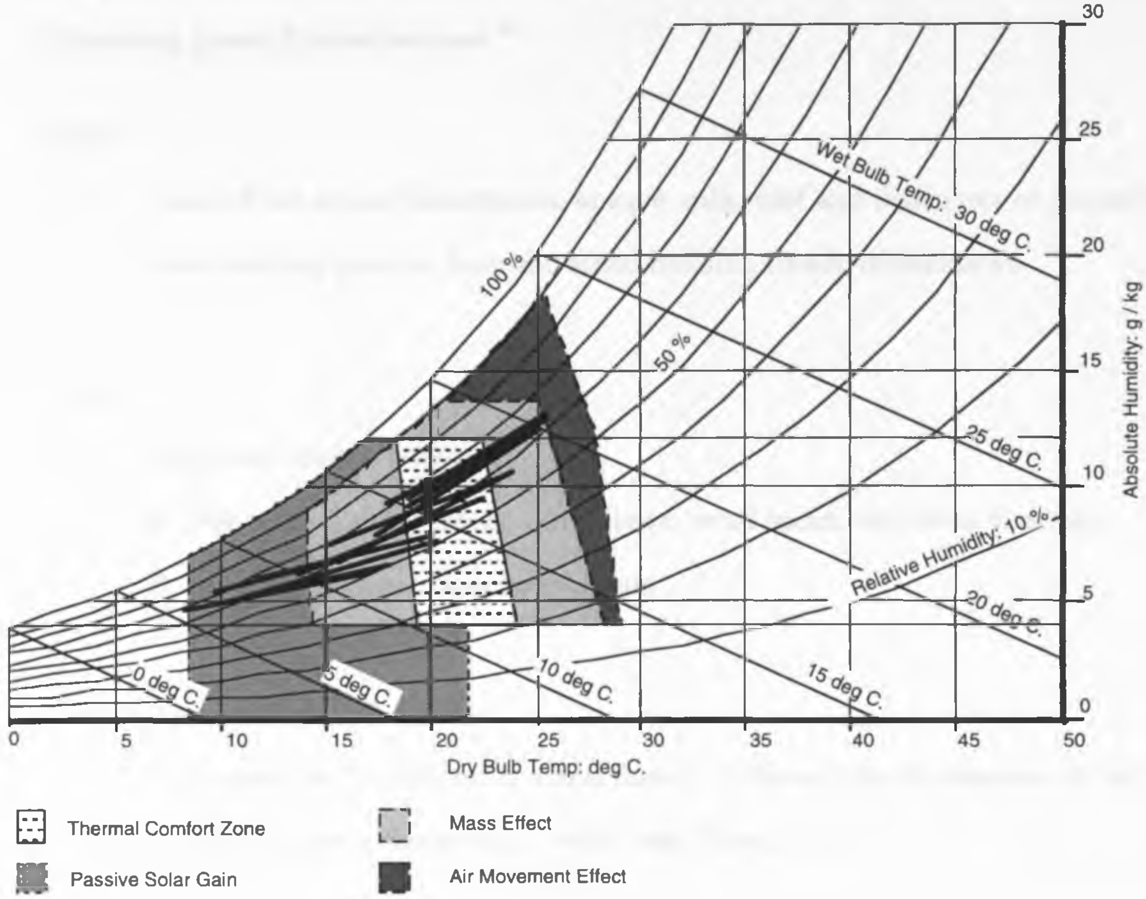

Figure E.01: Building Bioclimatic Chart (including control zones)

Appendix F: Heating and Cooling Load Calculations

Heating Load Calculations [23]

Step 1:

Take off net area of fenestration, opaque walls, roof and floor (area or perimeter) from building plans or from the actual building (inside dimensions).

Step 2:

Determine design criteria.

A. Select the design outdoor temperature, wind speed, and wind direction.

B. Select the design indoor temperature.

Step 3:

Determine the "coefficient of transmission" (U-factor) for all elements of the building envelope-fenestration, walls, roof, floors, etc.

Step 4:

Calculate transmission heat loss through each exterior surface:

Load = net area x U-factor x ΔT.

Step 5:

Determine outside air load due to ventilation , infiltration, or special exhaust:

Load = CFM (liters/sec) x O>A> factor x ΔT.

Step 6:

Add up all heat losses.

Heating Load Calculations						
Inside Design Temp		22				
Outside Design Temp		5.6				
Difference		16.4				
Item	Quantity	x U-value	x T	= W		
Glass	36.40	3.50	16.4	2089.4		
Net Wall (brl	88.65	0.77	16.4	1119.5		
Net Wall (mt	66.20	0.35	16.4	380.0		
Roof	207.00	2.00	16.4	6789.6		
Floor	190.00	1.43	16.4	4455.9		
Doors	8.50	1.22	16.4	170.1		
Outside Air	18417.00	1.20	16.4	362446.6		
				377451		
Notes:						
Bradshaw p 577						
O.A.	1.5 AC/H					
	1069 m3/H	AC/HxVol	/0.001(60)			
	17817 l/s					
Vent	8 l/s/p	Bradshaw p580				
	600 l/s	est 75 people				
total O.A.	18417 l/s					
Bradshaw p 33						
Summer	23-26					
Winter	20-22					
Bradshaw p 503						
	Lat	Long	Elevation	Winter		
				Mean	99%	97.50%
Sydney	33 52 S	151 12 E	138	38	40	42
				3.3	4.4	5.6
Summer						
1% DDB	2.5% DDB	5% DDB	Mean Rang	1% DWB	2.5% DWB	5% BWB
89	84	80	13	74	73	72
31.7	28.9	26.7	7.2	23.3	22.8	22.2
Prevailing Winds						
Winter	Knots	Summer				
N	8	NE				

Cooling Load Calculations[24]

Step 1:

Take off net areas of fenestration, opaque walls, and roof from building plans or from the actual building (inside dimensions). Areas should be tabulated separately for each orientation (north, south, east, west, etc)

Step 2:

Determine design criteria:

A. Select the design outdoor temperature and humidity conditions

B. Select the design indoor temperature and humidity conditions

C. Select the hour of peak load by finding the dominant load (south glass, west glass, roof, internal gains, etc.) and then determining by visual inspection of the appendix tables or by knowledge of the building operation schedule when the dominant load will peak.

Step 3:

Determine the solar heat gain factors and shading coefficients of the fenestration on each exposure (north, south, east, west and horizontal) and calculate the solar load.

Step 4:

Determine the U-factor of fenestration, opaque walls, and roof. Calculate transmission heat gains through each exterior surface:

Load = net area x U-factor x ΔT.

A. Fenestration ΔT = DB temperature - inside DB temperature.

B. Opaque walls and roof ΔT = respective sol-air temperature - inside DB temperature

Step 5:

Determine the sensible internal heat gain due to people, lights, equipment, etc.

Step 6:

Determine the sensible heat gain from outside air:

Sensible load = L/s - O.A. factor - ΔT

Step 7:

Add all loads from Steps 3 through 6 to obtain the total sensible load.

Step 8:

Determine the latent internal loads due to people and other sources of moisture.

Step 9:

Determine the latent load due to outside air.

Step 10:

Add up all loads from Steps 8 and 9 to obtain the total latent load.

Step 11:

Determine the total load by adding the results of Steps 7 and 10.

Cooling Load Calculations					
Space use		School Classrooms			
Floor area		189.7			
Volume		712.7			
Peak Load Date		Dec			
Time		12:00			
Hrs/Day of Op		15			
Glazing		single			
Shading		overhangs			
Wall Color		dark			
Roof Color		light			
Latitude		33 52 S			
Conditions	DB	WB	% RH	DP	Hum Ratio
Outdoor	28.9	22.8			15
Room	23		50		9
Difference	5.9				6
Sensible Loads					
Solar					
Exposure	Area	x SHGF	x SC	X TLF	= W
N	14.53	191	0.64	0.59	1048
E	1.26	134	1	0.76	128
S	15.28	128	0.64	0.76	951
W	1.26	134	1	0.76	128
					2256
Transmission	Area	x T	x U-value	x TLF	= W
Exposure					
Glass	32.33	5.9	3.5	1	668
Walls					
N-brk	26.22	31.7	0.77	0.28	179
N-mtl	13.3	19.3	0.35	0.28	25
E-brk	21.1	14.9	0.77	0.35	85
E-mtl	19.8	11	0.35	0.35	27
S-brk	22.23	14.3	0.77	0.6	147
S-mtl	13.3	10.3	0.35	0.6	29
W-brk	21.1	14.9	0.77	0.35	85
W-mtl	19.8	11	0.35	0.35	27
Roof	207	27.7	2.00	0.37	4243
Doors	11	11	1.22	0.35	52
					5565

O.A.					
Inf/Vent	x 1.2	x C			= W
18417	1.2	5.9			130392
Internal Heat					
People	Number	x W (each)	x BSF	X Diversity	= W
	70	80	0.84	1	4704
Lights	W	x Ballast	X BSF	x Diversity	= W
189.7x32.3	6127.3	1.2	0.8	0.8	4706
Equip	W		X BSF	x Diversity	= W
				1	0
Appliances	W		X BSF	x Diversity	= W
				1	0
					9410
			Total Sensible Load		= W
					147623
Latent Loads					
People	Number	x W (each)	x Diversity		= W
	70	80	1		5600
Appliances					= W
					0
O. A.	L/s	x g/kg	x 2.808		= W
	18417	6	2.808		310290
			Total Latent Load		= W
					315890
			Total Load		= W
					463513
Notes:					
Sol-air temps					
dark			light		
S	37.3		S	33.3	
E/W	37.9		E/W	34	
N	54.7		N	42.3	
R	76		R	50.7	

Appendix G: PLEA 99 Presentation

SIMULATION OF DAYLIGHTING STRATEGIES USING A "MIRROR-BOX" ARTIFICIAL SKY

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Abstract

In order to evaluate the effectiveness and suitability of a particular daylighting strategy for utilization in a specific space, some basis for comparison needs to be established. The use of physical scale models and an artificial sky light source provides one method of achieving this. Architects are comfortable with conceiving of space in miniture and are adept at generating their designs to scale. When this ability is combined with the technical aspects of photometrics and photography, lighting simulation results can generate information that is readily utilized.

1 Introduction

This report considers the procedure whereby scale models can be used in conjunction with a form of artificial sky referred to as a "mirror-box", to simulate the lighting situation within a classroom when different daylighting strategies are applied.

2 Luminous Environment

In order to design and analyze daylighting systems it is necessary to consider the location of the building to determine the specific luminance distribution and the luminance levels available. The product of this analysis is referred to as the design sky, the parameters of which define the variables used in calculations and simulations.

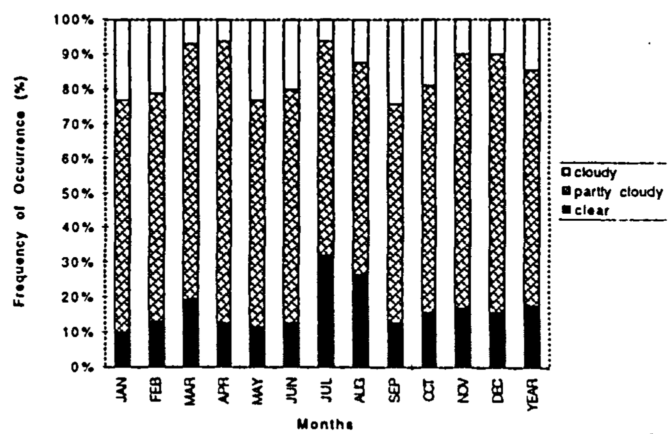

Fig. 2.1: Occurence of specific sky types (Ruck, p20)

This study was conducted using a building location in Sydney, Australia (Lat. 33' 52" S, Long. 151' 12" E). In analyzing this location consideration was given to sky type and annual sky cloudiness, as well as available illuminance levels. Figure 2.1 charts the occurrence of specific sky types as a percentage of each month. Sydney has predominantly partly cloudy skies, al-

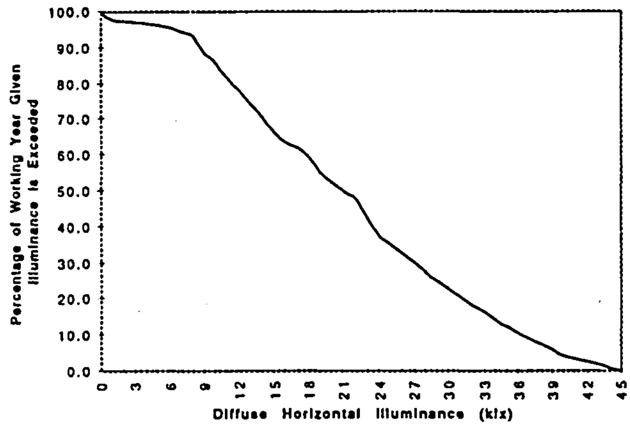

Fig. 2.2: Horizontal illuminance levels as a percentage of working year (Ruck, p42)

though a cloudy or overcast sky occurs from 10% to 25% of the time. Illuminance levels indicate the amount of light available from the sky vault. This information is presented as a percentage of the working year that a given illuminance is exceeded and is graphed in Figure 2.2.

From this data it is possible to formulate a luminous environment classification. The design sky model chosen was the International Commission on Illumination (CIE) overcast sky. This sky is defined as having a luminance distribution such that:

$$L\gamma = Lz\,(1 + 2\sin\gamma)/3$$

where:

$L\gamma$ = luminance at altitude angle γ
Lz = zenith luminance

This sky, although only occurring for a part of the year, is the worst case scenario. If a system is designed to perform within these parameters, in actuality, performance will be better than designed.

In determining exterior luminance levels for calculation purposes, a level of 8500 lux was chosen. The Experimental Building Station (EBS) follows Dresler and Brentwood in setting a lux value that results in daylighting being sufficient to provide the required lighting levels, unaided, for 90% of the working year.

3 Application

Once the luminous environment is defined, design analysis can be undertaken.

The procedure by which light interacts with a space is not a function of scale. Light will enter into and be distributed within a scale model of a space in a manner nearly identical to that which would occur in the building itself (Robbins, p221). Due to this scaleless nature of light, scale models can be used to represent spaces being analyzed.

The other aspect of the development of physical scale modeling is the introduction of artificial skies in order to gain an accurate and consistent light source that closely matched a designated sky type.

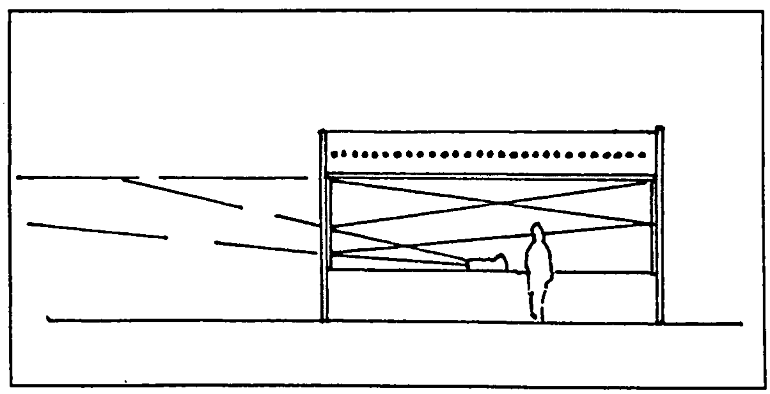

Fig. 3.1: Mirror-box Concept (Szokolay, p114)

The "mirror-box" type artificial sky is a rectangular light tight box of which the interior walls are clad with mirrors and the ceiling composed of fluorescent lamps and a diffuser panel to provide diffuse light. The multiple inter-reflectance generated by the mirrors creates a simulation of an overcast diffuse sky, with a luminance distribution similar to that of the CIE overcast sky. Figure 3.1 illustrates the "mirror-box" concept.

To produce useable results, the variables within the scale model that affect light penetration and distribution need to be accurately rendered. Interior surfaces need to have a reflectance similar to that of the actual space, and apertures need to be sized and placed correctly. Depending on the type of research being conducted, interior fixtures and furnishings can be included, but are not essential to overall general readings.

When a scale model is placed in the "mirror-box", photometric and photographic results can be generated for analysis.

3.1 Photometric Analysis

The design of daylighting systems involves analyzing both the quantity and quality of the light that penetrates into, and is distributed within, the space.

Photometric analysis provides information related to the quantity of light available at specific points within the space. Light sensors are used to measure the light levels achieved by the various systems being studied. Figure 3.2 indicates the location of the sensors within the study model.

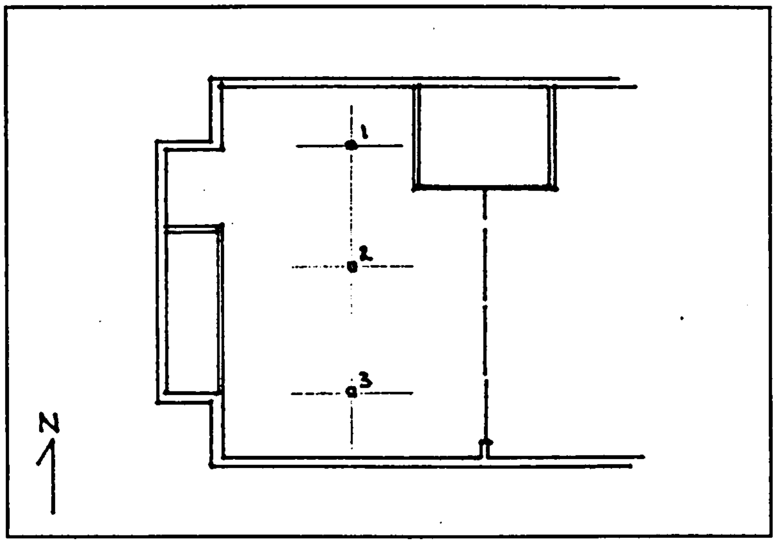

Fig 3.2: Location of Light Sensors

From these sensor readings graphs can be generated to indicate the distribution of light within the space and the variation in light levels across the space. The quantity of light can be measured as an illuminance level or as a factor of available exterior daylight.

3.2 Photographic Analysis

The quality of light within a space is as important as the quantity of light. The way in which light interacts with the physical design elements of the room will influence the success of a daylighting system.

Photographic analysis involves photographing the interior of the scale model in such a way that the space can be conceived as if it was being viewed at full scale. The photographs reproduced in this report were taken using a 28mm lens, set so that eye level was consistent with the scale model.

These images graphically indicate the nature of the light within the test space.

4 Results

An analysis was conducted of three top-lighting systems as applied to a prototype classroom design. Initially the basecase system of skylights was evaluated. Then a basic sawtooth system and monitor system were designed and tested.

The photometric results of this investigation are presented in the form of daylight factor (DF) graphs. The Australian Standard (AS1680.1-1990) requires that "design (of a daylighting system) should be based on a daylight factor capable of providing 200 lux or more throughout 90% of normal working hours" (AS1680.1-1990, p60). With an external luminance level of 8500 lux, this equates to a daylight factor of 2.35%, which is a little higher than the early recommendations of a 2% daylight factor in classrooms (Szokolay, p 142). The required illumination levels as specified in AS1680.2.3-1994 are 240 lux in a general classroom, increasing to 320 lux in a reading room.

Generally, due to the assumptions made concerning exterior luminance levels, daylighting systems will produce significantly greater interior illumination levels than the design baseline.

4.1 Basecase

The basecase is a homebase classroom block which is part of the Component Design Range of prototype school buildings designed by the New South Wales Department of Public Works and Services. The space is an open-plan classroom with an attached practical activities area and a shared withdrawal space. The classroom is approximately 8 m x 8 m, with the practical activities area being approximately 3 m x 6 m.

A top-lighting strategy is currently part of the design of the building. It consists of a series of strip skylights that run perpendicular to the ridge of the roof. These skylights were created by replacing part of the corrugated roof sheeting with panels of a polyester translucent roof sheeting. The space has a cathedral ceiling and directly below the translucent sheeting, a diffuser panel is set in line with the ceiling lining.

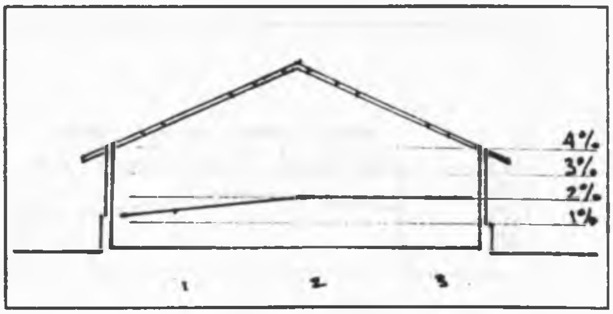

Fig. 4.11: Photometric results: Basecase

Figure 4.11 indicates the light levels achieved by this system. The values are low, although they are uniform. These skylights were designed to work in conjunction with large windows, and were not conceived as an isolated solution.

Fig. 4.12: Photograph results: Basecase

Figure 4.12 illustrates the low light levels occurring within the space. The skylights are unobtrusive and generally the ceiling is less dominant with this type of system. Glare is not a problem, due in part to the small amount of glazing used and the use of layers of diffusing materials.

4.2 Sawtooth System

The sawtooth system analyzed consisted of a series of four rooflights equally spaced across the depth of the room, with the glazed areas oriented North.

Figure 4.21 graphs the photometric results for this strategy. The graph displays the classic increase in lighting levels under successive apertures. This system produced the greatest luminance levels, especially against the South wall. A steady increase in light levels occurs across the space.

Figure 4.22 graphically demonstrates the advantages and disadvantages of this type of system. Light appears to be fairly evenly distributed within the space and the ceiling is well illuminated. The apertures have been extended to the side walls so that these walls receive high levels of light, although there is some shadowing related to the rhythm of the apertures. One of the problems associated with this system is glare as evidenced by the large, bright areas of glazing within the viewers field of vision.

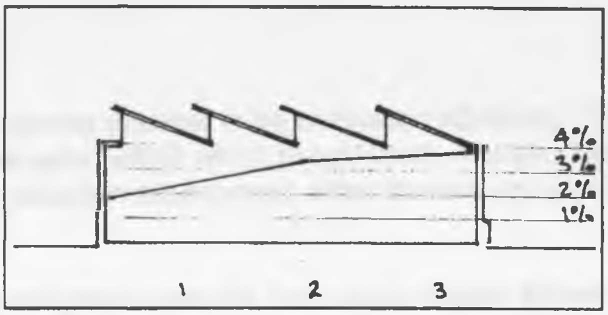

Fig. 4.21: Photometric results: Sawtooth

Fig. 4.22: Photographic results: Sawtooth

4.3 Monitor System

The monitor system studied comprised a series of four monitors spaced evenly across the depth of the room. The glazing in this system faces North and South. These monitors are placed relatively close together and therefore have a high glazed area to floor area ratio.

Figure 4.31 indicates the light values obtained when this system was tested. The light levels are significantly higher than those achieved by the basecase system and show a more uniform distribution than the results from the sawtooth system. The nature of the monitor system is bi-directional light penetration and significantly different results would be obtained if this system was tested under a clear sky situation.

Figure 4.32 displays the uniformity of light distribution within the space. The wall does show evidence of shadowing associated with the spacing of the monitors. Glare is apparent with this system, although less glazing is exposed than with the sawtooth system.

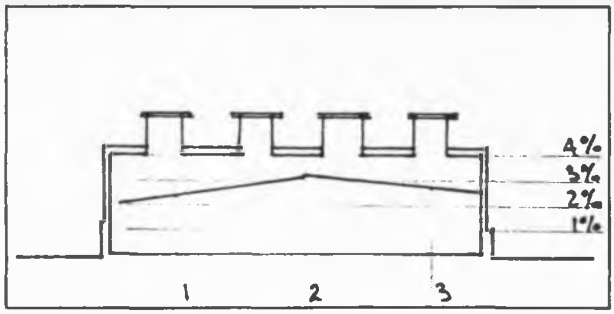

Fig. 4.31: Photometric results: Monitor

Fig 4.32: Photographic results: Monitor

5 Conclusion

Physical scale modeling allows a range of daylighting systems to be evaluated efficiently. The use of an artificial sky maintains a consistent situation within which to test these models. The "mirror-box" sky effectively imitates the lighting situation experienced when there is an overcast sky.

The ability to generate both photometric and photographic results from scale models allows the designer to consider the quality and the quantity of light that will be created in the space under investigation.

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Endnotes

[1] Barcan ,p 8.
[2] Barcan ,p 8.
[3] Barcan ,p10.
[4] Barcan ,p 17.
[5] Barcan ,p 8.
[6] Barcan ,p 19.
[7] Barcan ,p 19.
[8] Barcan ,p 21-22.
[9] Barcan ,p 23.
[10] Barcan ,p 24.
[11] Barcan ,p 25.
[12] Barcan ,p 26.
[13] Barcan ,p 27.
[14] Barcan ,p 29.
[15] Barcan ,p 30.
[16] Barcan ,p 30.
[17] Barcan ,p 33.
[18] Bassett, p207.
[19] Bassett, p207.
[20] Bassett, p207.
[21] Trewartha, p250-251.
[22] Szokolay, 1987, p13.
[23] Bradshaw, p95.
[24] Bradshaw, p95.

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