

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Selected solar design tools for sustainable residential land development

A thesis presented in fulfilment of the requirements for the degree
of
Master of Engineering

At Massey University, Palmerston North, New Zealand

Andrew Duncan
2005

Abstract

As New Zealand's natural gas reserves decline and electricity demand growth exceeds the building of new generation plants, greater focus needs to be applied to energy efficient design in domestic buildings and land developments.

A case study of residential land development was analysed in terms of its potential for energy efficiency gains and optimisation of solar resources. A design tool was developed to rapidly assess the solar energy loss of a specific building site due to existing land features. 'Solar obstruction contours' were produced that define the maximum permissible height of obstructions before solar shading occurs. These contours were produced based on a minimum percentage solar energy capture.

Thermal energy demand for the development case study was calculated by specification of a Building Performance Index relative to floor area. The demand was then balanced against on-site thermal energy production from biomass to give a percentage thermal energy self sufficiency.

The tools developed can be used to optimise the design of a residential land development resulting in an increase in renewable energy use above that of standard residential developments. The study concluded that incorporation of the tools as standard practice by municipalities is viable, and if implemented would increase the energy efficiency and renewable energy use of the New Zealand housing stock.

Acknowledgements

This work is the result of my planting a seed in the thought processes of land development three or four years ago. I would like to thank those around me who helped to nurture this seed into a full-blown development.

It goes without saying that I owe much thanks to my partner, Dolly, without whose understanding this work would not have been possible. The assistance of my family investors is very much appreciated, and being able to bounce mathematical ideas off Alan Duncan, invaluable. Last, but in no way least, I would like to thank Building Research (formerly BRANZ), who provided funding for this research.

Table of Contents

Chapter 1	Introduction	1-1
1.1	Introduction	1-1
1.2	Problem statement.....	1-3
1.3	Background.....	1-3
1.4	Objectives	1-5
Chapter 2	Present understanding of solar energy capture	2-8
2.1	Introduction	2-8
2.2	Theory of solar radiation	2-8
2.3	Solar Access planning	2-12
2.4	Building design overhangs	2-16
2.5	Energy Efficiency	2-17
2.6	Land Tenure and Management	2-19
2.7	New Zealand Building Code	2-21
2.8	Subdivision Code of practice	2-22
2.9	Shade Angles	2-23
2.10	Thermal energy self-sufficiency	2-24
Chapter 3	Sustainable property development – a case study.	3-25
3.1	Introduction	3-25
3.2	Site details.....	3-26
3.3	The development	3-28
3.4	Considering solar access in the design criteria	3-29
3.5	Land tenure for the development.....	3-30
3.6	Meteorological and geographical data	3-34
3.7	Energy capture	3-38
Chapter 4	Methods Developed	4-40
4.1	Determination of solar obstruction height data.....	4-40
4.2	Obstruction Contours.....	4-53
4.3	Application to Case Study.....	4-57
4.4	Whole Site Solar Access	4-60
4.5	Solar energy overlay	4-61
4.6	Solar Access Planning Discussion.....	4-65
4.7	Limitations of solar access planning	4-66
4.8	Other considerations.....	4-67
Chapter 5	Optimal window shading	5-69
5.1	Introduction	5-69
5.2	Temperature Data.....	5-70
5.3	The effect of ambient temperature on passive solar design ..	5-74
5.4	Specification of shading angles.....	5-76
5.5	Section summary	5-85
Chapter 6	Building thermal energy efficiency and site thermal energy self-sufficiency	6-86
6.1	Introduction	6-86
6.2	Background.....	6-86
6.3	On-site thermal energy provision.....	6-90
6.4	Discussion on Building energy efficiency	6-91
Chapter 7	Conclusions.....	7-93
7.1	Solar Access Planning	7-93
7.2	Shade Angles	7-94
7.3	Building Energy Efficiency.....	7-95
7.4	General	7-95

Chapter 8	Bibliography.....	8-97
Appendix A	Solar data for East Taratahi weather station, 2001.....	101
Appendix B	Temperature data for East Taratahi	103
Appendix C	Altitude and Azimuth angles for case study for specified Julian day numbers	110
Appendix D	Triangulation of solar obstruction points to give solar obstruction contours.....	118
Appendix E	Solar obstruction contours for case study site.....	120

List of Figures

Figure 1-1 Investigation process for case study land development	1-7
Figure 2-1 Sunpath diagram showing varying solar path at different times of the year (CCANZ, 2001)	2-10
Figure 2-2 Altitude and azimuth angles (EECA, 2003)	2-12
Figure 2-3 Solar shading butterfly showing a plan view of a tree, and a typical shadow area cast during a 12 month period	2-15
Figure 3-1 Location diagram showing Wairarapa case study development site and East Taratahi meteorological station	3-26
Figure 3-2 Aerial photograph of case study site showing subdivision outline (in blue), and adjacent Ruamahanga river	3-28
Figure 3-3 Scheme plan for case study subdivision showing individual lots and residual common land	3-33
Figure 3-4 Average hourly daily irradiation at East Taratahi (1995), average over a 12-month period	3-35
Figure 3-5 Polynomial regression curve fit against measured irradiation data from East Taratahi	3-36
Figure 3-6 Division of curved area for Simpson's rule calculations	3-37
Figure 3-7 Energy capture versus hours of capture for Simpson's method and Polynomial curve fit for East Taratahi solar data (1995)	3-39
Figure 4-1 Definition of slope, β , latitude, ϕ , and angle of incidence, θ relating to solar geometry	4-41
Figure 4-2 Definition of surface azimuth angle, γ_s	4-42
Figure 4-3 Altitude angle Vs Julian day number at given times of day, with sun location at 4:30pm shown for three different day numbers	4-45
Figure 4-4 Solar resource diagram for the case study site, where the shaded area indicates the apparent skyline, facing north with east to the right, and west to the left.	4-47
Figure 4-5 Solar shading geometries showing relationship between solar altitude angle and obstruction height (Reilly & Duncan, 2004)	4-49
Figure 4-6 Solar obstruction contours for 85% energy capture at case study site	4-54
Figure 4-7 Example of amalgamated solar obstruction contour for offset observation points	4-55
Figure 4-8 Amalgamated solar obstruction contour diagram for 20m East-West building face, with contours at 5m intervals.	4-56
Figure 4-9 Simplified amalgamated 5m and 10m solar obstruction contours overlaid onto part of the case study site plan, showing minimal interference between lots given a maximum building height of 10m.	4-57
Figure 4-10 Solar obstruction contours for case study site (see appendix E for scale plan)	4-59
Figure 4-11 Solar energy diagram indicating percentage distribution of total yearly solar energy for each daylight hour (East Taratahi 1995 data)	4-62
Figure 4-12 Solar energy overlay for East Taratahi Data (1995)	4-63
Figure 4-13 Hypothetical solar resource diagram for site with hills to the east to demonstrate use of solar energy overlay	4-64
Figure 4-14 Minimum altitude angle based solar energy capture diagram.	4-68

Figure 5-1 New Zealand mean annual temperature (reproduced by permission from National Institute of Water and Atmospheric research)	5-69
Figure 5-2 Average monthly temperature variation, East Taratahi (1995-2003), taken on average solar days	5-71
Figure 5-3 Average monthly daily temperature variation by hour (24-hour clock) for East Taratahi (1995-2003)	5-73
Figure 5-4 Traditional eave overhang design showing summer and winter shading angles.....	5-79
Figure 5-5 Traditional eave overhang with 60° sun altitude angle, showing undesirable solar access on this day (Feb. 6 th)	5-80
Figure 5-6 Human comfort temperature range with daily air temperature (average 1995-2003 East Taratahi data).....	5-81
Figure 5-7 Traditional eave overhang with 36° sun angle showing partial shading of window in August	5-82
Figure 5-8 Alternative architectural design to optimise shade angles, showing shading/solar access of different sun angles	5-83
Figure 5-9 Criteria for optimised shading angle design	5-84

List of Tables

Table 4-1 Definition of day numbers used for solar obstruction contouring.....	4-43
Table 4-2 Time-varied and solstice altitude angles, showing minimum altitude angle between 8:30 am and 4:30pm through the year, for the case study location at 40° latitude.....	4-44
Table 4-3 Calculated northings and eastings for 5 metre distance from point of observation, and maximum obstruction height before shading occurs at point of observation	4-51
Table 4-4 Obstruction heights, northings, and eastings 5-50m radii .	4-52
Table 5-1 Altitude angles on monthly average solar days (East Taratahi), with average daily air temperature	5-74
Table 5-2 Suggested shading angles for case study location.....	5-76
Table 5-3 Altitude angles versus average air temperature (Kaitaia)..	5-77
Table 5-4 Altitude angles versus average air temperature (Invercargill)	5-77
Table 6-1 Proposed building performance index requirement for case study dwellings, relative to proposed building floor area	6-88

Chapter 1 Introduction

1.1 Introduction

When land is developed for residential purposes in New Zealand and elsewhere, little consideration is given towards planning for solar energy benefits. Passive solar building design, building orientation, solar water heating and photovoltaic electricity generation are at present rarely considered by developers, designers or builders.

This thesis investigates a selection of design tools intended to promote use of solar energy and building energy efficiency in residential subdivisions. The hypothesis presented is that simple, effective design tools optimising the solar design of both dwellings, and residential developments can be developed using climate and topographic data on a district scale.

These tools and procedures are then applied to a case study on a subdivision in the Wairarapa to gauge the viability. Whilst both the applicability and perception may change between regions in New Zealand, there will be aspects common to all. It is hoped that successful design methods highlighted by this study may be adopted throughout New Zealand.

Topics such as wastewater reuse, community interaction, and ecological initiatives were included in the subdivision design, but fall outside the scope of this thesis topic, so are not discussed further in this report. Building design for energy efficiency, solar access planning, and window shading have relevant energy components and are all included.

Involvement in the land development industry in the Wairarapa, where agriculture dominates land use, has shown that when land is subdivided access to renewable energy resources can, and frequently is,

compromised. Without incentives from central government or local authorities, developers perceive additional risk in departing from the norm, and hence novel incorporation of specific sustainability practices is generally only carried out by minority groups. Without suitable planning tools, education, and working examples of how the situation may be improved, it seems likely that today's non-sustainable practices of land development will continue.

In order to effect an improvement in the incorporation of renewable energy resource design in residential land development there is therefore a need to break the current cycle by researching and implementing a development that recognizes the importance of renewable energy production and energy efficiency issues, and can demonstrate their use.

This need was the catalyst for a case study subdivision development in the Wairarapa, an essential element in bringing together theoretical and practical issues. This thesis describes the case study development and the tools developed to assess the passive solar potential and meet the goals of the land development.

The primary goals of the case study subdivision are to:

- optimise the use of renewable energy resources;
- introduce energy efficiency concepts at both individual and community level;
- foster an ethos of stewardship;
- include ecological considerations; and
- develop a sense of community.

As a general concept, the overall aim was to strive for improved sustainability above that normally achieved by traditional subdivision practices.

1.2 Problem statement

The problem is that there are no simple design tools or regulations to assure local authorities, developers, builders, designers, and future homeowners of continued access to solar energy on developed building sites.

Similarly there are no design tools available to define optimum shade angles in building designs relative to location and micro-climate, to ensure that summer overheating and winter underheating are minimised.

Current planning gives scant attention to the thermal energy requirements of residential subdivisions, and there are no design tools to assess and minimise these requirements.

1.3 Background

The sun is the dominant energy source for the Earth, affecting temperature and weather patterns. An understanding of the sun's relative movement across the sky and how it interacts with man-made features is termed solar planning.

The predictability of the solar path across the sky has enabled solar planning to exist, to some extent, for hundreds, perhaps thousands of years. Neolithic man used standing stones, or menhirs, to mark solar paths, and give confirmation of solar equinoxes and solstices.

Solar access planning for communities has been carried out since Ancient Greek times when the city of Olynthus was reportedly designed with this in mind in 500B.C. (Chiras, 2000).

The extent and *type* of solar planning carried out has varied historically, and still varies in the present, depending on the naturally occurring conditions surrounding the proposed dwelling or workplace. In geographic regions where the surrounding environment closely matches

the human temperature comfort range, less importance has been placed on underheating or overheating. Where there is a large disparity between the average surrounding environment and the human temperature comfort zone, the effects of overheating due to solar energy, or the desire to use solar energy as a heat source become of higher importance.

This changed with the introduction of more effective methods of controlling building internal temperatures, notably more refined construction methods/materials; the introduction of fossil fuels as an energy source; and more recently the introduction of heating and cooling by air conditioning. The domination of the surrounding environmental conditions by technology has persisted as the major design ethos for the last century. It is only recently as the global use of energy has been identified as a problem area, that greater interest has been shown in development of construction that responds better to the surrounding environment.

It is in this context that this study investigates possible improvements to the design of land developments to place greater emphasis on the use and control of (predominantly) solar energy.

When land is developed for residential use, there are distinct steps in the process:

- concept design
- resource consent
- legal land subdivision, and
- construction

The design stage of the land development process is the stage at which the greatest effect on energy efficiency and sustainability can be applied to land use, yet it often fails to do so. Whilst the principles of passive solar dwelling design are well documented, and information is available to architects, designers, builders, and developers, it is the author's experience that, at least in the Wairarapa region of New Zealand, passive solar design and energy efficiency measures are rarely

incorporated into domestic building design. To implement an improvement in domestic building energy efficiency it is therefore necessary to increase regulatory control, provide simplified design tools (as many are too complex for widespread use), or impose land covenants. Education of the general public, designers, and builders and is also an important factor, but is beyond the scope of this work.

There appears to be a large gap between the understanding of specialised architectural design professionals and building practitioners on theoretical solar design criteria. The challenge is therefore to create design tools that enable the homeowner, builder, or developer to allow for solar energy capture. The availability of such tools will also help to influence the ability of territorial authorities or the New Zealand Building Code to require the use of such measures.

1.4 Objectives

This research details avenues that developers and interested community groups could investigate in the process of creating more sustainable communities. It seeks to define both generic energy efficiency improvements at a district level, and site-specific criteria that can be applied at the land development level. The criteria are most applicable to low-density housing, but the technique may be equally used to aid building and subdivision design in other situations. To be of use the results must be simple to understand for use by layman and designer alike.

The specific objectives of this study were to:

- review literature on site criteria effecting solar energy availability;
- derive a simple-to-use tool that indicates of the percentage of solar energy available in terms of a site's theoretical maximum (section 4);

- develop a method of analysis that allows a site's latitude and longitude to be used to calculate 'solar obstruction contours' (section 4);
- analyse temperature and solar altitude angle trends with the goal of specifying optimum eave shading angles for a given site (section 5);
- apply the above methodology to a case study in the Wairarapa (section 3); and
- identify areas for further study that may enhance the adoption of sustainable land development practices.

In the forming of the case study development, a process was followed that enabled the solar potential of the site to be optimised. (Fig. 1-1).

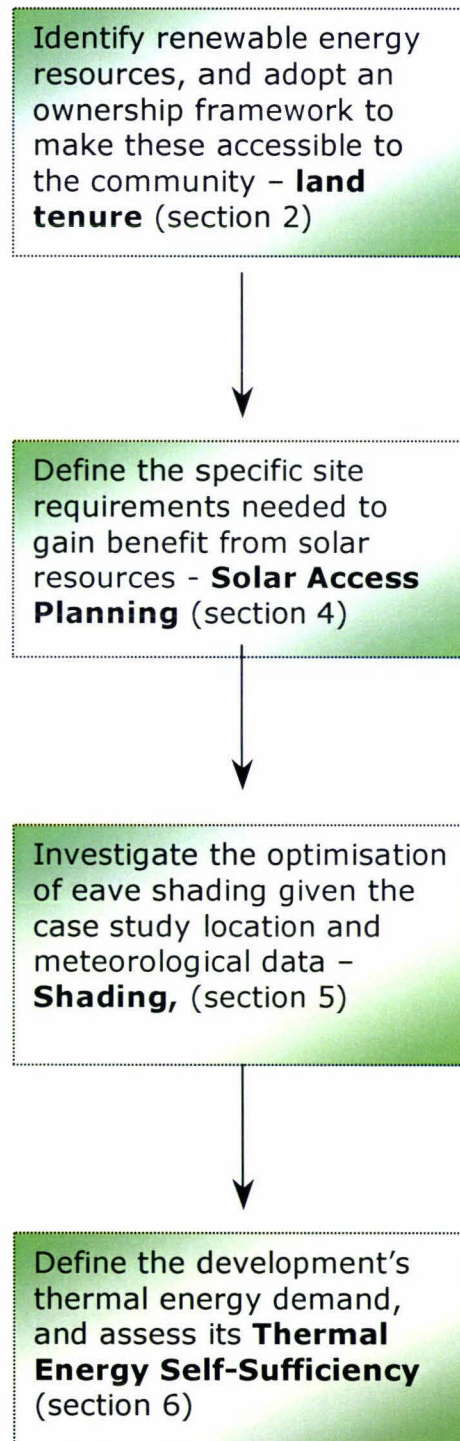


Figure 1-1 Investigation process for case study land development

Chapter 2 Present understanding of solar energy capture

2.1 Introduction

An understanding of the geometries of the sun's path across the sky allows the beneficial incorporation of this information in land development planning. Maximising the use of solar energy can effect boundary shapes, house lot location, planting restrictions, and acceptable building height. Such differentiations can have great effect on the available solar resource at a proposed dwelling location.

In developing the case study and design tools the current literature was first reviewed to provide a theoretical basis for analysing and achieving solar energy efficiencies. Where such methods were used in the case study, they have been described, and their benefits and limitations discussed. This section summarises current practice in New Zealand and Australia, with additional information from elsewhere. The field is limited mainly to solar access design and solar energy planning since land tenure options overseas are diverse, and play little part in practical development applications in New Zealand.

The direction of land development in New Zealand in terms of sustainability is affected by legislation, market demands, and legislation. It is generally considered (P.C.E, 2002; SNZ, 2001) that responsibility for change towards a more sustainable lifestyle in New Zealand lies as much with the actions and lifestyles of individuals or small groups as with government agencies. Lack of knowledge is seen as a key factor in sustainable options not being adopted, and improvements are often brought about by the actions of a few committed individuals.

2.2 Theory of solar radiation

The sun is a sphere of dense, extremely hot gases (5777° Kelvin), and is, on average, 1.5×10^{11} m from Earth varying slightly with the time of

year. Hence the energy reaching the Earth also varies depending on time of the year (Duffie and Beckmann, 1991).

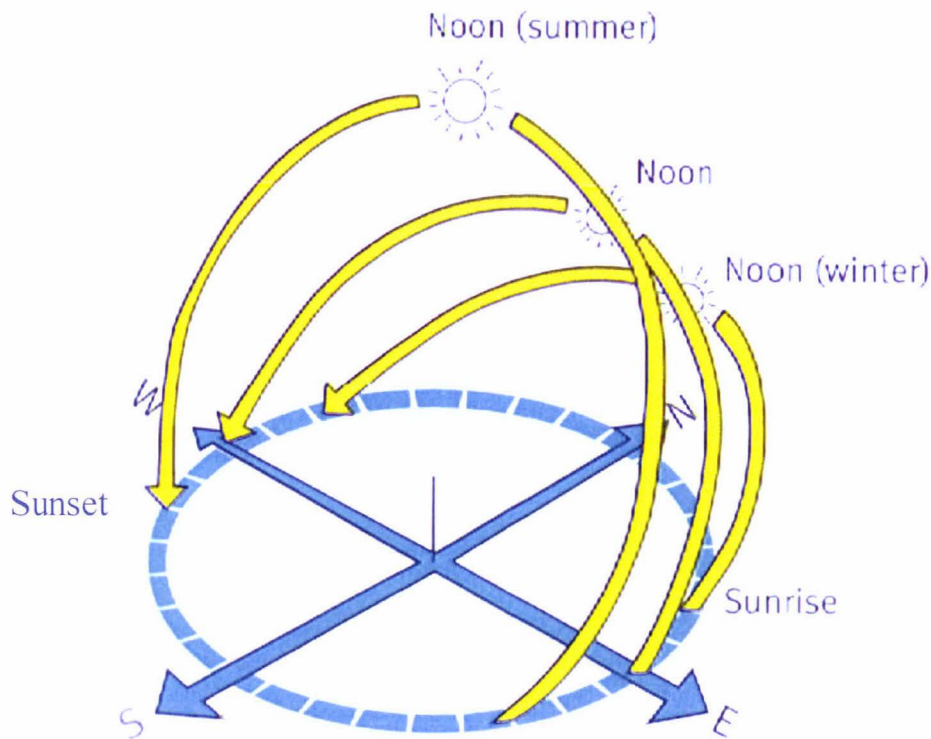
The sun is, in effect, a huge fusion reactor in which the most important reaction is thought to be the conversion of hydrogen to helium. The energy given off in this reaction is radiated into space, and is received on the Earth as solar radiation. The average intensity of this radiation on a surface perpendicular to the line of radiation, and measured just outside the Earth's atmosphere is 1367W/m^2 .

Only a portion of this energy reaches the Earth's surface: some is reflected, and some absorbed by cloud formations or other particulate matter in the atmosphere. The fraction reaching the surface at a given location defines the *clearness index*.

The Earth's rotation about the sun, and the tilt of its axis determine the angle that the sun reaches in the sky at any given location and time. The *declination* is the angular position of the sun at solar noon relative to the plane of the equator. In practice this means that the noon sun is overhead the equator twice a year at the equinox¹ (about March 21st and September 23rd), overhead the tropic of Capricorn on about June 21st, and the tropic of Cancer on about December 21st (CSIRO, 2002).

The anomalies in the orbit of the Earth around the sun gives rise to a difference between solar time, and clock time, which averages out these anomalies (section 4.1). Solar noon differs from clock noon depending on the time of year, and daylight saving (summertime) clock changes.

¹ From Latin *aequus*, equal, and *nox* or *noctis*, night, signifying equal length night and day.



The sun's azimuth

Figure 2-1 Sunpath diagram showing varying solar path at different times of the year (CCANZ, 2001)

These factors influence the amount of energy reaching the ground at any location and any given time of the year. Generally there is a higher sun altitude angle and energy in the summer, lower angle and lower energy in the winter. The intensity of solar irradiation at any point varies during the day, with a peak intensity normally occurring at solar noon, when the sun is in line with the local meridian (line of longitude), and is at the highest point in its trajectory.

Solar energy is emitted within a band of wavelengths, peaking at between 0.4 and 0.5 μm (Duffie & Beckmann, 1991). This wavelength can pass easily through glass, and can be used to warm elements of the building within the building envelope. As these elements warm up, they emit heat through convection, conduction, and radiation. The radiation component is of a different wavelength to that of the solar radiation, and

consequently cannot efficiently leave the building. The result of this is that if insulation methods are employed to reduce conduction of heat from inside to outside of a building, a net increase in thermal energy is possible inside the house from solar radiation. Houses designed to optimise the capture and retention of this energy are termed passive solar houses (Boyle, 2002).

Solar energy is also used in a similar way to heat water (primarily for domestic use), and can also be harnessed using *photovoltaic* panels, which convert a portion of the energy into electricity. All of these methods of energy capture benefit from uninterrupted access to the sun's rays.

The solar energy available on a flat site is dependent on the latitude and longitude of the site, and the associated paths described by the sun through the day (SEIAA, 1995). At a fixed time of day the solar position varies throughout the year both in altitude angle² and azimuth³ (Fig. 2.2), and hence the effective shadow caused by buildings, trees, or other obstructions in the vicinity is dependent on the time of day, day of the year, latitude, and longitude. The long-term optimisation of collection of the sun's energy and the control of shading is collectively termed *solar access planning*.

² Altitude angle is described as the angle between the horizontal and the line to the sun. It is the complement of the zenith angle.

³ The deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due North, East positive and West negative.

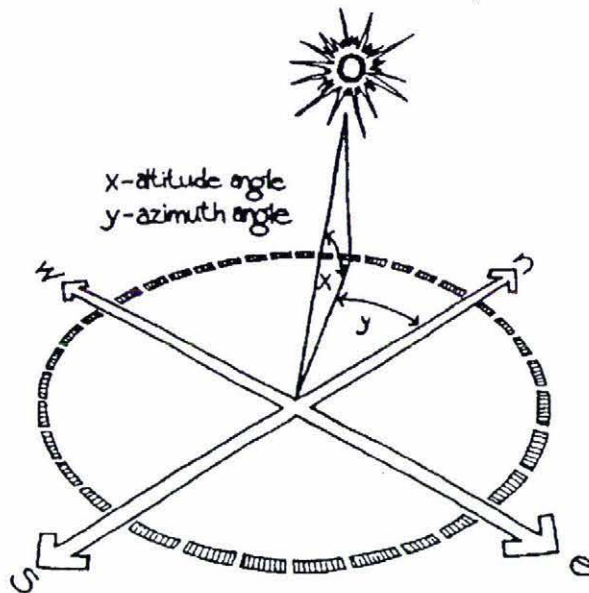


Figure 2-2 Altitude and azimuth angles (EECA, 2003)

2.3 Solar Access planning

Relevant texts concerning solar access planning are reviewed in this section, and their applicability to land development in New Zealand discussed.

The predictable nature of the sun's path across the sky on a daily basis makes it one of the easiest of the renewable energy options to predict on a long-term basis excepting the intermittency and unpredictability of cloud cover. The concept of inclusion or exclusion of sunlight from a building is ancient. Throughout history man has employed the use of natural surroundings and other buildings to modify building internal temperatures. Olgyay (1967) in 'Design with Climate; bioclimatic approach to architectural regionalism' provided the definitive work on the interaction between the living environment and architectural design. The detail and scope of topics described remain unparalleled despite the length of time since its first publication.

Sealey (1979) noted "If we seek respectability for the subject in scholarship, we will find in the earliest written work for the architect, the *Ten Books of Architecture* dating from the first century A.D., that Vitruvius not only observes the tradition, but also gives case studies from his own time of the penalties for ignoring local climatic conditions in the planning of towns and buildings". Solar design of buildings has therefore been recognised for centuries, and its importance in assisting to create a comfortable living environment remains unchanged.

Developed sites with good access to a solar resource have choice as to utilising this resource or not. Sites without this access have no such choice. Detailed work has been carried out on the methods of obtaining efficient use of available solar resources in New Zealand (EECA, 2002). However no definitive information is available on the ability of a site in New Zealand to be developed in such a way as to ensure that these resources are accessible by each of the developed lots.

One objective was to investigate the relationships between solar paths and predictable site features throughout the year, and to develop relationships between them to allow specification of conditions that define access to solar energy. Solar access planning in this context may be considered to be the specification of the spatial geometries of existing and predictable site features with the intent of optimising the percentage of solar energy that can be usefully harvested at each developed building site.

Solar access planning in New Zealand has traditionally been based around the necessity for passive solar heating during the winter months. Whilst overheating in summer may be more problematic in the north of the North Island, underheating is generally more prevalent, with conditions becoming more severe to the south of South Island. Most architectural and energy engineering practices are therefore primarily focussed on heating with solar energy able to provide a notable contribution to domestic water and space heating (EECA, 2000).

The percentile energy capture used in Australasia for similar purposes varies on intended use of the energy, and the planning regime in which the site lies. For example the recommended energy capture (Bensemam & Cook) for Wellington, and specifically for winter passive solar design, is five hours, which equates to around 60% of the total available. In contrast the New South Wales (NSW) Sustainable Energy Development Authority promotes a minimum three-hour access period, but this is primarily concerned with medium to high density housing developments and the winter heating requirements are not as onerous (SEDA, 2004).

Models such as that used in NSW (SEDA, 2004) provide detailed information on a very specific topic i.e. the provision of a minimum solar access period over a certain portion of the lot, with assumptions as to the surrounding building heights and locations. The drawbacks with this method are the limited information that it supplies, and lack of adaptability or options. Presentation of one case, the minimum requirement, tends to have the effect of all developments reaching only minimum solar access standards. A more flexible tool could provide details of the minimum requirements, but also provide details of higher solar access goals. This allows competition and market awareness of differential between minimum standards and those developments that have higher standards.

As photovoltaic technology becomes more refined and affordable, there is likely to be a desire for more energy capture from dwellings. A good solar access tool should allow indication of how successful such a course of action would be.

The analysis of solar geometry is well documented. For this research the calculation procedures taken (Duffie & Beckmann, 1991), gave detailed information on solar paths, equations of time, shade angles, and a variety of other topics. However there was no information provided of

benefit for the broader topic of site design to achieve satisfactory solar access.

The most detailed of the texts for New Zealand is '**Design for the Sun**', (EECA, 2002) in which the topics of solar shading and passive solar design are well developed. The concept of a "solar access butterfly" is demonstrated, where shadow lengths for known solar obstructions are plotted for varying times of day (for winter solstice conditions). The resultant plot is a solar access butterfly, a kidney-shaped area of shade depicted on an aerial plan (Fig.2-2).

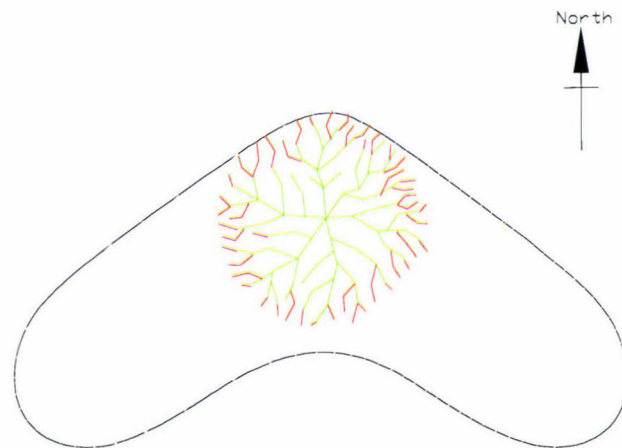


Figure 2-3 Solar shading butterfly showing a plan view of a tree, and a typical shadow area cast during a 12 month period

The process relies on knowing the exact location and height of solar obstruction (e.g. trees and other buildings) in relation to the proposed dwelling. The tool is also restricted to a specific time of year, and hence restricted azimuth angles.

These restrictions limit the usefulness in terms of total solar energy access, for example for photovoltaic use, and introduce variables that may be beyond the control of land developers. The continued access to solar energy as obstructions change over time (i.e. trees growing, or new building construction) becomes difficult to guarantee. The variables make specification onerous to say the least. As a tool for developers this system is currently rarely (if at all) used for land development in the

Wairarapa, and it is thought that without regulatory control this will continue to be the case.

2.4 Building design overhangs

'**Design for the Sun**' also detailed recommendations for fixed overhangs to prevent summer overheating. These are primarily based on solstice sun angles for summer and winter conditions, giving required summer and winter shade angles. It further details variations to these basic shade angles by making broad allowances for "warm" or "cool" conditions. This approach is further developed in section 6 where shade angles are related specifically to site conditions. Diurnal and yearly temperature variations differ markedly even over relatively short distances in New Zealand, giving differing requirements in terms of heating or cooling through the day and year. The optimisation of shade angles for a building provide a good basis for passive solar design, and it seems prudent to investigate the best suited configuration of shade eaves in any given district.

Sunlight Indicators (1978), an Australian publication defines periods of effective sunlight and 'sunlight indicators' for specific latitudes, on solstice and equinox dates. These show height contours for shade boundaries, but are restricted to a single day, and single latitude.

This study proposes a tool that has simple inputs of latitude and day number, and can assimilate the results from multiple Julian day⁴ numbers to create 'most onerous' solar obstruction contours (section 4.2).

Plots of solar paths for varying latitudes are readily available (EECA, 1985; CCANZ, 2001; CSIRO, 2002), and this topic is also developed into use for plotting skyline and solar obstructions. These are seen as valuable tools, and again are refined in this section 4.

⁴ Julian numbering, where each day of the year is sequentially numbered from 1 to 365, with January 1st having a day number of 1.

More detailed and specific requirements, once again in terms of winter solar access, are used in "Solar Access for Lots–Guidelines for Residential Subdivision in NSW" (SEDA, 2004). These specify building restrictions on varying 'standard lot types' to ensure minimum solar access across a whole development. The process is complicated and requires good conceptual skills to interpret and apply the information. Its use is therefore somewhat restricted to design professionals, but the mandatory requirement for its use ensures uptake on medium density housing developments. The solar access is limited to a three-hour period during the middle of the day at the winter solstice, and therefore has specific purpose, and limited use outside of solar water heating and minimum lighting requirements.

2.5 Energy Efficiency

The sun is the Earth's primary source of energy, and has a dominant effect on weather and temperature.

In New Zealand the winter air temperature is generally below the human comfort zone, and buildings need additional heating energy to warm the air to a comfortable, and healthy temperature (WSM, 2004 and BRANZ, 2004). The efficiency of capture and retention of thermal energy for this purpose is termed thermal energy efficiency.

The effective utilisation of solar energy for domestic thermal energy supply is dependant on the energy efficiency of the building. A poorly insulated building for example, will achieve only limited success for solar energy gain in terms of the daily and yearly temperature cycles (Boyle, 2002).

The analysis of the energy efficiency of buildings has been studied in detail by numerous agencies and government organisations worldwide, resulting in a number of software models and mathematical algorithms to aid in design. There are benefits and drawbacks associated with each model, the summary of which is beyond the scope of this research.

However one model was selected for use in this study, and is detailed below.

The ALF software was developed by the Building Research Association of New Zealand, a nationally recognised body committed to continual research and development in the building industry in New Zealand.

The ALF3 software was selected for this study because it successfully balances the requirements of accuracy against usability. For widespread adoption it is critical that such software is user-friendly for use by design professionals and the general population, and is well supported. ALF3 is designed for use solely in New Zealand, so no adjustment of climate factors is required. It is readily available and relatively inexpensive, even in terms of a solitary house design.

The energy efficiency of a dwelling depends on a number of factors including insulation level, window size, type, and orientation, airtightness, construction material type and weight, floor area, and number of occupants. The ALF3 (Annual Loss Factor) software (BRANZ 2003), uses regional climate data in combination with the building design criteria to calculate the energy required to heat the building to the required heating schedule. Thus the software has input requirements of building location, orientation, window size and location, insulation levels, material type, occupation level, required temperature etc. The software outputs a "Building Performance Index", which is defined as Annual heating energy/(degree-days⁵ x floor area), measured in kWh.degree days.m². This is the yearly amount of energy required to heat the building to a given temperature.

⁵ Degree Days: [DD] Measure of the severity of the climate. The larger the number of degree-days the cooler the climate. The number of the degree-days is defined in relation to a base temperature that is commonly either 15°C or 18°C. The number of heating degree days is calculated as the sum of the daily differences between the average ambient temperature and the base temperature for all the days on which the average ambient temperature is smaller than the base temperature. Example: The heating degree days (base 15°C) of three days with ambient temperatures 11°C, 9°C and 16°C is: (15-11) + (15-9) + 0 = 10DD15 (BRANZ, 2003).

Given the range of information and modelling software available, it begs the question of why energy efficiency investigations are not more commonly adopted by the wider design community and public. Many passive solar design techniques result in only minor construction cost increases (CCANZ, 2001), and more work has now been carried out to quantify previously intangible benefits of energy efficient design and natural lighting (Wellington School of Medicine, 2004). The reductions in absenteeism and increased work efficiency in workplaces utilising natural lighting and energy efficient design noted by Olgyay (1976), have been confirmed by more recent data, and further reported benefits have since been recorded, for example reduced length of stays in hospitals, and more favourable student grades (NZSSES, 2004).

2.6 Land Tenure and Management

The type of land tenure adopted in a land development has the greatest of influences on the nature of the finished development, and the ability to utilise the site's natural energy resources in the most efficient manner.

These natural resources may be from solar energy, wind energy, hydropower, or the ability to grow and utilise energy crops. Each of the above renewable energy resources generally vary in their abundance or availability at different locations on a site, and in order to make most efficient use of resources it is preferable that the optimum locations for the dominant renewable energy resources within the site are identified *before* subdivision takes place. These areas can then be placed in a form of land tenure that allows the capture of these resources for common or private energy production.

In general New Zealanders regard home ownership as a high priority, and invest significant capital in their homes (SNZ, 2001). The perception

of security of the home as an asset plays an important part in the acceptability to the public of different land tenure types.

The dominant form of land tenure in New Zealand is fee simple, or freehold title. With a fee simple land tenure the owner has exclusive use of the land parcel, which is readily mortgageable, has its boundaries defined by survey, and is guaranteed by the crown. The restrictions of a fee simple land tenure for the purposes of the case study development are that it poses restrictions and legal complexities for use by multiple or common users. There is also no provision for setting aside areas of land for priority uses.

Other types of tenure (SNZ, 2001) are:

1. *Tenancy in common* – where land and buildings may be owned by any number of parties in either equal or unequal proportions. Each person effectively owns an 'undivided' share in the real estate. A tenant in common may have a separate title issued for the undivided interest in a property. Disadvantages to this system are:
 - Failure to provide a separate title to a defined area of land under individual ownership.
 - Difficulty in raising loans against shared land ownership.
 - Management of common assets may become difficult.
2. *Cross lease*. Cross lease of land gives rise to two separate interests, firstly an undivided share in the underlying land (in fee simple), and secondly a leasehold on individual dwelling houses and accessory buildings. Crosslease titles are mortgageable and sellable, but have significant problems associated with them:
 - Dwellings have to be built before crosslease titles can be issued.
 - Any improvement to buildings or additions requires the preparation of a new plan.
 - The system does not provide any committee provisions for democratic regulation of common assets.

3. *Flat Owning Companies*. These are defined as companies that own the whole of the land and buildings, and issue shares and a 'license to occupy' a building. Although a form of certificate of title can be issued for a license to occupy, the reduced security means that lenders are reluctant to lend on this type of tenure.
4. *Unit Title*. This usually provides a fee simple to a defined geometrically identified space. Unit titles are governed by the requirements of the Unit Titles Act 1972 and its amendment in 1979. However in practice the requirements of the Act mean that a building must be erected on the Unit before title can be issued, an obvious detriment to marketing and pre-selling.

The economics and efficiency parameters of some renewable energy technologies, such as wind turbines, are more suited in terms of economics to load requirements greater than one dwelling. In order to capitalise on the possibility of assets communally owned between a group of people in a land development scheme, consideration needs to be given to types of land tenure that make the ownership of common land and communally owned assets as practicable as possible. Investigations on legal ownership for community power generation schemes (Irving, 2000) concluded that in New Zealand there are three dominant legal entities for such purposes

- crosslease
- flat owning companies
- unit title.

The addition of land ownership for other specific and general purposes makes the matter more involved. The type of land tenure most suitable is therefore dependent on the nature and scale of the development.

2.7 New Zealand Building Code

The New Zealand Building Code specifies verification methods and acceptable solutions for construction. These are not recommended good practice measures, but minimum acceptable standards. The Building

Code is currently under review, and energy efficiency is one of the issues of debate.

Clause H1 of the Building code (1992) requires new houses to meet minimum thermal energy efficiency requirements:

H1.3.1. The building envelope enclosing spaces where the temperature or humidity (or both) are modified must be constructed to—

- (a) provide adequate thermal resistance; and*
- (b) limit uncontrollable airflow.*

H1.3.2. Buildings must be constructed to Performance H1.3.2 applies only to ensure that the building performance index housing does not exceed:

- (a) 0.13 kWh in a warm location; and*
- (b) 0.12 kWh in a cool location.*

H1.3.3 Account must be taken of physical conditions likely to affect energy performance of buildings, including—

- (a) the thermal mass of building elements; and*
- (b) the building orientation and shape; and*
- (c) the airtightness of the building envelope; and*
- (d) the heat gains from services, processes and occupants; and*
- (e) the local climate; and*
- (f) heat gains from solar radiation.*

In reality standard construction practices have been adapted to meet these minimum requirements, and the housing stock currently in production is dominated by minimum requirement standards. These standards however no longer satisfy current thinking, where thermal efficiency plays a far more dominant role in both energy efficiency and occupant health.

2.8 Subdivision Code of practice

The current New Zealand National Standard for subdivision (SNZ, 1981) sets out prescriptive methods of achieving acceptable solutions for design and installation of the infrastructure required to support a residential subdivision. Current standards predate thinking on

sustainable development, and include little or no guidance on ecological, environmental, energy efficiency, or solar access planning.

A significant resource in terms of sustainable land development is 'Subdivision for People and the Environment' Handbook 44(SNZ, 2001). With the use of theory and case histories it explains some of the concepts behind the paradigm shift needed to change from the existing methods and policies, to new methods that focus more on the physical and mental wellbeing of the future occupants, and a more harmonious interaction with the environment. Much of the open space and environmental concepts researched in this thesis parallel and compliment those outlined in the handbook, although at times they were included with different goals in mind (for example the provision of communally owned open spaces).

2.9 Shade Angles

Many buildings in New Zealand incorporate eaves that extend the roofline beyond that of the external walls. These eaves provide protection for the walls from rain, and provide shading of the structure. In passive solar design where solar energy is used to heat indoor spaces, the angle that the eaves form relative to wall openings is critical in determining the amount of solar energy that can enter the building. This angle is termed the shade angle.

Considerable information is available on the effect of building eave or wing wall features on the shading under varying sun angles (CSIRO, 2002; CCANZ, 2001), but the conclusions drawn are usually generic in terms of sun angle and building features. There are however site specific features that may influence the optimum shading conditions for a dwelling. For example diurnal and seasonal temperature fluctuations will depend on altitude, proximity to the sea, aspect and so on. These aspects require optimum house design to reflect an holistic approach as suggested by Olgay (1967). His bioclimatic approach reviewed the meteorological and climatic records of the surrounding area and presents

methods of utilising this data to refine building design. Whilst the concept closely reflected the goals of this study, the data was limited to the United States, and required more specific research on a district rather than regional scale for application in New Zealand. It is only by the investigation of micro-climate conditions that building form can be guided to best reflect the extremely variable conditions that exist in New Zealand.

Thus correlation of solar irradiation and air temperature was investigated in this study with the aim of refining optimum shade angles in the development location (section 5).

2.10 Thermal energy self-sufficiency

The self-sufficiency of developments in terms of energy usage requires the specific consideration of both building energy efficiency and the ability of a site to provide energy from renewable sources. Through specification of minimum building energy efficiencies and maximum building size, the total heating energy demand for a development can be calculated and compared to the energy that may be provided by the site through renewable means. The objective for this part of the study was to investigate the feasibility of using these associations to produce a heating energy self-sufficiency factor (section 6).

Using a 20°C temperature base (24 hours per day), a Thermal Energy Self Sufficiency (TESS₂₀) indicator was developed for land development comparison or specification (section 6). Whilst information is available to estimate the thermal energy requirements of buildings in New Zealand (BRANZ, 2003; EECA, 2002) no relevant literature was available on residential land development in New Zealand balancing thermal energy requirement against production.

Chapter 3 Sustainable property development – a case study.

3.1 Introduction

The successful application of solar energy capture techniques and energy efficiency management in New Zealand requires a methodological framework to analyse any site's potential. There are currently no methodologies available for direct use in New Zealand. It was therefore necessary to develop such a framework, which involves solar path information and requires the assumption of specific site information. This would allow calculation of solar geometries, and investigations of the effect of the assumptions made for physical characteristics of the site.

A residential development in the Wairarapa was used as a case study and provided site information for calculation of solar geometries. The case study property came up for sale in August 2004, and was purchased by the author with the specific intent of investigating sustainable land development. By avoiding the usual client/engineer relationship, considerably greater freedom of expression was possible. The case study development is at grid reference 344,175 on NZMS260 series map T26 (Fig 3-1).

A literature review of major New Zealand references highlighted deficiencies in the information available to assist in practical implementation of sustainability concepts. Much of the information from overseas is not directly applicable for New Zealand and, more specifically, solar access information is dependant on the latitude and longitude of the site.

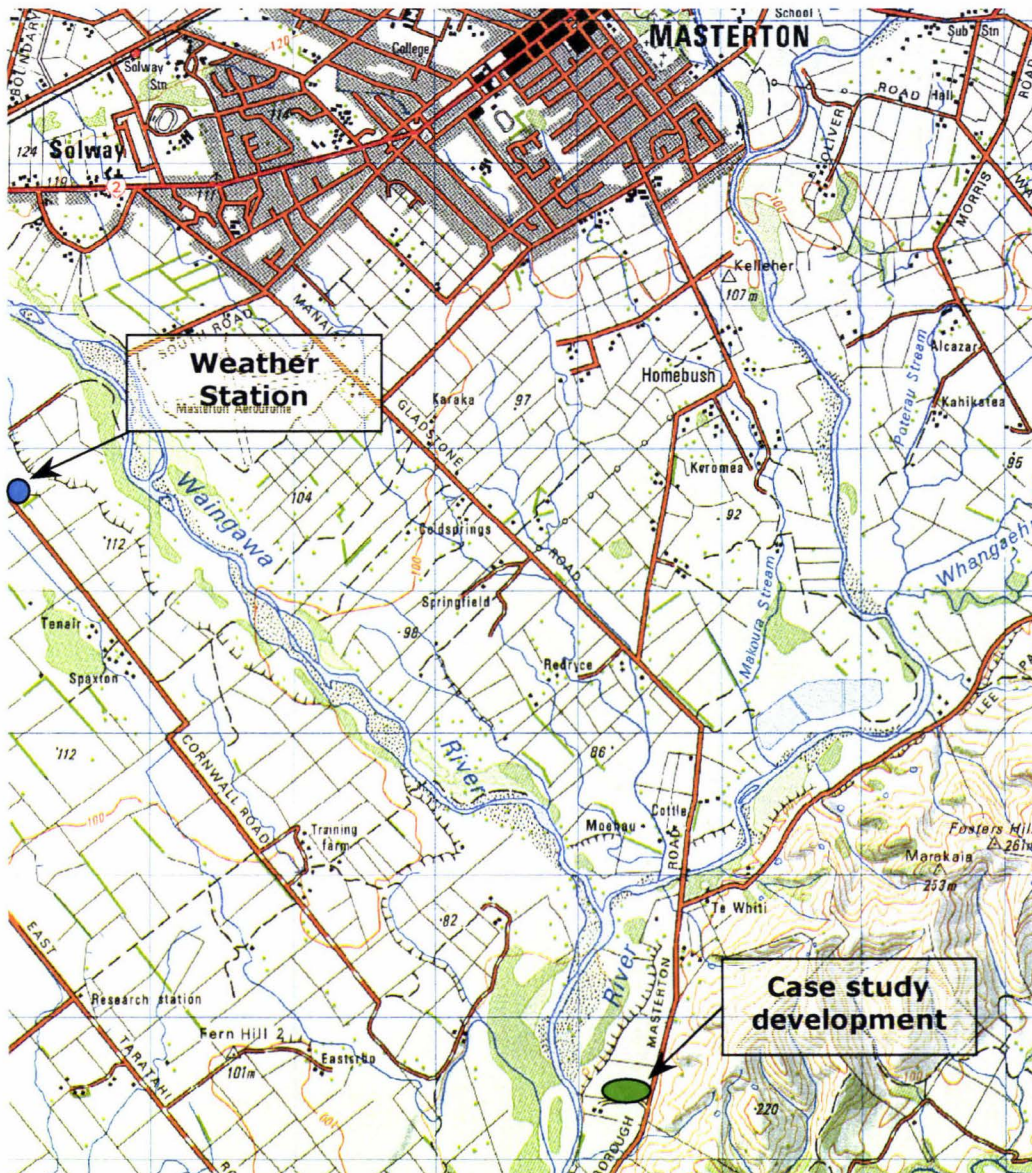


Figure 3-1 Location diagram showing Wairarapa case study development site and East Taratahi meteorological station

3.2 Site details

The 7 hectare site is adjacent to the Ruamahanga River (Fig. 3-2), and approximately eight kilometres south of Masterton. When purchased the site had one garage/cottage with a partly formed driveway, but otherwise was in pasture. A stormwater channel traversed the site from east to west, and then exited along the southern boundary.

The site (Lot 4 DP70396) sits on the middle terrace above the Ruamahanga River. A small area of is located on the lower terrace directly adjacent to the river, however the vast majority is located on

the upper terrace. A sharp, 10m steep escarpment separates the lower and upper terraces, the upper terrace extending roughly to the main road. From here the ground continues to rise into Wardell Hill country.

The slope of the escarpment has various existing native trees and bush. The main terrace has one mature Totara tree, the remainder being in pasture.

The area to the west of the road is now predominantly residential in use, with some lifestyle farming. Traditional farming occurs more distantly to the north and the south. The average rainfall is around 800mm/yr, and around 2050 hours of sunshine a year.



Figure 3-2 Aerial photograph of case study site showing subdivision outline (in blue), and adjacent Ruamahanga river

3.3 The development

Meteorological information was available from a weather station located approximately five kilometres from the case study site at East Taratahi (Fig. 3-1).

A subdivision development was planned and a resource consent sought to create eight individual lots (freehold) ranging in size from 1200m² to 2100m², located within a commonly owned residual lot of approximately 6 hectares (Fig 3-3).

The consent application was notably different from standard applications in the Wairarapa, and did not fit easily within the standard assessment criteria of the District Plan. For example, the

standard lot size for a controlled activity⁶ was a minimum of one hectare, compared to the proposed minimum lot size on the subdivision of 1200m². The proposal therefore fell within the discretionary activity⁷ criteria of the District Plan. The consent procedure is governed by the Resource Management Act 1991, where each proposal should be individually assessed in terms of the environmental impact from the proposal. Although the overall number of lots proposed was greater than that under the controlled activity rules, it was possible to show that the environmental impacts were less than those for a standard, controlled activity subdivision. Consent was therefore granted in February 2004 by Masterton District Council.

3.4 Considering solar access in the design criteria

Currently the only building or development regulations effecting solar access planning in the Wairarapa are limited to boundary separation distances and height restrictions between immediately adjacent properties (M.D.C, 1997). These planning regulations are however related more to access to light and amenity rather than energy capture and use. The case study provided an opportunity to investigate and apply solar energy harvesting design methods.

The objective in the analysis of the development layout was to ensure that each house lot has access to an acceptable proportion of the total theoretically available solar energy at that location. Solar access can be reduced by man-made constructions, natural topographic features, and existing or planted vegetation. Through the specification of separation distances and maximum heights of new features it is possible to ensure continued access to a given percentage of the available solar energy. When setting the percentage of solar energy capture that is to be achieved,

⁶ Under the District a controlled activity means a resource consent is required, but it will be granted provided that certain environmental standards can be met.

⁷ A discretionary activity requires resource consent and can be refused by the District Council if they believe that it is inconsistent with the policies of the District Plan.

consideration must be given to the restrictions and benefits that different percentages will result in. Higher percentile values yield more onerous requirements for avoiding shading, lower percentile values less onerous, as greater energy capture requires inclusion of lower sun altitude angles. For the case study an 85-percentile value of global solar energy was assumed as the desired value: it is viewed as a high-end compromise between the maximum energy available at the site, and the energy practically achievable.

The research undertaken for the case study asks the question "What is the maximum height that an obstruction can reach at any location relative to a proposed building before shading occurs at that building?" This research is extended beyond winter solar paths to include all seasons to ensure access to solar energy at any time of the year. The solar obstruction contours that were calculated (section 4.2) indicated the maximum height an object can be at any given distance from the observation point to ensure that at least 85% of solar energy will be accessible to that observation point.

The process can be likened to the reverse engineering of the solar access butterfly principle (section 2.3): that instead of finding shadow lengths from known obstruction heights and locations, the objective is to predict maximum obstruction heights at various locations given known shadow characteristics.

3.5 Land tenure for the development

The form of land tenure is an important consideration, and is one of the first issues that must be investigated. The form of land tenure adopted depends on the goals of the development (for example one objective may be the desire to generate income from export of electricity to the grid). With this in mind the following objectives and restraints were identified for the case study development.

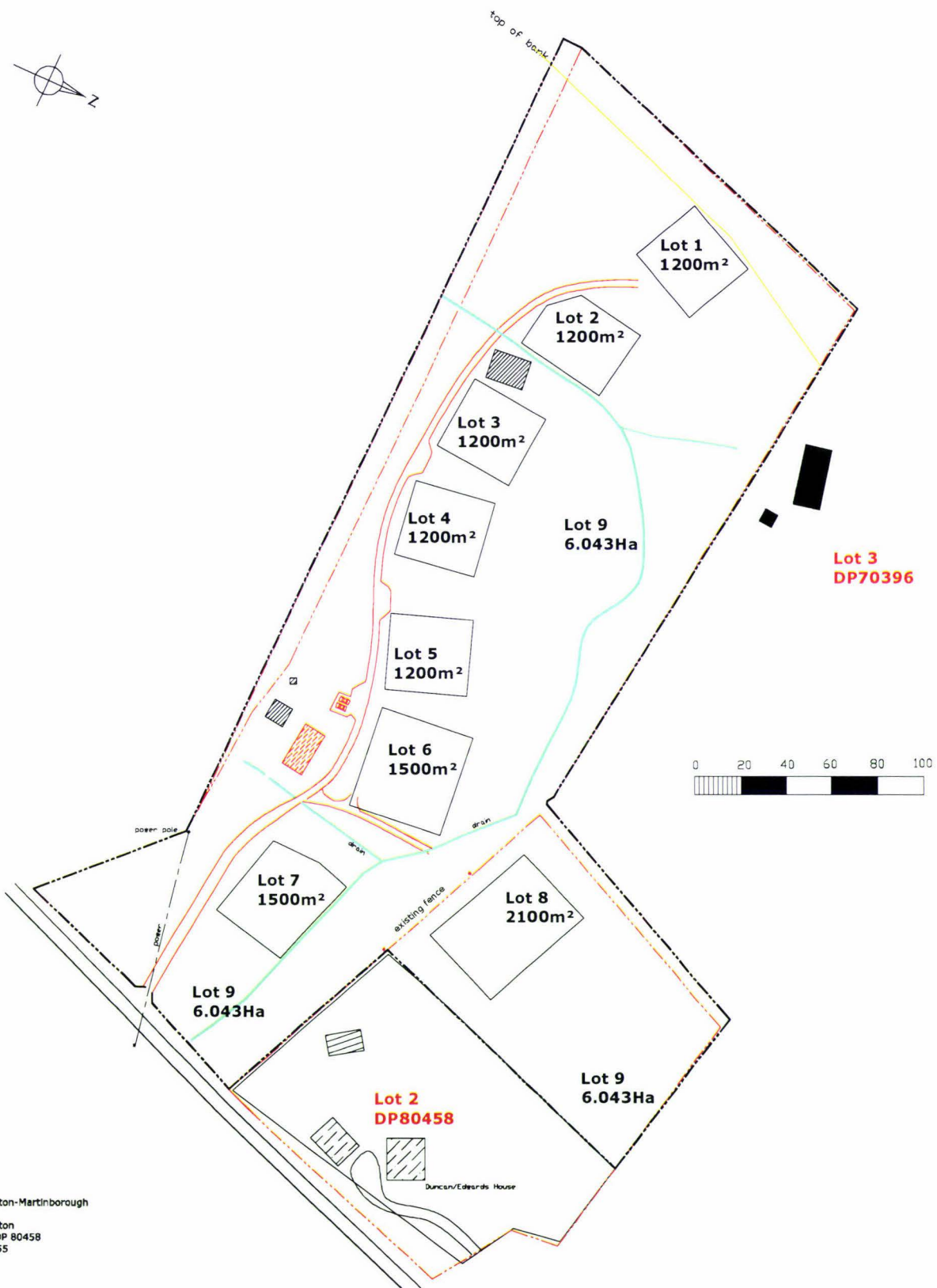
- The subdivision is best suited to a non-profit organization – electricity export not being a major objective.
- Access required to the substantial common land area provides opportunities for community interaction and optimum land use.
- Section saleability – public perception of land tenure types suggests that freehold titles increases saleability.
- The likely number of owners involved is from 8 to 15.
- From a developer's point of view there is a preference for flexibility on site by minimising the use of easements
- Governance of common facilities requires some form of legal authority to act on behalf of the common good.
- The governing body must also be able to collect rates from individuals.
- The land tenure form must allow individual ownership that is secure and mortgageable.
- Provides flexibility for future development of common assets on the common land.
- The land tenure type needs to be effective in enabling efficient use of renewable energy resources.

Given the objectives of the case study development, a composite approach was adopted. Individual titles were identified for a relatively small 'house site', with the remainder of the land held in one title, owned in undivided shares by the owners of the house sites (Fig. 3.3). Freehold title is therefore available for each house site (the preferred ownership option in New Zealand), but the majority of the land remains in common ownership, which is more suited to renewable energy capture and sustainability planning.

The governance of the common facilities and land requires a central entity, with legal authority to act on behalf of the common good. The type of legal entity is dependent on its function, number of contributors, and its profit-making status (Irving, 2000). In the case study analysis, this is to be performed by an Incorporated Society

comprised of the house site owners. Membership of the society is a prerequisite of land purchase. The rules of the society were established to allow for the:

- the employment of contractors or specialists to carry out the maintenance or construction of works or assets;
- the collection of rates from members;
- rules as to the use of the common land;
- the rights of the lot owners to undertake activities on this land;
- the capture of renewable energy for use or eventual export as electricity to the national grid.



84F
 Masterton-Martinborough
 Road,
 Masterton
 Lot 1 DP 80458
 47A/555

Figure 3-3 Scheme plan for case study subdivision showing individual lots and residual common land

3.6 Meteorological and geographical data

In order to determine the nature of the solar resource available it was necessary to have access to reliable meteorological information. Similarly understanding of the environment in which dwellings are to be built required knowledge of geographical information.

Meteorological information was taken from the National Institute of Water and Atmospheric research (NIWA) weather station at East Taratahi. The proposed development site is located on the eastern side of the Wairarapa plains, and the weather station is located in the central plains area. The weather station is 5 km from the development site, and small variations in latitude and longitude are ignored for the following calculations. The latitude and longitude assumed for the district are 41 degrees south and 176 degrees east respectively. The standard meridian is assumed to be 180 degrees east, and the time zone is that of New Zealand standard clock time (New Zealand has only one time zone).

The measurement of solar radiation can be carried out in different ways. A common method is the measurement of the total horizontal global radiation. This is a measure of the all radiation reaching the site, and is comprised of direct radiation from the sun, radiation refracted from clouds, and radiation reflected off the ground or landscape features. Records of total global solar radiation for one year's worth of data taken at one-hourly intervals was obtained from NIWA (appendix A).

The hourly values were averaged over the whole year to give a yearly daily average irradiation by hour (Fig. 3-4). The time shown is clock time, at New Zealand Standard Time.

Irradiation at East Taratahi weather station

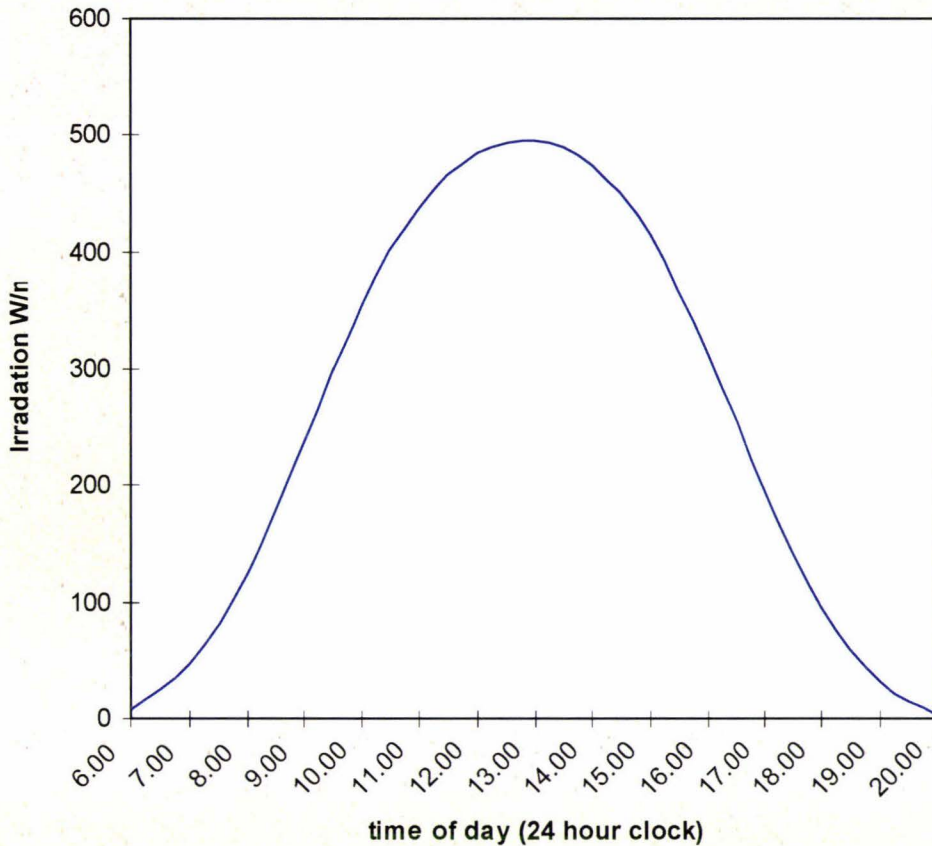


Figure 3-4 Average hourly daily irradiation at East Taratahi (1995), average over a 12-month period

The difference between the theoretical maximum irradiation (12:00 noon solar time) and the maximum data peak time (closer to 12:50pm NZ standard time) is partly due to the displacement between the standard meridian (180° east) and the observation point (Taratahi weather station at 176° East). There are also site specific meteorological conditions that may influence daily irradiation variations (see discussion section 4.6). The precision of determining the exact time of the peak irradiation is of only minor importance in the following calculations, and for convenience the peak for the data set is assumed to occur at 12.30pm solar time. Given the approximate symmetry of the irradiation curve about this time, an

equal time either side is assumed in the calculation of limits for irradiation totals. An 85-percentile value was assumed in this analysis, which corresponds approximately to an eight-hour energy capture period from 8:30 am to 4:30pm. The use of alternative energy capture times is reviewed in section 4.6.

The curve of the plot of irradiation against time may be approximated by a polynomial regression curve (Fig. 3-5).

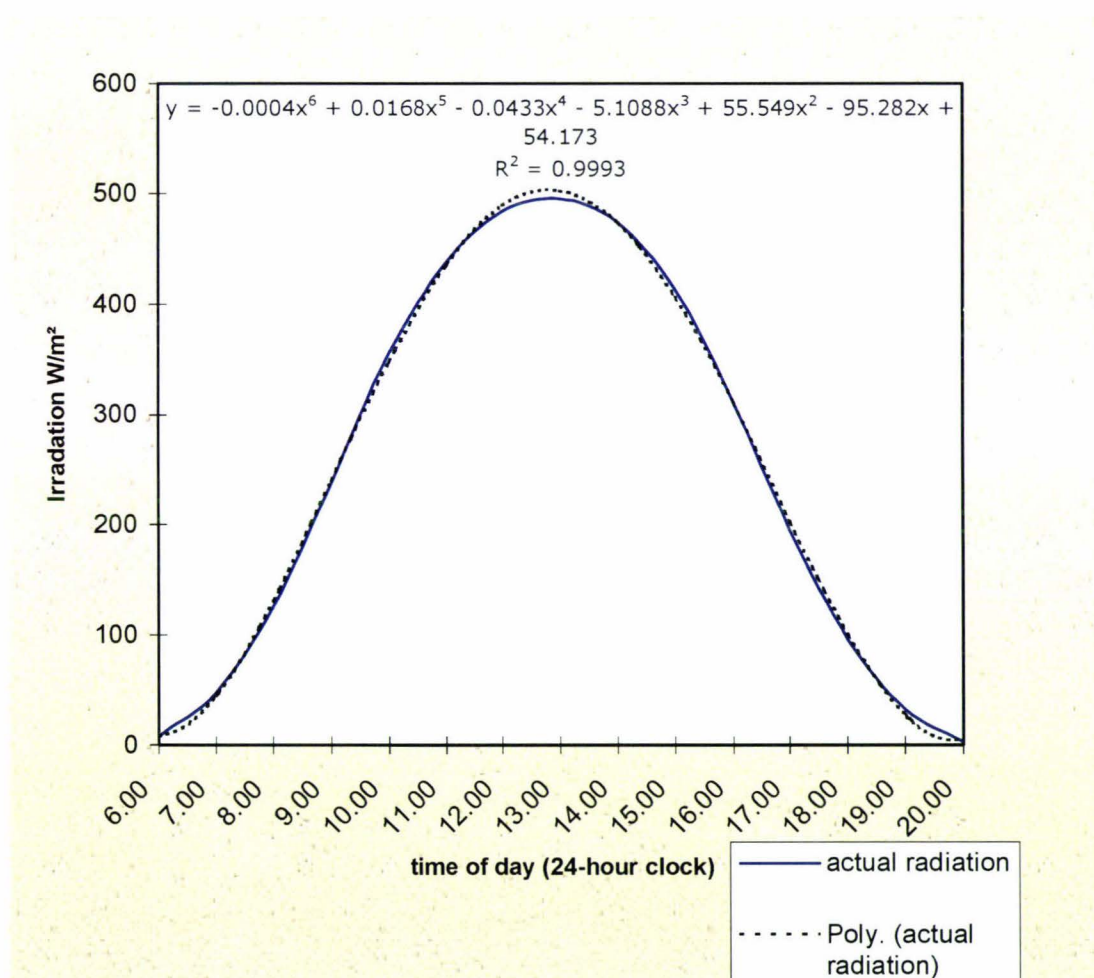


Figure 3-5 Polynomial regression curve fit against measured irradiation data from East Taratahi.⁸

The total average yearly daily irradiation (the area under the graph in figure 3-4), is the maximum theoretical solar energy available at

⁸ The R^2 value, also known as the coefficient of determination, is an indicator that ranges in value from 0 to 1 and reveals how closely the estimated values for the trendline correspond to the actual data. A trendline is most reliable when its R-squared value is at or near 1. The coefficient of determination shows a very good correlation to the measured data.

that location. Two methods were examined for calculation of the area between given limits, integration of a polynomial curve fit, and application of Simpson's rule (Malcolm, 1981).

a) Integrating the equation of the polynomial curve fit between appropriate values gave the total irradiation during this time period.

The polynomial expression representing the curve was derived using an excel spreadsheet, and is given by:

$$y = -0.0004x^6 + 0.0168x^5 - 0.0433x^4 - 5.1088x^3 + 55.549x^2 - 95.282x + 54.173 \text{ equation 3.1}$$

and area under the irradiation curve=

$$\int [-0.0004x^6 + 0.0168x^5 - 0.0433x^4 - 5.1088x^3 + 55.549x^2 - 95.282x + 54.173] \text{ equation 3.2}$$

The limits are defined in terms of hours from sunrise.

b) Calculation via Simpson's rule divides the area into a number of segments of equal width and applies Simpson's rule to calculate the area (Fig. 3-6).

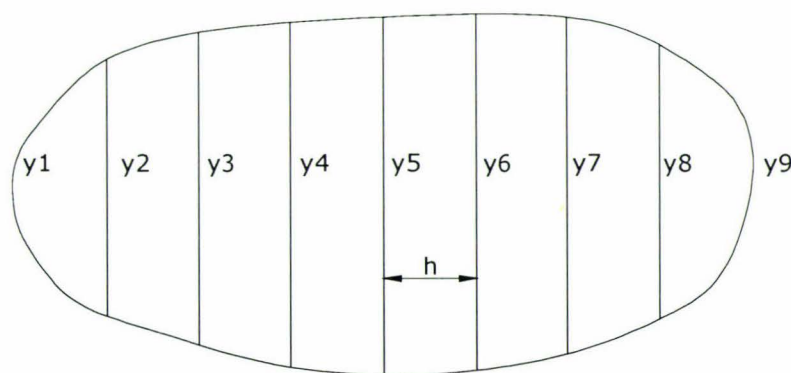


Figure 3-6 Division of curved area for Simpson's rule calculations

The area within the curved boundary (fig. 3-6) is given by Simpson's rule as;

$$\text{Area} = h/3 [y_1 + y_9 + 2(y_3 + y_5 + y_7) + 4(y_2 + y_4 + y_6 + y_8)]$$

equation 3.3

This was applied to the irradiation curve to calculate the area, and hence the total solar energy between specified limits. The results of each method are shown in figure 3-7.

3.7 Energy capture

Having considered the maximum amount of energy available on a district scale, it was then necessary to quantify the actual energy available at a specific site, taking into consideration obstacles that may shade the observation point. The available energy depends on the time period in question, or the *limits* selected in terms of equation 3.2.

The energy diagram (Fig 3-4) depicts the average daily energy variation for the entire year. For passive solar design it has been shown (Bensemam & Cook) that to reach 87.2% total energy capture in Wellington, only a five-hour period central about solar noon is required. This time period however only analyses the solar radiation over the winter period, when Wellington ambient temperatures are such that additional heat is required to provide comfortable living conditions. Analysis for total energy gain for the prospective site (for active solar energy use) gives a greater time requirement as this includes the longer summer daylight hours. The calculated variation of energy capture with time can be shown for both the Simpson's method, and the polynomial curve fit (fig. 3-7).

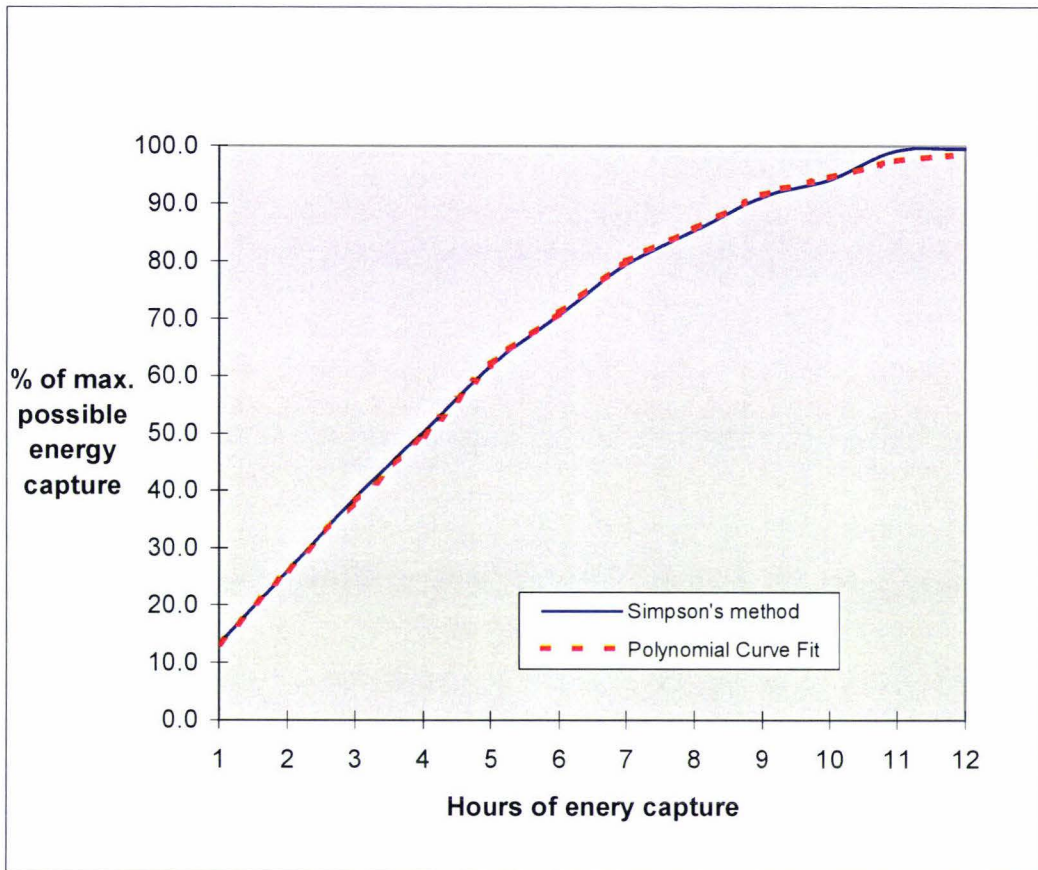


Figure 3-7 Energy capture versus hours of capture for Simpson's method and Polynomial curve fit for East Taratahi solar data (1995)

This calculation method allows further methodology to be developed for examination of solar energy capture and the effect of solar obstructions on a site.

Chapter 4 Methods Developed

4.1 Determination of solar obstruction height data.

At a specific location there are specific times within which solar radiation must be available in order to capture various percentages of energy.

Having established the energy capture percentage requirement (85% of total theoretical, section 3) , and hence times during which a dwelling requires unobstructed access to the sun, the property information (latitude, longitude etc) may be used to calculate the sun's altitude and azimuth angles at hourly intervals between these times using the formulae below (Duffie & Beckmann, 1991).

All times quoted for calculation of solar geometry parameters are in solar time (ST).

$$\text{Solar time} - \text{standard time} = 4(L_{\text{loc}} - L_{\text{st}}) + E \quad \text{equation 4.1}$$

Where L_{loc} is the longitude of the location,

L_{st} is the longitude of the meridian on which local standard time is based (in degrees East);

and E is the equation of time.

$$E = 229.2(0.0000075 + 0.001868 \cos B - 0.032077 \sin B - 0.014615 \cos 2B - 0.04089 \sin 2B) \quad \text{equation 4.2}$$

where $B = (n-1) 360/365$

and $n =$ Julian day number

The declination⁹, δ , can be found from

$$\delta = 23.45 \sin(360.(284+n)/365) \quad \text{equation 4.3}$$

The relationship between the various solar angles is defined by

$$\cos \theta = \sin \delta . \sin \phi . \cos \beta$$

⁹ Declination is the angular position of the sun at solar noon with respect to the plane of the equator, north positive; $-23.45^\circ \leq \delta \leq 23.45^\circ$.

$$\begin{aligned}
& - \sin\delta \cdot \cos\phi \cdot \sin\beta \cdot \cos\gamma \\
& + \cos\delta \cdot \cos\phi \cdot \cos\beta \cdot \cos\omega \\
& + \cos\delta \cdot \sin\phi \cdot \sin\beta \cdot \cos\gamma \cdot \cos\omega \\
& + \cos\delta \cdot \sin\beta \cdot \sin\gamma \cdot \sin\omega
\end{aligned}
\tag{equation 4.4}$$

where ϕ is the latitude in degrees, δ declination in degrees
 β is the slope, being the angle between the horizontal and the plane of the surface in question, γ_s is the surface azimuth angle,
 ω the hour angle, and θ the angle of incidence on the surface¹⁰ (fig 4-1).

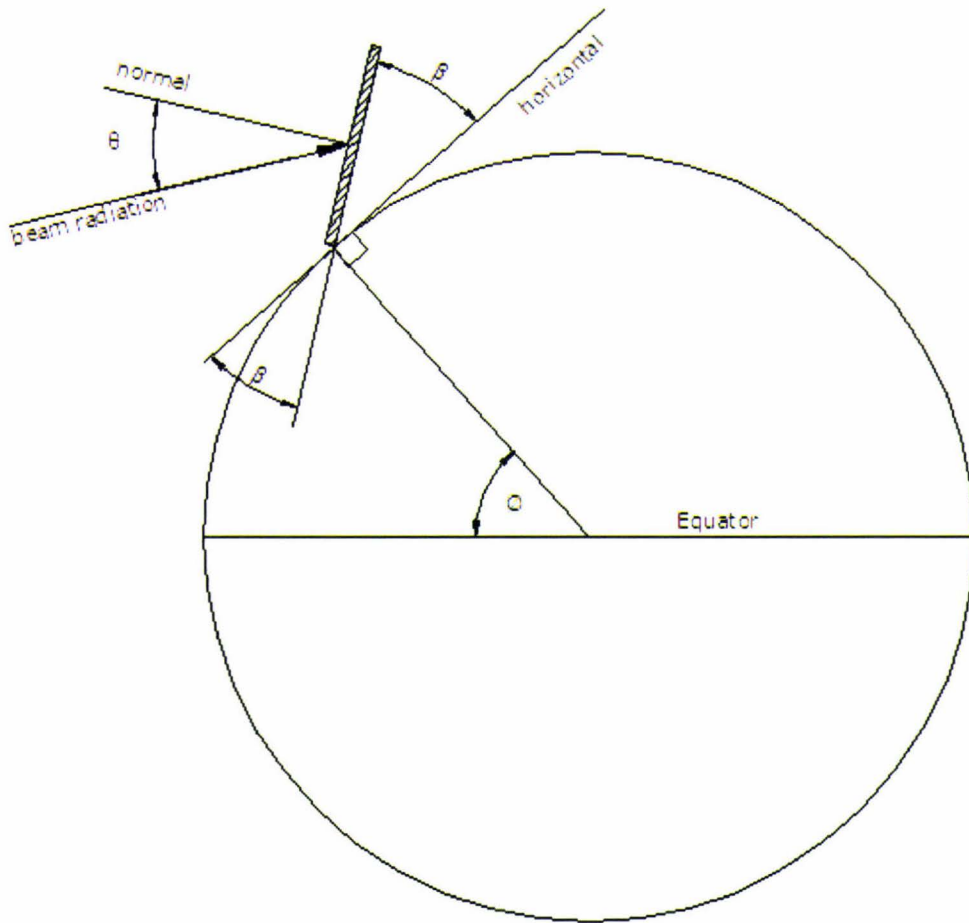


Figure 4-1 Definition of slope, β , latitude, ϕ , and angle of incidence, θ relating to solar geometry.

¹⁰ Angle of incidence, the angle between the beam radiation on a surface and the normal to that surface.

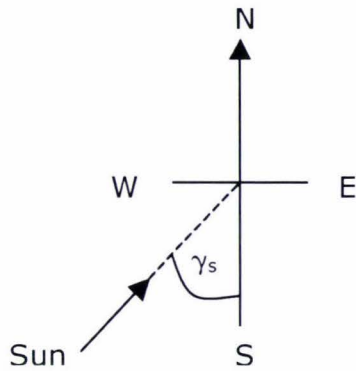


Figure 4-2 Definition of surface azimuth angle, γ_s

When the receiving surface is horizontal, $\beta = 0$, and equation 4.4 simplifies to:

$$\cos\theta = \cos\phi \cdot \cos\delta \cdot \cos\omega + \sin\phi \cdot \sin\delta \quad \text{equation 4.5}$$

To calculate γ_s the solar azimuth angle, it is necessary to know which quadrant the sun is in (Duffie & Backmann, 1991), and this done using the equation;

$$\gamma_s = C_1 C_2 \gamma_s' + C_3 ((1 - C_1 C_2) / 2) \times 180 \quad \text{equation 4.6}$$

where $\sin\gamma_s' = \sin\omega \cos\delta / \sin\theta_z$

and

$C_1 = 1$ if $\omega < \omega_{ew}$ or -1 otherwise,

$C_2 = 1$ if $\phi(\phi - \delta) \geq 0$, or -1 otherwise,

$C_3 = 1$ if $\omega \geq 0$, or -1 otherwise

$$\cos \omega_{ew} = \tan\delta / \tan\phi$$

Although the equation appears cumbersome, it is readily usable in a spreadsheet calculation to define altitude and azimuth angles given the Julian day number, standard meridian, and latitude.

Once the altitude and azimuth angles have been calculated, these can be used to determine the maximum height an object can be at any given location before it will obstruct solar radiation.

Both altitude and azimuth angles vary depending on the day of the year. However the lowest altitude angle attained (between certain

azimuth limits) is set by the sun path between sunrise and sunset on the winter solstice. Thus between the azimuth angles at 8:30am and that at 4:30pm (Section 3.6) on the winter solstice, the lowest altitude angle sun path can be found by calculation at hourly intervals.

As the Julian day number increases from the winter solstice (Julian day 172) towards the summer solstice (Julian day 355) the altitude angle increases at both 8:30am and 4:30pm to a maximum at the summer solstice.

The azimuth also varies with day number, and the variation can be approximated by calculation using a series of equally spaced days between the winter and summer solstices, with a curve fit between these points. For these calculations specific Julian day numbers were assumed (Table 4-1).

Table 4-1 Definition of day numbers used for solar obstruction contouring

Day	Julian day number	Date
a)	355	20-Dec
b)	324	19-Nov
c)	293	19-Oct
d)	262	18-Sep
e)	231	18-Aug
f)	200	18-Jul
g)	172	20-Jun

Given the 8:30am to 4:30pm time limits and the Julian day numbers from Table 4-1, it is possible to produce a table of minimum altitude angles for a given location and for a range of azimuth angles. In this

example this is between the azimuth angle at 8:30am on December 21st, and at 4:30pm on December 21st (Table 4-2).

Table 4-2 Time-varied and solstice altitude angles, showing minimum altitude angle between 8:30 am and 4:30pm through the year, for the case study location at 40° latitude.

Julian day number	Time of day	Altitude angle, degrees
355	08:30	40.2
324	08:30	38.3
293	08:30	32.7
262	08:30	24.4
231	08:30	15.5
200	08:30	9.1
172	08:30	7.1
172	09:30	16.8
172	10:30	22.2
172	11:30	25.2
172	12:30	25.2
172	13:30	22.2
172	14:30	16.8
172	15:30	9.2
172	16:30	0.2
200	16:30	2.1
231	16:30	8.1
262	16:30	16.4
293	16:30	24.4
324	16:30	29.9
355	16:30	31.7

These figures represent the lowest sun altitude angle between the times of 8:30am and 4:30pm for the entire year. The six-month period not shown is a mirror of those shown in terms of sun angles.

A curve of minimum altitude angle between 8:30 am and 4:30pm (Fig 4-3) indicates the minimum altitude angle assumed at any time of the year, which is used for solar obstruction contouring. As an example of how the curve is constructed, the sun location is depicted

for 4:30pm on Julian day numbers 172, 231, and 355. The sun location for the other Julian days are similarly used to construct the curve.

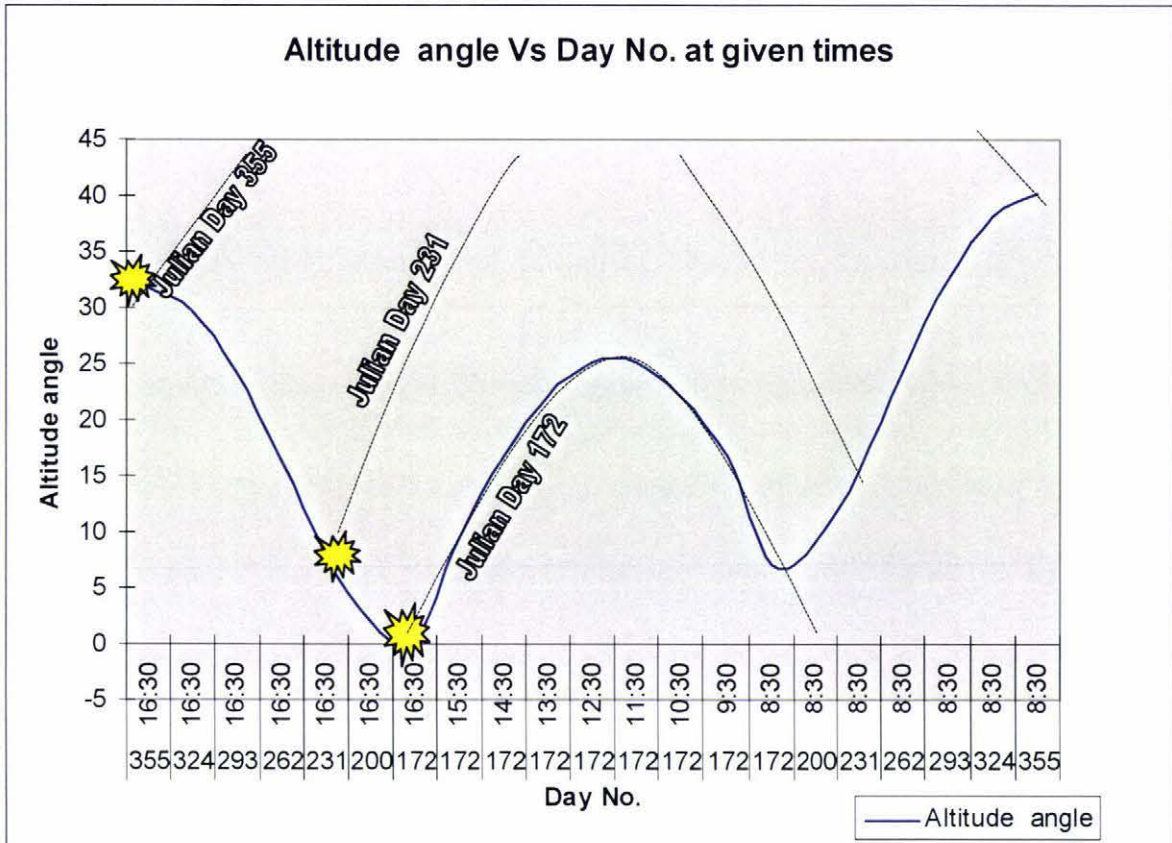


Figure 4-3 Altitude angle Vs Julian day number at given times of day, with sun location at 4:30pm shown for three different day numbers

These time-varied minimum altitude angles correspond specifically to the assumed 85-percentile energy capture. Similarly minimum altitude angles can be calculated for other percentile energy capture values.

There are practical restrictions to applying this method to energy capture as the altitude angle approaches zero (Fig. 4-3). No site in New Zealand (except perhaps Cape Reinga) will have clear aspects to both midwinter solstice sunrise and sunset without some form of obstruction. Solar obstructions from the apparent skyline can be easily evaluated by means of plotting on a solar resource diagram (Fig. 4-4). These limitations are acknowledged, and it is understood that there must be coordination between the solar resource planning

within the site, but also incorporating the effects of the apparent skyline from outside the site.

In the case study situation there is currently only marginal restriction from outside of the site (Fig. 4.4) with some obstruction at low altitude angles in the winter months at sunrise and sunset (for the 8:30am to 4:30pm timespan). This obstruction will alter the theoretical maximum available solar energy, however the effects are minimal in terms of the overall yearly energy available, and have therefore been ignored .

There is also a human aspect worthy of consideration in that there is a psychological benefit in having visual access to sunrise and sunset.

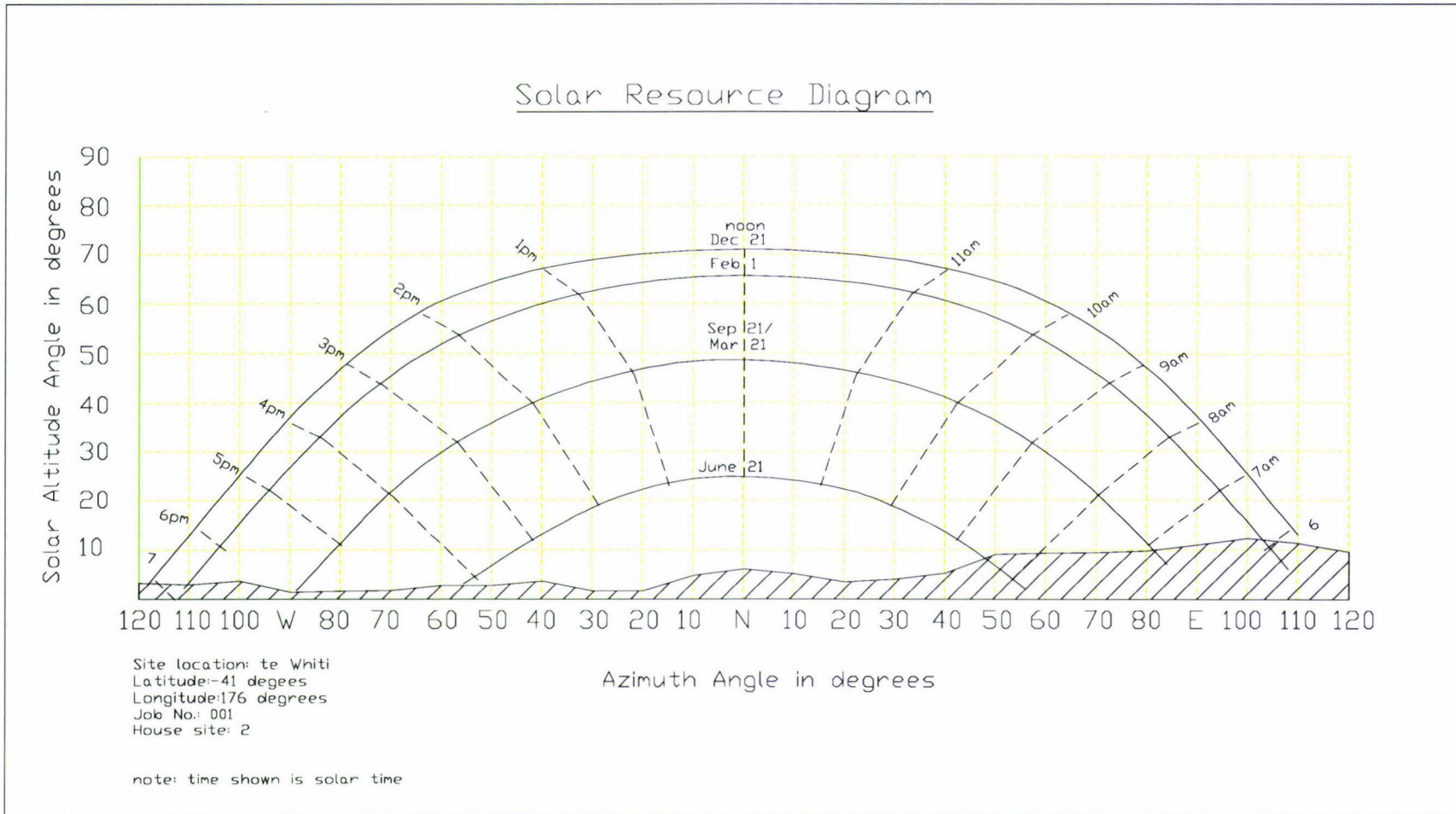


Figure 4-4 Solar resource diagram for the case study site, where the shaded area indicates the apparent skyline, facing north with east to the right, and west to the left.

Given the minimum altitude angles (Fig. 4-3), by trigonometry the height associated with this angle at any specified distance from the observation point can be calculated (Fig.4-5). If c = altitude angle, and d = the horizontal distance from the point of observation, in metres, then the height (h) of a point on a line from the point of observation to the sun at that time is given by;

$$h = d \tan c \qquad \text{equation 4.7}$$

This height is also the maximum permissible height of an obstacle at that distance before shading occurs on the point of observation. Obstacles shorter than this height will not cause a shadow on the point of observation, whereas obstacles higher will (Fig. 4-5).

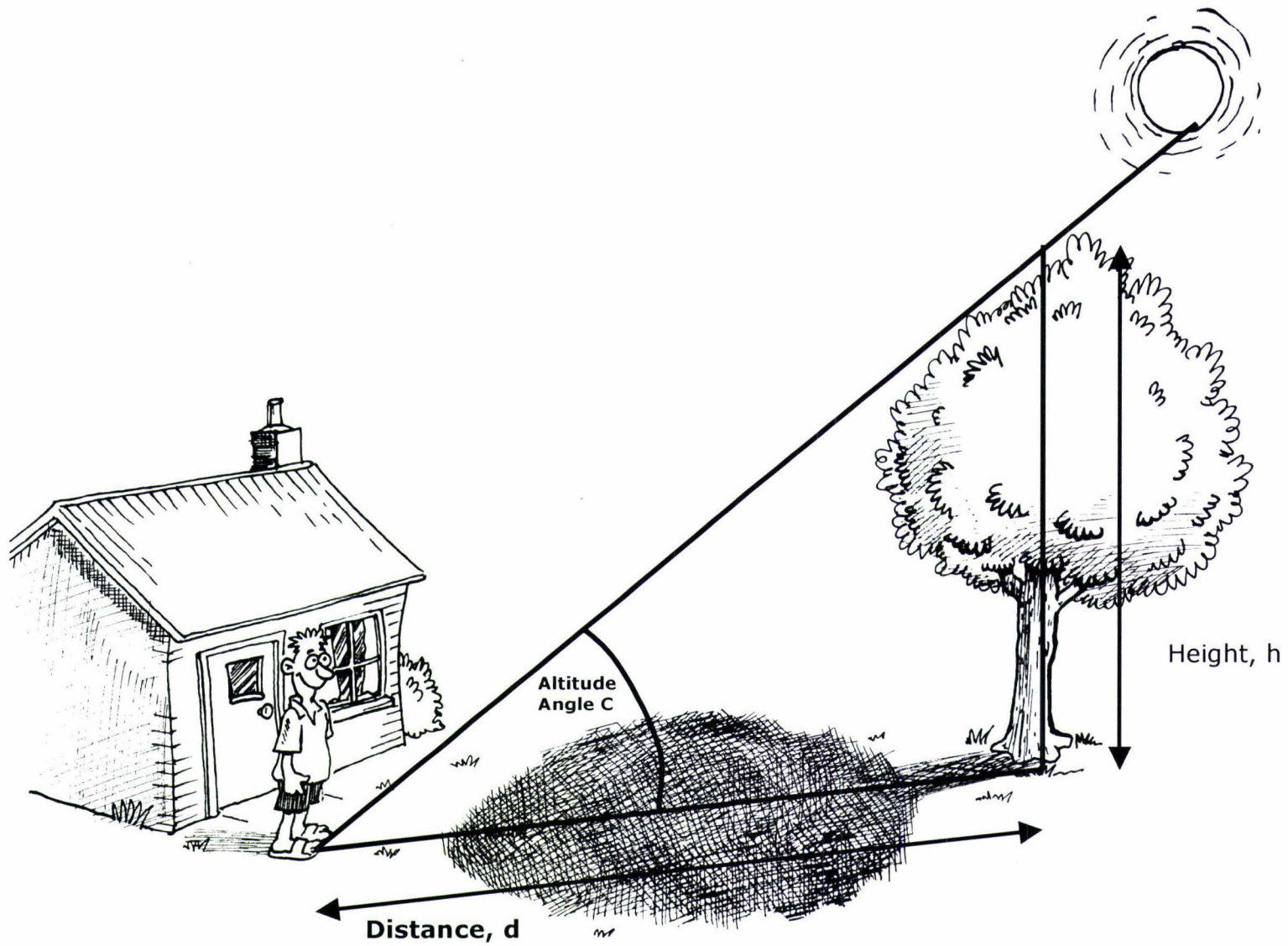


Figure 4-5 Solar shading geometries showing relationship between solar altitude angle and obstruction height (Reilly & Duncan,2004)

When the azimuth angle (Az) is taken as degrees east of north, then at distance 'd' from the point of observation, co-ordinates of any point in terms of northings¹¹ (N) and eastings⁶ (E) are given by;

$$N = d \cos(Az),$$

and

$$E = d \sin(Az)$$

For example on December 20th at 8:30 am the sun's altitude angle is 40.2 degrees, and its azimuth is 87.4 degrees east of north. For a distance of say five metres from the point of observation, then to the nearest 0.1m, the northing,

$$N = 5 \times \cos (87.4)$$

$$= 0.2 \text{ metres}$$

and easting

$$E = 5 \times \sin (87.4)$$

$$= 5.0 \text{ metres}$$

Now the maximum permissible obstruction height at this point before shading occurs,

$$h = d \tan c, \text{ or}$$

$$h = 5 \times \tan (40.2)$$

$$= 4.2 \text{ metres}$$

Calculating the eastings, northings, and heights for a 5m radius and adding to Table 4-2 gives;

¹¹ The *northing* is the distance from the observation point along an east-west line. Similarly the *easting* is the distance from the observation point along a north south line through the observation point.

Table 4-3 Calculated northings and eastings for 5 metre distance from point of observation, and maximum obstruction height before shading occurs at point of observation

Julian Day no.	Time	Azimuth Angle degrees	Altitude Angle degrees	tan of altitude	Distance (m) North ¹	Distance (m) East ²	Height (m)
355	08:30	87.4	40.2	0.8456	0.2	5.0	4.2
324	08:30	84.1	38.3	0.7909	0.5	5.0	4.0
293	08:30	75.7	32.7	0.6428	1.2	4.8	3.2
262	08:30	65.9	24.4	0.4526	2.0	4.6	2.3
231	08:30	57.4	15.5	0.2782	2.7	4.2	1.4
200	08:30	51.9	9.1	0.1607	3.1	3.9	0.8
172	08:30	50.2	7.1	0.1245	3.2	3.8	0.6
172	09:30	35.7	16.8	0.3009	4.1	2.9	1.5
172	10:30	22.3	22.2	0.4090	4.6	1.9	2.0
172	11:30	7.6	25.2	0.4700	5.0	0.7	2.4
172	12:30	-7.6	25.2	0.4700	5.0	-0.7	2.4
172	13:30	-22.3	22.2	0.4090	4.6	-1.9	2.0
172	14:30	-35.7	16.8	0.3009	4.1	-2.9	1.5
172	15:30	-47.5	9.2	0.1625	3.4	-3.7	0.8
172	16:30	-57.9	0.2	0.0038	2.7	-4.2	0.0
200	16:30	-59.8	2.1	0.0367	2.5	-4.3	0.2
231	16:30	-65.7	8.1	0.1420	2.1	-4.6	0.7
262	16:30	-74.3	16.4	0.2937	1.3	-4.8	1.5
293	16:30	-83.9	24.4	0.4532	0.5	-5.0	2.3
324	16:30	-91.7	29.9	0.5742	-0.1	-5.0	2.9
355	16:30	-94.7	31.7	0.6185	-0.4	-5.0	3.1

¹ Northing is negative when the point defined is south of the observation point

² Easting is negative when the point defined is west of the observation point

Repetition for a range of distances (Table 4-4) gives a series of three dimensional point references that define the boundaries between shading, and non shading obstruction heights at given distances from the point of observation.

A fifty metre radius was used as a practical size for application to the case study site.

Table 4-4 Obstruction Heights, northings, and eastings 5-50m radius

Day no.	Hour	Azimuth angle	Altitude angle	tan of altitude	radius 5			radius 10			radius 15			radius 20			radius 25		
					N	E	height	N	E	height	N	E	height	N	E	height	N	E	height
355	8:30	87.4	40.2	0.846	0.2	5.0	4.2	0.4	10.0	8.5	0.7	15.0	12.7	0.9	20.0	16.9	1.1	25.0	21.1
324	8:30	84.1	38.3	0.791	0.5	5.0	4.0	1.0	9.9	7.9	1.5	14.9	11.9	2.1	19.9	15.8	2.6	24.9	19.8
293	8:30	75.7	32.7	0.643	1.2	4.8	3.2	2.5	9.7	6.4	3.7	14.5	9.6	4.9	19.4	12.9	6.2	24.2	16.1
262	8:30	65.9	24.4	0.453	2.0	4.6	2.3	4.1	9.1	4.5	6.1	13.7	6.8	8.2	18.3	9.1	10.2	22.8	11.3
231	8:30	57.4	15.5	0.278	2.7	4.2	1.4	5.4	8.4	2.8	8.1	12.6	4.2	10.8	16.9	5.6	13.5	21.1	7.0
200	8:30	51.9	9.1	0.161	3.1	3.9	0.8	6.2	7.9	1.6	9.3	11.8	2.4	12.3	15.7	3.2	15.4	19.7	4.0
172	8:30	50.2	7.1	0.125	3.2	3.8	0.6	6.4	7.7	1.2	9.6	11.5	1.9	12.8	15.4	2.5	16.0	19.2	3.1
172	9:30	35.7	16.8	0.301	4.1	2.9	1.5	8.1	5.8	3.0	12.2	8.7	4.5	16.2	11.7	6.0	20.3	14.6	7.5
172	10:30	22.3	22.2	0.409	4.6	1.9	2.0	9.3	3.8	4.1	13.9	5.7	6.1	18.5	7.6	8.2	23.1	9.5	10.2
172	11:30	7.6	25.2	0.470	5.0	0.7	2.4	9.9	1.3	4.7	14.9	2.0	7.1	19.8	2.6	9.4	24.8	3.3	11.8
172	12:30	-7.6	25.2	0.470	5.0	-0.7	2.4	9.9	-1.3	4.7	14.9	-2.0	7.1	19.8	-2.6	9.4	24.8	-3.3	11.8
172	13:30	-22.3	22.2	0.409	4.6	-1.9	2.0	9.3	-3.8	4.1	13.9	-5.7	6.1	18.5	-7.6	8.2	23.1	-9.5	10.2
172	14:30	-35.7	16.8	0.301	4.1	-2.9	1.5	8.1	-5.8	3.0	12.2	-8.7	4.5	16.2	-11.7	6.0	20.3	-14.6	7.5
172	15:30	-47.5	9.2	0.163	3.4	-3.7	0.8	6.8	-7.4	1.6	10.1	-11.1	2.4	13.5	-14.7	3.3	16.9	-18.4	4.1
172	16:30	-57.9	0.2	0.004	2.7	-4.2	0.0	5.3	-8.5	0.0	8.0	-12.7	0.1	10.6	-17.0	0.1	13.3	-21.2	0.1
200	16:30	-59.8	2.1	0.037	2.5	-4.3	0.2	5.0	-8.6	0.4	7.5	-13.0	0.6	10.1	-17.3	0.7	12.6	-21.6	0.9
231	16:30	-65.7	8.1	0.142	2.1	-4.6	0.7	4.1	-9.1	1.4	6.2	-13.7	2.1	8.2	-18.2	2.8	10.3	-22.8	3.6
262	16:30	-74.3	16.4	0.294	1.3	-4.8	1.5	2.7	-9.6	2.9	4.0	-14.4	4.4	5.4	-19.3	5.9	6.7	-24.1	7.3
293	16:30	-83.9	24.4	0.453	0.5	-5.0	2.3	1.1	-9.9	4.5	1.6	-14.9	6.8	2.1	-19.9	9.1	2.7	-24.9	11.3
324	16:30	-91.7	29.9	0.574	-0.1	-5.0	2.9	-0.3	-10.0	5.7	-0.4	-15.0	8.6	-0.6	-20.0	11.5	-0.7	-25.0	14.4
355	16:30	-94.7	31.7	0.619	-0.4	-5.0	3.1	-0.8	-10.0	6.2	-1.2	-14.9	9.3	-1.6	-19.9	12.4	-2.1	-24.9	15.5

Day no.	Hour	Azimuth angle	Altitude angle	tan of altitude	radius 30			radius 35			radius 40			radius 45			radius 50		
					N	E	height	N	E	height	N	E	height	N	E	height	N	E	height
355	8:30	87.4	40.2	0.846	1.3	30.0	25.4	1.6	35.0	29.6	1.8	40.0	33.8	2.0	45.0	38.1	2.2	50.0	42.3
324	8:30	84.1	38.3	0.791	3.1	29.8	23.7	3.6	34.8	27.7	4.1	39.8	31.6	4.6	44.8	35.6	5.2	49.7	39.5
293	8:30	75.7	32.7	0.643	7.4	29.1	19.3	8.7	33.9	22.5	9.9	38.8	25.7	11.1	43.6	28.9	12.4	48.4	32.1
262	8:30	65.9	24.4	0.453	12.3	27.4	13.6	14.3	31.9	15.8	16.4	36.5	18.1	18.4	41.1	20.4	20.4	45.6	22.6
231	8:30	57.4	15.5	0.278	16.1	25.3	8.3	18.8	29.5	9.7	21.5	33.7	11.1	24.2	37.9	12.5	26.9	42.1	13.9
200	8:30	51.9	9.1	0.161	18.5	23.6	4.8	21.6	27.5	5.6	24.7	31.5	6.4	27.8	35.4	7.2	30.8	39.4	8.0
172	8:30	50.2	7.1	0.125	19.2	23.1	3.7	22.4	26.9	4.4	25.6	30.7	5.0	28.8	34.6	5.6	32.0	38.4	6.2
172	9:30	35.7	16.8	0.301	24.4	17.5	9.0	28.4	20.4	10.5	32.5	23.3	12.0	36.6	26.2	13.5	40.6	29.2	15.0
172	10:30	22.3	22.2	0.409	27.8	11.4	12.3	32.4	13.3	14.3	37.0	15.2	16.4	41.6	17.1	18.4	46.3	19.0	20.5
172	11:30	7.6	25.2	0.470	29.7	4.0	14.1	34.7	4.6	16.5	39.6	5.3	18.8	44.6	6.0	21.2	49.6	6.6	23.5
172	12:30	-7.6	25.2	0.470	29.7	-4.0	14.1	34.7	-4.6	16.5	39.6	-5.3	18.8	44.6	-6.0	21.2	49.6	-6.6	23.5
172	13:30	-22.3	22.2	0.409	27.8	-11.4	12.3	32.4	-13.3	14.3	37.0	-15.2	16.4	41.6	-17.1	18.4	46.3	-19.0	20.5
172	14:30	-35.7	16.8	0.301	24.4	-17.5	9.0	28.4	-20.4	10.5	32.5	-23.3	12.0	36.6	-26.2	13.5	40.6	-29.2	15.0
172	15:30	-47.5	9.2	0.163	20.3	-22.1	4.9	23.6	-25.8	5.7	27.0	-29.5	6.5	30.4	-33.2	7.3	33.8	-36.9	8.1
172	16:30	-57.9	0.2	0.004	15.9	-25.4	0.1	18.6	-29.7	0.1	21.2	-33.9	0.2	23.9	-38.1	0.2	26.5	-42.4	0.2
200	16:30	-59.8	2.1	0.037	15.1	-25.9	1.1	17.6	-30.2	1.3	20.1	-34.6	1.5	22.6	-38.9	1.7	25.2	-43.2	1.8
231	16:30	-65.7	8.1	0.142	12.4	-27.3	4.3	14.4	-31.9	5.0	16.5	-36.4	5.7	18.5	-41.0	6.4	20.6	-45.6	7.1
262	16:30	-74.3	16.4	0.294	8.1	-28.9	8.8	9.4	-33.7	10.3	10.8	-38.5	11.8	12.1	-43.3	13.2	13.5	-48.1	14.7
293	16:30	-83.9	24.4	0.453	3.2	-29.8	13.6	3.7	-34.8	15.9	4.3	-39.8	18.1	4.8	-44.7	20.4	5.3	-49.7	22.7
324	16:30	-91.7	29.9	0.574	-0.9	-30.0	17.2	-1.0	-35.0	20.1	-1.2	-40.0	23.0	-1.3	-45.0	25.8	-1.5	-50.0	28.7
355	16:30	-94.7	31.7	0.619	-2.5	-29.9	18.6	-2.9	-34.9	21.6	-3.3	-39.9	24.7	-3.7	-44.8	27.8	-4.1	-49.8	30.9

4.2 Obstruction Contours

Having calculated the three dimensional points in Table 4.4 it is then possible to construct *solar obstruction contours* -lines connecting points of equal height defining the boundary between obstruction heights that will cause shading, and those that will not.

Table 4.4 has been calculated for the case study location based on sun path information in terms of altitude and azimuth angles and the 85 percentile energy capture from the meteorological data.

The results are in suitable format (northing, easting, and height) to be contoured (Fig. 4-6). This was carried out using standard land survey contouring software (the '12d' basic software module).

The maximum permissible obstruction height (before shading occurs) varies considerably on location, but is at a minimum to the northeast and northwest of the observation point (Fig 4-6).

It should be noted that different percentile energy capture requirements affect the minimum altitude angle, and hence the maximum obstruction height before solar shading occurs. Adopting a lower percentile energy capture requirement would lead to less restrictive solar access contours.

Max. obstruction height
(m) before shading
occurs at observation
point

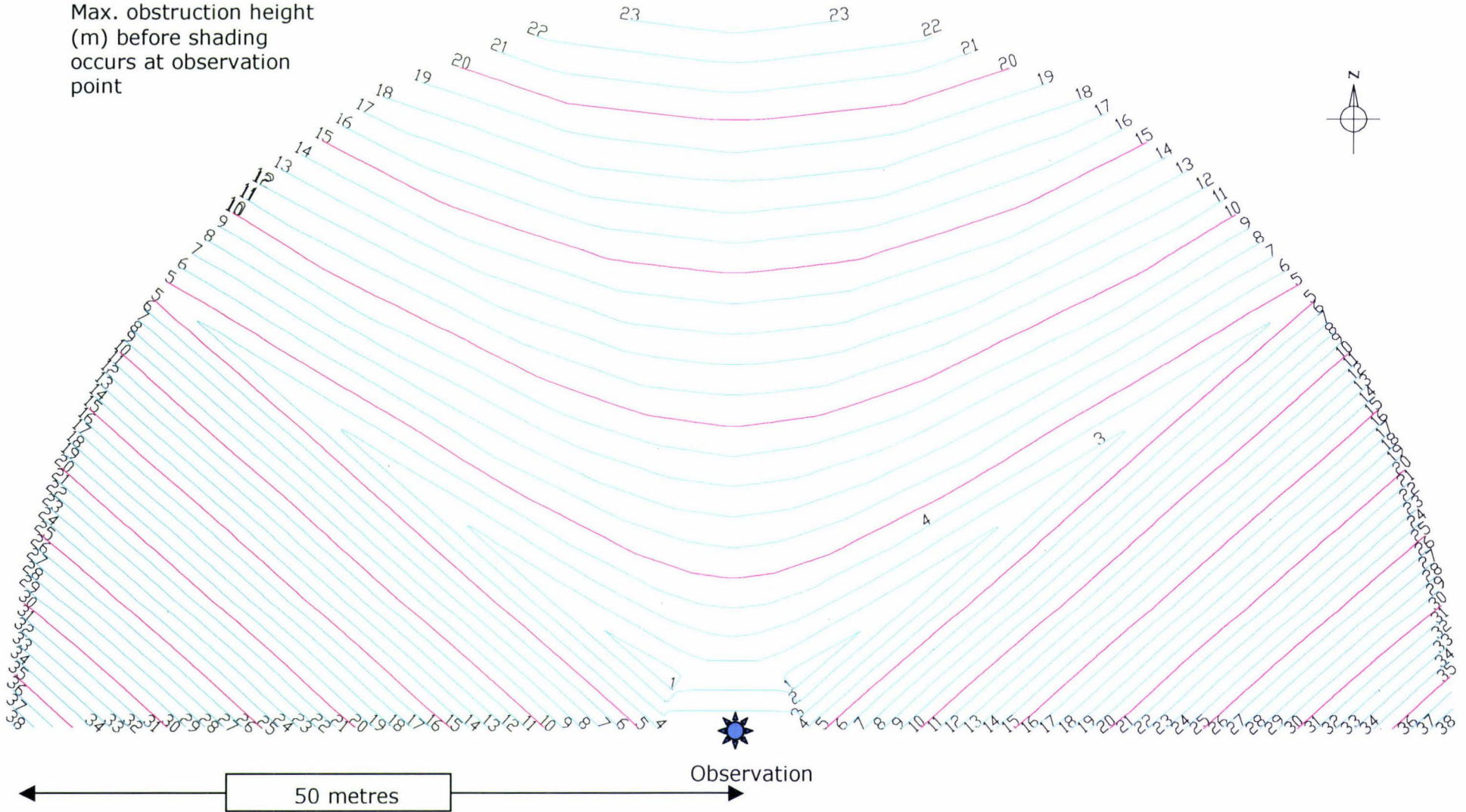


Figure 4-6 Solar obstruction contours for 85% energy capture at case study site

These obstruction contours plotted are for an isolated point of observation. For passive solar design or unrestricted active energy capture it is preferable that solar capture is possible of the entire face of a building. For the case study a building width of twenty metres was assumed to be oriented in an east-west direction. The solar contour plot (Fig. 4-6) was copied and displaced 1m to the east and similarly 1m to the west of the centre of the assumed north face of the building. This was repeated until the 20m northerly face of the building had been covered. An example of this process is shown in figure 4-7.

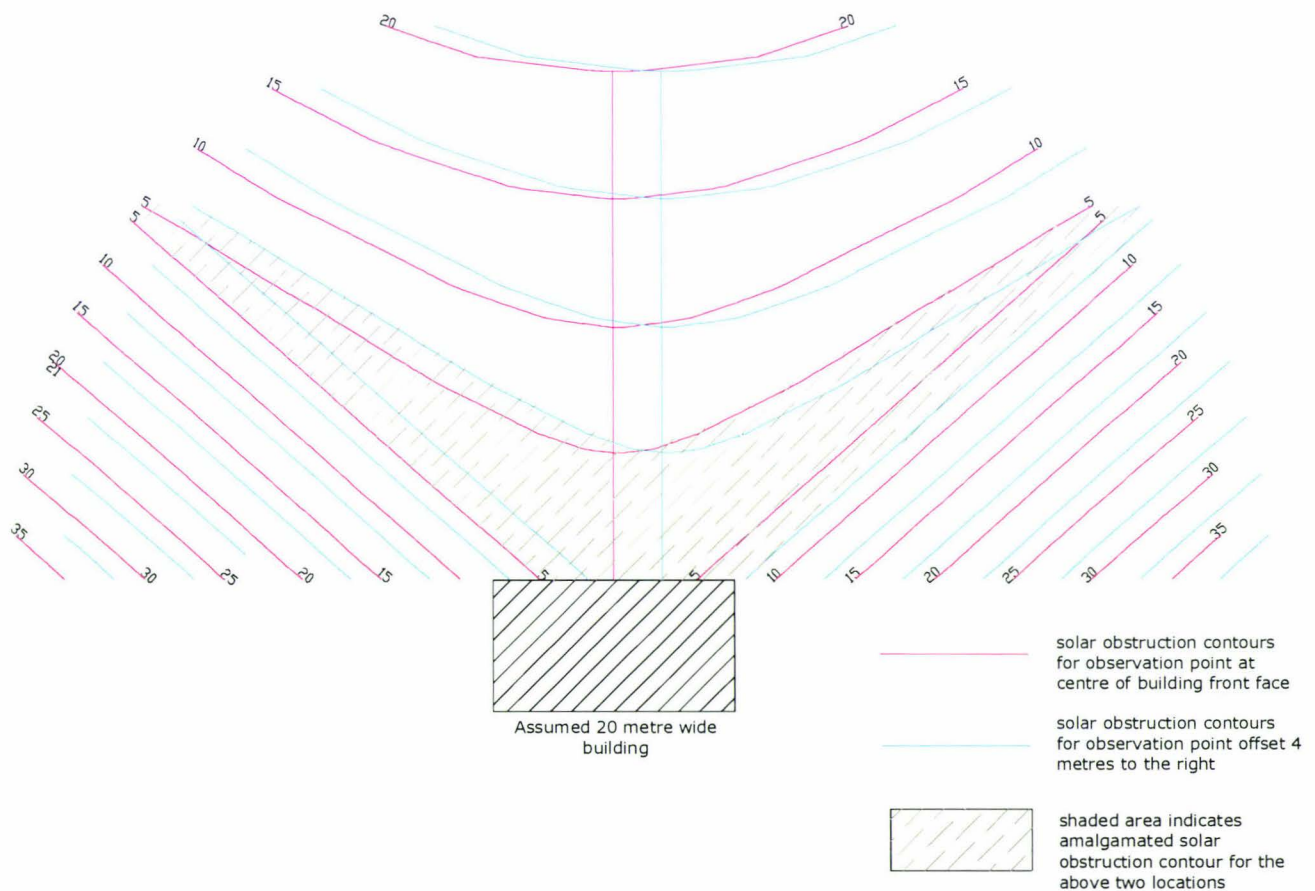


Figure 4-7 Example of amalgamated solar obstruction contour for offset observation points

The resultant amalgamated solar obstruction contour is shown in figure 4-8.

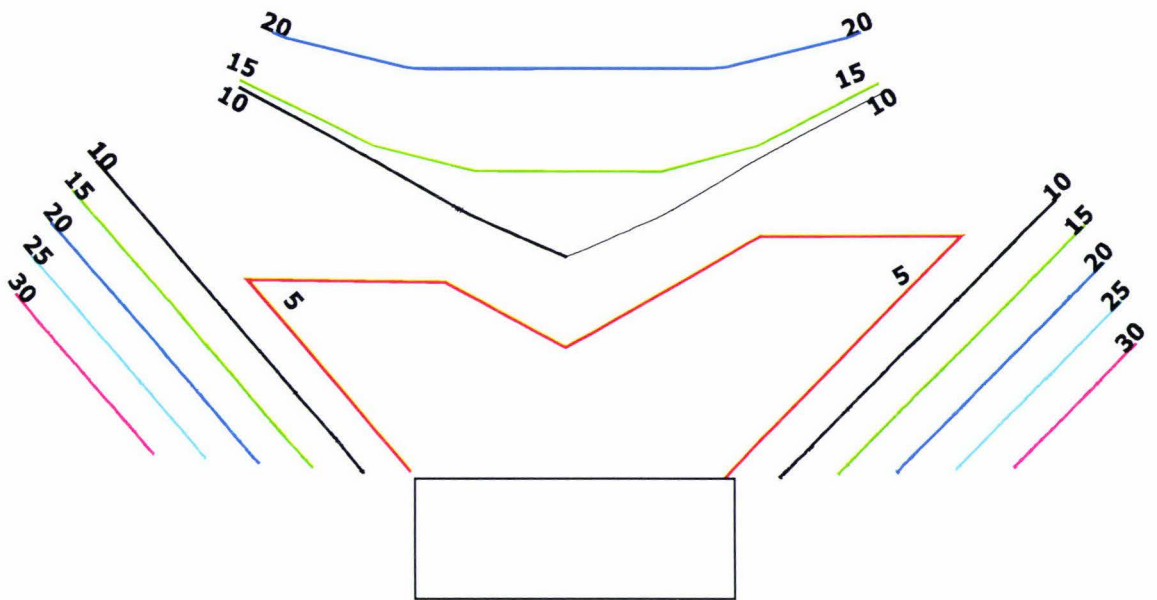


Figure 4-8 Amalgamated solar obstruction contour diagram for 20m East-West building face, with contours at 5m intervals.

4.3 Application to Case Study

The amalgamated solar contour diagram (Fig. 4-8) can now be overlaid on a site scheme plan for the proposed development. When carried out for the case study (Fig 4-9), the degree of interference between each building became readily apparent. Using this method the scheme plan was iteratively modified until minimal interference between buildings was achieved.

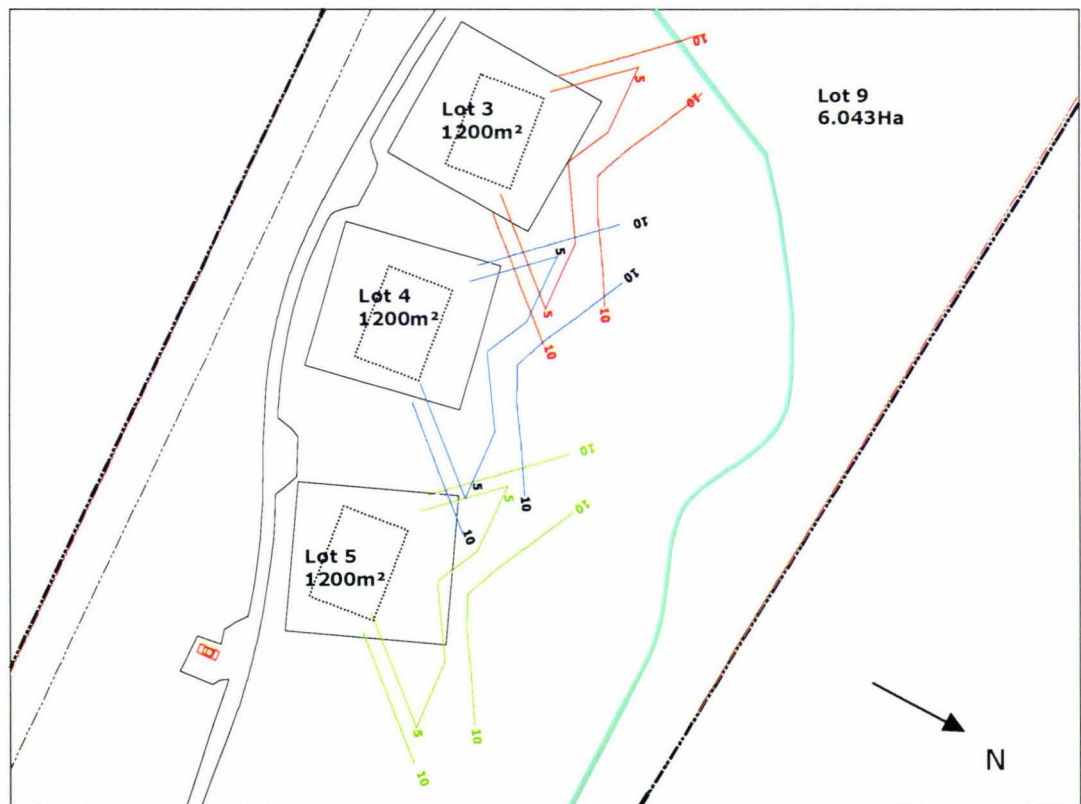


Figure 4-9 Simplified amalgamated 5m and 10m solar obstruction contours overlaid onto part of the case study site plan, showing minimal interference between lots given a maximum building height of 10m.

In order to provide a useful end product for the development site it is necessary to either restrict dwelling location or lot size such that the variation between theoretical and actual house location is minimised.

In the case study situation lot sizes were made sufficiently small (generally 1200m²) that variation of house location within the lot did not lead to major interference with solar contours.

Contour lines from each house site were extrapolated until they intersected. Some subjective interpretation was also needed to connect elements outside of the azimuth angles investigated, and some allowance introduced for easterly and westerly building aspects. For future investigations it may be worthwhile to adopt a series of 'model' house designs of varying dimensions, and to calculate amalgamated solar obstruction diagrams that include the north-south dimensions.

The final solar obstruction contours from this process were overlaid on the original site plan (Fig. 4-10).



Figure 4-10 Solar obstruction contours for case study site (see appendix E for scale plan)

4.4 Whole Site Solar Access

Section 4.3 investigates the effect of objects near to the observation point. Another aspect that requires consideration is the effect of objects distant from the observation point, or the 'apparent skyline'. Hills or mountains may have a significant effect on the solar access for a site even if they are many kilometres from the site, if they lie towards the northwest or northeast of the site. It is therefore necessary to investigate the 'whole site solar access'.

The apparent skyline viewed from the case study site does not significantly impose on the solar access for the time period assumed (Fig. 4-4). This will not however always be the case, and some sites will be significantly affected in terms of solar access by the surrounding topography. It may be possible to include this aspect by inspecting the solar access diagram and correlating the hour at which solar access is compromised with the solar energy distribution curve for that site.

For the case study site this can be done simply by inspection. Figure 4-4 shows the latest morning solar obstruction occurring at approximately 8:30am solar time in winter, and similarly from 4:20-4:30pm. The assumed solar obstruction contours are based on a time period of 8:30am to 4:30pm, so the apparent skyline and local obstruction contours have in this case, coincidental imposition on the maximum available solar resource.

The process becomes significantly more complicated for undulating skylines within the desired solar capture times. It is envisaged that a simplification process would be required, perhaps by conservatively limiting the local solar obstruction contours classification to the uninterrupted timelines on the site solar access diagram.

There are currently no tools available to give a quick indication of the implications of the apparent skyline on the solar access of a site. This

would be of great benefit in assessing the solar energy capability of potential house sites.

4.5 Solar energy overlay

An easy-to-use tool is required that indicates the percentage reduction in the available solar energy at a site due to shading from the apparent skyline (section 4.3).

The information derived in section 3.7 is used here to produce such a *solar energy overlay*.

The solar irradiation data was analysed in terms of the percentage of the total irradiation received during each hour of the day. This was done by using the integration of the polynomial curve fit equation, and setting the limits for a specific hour. This was then repeated for each daylight hour.

The results were then overlaid on the solar resource diagram, which gives an immediate visual assessment of the amount of available energy at a particular location (Fig. 4-11) on an hour by hour basis. The overlay is copied onto a transparency (Fig. 4-12), and overlaid on the solar resource diagram (Fig. 4-13). The apparent skyline from the solar resource diagram can be traced relative to the energy percentage lines, and an estimate of the available energy made.

This is seen as a very easy-to-use tool for rapid evaluation of the amount of solar energy available at a given site as a percentage of the theoretical maximum for that location.

In the hypothetical example (Fig. 4-12 & 13) the site loses 26 ½ % of the maximum theoretical solar energy because of the hills to the east.

The distribution of average daily solar energy will vary depending on location, topography, and localised weather patterns.

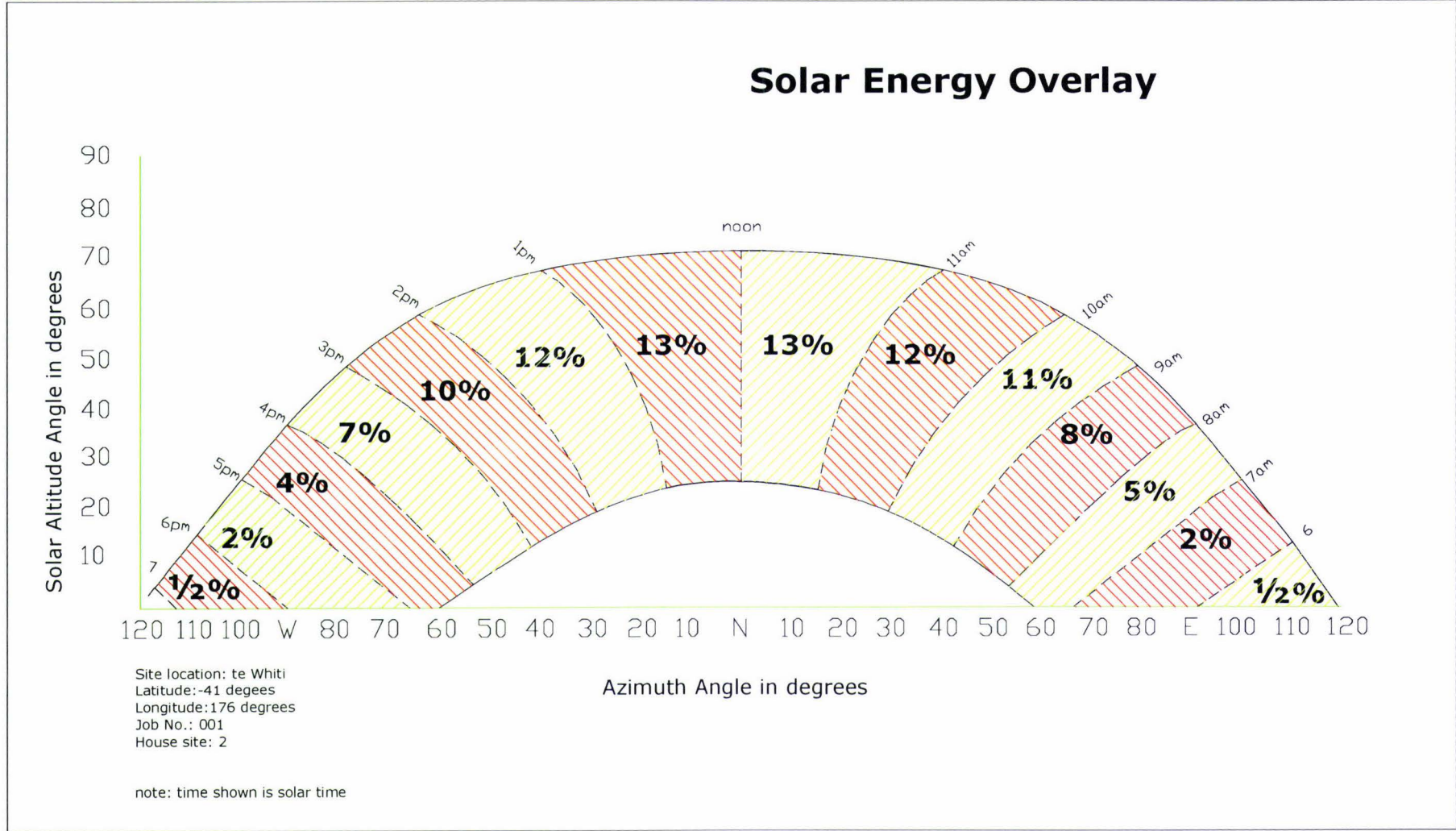


Figure 4-11 Solar energy diagram indicating percentage distribution of total yearly solar energy for each daylight hour (East Taratahi 1995 data)

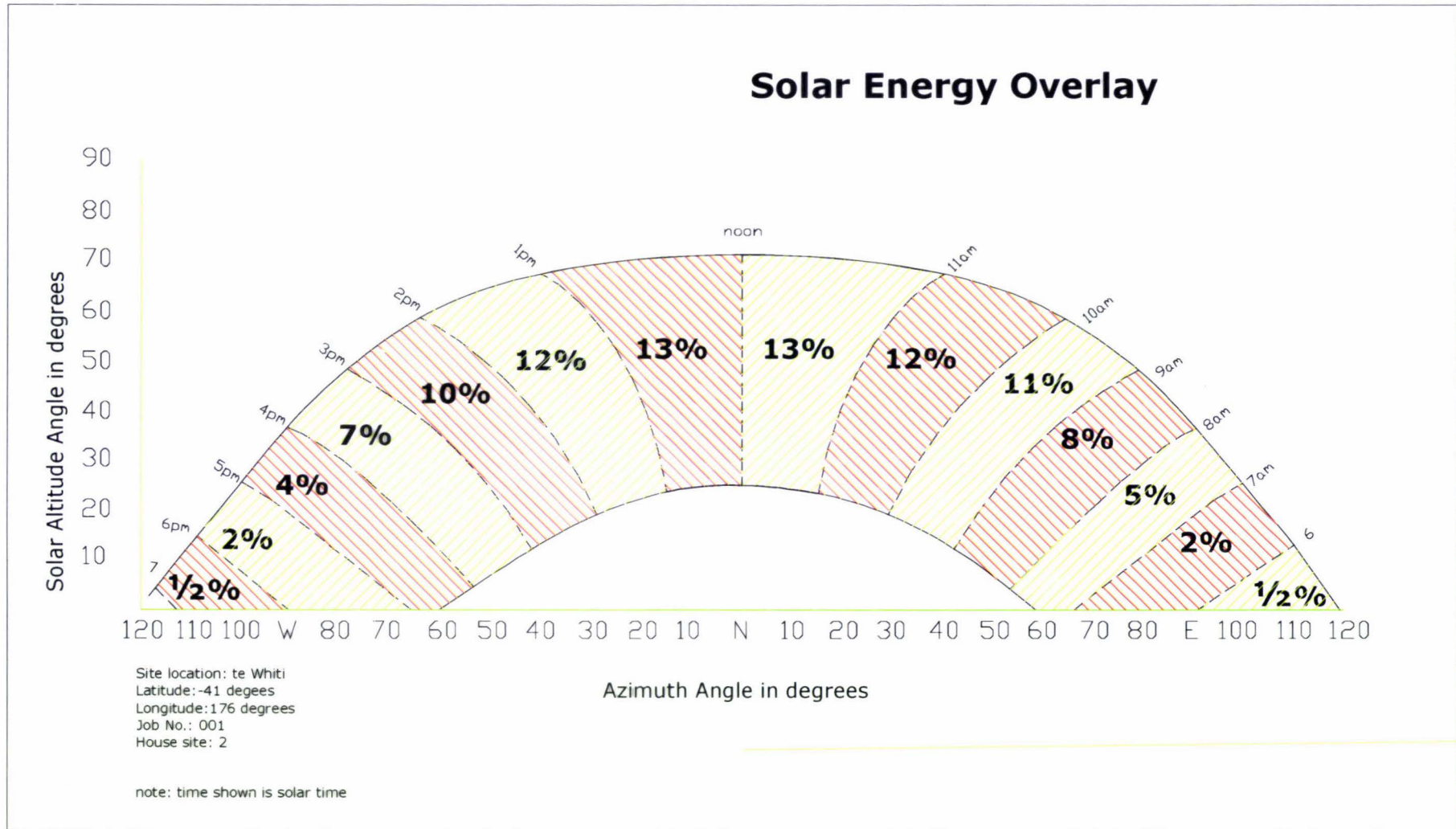
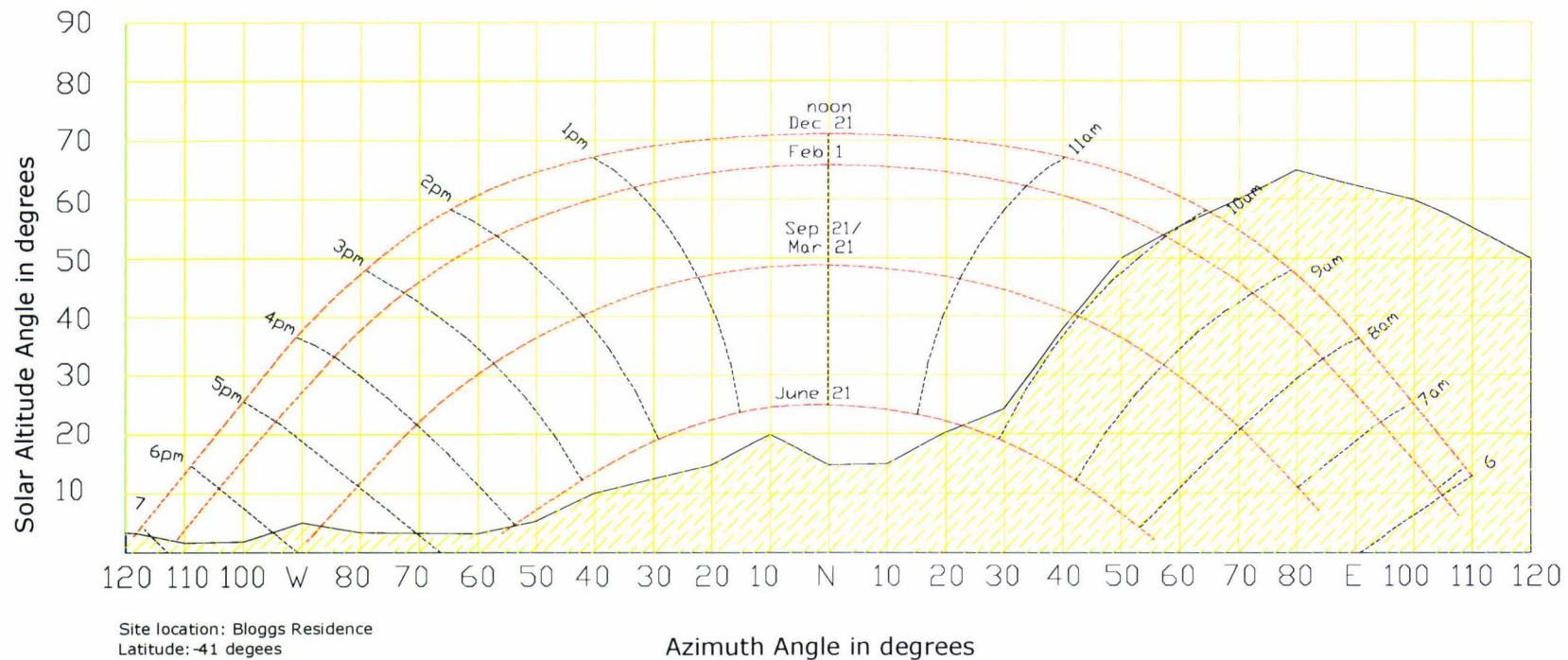


Figure 4-12 Solar energy overlay for East Taratahi Data (1995)



Site location: Bloggs Residence
 Latitude: -41 degrees
 Longitude: 176 degrees
 Job No.: 001
 House site: 1

Solar Resource Diagram

note: time shown is solar time

Figure 4-13 Hypothetical solar resource diagram for site with hills to the east to demonstrate use of solar energy overlay

4.6 Solar Access Planning Discussion

Using the process outlined a proposed site can either be assessed in terms of attainable solar energy capture, or developed to meet a percentile energy capture requirement. This relationship will vary according to location, not only due to latitude and associated day duration and altitude angle, but also there may be specific microclimate weather patterns that influence diurnal solar radiation patterns e.g. cloud formation in morning/afternoon. The Wairarapa plain experiences a notable such phenomenon: the calm mornings abruptly change as winds start to blow at noon, affecting cloud cover that generally originates from the west.

Similarly microclimate influences connected with the apparent skyline will also have an effect on the energy capture, and these may be incorporated to produce the required percentile energy capture.

The investigations into solar access planning suggest that it is possible to specify criteria governing the amount of solar energy available at prospective house sites for a land development in the form of solar obstruction contours. For sites with apparent skylines that have only minor impact on solar access, the matter is relatively straightforward, becoming increasingly more complicated as the apparent skyline imposes more restrictions to solar access.

Solar obstruction contours may be of benefit:

- for local authority planning, encouragement, and enforcement of minimum standards for solar energy access.
- for the formation of national standards, or amendment to NZS4404 subdivision standard (SNZ, 1981) for the investigation of solar energy availability on proposed subdivisions. Recent development work on a design Tool for Urban Sustainability (TUSC)(NZSSES, 2004) identified the need for solar access work in New Zealand;

- for developers wanting to gain a market advantage by providing sections with known solar access characteristics.
- for purchasers by allowing easy estimation of the limitations or benefits of different sites.

4.7 Limitations of solar access planning

Detailed solar access planning provides occupiers with information essential to decision making for solar energy harvesting. The methodology used in this study uses a simplistic energy analysis, assuming a total energy capture calculation symmetrical about the maximum. Whilst this may prove sufficient for many sites, and in conjunction with an apparent skyline plot provides an easy assessment of the available solar energy, there will clearly be a number of sites for which this will not provide the optimum information. In particular sites with substantial morning or afternoon shading will disrupt the symmetry of the energy curve, and will require more detailed analysis.

Nonetheless the process is still a valuable one, and can be adjusted to compensate for individual site characteristics. Analysis of the actual solar irradiation curve for any site will yield specific time patterns relating to specific energy capture percentages. Baseline analysis for total theoretical available energy in the district, or for data from nearby sites substantially free of solar obstructions, can provide a comparison of the benefits or limitations of a proposed land development.

The calculations in section 3.6 effectively used the integration of the irradiation curve between limits on the x-axis (time axis). The extreme low sun angles at sunrise and sunset yield little energy, and in terms of use for passive solar heating are not of major importance. It may be possible to examine the irradiation data to find total energy capture percentages relative to a set of limits on the y-axis, which relates to an irradiation intensity, and generally speaking also altitude angle. Although considerably more complex, the optimisation of solar energy capture is likely to be more efficient using this method as the varying altitude angle

with day number becomes less relevant, and the time periods for energy capture more specific. This topic is however beyond the scope of this study, and is thought to enter into an area too complicated for simple inclusion in land development practice.

4.8 Other considerations

The whole-site solar access also has other implications, for example reduced solar access is commonly associated with reduced evapotranspiration, increased ground and air moisture, and reduced temperatures. It may therefore be that studies (Wellington School of Medicine, 2004) linking public health to temperature and moisture environments within buildings could benefit from the inclusion of solar access studies, or in other words that there could be benefits to public health from ensuring development sites have minimum solar access requirements.

We may yet therefore see the development of 'healthy house sites' incorporating these aspects (amongst others), as well as the 'healthy homes' investigated by the Wellington School of Medicine.

It is possible that low irradiance values associated with these low altitude angles could be forfeited in favour of higher capture rate of the longer summer hours. This can be depicted graphically (Fig. 4-14), where an arbitrary altitude angle has been selected. All altitude angles below this value would then be ignored i.e. shading within these times accepted. Longer capture times could therefore be used i.e. from 7:00am to 7:00pm. It may be possible to achieve higher total energy capture for the year by this method. The implication associated with this choice is the compromise between total yearly solar energy gain versus optimised winter gain. It may be that there is an economic balance between these two, which may be affected by, for example, insulation levels in the proposed building.

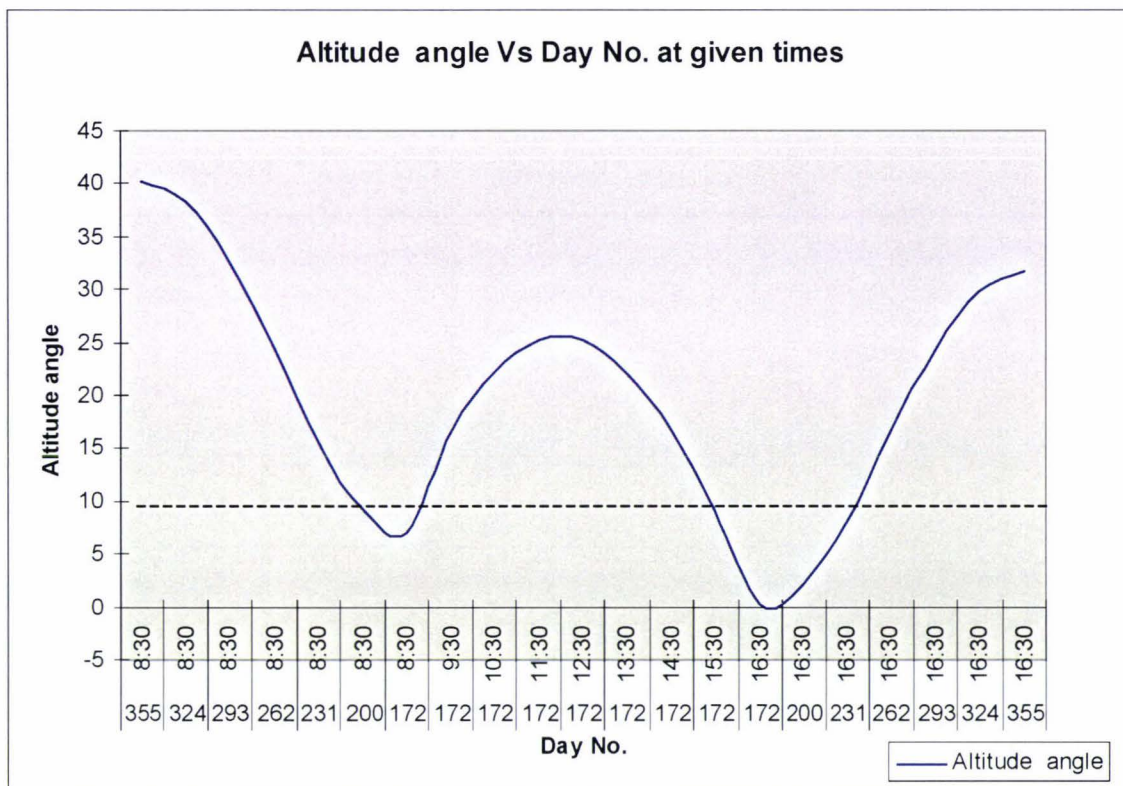


Figure 4-14 Minimum altitude angle based solar energy capture diagram.

An important aspect of solar capture in New Zealand is the use of solar energy to heat buildings, and the exclusion of solar rays when the indoor temperature is at or above the human temperature comfort range. The optimisation of the use and exclusion of solar energy in dwellings is described in section 5.

Chapter 5 Optimal window shading

5.1 Introduction

For dwelling construction, solar altitude angles play an important part in the design of eaves, window placement and size.

Each and every location in New Zealand has individual meteorological characteristics unique to that site. The diurnal and yearly temperature fluctuations at any site may be influenced by a variety of factors including altitude, solar obstructions, latitude, surrounding land form, aspect, proximity to water bodies or open spaces, and its geographical location in terms of national weather patterns (Fig. 5.1).

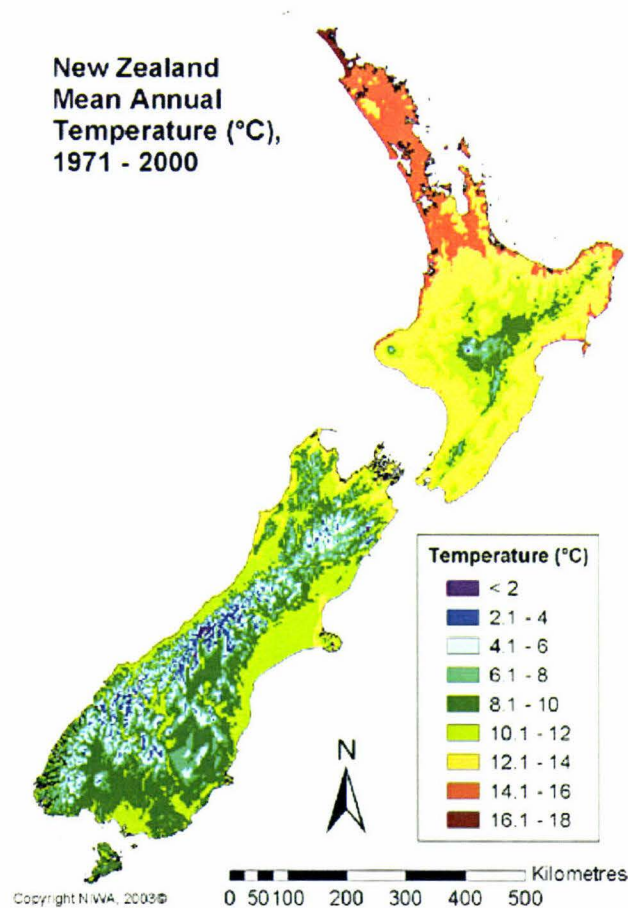


Figure 5-1New Zealand mean annual temperature (reproduced by permission from National Institute of Water and Atmospheric research)

The increasing necessity for improved energy efficiency and reduction in use of non-renewable resources will require more systematic use of passive solar techniques as a matter of course, and a greater understanding of the implications of microclimates in controlling the internal temperatures in dwellings.

Differences in temperature patterns may be broken down into discreet regional climates, district climates, and microclimates. As the climate area is progressively narrowed down, it is possible to achieve greater accuracy in the detailing of passive solar designs, once the design conditions become closer to the actual physical site conditions.

Traditional eave design (E.E.C.A, 1985) is the dominant form of window shading in New Zealand, with specialised structures or blinds being used in only a small percentage of dwellings (based on the author's observation). Many dwelling designs use eaves based on standard summer and winter sun angles (CCANZ, 2001). These do not take into account site-specific variations that may influence the extent of solar shading required.

In this investigation local temperature records were analysed in conjunction with calculated solar path information for the development location in an attempt to define correlations or possible guidelines to optimise passive solar design. Whilst there are additional methods such as pergolas and shade sails that may be employed to increase the efficiency of solar energy capture or exclusion, recognition of optimum shade angles for a district area has greater potential to increase the energy efficiency of the housing stock if generally adopted into design criteria for the district.

5.2 Temperature Data

Temperature data for the Taratahi weather station were obtained from NIWA for the period of 1995-2003 (Appendix B). The variation both

diurnally and yearly is large, with the majority of the year being below the comfortable habitation temperature range.

Examination of the data yields the following information:

- Average temperatures for January and February were close to 18°C, an acceptable temperature in terms of domestic comfort temperature range.
- Average daily temperatures for the period from April through to November were below 15°C, with maximums from 10.8°C to 20.1°C i.e. less than or within the normal domestic comfort temperature range.
- Minimum average temperatures vary between 4.8°C in June to 12.2°C in February.

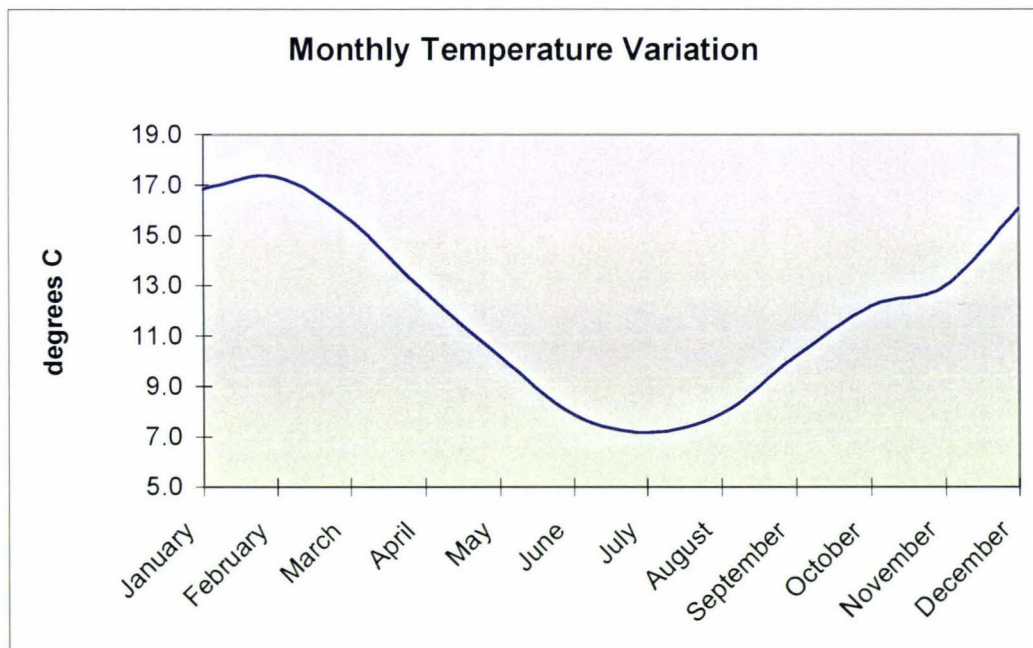


Figure 5-2 Average monthly temperature variation, East Taratahi (1995-2003), taken on average solar days

The temperature variation on monthly average solar days has been taken from the main data set (1995-2003) (Fig. 5-2), and the hourly changes on those days (Fig. 5-3). The diurnal variation shows patterns typical of much of New Zealand, where morning easterly and south-easterly irradiation although not needed in total heat energy terms (in the summer), is welcome due to low temperatures in the early morning.

Conversely in summer the westerly evening sun is not welcome as overheating occurs, the ambient temperature at this time already being at or above the comfortable habitation range.

The hourly temperature fluctuation through the day may be plotted relative to the human temperature comfort range (Fig. 5-3), taken here as between 18 and 22 degrees Celsius, with a minimum desirable temperature of 16 degrees (WSM, 2004) assumed.

The area under the curve for any given month and above an assumed temperature indicates the period when no additional energy is required to meet the desired temperature. The area below this temperature line and above the curve represents the period when additional energy is required to reach the desired temperature. Where the two areas are equal, it is theoretically possible to achieve the desired temperature by storing energy and releasing it during the cooler period.

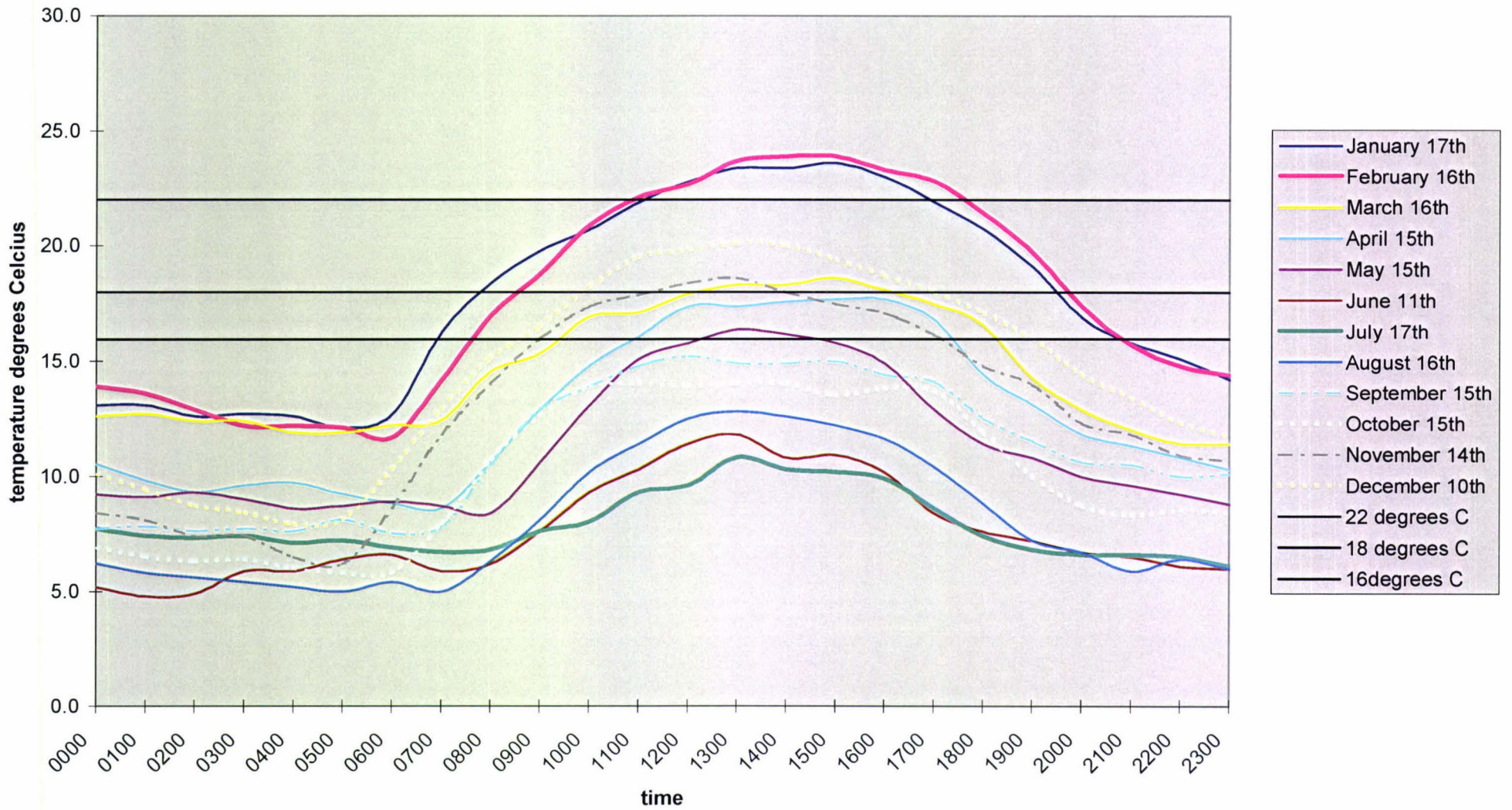


Figure 5-3 Average monthly daily temperature variation by hour (24-hour clock) for East Taratahi (1995-2003)

By observation optimum dwelling configuration for the months of January and February should have sufficient thermal mass and insulation to smooth indoor temperature fluctuations and attenuate peaks and troughs. Little or no passive solar heating is required over this period.

5.3 The effect of ambient temperature on passive solar design

It is possible to examine the solar path data from section 4 in combination with the temperature information gathered above. For this analysis, average solar days were assumed for each month (Duffie & Beckman, 1991), and average temperatures taken from the data set for each month.

In general terms dwelling design may be broken down into component walls, each with its own orientation. It is satisfactory for most purposes to assume wall orientations as being parallel to one of the principal eight compass directions, i.e. southeast, east, northeast, north, northwest, west, southwest and south. Solar altitude angles (at the case study location) at major building orientations for the relevant dates are shown in Table 5-1.

Table 5-1 Altitude angles on monthly average solar days¹² (East Taratahi), with average daily air temperature

	Altitude Angle, Masterton											
	Jan 17th	Feb 16th	March 16th	April 15th	May 15th	June 11th	July 17th	Aug 16th	Sept 15th	Oct 15th	Nov 14th	Dec 10th
SE	-											
E	33	20	4							15	29	37
NE	65	54	40	27	17	12	13	24	37	49	61	66
N	70	62	51	40	30	26	29	36	47	59	68	72
NW	65	54	40	27	17	12	13	24	37	49	61	66
W	33	20	4							15	29	37
SW	-											
Average Temp °C	16.9	17.4	15.7	12.8	10.2	7.9	7.2	7.9	10.2	12.2	13.0	16.1

¹² Duffie & Beckmann, 1991

It can be seen that the peak yearly temperatures are out of phase with the peak solar altitude angles, with maximum temperatures occurring in February, and maximum solar altitudes in December. This lack of symmetry poses problems for efficient passive solar design. In order to prevent overheating in February, sunlight should be prevented from entering the building, yet imposition of shading angle¹³ restrictions will have a negative effect in November, where altitude angles are higher than those in February, but the temperature is markedly lower. Without the use of moveable shading devices, a compromise must be accepted. For the case study location houses are more likely to be set up for heating rather than cooling, so under-heating in November would be easier to address than overheating in February. The recommended eave angle is therefore biased in favour of this approach.

Given the average daily temperatures it is clear that for this location solar energy is desirable to passively heat dwellings between the months of March and October, and that shading, or eaves angles should not inhibit solar access during this time. Given that the average temperature during these months is below the normal habitable comfort range, and if it is assumed that internal thermal mass is incorporated in the design, a comfortable temperature should be achievable by allowing full solar access during the cooler months, and regulating any over-heating on exceptionally warm days by convection ventilation.

Specification of suitable shading angles for each orientation can therefore be made such that in each direction solar rays can enter the building between March and October (or more specifically when the average daily air temperature is below 16°C), and be progressively excluded outside of these months as the average air temperature rises.

¹³ Shading angle refers to the angle formed between the base of a window and the structure's eave. Sun altitude angles below this will enter the building through the glass. Where the sun altitude angle is higher, the window will be in shade.

5.4 Specification of shading angles

Suggested shading angles¹⁴ for these conditions (Table 5-2) were derived from examination of Table 5-1 by assuming a minimum required average temperature of 16 degrees Celsius, and estimating the effect of different shade angles compared to the altitude angle at each month.

Table 5-2 Suggested shading angles for case study location

East	20
North-east	50
North	60
North-west	50
West	15

A shading angle of 15° in the westerly direction all but prevents westerly sunlight entering a building in February, whilst allowing access for all of October. An angle of 20° to the east allows more solar access in the cooler mornings.

For passive solar design, window orientations to the Southeast, South, and Southwest have a negative effect on dwelling thermal efficiency. At the latitude of the case study site the solar energy at these angles is relatively minor, and principal effects are by heat loss during the winter months.

The values in Table 5-2 compromise under-heating in November to prevent excessive overheating in January and February. Low shading angles in the Westerly and Easterly directions may be difficult to obtain, and in accordance with general design advice (EECA, 2002), windows in these directions may need vertical shading or other solar shading mechanisms.

The case study site has an even solar access distribution through the day (between 8:30am and 4:30pm), as shown in Figure 4-4, however it can

¹⁴ The angle at which the sun's rays are prevented from entering building windows etc.

be seen that for different locations there may be more definitive links between temperatures and desirable shading angles.

For example, comparison against data for Invercargill and Kaitaia indicates substantial variations in both annual temperature averages and solar altitude angles (NIWA, 2004).

Table 5-3 Altitude angles versus average air temperature (Kaitaia)

Altitude Angle, Kaitaia												
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
SE	-											
E	39	23	4							17	34	43
NE	71	61	50	33	21	16	19	28	42	57	68	74
N	76	68	57	46	36	32	34	42	53	65	74	78
NW	71	61	50	33	21	16	19	28	42	57	68	74
W	39	23	4							17	34	43
SW												
Average Temp °C	19.6	20	18.5	16.9	14.7	12.6	12.1	12.1	13.1	14.4	15.8	17.9

Table 5-4 Altitude angles versus average air temperature (Invercargill)

Altitude Angle, Invercargill												
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
SE	-											
E	29	17	4							13	26	32
NE	57	47	35	23	12	7	9	18	31	43	55	60
N	64	56	45	36	24	20	22	30	41	53	62	66
NW	57	47	35	23	12	7	9	18	31	43	55	60
W	29	17	4							13	26	32
SW	-											
Average Temp °C	14	13.8	12.4	10.4	7.8	5.5	5.2	6.4	8.3	9.9	11.4	13

By examination of Tables 5-1, 5-3 and 5-4 it can be seen that specification of appropriate optimum shade angles may differ considerably for different locations. A 60° shade angle in Invercargill would prevent some solar access in November, when average temperatures are as low as 11.4°C, and may not be appropriate. It follows that each location requires individual investigation to deduce an appropriate maximum shading angle.

Generic, and more specific information is given on shading angles in both Design for the Sun (EECA, 2002) and Designing Comfortable Homes (CCANZ, 2001).

The former text suggests 72.2° for average window size, and similarly the data given in the latter text for the Wellington Region suggests an exclusion angle of 72°15' (approximately equivalent to the maximum altitude angle reached on December 21st) (Fig 5-4).

Although 'Design for the Sun' describes alternative options for optimising either winter or summer shading angles, the assumption of a traditional eave format restricts the user, without further information, to compromising during either the summer or the winter. Analysis may however be carried out to assess the optimum shading angles for the case study site.

Given the 72°15' used in CCANZ, it follows that say, one minute before or after solar noon, there will therefore be some solar access through windows designed using this criteria. Similarly from December 22nd onwards as the sun altitude angle wanes, progressively more sun will enter the windows.

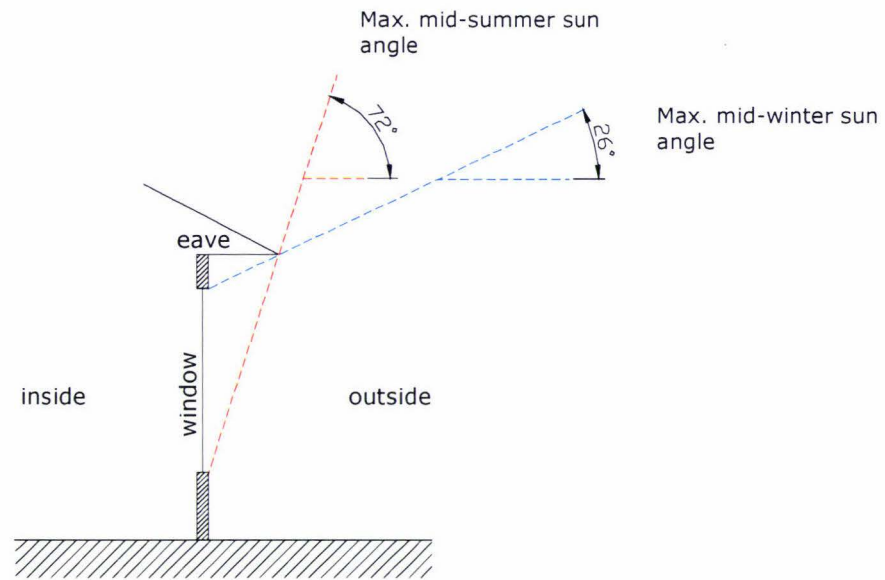


Figure 5-4 Traditional eave overhang design showing summer and winter shading angles

For the case study site on February 6th (the approximate yearly highest average daily temperature), the sun reaches an altitude angle of approximately 60° at 10.45am solar time, (11.15am standard time), and again at 1.15pm solar time (1:45p.m standard time) (Fig 5-5). The maximum angle reached on this day is approximately 65°.

For north facing windows, the recommended shading angle of 72.2° therefore allows about 16% $[(72-65)/46]$ solar access at noon on the hottest day, and 26% $[(72-60)/46]$ solar access during the hottest period of the day (early afternoon).

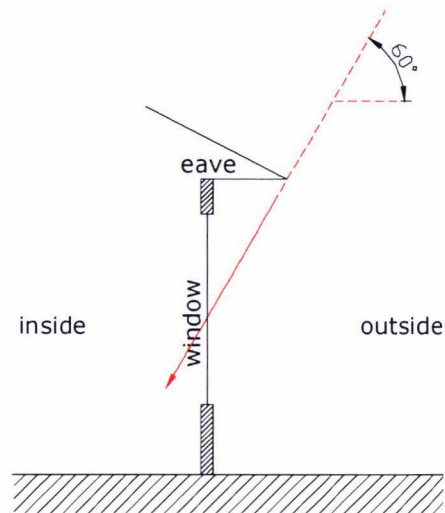


Figure 5-5 Traditional eave overhang with 60° sun altitude angle, showing undesirable solar access on this day (Feb. 6th)

During this period there will also be a net energy gain inside the building from:

- internal gains – human activity, hot water storage, appliance use etc;
- heat penetration from roof and walls heated by solar energy;
- solar gain from reflected light entering the building; and
- movement of warm air into the building.

Although a detailed examination of the mechanics of these cumulative effects is beyond the scope of this research, a brief examination of the order of magnitude of these factors suggests that direct solar gain is not required to obtain temperatures within an acceptable comfort range during the summer months.

The daily temperature chart for February 16th (the average solar day for February) shows an average temperature of 17.7°C. Based on free air movement and sufficient thermal mass, it follows that no direct solar gain is required, or wanted at this time of year. Examination of the hourly temperature fluctuation for this time of year (Fig. 5-6) shows an average temperature above the minimum human comfort level without any additional heating.

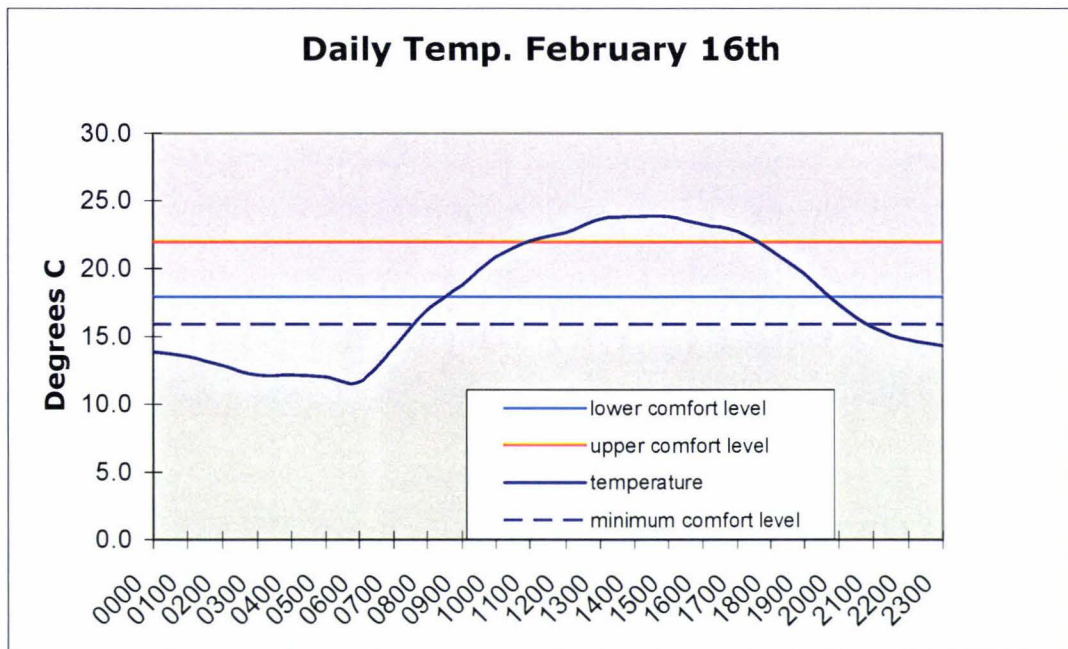


Figure 5-6 Human comfort temperature range with daily air temperature (average 1995-2003 East Taratahi data)

Given that the average temperature for this day and the normal comfortable habitable range, it appears that at the case study site a greater degree of summer shading may be appropriate compared to that adopted by standard texts.

Adoption of a minimum average 16°C base temperature, and analysis of the yearly average daily temperature in relation to altitude angle (Table 5-1), gives a north-oriented optimum summer shading angle of around 60°. The definition of the shading angle is however somewhat subjective, and balances overheating in Jan/Feb with possible underheating in November.

By a similar process, specification of the minimum shading angle (i.e. the angle above which partial shading of the window occurs) requires detailed consideration. For example Design for the Sun (EECA, 2002) recommended a minimum shade angle of 25.5° under normal conditions.

There are however implications associated with design based on this assumption. At the case study site temperatures in August are only marginally above minimum temperatures reached in July, however on

the average solar day in August the sun altitude angle reaches 25° at 9:30am solar time, and falls below 25° at 2:30pm solar time, reaching a maximum of 35.5° . There is therefore an obvious loss of efficiency as the windows are partially obscured during this time (Fig 5-7).

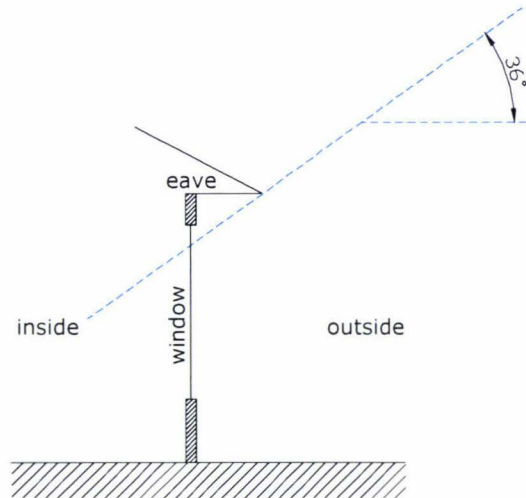


Figure 5-7 Traditional eave overhang with 36° sun angle showing partial shading of window in August

This outcome indicates that there is benefit in analysing the temperature data to see what effect partial shading has at different times of the year. The detailed mechanics are beyond the scope of this research, however examination of Table 5-2 indicates that a practical minimum shade angle of between 40° and 45° will give substantial solar access during the cooler months, progressively introducing partial shading as the average temperature rises. Traditional flat eaves cannot always provide the necessary geometry to meet both winter and summer sun angle requirements.

Removing the constraint of a traditional eave overhang allows the opportunity of innovative architectural form to optimise shading angles (Fig 5-8) by altering roof pitch and eave formation.

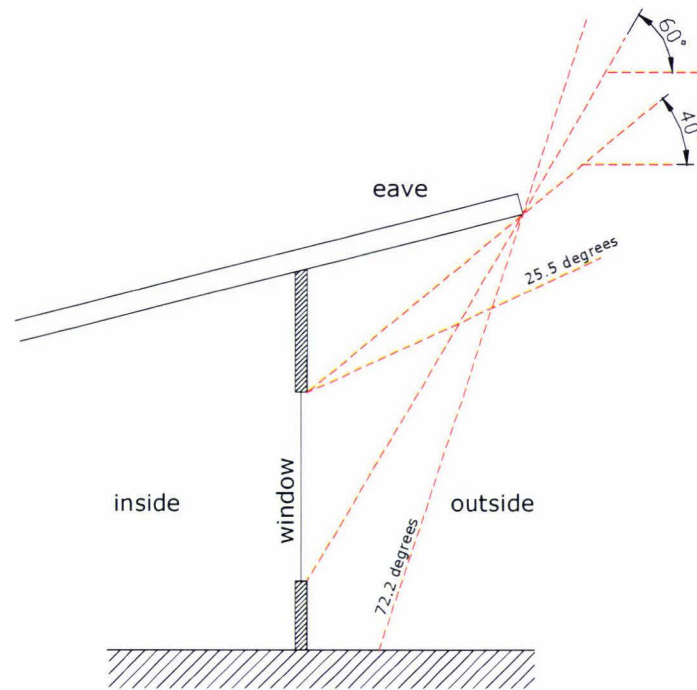


Figure 5-8 Alternative architectural design to optimise shade angles, showing shading/solar access of different sun angles

The optimum shade angles can be calculated by using the following equations, which may also be illustrated diagrammatically (Fig. 5-9).

$$H = A \tan (M_i), \quad \text{equation 5.1}$$

and,

$$\tan(M_a) = (W + H)/A \quad \text{equation 5.2}$$

where,

M_i = the minimum shading angle,

M_a = the maximum shading angle

A = the overhang width,
W = the window height, and
H = the height above the window to the overhang,

Substituting for H,

$$\tan(M_a) = \frac{W + A \cdot \tan(M_i)}{A}$$

Or
$$A = \frac{W}{\tan(M_a) - \tan(M_i)} \quad \text{equation 5.3}$$

Equations 5.1 and 5.2 are easily incorporated into a spreadsheet to allow trial configurations, or to view the effect of using different M_i and M_a values.

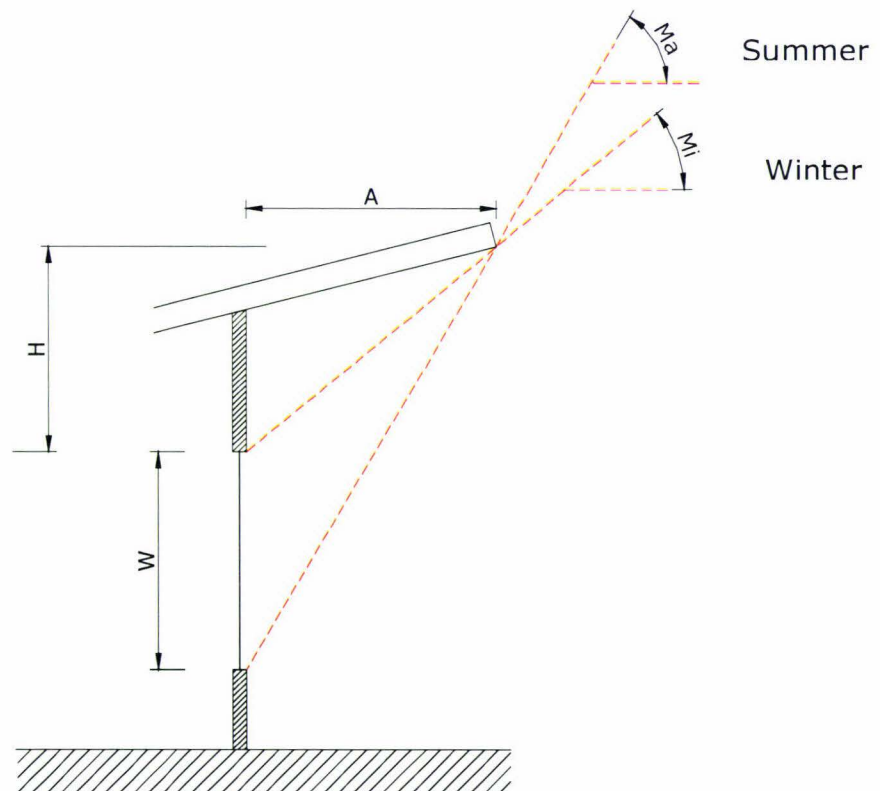


Figure 5-9 Criteria for optimised shading angle design

The dimensions calculated from equation 5.3 become the desired optimum design criteria for roof design in terms of solar access, where M_a and M_i are defined by reference to yearly temperature patterns at the site location (Table 5-2). This defines the point coordinates for optimal shading; the method of achieving this is then left to the innovation of the designer.

5.5 Section summary

Solar shading masks are tools used to predict the shading pattern caused by given shapes of shades or obstructions. Since an evaluation of times during which it is undesirable that solar radiation enters a building can be carried out using temperature analysis as outlined (section 5.2), it may be possible to use the notion of solar shading masks to reverse-engineer the process to define optimum shade shapes to minimise overheating. This has been achieved in basic format, however without attempting to use the shade mask tools. Combination of the techniques used in section 5 with a solar mask tool may allow optimum specification of, for example, a freeform eave overhang that would be specific to the building and its surrounding environment.

The optimisation of eave shade angles has bearing on the efficiency with which the building can utilise solar energy, and therefore effects the building thermal energy efficiency. This is discussed in section 6.

Chapter 6 Building thermal energy efficiency and site thermal energy self-sufficiency

6.1 Introduction

Building thermal energy efficiency is a measure of the energy required for a building to maintain a specified temperature. It is of primary importance in both the amount of energy that will be used by the building during its life and the comfort and health of the occupants. If as a nation we are to move towards a more sustainable lifestyle, it is important that the amount of energy currently used for domestic space heating is greatly reduced.

The source of energy to provide domestic space heating also has implications in terms of the carbon footprint for the dwelling. Imported electricity produced from gas-fired power stations has a greater footprint than that from hydropower. Energy provided from renewable energy resources on site has no transportation losses or embodied energy of transportation. The ability of a site to produce renewable energy for domestic space heating therefore affects the sustainability of the development.

This section investigates a method of estimating the ability of a development to meet its own thermal energy requirement for space heating, or its *thermal energy self-sufficiency*.

6.2 Background

The New Zealand Building Code (B.I.A, 1992) requires minimum insulation levels, but provides only minimal regulation of the thermal efficiency of buildings in terms of solar energy capture, thermal mass, or other design features.

The subdivision stage is an appropriate point to introduce energy efficiency requirements to guide and enforce the development of more

sustainable building design, as covenants may be applied ensuring that buildings must meet the required specifications.

Detailed investigation into the behaviour of houses under New Zealand conditions has been carried out by BRANZ, and modelled using an Annual Loss Factor approach. Software is readily available (ALF3 – branz.org.nz) to aid designers to evaluate the thermal efficiency performance of proposed buildings. The software produces a report on the Building Performance Index (BPI), a measure of the required heating energy to heat the home to 20°C, 24 hours per day. Other base temperature values can be used, but require conversion factors to apply the ALF method.

One of the goals of the development was to promote discussion on the thermal energy self-sufficiency of land developments. Given the Building Performance Index and floor area of a building it is possible to derive the approximate energy requirement to heat the building to a specified level. Conversely it is also possible to specify a maximum theoretical energy demand per house.

The former method was used to specify minimum building energy efficiency on the case study development, and quoted a sliding scale (Table 6-1). In order to ensure that these performance requirements are met by future owners, a covenant was placed on each title making adherence to the table mandatory, and is legally binding. Proposed dwellings must meet these requirements before building permit consent may be issued.

Table 6-1 Proposed building performance index requirement for case study dwellings, relative to proposed building floor area

Floor area (m²)	Max. B.P.I
100	0.100
125	0.080
150	0.070
175	0.060
200	0.050
225	0.045

There are several benefits of adopting this strategy:

- the decreasing Building Performance Index with increasing floor area provides an obvious incentive for owners to give consideration to the floor area that they really need. As the required Building Performance Index decreases construction costs increase, so larger houses become progressively more expensive to build per unit area. It also provides a maximum practicable building size restriction, desirable in terms of the case study to reduce the possibility of visual eyesores.
- the theoretical thermal energy demand for each house will be equal, and therefore the demand for the entire development can also be calculated.
- the Building Performance Index requirement ensures that some investigation into building form is carried out by specialists in building energy efficiency.

Given the theoretical thermal energy requirement for each house, it is possible to calculate the theoretical thermal energy demand for the entire case study development. There are variables associated with these calculations, for example the desired temperature in the house, and the time period through the day for which this temperature is to be

maintained. Although variations in these criteria are dependent on the owners of individual buildings, and are therefore unpredictable, some standard criteria are nonetheless required for comparison and evaluation of options.

For the purposes of the case study the standard criteria (Building Code , 1979) used in the formation of the base information for the Building Performance Index are used i.e. the whole building heated to 20°C, 24hours per day.

Apart from minor rounding to suitable figures, the sliding scale is such that the product of the floor area and the Building Performance Index is a constant at 10kWh/year.degree days¹⁵.

The Building Performance Index is defined as:

Annual heating energy/(degree-days x floor area), measured in kWh.degree days.m².

Therefore,

Annual heating energy (A.H.E)(kWh) = B.P.I x degree-days x floor area(m²)

For the case study development site, where the annual degree days is 920 (BRANZ, 2003) the annual base₂₀ heating energy per house is therefore;

$$\begin{aligned} \text{A.H.E} &= 920 \times 10 \\ &= 9200 \text{ kWh} \end{aligned} \qquad \text{Equation 6.1.1}$$

and for the whole eight lot development,

$$\begin{aligned} \text{A.H.E} &= 9200 \times 8 \\ &= 73600 \text{ kWh} \end{aligned} \qquad \text{Equation 6.1.2}$$

¹⁵ Degree Days: [DD] Measure of the severity of the climate. The larger the number of degree-days the cooler the climate. The number of the degree-days is defined in relation to a base temperature. The base temperature is commonly either 15°C or 18°C. The number of heating degree days is calculated as the sum of the daily differences between the average ambient temperature and the base temperature for all the days on which the average ambient temperature is smaller than the base temperature. Example: The heating degree days (base 15°C) of three days with ambient temperatures 11°C, 9°C and 16°C is: (15-11) + (15-9) + 0 = 10DD15 (BRANZ, 2003)

6.3 On-site thermal energy provision

Having determined the required thermal energy required by the development, methods of providing a renewable energy supply on-site were evaluated.

The site has no hydro potential, no geothermal potential, intermittent wind power generation potential, and good solar access and biomass potential. The predominant space heating methods in the Wairarapa are log burners, gas, and electric heaters. Of these the simplest and most economical method of providing an on-site energy supply is by biomass.

Part of the case study site has been set aside and planted with coppicing firewood trees. The provision of such a renewable energy source on site has obvious advantages in that:

- coppicing firewood trees are a renewable, carbon neutral energy source;
- for thermal energy production there are no efficiency losses in conversion from one form to another before final use; and
- it requires no transport energy as it is produced at point of use.

Three species of tree were planted, *Eucalyptus nitens*, *Eucalyptus ovata*, and *Acacia dealbata*. *E.nitens* and *E.ovata* have performed extremely well in energy production rates in trials undertaken by Massey University (Sims, 1996), and *A.dealbata* as well as performing well has the advantage of colourful Spring blossom. An area of 0.6 hectares was planted in roughly equal proportions of these three species.

Using an annual oven-dry wood production of 20 tonnes/ha (Sims, 1996), and an energy value of 15GJ/tonne (Sims, 1996), an energy production value of 300GJ (83.3MWh)/ha was assumed. It follows that the annual energy production capacity of the coppicing firewood lot is $0.6 \times 83.3 = 50,000$ MWh.

This figure can then be compared against the annual heating energy demand for the development from equation 6.1.2, showing that for all

the houses heated to 20°C, twenty-four hours per day, the firewood lot could provide

$50,000/73600 \times 100 = 68\%$ of the heating energy demand ignoring stove losses. Including for an average stove efficiency of 70% yields a net provision of around 50% of the heating requirement of the subdivision if all the houses were heated to 20°C 24 hours per day.

In practice few, if any, New Zealand houses are permanently heated throughout to 20°C, and the value in equation 6.1.2 is conservative. Nonetheless it offers an easily achievable means of comparing the thermal energy requirements of development options, and their self-sufficiency in these terms.

Alternative energy supply sources could also be used, and if the base₂₀ (20°C) standard continues to be used for house thermal energy efficiency, comparison between competing energy sources can be easily assessed.

The adoption of a Thermal Energy Self Sufficiency (TESS₂₀) index appears to be a realistically achievable, and indeed relatively straightforward process for comparison of land development options. There is also scope for inclusion in District, Regional, or National energy efficiency standards, or subdivision standards such as NZS4404.

Further research or monitoring is required to correlate the base₂₀ index to the actual thermal energy usage for dwelling using this energy balancing approach.

6.4 Discussion on Building energy efficiency

Specification of minimum building thermal energy efficiency relative to floor area by covenant or local authority legislation enables the total theoretical thermal energy requirement of a proposed land development to be evaluated quickly and easily. The investigations in this research assumed a 20°C, 24 hour heating base, as is used in the BRANZ Building Performance Index calculations, and this in turn was adopted because of Building Code analysis requirements. It is possible to use multiplication

factors to convert this heating schedule demand to a different base, however adoption of heating base will always be subjective, or at least specific to the occupier of the building. It also seems likely that the average temperature heating standard adopted will vary depending on location in the country, as inhabitants will be somewhat adapted to different temperature regimes.

It would therefore seem logical to adopt the 20°C standard so that the calculations can be referenced to the ALF software, and carried out very easily. Regional factors could be estimated from monitoring of actual land developments, to measure the actual energy usage and thus a multiplication factor to derive the actual Thermal Energy Self Sufficiency (TESS_{act}).

Such processes may also require the incorporation of allowances for other thermal energy efficiency measures such as solar water heating used for space heating.

There are suggestions to make the disclosure of energy efficiency of buildings mandatory at time of sale, allowing the purchaser to make an informed decision on the likely comfort and operating expense if purchased. Although more difficult in its application, it may similarly be possible to require subdivisions to disclose their TESS₂₀ value.

The evaluation of the TESS₂₀ value for the case study subdivision takes a significant step towards providing future developers and councils with tools for evaluating the sustainability of potential developments in terms of space heating energy requirements.

Chapter 7 Conclusions

7.1 Solar Access Planning

Land development in New Zealand takes place over a wide variety of landforms, climatic regions, and latitudes. Each of these components has significant effects on the environment that immediately surrounds the development, and the amount of energy needed to heat the dwellings. This will be most obvious in solar path and solar intensity, and in diurnal and yearly air temperature fluctuations, but also in humidity, wind patterns, soil temperature and moisture content, rainfall etc. Each of these components has an effect on the energy efficiency, and therefore sustainability of construction types selected for the land development. The ability of a designer or developer to recognise the relative importance of these components, and to design around the site's weak and strong points, will have a substantial effect on the user comfort and energy efficiency of the finished building.

Of these components solar access is one of the most universally important, contributing to direct thermal energy gain and natural lighting. The solar energy overlay tool presented in this thesis provides a method of quickly assessing the comparative percentage of solar energy available at proposed building location. It is intended that this tool should be used by developers, land owners, and council staff to aid in the site selection, building orientation and design process.

The development of solar access contours based on an assumed minimum percentage solar energy capture requirement appears to be realistic, to give guidance to developers and territorial authorities when planning or approving land development. Given the actual yearly average solar energy at a specific site, it is possible to produce solar access contours to preserve a minimum energy capture in terms of kWh per year. This has obvious potential in terms of matching energy capture to energy use.

The interaction of solar access contours for cumulative observation points, or building locations, allows the designer to establish obstruction contours for the whole development site. These may then be used to define building or vegetation maximum heights and location, and may prove to be a key instrument in ensuring solar access for individual properties.

The solar access planning method proposed fills a void in the current solar access planning process, which generally uses either extremely basic or extremely complicated planning tools.

It is not clear where or how the boundaries of applicability will be defined. Obviously changes in latitude will effect accuracy, but also given New Zealand's topographical form, there may be substantial differences between locations close in distance, but different in climate or topography. These aspects can only be concluded by comparison of climatic data from individual locations. Notwithstanding, it is possible to develop a series of models for each district or region in New Zealand such that specific solar access contour overlays can be produced for each district for defined minimum energy capture percentages. This is seen as a positive step in improvement of the sustainability of land development.

7.2 Shade Angles

The optimisation of solar shading angles is substantially effected by a site's microclimate. The desirability of solar radiation, and hence thermal energy, entering a building is closely linked to the ambient temperature and humidity, which in turn affect the comfort level in the building. This research provides a framework from which the analysis of sites may be carried out to define optimum shading angles.

This optimisation process should lead to reduction in summer overheating, and provide greater efficiency in capture of winter solar energy. The end goals are increased human comfort and decreased energy use.

7.3 Building Energy Efficiency

Although the average family size is falling, there is an increasing trend in New Zealand for larger dwelling size. Increasing house size can only lead to either increased energy demand or decreased comfort and health conditions, unless the energy efficiency of the building is correspondingly increased. A case study rural land development was used to demonstrate how minimum thermal energy requirements (as measured by the ALF3 software) should be calculated, and is related by a sliding scale to the size of the dwelling. The market acceptance of this strategy has yet to be tried, but it is hoped that it will provide a course of action for territorial authorities to pursue an increase in the energy efficiency of the housing stock. Further use of these concepts to derive thermal energy requirements of development projects and hence thermal energy self-sufficiency is straightforward. It may also be used as a tool for increased sustainability of land development options.

It may be possible to use the results of this work with further analysis of desirable national housing thermal energy efficiency strategies.

Also of importance is the role that such strategies play in the education of the population. It is the author's experience that a high percentage of the general public are unaware of their ability to make energy efficiency choices at the building stage. The adoption, for example, of a building energy efficiency requirement based on a scale relative to building size, demands that more homeowners will be confronted by some kind of a choice involving energy efficiency.

7.4 General

One of the main aims of the study was to further the adoption of sustainable practices associated with residential land development. Two key points became apparent during the course of this research: the large gap between theorists and specialised architects or engineers and the general public, builders, council staff, and land developers; and the poor mechanisms for communicating this information in a language and

format suitable for the recipient. An education programme to improve public awareness of basic house siting and energy efficiency criteria would be of benefit in improving the future housing stock.

Several areas in which further research could be carried out were identified by the study:

- calculation of solar obstruction contours for each district in New Zealand with the aim of building a national solar access standard;
- investigation of the possibility of solar access contours being defined by minimum altitude angle, rather than one continuous time block during the middle of the day; and
- as with the solar obstruction contours, optimum shading angles based on actual yearly temperature data could be calculated for a number of centres in New Zealand, for possible inclusion in a national design manual.

This research has focussed mainly on solar energy as the main renewable energy source for space heating, water heating, and the generation of electricity, and assessment was made of methods of ensuring that the resource is available for each developed lot. It may be possible to carry out similar research using other renewable energy forms, for example wind power generation. Basic analysis has been carried out on the case study development site and key wind generation areas were retained in common ownership. It may be possible to also produce wind obstruction contours to ensure access to the prevailing wind resource.

As we take the first steps into a decarbonised world with the Kyoto protocol, renewable energy resources will play an increasingly important role in providing energy for residential development and life, and those developments that optimise its use will be paving the way to a truly sustainable future.

Chapter 8 Bibliography

Bastings, L (1967) Sunshine and shade. Building Research Association of New Zealand. Wellington, New Zealand. 29 pages.

Bennett R. (1978) Sun angles for design. Melrose Plantation Press. PA, USA

Boyle G. (1996) Renewable Energy. Power for a sustainable future. Oxford University Press. ISBN 0-19-856451-1

BRANZ (2003) Annual loss factor software, 3rd revision (ALF3). Building Research Association of New Zealand, Wellington, New Zealand
www.branz.co.nz

BRANZ (2004) Home energy end-use program. Building Research Association of New Zealand, Wellington, New Zealand www.branz.co.nz

BIA (1992), The New Zealand Building Code. Building Industry Authority. Wellington, New Zealand. www.building.dbh.govt.nz

CCANZ(2001). Cement & Concrete Association of New Zealand, Designing Comfortable Homes. Wellington, New Zealand. ISBN 0-908956-13-4

Chiras D. (2000) The Natural House a complete guide to healthy, energy efficient, environmental homes. White river junction, Vermont/ Totnes, England. ISBN 1-890132-57-8

Crowley J. & Zimmerman L .(1984). Practical Passive Solar Design. A guide to homebuilding and land development. New York. Published McGraw-Hill.

CSIRO (1948 –reprinted 2002). Sunshine and Shade in Australasia. Collingwood, Victoria, Australia. www.publish.csiro.au

Duffie J and Beckmann W (1991). Solar Engineering of Thermal Processes, second edition. Published J Wiley & Sons inc, USA. ISBN 0-471-51056-4

EECA & CAE (1996). New and Emerging Renewable Energy Opportunities in New Zealand. Energy Efficiency and Conservation Authority & Centre for Advanced Engineering, Christchurch, New Zealand. ISBN 0-908993-11-0

EECA (1985) Design for the Sun. Residential design guidelines for New Zealand. Energy Efficiency and Conservation Authority (formerly produced by the Ministry of Energy), Wellington, New Zealand.

EECA (2000). Passive Solar Design for New Zealand Homes – energywise series. www.eeca.govt.nz Energy Efficiency and Conservation Authority, Wellington, New Zealand.

Irving G (2000). Community Owned and Operated Renewable Energy Schemes in New Zealand. Thesis in fulfilment of requirements for Master of Engineering, Massey University, Palmerston North, New Zealand

Mazria, E. (1979)The passive solar energy book. Emmaus, PA, USA. Rodale Press.

MDC (1997) Masterton District Council District Plan, Masterton, New Zealand.

Malcolm J (1981) Elementary surveying. University tutorial press, Slough, England. ISBN 0 7231 0673 8

New South Wales Planning and Environment Commission (1978), Technical Bulletin 13, Sunlight Indicators. New South Wales, Australia.

NIWA (2004) National Institute of Water & Atmospheric Research, New Zealand <http://www.niwa.cri.nz>

NZSSES (2004) Proceedings of first international conference, Auckland, July 2004. New Zealand Society for Sustainability, Engineering and Science. www.nzsses.org.nz

www.tusc.org.nz Tool for Urban Sustainability Code of Practice

Olgay V (1963) Design with Climate. Bioclimatic approach to architectural regionalism. Princeton University Press, Princeton, NJ, USA.

PCE (2002). Parliamentary Commissioner for the Environment Creating our Future – Sustainable Development for New Zealand. Wellington, New Zealand. ISBN 1-877274-03-8

PCE (2004). Parliamentary Commissioner for the Environment See Change Learning and education for sustainability. Wellington, New Zealand. ISBN 1-877274-12-7

Sealey A. (1979) Introduction to Building Climatology. CAA and CFTC, London, UK.

SEDA (2004) 2004 Solar Access for Lots –Guidelines for Residential Subdivision in NSW. Sustainable Energy Development Authority <http://www.seda.nsw.gov.au>

Sims. R , Handford.P, Bell.T, (1990) Wood fuel supply and utilisation from short rotation energy plantations. Palmerston North, New Zealand.

SEIAA (1995), Remote Area Power Supply systems. Solar Energy Industries Association of Australia Inc. Dickson, ACT, Australia.

SNZ (2001). Subdivision for People and the Environment, SNZ HB44:2001 Standards New Zealand, Wellington, New Zealand

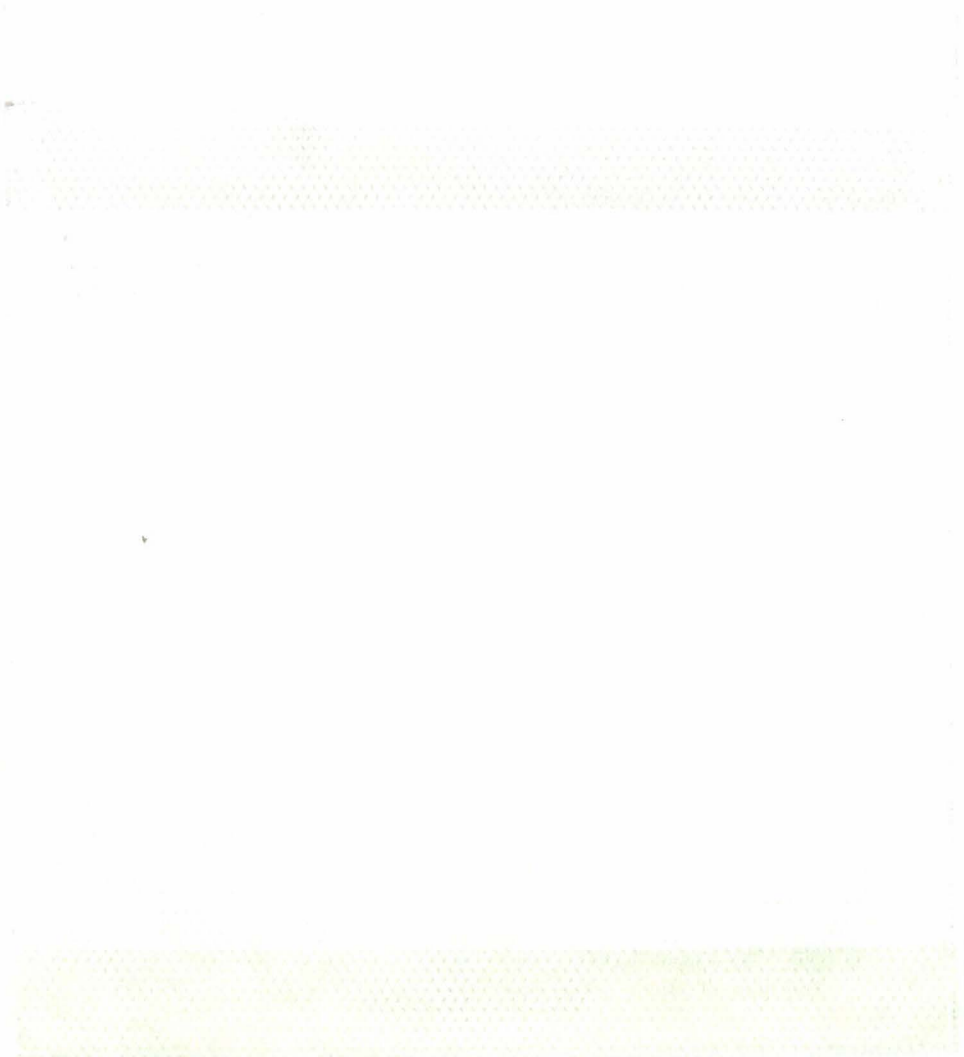
SNZ (1981) NZS4404 Code of Practice for Urban Land Subdivision. Standards New Zealand, Wellington, New Zealand

United Nations Centre for Human Settlement (1989). Bibliography on Passive Solar systems in Buildings. www.hq.unhabitat.org

Watts,S. (1978)Sunlight Indicators. Technical Publication 13, New South Wales Planning and Environment Commission, New South Wales, Australia.

WSM (2004) Healthy Housing Index. Wellington School of Medicine, Wellington, New Zealand <http://www.wnmeds.ac.nz>

Appendix A Solar data for East Taratahi weather station, 2001



Appendix B Temperature data for East Taratahi

Mean Dry-Bulb Air Temperatures (degrees C) 1995-2003

DATE:

TIME (NZST)

	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
1-Jan	12.5	12.0	11.7	11.6	11.8	11.4	13.1	15.8	17.5	19.3	20.6	21.9	22.4	23.2	23.9	24.1	24.0	23.2	22.2	20.2	17.6	16.0	14.6	13.9
2-Jan	13.1	13.1	12.7	12.1	11.6	11.4	13.0	17.0	19.4	21.3	22.1	22.9	23.1	24.0	23.9	23.7	23.1	22.7	21.4	19.4	17.3	15.7	14.6	13.7
3-Jan	12.6	11.7	11.4	11.6	11.4	11.0	12.3	15.8	17.5	19.2	20.3	21.5	22.4	22.9	23.5	23.8	23.0	22.1	21.0	18.7	16.9	15.2	13.3	13.4
4-Jan	12.9	12.0	11.1	10.9	10.4	10.1	11.7	14.7	17.1	19.4	21.0	21.7	22.6	21.9	21.7	21.7	20.9	19.8	19.0	17.6	15.2	14.0	13.2	12.7
5-Jan	12.3	12.1	11.3	11.1	10.9	10.5	11.8	14.8	17.2	18.6	19.8	20.9	20.9	22.1	22.1	21.9	22.1	21.7	20.3	18.8	15.9	14.2	13.0	12.6
6-Jan	12.3	11.6	10.7	10.1	9.4	8.8	10.4	14.3	17.0	18.3	19.4	20.6	21.7	22.0	22.5	23.1	22.1	20.9	20.0	18.3	15.9	14.6	13.6	12.9
7-Jan	12.3	11.7	11.5	11.4	11.2	10.2	12.1	15.7	17.9	19.7	21.3	22.8	23.7	24.3	24.3	24.8	23.7	21.5	20.6	18.7	16.6	15.7	14.9	14.0
8-Jan	13.4	13.0	12.3	11.8	12.1	12.6	13.3	15.6	17.7	19.7	21.1	21.8	22.4	22.4	22.4	22.6	22.1	20.8	19.4	17.6	16.1	15.0	14.3	13.9
9-Jan	13.4	13.4	13.2	13.1	13.1	12.7	13.6	14.4	15.9	16.6	17.3	17.7	18.4	18.2	18.4	18.3	18.0	17.8	16.8	16.0	14.9	13.7	12.8	13.0
10-Jan	12.8	12.7	12.7	12.4	12.3	12.2	12.6	14.1	15.7	16.7	17.4	18.3	19.1	20.0	19.5	19.3	19.1	18.2	17.3	16.1	15.3	14.8	14.2	14.0
11-Jan	13.8	13.7	13.1	12.4	12.3	12.0	13.0	14.6	15.9	17.1	18.6	19.3	20.0	20.2	20.7	20.6	20.0	18.9	18.2	17.2	15.7	15.2	14.7	14.6
12-Jan	14.4	13.7	13.0	13.0	12.9	12.8	13.3	15.8	16.8	18.2	19.1	20.0	20.7	21.1	21.4	21.2	20.3	19.6	18.1	16.8	15.3	14.0	13.3	12.9
13-Jan	12.1	11.6	11.1	10.4	10.0	9.8	10.7	13.7	15.9	17.6	18.7	18.9	19.9	20.6	21.2	21.4	21.6	20.2	19.1	17.7	15.3	13.6	12.9	11.9
14-Jan	11.7	11.1	10.9	10.3	10.4	10.1	11.1	13.0	15.1	16.9	18.4	19.2	20.7	20.6	21.9	20.9	21.3	20.8	20.2	18.9	16.2	14.6	13.6	13.4
15-Jan	13.0	13.1	13.5	13.4	13.2	12.2	12.9	15.3	17.0	17.9	18.3	19.0	19.4	20.1	20.8	21.1	20.6	19.8	18.8	17.6	15.5	14.1	13.2	12.4
16-Jan	12.7	12.6	12.6	12.6	12.9	13.3	13.8	15.9	17.2	18.7	19.9	20.5	21.4	22.2	22.4	21.8	21.1	20.7	19.8	18.4	16.4	15.2	14.7	14.3
17-Jan	13.1	13.1	12.6	12.7	12.6	12.1	12.7	15.3	18.4	19.8	20.7	21.9	22.8	23.4	23.4	23.6	23.0	21.9	20.7	19.1	16.9	15.8	15.1	14.2
18-Jan	14.0	13.1	12.4	12.0	11.7	11.4	11.8	14.9	17.1	18.6	19.7	20.5	20.9	21.3	22.2	22.4	21.7	20.7	20.7	18.8	17.0	16.0	15.3	14.7
19-Jan	13.9	13.1	12.8	12.7	12.6	12.4	13.1	15.4	17.7	19.4	19.9	20.7	20.9	21.0	21.4	20.8	20.7	20.1	19.0	17.2	15.8	14.8	14.1	14.1
20-Jan	14.0	13.7	13.3	12.7	12.4	11.8	12.6	14.4	16.4	17.1	18.6	19.8	20.8	21.6	21.9	22.0	21.2	20.8	19.7	17.7	15.6	14.3	13.2	12.4
21-Jan	11.6	11.1	10.9	10.7	10.6	10.4	11.3	15.2	17.7	19.4	20.3	21.4	22.2	22.1	22.4	22.1	22.2	21.4	20.4	18.4	16.5	15.6	14.6	13.9
22-Jan	13.2	12.6	13.1	13.2	13.4	13.4	14.1	16.7	19.4	20.6	21.6	22.4	23.4	23.8	24.1	24.0	23.1	22.4	21.6	19.8	17.8	16.8	16.0	15.8
23-Jan	15.2	14.8	13.9	13.6	13.2	12.9	13.2	15.3	17.9	20.0	20.1	20.8	21.4	21.8	22.1	22.0	21.3	20.6	19.1	17.6	16.3	15.0	15.4	15.4
24-Jan	14.4	14.3	13.9	13.4	13.6	13.4	13.8	16.1	18.4	19.9	20.7	22.2	22.8	23.7	23.4	23.6	22.9	22.4	20.9	19.0	17.2	16.1	15.4	15.2
25-Jan	14.6	13.9	13.6	13.3	12.4	12.8	12.9	15.1	17.0	18.4	19.2	20.1	19.9	20.1	21.1	20.4	19.6	19.0	18.0	16.8	15.7	14.8	14.2	13.9
26-Jan	13.2	13.2	13.2	13.1	12.9	12.0	12.2	13.7	15.3	16.1	17.6	18.1	18.4	19.1	19.6	19.9	19.9	18.0	17.4	16.6	15.1	13.9	12.9	12.4
27-Jan	11.7	11.6	11.0	10.2	10.0	10.2	11.0	14.4	16.3	18.2	19.8	20.7	21.4	21.3	21.5	21.3	21.4	20.3	18.8	17.3	15.7	14.7	13.8	13.0
28-Jan	12.2	11.4	11.3	10.7	10.2	10.2	10.4	13.0	15.3	17.1	18.6	19.3	20.0	20.8	21.2	21.8	21.8	20.6	19.7	18.2	15.9	14.9	13.6	13.2
29-Jan	12.8	12.3	11.4	11.0	10.6	10.3	11.2	14.7	16.8	18.8	19.6	20.7	21.2	22.3	22.4	22.2	22.1	21.3	20.1	18.9	16.8	15.1	14.1	13.7
30-Jan	13.6	12.9	12.6	12.0	11.9	11.4	11.7	15.2	18.3	20.7	22.1	23.1	24.1	25.4	25.6	25.2	25.7	24.6	23.0	21.4	18.5	16.9	15.3	14.5
31-Jan	14.1	14.1	14.3	14.1	14.0	13.8	14.4	16.7	19.0	20.4	21.8	23.4	24.3	24.4	24.4	24.6	24.2	23.4	21.7	20.0	17.8	16.4	14.7	14.2
1-Feb	13.6	13.1	12.5	12.4	12.6	12.6	12.8	14.9	16.3	17.6	19.0	20.2	20.8	21.4	21.7	22.4	21.9	21.1	20.1	18.2	16.1	14.7	13.8	13.1
2-Feb	12.4	12.2	12.1	11.4	11.3	11.3	11.2	14.6	17.1	18.4	19.6	20.2	20.7	21.0	20.1	19.7	19.4	19.0	18.1	17.3	15.8	14.6	13.9	13.4
3-Feb	12.8	12.1	11.9	11.9	11.8	11.4	11.4	13.3	15.7	17.4	19.2	20.1	21.2	22.0	22.9	23.1	22.3	22.7	20.9	19.3	17.2	15.9	15.3	14.7
4-Feb	14.2	13.2	13.1	12.7	11.7	11.3	11.6	14.7	17.1	19.4	20.7	21.8	22.8	23.3	22.9	23.3	22.3	21.2	19.8	18.7	17.1	16.0	15.2	14.6
5-Feb	14.0	13.0	12.6	12.4	12.6	12.1	12.2	14.8	17.0	19.2	20.3	21.7	22.6	23.0	23.1	23.3	23.4	22.7	20.2	18.6	16.9	16.0	15.0	14.8
6-Feb	14.4	14.0	13.8	12.7	12.4	12.5	12.3	14.6	16.3	18.8	19.8	20.4	21.3	21.9	22.5	22.2	21.7	21.0	20.6	19.0	16.9	15.7	14.8	13.8
7-Feb	13.4	13.3	13.0	12.2	12.2	12.1	11.8	14.0	16.4	18.7	20.2	21.3	22.1	22.8	23.3	23.8	23.6	22.9	21.8	19.2	16.9	15.7	14.8	14.1
8-Feb	13.8	13.9	13.4	13.0	12.3	12.0	11.8	13.8	16.6	19.3	20.9	21.7	22.2	22.9	23.0	22.9	22.1	21.1	19.8	18.1	16.0	15.2	14.6	14.2
9-Feb	14.0	14.0	13.9	13.8	13.3	13.0	12.8	15.7	18.1	20.0	21.4	22.4	23.4	23.8	23.8	23.9	23.8	22.8	21.3	19.6	17.6	15.7	15.3	14.9
10-Feb	14.6	14.4	14.2	13.7	13.4	13.4	13.4	15.7	18.5	20.2	21.2	22.3	22.9	23.2	23.4	22.9	22.7	21.4	20.4	19.2	17.3	16.4	15.4	14.8
11-Feb	14.0	13.8	13.9	14.2	14.7	14.9	15.3	16.0	17.7	19.2	20.4	21.2	22.1	22.6	22.6	22.9	22.8	22.2	21.7	20.2	18.7	17.9	17.1	16.5
12-Feb	16.1	15.8	15.5	15.1	14.7	14.7	14.7	16.4	18.9	20.3	21.0	22.4	23.3	23.8	23.7	23.7	22.7	21.6	20.4	19.0	17.4	16.6	16.0	15.2
13-Feb	14.7	14.1	14.0	13.2	13.3	13.5	13.8	15.1	17.1	18.9	20.2	21.0	22.2	22.4	22.7	22.9	22.1	21.5	21.0	18.9	17.2	16.0	15.6	15.1
14-Feb	14.8	14.3	13.6	13.3	13.6	13.4	13.3	15.4	17.5	19.9	21.7	22.3	23.1	23.7	23.9	23.8	23.4	22.1	21.7	19.0	17.0	16.4	15.9	15.8
15-Feb	15.2	14.8	14.0	13.6	13.1	12.8	12.9	14.8	17.1	19.0	20.4	21.2	21.9	23.1	23.3	24.1	23.2	22.2	21.1	19.0	17.0	15.7	14.7	14.0
16-Feb	13.9	13.6	12.9	12.2	12.2	12.1	11.7	14.2	17.0	18.8	20.9	22.1	22.7	23.7	23.9	23.9	23.3	22.8	21.4	19.7	17.4	15.7	14.8	14.4
17-Feb	13.6	13.1	12.4	11.8	11.6	11.3	11.2	14.0	17.7	20.4	22.1	23.2	23.6	25.1	25.7	25.2	24.6	23.2	21.9	20.1	18.4	16.9	16.4	15.3
18-Feb	15.0	14.9	14.2	14.1	14.1	13.5	13.4	15.7	18.1	19.6	20.3	21.3	22.2	23.1	23.2	23.6	23.0	21.9	20.7	18.8	17.3	16.1	15.4	15.0
19-Feb	14.3	13.8	13.2	13.1	12.9	12.6	12.7	14.9	17.9	19.6	21.3	22.3	23.2	23.8	23.1	23.0	22.4	21.9	21.0	18.6	17.8	16.9	15.7	14.9
20-Feb	14.4	14.0	14.3	13.9	13.9	14.1	13.4	15.3	17.5	18.7	20.1	21.3	21.8	22.2	22.2	21.3	21.1	19.2	18.3	17.3	15.9	15.1	14.2	13.5
21-Feb	13.7	13.0	13.1	13.0	13.0	12.6	12.9	13.8	16.1	17.6	18.2	18.9	19.8	20.6	19.5	19.9	19.7	18.9	18.4	16.8	15.4	14.4	13.6	13.2
22-Feb	13.0	12.2	11.8	11.8	11.3	10.9	10.3	12.1	15.4	17.8	19.6	21.0	21.6	21.7										

DATE:

TIME (NZST)

	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
1-Mar	15.2	15.0	14.9	14.6	14.6	14.3	13.9	14.8	16.8	19.1	20.8	21.4	22.3	21.6	22.2	22.0	22.2	21.6	19.7	17.9	16.7	15.8	15.6	14.6
2-Mar	13.8	14.0	13.6	13.0	13.1	13.1	12.8	13.6	16.2	17.9	19.2	20.1	20.6	21.2	21.3	21.3	20.9	20.7	19.5	17.3	15.5	14.4	13.9	13.4
3-Mar	12.9	12.1	11.9	11.5	11.4	11.4	11.0	11.9	14.2	16.7	18.4	19.3	20.4	21.0	20.9	20.9	20.1	18.9	17.3	15.9	15.2	14.8	14.3	13.7
4-Mar	13.4	12.9	12.8	12.4	12.4	12.7	12.8	13.4	14.8	16.6	17.3	18.9	19.7	20.4	21.2	21.0	20.8	20.2	18.9	16.4	14.4	13.7	12.9	12.5
5-Mar	11.4	11.4	11.3	10.9	10.9	10.6	9.6	10.9	14.3	16.9	18.8	19.7	20.4	21.2	22.4	22.6	21.7	20.8	19.1	16.6	14.5	14.1	12.9	12.6
6-Mar	12.3	12.0	11.7	11.7	11.4	11.3	10.8	11.4	14.7	17.3	18.9	20.2	20.7	20.9	22.0	21.6	20.8	20.4	19.2	17.0	15.6	15.3	14.1	13.6
7-Mar	13.9	13.8	13.4	13.3	12.9	12.4	12.2	13.0	15.3	16.7	17.4	18.9	19.3	20.2	20.8	20.7	20.3	20.0	19.6	16.9	15.1	13.8	13.2	12.9
8-Mar	12.4	12.2	12.0	11.8	11.7	11.5	11.2	12.2	15.5	17.8	19.6	20.2	21.0	21.4	21.6	21.8	21.7	21.3	20.3	17.8	16.6	15.3	14.1	12.8
9-Mar	12.3	11.6	11.3	11.2	11.0	11.5	11.3	12.1	15.0	17.8	19.6	21.0	21.7	22.0	22.5	22.6	22.8	21.3	19.8	17.2	16.1	14.7	14.1	13.4
10-Mar	12.6	12.9	12.4	12.4	12.2	11.9	11.6	12.6	15.1	17.4	19.1	20.0	20.7	21.1	20.8	20.0	18.9	18.3	17.4	16.1	14.4	13.9	13.7	13.2
11-Mar	13.2	12.6	11.7	11.4	12.0	11.6	11.1	11.6	13.6	14.9	16.4	17.6	19.5	19.9	20.5	20.3	20.1	19.3	17.8	16.1	14.6	13.8	12.9	12.3
12-Mar	11.8	11.1	10.9	10.3	10.0	10.2	10.3	11.4	13.5	16.3	18.0	18.5	19.2	19.2	19.2	19.3	19.2	18.1	17.1	15.1	14.0	13.1	12.3	11.9
13-Mar	11.7	11.3	10.9	10.8	10.7	10.7	10.6	11.1	13.3	15.7	17.6	19.0	20.0	20.9	21.1	21.3	20.9	20.2	18.7	16.3	14.8	13.9	13.2	12.5
14-Mar	12.0	11.8	11.3	11.2	11.6	11.5	11.1	11.6	14.1	16.6	18.2	19.2	20.0	20.2	21.0	21.1	20.7	19.1	17.2	15.8	14.7	13.8	13.4	12.9
15-Mar	12.7	12.1	12.0	11.7	12.3	12.3	11.9	12.1	14.4	16.6	18.7	19.2	19.6	19.8	19.5	19.0	18.4	18.3	16.7	14.6	13.9	13.3	12.8	12.7
16-Mar	12.6	12.7	12.4	12.4	11.9	11.9	12.2	12.4	14.5	15.3	16.9	17.1	17.9	18.3	18.3	18.6	18.1	17.5	16.6	14.3	12.9	12.0	11.4	11.4
17-Mar	10.8	10.2	10.4	10.6	10.4	10.2	10.1	10.3	13.4	15.7	17.8	18.6	19.3	19.4	19.6	19.6	19.3	18.4	16.7	14.9	13.7	12.7	12.0	12.0
18-Mar	11.7	10.9	10.3	10.1	9.8	9.5	9.0	9.3	13.5	16.1	17.7	19.0	19.7	20.0	20.4	20.9	20.4	19.2	17.6	14.9	13.1	12.0	12.0	11.5
19-Mar	11.2	11.2	11.2	10.8	10.2	10.0	9.9	10.2	14.6	17.3	19.0	19.9	20.4	20.4	20.4	20.3	20.0	19.3	17.9	15.7	14.3	14.3	14.2	14.2
20-Mar	14.2	13.8	13.1	13.7	13.6	13.0	12.7	12.9	16.2	17.9	18.9	20.6	21.5	22.0	22.1	22.4	21.7	20.8	19.1	17.2	16.0	15.4	14.6	13.7
21-Mar	13.1	12.8	12.0	12.0	11.8	11.6	11.2	12.0	15.3	18.0	19.4	20.6	21.6	21.7	21.9	21.3	21.3	20.9	19.2	17.1	15.9	14.7	13.9	13.8
22-Mar	13.5	13.2	13.1	13.2	12.1	12.4	12.2	12.4	14.8	17.0	18.6	19.8	20.1	21.1	21.3	21.0	20.9	19.2	17.5	15.2	13.7	12.4	11.9	11.7
23-Mar	11.9	11.8	11.4	11.4	11.1	10.7	10.3	11.1	13.7	16.3	18.3	19.2	20.1	20.4	20.4	20.0	19.6	18.8	17.6	15.8	14.9	13.9	13.7	12.9
24-Mar	12.4	11.4	11.0	10.3	10.0	9.6	9.8	10.3	12.8	15.7	17.4	18.7	19.3	20.3	20.8	20.8	20.3	19.8	17.7	15.2	13.7	12.2	11.7	11.0
25-Mar	10.4	10.0	10.4	10.2	10.2	9.9	9.9	10.6	13.2	16.5	18.4	19.2	19.9	19.7	19.9	20.0	19.4	18.9	17.2	15.9	14.9	14.6	13.9	13.7
26-Mar	12.9	12.8	12.3	11.9	11.9	11.9	11.8	12.0	13.8	15.7	17.2	18.0	18.7	18.9	19.2	19.0	18.8	17.8	16.5	15.0	14.2	13.3	13.0	12.6
27-Mar	12.0	11.7	11.7	11.4	11.4	11.1	11.2	11.3	13.3	15.9	17.9	19.2	19.9	21.1	21.7	21.4	21.7	21.1	18.3	15.8	14.4	13.5	12.8	12.1
28-Mar	12.2	12.1	11.6	11.0	11.2	11.2	11.1	11.6	14.1	17.1	18.9	20.3	21.3	21.8	22.6	22.6	21.8	19.9	18.0	16.1	14.7	13.7	13.1	12.7
29-Mar	12.7	13.4	13.6	13.0	13.2	13.4	13.4	13.2	15.6	18.2	20.3	21.2	22.1	22.6	22.3	21.8	21.4	20.4	18.4	16.9	15.3	15.0	14.9	14.4
30-Mar	14.5	13.8	13.7	13.2	12.8	12.0	12.5	12.4	14.7	16.5	18.0	18.7	20.1	20.8	20.9	21.0	20.4	19.1	17.3	15.7	14.9	14.1	13.4	12.9
31-Mar	12.8	12.8	12.4	12.3	11.9	11.6	11.3	11.0	14.0	16.4	18.3	19.4	20.5	20.4	20.7	21.0	20.3	19.1	16.5	14.4	13.1	11.9	11.6	11.4
1-Apr	10.9	9.9	10.1	10.0	10.4	10.8	10.7	10.8	13.2	15.3	17.4	18.4	18.5	19.4	18.8	17.7	17.3	16.8	15.4	14.4	14.1	13.7	13.2	13.8
2-Apr	12.9	12.7	12.2	12.4	12.8	12.2	12.1	11.6	13.0	14.4	15.3	16.1	16.2	16.3	17.0	16.8	16.2	14.9	13.5	12.6	11.7	11.5	11.4	10.9
3-Apr	10.7	10.3	10.2	10.1	10.1	10.0	10.0	9.7	12.4	15.4	17.0	18.0	19.1	18.6	19.3	19.1	17.8	17.4	15.2	13.8	12.6	12.7	12.4	12.4
4-Apr	12.3	12.2	11.6	11.5	10.9	10.7	10.5	10.4	13.2	15.7	17.1	18.2	18.9	19.4	19.2	19.8	19.0	18.3	16.4	14.3	13.1	12.4	12.0	11.1
5-Apr	10.6	11.0	11.1	11.1	10.6	10.7	11.9	12.8	14.8	16.2	17.1	17.8	18.4	18.7	18.4	18.6	18.2	17.4	16.2	15.8	15.3	15.2	14.7	14.7
6-Apr	14.7	14.4	14.2	13.8	13.9	13.8	13.7	13.3	14.6	16.3	17.6	18.6	19.0	19.2	19.0	18.6	18.0	17.2	16.4	16.0	15.8	15.3	14.8	14.7
7-Apr	13.7	12.9	13.0	13.1	13.1	13.0	13.3	14.0	15.1	16.0	16.8	17.9	18.9	18.8	18.6	17.9	17.7	16.4	14.6	13.4	13.0	12.9	12.1	11.3
8-Apr	11.5	11.1	10.6	10.3	10.0	10.2	10.1	10.0	12.1	14.6	16.3	17.3	18.2	18.2	18.3	18.0	17.8	17.3	15.3	13.7	12.7	11.8	11.7	11.2
9-Apr	11.0	10.6	10.1	10.2	10.1	10.1	10.1	10.6	12.1	14.1	15.6	16.8	17.5	18.2	18.1	18.5	18.2	17.3	15.5	14.2	13.7	12.5	12.2	11.6
10-Apr	11.5	12.2	12.3	11.8	11.4	11.1	11.3	11.2	12.3	13.9	15.2	16.0	16.1	16.9	18.0	17.4	16.6	15.8	13.8	12.6	12.3	11.6	11.0	10.7
11-Apr	9.8	8.9	8.3	8.1	8.2	7.7	7.9	7.6	9.6	12.0	14.1	15.1	16.5	16.2	16.6	16.5	16.1	15.3	13.5	12.0	11.7	11.5	11.0	10.0
12-Apr	9.6	9.7	9.3	9.3	8.9	8.6	8.4	8.9	10.2	12.7	15.0	16.9	17.4	18.1	18.6	18.5	17.9	17.2	14.7	12.8	11.7	11.0	10.6	10.0
13-Apr	10.3	9.7	9.3	9.5	9.4	9.4	9.4	9.4	11.0	12.9	14.7	16.2	16.9	17.4	17.8	18.0	17.8	16.9	14.9	12.9	11.9	11.0	10.7	10.1
14-Apr	9.8	9.9	9.6	8.8	8.2	8.3	7.8	7.6	9.8	13.1	15.4	16.9	17.4	17.3	17.6	17.3	16.8	16.0	14.3	13.1	12.4	11.8	10.9	10.9
15-Apr	10.5	9.8	9.3	9.6	9.7	9.2	8.8	8.6	10.6	12.9	14.8	16.1	17.4	17.4	17.6	17.7	17.7	16.8	14.4	13.1	11.8	11.3	10.8	10.3
16-Apr	9.2	8.9	9.2	8.9	8.7	8.7	7.9	7.8	10.2	13.5	15.6	16.6	18.0	18.1	17.7	17.7	17.8	16.1	13.9	12.7	11.9	11.2	10.6	10.0
17-Apr	9.4	9.0	8.1	7.2	7.3	7.4	7.0	6.9	9.1	12.0	13.9	15.4	16.2	16.9	17.2	17.6	16.9	15.8	13.3	11.7	10.2	9.7	9.1	8.1
18-Apr	7.7	7.6	7.3	6.7	7.7	7.7	7.2	7.2	9.7	12.9	15.3	16.7	17.0	17.2	17.1	17.1	16.3	15.2	12.8	11.0	9.8	9.8	9.6	9.1
19-Apr	8.5	7.6	7.3	6.9	6.9	6.8	7.2	7.6	8.9	11.5	13.3	14.6	15.3	16.2	16.9	16.4	16.1	15.1	13.1	12.2	11.7	11.3	11.1	10.7
20-Apr	10.4	10.3	9.7	9.7	9.4	9.0	8.9	9.4	11.2	13.4	15.4	16.9	17.7	18.1	18.3	18.4	18.7	17.3	14.6	13.3	12.3	12.0	11.0	10.6
21-Apr	10.4	10.2	10.0	9.2	9.4	9.6	9.5	9.6	10.7	12.8	14.6	15.8	16.3	16.7	16.6	15.9	15.2	14.6	13.4	12.7	12.1	11.8	11.6	11.4
22-Apr	11.2	10.7	10.7	10.1	9.9	9.9	9.4	9.2	10.4	13.0	14.3	15.8	16.3	17.1	17.0	16.9	16.3	14.9	13.1	12.3	11.0	10.8	10.4	9.6
23-Apr	9.3																							

DATE:	TIME (NZST)																							
	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
1-May	80	79	73	80	84	83	85	83	87	118	140	153	161	164	170	165	157	143	129	118	111	102	98	93
2-May	92	91	91	92	90	91	90	88	94	120	140	157	168	169	170	168	162	148	128	117	107	98	94	92
3-May	86	79	70	65	63	60	56	54	59	104	129	148	156	164	173	167	159	147	117	104	96	90	90	86
4-May	84	78	81	80	80	86	81	86	98	126	140	153	165	171	178	176	172	153	125	111	106	101	96	89
5-May	90	84	80	81	79	77	75	74	78	99	122	140	154	158	154	150	144	133	113	103	90	90	84	82
6-May	80	77	71	69	68	70	73	73	81	108	130	142	154	160	163	161	153	140	117	107	99	93	97	86
7-May	90	88	88	83	80	81	85	89	93	107	120	133	144	152	151	152	144	136	116	109	109	105	102	99
8-May	98	101	97	95	96	94	93	89	91	109	129	140	151	154	158	156	148	129	106	93	86	77	72	68
9-May	64	60	56	54	50	47	46	48	52	94	129	147	161	164	163	158	147	126	104	96	86	77	72	72
10-May	79	76	76	68	67	73	73	71	78	111	132	148	159	168	169	165	159	138	111	99	92	83	77	74
11-May	70	72	77	78	68	67	67	72	74	105	136	150	162	170	170	168	158	139	118	107	100	98	93	90
12-May	88	83	83	89	88	87	87	91	91	113	134	148	154	161	163	160	159	140	121	106	99	98	94	92
13-May	89	88	84	80	80	76	69	70	71	101	126	141	152	160	161	154	146	124	104	98	93	93	88	89
14-May	91	89	92	91	84	83	76	77	81	107	127	140	149	152	153	154	150	127	116	108	100	96	97	94
15-May	92	91	93	90	86	87	89	87	84	106	131	151	158	164	162	158	149	129	114	108	100	96	92	88
16-May	82	76	79	69	76	76	77	79	86	115	137	149	154	156	157	161	146	128	103	92	83	74	68	60
17-May	59	57	53	49	43	41	39	38	42	73	111	127	140	146	154	150	149	116	90	73	64	53	48	46
18-May	42	37	36	27	22	18	16	18	37	67	101	122	138	142	150	150	144	120	86	68	60	50	47	46
19-May	49	40	40	39	46	46	44	43	49	77	112	137	149	154	154	158	158	124	107	100	94	88	90	89
20-May	89	87	80	82	86	84	77	74	78	109	129	146	156	162	163	158	157	136	113	106	94	97	98	98
21-May	94	91	89	89	87	88	86	81	88	112	131	144	152	151	153	151	143	129	116	110	101	97	94	91
22-May	96	98	96	88	86	78	79	78	74	99	119	134	148	144	146	138	134	119	103	92	91	88	92	87
23-May	82	88	83	81	78	82	85	82	80	100	120	132	138	138	146	141	140	122	105	99	91	84	74	71
24-May	64	63	66	60	61	62	65	61	67	87	107	121	135	141	150	149	141	122	107	99	92	91	81	76
25-May	76	72	70	69	64	66	65	63	67	90	114	129	139	142	147	142	138	118	107	97	93	87	84	82
26-May	72	72	69	68	63	62	64	52	53	76	101	121	130	138	139	135	121	107	89	82	76	75	74	74
27-May	79	74	72	69	69	67	82	88	89	101	110	113	121	122	122	126	117	107	97	93	87	86	84	87
28-May	84	90	85	80	76	75	73	70	74	89	108	117	123	128	123	127	119	103	89	78	68	72	62	57
29-May	50	49	49	49	44	50	48	49	51	75	97	119	133	140	140	140	139	109	89	90	83	78	80	77
30-May	79	76	73	70	76	72	71	71	69	88	109	127	132	137	137	134	131	118	105	103	97	96	98	94
31-May	98	93	92	88	87	81	79	71	72	95	117	136	150	153	152	146	138	116	96	87	78	71	62	60
1-Jun	63	61	59	58	53	53	53	56	54	74	99	112	120	130	128	130	119	97	79	71	63	58	53	56
2-Jun	56	60	60	63	62	60	64	60	68	75	90	112	124	128	124	126	114	102	91	87	80	76	76	77
3-Jun	73	73	73	71	65	66	59	58	53	72	97	110	116	119	119	113	107	84	70	59	51	44	47	49
4-Jun	48	47	46	48	46	42	43	44	49	66	88	106	113	118	120	120	113	90	76	64	62	59	58	49
5-Jun	43	42	41	37	38	36	39	46	51	64	91	112	125	124	127	123	120	97	78	66	59	55	57	49
6-Jun	50	46	47	47	42	39	35	32	30	56	92	111	124	131	132	131	122	96	75	62	58	48	46	39
7-Jun	39	41	38	38	39	39	40	36	41	69	96	120	128	137	139	136	128	99	75	66	58	53	51	61
8-Jun	58	62	60	59	54	52	48	48	47	75	107	132	141	147	147	144	131	104	80	70	66	67	59	52
9-Jun	54	56	52	58	63	70	73	78	78	101	118	136	137	148	149	142	138	120	103	91	88	82	82	81
10-Jun	84	91	90	92	96	93	90	88	86	96	108	110	113	118	119	111	104	91	81	78	73	69	61	61
11-Jun	52	48	49	59	59	64	66	59	62	76	93	103	114	118	108	109	102	84	76	72	67	65	61	60
12-Jun	55	52	52	64	63	64	66	66	64	77	90	104	109	113	113	114	109	94	83	79	78	80	79	80
13-Jun	78	79	77	76	74	73	74	76	78	84	99	110	118	116	113	115	106	98	83	86	86	77	72	71
14-Jun	72	70	61	59	57	60	63	61	57	67	89	106	118	123	122	123	114	102	92	81	78	76	79	78
15-Jun	77	78	78	73	69	77	77	76	76	84	107	117	129	132	130	125	120	108	96	89	82	79	79	77
16-Jun	79	74	77	74	69	68	70	67	69	79	102	114	121	122	124	120	114	100	86	81	77	73	70	70
17-Jun	67	62	62	69	73	70	73	71	74	83	106	119	120	124	124	125	122	110	99	94	96	91	90	88
18-Jun	87	83	79	76	74	72	71	72	69	79	90	101	107	111	110	107	103	84	70	64	58	57	56	48
19-Jun	40	34	32	28	28	34	40	33	37	57	80	98	112	119	111	109	103	78	55	46	40	31	30	32
20-Jun	29	26	26	24	27	23	20	23	44	74	96	109	119	119	121	121	117	88	64	57	48	39	32	26
21-Jun	23	19	21	18	17	13	23	26	21	49	91	114	128	134	131	135	121	92	66	56	52	44	44	38
22-Jun	36	33	26	25	32	23	30	30	34	58	91	120	126	130	133	128	129	101	83	74	70	69	68	63
23-Jun	60	59	62	62	58	56	59	57	59	71	97	116	127	132	134	135	129	103	87	84	77	69	68	63
24-Jun	59	58	56	54	54	50	46	43	47	64	93	110	116	121	126	122	116	89	73	58	56	54	49	42
25-Jun	43	42	40	42	38	37	42	51	53	68	97	116	127	132	136	132	131	100	76	68	63	58	53	49
26-Jun	50	52	51	54	57	58	61	56	60	80	110	130	137	140	136	130	126	104	89	86	81	77	77	70
27-Jun	66	63	58	60	60	60	55	60	58	71	92	108	116	121	123	120	113	90	78	72	68	66	62	58
28-Jun	54	49	49	44	46	43	42	40	40	57	74	96	109	116	116	115	113	101	91	80	73	76	71	64
29-Jun	62	61	59	59	57	53	48	43	42	57	86	103	119	123	129	127	122	107	94	86	82	76	72	70
30-Jun	67	61	63	60	59	56	65	62	63	75	97	112	119	124	127	124	120	103	92	90	82	86	76	71

DATE:	TIME (NZST)																							
	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
1-Jul	6.8	7.7	7.8	7.5	7.6	7.2	7.0	6.9	6.2	7.0	9.0	10.1	10.9	10.9	11.0	10.5	10.0	8.2	6.9	7.0	6.9	6.6	6.6	6.0
2-Jul	5.9	6.2	5.9	5.8	5.4	5.8	5.3	5.2	5.9	6.8	8.4	10.1	10.4	10.6	10.4	10.2	9.9	9.0	8.1	8.0	7.9	8.0	7.6	7.8
3-Jul	7.9	7.8	7.8	7.2	7.4	7.1	6.9	6.3	6.4	7.2	8.7	9.4	11.0	11.4	11.8	11.0	10.8	8.6	7.1	6.6	6.5	5.6	5.3	5.4
4-Jul	4.9	5.0	4.9	4.4	4.8	4.3	3.8	3.6	4.0	4.5	6.5	8.0	9.2	9.8	10.3	10.5	10.3	8.2	6.3	5.3	5.3	4.9	4.3	4.7
5-Jul	4.1	4.3	4.2	4.1	4.2	4.6	4.5	4.3	4.4	5.5	6.9	7.7	8.8	9.4	9.3	9.5	9.0	7.8	7.0	6.3	6.0	5.4	4.7	4.6
6-Jul	4.1	4.1	3.9	3.9	4.1	3.8	3.7	3.3	3.6	5.1	7.6	9.0	10.3	11.0	11.2	11.3	10.8	8.8	7.1	6.1	5.3	4.4	4.0	4.2
7-Jul	4.5	3.9	4.2	3.4	3.3	3.8	4.1	3.7	3.6	5.1	7.7	9.8	11.0	11.1	11.4	11.8	10.9	9.3	8.2	7.4	6.8	6.5	7.0	6.4
8-Jul	6.5	6.3	6.2	6.1	5.9	5.8	5.4	5.3	5.6	6.8	8.0	9.2	10.3	10.6	10.8	10.7	10.3	8.6	7.6	7.0	5.9	5.2	4.6	4.1
9-Jul	3.9	3.7	3.4	3.4	3.3	3.9	4.5	4.4	4.9	5.5	8.1	10.1	11.1	11.7	11.7	11.6	10.4	9.6	8.2	7.7	6.7	6.6	6.8	5.8
10-Jul	5.7	5.4	5.6	5.5	5.2	5.1	5.0	5.0	5.1	6.8	8.9	10.7	11.8	12.0	12.6	12.5	12.1	9.9	7.4	5.9	5.2	5.3	5.3	5.1
11-Jul	4.8	4.8	4.4	4.1	4.0	4.0	4.3	4.4	4.7	6.5	8.4	10.2	10.8	11.4	11.2	11.0	10.4	8.7	6.5	5.7	4.9	4.5	4.2	4.3
12-Jul	4.1	3.7	4.0	4.2	4.0	4.2	4.3	4.7	4.8	5.9	8.1	9.2	10.3	10.6	10.6	10.7	10.4	8.6	6.6	5.7	6.0	6.2	6.6	6.1
13-Jul	6.0	5.6	5.3	5.0	4.6	4.1	3.8	3.4	3.7	5.5	8.1	10.0	11.2	11.8	11.8	11.6	10.9	8.7	6.4	5.4	4.6	3.8	3.4	3.6
14-Jul	3.3	3.0	3.1	3.1	2.8	2.3	2.3	1.8	2.3	4.2	6.4	8.0	9.2	9.9	10.4	10.4	9.7	8.6	7.1	6.4	6.0	6.0	6.1	5.8
15-Jul	5.8	5.2	5.1	5.3	5.0	5.3	5.6	5.9	6.0	6.8	8.2	9.6	10.2	10.8	10.9	11.1	10.9	9.2	8.0	7.8	7.6	7.4	6.8	6.7
16-Jul	6.8	6.3	6.2	6.5	5.9	6.0	5.9	6.0	7.0	8.0	9.2	9.9	10.3	10.7	10.6	10.1	9.2	8.7	8.2	7.9	8.2	8.0	8.0	7.8
17-Jul	7.7	7.4	7.3	7.4	7.1	7.2	6.9	6.7	6.8	7.6	8.0	9.3	9.6	10.8	10.3	10.2	9.9	8.6	7.4	6.8	6.6	6.6	6.5	6.1
18-Jul	5.9	5.5	5.0	5.1	5.0	4.6	4.7	4.5	4.3	5.9	8.0	9.8	10.3	11.4	11.6	11.9	11.4	9.4	7.1	5.7	4.7	4.6	3.6	3.6
19-Jul	4.1	3.9	3.8	3.6	3.8	4.0	4.1	4.4	4.4	5.7	8.1	9.9	10.9	11.6	12.1	12.1	11.0	9.8	9.0	8.3	7.8	7.5	6.9	6.7
20-Jul	7.0	6.3	6.1	5.9	5.6	5.3	5.1	4.8	6.3	8.9	10.7	11.4	11.8	12.3	12.1	11.7	10.1	8.4	7.7	7.4	6.7	6.0	6.3	6.3
21-Jul	6.3	6.4	6.4	6.4	6.6	6.6	6.2	6.8	7.9	9.3	10.6	11.1	11.2	11.6	11.8	11.9	10.7	9.7	9.2	8.7	8.2	8.0	8.0	8.0
22-Jul	7.5	7.1	7.3	7.6	7.4	7.3	7.0	7.1	7.1	8.5	10.3	11.6	12.1	12.2	12.6	12.0	12.1	10.8	9.2	8.4	8.4	8.0	7.7	7.1
23-Jul	7.2	6.8	6.4	6.6	6.1	6.0	5.5	5.2	5.6	7.1	9.8	11.2	11.8	12.3	12.1	12.1	11.4	10.0	8.7	8.3	7.6	7.2	6.8	6.3
24-Jul	6.3	5.9	5.7	5.4	5.0	4.8	4.3	4.1	3.9	6.0	8.8	10.6	11.9	12.9	13.3	13.0	12.3	10.1	8.0	7.2	6.7	6.1	5.8	5.3
25-Jul	5.0	4.7	4.2	3.6	2.3	2.0	1.9	1.7	2.2	4.4	7.6	9.8	11.1	11.8	12.1	12.2	11.4	9.9	7.2	6.0	5.8	5.3	5.1	5.1
26-Jul	5.1	4.8	4.4	4.7	4.2	4.4	4.6	4.6	4.8	6.7	8.8	10.1	11.6	11.9	11.8	11.5	11.3	9.8	7.8	6.3	6.0	5.3	4.8	4.7
27-Jul	4.7	4.7	4.1	4.2	3.9	3.7	3.7	2.9	3.3	5.6	7.8	9.6	10.7	11.0	11.7	11.8	11.2	10.0	7.5	6.6	6.4	5.9	5.7	6.2
28-Jul	6.1	5.3	4.9	4.6	4.6	4.0	4.3	4.6	6.0	7.5	8.9	9.9	10.6	11.2	11.4	11.3	10.9	9.4	8.2	7.6	6.7	6.6	6.4	6.4
29-Jul	5.6	5.2	5.2	4.4	4.3	3.8	3.3	2.9	3.2	5.9	8.2	10.7	11.2	12.2	12.6	12.2	11.6	10.2	9.0	7.8	7.1	6.3	6.0	5.8
30-Jul	4.9	4.9	4.9	4.6	3.7	3.3	3.2	3.0	3.4	5.6	8.1	9.6	10.5	11.3	11.4	11.9	11.0	9.3	7.0	6.9	6.7	5.9	5.1	5.3
31-Jul	5.5	4.7	4.4	3.7	3.3	2.7	2.5	2.4	2.7	5.4	8.4	10.2	10.8	11.9	12.3	12.2	11.8	10.3	7.9	6.7	5.8	5.4	4.9	4.0
1-Aug	4.1	4.6	3.6	3.4	2.9	2.3	2.0	2.0	2.7	5.2	7.9	9.7	10.9	11.6	11.8	11.9	11.2	9.7	7.5	6.1	5.8	5.4	5.0	4.9
2-Aug	4.7	4.7	4.7	4.9	4.8	4.6	4.7	4.6	4.9	6.6	8.3	9.8	10.4	10.9	11.2	11.5	10.8	9.7	8.6	7.8	7.6	7.0	6.6	6.1
3-Aug	5.4	5.1	5.2	4.9	4.8	4.4	4.3	4.2	4.2	6.1	8.1	9.9	10.4	11.2	11.4	11.4	10.8	9.3	7.4	6.4	5.9	5.5	5.9	5.7
4-Aug	5.1	5.1	4.4	4.5	4.3	3.9	3.9	3.6	4.0	7.3	9.2	10.8	11.4	12.1	12.3	12.4	12.3	11.2	9.2	7.9	7.1	6.0	5.6	5.0
5-Aug	4.4	3.7	4.0	3.5	3.3	3.3	3.5	3.1	3.2	6.0	8.3	10.1	11.6	12.2	11.9	11.5	11.0	10.0	8.1	7.2	6.7	6.1	5.3	5.2
6-Aug	4.9	4.7	4.7	4.6	4.7	4.7	4.8	4.6	5.0	7.6	10.1	11.0	11.6	12.1	11.9	12.0	11.8	10.7	8.9	8.4	7.4	6.8	6.3	6.4
7-Aug	6.4	6.4	6.6	6.6	6.8	6.7	6.3	6.3	7.0	8.4	9.7	11.2	11.8	12.4	12.8	12.7	11.7	10.4	8.5	7.3	6.7	6.2	5.7	5.2
8-Aug	4.7	4.4	4.3	4.1	3.9	4.0	4.1	4.3	4.9	7.1	9.2	10.2	11.8	12.1	12.4	12.5	12.0	10.3	8.3	6.8	6.6	6.6	6.0	5.9
9-Aug	5.6	4.8	4.2	4.2	4.2	5.0	4.4	4.3	4.2	6.5	8.6	10.5	11.6	12.3	13.0	13.2	12.3	11.1	8.8	7.3	7.1	6.4	6.3	6.6
10-Aug	6.1	6.1	5.4	5.1	5.2	5.3	5.3	5.4	6.0	8.4	10.4	11.6	12.4	13.0	12.9	13.0	13.1	12.3	9.6	8.7	7.8	7.3	6.9	6.8
11-Aug	6.5	6.2	6.0	6.0	5.4	5.1	5.5	6.0	6.2	8.5	10.4	11.4	12.7	13.1	13.4	12.7	12.2	11.0	10.0	9.8	9.0	9.2	8.6	8.7
12-Aug	8.6	8.8	8.0	8.2	7.9	8.0	7.4	7.7	7.8	9.6	11.2	11.6	12.0	11.6	12.0	11.9	11.6	10.7	9.4	8.3	7.8	7.3	6.6	6.6
13-Aug	6.3	6.1	6.0	5.3	5.2	4.8	5.0	4.7	5.3	7.4	9.8	11.3	12.3	12.7	13.2	13.1	12.8	11.7	9.7	9.0	8.8	8.4	8.3	8.3
14-Aug	8.1	7.8	6.9	7.0	6.6	6.4	6.6	6.6	6.9	7.9	8.8	9.7	10.3	11.3	11.9	10.9	10.6	9.8	7.3	6.3	5.6	5.1	5.0	4.4
15-Aug	4.1	3.8	3.6	3.2	3.8	4.3	4.3	4.7	5.3	7.9	9.7	10.8	11.6	11.6	12.7	12.5	12.1	11.6	9.4	8.4	7.7	7.0	6.7	6.9
16-Aug	6.2	5.8	5.6	5.4	5.2	5.0	5.4	5.0	6.3	8.1	10.2	11.4	12.5	12.8	12.6	12.2	11.6	10.4	8.8	7.2	6.7	5.9	6.4	6.0
17-Aug	6.2	5.6	5.8	5.0	5.6	5.6	6.2	5.7	7.2	9.3	11.3	12.2	13.0	13.4	13.6	13.0	12.4	11.3	9.3	8.2	7.7	7.0	6.6	6.8
18-Aug	6.7	6.9	6.6	6.1	6.1	6.1	6.1	5.7	6.7	8.4	9.9	10.9	12.1	12.1	12.1	11.9	11.7	11.0	8.4	7.6	6.8	6.1	5.7	5.1
19-Aug	4.9	4.6	4.3	4.0	4.0	4.0	4.1	3.9	4.4	7.3	9.9	11.4	11.9	12.8	13.2	12.9	12.4	11.1	8.9	8.1	7.4	7.1	6.8	6.7
20-Aug	6.4	5.4	5.3	5.3	5.2	6.0	6.2	6.1	6.9	8.0	9.4	10.2	10.9	11.6	11.9	11.9	11.6	10.4	9.0	8.3	8.1	8.0	7.6	7.8
21-Aug	7.7	7.4	7.0	6.4	6.7	6.8	6.8	6.8	7.4	9.2	10.3	10.9	11.9	12.6	12.7	12.2	12.6	11.2	9.9	9.0	8.0	7.8	7.4	7.1
22-Aug	6.8	6.2	5.8	5.3	5.1	4.9	5.0	4.8	5.6	7.3	9.1	10.3	10.9	10.8	11.3	11.1	10.4	10.1	8.2	7.1	6.3	5.5	5.1	4.2
23-Aug	3.8	3.4	3.0	2.9	2.3	2.4	2.6	2.6	3.4	7.0	9.4	10.9	11.0	11.7	12.2	12.2	11.7	11.1	8.1	7.0	6.6	6.1	5.8	5.6
24-Aug	5.1	5.4	5.4	5.3	5.8	5.9	6.0	6.1	6.7	8.8	10.6	11.6	12.7	13.3	13.1	13.2	13.1	12.2	11.0	9.6	8.6	8.1	8.0	7.2
25-Aug	7.6	7.3	6.3	5.9	5.3	5.1	5.3	4.6	5.6	8.5	10.0	10.9	11.8	12.6	12.7	12.8	12.7	11.3	9.0	7.8	7.7	7.3	7.2	7.2
26-Aug	7.3	7.3	7.1	7.0	6.9	6.4	6.3	5.9	6.8	8.2	9.9	11.1	11.7	11.9	12.4	11.6	11.7	10.8	9.4	8.8	8.7	7.9	7.4	7.2
27-Aug	6.8	6.8	6.9	6.7	6.6	6.3	5.9																	

DATE:	TIME (NZST)																							
	0900	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
1-Sep	4.5	4.4	4.4	4.1	3.8	3.6	3.2	3.9	5.9	9.0	11.4	12.9	13.5	14.0	14.7	14.5	14.1	12.9	10.4	8.8	7.9	7.7	6.9	6.0
2-Sep	5.6	5.2	5.7	4.9	4.9	5.1	5.1	5.4	7.1	10.0	12.1	13.4	14.1	13.7	13.6	12.9	12.2	11.4	9.9	8.9	8.6	8.6	8.6	8.8
3-Sep	8.6	7.8	7.4	7.5	7.4	7.2	6.9	6.3	8.1	10.0	11.6	12.2	13.0	13.2	13.0	12.8	11.9	10.8	9.7	9.0	8.2	7.9	7.6	7.6
4-Sep	7.2	6.8	7.0	6.7	6.8	6.4	6.3	6.3	8.1	9.8	11.3	12.6	13.1	13.9	14.7	14.4	13.6	12.8	10.8	9.4	8.8	8.1	7.8	8.0
5-Sep	8.2	8.0	7.9	7.7	7.1	7.3	7.4	7.9	8.8	11.1	12.4	13.6	13.8	14.1	14.1	14.1	13.7	12.8	11.3	10.4	9.9	9.3	9.2	9.0
6-Sep	8.7	8.7	8.6	8.7	8.7	9.4	8.9	8.7	10.6	12.1	13.4	14.3	15.7	15.8	15.4	14.9	14.7	14.2	12.8	11.6	10.7	10.0	9.7	9.7
7-Sep	9.4	9.1	9.1	8.3	8.2	7.0	7.0	6.4	8.2	10.2	12.2	12.8	13.2	13.4	13.8	13.1	12.8	11.8	10.7	10.0	9.6	8.7	8.7	8.1
8-Sep	7.9	7.6	7.1	7.7	7.4	7.9	7.9	7.6	9.1	10.8	11.4	12.3	12.6	12.6	13.2	12.7	12.0	11.1	10.1	9.4	9.9	9.3	8.7	8.9
9-Sep	8.4	8.3	7.8	7.1	7.1	6.9	7.0	7.3	8.8	10.7	11.7	12.0	11.8	12.3	13.0	12.1	11.3	10.9	9.6	8.3	7.6	7.3	7.0	6.6
10-Sep	6.4	6.3	6.2	6.1	6.3	6.2	5.9	6.3	7.9	9.7	11.0	12.0	12.3	13.0	13.2	13.1	12.3	11.9	10.4	9.4	8.7	8.1	7.6	7.6
11-Sep	7.0	6.2	6.1	5.4	5.7	5.6	5.3	4.9	7.6	10.4	12.2	13.0	13.8	14.2	14.0	13.2	12.9	11.6	10.4	8.9	7.8	7.4	6.9	6.2
12-Sep	5.8	5.3	4.9	4.7	4.8	4.3	4.5	5.0	7.4	9.3	10.8	12.1	12.9	13.2	13.8	13.6	13.2	12.6	10.8	9.3	8.2	7.3	6.0	6.1
13-Sep	5.2	5.0	4.5	4.2	4.8	4.1	4.5	4.9	7.8	10.8	12.4	13.8	14.5	14.4	14.8	14.5	13.8	12.6	11.3	9.4	8.4	8.2	7.4	6.5
14-Sep	6.9	6.0	5.6	5.8	5.1	5.1	5.3	5.3	7.6	11.1	12.4	14.1	14.4	15.6	15.6	15.5	15.1	13.8	11.9	10.3	9.6	8.5	7.9	7.5
15-Sep	7.7	7.8	7.6	7.7	7.6	8.1	7.5	7.8	10.5	12.9	13.9	14.8	15.2	14.9	14.9	15.0	14.4	14.1	12.5	11.5	10.6	10.5	10.0	10.1
16-Sep	9.3	8.4	8.1	8.1	7.8	7.6	7.2	7.4	10.4	13.0	14.1	15.1	14.9	15.1	15.4	15.3	15.0	14.1	12.0	10.1	9.4	8.6	8.4	8.4
17-Sep	7.3	7.1	6.8	6.6	6.4	5.8	6.3	6.5	9.4	12.3	14.5	15.5	15.9	16.5	17.0	17.0	16.4	15.4	13.5	11.4	10.5	9.8	9.3	8.9
18-Sep	8.6	8.9	8.6	8.4	7.9	7.4	7.9	8.3	10.3	11.8	13.1	14.0	13.9	14.3	14.5	14.5	14.4	13.9	12.4	11.5	10.6	9.9	9.5	9.4
19-Sep	9.4	9.0	8.8	8.9	9.1	8.5	8.5	9.0	10.9	12.5	13.6	14.5	14.9	15.4	15.6	15.6	15.4	14.4	12.7	10.8	10.0	9.7	9.1	9.0
20-Sep	8.6	7.9	7.5	7.2	6.8	6.6	6.3	6.9	8.9	11.8	13.4	14.3	14.8	15.4	15.4	15.6	15.0	14.1	11.8	10.4	9.0	9.1	9.6	8.3
21-Sep	7.9	8.1	8.4	7.7	7.3	6.6	6.9	7.4	9.4	10.3	11.9	13.0	14.0	14.0	14.4	13.9	13.4	13.0	10.9	9.0	8.8	8.4	7.3	6.1
22-Sep	5.3	5.0	5.3	6.2	7.1	7.1	7.3	8.6	11.0	13.3	13.6	14.5	15.0	15.6	16.3	15.6	15.1	14.6	12.9	11.1	9.6	8.7	7.9	7.6
23-Sep	7.0	6.6	6.3	5.7	5.0	4.1	4.4	5.6	9.5	11.6	13.5	14.6	15.4	15.6	15.9	15.9	15.3	14.5	13.0	11.0	10.1	9.6	9.6	9.1
24-Sep	8.6	7.9	7.1	7.0	7.0	7.0	7.9	10.5	12.5	14.1	15.4	15.6	15.7	15.4	15.4	13.9	13.3	11.4	10.4	9.4	8.7	8.0	7.6	7.6
25-Sep	7.6	7.5	7.1	6.3	6.6	6.6	6.5	7.4	9.4	10.7	11.8	12.4	12.4	13.0	13.3	12.8	12.6	11.9	10.6	9.9	8.9	7.9	7.4	6.6
26-Sep	5.9	5.5	5.1	4.9	4.9	4.5	4.1	5.8	8.9	11.7	13.4	13.6	14.5	14.8	14.9	15.1	14.9	13.5	11.9	10.5	10.5	10.0	9.6	10.0
27-Sep	9.4	9.6	9.6	9.2	8.9	8.8	8.5	9.6	12.1	13.2	14.5	15.4	15.9	15.9	16.0	15.6	15.4	14.4	12.2	11.0	10.1	10.0	9.6	8.9
28-Sep	8.8	8.8	8.4	7.7	7.1	7.3	7.3	8.1	11.1	12.8	14.3	15.1	15.7	16.6	16.8	16.7	15.6	15.1	13.4	11.8	10.6	10.3	9.4	9.3
29-Sep	9.0	8.4	8.3	8.3	8.3	7.9	8.0	9.1	11.6	13.7	14.6	15.4	14.9	15.6	16.3	16.3	15.6	14.4	13.1	11.1	10.4	10.1	9.4	8.8
30-Sep	8.9	8.8	8.4	8.2	7.6	7.9	8.3	9.5	11.8	13.7	14.5	14.9	15.9	16.1	16.1	16.2	15.8	14.9	13.6	11.9	10.9	9.7	9.3	9.1
1-Oct	9.0	8.3	8.1	8.0	7.5	8.0	7.9	8.9	11.6	13.0	14.8	16.2	17.1	17.8	18.1	18.1	17.1	16.5	14.9	12.9	11.7	11.3	10.9	10.5
2-Oct	10.2	10.0	9.8	9.3	9.9	10.0	9.8	11.5	13.5	15.3	16.0	17.5	17.5	17.5	17.2	17.2	17.1	16.5	14.8	13.0	12.5	12.2	12.0	11.0
3-Oct	10.9	10.1	10.0	10.1	10.1	9.7	9.9	11.5	13.4	14.4	15.7	15.8	16.3	16.8	16.7	16.4	15.0	14.8	13.2	11.0	10.4	9.9	9.9	8.9
4-Oct	8.8	8.3	8.0	8.4	8.4	8.7	8.6	10.0	12.8	14.6	14.9	15.9	15.8	16.3	16.3	15.7	15.5	15.3	13.5	11.1	9.7	9.1	8.4	8.1
5-Oct	8.0	7.5	7.2	7.7	7.4	7.9	7.7	9.6	12.3	13.6	14.6	15.2	15.6	15.5	15.6	15.6	15.1	14.3	12.8	11.0	10.4	9.6	9.0	8.3
6-Oct	8.2	7.9	7.7	7.4	6.9	6.2	6.4	9.3	11.9	13.7	14.5	15.5	16.2	16.5	16.5	15.7	15.6	15.1	13.5	12.1	11.1	10.7	10.3	9.8
7-Oct	9.8	9.3	9.2	9.1	8.9	8.4	8.3	9.0	10.7	11.8	12.9	13.1	14.0	14.8	14.9	14.4	14.1	13.4	12.0	10.9	10.2	9.6	9.4	9.1
8-Oct	9.0	8.8	8.7	8.3	8.4	8.4	8.4	10.1	12.4	14.0	15.6	16.4	17.3	17.6	17.5	17.0	16.8	15.8	14.1	12.8	12.2	11.1	10.4	10.3
9-Oct	10.0	9.8	10.1	10.1	9.9	10.0	10.9	13.0	14.1	14.9	15.7	16.3	16.8	16.5	16.6	16.0	15.5	14.0	11.6	10.5	10.1	9.3	8.8	8.8
10-Oct	8.4	7.8	7.7	7.6	7.6	7.5	7.4	9.0	11.5	12.8	13.6	14.8	15.3	15.8	16.4	16.0	15.1	14.1	13.1	11.3	10.5	10.3	10.0	9.8
11-Oct	9.8	9.3	9.3	9.8	9.3	8.1	7.9	10.0	11.3	12.4	13.0	13.9	14.5	15.3	15.2	14.5	14.4	14.2	12.8	11.5	9.9	9.6	9.3	9.1
12-Oct	9.9	10.3	10.8	10.5	11.4	11.4	10.9	12.3	13.7	14.0	14.6	15.0	15.3	14.9	14.8	14.3	13.9	13.1	12.5	11.5	11.1	11.1	10.8	10.4
13-Oct	10.3	10.1	9.9	9.5	9.5	9.7	9.6	11.0	11.8	12.8	13.3	13.8	13.8	13.9	14.5	14.3	13.9	12.9	12.1	11.0	10.5	9.6	9.5	9.1
14-Oct	8.3	7.9	7.7	7.1	7.3	6.8	6.5	8.5	9.8	11.9	13.0	13.4	13.9	12.6	13.0	12.8	12.4	11.8	11.1	9.9	9.4	8.5	7.9	7.5
15-Oct	6.9	6.5	6.3	6.4	6.0	5.8	5.8	7.9	10.7	12.6	13.9	14.0	13.9	14.0	14.0	13.5	13.8	13.7	11.9	10.0	8.7	8.3	8.5	8.4
16-Oct	8.8	7.9	7.9	8.0	8.3	8.0	8.3	9.9	11.7	13.4	13.8	14.4	15.4	15.4	15.2	15.4	14.8	14.2	13.3	11.0	9.7	9.3	9.1	8.3
17-Oct	8.0	7.6	7.1	6.9	7.4	7.1	6.9	9.9	12.3	14.0	14.9	15.6	16.0	16.0	15.8	15.6	15.1	14.4	13.0	10.9	10.0	9.4	8.8	9.0
18-Oct	8.4	8.1	8.6	8.5	8.1	8.4	8.1	10.1	13.5	14.9	16.0	16.8	17.6	16.5	16.1	16.5	15.4	13.8	11.6	10.6	9.8	9.1	8.3	8.3
19-Oct	8.0	7.6	7.1	7.3	7.5	7.4	7.5	10.3	13.2	14.1	14.8	15.3	16.0	16.3	16.0	16.4	15.5	15.1	13.8	12.0	11.2	10.9	10.4	9.9
20-Oct	9.9	9.1	9.0	8.5	8.1	8.2	8.0	10.4	12.9	14.3	15.3	16.0	16.9	17.1	17.4	17.0	16.5	16.1	14.8	12.9	12.3	11.8	12.1	11.3
21-Oct	12.0	11.9	11.7	11.0	10.6	10.2	10.5	11.5	13.4	14.9	14.6	15.1	15.0	15.3	15.0	14.9	14.8	14.3	13.1	12.1	11.5	11.5	11.1	10.6
22-Oct	10.3	10.0	9.2	8.9	8.4	8.4	8.8	10.8	12.6	13.5	14.4	15.5	15.9	16.8	17.0	16.4	15.9	15.1	13.6	11.1	9.6	8.0	7.1	6.6
23-Oct	6.1	6.0	5.8	5.4	5.3	5.5	6.4	9.4	11.4	13.3	14.4	14.8	15.5	15.8	16.3	16.0	15.6	14.9	13.6	11.5	10.2	9.3	8.6	8.1
24-Oct	7.6	6.8	6.5	6.0	5.6	5.5	5.8	8.8	11.0	12.5	13.6	14.5	15.3	15.8	16.2	16.4	15.6	15.2	13.4	10.6	9.0	8.3	8.4	7.8
25-Oct	6.9	6.6	6.6	6.4	5.9	5.6	6.5	9.6	12.6	14.6	16.5	17.8	18.1	18.4	18.6	19.0	18.8	17.6	16.4	13.3	11.7	10.6	10.5	10.0
26-Oct	10.0	9.5	8.9	8.4	8.0	7.3	8.3	11.3	13.7	15.9	16.8													

DATE:	TIME (NZST)																								
	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	
1-Nov	11.6	11.3	10.7	10.3	10.4	10.2	11.1	12.3	13.7	15.1	16.1	16.4	17.0	16.4	16.4	17.0	16.6	15.7	13.6	12.1	11.5	11.0	10.9	10.4	
2-Nov	10.0	9.8	9.8	9.9	9.9	9.1	9.4	11.3	13.0	14.1	14.0	14.8	15.4	15.6	15.6	15.4	15.0	13.9	13.1	10.7	10.7	9.8	9.5	8.9	
3-Nov	8.1	8.1	7.8	7.4	7.4	7.7	8.8	10.6	12.1	13.4	14.3	14.6	15.3	15.6	15.2	14.9	14.4	13.7	13.1	11.8	10.9	10.1	9.9	9.4	
4-Nov	9.0	8.9	8.6	8.6	8.6	8.4	9.0	10.1	12.1	13.1	14.3	15.0	15.3	15.1	14.9	14.4	14.0	13.8	12.9	11.6	11.3	10.9	11.1	10.8	
5-Nov	10.6	9.5	8.6	8.8	8.8	8.4	9.0	11.3	12.6	14.0	14.9	15.5	16.1	16.3	15.8	15.9	15.8	14.8	14.0	12.1	11.3	10.4	9.6	9.1	
6-Nov	8.5	8.5	8.2	8.0	8.1	7.7	9.0	11.6	13.5	14.9	15.5	16.6	17.4	17.8	17.7	17.3	17.5	16.3	15.3	12.9	11.3	10.3	9.3	8.9	
7-Nov	8.8	8.3	7.9	7.5	7.3	7.5	8.6	12.1	14.5	15.5	16.3	16.7	17.0	17.8	17.6	17.0	16.5	15.9	14.6	12.6	11.4	11.1	10.4	10.0	
8-Nov	9.8	10.0	9.8	9.6	9.8	9.6	10.5	12.4	13.9	15.0	15.9	16.4	16.5	17.1	17.3	17.3	17.1	16.1	14.8	13.1	11.6	11.3	10.6	10.5	
9-Nov	9.9	9.4	9.5	9.3	8.4	9.1	9.8	12.4	14.0	15.9	16.8	16.8	16.9	17.1	17.4	17.1	17.0	16.3	15.4	13.6	12.4	12.1	12.0	11.3	
10-Nov	11.0	11.1	11.0	10.8	10.4	10.6	11.1	12.8	14.1	15.3	16.5	17.0	17.5	17.6	17.7	17.8	17.6	16.6	15.0	13.3	11.8	11.1	10.8	10.7	
11-Nov	10.4	9.6	9.5	9.4	10.0	9.3	10.5	13.0	14.4	15.8	16.4	17.0	17.6	18.3	17.9	17.8	17.8	16.9	15.8	13.6	12.4	11.3	10.4	9.5	
12-Nov	9.8	9.5	9.5	9.3	9.0	9.4	10.4	12.3	13.6	14.9	15.3	16.0	15.8	17.3	16.4	16.5	16.0	14.6	13.8	12.8	11.9	11.3	10.8	10.2	
13-Nov	9.8	9.1	9.1	8.4	8.3	8.5	9.5	11.5	12.9	13.8	15.1	15.3	15.3	15.9	16.6	16.9	16.6	15.8	14.4	12.6	10.9	10.1	9.5	9.4	
14-Nov	8.4	8.1	7.4	7.4	6.5	6.2	8.6	11.8	14.0	16.0	17.4	17.9	18.4	18.6	18.0	17.5	17.1	16.2	14.8	14.0	12.3	11.8	10.9	10.7	
15-Nov	10.3	9.4	9.1	9.0	8.5	8.5	10.1	12.9	14.4	15.6	16.0	16.5	16.9	17.0	17.0	17.3	17.0	15.9	15.0	13.5	12.3	11.5	11.1	10.7	
16-Nov	9.9	9.9	9.5	9.1	9.1	8.5	10.4	12.8	15.0	16.3	16.9	17.3	17.8	18.3	18.2	17.9	17.8	16.8	15.6	14.0	12.0	11.1	10.4	10.0	
17-Nov	9.6	9.6	9.5	9.4	10.1	9.9	11.1	12.6	13.8	15.1	16.0	16.7	16.6	16.8	16.8	16.8	16.8	15.6	15.2	13.9	12.4	10.8	9.9	9.4	8.5
18-Nov	8.4	7.9	7.7	8.0	7.8	8.0	9.1	11.4	13.2	14.6	15.8	16.2	16.5	16.5	16.8	16.6	16.0	15.4	14.6	13.3	12.3	11.8	11.8	11.2	
19-Nov	11.0	10.6	10.4	11.1	11.1	11.0	11.4	12.8	13.7	14.4	15.1	15.6	15.5	15.6	16.0	15.9	16.0	15.0	14.5	13.1	12.3	11.4	11.3	11.2	
20-Nov	11.1	11.0	10.9	10.8	10.8	10.8	11.5	12.5	14.0	14.0	14.6	15.3	15.0	15.0	15.0	14.3	13.9	13.8	13.0	12.4	11.8	11.5	10.4	10.4	
21-Nov	9.6	9.3	9.5	9.5	9.1	9.3	10.4	12.3	13.7	14.1	15.4	15.3	14.5	14.4	15.1	14.9	14.5	14.1	12.8	11.5	11.1	10.6	9.9	9.7	
22-Nov	9.1	8.9	8.9	8.9	8.8	8.8	9.6	11.4	12.3	13.0	13.8	14.4	14.5	15.6	16.0	15.6	15.0	13.4	14.4	13.5	12.0	10.6	9.8	9.0	8.3
23-Nov	7.6	7.0	6.3	6.1	5.5	5.4	7.4	10.5	12.7	14.3	15.9	16.5	17.5	18.0	18.7	18.8	18.1	17.6	16.8	14.6	11.8	10.5	9.8	8.9	
24-Nov	8.1	7.6	7.3	7.3	6.8	7.0	9.5	12.6	14.4	16.1	17.5	18.3	18.4	18.1	18.1	17.9	17.3	16.6	15.8	14.5	13.4	13.1	12.8	12.4	
25-Nov	12.8	12.1	11.6	11.0	10.6	10.4	11.3	12.9	13.8	14.9	15.6	16.6	17.0	17.9	17.9	17.8	17.1	16.5	15.4	14.3	12.7	11.8	10.9	10.5	
26-Nov	9.6	8.9	8.4	7.8	7.5	7.1	9.6	12.0	14.6	16.9	18.1	19.4	18.6	19.3	19.3	19.3	18.5	18.3	17.0	14.6	13.2	12.0	11.3	10.7	
27-Nov	11.0	10.4	9.8	9.8	10.0	9.8	11.8	14.1	15.9	16.5	17.1	17.7	17.4	17.4	17.6	17.9	17.1	16.0	15.4	14.0	12.7	12.4	11.9	11.8	
28-Nov	11.5	11.3	11.0	10.6	10.0	9.9	11.4	13.3	14.8	15.6	16.5	17.2	17.3	17.1	16.8	16.6	16.3	16.0	15.1	14.4	13.5	12.8	12.6	12.3	
29-Nov	11.9	11.4	11.2	11.4	11.4	11.4	11.9	13.0	14.3	15.6	17.3	17.4	17.1	17.6	17.9	17.4	16.8	16.3	15.1	14.3	13.4	12.5	11.9	11.8	
30-Nov	11.5	11.5	10.8	10.8	10.8	10.9	12.0	14.4	16.0	16.8	18.0	18.9	20.0	20.3	20.2	20.4	20.6	19.8	18.6	17.4	15.8	15.0	14.5	14.2	
1-Dec	13.8	13.1	13.1	12.5	12.1	12.1	14.1	16.9	18.1	19.6	20.6	20.7	20.9	21.1	21.5	21.7	21.1	19.7	18.6	17.1	15.7	14.3	13.7	13.8	
2-Dec	13.6	13.6	13.0	13.0	13.1	12.9	14.1	16.3	17.3	18.4	19.3	20.0	20.8	21.6	21.9	21.9	21.9	20.9	19.5	17.6	15.9	15.5	15.5	15.5	
3-Dec	15.4	15.4	15.1	15.3	14.4	14.4	14.9	16.0	17.0	18.1	18.4	19.3	19.9	19.9	19.4	19.5	19.0	18.5	17.9	16.4	15.2	14.6	14.0	13.5	
4-Dec	13.0	12.5	12.8	12.3	12.0	11.9	13.1	15.3	16.6	18.5	19.6	20.6	20.8	21.8	21.6	20.9	20.4	18.9	17.8	16.5	15.1	13.9	13.6	13.2	
5-Dec	12.5	12.0	11.9	11.3	11.0	10.7	13.0	15.3	17.1	18.1	19.4	20.4	20.3	20.4	21.3	21.1	20.8	20.0	18.3	16.8	15.0	13.9	13.1	12.6	
6-Dec	12.4	11.8	11.4	11.4	11.8	11.3	13.1	15.3	17.0	18.6	19.6	20.7	20.6	20.6	20.0	19.8	18.8	18.1	17.8	16.4	15.3	14.6	14.0	13.7	
7-Dec	13.0	12.1	12.2	11.8	11.1	11.1	13.9	15.8	16.9	17.8	18.8	19.4	19.9	19.8	19.7	19.6	18.9	18.4	17.3	16.0	14.5	13.4	12.5	11.9	
8-Dec	12.0	11.1	10.9	10.9	10.4	10.4	11.9	13.6	15.3	16.1	16.6	17.3	17.9	18.1	18.6	18.4	17.9	16.7	15.8	14.4	12.8	11.5	11.0	10.2	
9-Dec	10.0	9.6	9.2	9.3	9.1	9.0	10.3	12.3	13.6	14.6	15.1	15.9	16.4	16.4	16.8	17.1	16.9	16.6	15.6	14.4	12.8	11.6	11.0	10.8	
10-Dec	10.1	9.4	8.7	8.4	7.9	8.1	10.3	12.9	15.1	16.5	18.2	19.5	19.8	20.1	20.0	19.4	18.7	18.0	17.1	16.0	14.4	13.4	12.3	11.7	
11-Dec	11.7	10.9	11.6	10.9	10.3	10.7	12.3	14.4	16.0	17.1	18.6	18.8	18.6	19.1	19.1	18.4	18.8	18.0	17.3	15.6	14.5	13.9	13.1	12.0	
12-Dec	11.8	11.4	11.6	11.4	11.5	11.6	13.3	15.9	17.4	18.6	19.6	19.8	20.4	20.3	20.6	20.1	20.6	19.9	18.8	17.1	15.1	14.0	13.1	12.9	
13-Dec	12.4	12.0	11.4	11.4	11.3	11.7	13.3	15.4	16.1	16.4	18.0	19.3	20.6	20.8	20.5	20.6	20.1	19.5	18.5	17.0	15.4	14.6	14.0	14.1	
14-Dec	13.9	13.8	13.4	13.1	12.8	12.4	13.1	15.1	16.4	17.5	17.9	18.9	19.4	19.0	19.9	20.4	20.0	19.4	18.0	16.9	15.3	14.1	13.4	13.0	
15-Dec	12.6	11.9	12.4	10.9	11.5	11.3	12.9	14.6	15.9	17.7	18.4	19.7	20.7	21.1	21.8	22.0	21.8	20.4	18.9	17.1	15.1	13.8	13.1	12.5	
16-Dec	12.0	12.0	11.1	11.0	10.5	9.9	11.8	15.0	16.7	18.6	19.8	20.9	21.9	22.0	22.1	22.3	21.3	20.6	19.9	18.0	15.8	14.4	13.6	12.7	
17-Dec	12.4	11.6	11.1	11.0	11.1	10.7	12.5	15.9	17.7	19.5	20.3	21.2	21.0	21.5	20.9	20.0	19.4	18.7	18.1	17.3	15.7	15.4	15.0	14.6	
18-Dec	14.3	14.3	14.0	14.0	14.1	14.8	15.6	16.1	16.1	17.5	18.3	18.6	19.4	19.3	18.9	19.0	18.5	17.4	16.5	15.9	15.6	15.1	14.7	14.7	
19-Dec	14.0	13.8	13.4	13.3	12.8	13.1	14.1	15.6	17.0	18.5	19.1	20.1	20.8	21.1	20.9	20.6	20.1	19.3	18.1	17.3	16.2	15.6	14.6	14.4	
20-Dec	13.9	13.4	13.2	12.6	12.5	12.5	13.6	15.8	16.9	18.6	19.0	19.6	20.4	20.9	20.6	20.8	20.0	19.7	19.3	17.5	15.8	15.3	15.0	14.8	
21-Dec	15.3	14.3	13.6	13.5	13.5	13.1	13.9	15.8	17.2	18.9	19.3	20.5	20.8	21.6	21.7	21.5	21.1	20.0	18.9	17.3	15.2	14.0	13.0	12.0	
22-Dec	11.5	11.1	11.0	11.0	11.1	10.8	12.4	14.4	15.9	17.5	19.3	20.6	20.6	21.6	21.9	22.1	21.4	20.8	20.0	18.6	16.2	14.6	13.4	12.7	
23-Dec	11.6	11.4	11.2	11.5	11.5	11.4	13.3	16.0	18.3	20.1	21.0	21.2	21.9	22.1	21.4	21.1	21.1	20.3	19.6	18.9	17.1	17.0	16.4	16.2	
24-Dec	16.3	15.9	15.5	15.0	14.6	14.3	15.5	17.6	19.0	20.1	21.0	21.3													

Appendix C Altitude and Azimuth angles for case study for specified Julian day numbers

Solar angle data calculation sheet

Input parameters:

Location parameters

latitude	-41 degrees	-0.71558 radians
longitude	176 degrees	3.071779 radians
standard meridian	180 degrees	3.141593 radians

Time of year

Julian day number	355	
declination	-23.4498 degrees	-0.40928 radians
equon of time	2.17419 minutes	B= 6.093829

Results:

Time of day 24 hour decimal	Clock time	Solar time	Zenith angle (degrees)	Altitude angle (degrees)	Azimuth angle (degEofN)	Azimuth angle (degWofS)	hour angle theta (radians)	gammas'	C1	C2	C3	wew	X	Y	
	4:43	4:30	0	0	180	0	-1.9635	90.22265	0	-1	-1	-1	1.048356	0	0
	4:58	4:45	87.79253	2.207468	119.6148	-60.3852	-1.89805	87.79253	-60.3852	-1	-1	-1	1.048356	76.32398	-43.3841
	5:13	5:00	85.30365	4.69635	117.2353	-62.7647	-1.8326	85.30365	-62.7647	-1	-1	-1	1.048356	75.84641	-39.0389
	5:28	5:15	82.76153	7.238471	114.9046	-65.0954	-1.76715	82.76153	-65.0954	-1	-1	-1	1.048356	75.06554	-34.8516
	5:43	5:30	80.17136	9.828644	112.615	-67.385	-1.7017	80.17136	-67.385	-1	-1	-1	1.048356	74.00693	-30.8289
	5:58	5:45	77.53801	12.46199	110.3586	-69.6414	-1.63625	77.53801	-69.6414	-1	-1	-1	1.048356	72.69451	-26.975
	6:13	6:00	74.86611	15.13389	108.1269	-71.8731	-1.5708	74.86611	-71.8731	-1	-1	-1	1.048356	71.15047	-23.2926
	6:28	6:15	72.16005	17.83995	105.9114	-74.0886	-1.50535	72.16005	-74.0886	-1	-1	-1	1.048356	69.39536	-19.7827
	6:43	6:30	69.42404	20.57596	103.7027	-76.2973	-1.4399	69.42404	-76.2973	-1	-1	-1	1.048356	67.44808	-16.4455
	6:58	6:45	66.66218	23.33782	101.4909	-78.5091	-1.37445	66.66218	-78.5091	-1	-1	-1	1.048356	65.32604	-13.2799
	7:13	7:00	63.87851	26.12149	99.26498	-80.735	-1.309	63.87851	-80.735	-1	-1	-1	1.048356	63.04517	-10.2845
	7:28	7:15	61.07705	28.92295	97.01306	-82.9869	-1.24355	61.07705	-82.9869	-1	-1	-1	1.048356	60.6201	-7.45724
	7:43	7:30	58.26193	31.73807	94.72163	-85.2784	-1.1781	58.26193	-85.2784	-1	-1	-1	1.048356	58.06421	-4.79582
	7:58	7:45	55.4374	34.5626	92.37534	-87.6247	-1.11265	55.4374	-87.6247	-1	-1	-1	1.048356	55.38977	-2.29763
	8:13	8:00	52.60805	37.39195	89.95642	-90.0436	-1.0472	52.60805	-89.95642	1	-1	-1	1.048356	52.60803	0.040012
	8:28	8:15	49.77883	40.22117	87.44407	-92.5559	-0.98175	49.77883	-87.4441	1	-1	-1	1.048356	49.72931	2.21987
	8:43	8:30	46.95534	43.04466	84.81348	-95.1865	-0.9163	46.95534	-84.8135	1	-1	-1	1.048356	46.76309	4.24468
	8:58	8:45	44.14399	45.85601	82.03477	-97.9652	-0.85085	44.14399	-82.0348	1	-1	-1	1.048356	43.71811	6.117126
	9:13	9:00	41.35239	48.64761	79.07143	-100.929	-0.7854	41.35239	-79.0714	1	-1	-1	1.048356	40.60243	7.839792
	9:28	9:15	38.58971	51.41029	75.8784	-104.122	-0.71995	38.58971	-75.8784	1	-1	-1	1.048356	37.42353	9.41514
	9:43	9:30	35.86736	54.13264	72.39955	-107.6	-0.6545	35.86736	-72.3995	1	-1	-1	1.048356	34.18835	10.84548
	9:58	9:45	33.19978	56.80022	68.56454	-111.435	-0.58905	33.19978	-68.5645	1	-1	-1	1.048356	30.90335	12.13296
	10:13	10:00	30.60563	59.39437	64.26519	-115.715	-0.5236	30.60563	-64.2852	1	-1	-1	1.048356	27.5746	13.27954
	10:28	10:15	28.10934	61.89066	59.45168	-120.548	-0.45815	28.10934	-59.4517	1	-1	-1	1.048356	24.20779	14.28699
	10:43	10:30	25.74331	64.25669	53.9302	-126.07	-0.3927	25.74331	-53.9302	1	-1	-1	1.048356	20.80833	15.1569
	10:58	10:45	23.55045	66.44955	47.56535	-132.435	-0.32725	23.55045	-47.5654	1	-1	-1	1.048356	17.38135	15.89064
	11:13	11:00	21.58687	68.41313	40.19423	-139.806	-0.2618	21.58687	-40.1942	1	-1	-1	1.048356	13.93175	16.48937
	11:28	11:15	19.92337	70.07663	31.68346	-148.317	-0.19635	19.92337	-31.6835	1	-1	-1	1.048356	10.46427	16.95405
	11:43	11:30	18.64284	71.35716	21.99927	-158.001	-0.1309	18.64284	-21.9993	1	-1	-1	1.048356	6.983512	17.28543
	11:58	11:45	17.82974	72.17026	11.30091	-168.699	-0.06545	17.82974	-11.3009	1	-1	-1	1.048356	3.493947	17.48405
	12:13	12:00	17.55022	72.44978	0	180	0	17.55022	0	1	-1	1	1.048356	0	17.55022
	12:28	12:15	17.82974	72.17026	-11.3009	168.6991	0.06545	17.82974	11.30091	1	-1	1	1.048356	-3.49395	17.48405
	12:43	12:30	18.64284	71.35716	-21.9993	158.0007	0.1309	18.64284	21.99927	1	-1	1	1.048356	-6.98351	17.28543
	12:58	12:45	19.92337	70.07663	-31.6835	148.3165	0.19635	19.92337	31.68346	1	-1	1	1.048356	-10.4643	16.95405
	13:13	13:00	21.58687	68.41313	-40.1942	139.8058	0.261799	21.58687	40.19423	1	-1	1	1.048356	-13.9317	16.48937
	13:28	13:15	23.55045	66.44955	-47.5654	132.4346	0.327249	23.55045	47.56535	1	-1	1	1.048356	-17.3813	15.89064
	13:43	13:30	25.74331	64.25669	-53.9302	126.0698	0.392699	25.74331	53.9302	1	-1	1	1.048356	-20.8083	15.1569
	13:58	13:45	28.10934	61.89066	-59.4517	120.5483	0.458149	28.10934	59.45168	1	-1	1	1.048356	-24.2078	14.28699
	14:13	14:00	30.60563	59.39437	-64.2852	115.7148	0.523599	30.60563	64.28519	1	-1	1	1.048356	-27.5746	13.27954
	14:28	14:15	33.19978	56.80022	-68.5645	111.4355	0.589049	33.19978	68.56454	1	-1	1	1.048356	-30.9033	12.13296
	14:43	14:30	35.86736	54.13264	-72.3995	107.6005	0.654498	35.86736	72.39955	1	-1	1	1.048356	-34.1883	10.84548
	14:58	14:45	38.58971	51.41029	-75.8784	104.1216	0.719948	38.58971	75.8784	1	-1	1	1.048356	-37.4235	9.41514
	15:13	15:00	41.35239	48.64761	-79.0714	100.9286	0.785398	41.35239	79.07143	1	-1	1	1.048356	-40.6024	7.839792
	15:28	15:15	44.14399	45.85601	-82.0348	97.96523	0.850848	44.14399	82.03477	1	-1	1	1.048356	-43.7181	6.117126
	15:43	15:30	46.95534	43.04466	-84.8135	95.18652	0.916298	46.95534	84.81348	1	-1	1	1.048356	-46.7631	4.24468
	15:58	15:45	49.77883	40.22117	-87.4441	92.55593	0.981748	49.77883	87.44407	1	-1	1	1.048356	-49.7293	2.21987
	16:13	16:00	52.60805	37.39195	-89.9564	90.04358	1.047198	52.60805	89.95642	1	-1	1	1.048356	-52.608	0.040012
	16:28	16:15	55.4374	34.5626	-92.3753	87.62466	1.112647	55.4374	87.62466	-1	-1	1	1.048356	-55.3698	-2.29763
	16:43	16:30	58.26193	31.73807	-94.7216	85.27837	1.178097	58.26193	85.27837	-1	-1	1	1.048356	-58.0642	-4.79582
	16:58	16:45	61.07705	28.92295	-97.0131	82.98694	1.243547	61.07705	82.98694	-1	-1	1	1.048356	-60.6201	-7.45724
	17:13	17:00	63.87851	26.12149	-99.265	80.73502	1.308997	63.87851	80.73502	-1	-1	1	1.048356	-63.0452	-10.2845
	17:28	17:15	66.66218	23.33782	-101.491	78.50914	1.374447	66.66218	78.50914	-1	-1	1	1.048356	-65.326	-13.2799
	17:43	17:30	69.42404	20.57596	-103.703	76.29729	1.439897	69.42404	76.29729	-1	-1	1	1.048356	-67.4481	-16.4455
	17:58	17:45	72.16005	17.83995	-105.911	74.08859	1.505346	72.16005	74.08859	-1	-1	1	1.048356	-69.3954	-19.7827
	18:13	18:00	74.86611	15.13389	-108.127	71.87306	1.570796	74.86611	71.87306	-1	-1	1	1.048356	-71.1505	-23.2926
	18:28	18:15	77.53801	12.46199	-110.359	69.64144	1.636246	77.53801	69.64144	-1	-1	1	1.048356	-72.6945	-26.975
	18:43	18:30	80.17136	9.828644	-112.615	67.38498	1.701696	80.17136	67.38498	-1	-1	1	1.048356	-74.0069	-30.8289
	18:58	18:45	82.76153	7.238471	-114.905	65.09537	1.767146	82.76153	65.09537	-1	-1	1	1.048356	-75.0655	-34.8516
	19:13	19:00	85.30365	4.69635	-117.235	62.76468	1.832596	85.30365	62.76468	-1	-1	1	1.048356	-75.8464	-39.0389
	19:28	19:15	87.79253	2.207468	-119.615	60.38523	1.898046	87.79253	60.38523	-1	-1	1	1.048356	-76.324	-43.3841
	19:43	19:30	0	0	180	0	1.963495	90.22265	0	-1	-1	1	1.048356	0	0
	19:58	19:45	0	0	180	0	2.028945	92.58808	0	-1	-1	1	1.048356	0	0
	20:13	20:00	0	0	180	0	2.094395	94.88254	0	-1	-1	1	1.048356	0	0

Solar angle data calculation sheet

Input parameters:

Location parameters

latitude	-41 degrees	-0.71558 radians
longitude	176 degrees	3.071779 radians
standard meridian	180 degrees	3.141593 radians

Time of year

Julian day number	324
declination	-20.2407 degrees -0.35327 radians
equon of time	14.08471 minutes B= 5.560189

Results:

Time of day 24 hour decimal	Clock time	Solar time	Zenith angle (degrees)	Altitude angle (degrees)	Azimuth angle (degEofN)	Azimuth angle (degWofS)	hour angle theta (radians)	gammas'	C1	C2	C3	wew	X	Y	
4:31	4:30		0	0	180	0	-1.9635	92.52221	0	-1	-1	-1	1.132739	0	0
4:46	4:45		0	0	180	0	-1.89805	90.03665	0	-1	-1	-1	1.132739	0	0
5:01	5:00	87.49525	2.50475	114.8864	-65.1136	-1.8326	87.49525	-65.1136	-1	-1	-1	1.132739	7.937082	-3.68197	
5:16	5:15	84.90377	5.096232	112.5012	-67.4988	-1.76715	84.90377	-67.4988	-1	-1	-1	1.132739	7.844018	-3.24929	
5:31	5:30	82.26758	7.732423	110.1562	-69.8438	-1.7017	82.26758	-69.8438	-1	-1	-1	1.132739	7.722924	-2.83478	
5:46	5:45	79.59174	10.40826	107.8426	-72.1574	-1.63625	79.59174	-72.1574	-1	-1	-1	1.132739	7.576353	-2.43872	
6:01	6:00	76.88107	13.11893	105.5512	-74.4488	-1.5708	76.88107	-74.4488	-1	-1	-1	1.132739	7.406654	-2.06118	
6:16	6:15	74.14014	15.85986	103.2726	-76.7274	-1.50535	74.14014	-76.7274	-1	-1	-1	1.132739	7.215978	-1.70214	
6:31	6:30	71.3734	18.6266	100.9965	-79.0035	-1.4399	71.3734	-79.0035	-1	-1	-1	1.132739	7.00629	-1.36144	
6:46	6:45	68.58519	21.41481	98.71231	-81.2877	-1.37445	68.58519	-81.2877	-1	-1	-1	1.132739	6.779381	-1.03888	
7:01	7:00	65.77983	24.22017	96.40827	-83.5917	-1.309	65.77983	-83.5917	-1	-1	-1	1.132739	6.536883	-0.73418	
7:16	7:15	62.96171	27.03829	94.07156	-85.9284	-1.24355	62.96171	-85.9284	-1	-1	-1	1.132739	6.28028	-0.44704	
7:31	7:30	60.13534	29.86466	91.68789	-88.3121	-1.1781	60.13534	-88.3121	-1	-1	-1	1.132739	6.010925	-0.17713	
7:46	7:45	57.30549	32.69451	89.24111	-90.7589	-1.11265	57.30549	-89.2411	1	-1	-1	1.132739	5.730046	0.075899	
8:01	8:00	54.47731	35.52269	86.71272	-93.2873	-1.0472	54.47731	-86.7127	1	-1	-1	1.132739	5.438767	0.312386	
8:16	8:15	51.65648	38.34352	84.08124	-95.9188	-0.98175	51.65648	-84.0812	1	-1	-1	1.132739	5.138111	0.532673	
8:31	8:30	48.84945	41.15055	81.32148	-98.6785	-0.9163	48.84945	-81.3215	1	-1	-1	1.132739	4.829015	0.737091	
8:46	8:45	46.06365	43.93635	78.40354	-101.596	-0.85085	46.06365	-78.4035	1	-1	-1	1.132739	4.512338	0.925959	
9:01	9:00	43.30787	46.69213	75.29165	-104.708	-0.7854	43.30787	-75.2916	1	-1	-1	1.132739	4.18887	1.099582	
9:16	9:15	40.5927	49.4073	71.9427	-108.057	-0.71995	40.5927	-71.9427	1	-1	-1	1.132739	3.859339	1.258243	
9:31	9:30	37.93113	52.06887	68.3046	-111.695	-0.6545	37.93113	-68.3046	1	-1	-1	1.132739	3.524418	1.402208	
9:46	9:45	35.33936	54.66064	64.31444	-115.686	-0.58905	35.33936	-64.3144	1	-1	-1	1.132739	3.184734	1.531721	
10:01	10:00	32.83774	57.16226	59.89689	-120.103	-0.5236	32.83774	-59.8969	1	-1	-1	1.132739	2.840873	1.647002	
10:16	10:15	30.45215	59.54785	54.96351	-125.036	-0.45815	30.45215	-54.9635	1	-1	-1	1.132739	2.493381	1.748252	
10:31	10:30	28.21541	61.78459	49.41446	-130.586	-0.3927	28.21541	-49.4145	1	-1	-1	1.132739	2.142778	1.835645	
10:46	10:45	26.16881	63.83119	43.14525	-136.855	-0.32725	26.16881	-43.1452	1	-1	-1	1.132739	1.789555	1.909335	
11:01	11:00	24.3631	65.6369	36.06259	-143.937	-0.2618	24.3631	-36.0626	1	-1	-1	1.132739	1.43418	1.969451	
11:16	11:15	22.85783	67.14217	28.11345	-151.887	-0.19635	22.85783	-28.1134	1	-1	-1	1.132739	1.077104	2.016098	
11:31	11:30	21.71749	68.28251	19.32716	-160.673	-0.1309	21.71749	-19.3272	1	-1	-1	1.132739	0.718766	2.049358	
11:46	11:45	21.00303	68.99697	9.85813	-170.142	-0.06545	21.00303	-9.85813	1	-1	-1	1.132739	0.359591	2.069291	
12:01	12:00	20.75932	69.24068	0	180	0	20.75932	0	1	-1	-1	1.132739	0	2.075932	
12:16	12:15	21.00303	68.99697	-9.85813	170.1419	0.06545	21.00303	9.85813	1	-1	-1	1.132739	-0.35959	2.069291	
12:31	12:30	21.71749	68.28251	-19.3272	160.6728	0.1309	21.71749	19.32716	1	-1	-1	1.132739	-0.71877	2.049358	
12:46	12:45	22.85783	67.14217	-28.1134	151.8866	0.19635	22.85783	28.11345	1	-1	-1	1.132739	-1.0771	2.016098	
13:01	13:00	24.3631	65.6369	-36.0626	143.9374	0.261799	24.3631	36.06259	1	-1	-1	1.132739	-1.43418	1.969451	
13:16	13:15	26.16881	63.83119	-43.1452	136.8548	0.327249	26.16881	43.14525	1	-1	-1	1.132739	-1.78955	1.909335	
13:31	13:30	28.21541	61.78459	-49.4145	130.5855	0.392699	28.21541	49.41446	1	-1	-1	1.132739	-2.14278	1.835645	
13:46	13:45	30.45215	59.54785	-54.9635	125.0365	0.458149	30.45215	54.96351	1	-1	-1	1.132739	-2.49338	1.748252	
14:01	14:00	32.83774	57.16226	-59.8969	120.1031	0.523599	32.83774	59.89689	1	-1	-1	1.132739	-2.84087	1.647002	
14:16	14:15	35.33936	54.66064	-64.3144	115.6856	0.589049	35.33936	64.31444	1	-1	-1	1.132739	-3.18473	1.531721	
14:31	14:30	37.93113	52.06887	-68.3046	111.6954	0.654498	37.93113	68.3046	1	-1	-1	1.132739	-3.52442	1.402208	
14:46	14:45	40.5927	49.4073	-71.9427	108.0573	0.719948	40.5927	71.9427	1	-1	-1	1.132739	-3.85934	1.258243	
15:01	15:00	43.30787	46.69213	-75.2916	104.7084	0.785398	43.30787	75.29165	1	-1	-1	1.132739	-4.18887	1.099582	
15:16	15:15	46.06365	43.93635	-78.4035	101.5965	0.850848	46.06365	78.40354	1	-1	-1	1.132739	-4.51234	0.925959	
15:31	15:30	48.84945	41.15055	-81.3215	98.67852	0.916298	48.84945	81.32148	1	-1	-1	1.132739	-4.82902	0.737091	
15:46	15:45	51.65648	38.34352	-84.0812	95.91876	0.981748	51.65648	84.08124	1	-1	-1	1.132739	-5.13811	0.532673	
16:01	16:00	54.47731	35.52269	-86.7127	93.28728	1.047198	54.47731	86.71272	1	-1	-1	1.132739	-5.43877	0.312386	
16:16	16:15	57.30549	32.69451	-89.2411	90.75889	1.112647	57.30549	89.24111	1	-1	-1	1.132739	-5.73005	0.075899	
16:31	16:30	60.13534	29.86466	-91.6879	88.31211	1.178097	60.13534	88.31211	-1	-1	-1	1.132739	-6.01092	-0.17713	
16:46	16:45	62.96171	27.03829	-94.0716	85.92844	1.243547	62.96171	85.92844	-1	-1	-1	1.132739	-6.28028	-0.44704	
17:01	17:00	65.77983	24.22017	-96.4083	83.59173	1.308997	65.77983	83.59173	-1	-1	-1	1.132739	-6.53688	-0.73418	
17:16	17:15	68.58519	21.41481	-98.7123	81.28769	1.374447	68.58519	81.28769	-1	-1	-1	1.132739	-6.77938	-1.03888	
17:31	17:30	71.3734	18.6266	-100.997	79.00349	1.439897	71.3734	79.00349	-1	-1	-1	1.132739	-7.00629	-1.36144	
17:46	17:45	74.14014	15.85986	-103.273	76.72744	1.505346	74.14014	76.72744	-1	-1	-1	1.132739	-7.21598	-1.70214	
18:01	18:00	76.88107	13.11893	-105.551	74.44877	1.570796	76.88107	74.44877	-1	-1	-1	1.132739	-7.40665	-2.06118	
18:16	18:15	79.59174	10.40826	-107.843	72.1574	1.636246	79.59174	72.1574	-1	-1	-1	1.132739	-7.57635	-2.43872	
18:31	18:30	82.26758	7.732423	-110.156	69.84379	1.701696	82.26758	69.84379	-1	-1	-1	1.132739	-7.72292	-2.83478	
18:46	18:45	84.90377	5.096232	-112.501	67.49881	1.767146	84.90377	67.49881	-1	-1	-1	1.132739	-7.84402	-3.24929	
19:01	19:00	87.49525	2.50475	-114.886	65.11365	1.832596	87.49525	65.11365	-1	-1	-1	1.132739	-7.93708	-3.68197	
19:16	19:15	0	0	180	0	1.898046	90.03665	0	-1	-1	-1	1.132739	0	0	
19:31	19:30	0	0	180	0	1.963495	92.52221	0	-1	-1	-1	1.132739	0	0	
19:46	19:45	0	0	180	0	2.028945	94.94581	0	-1	-1	-1	1.132739	0	0	
20:01	20:00	0	0	180	0	2.094395	97.30084	0	-1	-1	-1	1.132739	0	0	

Solar angle data calculation sheet

Input parameters:

Location parameters

latitude -41 degrees -0.71558 radians
 longitude 176 degrees 3.071779 radians
 standard meridian 180 degrees 3.141593 radians

Time of year

Julian day number 293
 declination -11.4031 degrees -0.19902 radians
 equon of time 15.36044 minutes B= 5.026548

Results:

Time of day 24 hour decimal	Clock time	Solar time	Zenith angle (degrees)	Altitude angle (degrees)	Azimuth angle (degEofN)	Azimuth angle (degWofS)	hour angle theta (radians)	gammas' (degrees)	C1	C2	C3	wew	X	Y	
4:30	4:30		0	0	180	0	-1.9635	98.82425	0	-1	-1	-1	1.336643	0	0
4:45	4:45		0	0	180	0	-1.89805	96.20552	0	-1	-1	-1	1.336643	0	0
5:00	5:00		0	0	180	0	-1.8326	93.54129	0	-1	-1	-1	1.336643	0	0
5:15	5:15		0	0	180	0	-1.76715	90.83772	0	-1	-1	-1	1.336643	0	0
5:30	5:30	88.1006	1.899404	103.4905	-76.5095	-1.7017	88.1006	-76.5095	-1	-1	-1	1.336643	8.566977	-2.05525	
5:45	5:45	85.33535	4.664651	101.0643	-78.9357	-1.63625	85.33535	-78.9357	-1	-1	-1	1.336643	8.374917	-1.63768	
6:00	6:00	82.54719	7.452813	98.65504	-81.345	-1.5708	82.54719	-81.345	-1	-1	-1	1.336643	8.160716	-1.24221	
6:15	6:15	79.74114	10.25886	96.25153	-83.7485	-1.50535	79.74114	-83.7485	-1	-1	-1	1.336643	7.926696	-0.86833	
6:30	6:30	76.92217	13.07783	93.84223	-86.1578	-1.4399	76.92217	-86.1578	-1	-1	-1	1.336643	7.674927	-0.51545	
6:45	6:45	74.0952	15.9048	91.41506	-88.5849	-1.37445	74.0952	-88.5849	-1	-1	-1	1.336643	7.40726	-0.18298	
7:00	7:00	71.26527	18.73473	88.9572	-91.0428	-1.309	71.26527	-88.9572	1	-1	-1	1.336643	7.125347	0.129697	
7:15	7:15	68.4376	21.5624	86.45491	-93.5451	-1.24355	68.4376	-86.4549	1	-1	-1	1.336643	6.830664	0.423177	
7:30	7:30	65.61768	24.38232	83.89325	-96.1068	-1.1781	65.61768	-83.8932	1	-1	-1	1.336643	6.524533	0.698049	
7:45	7:45	62.81146	27.18854	81.2558	-98.7442	-1.11265	62.81146	-81.2558	1	-1	-1	1.336643	6.208139	0.95488	
8:00	8:00	60.02543	29.97457	78.52439	-101.476	-1.0472	60.02543	-78.5244	1	-1	-1	1.336643	5.882549	1.19421	
8:15	8:15	57.26685	32.73315	75.67869	-104.321	-0.98175	57.26685	-75.6787	1	-1	-1	1.336643	5.548721	1.416549	
8:30	8:30	54.54393	35.45607	72.69586	-107.304	-0.9163	54.54393	-72.6959	1	-1	-1	1.336643	5.207523	1.622375	
8:45	8:45	51.86609	38.13391	69.55017	-110.45	-0.85085	51.86609	-69.5502	1	-1	-1	1.336643	4.859741	1.812134	
9:00	9:00	49.24426	40.75574	66.21262	-113.787	-0.7854	49.24426	-66.2126	1	-1	-1	1.336643	4.506088	1.986236	
9:15	9:15	46.69123	43.30877	62.65069	-117.349	-0.71995	46.69123	-62.6507	1	-1	-1	1.336643	4.147219	2.145061	
9:30	9:30	44.22208	45.77792	58.82831	-121.172	-0.6545	44.22208	-58.8283	1	-1	-1	1.336643	3.78373	2.288954	
9:45	9:45	41.85457	48.14543	54.70626	-125.294	-0.58905	41.85457	-54.7063	1	-1	-1	1.336643	3.416173	2.418225	
10:00	10:00	39.60967	50.39033	50.24325	-129.757	-0.5236	39.60967	-50.2433	1	-1	-1	1.336643	3.045059	2.533156	
10:15	10:15	37.51191	52.48809	45.39823	-134.602	-0.45815	37.51191	-45.3982	1	-1	-1	1.336643	2.670864	2.633993	
10:30	10:30	35.58956	54.41044	40.1342	-139.866	-0.3927	35.58956	-40.1342	1	-1	-1	1.336643	2.294033	2.720953	
10:45	10:45	33.87456	56.12544	34.42431	-145.576	-0.32725	33.87456	-34.4243	1	-1	-1	1.336643	1.914986	2.794223	
11:00	11:00	32.40158	57.59842	28.25992	-151.74	-0.2618	32.40158	-28.2599	1	-1	-1	1.336643	1.534125	2.85396	
11:15	11:15	31.20641	58.79359	21.66015	-158.34	-0.19635	31.20641	-21.6602	1	-1	-1	1.336643	1.15183	2.900291	
11:30	11:30	30.32306	59.67694	14.68048	-165.32	-0.1309	30.32306	-14.6805	1	-1	-1	1.336643	0.768472	2.933314	
11:45	11:45	29.78015	60.21985	7.41661	-172.583	-0.06545	29.78015	-7.41661	1	-1	-1	1.336643	0.384411	2.9531	
12:00	12:00	29.59691	60.40309	0	180	0	29.59691	0	1	-1	1	1.336643	0	2.959691	
12:15	12:15	29.78015	60.21985	-7.41661	172.5834	0.06545	29.78015	7.41661	1	-1	1	1.336643	-0.38441	2.9531	
12:30	12:30	30.32306	59.67694	-14.6805	165.3195	0.1309	30.32306	14.68048	1	-1	1	1.336643	-0.76847	2.933314	
12:45	12:45	31.20641	58.79359	-21.6602	158.3398	0.19635	31.20641	21.66015	1	-1	1	1.336643	-1.15183	2.900291	
13:00	13:00	32.40158	57.59842	-28.2599	151.7401	0.261799	32.40158	28.25992	1	-1	1	1.336643	-1.53412	2.85396	
13:15	13:15	33.87456	56.12544	-34.4243	145.5757	0.327249	33.87456	34.42431	1	-1	1	1.336643	-1.91499	2.794223	
13:30	13:30	35.58956	54.41044	-40.1342	139.8658	0.392699	35.58956	40.1342	1	-1	1	1.336643	-2.29403	2.720953	
13:45	13:45	37.51191	52.48809	-45.3982	134.6018	0.458149	37.51191	45.39823	1	-1	1	1.336643	-2.67086	2.633993	
14:00	14:00	39.60967	50.39033	-50.2433	129.7567	0.523599	39.60967	50.24325	1	-1	1	1.336643	-3.04506	2.533156	
14:15	14:15	41.85457	48.14543	-54.7063	125.2937	0.589049	41.85457	54.70626	1	-1	1	1.336643	-3.41617	2.418225	
14:30	14:30	44.22208	45.77792	-58.8283	121.1717	0.654498	44.22208	58.82831	1	-1	1	1.336643	-3.78373	2.288954	
14:45	14:45	46.69123	43.30877	-62.6507	117.3493	0.719948	46.69123	62.65069	1	-1	1	1.336643	-4.14722	2.145061	
15:00	15:00	49.24426	40.75574	-66.2126	113.7874	0.785398	49.24426	66.21262	1	-1	1	1.336643	-4.50609	1.986236	
15:15	15:15	51.86609	38.13391	-69.5502	110.4498	0.850848	51.86609	69.55017	1	-1	1	1.336643	-4.85974	1.812134	
15:30	15:30	54.54393	35.45607	-72.6959	107.3041	0.916298	54.54393	72.69586	1	-1	1	1.336643	-5.20752	1.622375	
15:45	15:45	57.26685	32.73315	-75.6787	104.3213	0.981748	57.26685	75.67869	1	-1	1	1.336643	-5.54872	1.416549	
16:00	16:00	60.02543	29.97457	-78.5244	101.4756	1.047198	60.02543	78.52439	1	-1	1	1.336643	-5.88255	1.19421	
16:15	16:15	62.81146	27.18854	-81.2558	98.7442	1.112647	62.81146	81.2558	1	-1	1	1.336643	-6.20814	0.95488	
16:30	16:30	65.61768	24.38232	-83.8932	96.10675	1.178097	65.61768	83.89325	1	-1	1	1.336643	-6.52453	0.698049	
16:45	16:45	68.4376	21.5624	-86.4549	93.54509	1.243547	68.4376	86.45491	1	-1	1	1.336643	-6.83066	0.423177	
17:00	17:00	71.26527	18.73473	-88.9572	91.0428	1.308997	71.26527	88.9572	1	-1	1	1.336643	-7.12535	0.129697	
17:15	17:15	74.0952	15.9048	-91.4151	88.58494	1.374447	74.0952	88.58494	-1	-1	1	1.336643	-7.40726	-0.18298	
17:30	17:30	76.92217	13.07783	-93.8422	86.15777	1.439897	76.92217	86.15777	-1	-1	1	1.336643	-7.67493	-0.51545	
17:45	17:45	79.74114	10.25886	-96.2515	83.74847	1.505346	79.74114	83.74847	-1	-1	1	1.336643	-7.9267	-0.86833	
18:00	18:00	82.54719	7.452813	-98.655	81.34496	1.570796	82.54719	81.34496	-1	-1	1	1.336643	-8.16072	-1.24221	
18:15	18:15	85.33535	4.664651	-101.064	78.93568	1.636246	85.33535	78.93568	-1	-1	1	1.336643	-8.37492	-1.63768	
18:30	18:30	88.1006	1.899404	-103.491	76.50947	1.701696	88.1006	76.50947	-1	-1	1	1.336643	-8.56698	-2.05525	
18:45	18:45		0	0	180	0	1.767146	90.83772	0	-1	-1	1	1.336643	0	0
19:00	19:00		0	0	180	0	1.832596	93.54129	0	-1	-1	1	1.336643	0	0
19:15	19:15		0	0	180	0	1.898046	96.20552	0	-1	-1	1	1.336643	0	0
19:30	19:30		0	0	180	0	1.963495	98.82425	0	-1	-1	1	1.336643	0	0
19:45	19:45		0	0	180	0	2.028945	101.3909	0	-1	-1	1	1.336643	0	0
20:00	20:00		0	0	180	0	2.094395	103.8981	0	-1	-1	1	1.336643	0	0

Solar angle data calculation sheet

Input parameters:

Location parameters

latitude -41 degrees -0.71558 radians
 longitude 176 degrees 3.071779 radians
 standard meridian 180 degrees 3.141593 radians

Time of year

Julian day number 262
 declination 0.605442 degrees 0.010567 radians
 eqn of time 6.14873 minutes B= 4.492908

Results:

Time of day 24 hour decimal	Clock time	Solar time	Zenith angle (degrees)	Altitude angle (degrees)	Azimuth angle (degEofN)	Azimuth angle (degWofS)	hour angle theta (radians)	gammas ¹ (degrees)	C1	C2	C3	wew	X	Y	
4.39	4:30	4:30	0	0	180	0	-1.9635	107.2014	0	-1	-1	-1	1.582953	0	0
4.54	4:45	4:45	0	0	180	0	-1.89805	104.4487	0	-1	-1	-1	1.582953	0	0
5.09	5:00	5:00	0	0	180	0	-1.8326	101.6688	0	-1	-1	-1	1.582953	0	0
5.24	5:15	5:15	0	0	180	0	-1.76715	98.86813	0	-1	-1	-1	1.582953	0	0
5.39	5:30	5:30	0	0	180	0	-1.7017	96.0523	0	-1	-1	-1	1.582953	0	0
5.54	5:45	5:45	0	0	180	0	-1.63625	93.22689	0	-1	-1	-1	1.582953	0	0
6.09	6:00	6:00	0	0	0	-180	-1.5708	90.3972	0	1	-1	-1	1.582953	0	0
6.24	6:15	6:15	87.56849	2.431514	87.08086	-92.9191	-1.50535	87.56849	-87.0809	1	-1	-1	1.582953	8.745486	0.445957
6.39	6:30	6:30	84.74598	5.254018	84.60636	-95.3936	-1.4399	84.74598	-84.6064	1	-1	-1	1.582953	8.437076	0.796594
6.54	6:45	6:45	81.93503	8.064969	82.1074	-97.8926	-1.37445	81.93503	-82.1074	1	-1	-1	1.582953	8.115888	1.125104
7.09	7:00	7:00	79.14117	10.85883	79.57158	-100.428	-1.309	79.14117	-79.5716	1	-1	-1	1.582953	7.78339	1.43251
7.24	7:15	7:15	76.37021	13.62979	76.98607	-103.014	-1.24355	76.37021	-76.9861	1	-1	-1	1.582953	7.440867	1.719765
7.39	7:30	7:30	73.62838	16.37162	74.33752	-105.662	-1.1781	73.62838	-74.3375	1	-1	-1	1.582953	7.089446	1.987746
7.54	7:45	7:45	70.9224	19.0776	71.61191	-108.388	-1.11265	70.9224	-71.6119	1	-1	-1	1.582953	6.730122	2.23726
8.09	8:00	8:00	68.25963	21.74037	68.7945	-111.206	-1.0472	68.25963	-68.7945	1	-1	-1	1.582953	6.363771	2.469047
8.24	8:15	8:15	65.64819	24.35181	65.8697	-114.13	-0.98175	65.64819	-65.8697	1	-1	-1	1.582953	5.991173	2.683784
8.39	8:30	8:30	63.09709	26.90291	62.82111	-117.179	-0.9163	63.09709	-62.8211	1	-1	-1	1.582953	5.613021	2.882087
8.54	8:45	8:45	60.6164	29.3836	59.63157	-120.368	-0.85085	60.6164	-59.6316	1	-1	-1	1.582953	5.229937	3.064513
9.09	9:00	9:00	58.21737	31.78263	56.28332	-123.717	-0.7854	58.21737	-56.2833	1	-1	-1	1.582953	4.842478	3.231568
9.24	9:15	9:15	55.91262	34.08738	52.75835	-127.242	-0.71995	55.91262	-52.7583	1	-1	-1	1.582953	4.451149	3.383709
9.39	9:30	9:30	53.71618	36.28382	49.03896	-130.961	-0.6545	53.71618	-49.039	1	-1	-1	1.582953	4.056407	3.521341
9.54	9:45	9:45	51.64364	38.35636	45.10858	-134.891	-0.58905	51.64364	-45.1086	1	-1	-1	1.582953	3.658671	3.64483
10.09	10:00	10:00	49.7121	40.2879	40.95295	-139.047	-0.5236	49.7121	-40.9529	1	-1	-1	1.582953	3.258325	3.754497
10.24	10:15	10:15	47.94002	42.05998	36.5616	-143.438	-0.45815	47.94002	-36.5616	1	-1	-1	1.582953	2.855723	3.850623
10.39	10:30	10:30	46.34698	43.65302	31.92979	-148.07	-0.3927	46.34698	-31.9298	1	-1	-1	1.582953	2.451197	3.933454
10.54	10:45	10:45	44.95314	45.04686	27.06049	-152.94	-0.32725	44.95314	-27.0605	1	-1	-1	1.582953	2.045057	4.003197
11.09	11:00	11:00	43.77846	46.22154	21.9665	-158.034	-0.2618	43.77846	-21.9665	1	-1	-1	1.582953	1.637596	4.060027
11.24	11:15	11:15	42.84177	47.15823	16.67195	-163.328	-0.19635	42.84177	-16.672	1	-1	-1	1.582953	1.229095	4.104084
11.39	11:30	11:30	42.15954	47.84046	11.213	-168.787	-0.1309	42.15954	-11.213	1	-1	-1	1.582953	0.819821	4.135476
11.54	11:45	11:45	41.74468	48.25532	5.636972	-174.363	-0.06545	41.74468	-5.63697	1	-1	-1	1.582953	0.410037	4.154281
12.09	12:00	12:00	41.60544	48.39456	0	180	0	41.60544	0	1	-1	1	1.582953	0	4.160544
12.24	12:15	12:15	41.74468	48.25532	-5.63697	174.363	0.06545	41.74468	5.636972	1	-1	1	1.582953	-0.41004	4.154281
12.39	12:30	12:30	42.15954	47.84046	-11.213	168.787	0.1309	42.15954	11.213	1	-1	1	1.582953	-0.81982	4.135476
12.54	12:45	12:45	42.84177	47.15823	-16.672	163.328	0.19635	42.84177	16.67195	1	-1	1	1.582953	-1.22909	4.104084
13.09	13:00	13:00	43.77846	46.22154	-21.9665	158.035	0.261799	43.77846	21.9665	1	-1	1	1.582953	-1.6376	4.060027
13.24	13:15	13:15	44.95314	45.04686	-27.0605	152.9395	0.327249	44.95314	27.06049	1	-1	1	1.582953	-2.04506	4.003197
13.39	13:30	13:30	46.34698	43.65302	-31.9298	148.0702	0.392699	46.34698	31.92979	1	-1	1	1.582953	-2.4512	3.933454
13.54	13:45	13:45	47.94002	42.05998	-36.5616	143.4384	0.458149	47.94002	36.5616	1	-1	1	1.582953	-2.85572	3.850623
14.09	14:00	14:00	49.7121	40.2879	-40.9529	139.0471	0.523599	49.7121	40.95295	1	-1	1	1.582953	-3.25832	3.754497
14.24	14:15	14:15	51.64364	38.35636	-45.1086	134.8914	0.589049	51.64364	45.10858	1	-1	1	1.582953	-3.65867	3.64483
14.39	14:30	14:30	53.71618	36.28382	-49.039	130.961	0.654498	53.71618	49.03896	1	-1	1	1.582953	-4.05641	3.521341
14.54	14:45	14:45	55.91262	34.08738	-52.7583	127.2417	0.719948	55.91262	52.75835	1	-1	1	1.582953	-4.45115	3.383709
15.09	15:00	15:00	58.21737	31.78263	-56.2833	123.7167	0.785398	58.21737	56.28332	1	-1	1	1.582953	-4.84248	3.231568
15.24	15:15	15:15	60.6164	29.3836	-59.6316	120.3684	0.850848	60.6164	59.63157	1	-1	1	1.582953	-5.22994	3.064513
15.39	15:30	15:30	63.09709	26.90291	-62.8211	117.1789	0.916298	63.09709	62.82111	1	-1	1	1.582953	-5.61302	2.882087
15.54	15:45	15:45	65.64819	24.35181	-65.8697	114.1303	0.981748	65.64819	65.8697	1	-1	1	1.582953	-5.99117	2.683784
16.09	16:00	16:00	68.25963	21.74037	-68.7945	111.2055	1.047198	68.25963	68.7945	1	-1	1	1.582953	-6.36377	2.469047
16.24	16:15	16:15	70.9224	19.0776	-71.6119	108.3881	1.112647	70.9224	71.61191	1	-1	1	1.582953	-6.73012	2.23726
16.39	16:30	16:30	73.62838	16.37162	-74.3375	105.6625	1.178097	73.62838	74.33752	1	-1	1	1.582953	-7.08945	1.987746
16.54	16:45	16:45	76.37021	13.62979	-76.9861	103.0139	1.243547	76.37021	76.98607	1	-1	1	1.582953	-7.44087	1.719765
17.09	17:00	17:00	79.14117	10.85883	-79.5716	100.4284	1.308997	79.14117	79.57158	1	-1	1	1.582953	-7.78339	1.43251
17.24	17:15	17:15	81.93503	8.064969	-82.1074	97.8926	1.374447	81.93503	82.1074	1	-1	1	1.582953	-8.11589	1.125104
17.39	17:30	17:30	84.74598	5.254018	-84.6064	95.39364	1.439897	84.74598	84.60636	1	-1	1	1.582953	-8.43708	0.796594
17.54	17:45	17:45	87.56849	2.431514	-87.0809	92.91914	1.505346	87.56849	87.08086	1	-1	1	1.582953	-8.74549	0.445957
18.09	18:00	18:00	0	0	0	180	1.570796	90.3972	0	1	-1	1	1.582953	0	0
18.24	18:15	18:15	0	0	180	0	1.636246	93.22689	0	-1	-1	1	1.582953	0	0
18.39	18:30	18:30	0	0	180	0	1.701696	96.0523	0	-1	-1	1	1.582953	0	0
18.54	18:45	18:45	0	0	180	0	1.767146	98.86813	0	-1	-1	1	1.582953	0	0
19.09	19:00	19:00	0	0	180	0	1.832596	101.6688	0	-1	-1	1	1.582953	0	0
19.24	19:15	19:15	0	0	180	0	1.898046	104.4487	0	-1	-1	1	1.582953	0	0
19.39	19:30	19:30	0	0	180	0	1.963495	107.2014	0	-1	-1	1	1.582953	0	0
19.54	19:45	19:45	0	0	180	0	2.028945	109.9203	0	-1	-1	1	1.582953	0	0
20.09	20:00	20:00	0	0	180	0	2.094395	112.5982	0	-1	-1	1	1.582953	0	0

Solar angle data calculation sheet

Input parameters:

Location parameters

latitude -41 degrees -0.71558 radians
 longitude 176 degrees 3.071779 radians
 standard meridian 180 degrees 3.141593 radians

Time of year

Julian day number **231**
 declination 12.44562 degrees 0.217217 radians
 equn of time -4.04826 minutes B= 3.959267

Results:

Time of day 24 hour decimal	Clock time	Solar time	Zenith angle (degrees)	Altitude angle (degrees)	Azimuth angle (degEofN)	Azimuth angle (degWofS)	hour angle theta (radians)	gammas'	C1	C2	C3	wew	X	Y	
4:50	4:30		0	0	180	0	-1.9635	115.0505	0	-1	-1	-1	1.827491	0	0
5:05	4:45		0	0	180	0	-1.89805	112.2273	0	-1	-1	-1	1.827491	0	0
5:20	5:00		0	0	180	0	-1.8326	109.3982	0	-1	-1	-1	1.827491	0	0
5:35	5:15		0	0	0	-180	-1.76715	106.5688	0	1	-1	-1	1.827491	0	0
5:50	5:30		0	0	0	-180	-1.7017	103.744	0	1	-1	-1	1.827491	0	0
6:05	5:45		0	0	0	-180	-1.63625	100.9288	0	1	-1	-1	1.827491	0	0
6:20	6:00		0	0	0	-180	-1.5708	98.12824	0	1	-1	-1	1.827491	0	0
6:35	6:15		0	0	0	-180	-1.50535	95.34708	0	1	-1	-1	1.827491	0	0
6:50	6:30		0	0	0	-180	-1.4399	92.59035	0	1	-1	-1	1.827491	0	0
7:05	6:45	89.86321	0.13679	73.28367	-106.716	-1.37445	89.86321	-73.2837	1	-1	-1	1.827491	8.606564	2.584768	
7:20	7:00	87.17108	2.828919	70.80035	-109.2	-1.309	87.17108	-70.8004	1	-1	-1	1.827491	8.232249	2.866715	
7:35	7:15	84.5197	5.480303	68.26774	-111.732	-1.24355	84.5197	-68.2677	1	-1	-1	1.827491	7.85124	3.129509	
7:50	7:30	81.91519	8.084813	65.67533	-114.325	-1.1781	81.91519	-65.6753	1	-1	-1	1.827491	7.464325	3.374142	
8:05	7:45	79.36415	10.63585	63.01259	-116.987	-1.11265	79.36415	-63.0126	1	-1	-1	1.827491	7.072189	3.601503	
8:20	8:00	76.87371	13.12629	60.26901	-119.731	-1.0472	76.87371	-60.269	1	-1	-1	1.827491	6.675432	3.812386	
8:35	8:15	74.45162	15.54838	57.43407	-122.566	-0.98175	74.45162	-57.4341	1	-1	-1	1.827491	6.274579	4.007505	
8:50	8:30	72.10627	17.89373	54.49743	-125.503	-0.9163	72.10627	-54.4974	1	-1	-1	1.827491	5.870095	4.187496	
9:05	8:45	69.84677	20.15323	51.44901	-128.551	-0.85085	69.84677	-51.449	1	-1	-1	1.827491	5.462394	4.352926	
9:20	9:00	67.683	22.317	48.2793	-131.721	-0.7854	67.683	-48.2793	1	-1	-1	1.827491	5.051845	4.504304	
9:35	9:15	65.62559	24.37441	44.97962	-135.02	-0.71995	65.62559	-44.9796	1	-1	-1	1.827491	4.638779	4.64208	
9:50	9:30	63.68588	26.31412	41.54257	-138.457	-0.6545	63.68588	-41.5426	1	-1	-1	1.827491	4.223497	4.766654	
10:05	9:45	61.8759	28.1241	37.96253	-142.037	-0.58905	61.8759	-37.9625	1	-1	-1	1.827491	3.806271	4.878378	
10:20	10:00	60.20821	29.79179	34.23624	-145.764	-0.5236	60.20821	-34.2362	1	-1	-1	1.827491	3.387353	4.977563	
10:35	10:15	58.6957	31.3043	30.36347	-149.637	-0.45815	58.6957	-30.3635	1	-1	-1	1.827491	2.966972	5.064477	
10:50	10:30	57.3513	32.6487	26.34763	-153.652	-0.3927	57.3513	-26.3476	1	-1	-1	1.827491	2.545344	5.139352	
11:05	10:45	56.18768	33.81232	22.19638	-157.804	-0.32725	56.18768	-22.1964	1	-1	-1	1.827491	2.122671	5.202386	
11:20	11:00	55.21674	34.78326	17.92201	-162.078	-0.2618	55.21674	-17.922	1	-1	-1	1.827491	1.699141	5.253742	
11:35	11:15	54.44919	35.55081	13.54163	-166.458	-0.19635	54.44919	-13.5416	1	-1	-1	1.827491	1.274937	5.29355	
11:50	11:30	53.89403	36.10597	9.076914	-170.923	-0.1309	53.89403	-9.07691	1	-1	-1	1.827491	0.850233	5.321914	
12:05	11:45	53.55808	36.44192	4.553517	-175.446	-0.06545	53.55808	-4.55352	1	-1	-1	1.827491	0.425199	5.338903	
12:20	12:00	53.44562	36.55438	0	180	0	53.44562	0	1	-1	1	1.827491	0	5.344562	
12:35	12:15	53.55808	36.44192	-4.55352	175.4465	0.06545	53.55808	4.553517	1	-1	1	1.827491	-0.4252	5.338903	
12:50	12:30	53.89403	36.10597	-9.07691	170.9231	0.1309	53.89403	9.076914	1	-1	1	1.827491	-0.85023	5.321914	
13:05	12:45	54.44919	35.55081	-13.5416	166.4584	0.19635	54.44919	13.54163	1	-1	1	1.827491	-1.27494	5.29355	
13:20	13:00	55.21674	34.78326	-17.922	162.078	0.261799	55.21674	17.92201	1	-1	1	1.827491	-1.69914	5.253742	
13:35	13:15	56.18768	33.81232	-22.1964	157.8036	0.327249	56.18768	22.19638	1	-1	1	1.827491	-2.12267	5.202386	
13:50	13:30	57.3513	32.6487	-26.3476	153.6524	0.392699	57.3513	26.34763	1	-1	1	1.827491	-2.54534	5.139352	
14:05	13:45	58.6957	31.3043	-30.3635	149.6365	0.458149	58.6957	30.36347	1	-1	1	1.827491	-2.96697	5.064477	
14:20	14:00	60.20821	29.79179	-34.2362	145.7638	0.523599	60.20821	34.23624	1	-1	1	1.827491	-3.38735	4.977563	
14:35	14:15	61.8759	28.1241	-37.9625	142.0375	0.589049	61.8759	37.96253	1	-1	1	1.827491	-3.80627	4.878378	
14:50	14:30	63.68588	26.31412	-41.5426	138.4574	0.654498	63.68588	41.54257	1	-1	1	1.827491	-4.2235	4.766654	
15:05	14:45	65.62559	24.37441	-44.9796	135.0204	0.719948	65.62559	44.97962	1	-1	1	1.827491	-4.63878	4.64208	
15:20	15:00	67.683	22.317	-48.2793	131.7207	0.785398	67.683	48.2793	1	-1	1	1.827491	-5.05184	4.504304	
15:35	15:15	69.84677	20.15323	-51.449	128.551	0.850848	69.84677	51.44901	1	-1	1	1.827491	-5.46239	4.352926	
15:50	15:30	72.10627	17.89373	-54.4974	125.5026	0.916298	72.10627	54.49743	1	-1	1	1.827491	-5.8701	4.187496	
16:05	15:45	74.45162	15.54838	-57.4341	122.5659	0.981748	74.45162	57.43407	1	-1	1	1.827491	-6.27458	4.007505	
16:20	16:00	76.87371	13.12629	-60.269	119.731	1.047198	76.87371	60.26901	1	-1	1	1.827491	-6.67543	3.812386	
16:35	16:15	79.36415	10.63585	-63.0126	116.9874	1.112647	79.36415	63.01259	1	-1	1	1.827491	-7.07219	3.601503	
16:50	16:30	81.91519	8.084813	-65.6753	114.3247	1.178097	81.91519	65.67533	1	-1	1	1.827491	-7.46432	3.374142	
17:05	16:45	84.5197	5.480303	-68.2677	111.7323	1.243547	84.5197	68.26774	1	-1	1	1.827491	-7.85124	3.129509	
17:20	17:00	87.17108	2.828919	-70.8004	109.1996	1.308997	87.17108	70.80035	1	-1	1	1.827491	-8.23225	2.866715	
17:35	17:15	89.86321	0.13679	-73.2837	106.7163	1.374447	89.86321	73.28367	1	-1	1	1.827491	-8.60656	2.584768	
17:50	17:30		0	0	180	1.439897	92.59035	0	1	-1	1	1.827491	0	0	
18:05	17:45		0	0	180	1.505346	95.34708	0	1	-1	1	1.827491	0	0	
18:20	18:00		0	0	180	1.570796	98.12824	0	1	-1	1	1.827491	0	0	
18:35	18:15		0	0	180	1.636246	100.9288	0	1	-1	1	1.827491	0	0	
18:50	18:30		0	0	180	1.701696	103.744	0	1	-1	1	1.827491	0	0	
19:05	18:45		0	0	180	1.767146	106.5688	0	1	-1	1	1.827491	0	0	
19:20	19:00		0	0	180	1.832596	109.3982	0	-1	-1	1	1.827491	0	0	
19:35	19:15		0	0	180	1.898046	112.2273	0	-1	-1	1	1.827491	0	0	
19:50	19:30		0	0	180	1.963495	115.0505	0	-1	-1	1	1.827491	0	0	
20:05	19:45		0	0	180	2.028945	117.8621	0	-1	-1	1	1.827491	0	0	
20:20	20:00		0	0	180	2.094395	120.6556	0	-1	-1	1	1.827491	0	0	

Solar angle data calculation sheet

Input parameters:

Location parameters

latitude -41 degrees -0.71558 radians
 longitude 176 degrees 3.071779 radians
 standard meridian 180 degrees 3.141593 radians

Time of year

Julian day number 200
 declination 20.82494 degrees 0.363464 radians
 equn of time -6.19936 minutes B= 3.425627

Results:

Time of day 24 hour decimal	Clock time	Solar time	Zenith angle (degrees)	Altitude angle (degrees)	Azimuth angle (degEofN)	Azimuth angle (degWofS)	hour angle theta (radians)	gammas'	C1	C2	C3	wew	X	Y	
4:52	4:30	0	0	0	0	-180	-1.9635	120.2109	0	1	-1	-1	2.023676	0	0
5:07	4:45	0	0	0	0	-180	-1.89805	117.386	0	1	-1	-1	2.023676	0	0
5:22	5:00	0	0	0	0	-180	-1.8326	114.5704	0	1	-1	-1	2.023676	0	0
5:37	5:15	0	0	0	0	-180	-1.76715	111.7684	0	1	-1	-1	2.023676	0	0
5:52	5:30	0	0	0	0	-180	-1.7017	108.9845	0	1	-1	-1	2.023676	0	0
6:07	5:45	0	0	0	0	-180	-1.63625	106.2228	0	1	-1	-1	2.023676	0	0
6:22	6:00	0	0	0	0	-180	-1.5708	103.4878	0	1	-1	-1	2.023676	0	0
6:37	6:15	0	0	0	0	-180	-1.50535	100.7837	0	1	-1	-1	2.023676	0	0
6:52	6:30	0	0	0	0	-180	-1.4399	98.11522	0	1	-1	-1	2.023676	0	0
7:07	6:45	0	0	0	0	-180	-1.37445	95.48703	0	1	-1	-1	2.023676	0	0
7:22	7:00	0	0	0	0	-180	-1.309	92.90418	0	1	-1	-1	2.023676	0	0
7:37	7:15	0	0	0	0	-180	-1.24355	90.37203	0	1	-1	-1	2.023676	0	0
7:52	7:30	87.89627	2.103729	59.78076	-120.219	-1.1781	87.89627	-59.7808	1	-1	-1	2.023676	75.95168	44.23909	
8:07	7:45	85.48302	4.516984	57.23451	-122.765	-1.11265	85.48302	-57.2345	1	-1	-1	2.023676	71.88205	46.26357	
8:22	8:00	83.1388	6.861196	54.6158	-125.384	-1.0472	83.1388	-54.6158	1	-1	-1	2.023676	67.78203	48.14205	
8:37	8:15	80.87064	9.129358	51.9173	-128.083	-0.98175	80.87064	-51.9173	1	-1	-1	2.023676	63.655	49.88087	
8:52	8:30	78.68602	11.31398	49.13209	-130.868	-0.9163	78.68602	-49.1321	1	-1	-1	2.023676	59.50395	51.48563	
9:07	8:45	76.59294	13.40706	46.25386	-133.746	-0.85085	76.59294	-46.2539	1	-1	-1	2.023676	55.33154	52.96129	
9:22	9:00	74.59985	15.40015	43.27701	-136.723	-0.7854	74.59985	-43.277	1	-1	-1	2.023676	51.14015	54.31227	
9:37	9:15	72.71568	17.28432	40.19695	-139.803	-0.71995	72.71568	-40.197	1	-1	-1	2.023676	46.93194	55.54245	
9:52	9:30	70.94974	19.05026	37.01036	-142.99	-0.6545	70.94974	-37.0104	1	-1	-1	2.023676	42.70886	56.65526	
10:07	9:45	69.31164	20.68836	33.71543	-146.285	-0.58905	69.31164	-33.7154	1	-1	-1	2.023676	38.47271	57.65374	
10:22	10:00	67.81115	22.18885	30.31227	-149.688	-0.5236	67.81115	-30.3123	1	-1	-1	2.023676	34.22513	58.54052	
10:37	10:15	66.45804	23.54196	26.80311	-153.197	-0.45815	66.45804	-26.8031	1	-1	-1	2.023676	29.96766	59.31788	
10:52	10:30	65.26189	24.73811	23.19267	-156.807	-0.3927	65.26189	-23.1927	1	-1	-1	2.023676	25.70172	59.9878	
11:07	10:45	64.2318	25.7682	19.48832	-160.512	-0.32725	64.2318	-19.4883	1	-1	-1	2.023676	21.42868	60.55193	
11:22	11:00	63.37617	26.62383	15.70017	-164.3	-0.2618	63.37617	-15.7002	1	-1	-1	2.023676	17.1498	61.01167	
11:37	11:15	62.70236	27.29764	11.84102	-168.159	-0.19635	62.70236	-11.841	1	-1	-1	2.023676	12.86632	61.36811	
11:52	11:30	62.21648	27.78352	7.92614	-172.074	-0.1309	62.21648	-7.92614	1	-1	-1	2.023676	8.57943	61.6221	
12:07	11:45	61.92307	28.07693	3.972863	-176.027	-0.06545	61.92307	-3.97286	1	-1	-1	2.023676	4.290278	61.77426	
12:22	12:00	61.82494	28.17506	0	180	0	61.82494	0	1	-1	1	2.023676	0	61.82494	
12:37	12:15	61.92307	28.07693	-3.97286	176.0271	0.06545	61.92307	3.972863	1	-1	1	2.023676	-4.29028	61.77426	
12:52	12:30	62.21648	27.78352	-7.92614	172.0739	0.1309	62.21648	7.92614	1	-1	1	2.023676	-8.57943	61.6221	
13:07	12:45	62.70236	27.29764	-11.841	168.159	0.19635	62.70236	11.84102	1	-1	1	2.023676	-12.8663	61.36811	
13:22	13:00	63.37617	26.62383	-15.7002	164.2998	0.261799	63.37617	15.70017	1	-1	1	2.023676	-17.1498	61.01167	
13:37	13:15	64.2318	25.7682	-19.4883	160.5117	0.327249	64.2318	19.48832	1	-1	1	2.023676	-21.4287	60.55193	
13:52	13:30	65.26189	24.73811	-23.1927	156.8073	0.392699	65.26189	23.19267	1	-1	1	2.023676	-25.7017	59.9878	
14:07	13:45	66.45804	23.54196	-26.8031	153.1969	0.458149	66.45804	26.80311	1	-1	1	2.023676	-29.9677	59.31788	
14:22	14:00	67.81115	22.18885	-30.3123	149.6877	0.523599	67.81115	30.31227	1	-1	1	2.023676	-34.2251	58.54052	
14:37	14:15	69.31164	20.68836	-33.7154	146.2846	0.589049	69.31164	33.71543	1	-1	1	2.023676	-38.4727	57.65374	
14:52	14:30	70.94974	19.05026	-37.0104	142.9896	0.654498	70.94974	37.01036	1	-1	1	2.023676	-42.7089	56.65526	
15:07	14:45	72.71568	17.28432	-40.197	139.803	0.719948	72.71568	40.19695	1	-1	1	2.023676	-46.9319	55.54245	
15:22	15:00	74.59985	15.40015	-43.277	136.723	0.785398	74.59985	43.27701	1	-1	1	2.023676	-51.1402	54.31227	
15:37	15:15	76.59294	13.40706	-46.2539	133.7461	0.850848	76.59294	46.25386	1	-1	1	2.023676	-55.3315	52.96129	
15:52	15:30	78.68602	11.31398	-49.1321	130.8679	0.916298	78.68602	49.13209	1	-1	1	2.023676	-59.504	51.48563	
16:07	15:45	80.87064	9.129358	-51.9173	128.0827	0.981748	80.87064	51.9173	1	-1	1	2.023676	-63.655	49.88087	
16:22	16:00	83.1388	6.861196	-54.6158	125.3842	1.047198	83.1388	54.6158	1	-1	1	2.023676	-67.782	48.14205	
16:37	16:15	85.48302	4.516984	-57.2345	122.7655	1.112647	85.48302	57.23451	1	-1	1	2.023676	-71.882	46.26357	
16:52	16:30	87.89627	2.103729	-59.7808	120.2192	1.178097	87.89627	59.78076	1	-1	1	2.023676	-75.9517	44.23909	
17:07	16:45	0	0	0	180	1.243547	90.37203	0	1	-1	1	2.023676	0	0	
17:22	17:00	0	0	0	180	1.308997	92.90418	0	1	-1	1	2.023676	0	0	
17:37	17:15	0	0	0	180	1.374447	95.48703	0	1	-1	1	2.023676	0	0	
17:52	17:30	0	0	0	180	1.439897	98.11522	0	1	-1	1	2.023676	0	0	
18:07	17:45	0	0	0	180	1.505346	100.7837	0	1	-1	1	2.023676	0	0	
18:22	18:00	0	0	0	180	1.570796	103.4878	0	1	-1	1	2.023676	0	0	
18:37	18:15	0	0	0	180	1.636246	106.2228	0	1	-1	1	2.023676	0	0	
18:52	18:30	0	0	0	180	1.701696	108.9845	0	1	-1	1	2.023676	0	0	
19:07	18:45	0	0	0	180	1.767146	111.7684	0	1	-1	1	2.023676	0	0	
19:22	19:00	0	0	0	180	1.832596	114.5704	0	1	-1	1	2.023676	0	0	
19:37	19:15	0	0	0	180	1.898046	117.386	0	1	-1	1	2.023676	0	0	
19:52	19:30	0	0	0	180	1.963495	120.2109	0	1	-1	1	2.023676	0	0	
20:07	19:45	0	0	180	0	2.028945	123.0404	0	-1	-1	1	2.023676	0	0	
20:22	20:00	0	0	180	0	2.094395	125.8695	0	-1	-1	1	2.023676	0	0	

Solar angle data calculation sheet

Input parameters:

Location parameters

latitude -41 degrees -0.71558 radians
 longitude 176 degrees 3.071779 radians
 standard meridian 180 degrees 3.141593 radians

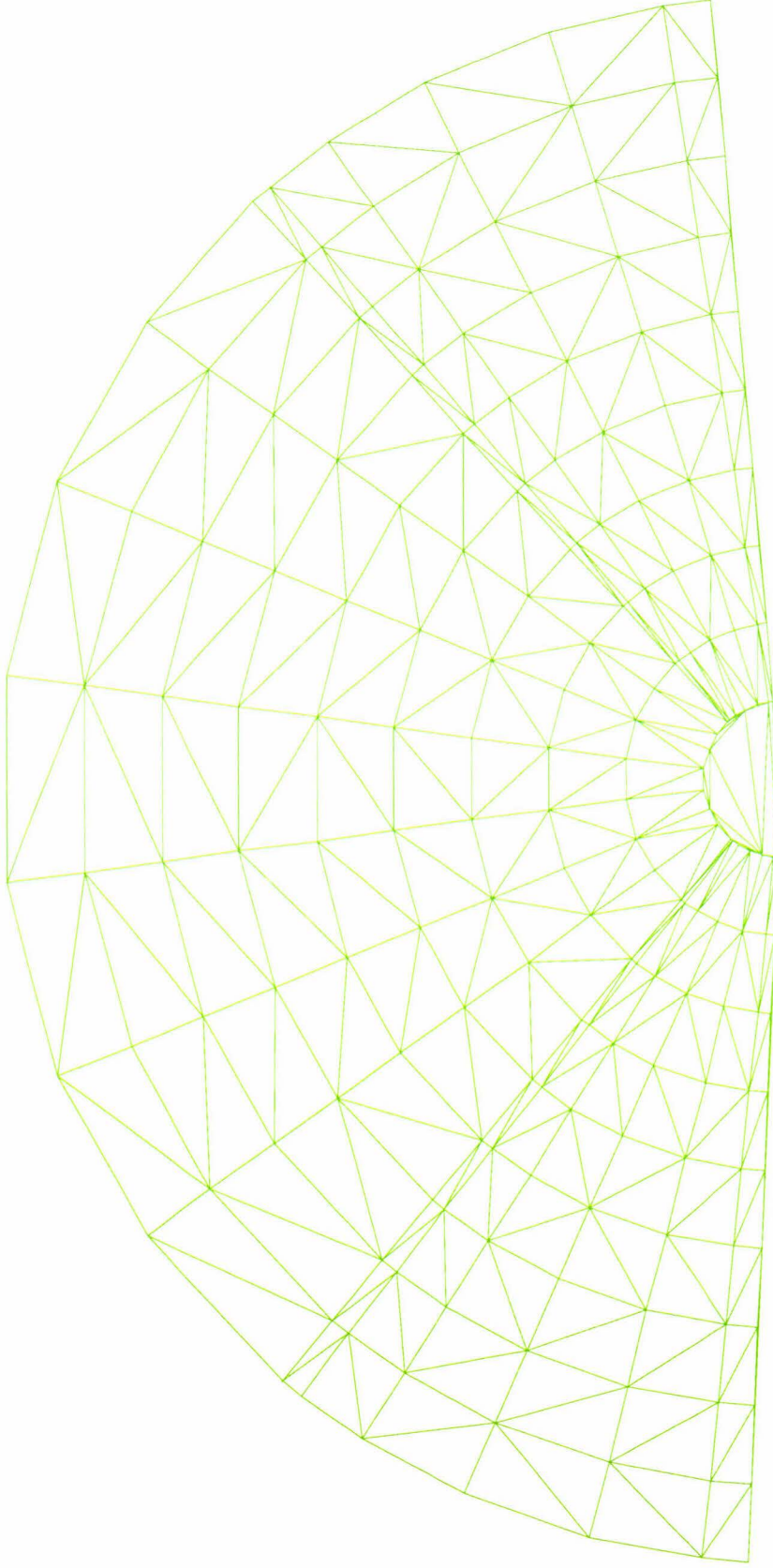
Time of year

Julian day number 172
 declination 23.44978 degrees 0.409276 radians
 equn of time -1.32473 minutes B= 2.943629

Results:

Time of day 24 hour decimal	Clock time	Solar time	Zenith angle (degrees)	Altitude angle (degrees)	Azimuth angle (degEofN)	Azimuth angle (degWofS)	hour angle theta (radians)	gamma's (degrees)	C1	C2	C3	wew	X	Y	
4.47	4.30		0	0	0	-180	-1.9635	121.7381	0	1	-1	-1	2.093236	0	0
5.02	4.45		0	0	0	-180	-1.89805	118.9229	0	1	-1	-1	2.093236	0	0
5.17	5.00		0	0	0	-180	-1.8326	116.1215	0	1	-1	-1	2.093236	0	0
5.32	5.15		0	0	0	-180	-1.76715	113.3378	0	1	-1	-1	2.093236	0	0
5.47	5.30		0	0	0	-180	-1.7017	110.576	0	1	-1	-1	2.093236	0	0
6.02	5.45		0	0	0	-180	-1.63625	107.84	0	1	-1	-1	2.093236	0	0
6.17	6.00		0	0	0	-180	-1.5708	105.1339	0	1	-1	-1	2.093236	0	0
6.32	6.15		0	0	0	-180	-1.50535	102.462	0	1	-1	-1	2.093236	0	0
6.47	6.30		0	0	0	-180	-1.4399	99.82864	0	1	-1	-1	2.093236	0	0
7.02	6.45		0	0	0	-180	-1.37445	97.23847	0	1	-1	-1	2.093236	0	0
7.17	7.00		0	0	0	-180	-1.309	94.69635	0	1	-1	-1	2.093236	0	0
7.32	7.15		0	0	0	-180	-1.24355	92.20747	0	1	-1	-1	2.093236	0	0
7.47	7.30	89.77735	0.222646	57.94964	-122.05	-1.1781	89.77735	-57.9496	1	-1	-1	2.093236	76.09367	47.64165	
8.02	7.45	87.41192	2.588084	55.45079	-124.549	-1.11265	87.41192	-55.4508	1	-1	-1	2.093236	71.9959	49.5725	
8.17	8.00	85.11746	4.882537	52.88189	-127.118	-1.0472	85.11746	-52.8819	1	-1	-1	2.093236	67.87209	51.36499	
8.32	8.15	82.90073	7.09927	50.23649	-129.764	-0.98175	82.90073	-50.2365	1	-1	-1	2.093236	63.72505	53.02499	
8.47	8.30	80.76889	9.231114	47.50864	-132.491	-0.9163	80.76889	-47.5086	1	-1	-1	2.093236	59.5573	54.55769	
9.02	8.45	78.72953	11.27047	44.69299	-135.307	-0.85085	78.72953	-44.693	1	-1	-1	2.093236	55.37108	55.96769	
9.17	9.00	76.79067	13.20933	41.78493	-138.215	-0.7854	76.79067	-41.7849	1	-1	-1	2.093236	51.16842	57.25906	
9.32	9.15	74.9607	15.0393	38.78086	-141.219	-0.71995	74.9607	-38.7809	1	-1	-1	2.093236	46.95114	58.43541	
9.47	9.30	73.24831	16.75169	35.67834	-144.322	-0.6545	73.24831	-35.6783	1	-1	-1	2.093236	42.72091	59.4999	
10.02	9.45	71.66241	18.33759	32.47639	-147.524	-0.58905	71.66241	-32.4764	1	-1	-1	2.093236	38.47928	60.45532	
10.17	10.00	70.21199	19.78801	29.17575	-150.824	-0.5236	70.21199	-29.1757	1	-1	-1	2.093236	34.22765	61.30409	
10.32	10.15	68.90601	21.09399	25.77905	-154.221	-0.45815	68.90601	-25.7791	1	-1	-1	2.093236	29.96736	62.04833	
10.47	10.30	67.75314	22.24686	22.29113	-157.709	-0.3927	67.75314	-22.2911	1	-1	-1	2.093236	25.69964	62.68984	
11.02	10.45	66.76161	23.23839	18.71906	-161.281	-0.32725	66.76161	-18.7191	1	-1	-1	2.093236	21.42567	63.23016	
11.17	11.00	65.93895	24.06105	15.07227	-164.928	-0.2618	65.93895	-15.0723	1	-1	-1	2.093236	17.14658	63.67056	
11.32	11.15	65.29173	24.70827	11.36245	-168.638	-0.19635	65.29173	-11.3624	1	-1	-1	2.093236	12.86344	64.01205	
11.47	11.30	64.82537	25.17463	7.603312	-172.397	-0.1309	64.82537	-7.60331	1	-1	-1	2.093236	8.577283	64.25542	
12.02	11.45	64.54389	25.45611	3.810287	-176.19	-0.06545	64.54389	-3.81029	1	-1	-1	2.093236	4.289138	64.40122	
12.17	12.00	64.44978	25.55022	0	180	0	64.44978	0	1	-1	1	2.093236	0	64.44978	
12.32	12.15	64.54389	25.45611	-3.81029	176.1897	0.06545	64.54389	3.810287	1	-1	-1	2.093236	-4.28914	64.40122	
12.47	12.30	64.82537	25.17463	-7.60331	172.3967	0.1309	64.82537	7.603312	1	-1	1	2.093236	-8.57728	64.25542	
13.02	12.45	65.29173	24.70827	-11.3624	168.6376	0.19635	65.29173	11.36245	1	-1	1	2.093236	-12.8634	64.01205	
13.17	13.00	65.93895	24.06105	-15.0723	164.9277	0.261799	65.93895	15.07227	1	-1	1	2.093236	-17.1466	63.67056	
13.32	13.15	66.76161	23.23839	-18.7191	161.2809	0.327249	66.76161	18.71906	1	-1	1	2.093236	-21.4257	63.23016	
13.47	13.30	67.75314	22.24686	-22.2911	157.7089	0.392699	67.75314	22.29113	1	-1	1	2.093236	-25.6996	62.68984	
14.02	13.45	68.90601	21.09399	-25.7791	154.2209	0.458149	68.90601	25.77905	1	-1	1	2.093236	-29.9674	62.04833	
14.17	14.00	70.21199	19.78801	-29.1757	150.8243	0.523599	70.21199	29.17575	1	-1	1	2.093236	-34.2277	61.30409	
14.32	14.15	71.66241	18.33759	-32.4764	147.5236	0.589049	71.66241	32.47639	1	-1	1	2.093236	-38.4793	60.45532	
14.47	14.30	73.24831	16.75169	-35.6783	144.3217	0.654498	73.24831	35.67834	1	-1	1	2.093236	-42.7209	59.4999	
15.02	14.45	74.9607	15.0393	-38.7809	141.2191	0.719948	74.9607	38.78086	1	-1	1	2.093236	-46.9511	58.43541	
15.17	15.00	76.79067	13.20933	-41.7849	138.2151	0.785398	76.79067	41.78493	1	-1	1	2.093236	-51.1684	57.25906	
15.32	15.15	78.72953	11.27047	-44.693	135.307	0.850848	78.72953	44.69299	1	-1	1	2.093236	-55.3711	55.96769	
15.47	15.30	80.76889	9.231114	-47.5086	132.4914	0.916298	80.76889	47.50864	1	-1	1	2.093236	-59.5573	54.55769	
16.02	15.45	82.90073	7.09927	-50.2365	129.7635	0.981748	82.90073	50.23649	1	-1	1	2.093236	-63.725	53.02499	
16.17	16.00	85.11746	4.882537	-52.8819	127.1181	1.047198	85.11746	52.88189	1	-1	1	2.093236	-67.8721	51.36499	
16.32	16.15	87.41192	2.588084	-55.4508	124.5492	1.112647	87.41192	55.45079	1	-1	1	2.093236	-71.9959	49.5725	
16.47	16.30	89.77735	0.222646	-57.9496	122.0504	1.178097	89.77735	57.94964	1	-1	1	2.093236	-76.0937	47.64165	
17.02	16.45	0	0	0	180	1.243547	92.20747	0	1	-1	1	2.093236	0	0	
17.17	17.00	0	0	0	180	1.308997	94.69635	0	1	-1	1	2.093236	0	0	
17.32	17.15	0	0	0	180	1.374447	97.23847	0	1	-1	1	2.093236	0	0	
17.47	17.30	0	0	0	180	1.439897	99.82864	0	1	-1	1	2.093236	0	0	
18.02	17.45	0	0	0	180	1.505346	102.462	0	1	-1	1	2.093236	0	0	
18.17	18.00	0	0	0	180	1.570796	105.1339	0	1	-1	1	2.093236	0	0	
18.32	18.15	0	0	0	180	1.636246	107.84	0	1	-1	1	2.093236	0	0	
18.47	18.30	0	0	0	180	1.701696	110.576	0	1	-1	1	2.093236	0	0	
19.02	18.45	0	0	0	180	1.767146	113.3378	0	1	-1	1	2.093236	0	0	
19.17	19.00	0	0	0	180	1.832596	116.1215	0	1	-1	1	2.093236	0	0	
19.32	19.15	0	0	0	180	1.898046	118.9229	0	1	-1	1	2.093236	0	0	
19.47	19.30	0	0	0	180	1.963495	121.7381	0	1	-1	1	2.093236	0	0	
20.02	19.45	0	0	0	180	2.028945	124.5626	0	1	-1	1	2.093236	0	0	
20.17	20.00	0	0	180	0	2.094395	127.392	0	-1	-1	1	2.093236	0	0	

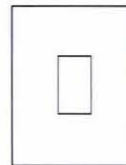
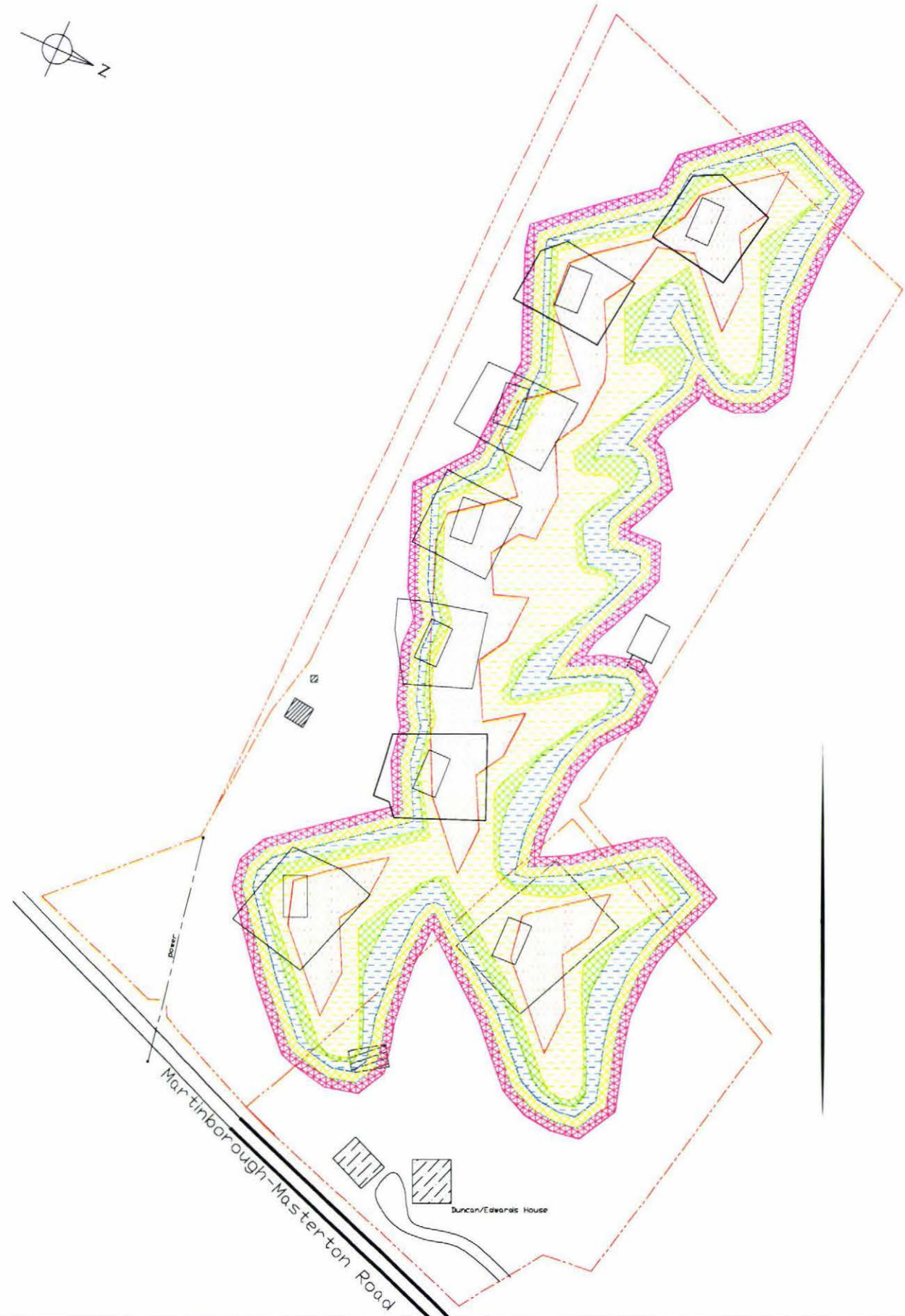
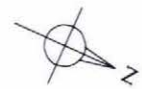
**Appendix D Triangulation of solar obstruction
points to give solar obstruction contours**




Appendix D

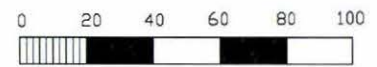
Triangulation of solar obstruction points to give solar obstruction contours

Appendix E Solar obstruction contours for case study site



Proposed lot boundary with hypothetical building indicated

-  Maximum tree or obstruction height 5m
-  Maximum tree or obstruction height 5-10m
-  Maximum tree or obstruction height 10-15m
-  Maximum tree or obstruction height 15-20m
-  Maximum tree or obstruction height 20-25m
-  Maximum tree or obstruction height 25-30m
-  Maximum tree or obstruction height >30m



Notes:

1. This drawing and contents are the intellectual property of The Cholwell Trust, and may not be reproduced in whole or in part without their permission.
2. This drawing is to be read in conjunction with the Resource Consent application, Assessment of Environmental Effects, and drawings Ch002-005
3. The details noted on this drawing are specific to the site, and should not be used for comparison of other sites.
4. The recommended maximum obstruction/vegetation heights are to be applied to any new vegetation planting carried out on the development, whether on private or common title. These planting restrictions are to be registered on each title. Details may be found on drawing Ch002.
5. Lots 1 to 8 are freehold titles, fee simple. The access lot, Lot 9 is held in eight equal, undivided shares between lots 1-8. The use and operation of the common land, buildings, and facilities is to be governed by an Incorporated Society. No dwellings are to be constructed on lot 9, however communal facilities or buildings may be.

*Cholwell Trust
Proposed
Subdivision*

*Solar Obstruction
Contours -
Maximum
Vegetation Heights*

*Proposed Subdivision of Lot
1 DP80458 and Lot 4
DP70396*

Date: 11/10/03

Drawn: AGD Revision: e

Scale: 1:2000

*Drawing No.:
Ch002*