Designing Comfortable Homes

GUIDELINES ON THE USE OF GLASS, MASS AND INSULATION FOR ENERGY EFFICIENCY

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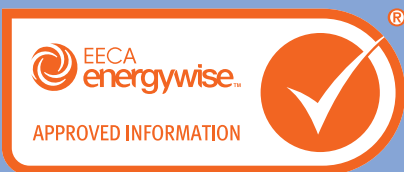
Designing Comfortable Homes

2nd Edition

GUIDELINES ON THE USE OF GLASS, MASS AND INSULATION FOR ENERGY EFFICIENCY

contents

The first edition of this book was published in 2001 and quickly became recognised as an invaluable plain English guide for anyone interested in designing comfortable energy efficient homes. As well as providing general guidance on solar design considerations that are important to enhance energy efficiency and comfort, the book also provided data on expected performance of homes based on three different combinations of glass, mass and insulation. These were defined as 'code minimum', 'better' and 'best'.

As a direct result of the 2001 edition of *Designing Comfortable Homes*, Standards New Zealand published a specification document (SNZ PAS 4244) in 2003. This specification used the 'code minimum', 'better' and 'best' insulation options from *Designing Comfortable Homes* as its basis.

When the Department of Building and Housing put in place new minimum insulation requirements in 2007 they were almost identical to the 'better' level first defined in this book in 2001 and subsequently published in SNZ PAS 4244.

With Code minimum now at the level defined as 'better' in the 2001 edition, and the development of improved products and systems making very high energy efficiency more achievable, it was time to create this second edition. If it is as successful as the first, perhaps we will see the code minimum requirements being increased further in the future based on the 'better' level defined in this edition, and perhaps a third edition of *Designing Comfortable Homes* following that change.

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preface

introduction

Chapter 1: Introduction

This book's primary aim is to provide you with an understanding of the basic principles of passive solar design – the key to comfort and reduced energy use in New Zealand homes. The premise of this book is that homes can be naturally warm in winter and cool in summer – provided appropriate combinations of glass, thermal mass and insulation are used.

Designing Comfortable Homes is written with the 'average' home owner in mind, rather than the committed passive solar enthusiast. Passive solar design principles are not only essential for good home design but they are also generally easy to understand. We encourage you to embrace these simple concepts when you build so that you get a much more comfortable and energy efficient home.

This book is also intended to address a widely held misconception that compliance with the energy efficiency requirements of the New Zealand Building Code is best practice – this is far from the truth. The Code sets minimum performance requirements only – in other words they are the levels that it is illegal to go below. To get better performance, you need to move beyond Code requirements. This book defines two higher levels of insulation – *Better Practice* and *Best Practice* – and through computer modelling shows the comfort and energy efficiency benefits these and other improvements can provide.

This first chapter provides a brief introduction to passive solar design and its benefits, followed by:

- Chapter Two – Key design considerations for glass, thermal mass and insulation
- Chapter Three – Information on other important design considerations such as site selection
- Chapter Four – The value of passive solar design demonstrated through computer modelling.

Basic Principles of Passive Solar Design

The principles of passive solar design for a comfortable energy efficient house can be summarised very simply:

- **INSULATE:** Use insulation to slow the flow of heat in and out of the house – heat from the sun is used more effectively in houses that are well-insulated. Insulation helps to maintain more constant internal temperatures and reduces the need for heating in winter and cooling in summer.
- **GLAZE:** Use glazing to bring heat from the sun into the house – though glass must be selected, placed and sized

carefully as it is a poor insulator (windows should be double glazed as a minimum to reduce heat loss).

• **ADD THERMAL MASS:** Use heavyweight materials (thermal mass) to soak up heat from the sun and release it slowly into the house when temperatures drop. A house with appropriate mass will maintain more comfortable temperatures – it will overheat less often and not get as cold overnight.

• **STOP AIR LEAKAGE:** Use weather-stripping, high-quality sealants and less complicated house designs to reduce air leakage. Once a house is well-insulated and appropriately glazed, the biggest potential heat loss is through draughts around windows, doors and other construction joints.

• **SHADE:** Use external shading to manage the heat gain from the sun. Well-designed window systems must not only collect heat from the sun when desirable, but also exclude it at times when it might cause overheating.

• **VENTILATE:** Use openable windows and other ventilation to reduce overheating and maintain good indoor air quality. Appropriate placement of windows for good cross flow of air through rooms will make them more effective for cooling on hot days. Good ventilation also helps to reduce condensation and remove cooking and other odours.

Other important factors that you should consider when designing a house, such as site selection, house placement and orientation, are covered in Chapter Three. It is important to consider these, in combination with the factors above, when designing a comfortable energy efficient house.

Glass, Mass and Insulation Explained

Although this book provides information on a wide range of factors that you should consider when designing a comfortable energy efficient house, Chapter Two focuses on the three factors that are most important to gaining benefit from the free energy from the sun:

• Glass – to collect the sun's heat

• Thermal mass – to store the heat

• Insulation – to keep the heat in.

Glass

Glass is typically not only the single greatest source of heat gain, but also the greatest contributor to heat loss in a house. A single sheet of glass can conduct over 10 times more heat than the same area of insulated wall.

Glass
to collect the sun's heat

Mass
to store the heat

Insulation
to keep the heat in

Fortunately, with the now widespread use of 'Insulating Glazing Units' (IGUs), most commonly standard double glazing, heat loss through glass can be substantially reduced. However, performance of an IGU is determined by both the glass and the frame of the window – heat loss through standard double glazing can be significantly reduced by using better frames. More information about the relative benefits of various glazing and frame options is provided in Chapter Two.

It is useful to understand that the insulation of the house and its windows is much more important than the heating effect of the sun shining through the windows. The major driver of heating requirement for a house is cold outside temperatures – the varying sunshine levels around the country make very little difference to the heating required.

For example, Nelson receives much more sunshine per year than Wellington but its houses must be insulated to a higher level than those in Wellington to maintain the same annual heating energy use because of the colder winter temperatures.

The following graph illustrates these differences using the calculated building performance results from Chapter Four[1]. Energy inputs – solar heating and purchased energy – are shown as positive and heat losses to the outside are shown as negative. These show the house in Wellington – in Building Code Climate Zone Two[2] – requires about the same purchased heating energy (the red part of each bar) as the same design house in Nelson, which is insulated to the higher levels of Climate Zone Three.

Heat losses and gains for the same house in Wellington or Nelson

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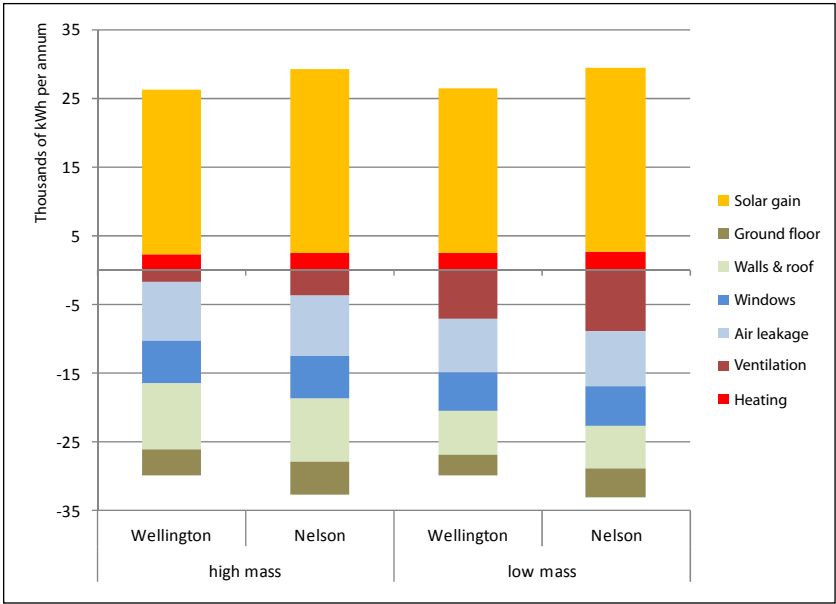
1   *The two-storey house referred to on page 41 was used for these calculations.*
2   *For more information about climate zones, see Appendix 2 on page 75.*

Thermal mass

All building materials require a certain amount of heat energy to warm up. In this respect, all building materials have a 'thermal mass'. Materials like concrete masonry and brick, however, require much more heat to warm up than materials like timber or plastic. They therefore store greater amounts of energy which makes them more effective for heating and cooling a house.

In this book, the term 'thermal mass' is used to describe materials that have a significant capacity to store heat. Typically, these building materials are also 'heavy'. Houses that contain high thermal mass are often referred to as being of 'heavyweight' construction, in contrast to houses of 'lightweight' construction, such as ones built with steel-framed or timber-framed walls.

A house incorporating appropriate levels of thermal mass should be more comfortable in all seasons and less expensive to keep warm in winter as long as it is insulated well.

The most common high thermal mass material used in house construction is concrete (commonly in floor slabs and masonry walls). Concrete is readily available and can be used for the structure of the house as well as providing thermal mass. Other forms of thermal mass used in house construction are rammed earth, natural stone and brick. For ease of reading, 'concrete' is often used as an example of a high thermal mass material in this book, though these other forms of thermal mass can provide similar comfort and energy efficiency benefits.

High thermal mass materials such as concrete have not been very widely used for house wall construction in the past and as a result you may be concerned about factors such as earthquake resistance. Concrete, like all other materials used for house construction, must meet all the durability and structural safety requirements of the Building Code. You can therefore be assured that houses built from high thermal mass materials such as concrete are at least as safe and durable as timber-framed houses. High thermal mass materials are also fire resistant and reduce airborne noise transmission.

Insulation

In winter a solar heated house collects the sun's heat through glass, then stores it in thermal mass and finally makes sure the house retains heat by wrapping it in insulation. Good insulation is the most important component influencing the benefits that result.

All materials have an insulation value; however, materials such as glass have a very low insulation value, which is why

> "A house incorporating appropriate levels of thermal mass should be more comfortable in all seasons and less expensive to keep warm in winter as long as it is insulated well."

condensation forms on the inside of single glazed windows on cold days. It is important to understand that high thermal mass materials like concrete and brick, in the thicknesses commonly used in buildings, also have poor insulation values. Their function as heat storage is in part due to this ability to conduct heat. Wood of the thickness of a rafter or a stud in a wall has a much higher insulation value than high mass materials, but still much lower than that of materials specifically designed to be used as insulation.

In keeping with common practice, when this book refers to 'insulation' it means materials with a high insulation value such as fibreglass, polyester, wool or polystyrene.

Energy Modelling

The first part of this book covers the basic design principles relating to glass, thermal mass and insulation and other issues related to the design of comfortable homes. Chapter Four illustrates the value of these principles through computer modelling. This computer modelling demonstrates expected performance and allows you to predict how your house will perform before it is built.

The computer studies are of standard house designs in three different cities and for differing amounts of glass, thermal mass and insulation. These computer studies measure comfort, energy use and heater size requirements. The cities chosen are Auckland, Wellington and Christchurch. Although these cities are not representative of all climates within New Zealand, the results, and the relationship between them, give a reasonable idea of how a particular design will perform in another location[3].

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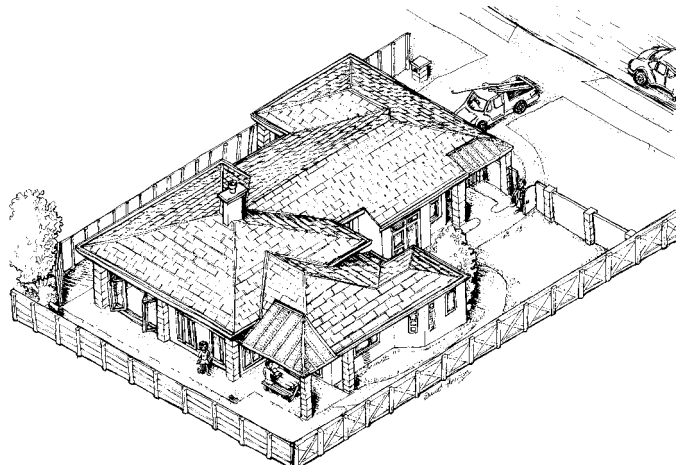
3   For more information about climate zones, see Appendix 2 on page 75 and the calculations on page 43 of the performance of the same building in 18 different climates across New Zealand

The computer studies look at the performance of two specific house designs. Performance will, of course, be different for each individual house design. However, the example houses should provide good guidance on the general effects of various design options. The houses studied in this book are a single-storey design of around 200 square metres (excluding the garage) and a two-storey house with similar floor areas.

If it is important for you to have accurate thermal performance data for your design, you will need to conduct your own computer studies (or get a computer modelling specialist to do it for you). There are a number of suitable programs[4] available. The studies in this book were conducted by the Centre for Building Performance Research, School of Architecture, Victoria University of Wellington, using the SUNREL computer performance simulation program developed by the National Renewable Energy Laboratory in the USA (see www.victoria.ac.nz/cbpr).

Other Considerations

Cost effectiveness

Building is a series of trade-offs. Most people start with a fixed budget and make a series of decisions on where to invest their money within that budget. Although some features, such as high-performing windows, can add significant additional cost, by investing in these features the thermal performance of the house can be dramatically improved.

Fortunately most passive solar design principles can be incorporated at little or no additional cost. For example, the additional cost of higher-performing insulating materials is generally relatively small. Major comfort and energy efficiency gains can also be achieved simply through careful consideration of how glazing and mass are placed and used in combination.

Sometimes compromises will be made on thermal performance for reasons other than cost, and there will be the inevitable trade-offs between conflicting design requirements. Data provided in Chapter Four of this book should help you to evaluate the effect of trade-offs on energy use and comfort.

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4   *SUNREL (www.nrel.gov), AccurateNZ (www.energywise.govt.nz), IES Virtual Environment (www.iesve.com/A-NZ) and EnergyPlus (http://apps1.eere.energy.gov/buildings/energyplus/).*

Health

Good passive solar design results in even, comfortable temperatures within a house and this creates a more healthy living environment. This is particularly important for older people and the very young who are more susceptible to cold temperatures. Low temperatures have also been associated with asthma and other allergic reactions.

Because the surface temperatures of well-insulated high thermal mass walls are more stable, they are less likely to fall below the level at which condensation occurs. Condensation leads to the growth of mould and fungi which can exacerbate respiratory conditions.

Occupant behaviour

One very significant influence on comfort and energy efficiency is occupant behaviour. The number of people who live in the house, when and how they occupy it and how they use appliances (such as heaters and air conditioners) can have a significant impact on energy use and comfort. A house that is occupied for most of the day, most days of the year and with heaters switched on by thermostats will perform quite differently from a 'weekender' that is occupied regularly for two days a week and relies on occupants to operate heaters.

The ideal mix of glass, thermal mass and insulation is very much dependent on occupant lifestyle, so you should consider this at the outset. For example, a high thermal mass house is less likely to overheat in summer, but in winter will heat up more slowly than a low thermal mass house with similar insulation.

Energy efficient appliances provide further energy gains

This book focuses on design for comfortable temperatures and reduced space heating and cooling requirements. However, energy efficient heating is also important to lock in the potential savings from good design. Thorough research into the various space heating options is important, particularly as new technologies emerge. When choosing a heater, refer to the 'heater size' notes in Chapter Four. These are for the whole 200 square metre house. Don't install a large heater in the living room unless you have a way of effectively distributing its heat to the other rooms. Go to energywise.govt.nz for impartial advice.

In warmer parts of the country a well-designed house may need little or no purchased heating or cooling. To ensure you don't over invest in heating, it may be wise to delay purchasing heaters until you have lived in the house for a while and assessed your actual heating needs.

The pie chart[5] below shows that for an average existing New Zealand house space heating energy use is about one-third of total energy use. The glass, mass and insulation strategies outlined in this book have the potential to reduce the space heating considerably and therefore increase the proportion of total energy use associated with other aspects such as water heating, lighting and appliances.

Typical energy consumption for an average existing NZ house

"Space heating is about a third of total energy use in an average existing house. New houses should use much less, making water heating a greater proportion of total energy use"
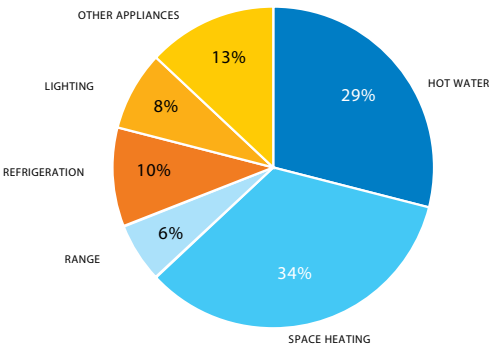
In most New Zealand houses a major contributor to energy use is water heating. Technologies such as solar water heaters, heat pump water heaters and energy efficient shower heads can significantly reduce the energy costs for hot water (by 50-75% in the case of solar water heating, for example).

Appliances are also significant energy users. Energy performance labels are now available on many appliances to assist you to make informed decisions. In addition, electronic controls on some appliances can result in added energy savings. Heated towel rails, for example, have a relatively low energy consumption per hour but use considerable energy if they are left running 24/7. Through the use of timers, that turn off items like towel rails when they are not needed, you can significantly reduce this energy use.

Lighting is another area where energy savings can be made. Technology improvements, such as the introduction of compact fluorescents (CFLs) over recent years mean that efficient light bulbs that perform very well are now available at low cost. CFLs are around five times more efficient at producing light than traditional electric light bulbs and last considerably longer. LED (light emitting diode) lighting is another energy efficient lighting technology that is now available. Well-designed windows provide good daylight which also reduces the need to use electric lights.

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5   *BRANZ HEEP Study – Energy use in New Zealand households.*

Because ceiling insulation must be kept clear of many types of recessed down-lights to avoid fire risk, this can result in large gaps in the ceiling insulation. A convection effect can also create further heat losses through the ceiling. Recessed down-lights of this type are therefore not recommended.

Embodied energy

A more holistic view of energy efficiency takes into account the energy required to produce, transport and construct on site the materials used to build a house – the 'embodied energy'. Increasingly, this type of analysis also accounts for the embodied carbon dioxide. The cost of this embodied energy is built into the cost of the building materials. The more energy intensive the material, the more expensive it is likely to be.

Although larger amounts of glass, thermal mass or insulation increase the embodied energy of a house, if well-designed, the total energy used by that house over its life will be less (relative to an ordinary design). For example, using the higher levels of insulation proposed in this book results in operational energy savings that far outweigh any increased embodied energy.

Thermal mass installed with good external insulation can significantly reduce operational energy use. If we assume the thermal mass is concrete, its use in construction adds embodied energy, but the energy savings over time result in an approximately neutral energy impact. A good source of accurate data on embodied energy and CO_2 in New Zealand is the Victoria University Centre for Building Performance Research website (www.victoria.ac.nz/architecture/cbpr).

Sustainability

If you want to design a more sustainable house there are many other issues to consider besides energy efficiency. Sustainable development is dependent on following sound individual design decisions for every aspect of the house. The sustainable house must balance a wide range of issues in line with your personal needs and aspirations. These include but are not limited to:

- using materials from sustainable resources
- using materials whose mining and manufacture produces a minimum of pollutants
- using materials that minimise the life cycle impact of the house on the atmosphere
- using low-maintenance materials

- avoiding building materials that emit chemical pollutants into the house after they are installed

- recycling and re-using materials in construction – and facilitating recycling in the building during its operation.

If you are interested in pursuing these issues in more depth there are numerous publications available. A couple of useful starting points are *A Deeper Shade of Green* – Ed. Johann Bernhardt, Balasoglou Books, Auckland 2008 and The Ministry for the Environment website (www.mfe.govt.nz).

Chapter 2: Glass, Thermal Mass and Insulation

Good passive solar design simply makes effective use of the sun (and, to a lesser extent, other natural resources such as wind and landscape) to ensure comfortable and energy efficient houses. All houses make use of passive solar design to some extent, but many don't make very good use of the sun. By providing detailed information on passive solar principles and the impact of design decisions, this book should help you to get the most from your house design.

This section follows the path of solar heat gain through the house. It starts with glass that allows the sun's heat to enter the house, moves onto thermal mass which helps to store this heat and concludes with insulation which traps the heat in the house.

Glass – Heat Collection

Windows provide the simplest way for heat from the sun to be collected – they are also the most poorly insulated part of the building and therefore allow large heat losses. To maximise solar collection benefits and minimise energy losses, window size, type and orientation need to be carefully planned.

Orientation

Window orientation guide

North-facing – more and moderately large

East-facing – less and smaller

West-facing – less and smaller

South-facing – as few as possible and as small as possible

Unobstructed north-facing glazing[6] is best as:

1) it captures solar energy in winter (when the sun is low in the sky)

2) it is easiest to shade from direct sun during summer (when the sun is high in the sky) by providing north-facing eaves.

Where practical, the longer axis of a house should be orientated east-west to optimise the north-facing exposure. Rooms may also be stacked or staggered to achieve a greater north-facing aspect. North-facing clerestory windows and skylights can be used to get direct sun into deep plan shapes. Particular care should be taken over the positioning of skylights as they are typically placed in a sloping roof so they tend to collect heat more in summer than in winter and they can be difficult to shade. Heat loss through a skylight, particularly on cold nights, is also much greater than through a window of the same size.

East- and west-facing windows allow penetration of morning and evening sun, which can cause problems with glare (morning or evening) and overheating (more often in the evening). These factors should be considered when positioning east and west glazing. Adjustable shading systems such as interior vertical blinds or louvres can help prevent
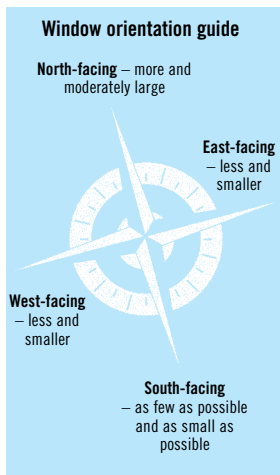
6   *See page 45 for information about the effect of different orientations.*

glare problems, but do little to reduce overheating. Exterior shading devices such as awnings are much more effective for preventing overheating. East- or west-facing glazing can be limited in size to reduce these problems.

South-facing glazing receives very little direct sun and therefore allows heat loss without any significant compensating solar gain. South-facing windows are generally required for light and air but don't necessarily need to be large to achieve this. If you want to be able to enjoy a view to the south one effective option is to use smaller windows that frame or shape the view rather than large picture windows.

Heat loss from glass

Significant energy and comfort benefits can be achieved by using more energy efficient windows.

Double glazing is now widely used throughout New Zealand. In addition to improved energy performance, double glazing also minimises window condensation and reduces noise transmission. The higher the performance specification of double glazing, the higher the inside surface temperature of a double glazed window, and therefore the warmer people will feel when close to this glass. The best performing windows allow less than half the heat loss of standard double glazing, and less than a quarter the heat loss of standard single glazing.

Thermally broken metal frames perform 20% better than standard metal frames. Wooden and other low heat conduction frames such as PVC units can perform 40% better than standard metal frames, 'low-E' coating on the inner pane of double glazing can provide up to a 30% benefit and argon gas between the double glazing provides an additional benefit. The following graph demonstrates that simple double glazing is only half as effective as the best double glazing option.

Comparison of insulation value of window types

R-Values (insulation value – bigger is better)

Window type	R-Value
Double glazed aluminium frame	0.24
Double glazed thermally broken aluminium frame	0.28
Double glazed PVC frame	0.33
Double glazed timber-framed	0.33
Double glazed low-E, timber-framed	0.47
Double glazed low-E, argon fill, timber-framed	0.50
Triple glazed with low-E timber-framed	0.62

For the medium glazed house used in the calculations for this book, the heat losses through the standard double glazed windows alone amount to 25-30% of the total heat losses. This glass represents only 10% of the total external surface area of the building. The roof accounts for only 10% of the heat losses but is 30% of the total external surface area. The benefit from doubling the insulation value of windows will therefore be far greater than doubling the insulation value of the roof.

To help in the selection of windows and glass doors that best meet your needs, the Window Association has developed a simple five-star rating system known as WERS (window efficiency rating system). WERS uses an accredited computer program to test specific glass and frame combinations. Window suppliers who participate in this scheme provide a certificate which verifies the WERS rating of the windows and doors supplied. A table of WERS ratings is available at www.wanz.org.nz

Good quality curtains that sit flush against all the window frame surfaces and thus seal well against draughts can significantly improve the performance of double glazing. Pelmets are one way of ensuring an effective seal at the top of the curtains. Of course curtains are only effective if they are drawn and sealed against the window frame when it is cold. Many curtains don't seal well against the window frame and therefore don't greatly improve energy efficiency.

Area of glass

While north-, east- and west-facing glass is effective in capturing solar energy, this glass is also a major contributor to heat loss from the house. Maximising these window sizes will therefore not necessarily maximise comfort levels or energy efficiency – if it did, we would all live in glass houses! The ideal size for these windows is not easy to determine – factors to take into account include thermal mass, insulation and climate. The information in Chapter Four shows how various combinations of glass, thermal mass and insulation affect the comfort and energy efficiency in a 'typical' house. This information should help you to evaluate the likely impacts of various glazing options.

Sunspaces

Sunspaces are simply highly glazed rooms, and are otherwise known as sunrooms or conservatories. They are a means of providing additional living area as well as providing a special mechanism for capturing solar energy. Properly operated sunspaces that are more than half the length of the north face of a well-insulated house can reduce space heating energy consumption by as much as 20-30% in the South Island and 40-70% in the north of the North Island. They are, however,

a relatively expensive heating system and also require very proactive operation by the occupants to achieve large energy savings.

For effective operation, a sunspace should be able to be shut off completely from the main living areas of the house. This is because sunspaces are most effective as solar collectors when they are designed to overheat. The excess heat is then distributed to other rooms. Sunspaces that are designed as effective solar collectors can therefore sometimes get too hot to be used as a normal living space. Because of the high glazing area of sunspaces they also lose heat quickly when the sun is not shining. This means they can be uncomfortably cold on cold cloudy days and cold nights. Roof glazing of sunspaces can often make overheating worse in summer, and increase heat losses in winter. An optimum sunspace therefore has a well-insulated roof and large areas of north-facing glazing.

Winter   *Summer*
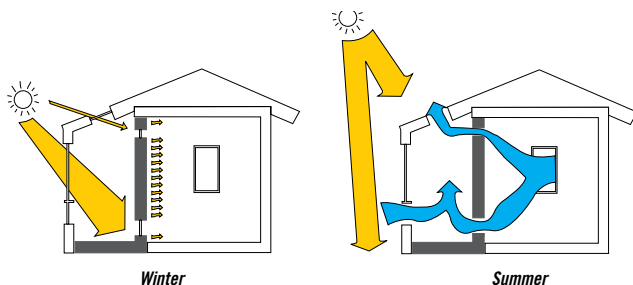
In New Zealand's breezy climate the inside-outside transition zone provided by a sunspace can be a useful extra living area. It should be designed with good thermal storage or the temperature swings will be huge and much of the solar heat gain will be lost back to the outside. A concrete floor or a concrete or brick wall between the sunspace and the living areas of the house will provide that thermal storage if it sits in the sun for most of the day. A dark colour will greatly increase the ability to absorb heat – coloured concrete or a covering such as tiles can achieve this. Openings such as doors and windows are important for heat distribution. These openings must be to the outside for venting when the sunspace is too hot in summer and to the inside when the sunspace is hot in winter.

As sunspaces have such a direct path for heat losses and gains through the glass, they should never be heated. It is quite easy to more than double the whole house heating energy use just by using a sunspace heater 'to take the chill off'.

Thermal Mass – Heat Storage

How thermal mass works

High thermal mass materials help to maintain stable, comfortable indoor temperatures and reduce the need for heating and cooling. The obvious advantage of well-utilised thermal mass is that heat energy from the sun is free.

Thermal mass works in two ways. Firstly, when the sun shines through windows onto a high thermal mass surface, the solar radiation is absorbed directly – the thermal mass is more effective when it receives direct sunlight and is a dark colour which absorbs more heat. Secondly, thermal mass absorbs heat from the air inside a house when that air is hotter than the thermal mass. The heat stored by the thermal mass is released back into the room when the room temperature drops below that of the thermal mass.

High thermal mass materials such as concrete floors and walls need more energy to heat up, so they heat up more slowly than lightweight materials. This reduces overheating as the thermal mass soaks up some of the excess heat. The following graphs illustrate this clearly. In these studies[7] the insulation values were the same for both timber and concrete test buildings and the windows were the same size and orientation. The difference in inside temperature can therefore be attributed entirely to the thermal mass.

Mean daily minimum and maximum air temperatures in the Lincoln University test buildings
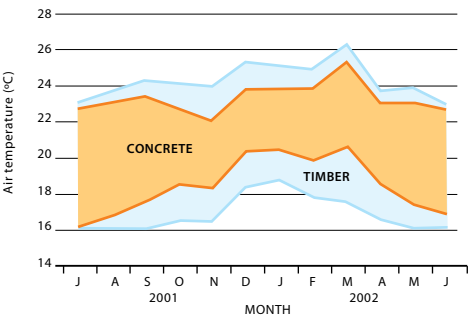
Air temperatures in the Lincoln University test buildings on 11 February 2002
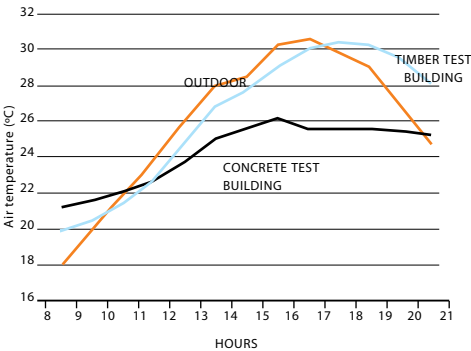
Even at the same room air temperature, a well-insulated high thermal mass house will often feel warmer than a well-insulated lighter-weight house. This is because our perception of warmth depends not only on the air temperature, but also on the radiant heat from our surroundings. If those surroundings stay warmer as the air temperatures fall, we feel warmer too. If they are cooler, our perception is that the air temperature is colder.

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7 Data from Bellamy, L.A. & Mackenzie, D.W. (2003). *Energy efficiency of buildings with heavy walls, BRANZ Study Report 116. City: Building Research Association of New Zealand.*

To be effective in collecting and storing the sun's heat and maintaining stable indoor temperatures the thermal mass must not be isolated from the inside of the house by carpet or other insulating materials. However, no matter where it is placed inside a building, thermal mass must be insulated from contact with the outside air and the ground.

Thermal mass can be provided in a house in a number of ways and potentially by a number of different materials. In practice, however, concrete masonry, concrete floor slabs or pre-cast concrete are the most common means of incorporating thermal mass into a house. Concrete floor slabs are now almost universally used on flat or moderately sloping sites. These floor slabs can be very effective in capturing the sun's heat as they generally receive a lot of direct sun. Using high thermal mass floor coverings such as ceramic or concrete tiles, or polished or coloured concrete, will ensure the thermal mass of the floor slab is 'available' for heat storage.

Many homeowners prefer to have carpets or similar floor coverings which unfortunately isolate the thermal mass. If this is the case, having a one metre wide border of tiles or other high mass materials can be an effective way of still providing some thermal mass, even if the rest of the room is carpeted. Heat storage can also be provided by using thermal mass such as concrete exterior walls, interior walls, intermediate floors, staircases and even ceilings/roofs. Relying on the thermal mass of a floor slab alone may be unwise as it is likely to be carpeted at some stage in its life, thereby reducing its heat storage effect dramatically.

"Relying on the thermal mass of a floor slab alone may be unwise as it is likely to be carpeted at some stage in its life, thereby reducing its heat storage effect dramatically."

Insulation limits heat loss from the room

Heat transfer between air and high mass floor and walls

Indirect heat transfer by air movement between rooms

Low angled winter sun penetrates under eaves

Concrete floor warmed by direct sun
Insulation limits heat loss to the ground
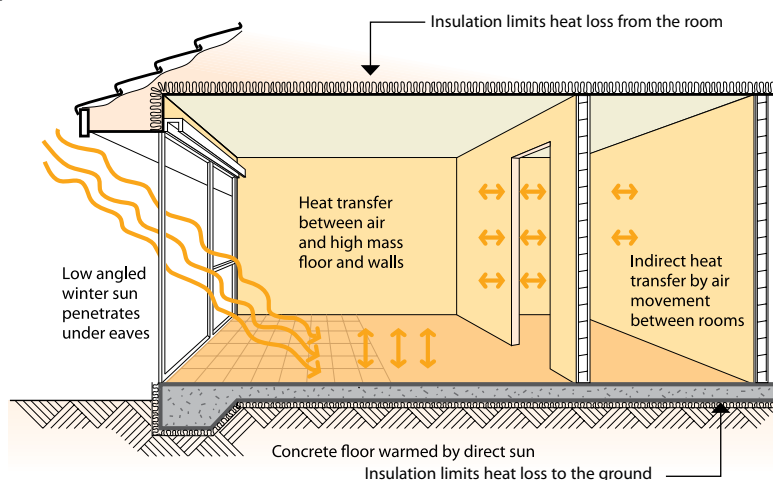
How much thermal mass?

The effectiveness of thermal mass is influenced by the amount and positioning of insulation and glass, the site and the climate in which the building is located. The interactions between these elements are complex, making it difficult to generalise about how much thermal mass to put into a house – more is not always better. The examples in Chapter Four are intended to provide guidance. The basic principle is that a large area of thermal mass should be in contact with the air in the north-facing rooms that get significant sun. This could be most of the floor, all of the walls, or a combination of the two. If you want to more accurately determine the optimal amount of thermal mass for a given climate and design, seek professional advice on one of the growing number of computer programs used for digital building performance simulation (e.g. AccuRateNZ, IES Virtual Environment, Energy Plus, SUNREL).

As thermal mass materials like concrete conduct heat very well, they absorb the sun's heat quickly to their core, storing heat much more effectively than lower mass materials like timber. This happens when the sun shines onto the thermal mass but at other times the heat flow reverses. This pattern means there is a concrete thickness beyond which there is generally no added benefit in terms of solar energy storage. This optimal thickness for storage of heat from day to night is 100-200mm. However, with a house insulated to the Best Practice level in Chapter Four, a greater thickness of thermal mass could be used to store heat for longer periods.

Thermal mass and energy efficiency

As thermal mass has the ability to capture free energy from the sun, you might expect that high thermal mass homes will be more energy efficient than lightweight homes. They can be, but only if they are well-insulated and have well-designed glazing. Without insulation, a high mass house would be very hard to heat as thermal mass is a very good heat conductor. A 200mm concrete wall with no insulation loses around six times the heat of a timber-framed wall insulated to Building Code minimums, so there is simply no point in trying to collect solar heat in thermal mass that is not well-insulated. There is also no point in hoping that the sun shining on the outside of a wall will somehow heat the living spaces. Most of the solar heat collected will be lost back out to the outside air as the wind blows across its hot surface. Good design requires that the solar heat is brought inside and heats the externally insulated thermal mass.

"Optimal thickness of thermal mass for heat storage from day to night is 100 – 200 mm"

Insulation – Heat Containment

Insulation is the most important factor in passive solar design. Appropriate levels of insulation are critical for energy efficiency and comfort in both summer and winter. By slowing the transfer of heat in and out of a house, insulation works in combination with thermal mass and glazing to reduce both heating and cooling needs.

Try to install as much insulation as you can

Because insulation is the most important factor influencing energy efficiency and comfort you should always try to use higher levels of insulation than Building Code minimum requirements. In many instances, better-performing insulation materials are only a little more expensive and, although the product cost is a little more the installation cost remains the same. It will always be more difficult and expensive to increase the insulation at some later date, so it pays to insulate really well first time around.

Install insulation correctly

The correct installation of insulation is critical to getting the best performance from it. For example, squeezing insulation into a space smaller or thinner than it was designed for will reduce its effectiveness markedly. Gaps as small as 2mm can also significantly reduce effectiveness. The New Zealand Standard NZS 4246 *Energy Efficiency – Installing Insulation in Residential Buildings* provides excellent advice on the best way to install all common insulation materials. It is available free from www.energywise.govt.nz

Insulating timber floors

There are two different types of suspended timber floor:

1) floors where there is an enclosed or semi-enclosed 'basement' space below the floor where the wind flow is limited

2) floors in pole houses and similar buildings where the floor is exposed to the elements.

Insulated floors over a basement space perform better than floors exposed to the elements because floor heat loss goes to the basement space and then through the basement walls. These floors should be insulated to at least two thirds of the R-Value of the walls of the house

Pole house floors require more insulation as they are directly exposed to the elements. A good rule of thumb is to insulate these floors to the same level as the walls as they lose heat at a similar rate. The insulation should be protected using materials such as plywood or fibre cement board.

"Insulation is the most important factor in passive solar design."

Insulating concrete floors

When the floor is intended to be heated, either by an underfloor heating system or by direct sun, under-slab and perimeter insulation should always be used. Fifty millimetre expanded polystyrene is most commonly used. Extruded polystyrene will give greater insulation value; however, it is significantly more expensive.

When the floor slab is used to capture direct solar heat, in-slab electric heating systems may be undesirable. For example, before sunrise on a cold winter's morning you will be likely to turn on the underfloor heating, purchasing electricity in order to store heat in the concrete slab. As the sun comes up, it adds further heat to the floor and the room can overheat. As a result, you are likely to open the windows to cool the house and waste expensive purchased energy.

Underfloor heating systems that use circulating fluid in pipes buried in concrete floors can distribute heat from the sun throughout the house, providing a considerable increase in the effectiveness of solar gain. To make the best gains, these systems should be able to be run in circulation mode only, with no purchased energy heating the fluid.

There are a number of proprietary concrete flooring systems available with different insulation details. With all these systems you should make sure the insulation under the slab and around the perimeter is continuous to prevent thermal bridging[8]. Thermal bridging can significantly reduce the overall insulation performance of these systems.

Insulating timber-framed walls

Insulating timber-framed walls is relatively simple. There is a range of readily available insulation materials which simply fit in the cavity between the internal lining and the external cladding. It is important to use insulation materials specifically designed for walls to avoid 'slump' (where the insulation sinks down the wall over time which reduces thermal efficiency and can encourage mould growth).

Another option is to use external insulation systems. The most well known are polystyrene-based systems that fix to the exterior of the timber frame to provide insulation and form the base for an exterior finishing system (most often plaster). With correct detailing of the battens that hold the external wall cladding in place, a range of insulation material can be used as external insulation. Combining external insulation with cavity insulation reduces the thermal bridging effect of the heat losses through the timber frame and significantly improves performance.

"You should always try to use higher than Building Code minimum levels of insulation."

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8   Thermal bridging refers to the increased heat loss through the uninsulated area.

To get a high level of thermal efficiency, 150 mm or 200mm framing could be used to allow sufficient space for increased cavity insulation. The thermal bridging effect of timber can be reduced with careful detailing. One approach could be to use the increased strength of the timber to increase the spacing between wall studs.

Veneer construction using materials like brick or concrete blocks is popular because of its durability and low maintenance. However, when used as a veneer on timber-frame construction the thermal mass is isolated from the interior of the house. From a thermal performance perspective, high thermal mass veneer external walls are the same as a low thermal mass construction with the same insulation level.

Insulating thermal mass walls

External insulation

External thermal mass walls can be a very effective way of providing heat storage, provided they are well-insulated. However, if insulation is placed on the inside of the wall it isolates the thermal mass from the interior of the house, making its heat storage properties ineffective. Insulation can be either fixed to the exterior surface of the concrete wall, or built into the wall near the exterior surface. Insulation levels can be varied by adjusting the thickness of insulation material.

Common external insulation systems are:

- fixing polystyrene sheeting to the exterior of concrete masonry or pre-cast concrete walls – all standard finishing systems can be used, including masonry veneers, weatherboards and plaster finishing systems

- casting polystyrene sheeting into a pre-cast wall (near the exterior surface)

- masonry blocks that have a polystyrene biscuit pre-fitted near the exterior surface.

Particular care should be taken to ensure there aren't any breaks in the continuity of the insulation material as this will significantly reduce the performance.

Internal insulation

In some situations, it may be sensible to isolate thermal mass; for example, if you want to ensure fast heat-up of rooms on the south side of a house that do not receive direct sun. This

can be done by carpeting concrete floors and internally insulating high mass walls. It is important to ensure that design and construction of these walls allow construction moisture to be dissipated and prevent trapping of condensation from warm indoor air. Some internal insulation options include:

- masonry and pre-cast walls strapped with timber and lined with plasterboard – with insulation between the strapping to improve energy efficiency

- masonry or pre-cast walls with polystyrene board directly fixed (usually glued) – finishing can be with plasterboard or applied plaster systems

- insulated concrete formwork (ICF) blocks – polystyrene blocks that are filled with ready mixed concrete.

Roof insulation

Traditional timber-framed roofs are the most common form of construction for New Zealand houses and insulation methods are well known. A wide range of insulation materials are commercially available and the desired insulation level can be achieved by using insulation material of appropriate insulation rating. As a general rule of thumb, try to install as much insulation as possible. For higher levels of insulation, it is advisable to lay the insulation over the top of the ceiling joists so timber, which has higher heat conduction properties than insulation, does not become a 'thermal bridge' leaking heat through the roof between the insulation.

Pre-cast and in-situ concrete roofs, though not widely used in New Zealand houses, can provide a useful means of storing heat. They must be insulated externally if the thermal mass of the roof is to be available for thermal storage. Normally, polystyrene sheet is used in a manner similar to the external insulation of concrete walls. Cladding and drainage of concrete roofs require special attention. The thermal storage of an internally exposed roof is much less effective than a wall or floor as its exposed surface receives no direct sun.

additional important design principles

Chapter 3: Additional Important Design Principles

Avoiding Overheating

In New Zealand, houses designed to capture high levels of solar energy have the potential to overheat, particularly in summer. There are a number of ways to protect against unwanted solar gain or to get rid of the excess heat when overheating occurs. Thermal mass and insulation can reduce overheating but these do not always provide sufficient protection alone. The most effective ways to deal with overheating are to:
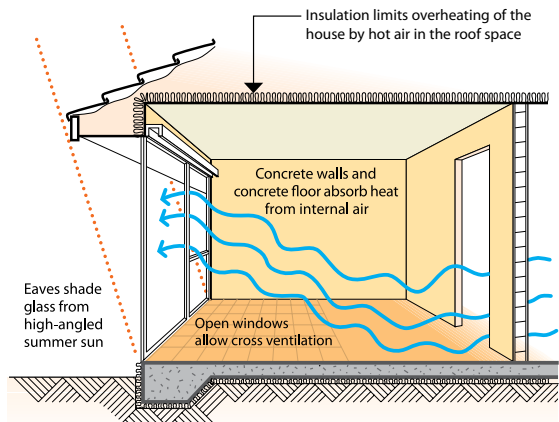
• provide shading to block the sun when it is not wanted

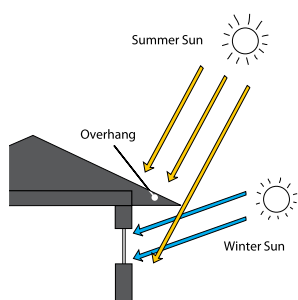• cross-ventilate the house to get rid of excess heat.

Common ways of trying to deal with overheating that should be avoided include:

• air conditioners (including heat pumps) – these are expensive to install, require purchased energy to work and are only effective in the area of the house where they operate

• drawing the curtains or blinds – this tends to trap the heat from the sun in the room (the sun's heat is inside the room by the time it reaches the curtains), prolonging overheating

• tinted windows (or coated with reflective film) – this reduces overheating markedly as heat gain through the glass can drop to a quarter of the clear glass amount. However, in winter this glass will lose the same amount of heat but will still only warm the house via solar gain at a quarter the rate of clear glass.

Shading

One simple way to protect against overheating from the sun is to provide appropriately sized fixed overhangs above north-facing windows and external shading on east- and west-facing

Insulation limits overheating of the house by hot air in the roof space

Concrete walls and concrete floor absorb heat from internal air

Eaves shade glass from high-angled summer sun

Open windows allow cross ventilation

windows. A simple overhang projecting above a window works well on the north of a house because it cuts off the sun when it is high in the sky in summer while allowing it to shine in through the windows when its heat is needed in winter. However, this type of shading is ineffective against the low-angled morning sun from the east and the late afternoon sun from the west. For these situations a vertical screen, such as an external louvred shutter or a blind is ideal. These can be movable to allow access to the view when the sun is not a nuisance.

Sun shades can also be in the form of awnings or other similar devices. It is wise for sun-shading devices to be light in colour as heat will tend to build up under and behind them if they are dark coloured.

Fixed overhangs need to be sized to allow winter sun to penetrate but also to exclude summer sun. Computer programs[9] can model 3D house designs for the sun for a particular location and time. With these programs it is easy to design external shading systems that work well for each compass direction that the house faces.

If you don't have access to these programs, the following calculation works on the principle of excluding all sun on north-facing windows at midday in mid-summer – but only just. This is normally adequate to control overheating, so long as a building does not also have large west-facing windows.

Using the table below and the adjacent diagram you can estimate the appropriate overhang size (a) for north-facing windows. Multiply the height of the sunshade above the window sill (h) by the factor in the table for your particular climate below (f1). For example, in Christchurch, if the height (h) of the sunshade above the window sill is 2m then the depth of the sunshade (a) should be 2m x 0.35 = 0.70m (a = h x f1).

f1	Auckland	0.24
	Wellington	0.32
	Christchurch	0.35
	Dunedin	0.39
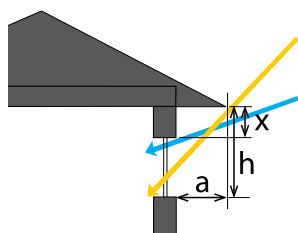
If the top of the window is too close to the sunshade, even low-angle winter sun does not penetrate the top part of the window. The distance from the top of the north-facing windows to the overhang (x), that will ensure the whole window receives winter sun, can be estimated using the following table. For the Christchurch example above, it is x = 0.15 x 2m = 0.30m (x = h x f2). The ratios in this second table assume the overhang depth (a) has been determined by the first calculation.

f2	Auckland	0.14
	Wellington	0.15
	Christchurch	0.15
	Dunedin	0.16

9 E.g. SketchUp, AutoCAD, Revit, Archicad and Microstation.

Sunpath diagrams[10] can be used to size overhangs for latitudes not in the tables above – or if you want to provide more or less shading than allowed for in the tables.

For the buildings[11] studied in Chapter Four, the importance of sunshades was evaluated in warmer and colder parts of the country. In all cases, the buildings without sunshades required slightly less heating, but suffered from significantly more overheating. Reductions in heating energy use were around 5-10%, but there was a doubling or tripling of the number of hours of overheating per year.

Having provided adequate shading to protect against unwanted heat gain, it is also important to ensure that overheating and glare do not occur due to sun bouncing off reflective ground surfaces outside the windows. Shading sun from the west is more difficult due to the low position of the sun in the sky. Shading the north-facing windows in the warmer autumn weather, but not in the cooler spring weather, is also difficult as the sun is in the same position in the sky. This shading can be provided by fixed vertical louvres, movable shades or adjustable louvres. Adjustable methods are effective provided they are operated at the appropriate times.

Another option is the use of deciduous trees, which are fully leaved during the warmest periods, but do not have leaves during the cooler periods when solar gain is advantageous. However, it is important to realise that even without leaves, shading from tree branches reduces solar gain by at least 20%.

Sun from the east does not often present an overheating problem as it occurs early in the morning when the house is at its coolest. In fact the warm-up effect is generally desirable, provided glare does not cause a problem.

In climates north of Taupo and in the central South Island where overheating might be a major problem, ensure that surfaces that have high exposure to the summer sun, like roofs, are light in colour. Overheating of the roof space causes heat gains to the interior of the house through the ceiling, which can only partially be prevented by ceiling insulation.
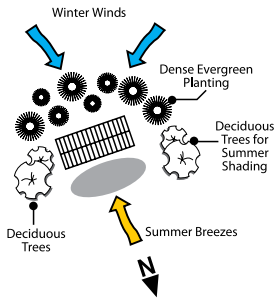
Ventilation

Throughout New Zealand, provided care is taken to protect against excessive solar gain in summer, ventilation through windows, doors and sometimes unglazed vents, should generally be all that is required to get rid of any build-up of unwanted heat. In New Zealand's climate, a house that frequently overheats due to the sun has simply been poorly designed.

Hedges and windbreaks that are planted for winter shelter should still allow, and even encourage, cooling summer breezes to penetrate the house. This involves both careful planting and also careful placement of windows and doors.

10   See page 37 for more information. Sunpath diagrams available at www. victoria.ac.nz/cbpr/resources

11   The two-storey house was used for this evaluation.

Winter Winds

Dense Evergreen Planting

Deciduous Trees for Summer Shading

Deciduous Trees

Summer Breezes

N

The key to effective venting of unwanted heat is openings that are positioned to encourage cross-ventilation. Windows on opposite walls are much more effective than windows on the same wall.

To encourage maximum air movement and better venting, efficiency inlets and outlets should be:

1) at different heights

2) not directly in line of each other across a room.

The goal is to ensure that cooling breezes pass through the whole of the occupied zone in a room and thus have the greatest chance of cooling people.
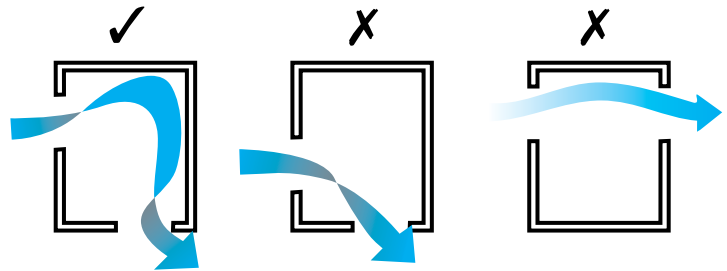
Fans can create air movement across your skin that can be cooling even on a hot day. Recent research[12] has demonstrated that quiet, well-designed, low-energy ceiling fans should provide sufficient cooling for well-designed houses in even the hottest parts of New Zealand.

The key to providing good ventilation through opening windows is to design practical openings for all circumstances. Openings should:

• be large enough to allow good flow of air

• be able to be shut completely and seal well against cold winter weather

• be able to be locked in a partially open position to allow continuous cooling during the day but still provide security

• still allow cool night air to enter the building, even after people have gone to bed for the night

• ensure people, especially children, cannot fall out of them.
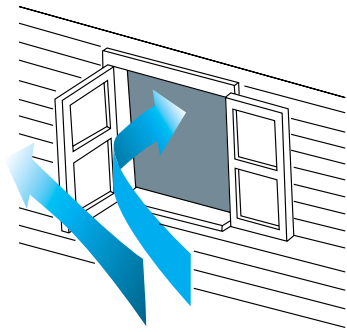

N

Summer Wind

Garage

Winter Wind
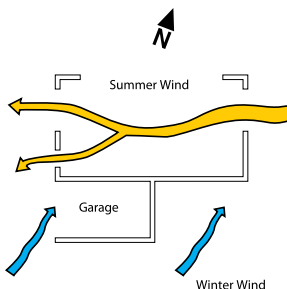
Casement windows pushed out into wind flow improve the efficiency of a simple opening. Small external projecting walls will also interact with the building to improve ventilation by increasing the area of wall around the window causing wind pressure to build up and force air through the window.

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12   Francois Garde: presentation to NZGBC Green Building Summit, October 2009. http://www.propertynz.co.nz/files/Events/Francois%20Garde.pdf (last accessed April 2010).

The natural effect of warm air rising can be exploited by providing a natural chimney through the building. The openings through which this air flows must be large as the driving force is relatively weak. Rooftop openings can enhance this natural heat flow. They can also enhance wind-

assisted ventilation. For wind-assisted ventilation, the effectiveness of these openings depends on the pressure field created by wind. For low pitch roofs, both windward and leeward faces of the roof are subject to suction. For these low pitch roofs, single-sided ventilation systems like clerestories, and inserts into the roof itself (such as skylights) are effective. For high pitch roofs, only leeward faces are subject to suction and rooftop multi-sided opening devices can help create suction when the wind blows. In all cases, the inlets should be at a low level so that the airflow cools the occupied spaces.

It is also important that ventilation devices are fully adjustable to control airflow on cold days. Windows should not be of a size and configuration that results in cold drafts when getting rid of cooking and other smells in winter. Combinations of large and small openings provide choice and a greater level of control.

Matching opening type to roof pitch

Wind Direction →   Wind Direction →   Wind Direction →
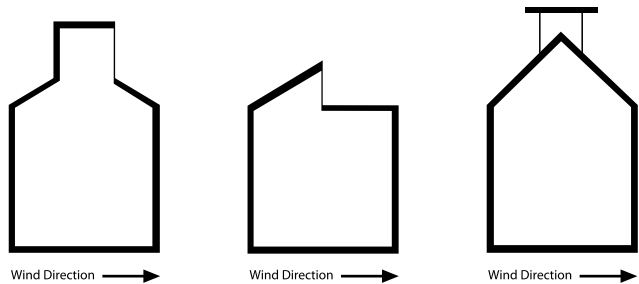
Direct ventilation

Bathrooms and kitchens produce both heat and water vapour. While the amount of heat produced is not generally a problem, the water vapour can be. This water vapour, if allowed to condense, is not only unsightly but may also lead to health problems and building maintenance issues. It is therefore important to provide a means of preventing

condensation and extracting water vapour. Generally mechanical extractor fans are needed to achieve the relatively high ventilation rates that are required. These should extract the waste air to the outside – never into the ceiling. Heaters may also be required, particularly in bathrooms, to maintain the room surface temperatures above condensation point. Although these fans and heaters do require purchased energy, the relatively small cost is justified, for both health and comfort.

Heat Distribution

Comfort and energy efficiency can be improved by distributing heat from warm areas to rooms that receive little direct sun. This can be achieved by taking advantage of the natural effect of warm air rising, but may also be assisted by the use of mechanical ventilation systems. These can range from a simple inexpensive fan to reasonably complex and expensive systems. Providing a fan with a thermostat control is an excellent low-cost option. You may of course choose to override this control but the thermostat ensures the design intention is obvious – and that the design will work even when you are not present or taking notice.

Large volumes of air need to be moved from warmer to cooler areas of a house before any significant heating results, so for both natural circulation and fan-assisted circulation to be effective, it is important to ensure that openings are large enough to allow adequate airflow. Doorways that open all the way to the ceiling will greatly assist this natural airflow. Allowance should also be made for shutting off openings as it may not always be desirable for heat gains to be distributed throughout the house. Also, colder rooms may need to be shut off from other rooms. For example, you will probably want to contain heat in living areas in the early part of the day (warm up period) and only distribute heat to the rest of the house in the latter part of the day when there is excess in the living areas and a need to warm up the other areas of the house (the bedrooms, for example).

For a two-storey house, this requires large openings between downstairs and upstairs and good control. Without good control of these heat flows, overheating of upstairs rooms can also be a major problem as can cold air flowing downstairs.

Thermal mass internal walls can be very effective in assisting in the distribution of heat to rooms that don't receive direct sun. For example, a concrete wall that separates a living area on the north from a bedroom to the south will quite effectively conduct heat through to the bedroom because of its low resistance to heat flow.

Airtightness

There is a link between building complexity and energy performance. More complicated designs with more construction joints tend to have more uncontrolled air leakage – technically known as infiltration - which can have a major impact on heating energy requirements. These leaks can be in the construction materials (for example, weatherboard exterior cladding and timber floorboards are inherently leaky) or they can result from the complexity of the plan itself (for example, corner joints, joints for cladding changes). The main ways to deal with these are:

- use sheet materials, or materials mortared together like brick or concrete walls which have fewer inherent leakage properties
- simplify the design to have less potential air leakage sites (e.g. fewer corners)
- take extra care during construction to seal all corner joints against air leakage
- Ensure penetrations in cladding or lining for plumbing or electrical fittings are well sealed
- Where design and construction still allow possible air leakage airtightness barriers could possibly be used. However, it is critical that they are vapour permeable and that the design and construction ensures construction moisture will be dissipated and condensation from warm indoor air will not be trapped.

For a well-constructed, well-insulated house, air leakage accounts for around 20-25% of the space heating energy use, so any reduction in heat loss from air leakage will have a significant benefit. Wind causes heat loss both through air leakage and by increasing the conduction heat loss, particularly through windows. There are therefore two primary ways of dealing with these heat losses:

- Ensure the house is well sealed, both its construction joints and by weather stripping windows and doors
- Use external wind breaks to reduce the impact of the wind on the house (these have the added advantage of making outdoor areas usable more often).

These should be used in combination. Weather-stripping can't deal with increased heat loss by conduction through the glass itself because the wind strips away the heat from the outer surface. Wind breaks can reduce this heat loss, but on their own only partially solve air leak problems that weather-stripping addresses."

Using Plan and Site Layout to Improve Comfort

There are many considerations that will influence the plan layout for a house – the site topography, the orientation to

the sun, the views and your likes and dislikes, to mention just a few. There are some simple layout guidelines which will improve the energy efficiency and comfort of your home. It may not always be possible to follow these guidelines completely because of constraints and preferences relating to other design considerations. However, an understanding of these simple guidelines will help you make informed decisions about the trade-offs that are an integral part of any design process.

Size and shape

A simplistic analysis of the heat losses through the surfaces of a building demonstrates that the 'best' building thermally is one that has the smallest external surface area. This ideal building is a sphere and is clearly impractical. The next best compact shape is a cube. A single-storey house is not cube-shaped but a two-storey house is much closer in overall shape to this ideal cube. Comparing the single-storey and two-storey houses studied in this book, the more compact two-storey house requires around 20% less heating energy than the single-storey house when both are insulated to Building Code minimum for Climate Zone Three[13] (when adjusted so the floor areas are identical).

The diagrams below show heat energy flows through the various components of a house that has been insulated to the levels required by the Building Code in Climate Zone Three. The single-storey and the two-storey house are very similar in total floor area. However, the diagrams demonstrate that heat losses through the windows are a far more significant proportion of the total heat loss for a two-storey house. This is because the floor and roof exposed to the outside are half the area of floor and roof of the single-storey house.

"Because the two-storey house is more compact it loses approximately 20% less heat than the single-storey house."

"Airflow heat loss from houses that have not been carefully designed and detailed can be two to four times that required to maintain a healthy home."

11% ROOF
FRESH AIR 14%
WINDOWS 36%
WALLS 20%
FLOOR 19%

6% ROOF
FRESH AIR 18%
WINDOWS 45%
WALLS 20%
FLOOR 11%
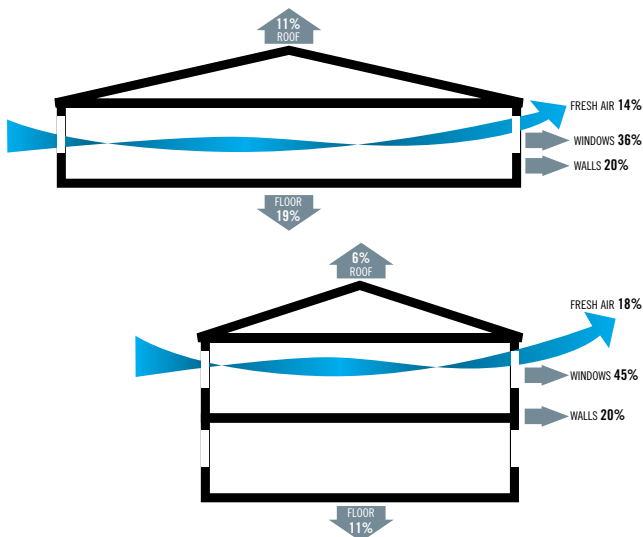
13   *See Appendix 2 on page 75 for information on climate zones.*

The heat loss figures for fresh airflow are based on the minimums required to maintain a healthy home. In real houses the heat loss through air leaks is sometimes two to four times greater. Air leakage can be by far the single greatest source of heat loss and therefore it is critical to design and detail to control unintended airflows. However, it is important to ensure that design and construction allow construction moisture to be dissipated and prevent trapping of condensation from warm indoor air.

Designing a house that is rectangular, so the north-facing facade is larger than the east or west facades, increases solar gain when it is most needed. It is also the easiest to control with simple shades when solar gain needs to be reduced. And the small east and west sides mean there is less potential for overheating and glare from low angle sun.

Making the building rectangular makes the plan less deep so that cross ventilation for cooling is easier to achieve. Also, making the plan less deep from north to south makes it far easier to distribute the heat from the north-facing rooms to the other less sunny parts of the house.

The heating and cooling requirements of a house are directly related to its size. You should think very carefully about how much space you really need if you are serious about comfort and energy efficiency. If you build a house that is twice the size you need, it will cost you roughly twice as much to heat and cool as a house the size you actually need.
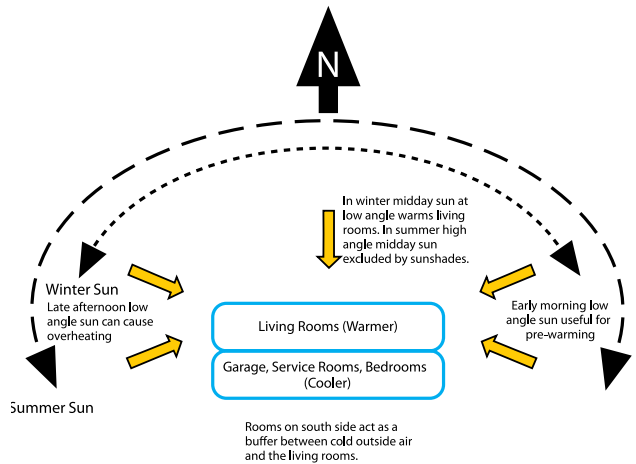
Orientation

North-facing glass provides the best access to solar gain. It is therefore preferable to orientate the house with the long axis in the east-west direction. This orientation to north can be plus or minus 20 degrees without having a major impact on solar gain.

If the house has northwest and northeast orientation of solar collecting windows, as is the case with the houses studied in Chapter Four[14], rotating by plus or minus 45 degrees makes little difference to solar gain.

Living areas should be located on the north face to maximise solar gain in these rooms. Living areas should be protected from the cold south face by placing the garage and service rooms to act as a buffer on this face. People often prefer not to heat bedrooms as much as living areas, and generally bedrooms don't need to be particularly warm during the day. Direct sun in bedrooms is therefore not necessarily important. These rooms can be heated by designing for warm air movement from living areas during the day.

14   *See page 45 for results of orientation studies.*

In winter midday sun at low angle warms living rooms. In summer high angle midday sun excluded by sunshades.

Winter Sun
Late afternoon low angle sun can cause overheating

Early morning low angle sun useful for pre-warming

Living Rooms (Warmer)

Garage, Service Rooms, Bedrooms (Cooler)

Summer Sun

Rooms on south side act as a buffer between cold outside air and the living rooms.

Site selection

It is obvious that a house in Auckland will be exposed to very different climatic conditions from a house in Christchurch and therefore performance will differ from climate to climate. It is less obvious, however, that within each town there can be very large differences in microclimate that impact on the comfort and energy efficiency of a house.

Site selection is critical to house performance as a site that receives limited sun during the winter will obviously get very little heating benefit from the sun when it is needed most. Be very cautious of a site that is being marketed as having great afternoon sun – often this means good sun in summer but very limited sun in winter.

The following sections are intended to assist with site selection, and to provide a means to optimise your design if you already have a site and want to make best use of what you have.

The only accurate way to establish microclimate data is to establish a weather station on the site. This is rarely a practical option, so therefore you must rely on your own observation and experience and that of local residents. Having gathered as much information as you can about the site microclimate, you are in a position to make informed design decisions that will make the most of the site.
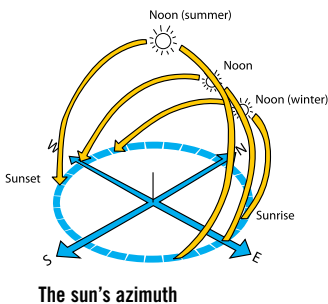
Sunpath diagrams

Visiting a site at various times of the day is a good way of checking how much sun the site gets, but it is rarely possible to do this for the whole year. Sunpath diagrams map the position of the sun relative to the site, both by time of day and time of year. A plan of the objects that will shade the site (currently and in the future) can be drawn onto the sunpath diagram. This diagram can then be used to assess the shading effect on the site and help you make decisions about the

The sun's azimuth

Noon (summer)
Noon
Noon (winter)
Sunset
Sunrise

position of the house on the site, and in particular the position of the north-facing windows (the primary solar collectors). If compromise is necessary, as a minimum, you should aim for unrestricted sun on solar collecting windows between 9am and 3pm in winter.

Sunpath diagrams can be downloaded from www.victoria.ac.nz/cbpr/resources. If your region does not have a specific named sunpath diagram you can use that of a nearby region as the differences will be insignificant. Alternatively, several computer programs[15] permit you to print diagrams specific to the precise latitude of a building site.

Topography

Sites on hillsides tend to experience uphill airflows during the day, as warmer air moves towards the top of the hill. At night this trend reverses, with cool air flowing down the hill and contributing to frosts in the valleys. Hedges and walls can dam this flow, contributing to local frost pockets, unless there are openings to allow the air to flow through.

Sloping sites also receive very different amounts of solar radiation. North-facing slopes receive significantly more solar gain than flat sites. This means that ground and air temperatures are higher and therefore heat loss from a building is lower on a north-facing slope. For example, a north-facing Christchurch site will experience temperatures similar to a flat site in Wellington.
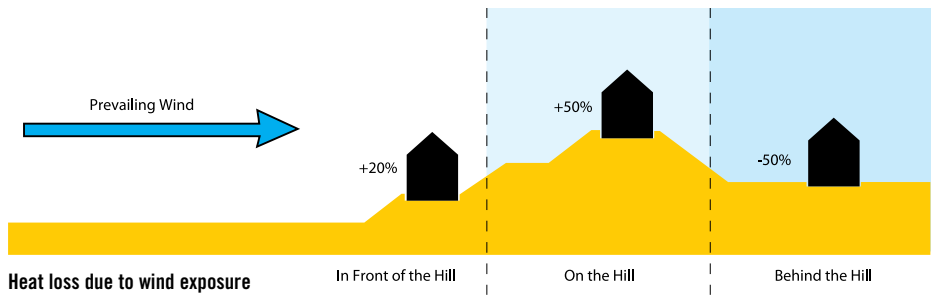
Ground surface cover around the house

The temperature extremes experienced in and around a house can be made better or worse by the surrounding ground cover. Paving, for example, particularly if it is dark coloured, can get very hot in summer. On the other hand, grass absorbs heat through evaporation and photosynthesis, resulting in temperatures over grass that are considerably lower than bare earth or paving. Air flowing over grass into the home will therefore have a cooling effect in summer. Other vegetation such as trees and shrubs have a similar effect to grass and can also contribute to summer cooling breezes, but of course care needs to be taken that this vegetation does not block winter sun.

Water moderates temperatures

The sea, and to a lesser extent lakes, have a temperature moderating effect. This is because the sea temperature varies as little as 10 degrees during the course of the year, and as little as one degree from day to night. In Wellington, for example, a site near the sea will experience maximum temperatures that are 1-2 degrees lower than elsewhere in

North Slope

Level

South Slope

---

15 Autodesk® Ecotect® 2010 (http://www.autodesk.com/ecotect-analysis) or Climate Consultant 4 (http://www.energy-design-tools.aud.ucla.edu/).

Prevailing Wind

+20%

+50%

-50%

Heat loss due to wind exposure

In Front of the Hill | On the Hill | Behind the Hill
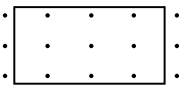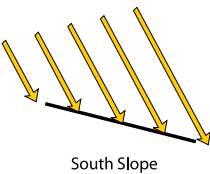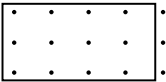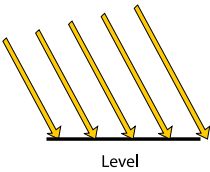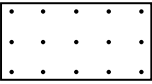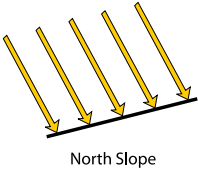
Wellington, and minimum temperatures that are 3-6 degrees higher. The other major effect is that during the day cool sea breezes tend to flow inland and at night the reverse occurs. It is also worth remembering that reflection of the setting sun off the water can as much as double heat gain through west-facing windows.

Wind contributes to heat losses

Wind can have a major impact on heat loss from a house. A house located on top of a ridge can have heat losses 50% greater than if it were on the flat.

In considering the need for wind barriers, it may be useful to obtain meteorological data on wind speed, direction and frequency for the region (available from the National Institute of Water and Atmospheric Research www.niwa.cri.nz). It will also be important to assess the local site conditions, which may vary considerably from the general regional data. Channelling in valleys, for example, can add 20% to wind speed.

Windbreaks are most effective if they are as close to the house and as high as possible. Porous windbreaks will cause less turbulence downstream. At 20-30% porosity, they will reduce wind speed by 50% for a distance up to 10 times the windbreak height. Solid barriers will provide greater shelter, but over a shorter distance. They will reduce wind speed by 75% for a distance up to five times the windbreak height.

Windbreaks should always be at right angles to the wind they are intended to provide shelter from.

Unfortunately it is seldom possible to provide optimum protection from winter winds without compromising winter sun, or the cooling breezes that are important in summer. As with most aspects of thermal design, and indeed design in general, compromise is necessary. One way of dealing with conflicting requirements is to provide movable screens. These can be very effective but do require active participation of the house occupants.

Chapter 4: Expected Performance
## Performance calculations

The information in this chapter is based on computer studies of the performance of a single-storey house of around 200 square metres (excluding the garage). It has not been purpose designed for this publication – it is a real house, which was built in Auckland at the time of writing of the first edition of this book. It is not even an optimum solar design, but has been selected because its size and layout are reasonably representative of a new family home in New Zealand today. Its orientation to the sun is likewise not optimum for solar design, but reflects constraints of the actual site on which it was built.

The single-storey house
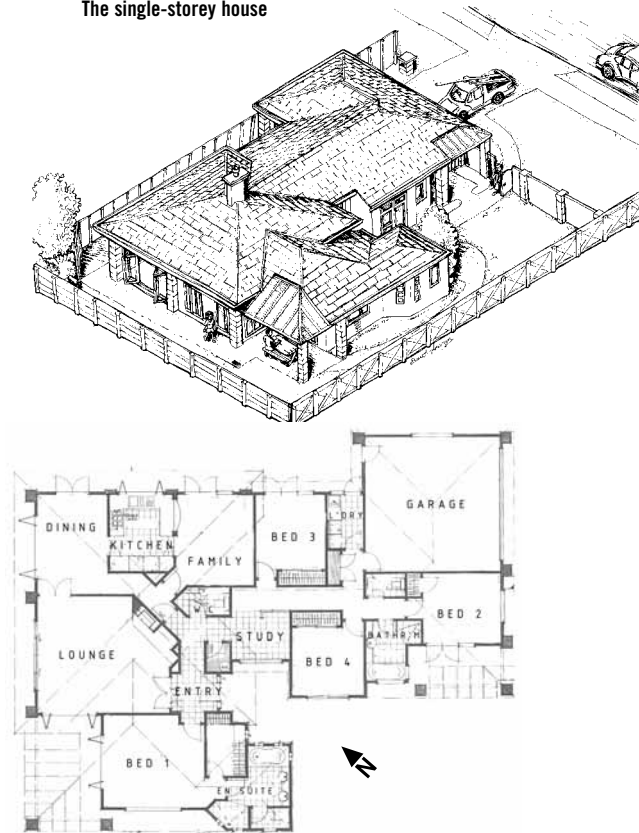
A limited number of studies were also conducted for a two-storey house of similar size. They show that the general trends demonstrated for the two-storey building are consistent with the single-storey building. Ultimately, the goal is to provide the basis for you to evaluate how your own design might perform using the lessons learnt from the various combinations of glass, mass and insulation in these houses. The results of the studies of the two-storey design are summarised in Appendix 1 on pages 71-74.

The two-storey house

CODE
INSULATION
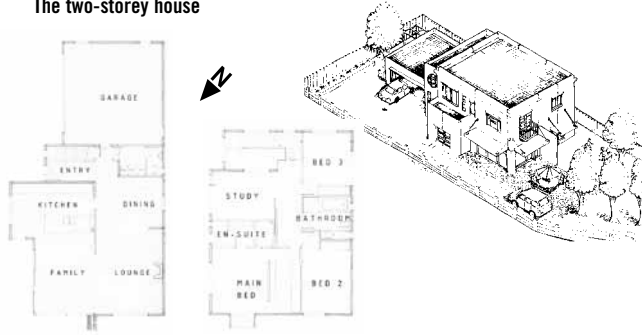
The electronic buildings

The computer studies have used the SUNREL program, developed by the USA's National Renewable Energy Laboratory. It is internationally recognised for its ability to accurately model building thermal performance. We have 'built' 27 electronic houses in each of three cities in New Zealand to study how three different levels of glass, mass and insulation (3x3x3) affect energy use and comfort.

BETTER
INSULATION
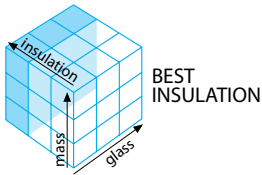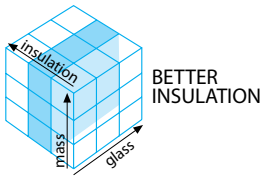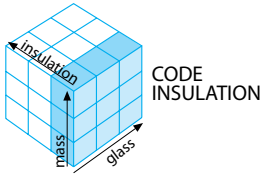
Locations

The e-buildings were 'built' in Auckland, Wellington and Christchurch. These locations were selected because of the large number of new homes built in these cities and because they represent a wide range of New Zealand climates. They are also representative of the three climate zones defined in the New Zealand Building Code. The weather data used in these studies was developed by NIWA for EECA and is freely downloadable from http://tinyurl.com/NZweather[1]

BEST
INSULATION

Expected performance in other climates

The performance conclusions were also tested for e-buildings[2] insulated to the best level defined in this chapter in all 15 other climates for which NIWA developed weather files. Both low and high mass designs were modelled with a high level of glazing. The following graphs show the results of these calculations. The graphs show positive energy (above the horizontal axis) entering the house as solar energy (in yellow) plus the purchased heating energy (in red) required to maintain comfortable temperatures. They are listed in increasing order of heating energy use. They show heat losses from the house below the horizontal axis. The first two houses are insulated to Climate Zone 1 best level (see page 52); the next 6 are insulated to Climate Zone 2 best level (see page 57); and the rest are insulated to Climate Zone 3 best level (see page 63).
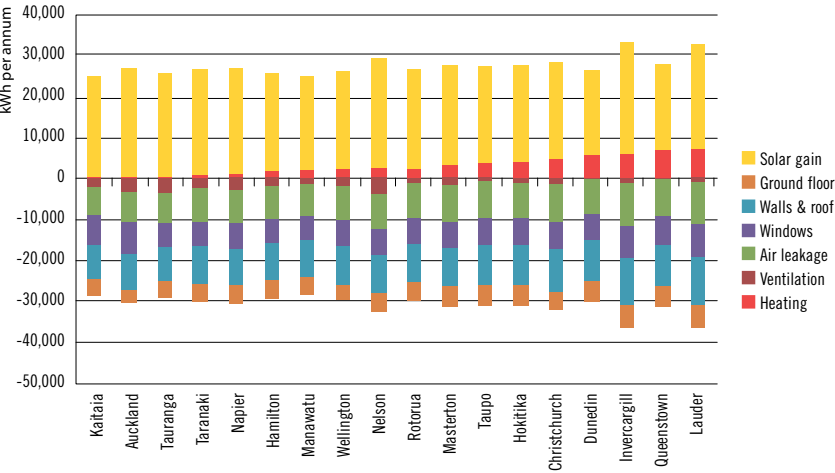
1   http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/
    region=5_southwest_pacific_wmo_region_5/country=NZL/cname=New%20
    Zealand]

2   The two-storey house was used for these studies.

Low mass, 55% glazing, best insulation
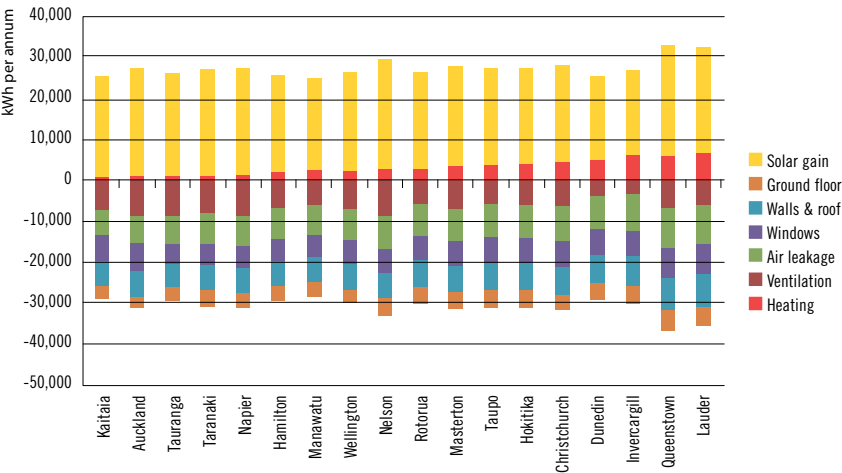
High mass, 55% glazing, best insulation

The results show that variation in sunshine hours for the 18 different climates has a relatively small influence on the heating energy requirement – the key factor influencing heating energy needed is the coldness of the climate. When insulated to the same level, houses in colder climates require more heating energy even if they have high sunshine hours.

Look carefully at the difference in 'Ventilation' energy heat loss between the low mass and the high mass buildings (just below the horizontal axis in the graphs). For the low mass building, the amount of heat that must be vented when the sun makes the building too hot is significantly bigger at the north of the North Island where high sunshine hours combine with high air temperatures. For the high mass building, with the same size windows and same levels of insulation there is much less wastage of solar energy.

The standard year for these studies was selected as an 'average year' from 30 years of temperature data. If you focus just on annual energy use and not on comfort, then the heating energy use can easily change by as much as 30% from year to year. This becomes obvious when looking carefully at the energy balance represented in the graphs – the purchased energy for heating (in red) is always tiny by comparison with the large heat loss totals below the horizontal axis which are balanced by the equally large solar heat gains. Even relatively small changes in the heat losses or the solar gains are proportionally large compared to the heating energy use. It is therefore not possible to adapt the information on the next few pages into precise predictions of performance for your own situation, whether a different design or different climate. However, there should be sufficient information on the performance of these e-buildings to help you to understand the general principles of solar design and thus anticipate the effect the coldness of climate, the anticipated heating schedule and the levels of glass, mass and insulation.

If you want to study these issues in more depth, we recommend you consult a building scientist capable of completing these calculations for a specific design. There are a number of computer programs available, including SUNREL (www.nrel.gov), AccurateNZ (www.energywise.govt.nz), IES Virtual Environment (www.iesve.com/A-NZ) and EnergyPlus (http://apps1.eere.energy.gov/buildings/energyplus/).

Variations in construction

For each of the main variables (glass, mass and insulation) three different levels have been selected. The effect on energy use and comfort of the 27 combinations (3x3x3) of these variables has been evaluated.
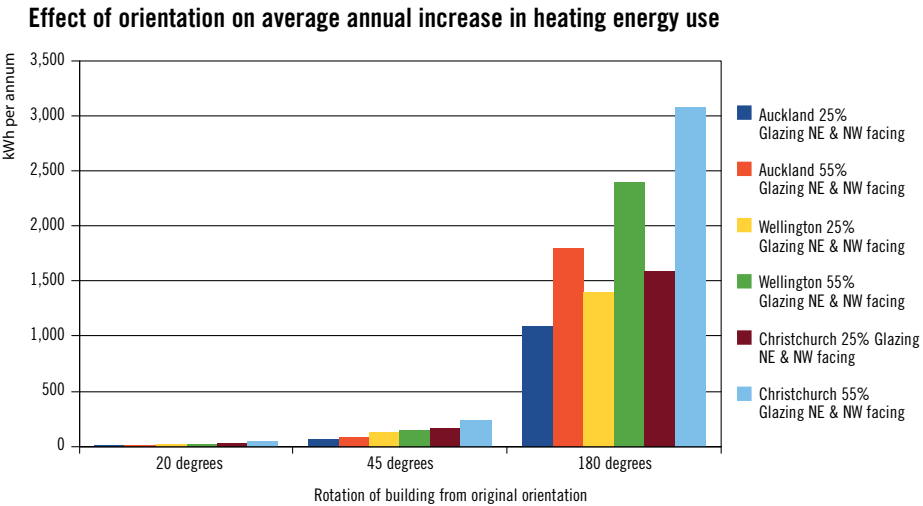
Glass

Glazing levels have been defined as low, medium and high, based on our understanding of typical practice in New Zealand. These levels are defined as a percentage of glazing relative to the total area of each face of the building. The following table summarises the levels selected. These levels are consistent for all three locations. Because the real building is not oriented square to north (because of site constraints) the building faces are NE, NW, SE and SW. Only windows in the NE and NW faces are varied, as these are the primary solar collecting windows.

		NW face	NE face	SE face	SW face	Total building
Low glazing	Window area	16.2m²	13.7m²	16.3m²	3.2m²	49.4m²
	Area ratio	25%	25%	34%	9%	23%
Medium glazing	Window area	24.2m²	23.2m²	16.3m²	3.2m²	66.8m²
	Area ratio	40%	40%	34%	9%	31%
High glazing	Window area	34.0m²	31.8m²	16.3m²	3.2m²	85.3m²
	Area ratio	55%	55%	34%	9%	38%

It is worth repeating that the e-building modelled for this exercise is not an optimised solar design. It has glass which faces northeast and northwest. It is therefore likely to overheat a little more than a house that faced due north because simple overhangs or eaves to shade against the summer sun are harder to make work well with these orientations.

"The effect on heating energy use of orientation of the 'NE and NW' glass within a span of plus or minus 45 degrees is small."

However, the upside of this is that the calculated performance is more likely to be typical of a normal house, rather than one where the whole focus was on solar optimum design. This shows up in the examination of the effect of orientation on the design. Some studies[3] looked at the impact of rotating the whole house to see what the effect would be on the heating energy use. The major point of note is how insensitive these houses are to quite large variations in the direction the living room glazing faces. However, when the

Effect of orientation on average annual increase in heating energy use

Legend:
- Auckland 25% Glazing NE & NW facing
- Auckland 55% Glazing NE & NW facing
- Wellington 25% Glazing NE & NW facing
- Wellington 55% Glazing NE & NW facing
- Christchurch 25% Glazing NE & NW facing
- Christchurch 55% Glazing NE & NW facing

y-axis: kWh per annum
x-axis: Rotation of building from original orientation (20 degrees, 45 degrees, 180 degrees)

3   Energy use is presented as the average of the low, medium and high mass buildings. The two-storey house was used for these studies.

45

"Rotating the e-building 180 degrees dramatically increased energy use."

house is completely spun on its axis so the living room windows face south (180 degree rotation) there is a very significant increase in the energy use. This is most marked when the house is more dependent on the heat from the sun – when the north window area is at its largest.

Mass

The levels of mass have been defined as low, medium and high. The amount of mass has been varied based on logical use of mass for various building components, rather than trying to use scaled steps based on weight of high mass components. The levels of mass have been kept consistent for all three locations and are summarised in the following table.

	Ground floor	External walls	Internal walls	Suspended intermediate floor	Ceiling/ roof
Low mass	Concrete with carpet throughout	Timber framed	Timber framed	Timber framed	Timber framed - lightweight
Medium mass	Concrete slab finished with tiles	Timber framed	Timber framed	Timber framed	Timber- framed - lightweight
High mass	Concrete slab finished with tiles	Concrete with Exterior insulation	Concrete	Concrete	Timber framed

"The benefits of medium mass are dependent on the floor slab being exposed. Insulating it with carpet will make it perform much the same way as low mass, unless some other mass is available such as high mass walls."

Pre-cast concrete walls have been used for all cases where concrete walls are studied. This has been done for consistency only. Concrete masonry, in-situ concrete or other high mass materials can all be used to add mass to a home. Remember, however, that if you wish to get maximum benefit from the thermal mass, the insulation must be on or near the exterior of external walls. For all external pre-cast walls the insulation was expanded polystyrene fixed externally, with a plaster finishing and waterproofing system. Likewise, thermal mass from internal walls, suspended floors and ground floor slabs will work best if insulating material does not isolate the mass. In the low mass examples, the concrete from the floor slab is isolated by carpet and therefore does not contribute significant thermal mass. In the medium and high mass examples, the concrete floor slab has no carpet.

The assumption that the carpet in the low thermal mass building insulates the thermal mass in the concrete floor and thus makes it behave as a lightweight building was tested in a series of calculations[4].

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4   The two-storey house was used for these studies.

The following graph shows the effect in the two-storey lightweight house of carpet insulating the concrete floor. It shows energy use for the Code and Best insulated e-building with either 25% or 55% of the northeast and northwest facades glazed. The heating energy use is a little less in the e-building with the concrete floor, despite the mass being isolated by carpet. It would seem that, despite the insulation of the carpet, when the house overheats (when it has 55% north glass) there may be some more heat stored in the concrete floor slab than is able to be stored and used in the timber floor house.

Annual heating energy use by floor type – concrete with carpet and timber with carpet
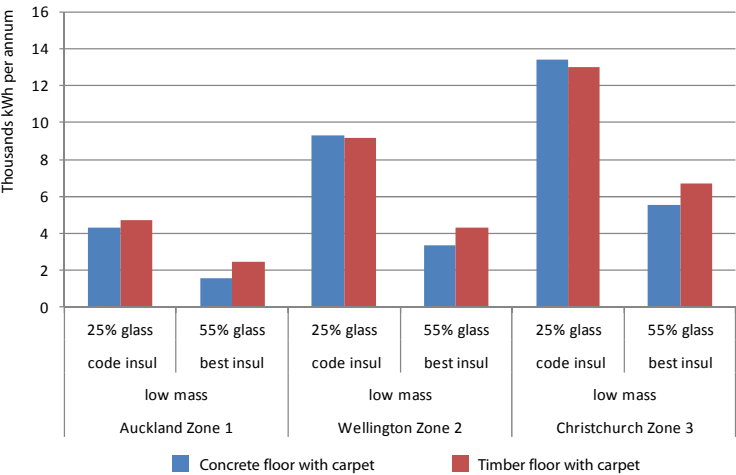
For the medium mass option there is considerable room for variation on where the mass is positioned. There is no precise definition of what constitutes a medium level of thermal mass. Some suggestions of a medium mass level are:

- exposed concrete ground floor, concrete external walls, lightweight internal walls

- exposed concrete floor, concrete internal walls, lightweight external walls

- carpeted floor, concrete external and internal walls.

Insulation

The three levels of insulation studied have been defined as: Code Compliance; Better Practice; and Best Practice. Because there are different Building Code minimum insulation requirements for Christchurch compared to Wellington and Auckland, it is not possible to keep the insulation levels consistent for the three locations. There are also quite different minimum insulation requirements for high mass and low mass external walls. This means that the three insulation levels for high mass (solid) external walls are different from the

corresponding insulation levels in low mass (non-solid) walls. The insulation levels studied are summarised for Auckland on page 52, for Wellington on page 57 and Christchurch on page 63. The R-values[5] used for all components are whole component R-Values. They therefore account for the different conduction of heat through the different elements that make up that building component.

Performance Results

Comfort

The results of these studies are presented as comfort ratings, energy use and required heater size. The comfort rating has two components: The first is based on the number of hours the living areas fall below 16°C; the second is based on the total number of hours that the living area temperature exceeds 26°C. The calculation models the windows being opened to allow ventilation when the temperature reaches 26°C. The ventilation rate achieved is dependent on the opening sizes of the windows and the amount of wind. Obviously if no one is home to open the windows the overheating problem will be much worse.

Energy use

The heating energy required for a home will be dependent on how the occupants heat the home and there is really no typical behaviour pattern. To give an idea of the likely range of energy use we have conducted some studies[6] to examine three very different heating schedules for the two-storey house:

• heating as required 24 hours a day (bedrooms to 16°C, living areas to 20°C)

• heating as required 7.00am-11.00pm only (bedrooms to 16°C, living areas to 20°C) – no heating 11.00pm – 7.00am

• heating as required 7.00am-9.00am and 5.00pm-11.00pm (bedrooms to 16°C, living areas to 20°C) – no heating 9.00am – 5.00pm or 11.00pm – 7.00am.

The following graph shows the difference in average annual heating energy use for the three heating schedules for both code and best insulation levels. Energy cost can be estimated using roughly $200 per 1,000kWh (at the time of writing).

5   See page 68 – Determining Insulation Values.

6   Energy use is presented as the average of the low, medium and high mass buildings with medium level of glazing. The two-storey house was used for these studies.

Comparison of average energy use of different heating schedules
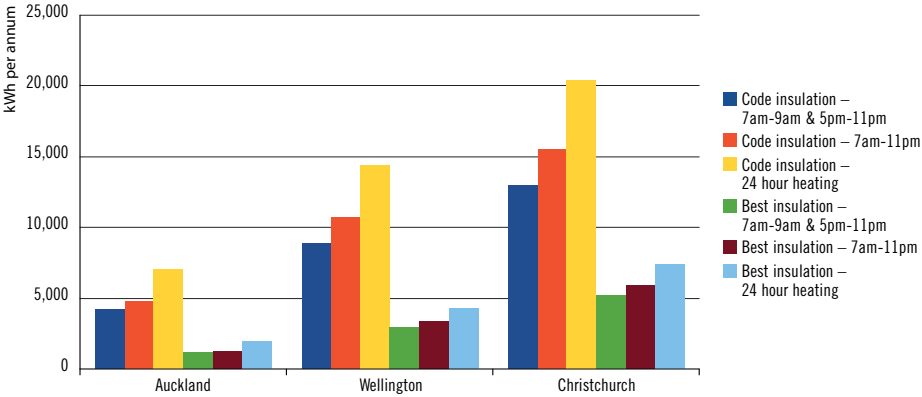
A much more dramatic change in energy use can be seen when the thermostat is set to a higher level. If the living room areas are heated to 22°C or 24°C instead of 20°C, then the use of energy for heating can dramatically increase. This shows what is likely to happen to your energy bills if you rely on remembering to turn off the heating or if you wait until it begins to feel a bit too hot before turning down the heaters. For the warmer climate zones the effect of raising the thermostat can at least double the energy use. Even in Christchurch the increase can be nearly 50%. The following graph shows the difference in average annual heating energy use for the three heating set points for both code and best insulation levels.

Comparison of average energy use with different temperature setpoints
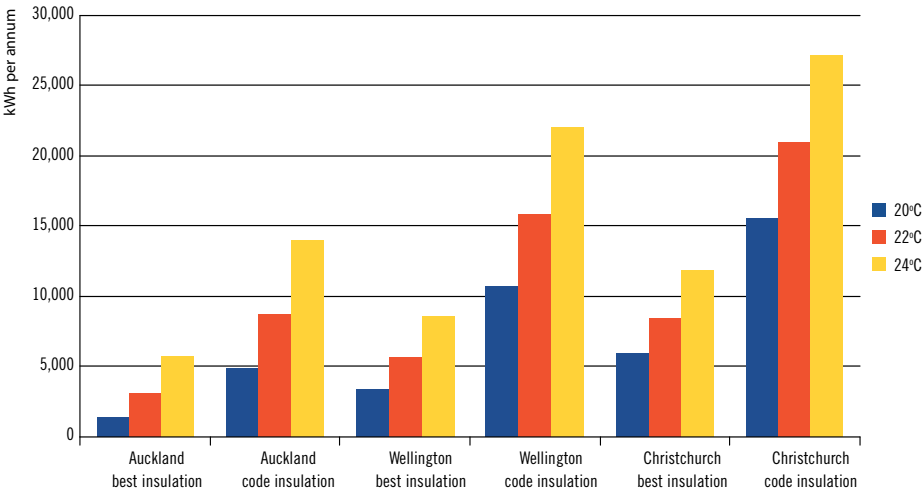
Although specific homeowners' heating patterns will often be quite different, the relationship between the options presented does allow estimation of the likely benefits of the design options. The absolute energy consumption of a design is less important than the comparison between different glass, mass and insulation options – with the same heating schedule. Remember that although energy efficiency is important to many people, comfort is of equal if not greater importance. After all, the reason we use energy for heating (and cooling) is to ensure we are comfortable in our homes. Improved comfort is a significant benefit even if there is no saving in energy costs.

Your specific design

The following sections covering expected performance in Auckland, Wellington and Christchurch should be all you need in most design situations. If it is important for you to have precise predictions for your specific design, and your specific location, consult a building scientist capable of conducting simulations. There are a number of computer programs available, including SUNREL (www.nrel.gov), AccurateNZ (www.energywise.govt.nz), IES Virtual Environment (www.iesve.com/A-NZ) and EnergyPlus (http://apps1.eere.energy.gov/buildings/energyplus/).

AUCKLAND

Auckland has a relatively warm climate with average ground temperatures of 20.3°C in summer and 12.8°C in winter. Overheating of homes is a much greater problem than in the cooler parts of New Zealand. Although Auckland homes generally require some heating to maintain comfortable temperatures in winter, the amount of heating required is relatively small. Any cost savings are therefore likely to be small in absolute terms, and may not be a major motivator. Reducing overheating is likely to be a much more important benefit to most people.
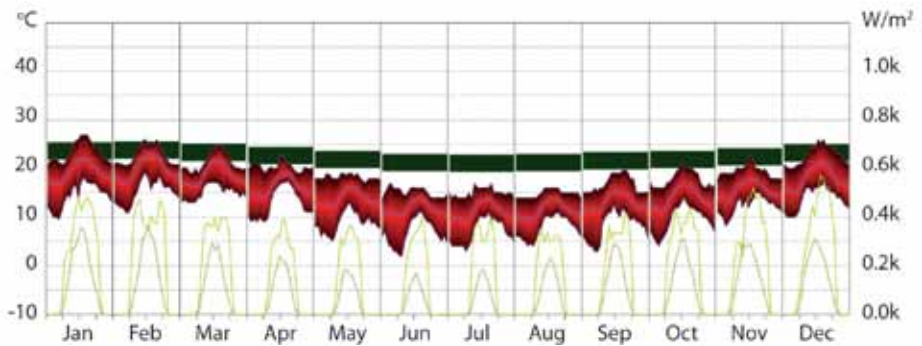
"Overheating of houses is a much greater problem in Auckland than it is in the cooler parts of New Zealand."

KEY:
Blue middle line = Average day temperature during allocated months
Wider red area = Range of day temperatures during allocated months
Green solid line = Average direct sunlight per day and month (W/m²)
Green dotted line = Average diffuse sunlight per day and month (W/m²)
Dark green bars = Comfortable temperature range for months

Summary created using Autodesk® Ecotect® 2010 of the Auckland weather data used in the house performance calculations

There are many ways in which the results presented in the following pages can guide your design. Remember – these studies can't be used to accurately predict energy use and comfort for different designs or different locations. You can however estimate performance by adjusting for coldness of climate, anticipated heating schedule and levels of glass, mass and insulation.

Construction details

The following table provides details of the constructions used to achieve the specified levels of insulation for the three insulation levels and the three mass levels. These construction systems have been chosen as they are all currently used in the New Zealand market. Other construction systems that achieve the same insulation R-Values will perform in the same way.

		Concrete ground floor slab	External walls	Roof	Window glazing
Low mass	Code compliance	Carpeted floor, R1.7 polystyrene edge insulation (R1.9)	Timber frame with R2.2 bulk insulation (R2.1)	Timber frame with R3.2 bulk insulation (R2.9)	Double clear glazing metal frames (R0.26)
	Better practice	Carpeted floor, R1.4 polystyrene under slab plus edge insulation (R3.1)	Timber frame with R2.6 bulk insulation (R2.4)	Timber frame withR3.6 bulk insulation (R3.4)	Double low-E Argon filled glazing timber frames (R0.5)
	Best practice	Carpeted floor, R1.4 polystyrene under slab plus edge insulation (R3.1)	Timber frame R2.6 + R2.2 bulk insulation (R4.2)	Timber frame with R5.0 + R5.0 bulk insulation (R9.5)	Triple glazing – one pane low-E, timber frame (R0.62)
Medium mass	Code compliance	R1.7 polystyrene edge insulation (R1.7)	Timber frame with R2.2 bulk insulation (R2.1)	Timber frame with R3.6 bulk insulation (R3.4)	Double clear glazing metal frames (R0.26)
	Better practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Timber frame with R2.6 bulk insulation (R2.4)	Timber frame with R4.0 bulk insulation (R3.7)	Double low-E Argon filled glazing timber frames (R0.5)
	Best practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Timber frame R2.6 + R2.2 bulk insulation (R4.2)	Timber frame with R5.0 + R5.0 bulk insulation (R9.5)	Triple glazing – one pane low-E, timber frame (R0.62)
High mass	Code compliance	R1.7 polystyrene edge insulation (R1.7)	Concrete with R0.5 external polystyrene insulation (R0.8)	Timber frame with R3.6 bulk insulation (R3.4)	Double clear glazing metal frames (R0.26)
	Better practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Concrete with R2.4 external polystyrene insulation (R2.7)	Timber frame with R5.0 bulk insulation (R4.5)	Double low-E Argon filled glazing timber frames (R0.5)
	Best practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Concrete with R4.2 external polystyrene insulation (R4.5)	Timber frame with R5.0 + R5.0 bulk insulation (R9.5)	Triple glazing – one pane low-E, timber frame (R0.62)

Note: the R-Value of the insulation material is provided along with the R-Value of the complete system (in brackets).

Temperature fluctuations

The 'sparklines' in the following charts are based on heating the living areas (as required) between 7.00am-11.00pm to 20ºC, but no heating between 11.00pm-7.00am.

These sparklines show the magnitude of the drop in temperature, below 16ºC, between 11.00pm and 7.00am (below the axis) and the magnitude of overheating, above 26ºC (above the axis) for all 365 days of the year. They therefore provide a good indication of the expected comfort of each house.

The house in the bottom left corner has a relatively small window area and is insulated to the current minimum required by the Building Code – it mainly needs heating.

Increasing the areas of north-facing glass in the bottom row of this code insulated group of houses increases the need for heating and introduces a need for cooling.

Moving up a row to the medium thermal mass buildings shows a very large reduction in the swings in temperature.

The effect of adding more insulation to a house can be seen by looking at the groups of sparklines for better and best insulation. Improving insulation removes most of the large drops in temperature at night but increases the amount of overheating during the day. Increasing mass levels in these more highly insulated houses has the same effect observed in the code insulated homes – it greatly reduces the swings in temperature.

Cooling need

"Increasing north-facing glass causes more overheating but increasing mass in the house greatly reduces this problem"

Overheating has been calculated as degree hours – the total for all hours over 26°C multiplied by the difference between 26°C and the actual temperature. This is a better indicator of the need for cooling than merely the hours over 26°C. For example, two houses might each total 10 hours over 26°C, but one is just one degree over on average, a total of 10 degree hours; the other being on average 4 degrees over would total 4 degrees times the 10 hours or 40 degree hours. Overheating hours will tend to be afternoon and evening hours in summer.

The following tables show the number of overheating degree hours (above 26°C) in each of the houses – even when the windows are opened for natural ventilation cooling. The calculation models the windows being opened to allow ventilation when the temperature reaches 26°C. The ventilation rate achieved is dependent on the opening sizes of the windows and the amount of wind. Obviously if no one is home to open the windows the overheating problem will be much worse.

Amount of overheating – degree hours above 26°C

mass	Code Insulation			Better Insulation			Best Insulation		
High	25	156	262	154	438	621	155	465	672
Medium	85	314	478	262	639	893	324	810	1100
Low	384	936	1301	544	1204	1658	593	1388	1898
	low	med.	high	low	med.	high	low	med.	high
		glazing			glazing			glazing	

Here the complex interaction of glass, thermal mass and insulation becomes clear. Increasing glass area facing north (left to right in each group) brings big increases in overheating degree hours. A doubling of the number of degree hours is approximately correlated with a doubling of the need for cooling energy. However, increasing the amount of available thermal mass within each insulation group – moving up from one row to the next – results in very large decreases in overheating.

"In medium and high mass houses temperatures virtually never fall below 16°C overnight."

Overnight temperature drop

A significant amount of energy can be saved by turning off the heating before going to bed for the night, but a major influence on the feeling of comfort in a house is how much the temperature in the house falls overnight. Underheating hours will tend to be pre-dawn hours in winter – they are based on how often the temperature drops below 16°C when the heaters are turned off at 11.00pm and turned on the next day at 7.00am. The following tables show how many degree hours below 16°C occur in each of these e-buildings.

Amount of underheating – degree hours below 16°C

mass	Code Insulation			Better Insulation			Best Insulation		
High	0	0	0	0	0	0	0	0	0
Medium	1	2	2	0	0	0	0	0	0
Low	348	434	516	142	196	248	1	3	12
	low	med.	high	low	med.	high	low	med.	high
		glazing			glazing			glazing	

The benefit of mass and insulation is obvious in these tables. The moderate amount of mass in the medium mass option is all that is needed to ensure essentially no underheating occurs in the living rooms. Increasing the insulation – moving from left to right across the groups – also reduces underheating.

Purchased energy for heating

Energy use is presented for just one heating schedule. You may, of course, operate a quite different heating schedule. The absolute energy use is less important than the comparison between different glass, mass and insulation options – with the same heating schedule. Many New Zealand homes are less well heated than the schedule presented and therefore energy use will be lower. As described earlier on page 49, heating for longer each day will increase your energy use, but not nearly as much as heating to a higher temperature (greater than the 20°C modelled). Energy cost can be estimated using roughly $200 per 1,000kWh (at the time of writing).

"Heating energy consumption decreases dramatically with increases in insulation."

The following tables show purchased energy (x 1,000kWh) required to maintain a minimum temperature of 16°C in bedrooms and 20°C in living rooms between 7.00am and 11.00pm, 365 days a year (no heating 11.00pm-7.00am). Use of air-conditioning units to control overheating has not been modelled so overheating may still occur as control is by opening windows only. Use of air-conditioning units, such as heat pumps, to control overheating can increase energy consumption very significantly.

Heating energy consumption (x 1,000kWh)

mass	Code Insulation (low / med. / high glazing)			Better Insulation (low / med. / high glazing)			Best Insulation (low / med. / high glazing)		
High	5.4	4.9	4.9	2.9	2.5	2.4	1.5	1.0	0.7
Medium	4.5	4.1	4.0	3.0	2.7	2.8	1.4	1.1	1.2
Low	4.7	4.6	4.9	3.3	3.3	3.6	1.6	1.5	1.7

The tables above demonstrate that improving insulation is by far the most effective way of reducing energy use. The set of e-buildings with Code level insulation on the left have much higher annual energy use than those to the right with higher levels of insulation.

By looking at the energy use, overheating and underheating tables you can see that if you increase the amount of north-facing glazing, in conjunction with increased thermal mass, you generally get heating energy and comfort benefits.

When you are comparing specific glass, mass and insulation combinations, don't just look at one factor in isolation. It pays to look at the sparklines, overheating, underheating, energy use and heater capacity tables together to get a good overall picture of the likely performance you can expect.

Required heater size

For each computer study, heating capacity required to meet peak demand on the coldest day is also presented for the 7.00am-11.00pm heating schedule. Typical domestic electric heaters have a capacity of 500W to 2.4kW, heat pumps 4-9kW, flued gas heaters 3-7kW and wood burners 8-15kW. Several of the e-buildings require less than 6kW heater capacity for the whole house.

Required heater capacity (kW)

mass	Code Insulation (low / med. / high glazing)			Better Insulation (low / med. / high glazing)			Best Insulation (low / med. / high glazing)		
High	9.8	9.8	10.9	7.8	7.8	8.0	4.6	4.4	4.3
Medium	8.9	9.1	9.4	8.6	8.7	9.0	5.6	5.2	5.8
Low	9.9	10.2	10.7	9.0	9.4	9.8	6.4	6.7	7.3

WELLINGTON

Wellington has a climate that is generally cooler than Auckland in the summer and warmer than Christchurch in the winter. Average ground temperatures are 18.6ºC in summer and 10.1ºC in winter. Wellington enjoys a relatively high number of sunshine hours. As would be expected from the climate, energy consumption required to maintain comfort in winter is significantly higher than Auckland but significantly lower than Christchurch. Overheating, though less of a problem than in Auckland, can still occur and be significant if not well accounted for in the house design.

KEY:
Blue middle line = Average day temperature during allocated months
Wider red area = Range of day temperatures during allocated months
Green solid line = Average direct sunlight per day and month (W/m²)
Green dotted line = Average diffuse sunlight per day and month (W/m²)
Dark green bars = Comfortable temperature range for months

Summary created using Autodesk® Ecotect® 2010 of the Wellington weather data used in the house performance calculations

"Heating energy needed in Wellington is much higher than Auckland, but lower than Christchurch – overheating is not generally a big problem, particularly in medium and high mass houses."

There are many ways in which the results presented in the following pages can guide your design. Remember – these studies can't be used to accurately predict energy use and comfort for different designs or different locations. You can, however, estimate performance by adjusting for coldness of climate, anticipated heating schedule and levels of glass, mass and insulation.
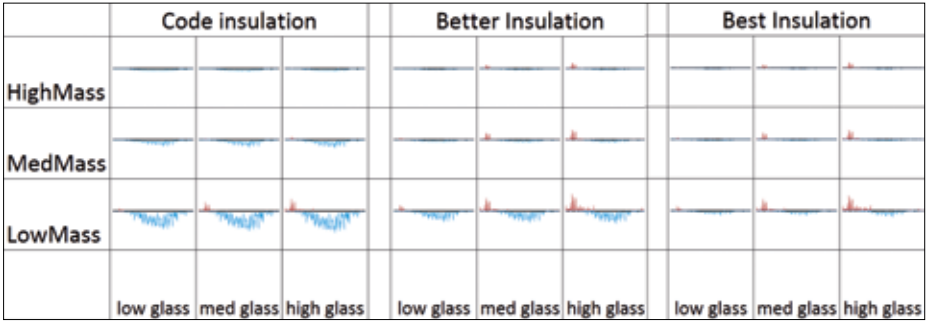
Construction details

The following table provides details of the constructions used to achieve the specified levels of insulation for the three insulation levels and the three mass levels. These construction systems have been chosen as they are all currently used in the New Zealand market. Other construction systems that achieve the same insulation R-Values will perform in the same way.

	Insulation level	Concrete ground floor slab	External walls	Roof	Window glazing
Low mass	Code compliance	Carpeted floor, R1.7 polystyrene edge insulation (R1.9)	Timber frame with R2.2 bulk insulation (R1.9)	Timber frame with R3.2 bulk insulation (R2.9)	Double clear glazing metal frames (R0.26)
	Better practice	Carpeted floor, R1.4 polystyrene under slab plus edge insulation (R3.1)	Timber frame with R2.6 bulk insulation (R2.4)	Timber frame with R3.6 bulk insulation (R3.4)	Double low-E Argon filled glazing timber frames (R0.5)
	Best practice	Carpeted floor, R1.4 polystyrene under slab plus edge insulation (R3.1)	Timber frame R2.6 + R2.2 bulk insulation (R4.2)	Timber frame with R5.0 + R5.0 bulk insulation (R9.5)	Triple glazing – one pane low-E, timber frame (R0.62)
Medium mass	Code compliance	R1.7 polystyrene edge insulation (R1.7)	Timber frame with R2.2 bulk insulation (R1.9)	Timber frame with R3.6 bulk insulation (R3.4)	Double clear glazing metal frames (R0.26)
	Better practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Timber frame with R2.6 bulk insulation (R2.4)	Timber frame with R4.0 bulk insulation (R3.7)	Double low-E Argon filled glazing timber frames (R0.5)
	Best practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Timber frame R2.6 + R2.2 bulk insulation (R4.2)	Timber frame with R5.0 + R5.0 bulk insulation (R9.5)	Triple glazing – one pane low-E, timber frame (R0.62)
High mass	Code compliance	R1.7 polystyrene edge insulation (R1.7)	Concrete with R1.0 external polystyrene insulation (R1.3)	Timber frame with R3.6 bulk insulation (R3.4)	Double clear glazing metal frames (R0.26)
	Better practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Concrete with R2.4 external polystyrene insulation (R2.7)	Timber frame with R4.0 bulk insulation (R3.7)	Double low-E Argon filled glazing timber frames (R0.5)
	Best practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Concrete with R4.2 external polystyrene insulation (R4.5)	Timber frame with R5.0 + R5.0 bulk insulation (R9.5)	Triple glazing – one pane low-E, timber frame (R0.62)

Note: the R-Value of the insulation material is provided along with the R-Value of the complete system (in brackets).

Temperature fluctuations

The 'sparklines' in the following charts are based on heating the living areas (as required) between 7.00am-11.00pm to 20°C, but no heating between 11.00pm-7.00am. These sparklines show the magnitude of the drop in temperature, below 16°C, between 11.00pm and 7.00am (below the axis) and the magnitude of overheating, above 26°C (above the axis) for all 365 days of the year. They therefore provide a good indication of the expected comfort of each house.

	Code insulation			Better Insulation			Best Insulation		
HighMass									
MedMass									
LowMass									
	low glass	med glass	high glass	low glass	med glass	high glass	low glass	med glass	high glass

The house in the bottom left corner has a relatively small window area and is insulated to the current minimum required by the Building Code – it mainly needs heating. Increasing the areas of north-facing glass in the bottom row of this code insulated group of houses increases the need for heating and introduces a need for cooling.

Moving up a row to the medium thermal mass row shows a very large reduction in the swings in temperature.

The effect of adding more insulation to a house can be seen by looking at the groups of sparklines for better and best insulation. Improving insulation removes most of the large drops in temperature at night but increases the amount of overheating during the day. Increasing mass levels in these more highly insulated houses has the same effect observed in the code insulated homes – it reduces the swings in temperature.

Cooling need

Overheating has been calculated as degree hours – the total for all hours over 26ºC multiplied by the difference between 26ºC and the actual temperature. This is a better indicator of the need for cooling than merely the hours over 26ºC. For example, two houses might each total 10 hours over 26ºC, but one is just one degree over on average, a total of 10 degree hours; the other being on average 4 degrees over would total 4 degrees times the 10 hours or 40 degree hours. Overheating hours will tend to be afternoon and evening hours in summer.

"Increasing north-facing glass causes more overheating but increasing mass in the house greatly reduces this problem."

The following tables show the number of overheating degree hours (above 26ºC) in each of the houses – even when the windows are opened for natural ventilation cooling. The calculation models the windows being opened to allow ventilation when the temperature reaches 26ºC. The ventilation rate achieved is dependent on the opening sizes of the windows and the amount of wind. Obviously if no one is home to open the windows the overheating problem will be much worse.

Because Wellington is relatively windy and has relatively mild temperatures, overheating is less of a problem than in Auckland.

Amount of overheating – degree hours above 26°C

mass	Code Insulation				Better Insulation				Best Insulation		
High	0	0	2		2	39	74		2	39	75
Medium	0	12	31		17	89	166		15	89	167
Low	21	123	240		56	242	474		43	223	436
	low	med.	high		low	med.	high		low	med.	high
		glazing				glazing				glazing	

Here the complex interaction of glass, thermal mass and insulation becomes clear. Increasing glass area facing north (left to right in each group) brings big increases in overheating degree hours. A doubling of the number of degree hours is approximately correlated with a doubling of the need for cooling energy (not accounted for in the energy consumption figures presented). However, increasing the amount of available thermal mass within each insulation group – moving up from one row to the next in each group – results in very large decreases in overheating.

"In medium and high mass houses temperatures virtually never fall below 16°C overnight – provided they are insulated above code minimum."

Overnight temperature drop

A significant amount of energy can be saved by turning off the heating before going to bed for the night, but a major influence on the feeling of comfort in a house is how much the temperature in the house falls overnight. Underheating hours will tend to be pre-dawn hours in winter – they are based on how often the temperature drops below 16°C when the heaters are turned off at 11.00pm and turned on the next day at 7.00am. The following tables show how many degree hours below 16°C occur in each of these e-buildings.

Amount of underheating – degree hours below 16°C

mass	Code Insulation				Better Insulation				Best Insulation		
High	0	4	2		0	0	0		0	0	0
Medium	111	158	199		6	10	13		0	0	0
Low	1408	1636	1820		410	470	525		39	52	93
	low	med.	high			med.	high		low	med.	high
		glazing				glazing				glazing	

The benefit of mass and insulation is obvious in these tables. For all insulation groups, the underheating figures in the bottom row (low mass) are significantly worse than in the next row up (medium mass). Increasing the insulation – moving from left to right across the groups – also reduces underheating for the low and medium mass houses. Virtually no underheating occurs in any of the high mass houses.
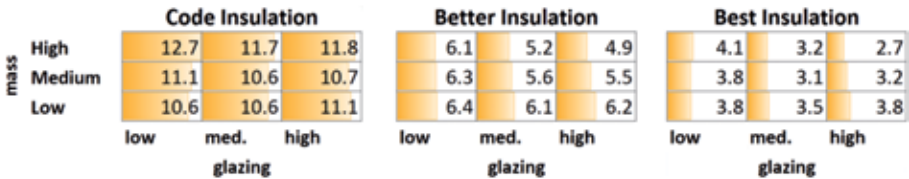
Purchased energy for heating

Energy use is presented for just one heating schedule. You may, of course, operate a quite different heating schedule. The absolute energy use is less important than the comparison between different glass, mass and insulation options – with the same heating schedule. Many New Zealand homes are less well heated than the schedule presented and therefore energy use will be lower. As described earlier on page 49, heating for longer each day will increase your energy use, but not nearly as much as heating to a higher temperature (greater than the 20°C modelled). Energy cost can be estimated using roughly $200 per 1000kWh (at the time of writing).

> "Heating energy consumption decreases dramatically with increases in insulation."

The following tables show purchased energy (x 1,000 kWh) required to maintain a minimum temperature of 16°C in bedrooms and 20°C in living rooms between 7.00am and 11.00pm, 365 days a year (no heating 11.00pm-7.00am). Use of air-conditioning units to control overheating has not been modelled so overheating may still occur as control is by opening windows only. Use of air-conditioning units, such as heat pumps, to control overheating can increase energy consumption very significantly.

Heating energy consumption (x 1,000kWh)

mass	Code Insulation			Better Insulation			Best Insulation		
High	12.7	11.7	11.8	6.1	5.2	4.9	4.1	3.2	2.7
Medium	11.1	10.6	10.7	6.3	5.6	5.5	3.8	3.1	3.2
Low	10.6	10.6	11.1	6.4	6.1	6.2	3.8	3.5	3.8
	low	med.	high	low	med.	high	low	med.	high
		glazing			glazing			glazing	

The tables above demonstrate that improving insulation is by far the most effective way of reducing energy use. The set of e-buildings with code level insulation on the left have much higher annual energy use than those to the right with higher levels of insulation.

By looking at the energy use, overheating and underheating tables you can see that if you increase the amount of north-facing glazing, in conjunction with increased thermal mass, you generally get comfort benefits – and at better and best insulation levels, reduced energy consumption.

When you are comparing specific glass, mass and insulation combinations, don't just look at one factor in isolation. It pays to look at the sparklines, overheating, underheating, energy use and heater capacity tables together to get a good overall picture of the likely performance you can expect.

Required heater size

For each computer study, heating capacity required to meet peak demand on the coldest day is also presented for the 7.00am-11.00pm heating schedule. Typical domestic electric heaters have a capacity of 500W to 2.4kW, heat pumps 4-9kW, flued gas heaters 3-7kW and wood burners 8-15kW. Several of the e-buildings require less than 7kW heater capacity for the whole house.

Required heater capacity (kW)

mass	Code Insulation				Better Insulation				Best Insulation		
	low	med.	high		low	med.	high		low	med.	high
High	10.0	10.5	11.3		7.7	8.0	8.4		6.2	6.7	5.9
Medium	10.4	10.5	10.9		8.8	8.9	9.1		6.7	6.7	7.1
Low	11.0	11.3	11.6		9.0	8.9	9.0		6.7	6.7	7.1

glazing   glazing   glazing

CHRISTCHURCH

Christchurch has a winter climate that is significantly colder than Wellington, with average ground temperatures of 18.6°C in summer and 7.1°C in winter. Energy consumption required to maintain comfort in Christchurch is therefore relatively high. If you live in Christchurch you will probably be very interested in energy efficiency as the potential cost savings are high. Summer temperatures can also get quite high and overheating can be a significant problem.
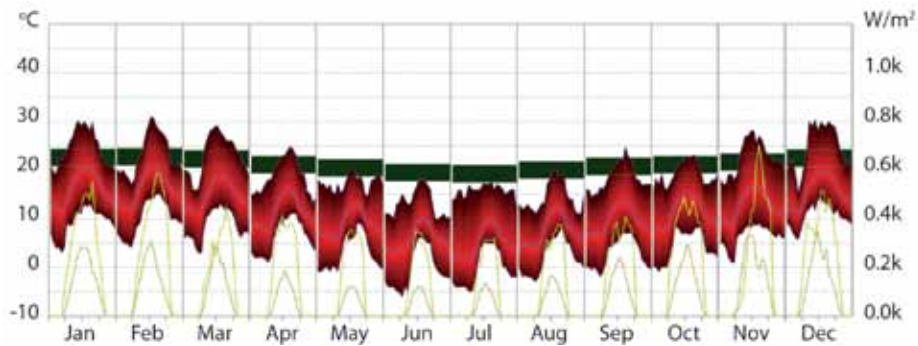
KEY:
Blue middle line = Average day temperature during allocated months
Wider red area = Range of day temperatures during allocated months
Green solid line = Average direct sunlight per day and month (W/m²)
Green dotted line = Average diffuse sunlight per day and month (W/m²)
Dark green bars = Comfortable temperature range for months

Summary created using Autodesk® Ecotect® 2010 of the Christchurch weather data used in the house performance calculations

"Heating energy needed in Christchurch is relatively high because of cold winter temperatures – however, high summer temperatures mean overheating can also be a problem."

There are many ways in which the results presented in the following pages can guide your design. Remember – these studies can't be used to accurately predict energy use and comfort for different designs or different locations. You can, however, estimate performance by adjusting for coldness of climate, anticipated heating schedule and levels of glass, mass and insulation.

Construction details

The following table provides details of the constructions used to achieve the specified levels of insulation for the three insulation levels and the three mass levels. These construction systems have been chosen as they are all currently used in the New Zealand market. Other construction system that achieve the same insulation R-Values will perform in the same way.

	Insulation level	Concrete ground floor slab	External walls	Roof	Window glazing
Low mass	Code compliance	Carpeted floor, R1.7 polystyrene edge insulation (R1.9)	Timber frame with R2.2 bulk insulation (R1.9)	Timber frame with R3.2 bulk insulation (R2.9)	Double clear glazing metal frames (R0.26)
	Better practice	Carpeted floor, R1.4 polystyrene under slab plus edge insulation (R3.1)	Timber frame with R2.6 bulk insulation (R2.4)	Timber frame R3.6 bulk insulation (R3.4)	Double low-E Argon filled glazing timber frames (R0.5)
	Best practice	Carpeted floor, R1.4 polystyrene under slab plus edge insulation (R3.1)	Timber frame R2.6 + R2.2 bulk insulation (R4.2)	Timber frame with R5.0 + R5.0 bulk insulation (R9.5)	Triple glazing – one pane low-E, timber frame (R0.62)
Medium mass	Code compliance	R1.7 polystyrene edge insulation (R1.7)	Timber frame with R2.2 bulk insulation (R1.9)	Timber frame with R3.6 bulk insulation (R3.4)	Double clear glazing metal frames (R0.26)
	Better practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Timber frame with R2.6 bulk insulation (R2.4)	Timber frame with R4.0 bulk insulation (R3.7)	Double low-E Argon filled glazing timber frames (R0.5)
	Best practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Timber frame R2.6 + R2.2 bulk insulation (R4.2)	Timber frame with R5.0 + R5.0 bulk insulation (R9.5)	Triple glazing – one pane low-E, timber frame (R0.62)
High mass	Code compliance	R1.7 polystyrene edge insulation (R1.7)	Concrete with R1.0 external polystyrene insulation (R1.3)	Timber frame with R3.6 bulk insulation (R3.4)	Double clear glazing metal frames (R0.26)
	Better practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Concrete with R2.4 external polystyrene insulation (R2.7)	Timber frame with R4.0 bulk insulation (R3.7)	Double low-E Argon filled glazing timber frames (R0.5)
	Best practice	R1.4 polystyrene under slab plus edge insulation (R2.9)	Concrete with R4.2 external polystyrene insulation (R4.5)	Timber frame with R5.0 + R5.0 bulk insulation (R9.5)	Triple glazing – one pane low-E, timber frame (R0.62)

Note: the R-Value of the insulation material is provided along with the R-Value of the complete system (in brackets).

Temperature Fluctuations

The 'sparklines' in the following charts are based on heating the living areas (as required) between 7.00am-11.00pm to 20°C, but no heating between 11.00pm-7.00am. These sparklines show the magnitude of the drop in temperature, below 16°C, between 11.00pm and 7.00am (below the axis) and the magnitude of overheating, above 26°C (above the axis) for all 365 days of the year. They therefore provide a good indication of the expected comfort in each house.
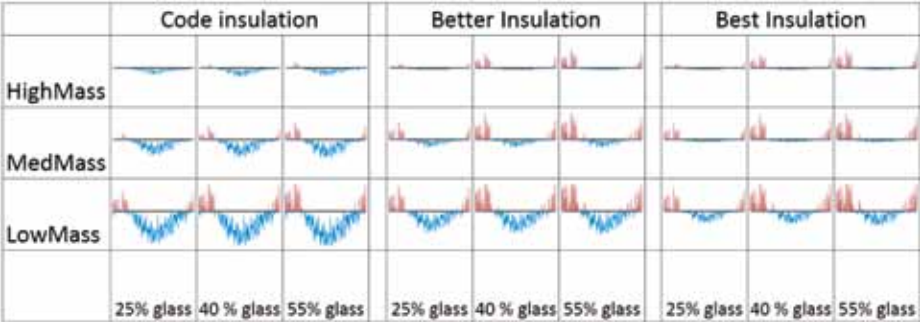
The house in the bottom left corner has a relatively small window area and is insulated to the current minimum required by the Building Code – it mainly needs heating. Increasing the areas of north-facing glass in the bottom row

of this code insulated group of houses increases the need for heating and cooling.

Moving up a row to the medium thermal mass row shows a very large reduction in the swings in temperature.

The effect of adding more insulation to a house can be seen by looking at the groups of sparklines for better and best insulation. Improving insulation removes most of the large drops in temperature at night but increases the amount of overheating during the day. Increasing mass levels in these more highly insulated houses has the same effect observed in the code insulated homes – it reduces the swings in temperature.

"Increasing north-facing glass causes more overheating but increasing mass in the house greatly reduces this problem."

Cooling need

Overheating has been calculated as degree hours – the total for all hours over 26°C multiplied by the difference between 26°C and the actual temperature. This is a better indicator of the need for cooling than merely the hours over 26°C. For example, two houses might each total 10 hours over 26°C, but one is just one degree over on average, a total of 10 degree hours; the other being on average 4 degrees over would total 4 degrees times the 10 hours or 40 degree hours. Overheating hours will tend to be afternoon and evening hours in summer.

The following tables show the number of overheating degree hours (above 26°C) in each of the houses – even when the windows are opened for natural ventilation cooling. The calculation models the windows being opened to allow ventilation when the temperature reaches 26°C. The ventilation rate achieved is dependent on the opening sizes of the windows and the amount of wind. Obviously if no one is home to open the windows the overheating problem will be much worse.

Amount of overheating – degree hours above 26°C

mass	Code Insulation			Better Insulation			Best Insulation		
High	0	33	57	68	267	411	73	271	439
Medium	62	209	309	276	567	797	269	565	768
Low	408	768	1035	567	1086	1510	507	1010	1383
	low	med.	high	low	med.	high	low	med.	high
		glazing			glazing			glazing	

Here the complex interaction of glass, thermal mass and insulation becomes clear. Increasing glass area facing north (left to right in each group) brings big increases in overheating degree hours. A doubling of the number of degree hours is approximately correlated with a doubling of the need for cooling energy (not accounted for in the energy consumption figures above). However, increasing the amount of available thermal mass within each insulation

group – moving up from one row to the next in each group – results in very large decreases in overheating.

Overnight temperature drop

A significant amount of energy can be saved by turning off the heating before going to bed for the night, but a major influence on the feeling of comfort in a house is how much the temperature in the house falls overnight. Underheating hours will tend to be pre-dawn hours in winter – they are based on how often the temperature drops below 16ºC when the heaters are turned off at 11.00pm and turned on the next day at 7.00am. The following tables show how many degree hours below 16ºC occur in each of these e-buildings.

Amount of underheating – degree hours below 16ºC

Code Insulation

mass	low glazing	med. glazing	high glazing
High	147	295	221
Medium	1001	1174	1306
Low	3691	4142	4477

Better Insulation

mass	low glazing	med. glazing	high glazing
High	0	0	0
Medium	217	225	230
Low	1605	1719	1833

Best Insulation

mass	low glazing	med glazing	high glazing
High	0	0	0
Medium	15	16	32
Low	578	656	844

The benefit of mass and insulation are obvious in these tables. For all insulation groups, the underheating figures in the bottom row (low mass) are significantly worse than in the next two rows up (medium and high mass). Increasing the insulation – moving from left to right across the groups – also reduces underheating.

Purchased energy for heating

Energy use is presented for just one heating schedule. You may, of course, operate a quite different heating schedule. The absolute energy use is less important than the comparison between different glass, mass and insulation options – with the same heating schedule. Many New Zealand homes are less well heated than the schedule presented and therefore energy use will be lower. As described earlier on page 49, heating for longer each day will increase your energy use, but not nearly as much as heating to a higher temperature (greater than the 20ºC modelled). Energy cost can be estimated using roughly $200 per 1000kWh (at the time of writing).

The following tables show purchased energy (x 1,000kWh) required to maintain a minimum temperature of 16ºC in bedrooms and 20ºC in living rooms between 7.00am and 11.00pm, 365 days a year (no heating 11.00pm-7.00am). Use of air-conditioning units to control overheating has not been modelled so overheating may still occur as control is by opening windows only. Use of air-conditioning units, such as heat pumps, to control overheating can increase energy consumption very significantly.

Heating energy consumption (x1,000 kWh)

mass	Code Insulation			Better Insulation			Best Insulation		
High	19.4	18.3	18.9	9.6	8.5	8.1	7.1	6.0	5.4
Medium	17.1	16.7	17.1	9.9	8.9	8.7	6.6	5.8	5.9
Low	15.9	16.0	16.9	9.9	9.4	9.6	6.5	6.1	6.6
	low	med.	high	low	med.	high	low	med.	high
		glazing			glazing			glazing	

The tables above demonstrate that improving insulation is by far the most effective way of reducing energy use. The set of e-buildings with code level insulation on the left have much higher annual energy use than those to the right with higher levels of insulation.

"Heating energy consumption decreases dramatically with increases in insulation."

By looking at the energy use, overheating and underheating tables you can see that if you increase the amount of north-facing glazing, in conjunction with increased thermal mass, you generally get comfort benefits – and at better and best insulation levels, reduced energy consumption.

When you are comparing specific glass, mass and insulation combinations, don't just look at one factor in isolation. It pays to look at the sparklines, overheating, underheating, energy use and heater capacity tables together to get a good overall picture of the likely performance you can expect.

Required heater size

For each computer study, heating capacity required to meet peak demand on the coldest day is also presented for the 7.00am-11.00pm heating schedule. Typical domestic electric heaters have a capacity of 500W to 2.4kW, heat pumps 4-9kW, flued gas heaters 3-7kW and wood burners 8-15kW. Several of the e-buildings require less than 10kW heater capacity for the whole house.

Required heater capacity (kW)

mass	Code Insulation			Better Insulation			Best Insulation		
High	13.7	14.6	15.9	10.3	10.5	10.7	8.4	8.4	7.8
Medium	14.7	15.3	15.9	12.3	12.1	12.2	9.4	9.1	9.6
Low	15.5	16.0	16.6	12.5	12.5	12.7	9.6	9.6	10.2
	low	med.	high	low	med.	high	low	med.	high
		glazing			glazing			glazing	

Chapter 5: NZ Building Code Requirements

Determining Insulation Values

The first step in checking a house for compliance with the Building Code is to determine the insulation values for the various building elements. The insulation value is expressed as a thermal resistance, which is a measure of how efficient each element is in resisting the flow of heat. These thermal resistances are known as R-values. The greater the R-value, the better the resistance to heat flow (better insulation value).

The R-value of a building component is essentially a combination of the R-values of the individual elements that make up that component. There is also a surface effect, both internally and externally, which adds a small amount to the overall R-value. For example, adding the R-value of a concrete masonry wall, the R-value of the insulation attached to that wall, and the R-values for the surface effects, gives an overall component R-value for the wall.

This simple calculation becomes more complicated when the layers are not continuous. When there is thermal bridging, as with a timber-framed wall for example, calculations are required to allow for this bridging effect. NZS 4214:2006 *Methods of Determining the Total Thermal Resistances of Parts of Buildings* details the calculation methods and provides R-values for a wide range of generic building materials. Commercial suppliers of insulating materials will be able to provide R-values for their products. BRANZ also produces a house insulation guide which provides R-values for a range of floor, wall and roof construction systems.

Methods of Compliance

Clause H1 of the New Zealand Building Code specifies the minimum performance requirements for the energy efficiency of houses. Clause H1 and its associated means of compliance can be downloaded free from www.dbh.govt.nz.

NZS 4218:2004 *Energy Efficiency – Small Building Envelope* is referenced as a means of compliance with Clause H1 (but with significant modification). This means houses that comply with this New Zealand Standard (as modified by H1/AS1) must be accepted by territorial authorities as code compliant.

There are 4 ways to comply with H1:

1. **Acceptable Solution**

- Schedule method
Here the design has to comply with minimum R-values for walls, roof, floor and glazing. This method can be used if the glazing does not exceed 30% of the external wall area.

Simple tables of the required R-Values are provided for both solid and non-solid construction.

- Calculation method
  This method allows lower insulation values in one building component (e.g. walls) to be traded off (via numerical calculation) against increased insulation in another component (e.g. roof), provided the overall efficiency of the house is not compromised.

This method can be used if the glazing does not exceed 50% of the external wall area. The calculation method allows a mix of solid and non-solid construction.

2. Verification method

- Modelling method
  This option uses sophisticated computer modelling to calculate the energy consumption of a proposed design in a specific location. The proposed house must perform as well as a house insulated to the Schedule Method above.

There are numerous modelling programmes available but a relatively easy to use 'home grown' option is AccuRateNZ (see www.energywise.govt.nz).

3. Building Performance Index (BPI)

- The annual heating energy of a house is calculated using standard assumptions (appropriate software, for example, ALF or AccuRateNZ). The BPI is then calculated using the annual heating energy and must not exceed a limit set in the Building Code.

4. Alternative Solution

- This approach allows the designer complete freedom to use any method to show compliance, provided the building consent authority (council) can be satisfied that the resulting design has adequate energy efficiency.

appendix

Chapter 6: Appendices

Appendix 1 – Two-Storey House Results

A two-storey house with a similar floor area to the house on which Chapter Four is based was also investigated, to ensure that the trends demonstrated for the single-storey house were more generally applicable. This two-storey house has also been the basis for the studies on the effects of climate and orientation to the sun and on pages 43 and 45. These studies confirmed that the general trends demonstrated in this book (for a single-storey design) are applicable to a two-storey design. See Chapter Four for more details on how to interpret the information presented in this appendix.
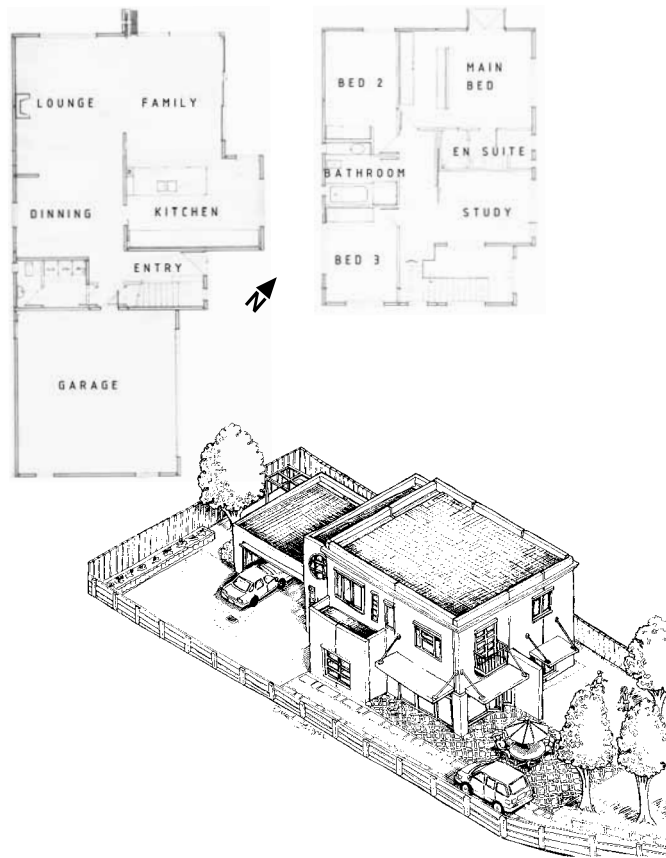
The 'sparklines' in the following charts for the three main centres represent overheating and underheating potential of the various combinations of glass, mass and insulation.

The horizontal axis of each chart represents the 365 days of the year. The red lines above the axis represent the house overheating – when the temperature is over 26°C in the living room. The blue lines below the axis represent the days when the living room temperature drops below 16°C overnight.

As with all the data in this book the purpose of the following sparklines is to describe the trends. The sparklines show that the trends demonstrated for the single-storey house are also consistent for the two-storey house. These trends include:

• increasing thermal mass, regardless of the insulation level, will reduce overheating

• increasing insulation greatly reduces of the overnight drops in temperature (below 16°C)

• increasing north-facing window area increases the temperature swings in the house.

The heating energy use data in the tables that follow is also consistent with the trends demonstrated for the single-storey house in Chapter Four. These trends include:

• Increasing insulation is the single biggest factor reducing heating energy consumption

• Increasing north-facing window area generally decreases heating energy consumption, the decrease is greatest with better and best insulation levels combined with high levels of mass.

For any specific glass, mass and insulation combinations that you want to compare don't just look at one factor in isolation, it pays to look at the sparklines, overheating, underheating and energy use tables that follow to ensure you get a good overall picture of the likely performance you can expect.

Auckland

Temperature fluctuations

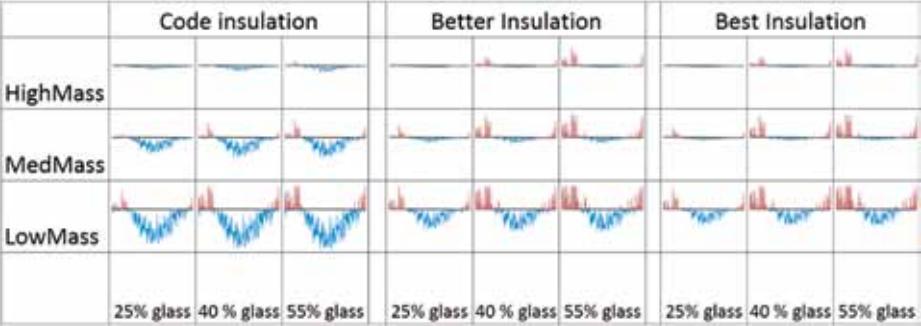|	Code insulation			Better Insulation			Best Insulation		
HighMass									
MedMass									
LowMass									
	25% glass	40 % glass	55% glass	25% glass	40 % glass	55% glass	25% glass	40 % glass	55% glass

The following table provides further overheating and
underheating data as well as heating energy consumption
data for the two-storey house.

		Code insulation			Better insulation			Best insulation		
		LOW GLASS	MED GLASS	HIGH GLASS	LOW GLASS	MED GLASS	HIGH GLASS	LOW GLASS	MED GLASS	HIGH GLASS
Degree hours underheating	HIGH MASS	0	0	0	0	0	0	0	0	0
	MEDIUM MASS	1	4	3	0	0	0	0	0	0
	LOW MASS	230	354	389	32	83	99	1	2	3
Degree hours overheating	HIGH MASS	0	30	110	26	187	371	40	263	473
	MEDIUM MASS	9	128	259	74	365	586	98	484	770
	LOW MASS	130	604	961	241	892	1,340	269	1,042	1,586
Energy consumption kWh x 1,000	HIGH MASS	7.7	6.2	5.2	3.8	2.9	2.3	2.2	1.2	0.7
	MEDIUM MASS	4.5	4.0	3.9	2.9	2.5	2.5	1.6	1.2	1.1
	LOW MASS	4.3	4.2	4.3	3.0	3.0	3.1	1.7	1.6	1.6

Wellington

Temperature fluctuations

|	Code insulation			Better Insulation			Best Insulation		
HighMass									
MedMass									
LowMass									
	25% glass	40 % glass	55% glass	25% glass	40 % glass	55% glass	25% glass	40 % glass	55% glass

The following table provides further overheating and
underheating data as well as heating energy consumption
data for the two-storey house.

		Code insulation			Better insulation			Best insulation		
		LOW GLASS	MED GLASS	HIGH GLASS	LOW GLASS	MED GLASS	HIGH GLASS	LOW GLASS	MED GLASS	HIGH GLASS
Degree hours underheating	HIGH MASS	0	0	1	0	0	0	0	0	0
	MEDIUM MASS	101	198	219	0	1	2	0	0	0
	LOW MASS	1,244	1,608	1,700	201	304	330	47	73	80
Degree hours overheating	HIGH MASS	0	0	1	0	13	52	0	17	53
	MEDIUM MASS	0	1	10	1	47	101	0	91	102
	LOW MASS	1	75	175	15	187	393	11	168	370
Energy consumption kWh x 1,000	HIGH MASS	14.4	12.9	11.9	7.3	5.8	4.9	5.3	3.7	2.9
	MEDIUM MASS	10.2	9.7	9.7	5.6	4.9	4.7	3.9	2.9	2.9
	LOW MASS	9.3	9.4	9.6	5.5	5.3	5.3	3.9	3.5	3.3

Christchurch

Temperature fluctuations

The following table provides further overheating and underheating data as well as heating energy consumption data for the two-storey house.

		Code insulation			Better insulation			Best insulation		
		LOW GLASS	MED GLASS	HIGH GLASS	LOW GLASS	MED GLASS	HIGH GLASS	LOW GLASS	MED GLASS	HIGH GLASS
Degree hours underheating	HIGH MASS	18	97	128	0	0	0	0	0	0
	MEDIUM MASS	889	1,237	1,294	62	94	95	11	18	18
	LOW MASS	3,553	4,294	4,476	1,165	1,366	1,415	689	779	803
Degree hours overheating	HIGH MASS	0	3	34	1	110	262	2	116	254
	MEDIUM MASS	9	114	201	99	367	568	90	349	546
	LOW MASS	207	561	826	326	882	1,303	292	802	1,200
Energy consumption kWh x 1,000	HIGH MASS	19.4	18.2	17.2	10.8	9.0	7.9	8.5	6.7	5.6
	MEDIUM MASS	14.9	14.7	14.8	8.4	7.5	7.2	6.5	5.4	5.1
	LOW MASS	13.4	13.7	14.1	8.2	7.8	7.8	6.2	5.7	5.6

Appendix 2 – Climate Zones

To summarise the climate of New Zealand, selected locations throughout the country have been grouped into broad climate zones (see maps below). The maps below show the National Institute of Water and Atmospheric Research (NIWA) general climate regions and the legal definitions for the operation of the Building Code of the three climate zones for which there are different insulation requirements. The map on the right shows the locations of the weather stations (two letter codes) for which there are Typical Meteorological Year (TMY) weather files for energy performance purposes.

The climate descriptions for the NIWA climate regions on the following pages have been kindly provided by NIWA and are available from their website (www.niwa.co.nz/education-and-training/schools/resources/climate/overview).
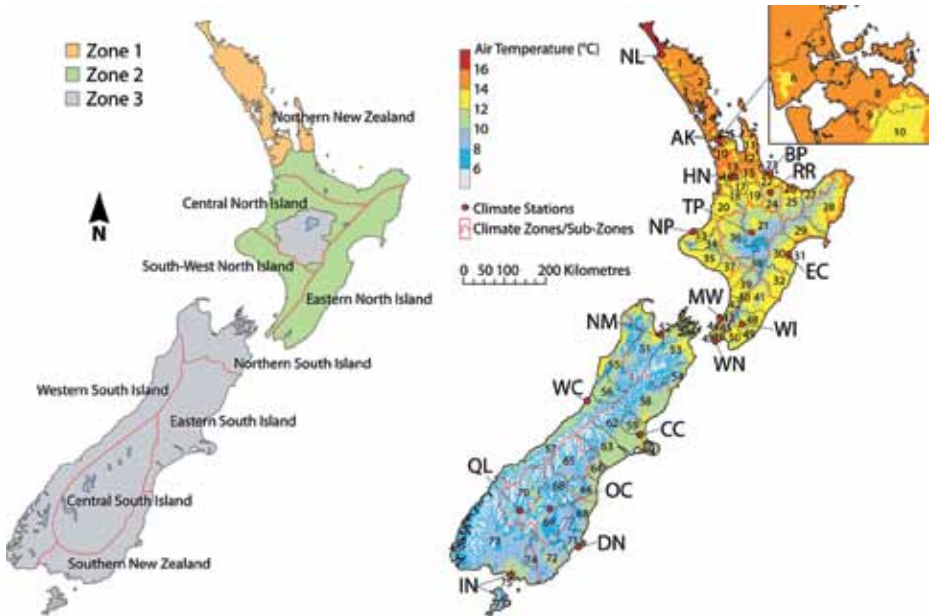
The map above shows the locations of the EECA Home Energy Rating Scheme weather files developed by NIWA and downloadable from the US Dept of Energy website http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_sources.cfm.

These weather files are the basis of the climate studies published on page 43.

The weather data from Auckland, Wellington and Christchurch are the basis of all the analyses of energy performance in this book.

TMY	Stations	Territorial Local Authorities
	ZONE 1	**Building Code plus NZS 4218**
NL	Kaitaia	Far North, Whangarei, Kaipara
AK	Auckland	Rodney, North Shore City, Waitakere City, Auckland City, Manukau City, Papakura, Franklin, Thames-Coromandel
	ZONE 2	**Building Code plus NZS 4218**
HN	Ruakura / Hamilton aero	Hauraki, Waikato, Matamata-Piako, Hamilton City, Waipa, Otorohanga, South Waikato, Waitomo
BP	Tauranga	Western Bay of Plenty, Tauranga, Whakatane, Kawerau, Opotiki
NP	New Plymouth	New Plymouth, Stratford, South Taranaki, Wanganui
EC	Napier	Gisborne, Wairoa, Hastings, Napier City, Central Hawke's Bay
MW	Paraparaumu	Southern Rangitikei, Manawatu, Palmerston North City, Horowhenua, Kapiti Coast
WI	Masterton	Tararua, Upper Hutt City, Masterton, Carterton, South Wairarapa
WN	Wellington	Porirua City, Hutt City, Wellington City
	ZONE 3	**Building Code plus NZS 4218**
RR	Rotorua	Rotorua
TP	Turangi / Taupo	Taupo, Ruapehu, Northern Rangitikei
NM	Nelson	Tasman, Nelson City, Marlborough, Kaikoura
WC	Hokitika	Buller, Grey, Westland
CC	Christchurch	Hurunui, Waimakariri, Christchurch City, Banks Peninsula, Selwyn, Ashburton, Timaru, Waimate
QL	Queenstown	Queenstown-Lakes
OC	Lauder	Mackenzie, Western Waitaki, Central Otago
DN	Dunedin / aero	Eastern Waitaki, Dunedin City, Clutha
IN	Invercargill	Southland, Gore, Invercargill City

Northern New Zealand
Kaitaia, Whangarei, Auckland, Tauranga

This is a sub-tropical climate zone, with warm humid summers and mild winters. Typical summer daytime maximum air temperatures range from 22°C to 26°C, but seldom exceed 30°C. Winter daytime maximum air temperatures range from 12°C to 17°C. Annual sunshine hours average about 2,000 in many areas. Tauranga is much sunnier with at least 2,200 hours. Southwesterly winds prevail for much of the year. Sea breezes often occur on warm summer days. Winter usually has more rain and is the most unsettled time of year. In summer and autumn, storms of tropical origin may bring high winds and heavy rainfall from the east or northeast.
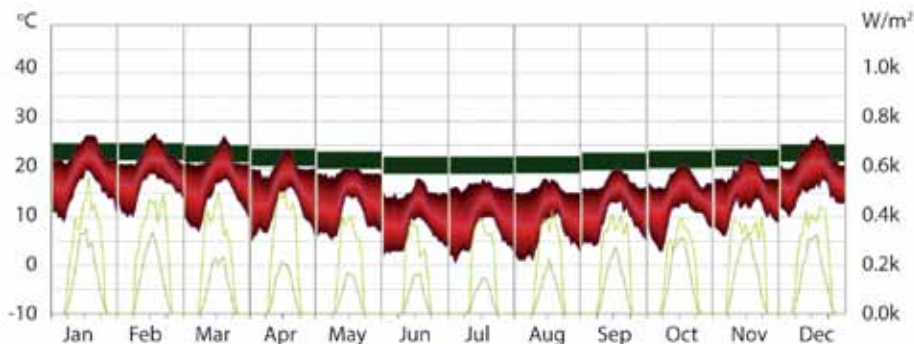
Kaitaia
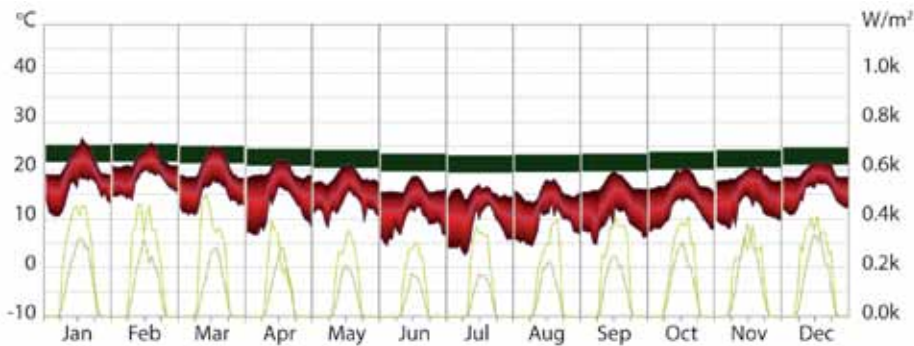
Auckland
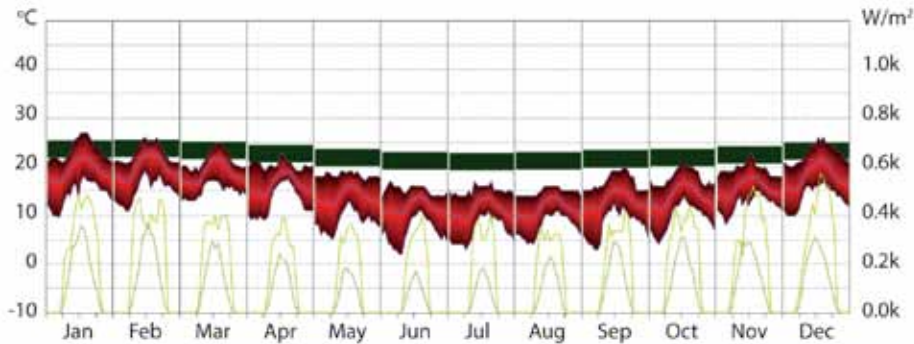
Tauranga

Central North Island
Hamilton, Taupo, Rotorua

As this region is sheltered by high country to the south and east, it has less wind than many other parts of New Zealand. Being inland, a wide range of temperature is experienced. Warm, dry and settled weather predominates during summer. Typical summer daytime maximum air temperatures range from 21°C to 26°C, rarely exceeding 30°C. Winters are cool and this is normally the most unsettled time of the year. Typical winter daytime maximum air temperatures range from 10°C to 14°C. Frosts occur in clear, calm conditions in winter. Sunshine hours average 2,000 to 2,100 in most places. Southwesterlies prevail. Lake breezes often occur in Taupo and Rotorua on warm summer days.
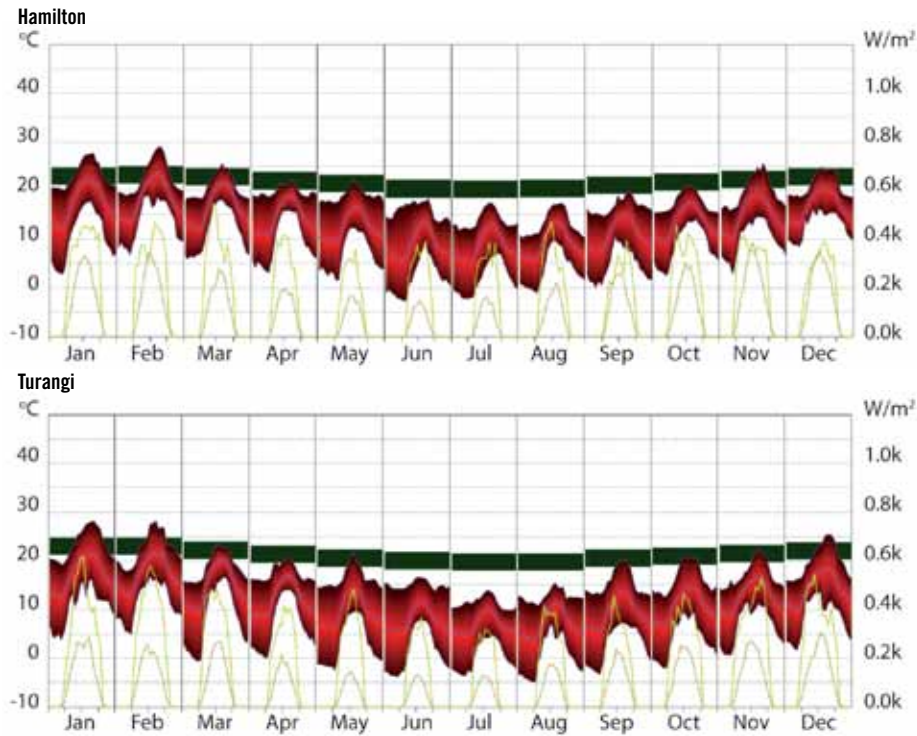
Hamilton

Turangi

KEY:

Blue middle line = Average day temperature during allocated months

Wider red area = Range of day temperatures during allocated months

Green solid line = Average direct sunlight per day and month (W/m²)

Green dotted line = Average diffuse sunlight per day and month (W/m²)

**Dark green bars** = Comfortable temperature range for months

South-West North Island
New Plymouth, Wanganui, Palmerston North, Wellington

Because of its exposure to disturbed weather systems from the Tasman Sea, this climate zone is often quite windy, but has few climate extremes. The most settled weather occurs during summer and early autumn. Summers are warm. Typical summer daytime maximum air temperatures range from 19°C to 24°C, seldom exceeding 30°C. Winters are relatively mild in New Plymouth and Wanganui, but cooler in Palmerston North and Wellington. This is normally the most unsettled time of the year. Typical winter daytime maximum air temperatures range from 10°C to 14°C. Frost occurs inland during clear, calm conditions in winter. Annual sunshine hours average about 2,000 hours, but inland at Palmerston North it is much cloudier. Northwesterly airflows prevail. Sea breezes occasionally occur along the coast during summer.

New Plymouth
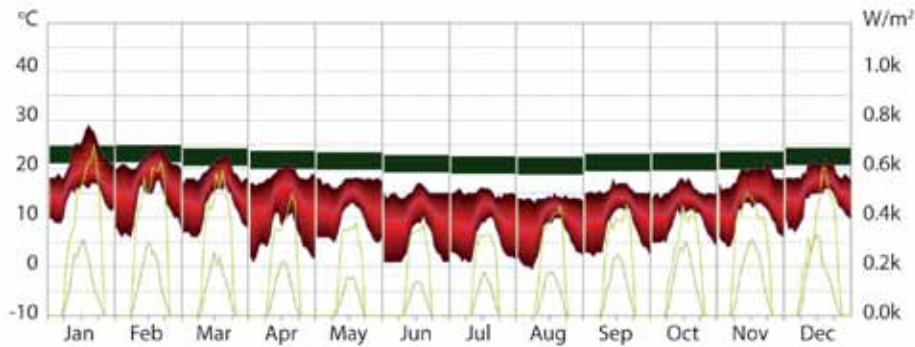
Wellington
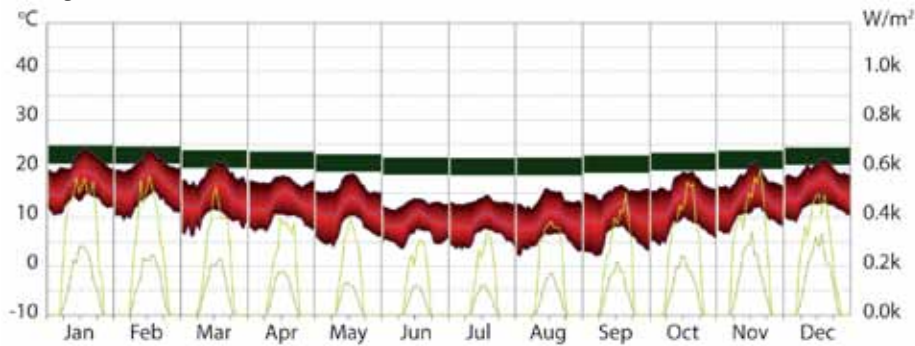
KEY:

Blue middle line = Average day temperature during allocated months

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Green solid line = Average direct sunlight per day and month (W/m²)

Green dotted line = Average diffuse sunlight per day and month (W/m²)

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Eastern North Island
Gisborne, Napier, Masterton

Sheltered by high country to the west, this zone enjoys a dry, sunny climate. Warm, dry settled weather predominates in summer. Frosts may occur in winter. Typical summer daytime maximum air temperatures range from 20°C to 28°C, occasionally rising above 30°C. High temperatures are frequent in summer, which may be accompanied by strong dry foehn[1] winds from the northwest. Extreme temperatures as high as 39°C have been recorded. Winter is mild in the north of this region and cooler in the south. Typical winter daytime maximum air temperatures range from 10°C to 16°C. Annual hours of bright sunshine average about 2,200 in Gisborne and Napier. Heavy rainfall can occur from the east or southeast. Westerly winds prevail. Sea breezes often occur in coastal areas on warm summer days.

Napier

Masterton

1   A foehn wind or föhn wind is a type of dry down-slope wind which occurs in the lee (downwind side) of a mountain range.
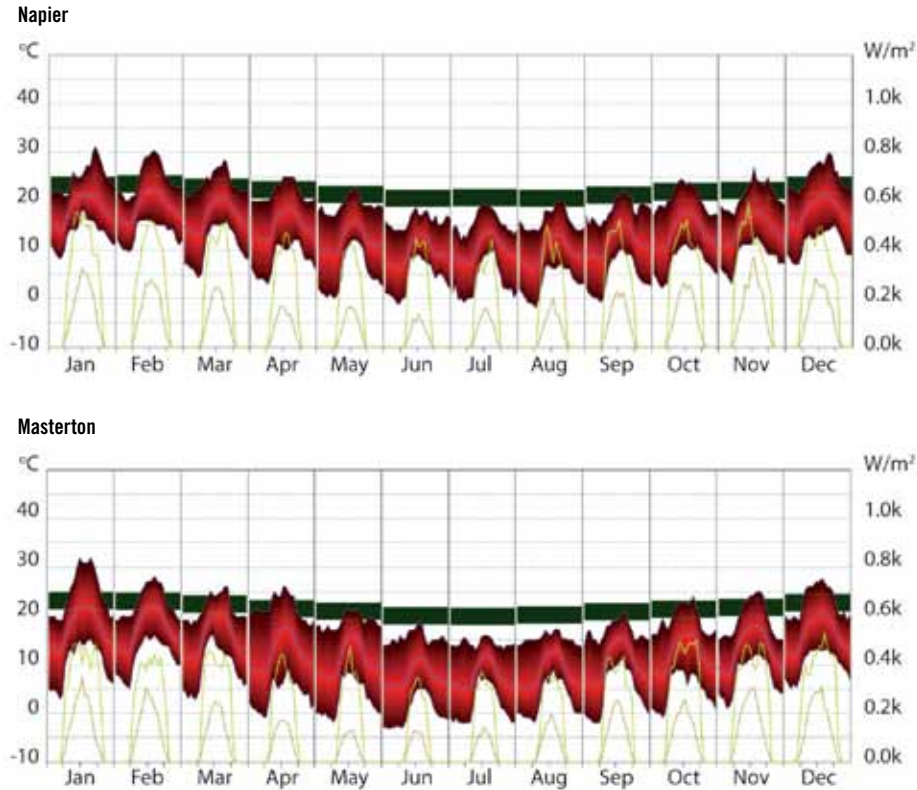
KEY:

Blue middle line = Average day temperature during allocated months

Wider red area = Range of day temperatures during allocated months

Green solid line = Average direct sunlight per day and month (W/m^2)

Green dotted line = Average diffuse sunlight per day and month (W/m^2)

Dark green bars = Comfortable temperature range for months

Northern South Island
Nelson, Blenheim

As much of this climate zone is sheltered by high country to the west, south and in some areas to the east, it is the sunniest region of New Zealand. Warm, dry and settled weather predominates during summer. Winter days often start with a frost, but are usually mild overall. Typical summer daytime maximum air temperatures range from 20°C to 26°C, but occasionally rise above 30°C. Late winter and early spring is normally the most unsettled time of the year. Typical winter daytime maximum air temperatures range from 10°C to 15°C. Annual hours of sunshine average at least 2,300 hours. Northnortheast winds prevail in Nelson, while southwesterlies prevail about Blenheim. Nelson has less wind than many other urban centres and its temperatures are often moderated by sea breezes. High temperatures are frequent in Blenheim and may be accompanied by foehn winds from the northwest.

Nelson

KEY:

Blue middle line = Average day temperature during allocated months

Wider red area = Range of day temperatures during allocated months

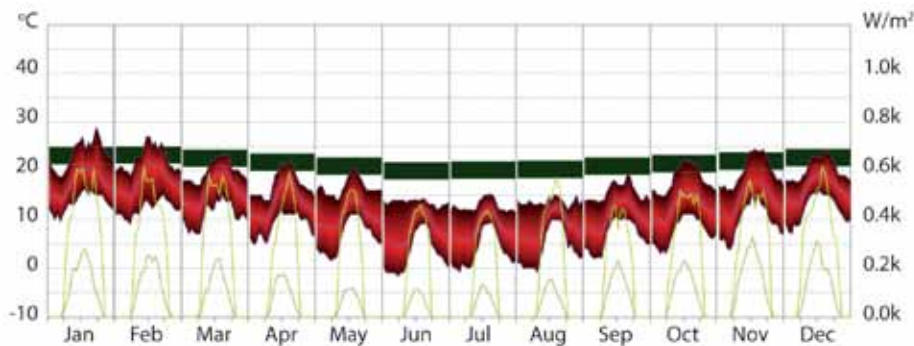**Green solid line** = Average direct sunlight per day and month (W/m²)

Green dotted line = Average diffuse sunlight per day and month (W/m²)

Dark green bars = Comfortable temperature range for months

Eastern South Island
Kaikoura, Christchurch, Timaru

The climate of this zone is greatly dependent on the lie of the massive Southern Alps to the west. Summer temperatures are warm, with highest temperatures occurring when hot, dry foehn northwesterlies blow over the Alps and plains. Mean annual rainfall is low, and long dry spells can occur, especially in summer. For much of the time summer temperatures are moderated by a cool northeasterly sea breeze. Typical summer daytime maximum air temperatures range from 18°C to 26°C, but may rise to more than 30°C. A temperature of 42°C has been recorded in Christchurch. Winters are cold with frequent frost. Typical winter daytime maximum air temperatures range from 7°C to 14°C. Northeasterlies prevail about the coast for much of the year. Southwesterlies are more frequent during winter.
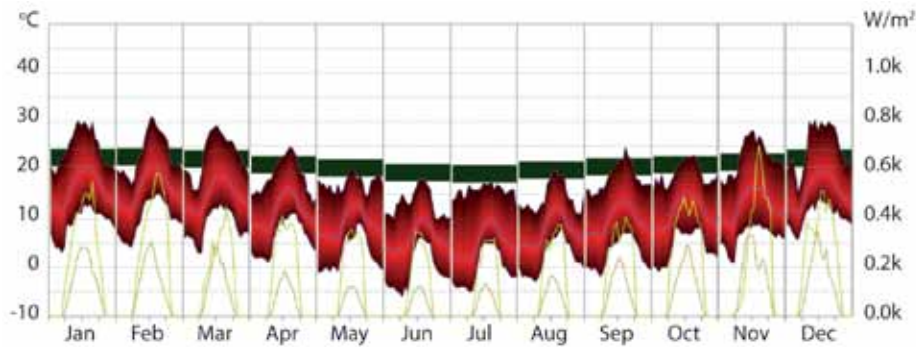
Christchurch

KEY:

Blue middle line = Average day temperature during allocated months

Wider red area = Range of day temperatures during allocated months

Green solid line = Average direct sunlight per day and month (W/m²)

Green dotted line = Average diffuse sunlight per day and month (W/m²)

Dark green bars = Comfortable temperature range for months

Western South Island
Wesport, Hokitika, Milford Sound

The climate of this area is greatly dependent on its exposure to weather systems from the Tasman Sea and the lie of the Southern Alps to the east. Although mean annual rainfall is very high, dry spells do occur, especially in late summer and during winter. Heavy rainfall occurs from the northwest. Summers are mild. Typical summer daytime maximum air temperatures range from 17°C to 22°C and seldom exceed 25°C. Winter days often start with frost. Typical winter daytime maximum air temperatures range from 10°C to 14°C. Northnortheast winds prevail along the coast in Westport and Hokitika while southwesterlies prevail in coastal areas further south. Sea breezes can occur on warm summer days.
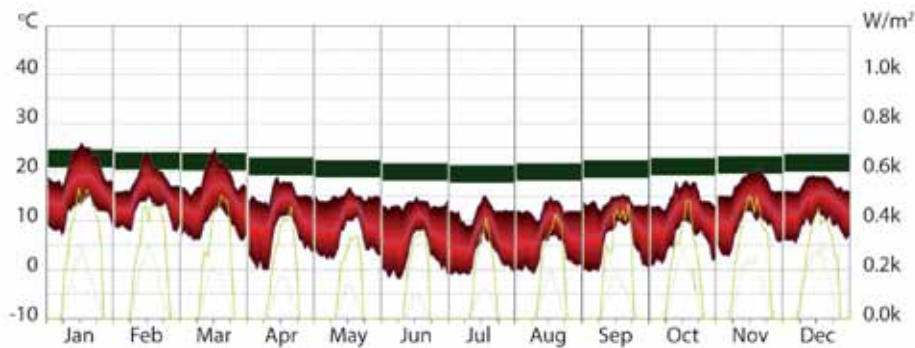
Hokitika

KEY:

Blue middle line = Average day temperature during allocated months

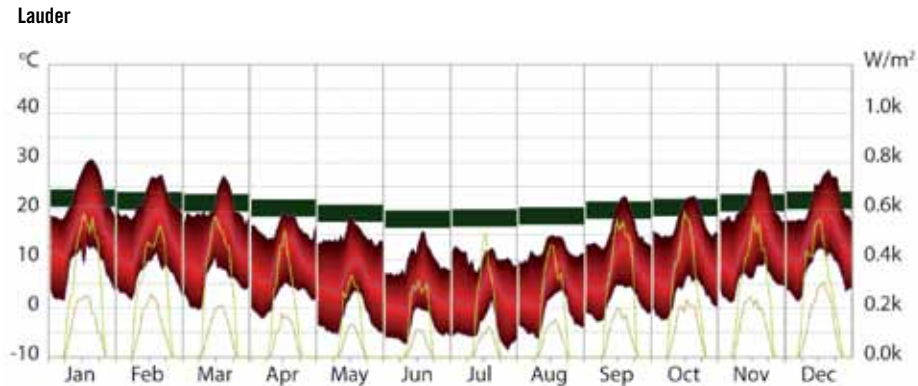**Wider red area** = Range of day temperatures during allocated months

Green solid line = Average direct sunlight per day and month (W/m²)

Green dotted line = Average diffuse sunlight per day and month (W/m²)

Dark green bars = Comfortable temperature range for months

Inland South Island

Lake Tekapo, Queenstown, Alexandra, Manapouri

The climate of this zone is largely dependent on the lie of the Southern Alps to the west, but many areas are also sheltered by high country to the south and east. Mean rainfall is low, and long dry spells can occur, especially in summer. Summer afternoons are very warm, with high temperatures occurring when hot, dry foehn northwesterlies blow over the Alps. Typical summer daytime maximum air temperatures range from 20°C to 26°C, occasionally rising above 30°C. Winters are very cold with frequent, often severe frosts, and occasional snowfalls. In severe cases, snow may lie for several days or longer. Typical winter daytime maximum air temperatures range from 3°C to 11°C. Wind flow is dependent on topography, however the strongest winds are often from the northwest.

Queenstown

Lauder

KEY:

Blue middle line = Average day temperature during allocated months

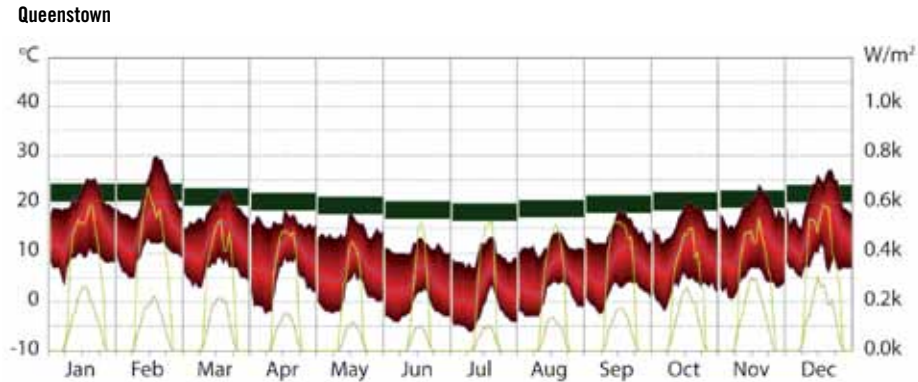**Wider red area** = Range of day temperatures during allocated months

Green solid line = Average direct sunlight per day and month (W/m²)

Green dotted line = Average diffuse sunlight per day and month (W/m²)

Dark green bars = Comfortable temperature range for months

Southern New Zealand
Dunedin, Invercargill

Most of this climate zone is characterised by cool coastal breezes, and absence of shelter from the unsettled weather that moves over the sea from the south and southwest. Hot northwesterly conditions in summer can occasionally bring high temperatures. Typical summer daytime maximum air temperatures range from 16°C to 23°C, occasionally rising above 30°C. Winters are cold with infrequent snowfall and frequent frost. Typical winter daytime maximum air temperatures range from 8°C to 12°C. Hours of bright sunshine average about 1,600 hours annually and are often affected by low coastal cloud or by high cloud in foehn wind conditions. Southwesterlies prevail for much of the time about Southland, but northeasterlies are more frequent from Dunedin north.
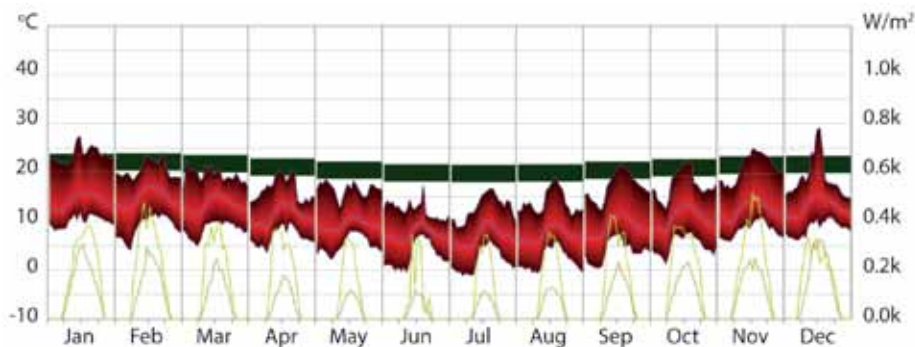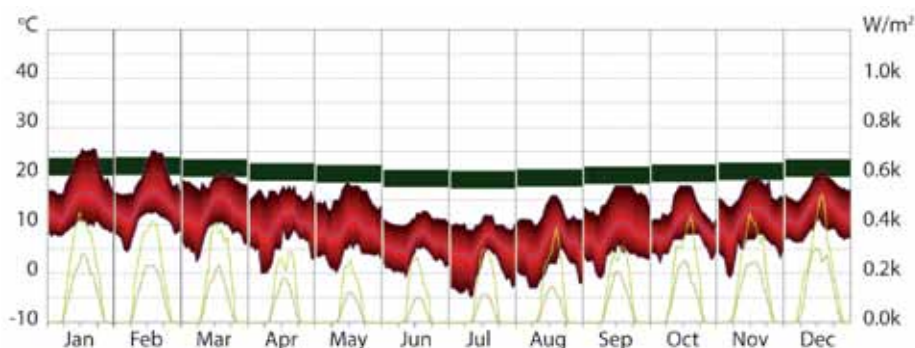
Dunedin

Invercargill

KEY:

Blue middle line = Average day temperature during allocated months

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Green solid line = Average direct sunlight per day and month (W/m²)

Green dotted line = Average diffuse sunlight per day and month (W/m²)

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