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Summertime Overheating in New Zealand Houses – Influences, Risks and Mitigation Strategies

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PREFACE

This study was designed to examine which physical and climatic parameters influence the amount and severity of summertime overheating in domestic buildings.

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READERSHIP

This report is intended for designers, environmental engineers and building technologists.

SUMMERTIME OVERHEATING IN NEW ZEALAND HOUSES – INFLUENCES, RISKS AND MITIGATION STRATEGIES

BRANZ Study Report No. 89 **Roman Jaques**

REFERENCE

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ABSTRACT

This study examined which physical and climatic parameters influence the amount and severity of summertime overheating in domestic buildings, both in terms of time and temperature. Thermal analysis was conducted using the SUNCODE simulation program, with three 'typical' New Zealand houses being modelled, altering the following parameters: location, climate, thermal mass, insulation levels, orientation, shading and ventilation. It was found that the external temperature has by far the greatest impact on indoor temperature, followed by the ventilation rate.

In addition, a method for estimating the likelihood of a specific house design overheating during summertime, was proposed. The maximum summertime indoor temperature could be established by four critical parameters: solar glazing area, floor area, effective thermal mass area and the climate zone. A look-up graph is provided as a quick calculation method.

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1. BACKGROUND

This study report is part of a much larger Foundation for Research, Science and Technology programme examining the building-related implications of climate change, along with associated possible remedies and mitigation strategies. Office buildings are examined in other studies, and this report deals only with domestic construction.

1.1 Objective

The objective of this work is to develop strategies that could be used by homeowners to reduce long-term disruptions due to climate change, by identifying what buildings are vulnerable to climate change, to assess the risks of occupant discomfort and to offer practical recommendations for adaptation. Specifically, it is:

- to assess which climate and physical parameters influence the amount (that is the length) of overheating
- to assess the significance of those climate and physical influences in terms of overheating
- to answer the question – what house types are likely to suffer from overheating?
- to answer the question – what parameters are the most effective for reducing overheating in houses?
- to suggest practical mitigation measures to significantly reduce the amount of overheating.

This report can be grouped into two distinct parts:

Part A: which examines which parameters significantly influence domestic overheating, by conducting a parametric study based on thermal simulations, and

Part B: which estimates the potential likelihood (or risk) a specific house design has of overheating during summertime, based on a heat loss equation.

1.2 Nomenclature

A_{sol}	solar glazing area (m^2)
mCp	effective diurnal heat capacity (Wh/m^2 °C)
Q_{sol}	transmitted solar heat gain per m^2 of solar glazing (kWh/m^2)
Q_{int}	internal heat gain in period examined (kWh)
RH	relative humidity (%)
t	time interval of energy balance (hours)
T_{dry}	dry bulb temperature (°C)
T_{dew}	dew point temperature (°C)
T_{max}	maximum interior temperature (at 3pm in °C)
T_{mean}	mean ambient summertime temperature (°C)
T_{out}	average outdoor temperature over the period examined (°C)
T_{set}	interior set point temperature, at start of warm-up (°C)
UA	building heat loss coefficient (W/°C)

2. PART A: PARAMETRIC STUDY ON INFLUENCES OF DOMESTIC OVERHEATING

2.1 Introduction

Determining the most appropriate way of finding what the influential parameters are when considering summertime overheating was not difficult. It is generally recognised that a flexible, easy-to-use computer-based thermal simulation tool based on actual climate data (and preferably field validated) would be appropriate. The thermal analysis program SUNCODE (Wheeling et al, 1981) meets all these criteria (Donn et al, 1990).

Thermally modelling buildings accurately, even ones as 'simple' as a house, is a complex business, involving interactions between the building elements, the occupier and the environment. The modelling performed as part of this study is only representative of reality. Since only a comparison of the factors which influence overheating was necessary, only a comparative study was performed. More realistic overheating figures are dependent on the occupant (e.g. venting set points, venting capacities, shading coefficients etc). As Stevens (1982) commented on simulation methods "...despite their comprehensive nature...their results should be viewed merely as an indication of heat flow patterns for what is inevitably a generalised model of the house".

2.2 Methodology

2.2.1 SUNCODE thermal analysis

A 'base case' house was constructed using the PC-based SUNCODE program. SUNCODE is a general purpose thermal analysis program for small buildings based on simulation. A thermal model is created by the user, and the program models heat flow through the building components in a one dimensional manner. Each building component's thermal resistance, capacitance, density, thickness and nodes are defined. Although SUNCODE simplifies the three dimensional nature of reality, it is recognised as providing a flexible and accurate method of thermal analysis.

As far as possible, a current 'typical' house was represented for this study's 'base case' thermal model; i.e. medium sized, medium thermal mass, in a moderate New Zealand climate, using standard construction techniques meeting the current building requirements. The house is 'free-running' – i.e. having no artificial summer-time heating. This base case house comprises of:

- three bedrooms
- concrete 'slab-on-ground' floor
- timber framing
- plasterboard lining
- total floor area of 120 m^2
- carpeted throughout (excluding garage)
- has an East-West aspect
- situated in Wellington (Kelburn), and
- is insulated to current Code requirements.

The base house was modelled as having six different thermal zones, of which the three most important living spaces (kitchen/dining room, lounge and a bedroom) were examined for overheating. Hourly indoor temperatures for each zone were generated over the extended summer period (i.e. October through April inclusive). Ventilation was modelled as having windows closed when the indoor temperature falls below 18°C, and fully open at all other times. The peak air change is 10 air changes per hour (ACH), which is estimated to be an absolute maximum if there is no mechanical assistance (Bassett, 1999). For more visual information on the base case building, refer to APPENDIX A: MEDIUM-SIZED 'BASE CASE' BUILDING FILE, and APPENDIX B: MEDIUM-SIZED 'BASE CASE' HOUSE PLANS.

In an attempt to be reasonably representative of the house sizes in New Zealand, two other sizes and house weights (i.e. thermal mass) were investigated. The smaller house was modelled as having a floor area of 81 m^2, while the larger house has a floor area of 245 m^2. The heavy weight buildings were modelled as having concrete block external walls with internal framing in timber. The lightweight buildings were modelled as having a timber framed walls.

The insulation levels in the three house sizes correspond to approximately the requirements of NZS 4218 (SNZ, 1996), see Table 1.

Table 1: R-values in the modelled houses

Building Element	R values ($m^2.^\circ C/W$)	
	Auckland and Wellington	Christchurch and Invercargill
Roof	1.9	2.5
Wall	1.5	1.9
Floor	1.3	1.3

Twelve variations of each of the three base case houses were performed, to examine the influence of altering building and climate parameters on the amount of overheating. The variations were (by type):

BUILDING-RELATED PARAMETERS:

1. Reduce the actual venting by 20%, 50% and 100%.
2. Increase the size of all the windows by 20%
3. Remove all carpet
4. Remove all eaves from all orientations
5. Reduce west glazing by 50%
6. Rotate whole house by 90° anticlockwise / 90° clockwise from East-West orientation
7. Change the mass level (to light weight or heavy-weight)
8. Change the insulation level (from NZS 4218:1996 compliance to none)
9. Install external shading devices, which cut out 20%, and 30% of the incident solar radiation

CLIMATE-RELATED PARAMETERS:

10. Transfer base case house to Auckland, Christchurch, and Invercargill.
11. Medium level climate change scenario for New Zealand in 2030 and 2070
12. Extreme level climate change scenario for New Zealand in 2030 and 2070.

2.2.2 Thermal comfort

Thermal comfort is dependent on a number of physical and physiological factors – including air temperature; mean radiant temperature, air velocity, humidity, clothing, and activity level (Bansal et al, 1994). As stated by Stevens (1978A), it is impossible to establish a temperature, which will please everyone. What the actual temperature required for comfort is, is highly variable, and may be as low as 17°C or as high as 30°C (Humphreys, 1978). For non-air-conditioned buildings (such as the houses modelled in this study), there is said to be a strong relationship between the monthly mean outdoor temperature and the indoor human comfort temperature (Humphreys, 1978); that is, the comfort temperature rises as the mean outdoor temperature rises.

Humphreys defines the following summertime comfort parameters:

- air temperature between 20°C and 24°C
- surface temperatures of nearby objects do not differ from the air temperature by more than 2-3°C, and a
- relative humidity between 40-60%.

As can be seen from the above ranges, the definition of comfort is far from precise. Relative humidity was also considered for this study, but discounted for two reasons: (1) air temperature is considered to be the most important factor for determining comfort (Auliciems and Szokolay, 1997 and Breuer, 1988); and (2) previous BRANZ studies found that during summer periods, the humidity will tend to be just below 50% indoors, on average (Cunningham, 1999).

In the BRANZ Climate Change study (Camilleri, 2000), the threshold temperature which divides comfort from discomfort was set at 25°C. Thermal discomfort as a result of overheating was simply defined as the amount of time that the indoor temperature was greater than 25°C. Although this definition is simplistic, it does provide a basis for examining various physical and climatic variables in a comparative fashion.

2.2.3 Modelling climate change

In the modelling of the climate change scenarios, the years 2030 and 2070 were investigated. The years 2030 and 2070 are commonly used for climate change research (Camilleri, 2000) since 2070 corresponds to the anticipated doubling of the 1990 CO_2 levels and 2030 is estimated to be about the halfway point. For this study, two climate change scenarios have been examined – 'medium' i.e. the mid point between the lower and upper bounds of the predicted temperature resulting from climate change, and 'high', i.e. the extreme or upper bound temperature (refer Table 2).

Table 2: Predicted climate change temperature increases

Temperature Scenarios	Year Examined	
	2030	**2070**
Medium	0.5 °C	1.7 °C
High	0.9 °C	2.7 °C

In SUNCODE simulations, there are three climate-related parameters that are directly affected by climate change and which can be predicted with at least some degree of certainty: ambient temperature, dew point temperature, and ground temperature. How these parameters are integrated into SUNCODE weather data files is important. Some work on the treatment of weather parameters for climate change-related studies has already been conducted in New Zealand (Energy Group, 1999), as part of this research.

SUNCODE weather data files are constructed using hourly weather data for five parameters – direct normal radiation, total horizontal radiation, ambient temperature, dew point temperature and wind speed. [The other climate-related parameter – ground temperature – is approximated as a constant for each of the four seasons]. An artificial 'average' weather year is constructed using an amalgamation of weather data over several years, for each of the main centres.

So how were the effects of climate change integrated into the SUNCODE weather data, for this study? It was decided to use the 'constant offset' approach for estimating both the new ground temperatures and the new ambient air temperatures. The constant offset technique simply adds the predicted climate change-induced temperature (refer Table 2) to the constructed 'average' weather year. Although this technique is an over-simplification of the actual hourly temperature behaviour, it was considered to be adequate for the purposes of this study. This technique has been used in other New Zealand-based climate studies, such as that carried out by the Energy Group (1999). A more sophisticated method applied by some researchers is to use a weather generator, which is able to simulate daily variations in temperature, solar radiation etc. to preserve the observed inter-relationships between the meteorological elements (Energy Group, 1999). However, there are disadvantages with using a weather generator approach, as the way in which a weather generator needs to be modified for a future climate is not straightforward (Thompson and Mullan, 1999).

For the estimation of the new (i.e. climate change-induced) diurnal variation in dew point temperature (T_{dew}), the methodology used by Energy Group (1999) was applied to this study in overheating. The new T_{dew} was calculated based on the minimum T_{dry} for each 24-hour period, assuming a relative humidity (RH) of 85%. The chosen RH is said to reflect New Zealand's (outdoor) climate well at the time of minimum daily temperature (Cunningham, 1999 and Energy Group, 1999). For the rest of that day, it was assumed that T_{dew} remains unchanged.

As for the other climate-related parameters (such as net solar radiation, changes in cloudiness etc), there is either little or no reliable information available about what effects climate change will have (Camilleri, 1999). For example, changes to cloudiness / sunshine hours cannot be quantified yet, making estimations of climate change-induced variations in net solar radiation impossible.

2.2.4 Accounting for heat flow between zones

At present, a shortcoming in the SUNCODE simulation package is that it does not account for heat flow from internal air movement. This horizontal air movement (technically known as advection) leads to inaccuracies, as even with a multi-zone programme such as SUNCODE the zones are modelled separately with heat transfer accounted for only in conduction and radiation. Thus modelling is done based on the assumption that the doors between zones are all closed.

Analysis of the hourly internal temperature data shows that there are significant temperature differences between zonal temperatures (that is the temperatures between the zones examined). This is unlikely to be the case in an occupied single-storey house, due to its occupants opening doors between rooms resulting in better temperature uniformity between the spaces. The idea of addressing this anomaly within the SUNCODE program was considered. Stoecklein (1999) provides a simple procedure which approximates the thermal equalisations by substituting the internal openings (i.e. doors) with an effective R value. The R-value chosen is proportional to the estimated temperature difference between the two zones considered. This approximation technique was not, however, applied to this study for two reasons: the limitations in the amount of wall types physically able to be input into the SUNCODE building component file itself, which was already at capacity for the medium-sized house; and that for the purposes of this study, only a representation of what actually happens is required. For a more detailed study, applying the approximation to at least the spaces being studied would be appropriate.

2.2.5 Accounting for heat flow in the concrete slab

Heat flows through a concrete slab into the ground are strongly three dimensional (Pollard and Stoecklein, 1998), due to the heat flow at the centre of the slab having to travel much further to the outside air. Because of this, the concrete slab in this overheating study was modelled as two separate components, where the core (everything excluding 0.75m edge) was differentiated from the perimeter (the remaining 0.75m edge). Pollard and Stoecklein's (1998) approach was taken, where the path lengths of the ground beneath the modelled concrete slabs were chosen so that the R-value for the core path was 4 m^2 °C W^{-1}, and 1 m^2 °C W^{-1} for the edge path. The ground temperature underneath the modelled houses was taken as the average seasonal ground temperature at one metre depth (see Table 3), as recorded by the New Zealand Meteorological Service.

Table 3: Average seasonal ground temperatures for four New Zealand locations, at a 1m depth

Location	Ground Temperature (at 1m depth)
Auckland	18.6
Wellington	17.3
Christchurch	18.4
Dunedin	13.6

3. RESULT TABLES

The results for of all the variations performed on the three house sizes in each of the four locations can be viewed in the Appendices. Each parameter examined is broken down into:

Action – the change made to the base case house, and

Analysis – the significance of the imposed action, using the base case house as a reference.

For the purposes of this study, months which have 'significant' overheating – that is, they achieve more than two hours (i.e. more than 8%) of temperatures above 25 °C per day – will be highlighted. Highlighting is performed so that a quick visual representation of the impact (resulting from the physical- or climate-related variations) can be made for comparative purposes.

The units for Table 10 through Table 68 are in 'percentage of time per day'. That is, 1% represents about 14 minutes, 5% equates to 1 hour 12 minutes (1.2 hours), 10% equates to 2 hours 24 minutes (2.4 hours) etc.

Although the intention was to thermally simulate a typical house as well as possible, many assumptions were necessary, and were to some degree subjective. It should be repeated that the absolute hours of overheating in these results may not be representative of the actual number of overheating hours that a building would experience if physically built, but is comparative so useful for design comparisons.

Note that the houses modelled were NOT 'designed for the sun' i.e. of good solar design. Rather, the modelled houses were selected by the author as being reflective of current building practice – that is not considering solar aspects. This is important to recognise when examining the influence of such factors as eaves.

4. SUMMARY OF PARAMETRIC STUDY

4.1 Interpretation

Table 4, Table 5 and Table 6 summarise the results of the parametric study, giving an indication of the significance of the 12 variations on the three house sizes examined.

The seriousness of the overheating experienced by the houses over the seven 'summer' months assessed was measured by:

Duration of overheating (hours): a summation of the length of time (in hours) for which the three rooms examined experience some overheating.

Absolute change in duration of overheating: the difference in the duration of overheating experienced as a result of applying a particular parameter, compared to the base case situation.

Absolute Importance: for all cases where the change in duration of overheating is greater than five hours, compared to the base case situation.

Relative Importance: when the change in duration of overheating is greater than 40%, compared to the base case house.

It is important to note that only the variations to the base case scenario, which have a major impact on overheating, would be targeted for mitigation measures. To ensure this was the case, both an absolute and relative measure of the severity of overheating were used for this study, due to the limitations each method has.

There are many other measures for determining the significance of overheating. It can be argued that being a physiological response, measuring comfort in a linear manner (as has been performed in this study) is not appropriate. For example, the experience of one hour of 30°C is not considered to be equivalent to five hours at 26°C. Also, the time at which overheating occurs might also be considered. For example, overheating at mid-day is much easier to cope with by the occupants, than if the same temperature was experienced during sleep-time. However, a simple linear measure of overheating was considered to be representative enough of the comfort, for this study.

4.2 Small House

Table 4: Summary of physical and climatic parameters for the small house

PHYSICAL OR CLIMATIC PARAMETER FOR *SMALL* HOUSE	**Measure of Overheating**			
	Duration of overheating over 7 'summer' months (hours)	Change in duration of overheating cf Base Case (hours)	**Relative Importance:** (i.e. >40% percentage change)	**Absolute Importance:** (i.e. >5 hours difference in o/heating duration)
Small-sized 'Base Case' House	**18.7**	**0**	**N/A**	**N/A**
Reduce ventilation by 20%	25.2	+6.5		Yes
Reduce ventilation by 50%	40.6	+21.9	Yes	Yes
Increasing window area by 20%	24.5	+5.8		Yes
Remove all carpet	5.0	-13.7	Yes	Yes
Remove eaves	28.6	+9.9	Yes	Yes
Reduce westerly glazing (50%)	12.0	-6.7		Yes
Rotate house +90 degrees	9.1	-9.6	Yes	Yes
Rotate house -90 degrees	18.0	-0.7		
Increasing mass level	2.4	-16.3	Yes	Yes
Reduce insulation levels	29.8	+11.1	Yes	Yes
External shading devices (20%)	12.7	-6.0		Yes
External shading devices (30%)	10.6	-8.1	Yes	Yes
Transfer to Auckland	72.7	+54.0	Yes	Yes
Transfer to Christchurch	35.3	+16.6	Yes	Yes
Transfer to Invercargill	12.2	-6.5		Yes
Moderate climate change 2030	23.0	+4.3		
Moderate climate change 2070	37.0	+18.3	Yes	Yes
High climate change 2030	27.8	+9.1	Yes	Yes
High climate change 2070	51.4	+32.7	Yes	Yes

From the above table, the nine parameters which **increase** overheating (from most important to least), which are either relatively and/or absolutely important are:

1. Transfer to Auckland
2. High climate change 2070
3. Decreasing ventilation (by 50%)
4. Moderate climate change 2070
5. Transfer to Christchurch

6. Reduce insulation levels
7. Remove eaves
8. Decreasing ventilation (by 20%)
9. Increase window area (by 20%).

The following five parameters were found to **reduce** overheating (from most important to least) and are either relatively and/or absolutely important:

1. Increasing thermal mass levels
2. Removing all carpet
3. Rotating house 90° (so house is orientated North-South)
4. To increase external shading by 30%
5. Reduce the west glazing area by 50%.

4.3 Medium House

Table 5: Summary of physical and climatic parameters for medium-sized house

PHYSICAL OR CLIMATIC PARAMETER FOR *MEDIUM* HOUSE	**Measure of Overheating**			
	Duration of overheating over 7 'summer' months (hours)	Change in duration of overheating cf Base Case (hours)	**Relative Importance:** (i.e. >40% percentage change)	**Absolute Importance:** (i.e. >5 hours difference in o/heating duration)
Medium 'Base Case' House	**14.6**	**0**	**N/A**	**N/A**
Reduce ventilation by 20%	17.5	+2.9		
Reduce ventilation by 50%	28.3	+13.7	Yes	Yes
Increasing window area by 20%	17.8	+3.1		
Remove all carpet	3.6	-11.0	Yes	Yes
Remove eaves	22.6	+8.0	Yes	Yes
Reduce westerly glazing (50%)	7.4	-7.2	Yes	Yes
Rotate house +90 degrees	9.4	-5.2		
Rotate house -90 degrees	10.8	-3.8		
Increasing mass level	10.8	-3.8		
Reduce insulation levels	26.4	+11.8	Yes	Yes
External shading devices (20%)	10.1	-4.5	Yes	
External shading devices (30%)	8.4	-6.2	Yes	Yes
Transfer to Auckland	53.8	+39.2	Yes	Yes
Transfer to Christchurch	27.6	+13.0	Yes	Yes
Transfer to Invercargill	11.5	-3.1		
Moderate climate change 2030	17.5	+2.9		
Moderate climate change 2070	28.8	+14.2	Yes	Yes
High climate change 2030	20.9	+6.3	Yes	
High climate change 2070	40.3	+25.7	Yes	Yes

From the above table, the seven parameters which **increase** overheating (from most important to least), which are either relatively and/or absolutely important are:

1. Transfer to Auckland
2. High climate change 2070
3. Moderate climate change 2070
4. Reduce ventilation by 50%
5. Transfer to Christchurch
6. Reduce insulation levels
7. Remove eaves.

The following three parameters were found to **reduce** overheating (from most important to least), and are either relatively and/or absolutely important:

1. Removing all carpet
2. Reduce the west glazing area by 50%
3. To increase external shading by 30%.

4.4 Large House

Table 6: Summary of physical and climatic parameters for large house

PHYSICAL OR CLIMATIC PARAMETER FOR *LARGE* HOUSE	Measure of Overheating			
	Duration of overheating over 7 'summer' months (hours)	Change in duration of overheating cf Base Case (hours)	**Relative Importance:** (i.e. >40% percentage change)	**Absolute Importance:** (i.e. >5 hours difference in o/heating duration)
Large-sized 'Base Case' House	**10.8**	**0**	**N/A**	**N/A**
Reduce ventilation by 20%	14.4	+3.6		
Reduce ventilation by 50%	25.2	+14.4	Yes	Yes
Increasing window area by 20%	14.2	+3.4		
Remove all carpet	4.8	-6.0	Yes	Yes
Remove eaves	14.9	+4.1		
Reduce westerly glazing (50%)	8.2	-2.6		
Rotate house +90 degrees	8.9	-1.9		
Rotate house -90 degrees	11.5	+0.7		
Increasing mass level	7.4	-3.4		
Reduce insulation levels	20.9	+10.1	Yes	Yes
External shading devices (20%)	8.2	-2.6		
External shading devices (30%)	7.0	-3.8		
Transfer to Auckland	48.7	+37.9	Yes	Yes
Transfer to Christchurch	24.5	+13.7	Yes	Yes
Transfer to Invercargill	8.4	-2.4		
Moderate climate change 2030	14.2	+3.4		
Moderate climate change 2070	24.2	+13.4	Yes	Yes
High climate change 2030	16.1	+5.3	Yes	Yes
High climate change 2070	35.5	+24.7	Yes	Yes

From the above table, the seven parameters which **increase** overheating (from most important to least), which are either relatively and/or absolutely important are:

1. Transfer to Auckland
2. High climate change 2070
3. Reduce ventilation by 50%
4. Transfer to Christchurch
5. Moderate climate change 2070
6. Reduce insulation levels
7. High climate change 2030.

The following parameter is the only one found to **reduce** overheating and be either relatively and/or absolutely important:

1. Removing all carpet.

4.5 Summary Table for all Houses

4.5.1 Overall ranking for changes to overheating

Table 7 and Table 8 summarise the parameters which result in the most significant (whether positive or negative) changes to overheating, for each of the three house sizes. The variables are all based on the base house, located in Wellington (Kelburn station).

Table 7: Overall ranking of parameters which increase overheating

Parameter Examined (Base Case = Wellington)	**Ranking of Parameter** (1=most significant)		
	Small House	**Medium House**	**Large House**
Transfer to Auckland	1	1	1
High climate change 2070	2	2	2
Reduce ventilation by 50%	3	4	3
Transfer to Christchurch	5	5	4
Moderate climate change 2070	4	3	5
Reduce insulation levels	6	6	6

Table 8: Overall ranking of parameters which decrease overheating

Parameter Examined (Base Case = Wellington)	**Ranking of Parameter** (1=most significant)		
	Small House	**Medium House**	**Large House**
Increasing mass levels	1	-	-
Removing all carpets	2	1	1
Rotating house 90 degrees clockwise	3	-	-
Increasing external shading by 30%	4	3	-
Reducing west glazing area by 50%	5	2	-

It can be seen that for the parameters which increase overheating, the rankings remain almost constant for all the house sizes, with the most important factor influencing overheating being climate (external temperature and solar radiation), then ventilation for all the houses. The picture is very different for parameters which decrease overheating – with little change in the order being displayed through the various house sizes. It can be seen that the small house is very sensitive to changes, and for all houses exposing the concrete slab is very important in reducing temperatures.

The parameters within Table 7 can be grouped into two categories:

Construction-related features – e.g. shading, mass levels, orientation, glazing
Occupant-determined features – e.g. carpet

4.5.2 Notes on overall ranking

For all the houses monitored, there is only one parameter that significantly reduces overheating which can be easily altered, post-construction. This is the removal of carpet, which is effective only if the house has a slab-on-ground concrete floor.

The parameters which reduce overheating are to a great degree dictated by the size of the house. Those which require minimum renovation are:

SMALL HOUSE:

- installing shading devices that reduce incoming solar radiation by at least 30%
- utilizing the concrete slab as a heat sink, by removing the carpet in the solar rooms.

MEDIUM-SIZED HOUSE:

- installing shading devices that reduce incoming solar radiation by at least 30%
- utilizing the concrete slab as a heat sink, by removing the carpet in the solar rooms.

LARGE HOUSE:

- utilizing the concrete slab as a heat sink, by removing the carpet in the solar rooms.

There are other construction-related parameters, which can reduce the overheating experienced, but require major renovation. These include: reducing the west glazing area by 50%; increasing the mass level, by substituting timber framing and plasterboard with concrete block; and rotating the house, so that the new axis is North-South. Once again, the variables are dependent on house size. For example, changing the amount of incident solar radiation is only useful for the small and medium-sized house types modelled here.

The small house is much more sensitive (i.e. more 'at risk') to the various overheating-related parameters used in this study, than the medium and large houses. This can be seen by examining the number of important parameters, which influenced the length of overheating. Thus, for smaller houses, there seem to be more possibilities for addressing overheating issues.

It was found that predicted increases in climate change would have a significant impact on the number of hours for which houses experience overheating. If the year 2030 is examined, only the extreme predicted temperature (equating to a 0.9°C rise in the overall external temperatures) will significantly affect the number of overheating hours. However, for the year 2070, both the medium (1.7°C rise) and high (2.7°C rise) climate change induced temperatures will result in significant increases in overheating, for all the buildings examined. It should be noted that the relationship between external and internal temperatures is not 1:1. Thus, a 1°C rise in the ambient temperature results in a greater than 1°C rise internally.

4.5.3 Notes on climate and temperature

In this study, comfort (or discomfort) was measured in terms of number of hours above a threshold temperature of 25°C, therefore addressing frequency, rather than severity. The physiological stresses experienced by the occupant were not addressed at all. Thus, an interior temperature of 26°C is treated just as 33°C – both classified as being 'uncomfortable'.

By examining the SUNCODE weather data files, it was found that during the summertime Christchurch (latitude 43.3 degrees South) experiences a total of the equivalent of 2.6 days above 25°C, while Auckland (latitude 36.5 degrees South) experiences only the equivalent of 2.2 days. Thus, from weather data files alone, Christchurch seems to have about 10 hours more overheating than Auckland. This seems to conflict with the building simulations performed as part of this report, where longer periods of (indoor) overheating were experienced in the Auckland.

This apparent anomaly of Christchurch having more (external) overheating than Auckland can be explained by three things: (1) Christchurch has much larger diurnal variations than Auckland – with buildings having to start from lower internal temperatures, therefore having to 'make up' more of a temperature gain; (2) the average daily maximum temperature for Auckland (at 23.2°C) is 1.7°C higher than that for Christchurch (at 21.5°C) for the summer period. Since the internal temperatures of the houses are usually several degrees above the ambient temperature, these average daily maximums would likely to be a fair indicator of overheating; and (3) the Christchurch house is better insulated, which results in a better thermal buffer, reducing the likelihood and amount of overheating.

Although not modelled in this study, it would be reasonable to expect that raising the level of ventilation (by say 20%) would significantly reduce the level of overheating also. Increasing ventilation to reduce summertime overheating is suggested whatever the building type (Breuer, 1994).

5. PART A: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions were drawn from the SUNCODE modelling of a 'typical' house, 120 m^2, timber framed with concrete slab, situated in Wellington, in an average summer, constructed to NZS 4218:1996.

1. External temperature (whether due to current location or as a result of climate change) has by far the greatest impact on indoor overheating (and therefore comfort), followed by the ventilation rate. These two factors are independent of house size.

2. The other features which affect overheating are: insulation levels, mass levels, external shading, altering the west glazing area, and altering the size of the eaves. The rankings of these other features are to some degree determined by house size.

3. The practical remedial choices which are applicable to all house sizes with only a small amount of difficulty are: using mechanically-assisted ventilation and using the concrete floor slab as a heat sink. For the small and medium-sized houses, there are also benefits from installing external shading devices.

4. The smaller the size of the building, the larger the number of variables influencing summertime overheating (i.e. the more responsive the building is, and therefore the greater the number of possibilities to mitigate this).

5. The top seven features which were found to be most influential in altering the amount of overheating can be grouped into: 'Construction-related' features – e.g. insulation levels, mass levels; 'Fixed' features – e.g. location, climate; and 'Occupant-determined' features – e.g. carpet, ventilation levels.

6. All houses examined were insensitive to an increase of window size by 20%; small reductions in ventilation (i.e. up to and including 20%); and small temperature changes (equal to or below 0.5°C).

5.2 Notes and Recommendations

1. The influence of some occupant-determined features is very dependent on the size of the building. An example of this is external shading devices, for which two scenarios were proposed. In the first scenario, 20% of the light incident on the windows was cut out, in the second scenario; this was increased to 30%. Viewing the tables, it can be seen that the greater the building size, the less of an effect the measure has on the overall zone performance. It should be noted the localized discomfort (if any) has not been investigated.

2. Ideally, a parametric study such as this should result in predictions with a good degree of confidence. This study however, focused on a narrow 'bandwidth' of house types, to get an initial idea of which factors influenced overheating. Thus, there were a very limited number of base case houses, all of which were constructed to today's building standards, attempting to be representative of today's 'typical' house. It was assumed that these houses would represent the bulk of the houses still habitable in 2070. However, some older houses, which were not built to current codes, will also exist in the year 2070 (the housing mortality rate is difficult to predict, refer Johnstone, 1994). These houses have not been represented in this study. Additional research is required to address this deficiency, as their characteristics in terms of thermal performance are likely to be quite different to those modelled. Also, passive solar houses have been neglected from this study, and should be included for comparative performance purposes.

3. A method of incorporating advection (horizontal heat flows between zones) within the SUNCODE program needs to be examined. There are various ways in which this problem could be addressed – whether it is by incorporating another program within SUNCODE, or by applying the procedure set out by Stoecklein (1999) (see section 2.2.4) in a modified form. Alternatively, the whole house could be treated as one thermal zone.

4. It is recommended that a more comprehensive study be performed using SUNCODE, to be more representative of the housing stock in 2030 and 2070. The scope of the study could include a wider range of house forms, window placements and insulation levels.

5. The use and application of external window shading devices, which reduce the incident sunlight by a significant amount, should be promoted. An investigation into the effectiveness of both artificial and natural means of providing this shading needs to be conducted.

6. Promoting the use of the exposed (uncarpeted) concrete slab as a heat sink in solar rooms, as a way of moderating temperature swings (and therefore discomfort) in summer is also recommended.

6. PART B: RISK OF OVERHEATING IN DOMESTIC BUILDINGS

6.1 Overheating Risks

This section deals with the risk aspects associated with summertime overheating in domestic buildings in New Zealand. The generic question which Part B attempts to answer is, what houses are likely to suffer from discomfort as a result of overheating? More specifically, is there a reasonably simple method of examining New Zealand houses to assess their risk of discomfort due to overheating in the summertime?

As for Part A, in this assessment, only the main comfort parameter – indoor temperature with a maximum threshold of 25°C – was considered. Various predictive tools – whether descriptive based or calculation based – were examined for their applicability in the determination of summertime overheating (i.e. in the form of maximum indoor temperatures) for domestic buildings.

In New Zealand the focus on indoor comfort is almost always related to wintertime heating, where a substantial national effort has been focused since the 1980s, in an effort to reduce space heating energy consumption (Breuer, 1988). This is because our temperate climate range tends to fall below the usual human comfort temperatures more often than it rises above. Of the summertime overheating studies carried out specifically for New Zealand, most deal with commercial buildings, at the exclusion of domestic construction (Stevens, 1978A and 1978B). However, there are some New Zealand – specific studies which do address domestic summertime overheating, based on thermal modelling or field testing (Stevens, 1982, Donn and Van Der Werff, 1990 and Breuer 1994).

In one such study, it was suggested that keeping the indoor temperature swing down to a low level would result in comfortable temperatures (Stevens, 1978A). The author suggested two standards of design – 'good' if the temperature swing is held to 3°C and 'poor' if it reaches 6°C. Thus, the indoor design temperature could be defined as (assuming sedentary situations):

Summertime: 20°C ± 3°C 'GOOD' 25°C ± 6°C 'POOR'

A variation on this theme to predict comfort levels (i.e. the indoor temperature) within a house is to estimate the expected maximum summertime indoor temperature, and therefore extrapolate some risk criteria directly from it. This approach was used in this study.

6.2 The Los Alamos Approach

The method selected for this study in predicting summertime indoor temperatures (and therefore the associated risk in overheating), was the Los Alamos approach (Balcomb, 1983). In this method, overheating is related to the house's thermal mass, solar glazing area and floor area. It is assumed that the internal temperature of the building rises from its lowest diurnal temperature to a maximum temperature between 6 am and 3 pm. The dynamic nature of the assessed building is represented by the static equation:

$$T_{max} = T_{set} + \frac{(Q_{sol} \times A_{sol} + Q_{int}) - (T_{set} - T_{out}) \times UA \times t}{mCp + (UA \times t/2)}$$

Equation 1: T_{max} equation based on the Los Alamos Approach

Where:

T_{max}	= maximum interior temperature (at 3pm in °C)
T_{out}	= average outdoor temperature over the period examined (°C)
T_{set}	= interior set point temperature, at start of warm-up (°C)
mCp	= (or 'M' on Figure 1) effective diurnal heat capacity (Wh/ °C)
UA	= building heat loss coefficient (W°C)
t	= time interval of energy balance (hours)
Q_{sol}	= transmitted solar heat gain per m^2 of solar glazing (kWh/m^2)
Q_{int}	= internal heat gain in period examined (kWh)
A_{sol}	= solar glazing area (m^2)

6.3 Derivation of T_{max} Table

Figure 1 shows the maximum average temperature expected indoors in summer for houses of various constructions. It can be used for estimating the overheating risk and therefore the level of comfort associated with a particular house design. Figure 1 is derived directly from Equation 1, using an artificial 'base case' house. A spreadsheet was constructed using Equation 1, with T_{max} curves derived by varying the 'base case' house's solar glazing area to floor area ratios and effective thermal mass levels.

The artificial 'base case' house was assessed over the three critical overheating months December through to February (as determined in the SUNCODE modelling). The base house (which was the medium-sized base house in Part A: Parametric Study) has the following characteristics:

- evenly distributed windows for the three solar aspects (west, north and east)
- a floor area of 120 m^2, medium weight construction and situated in a 'moderate' New Zealand climate (i.e. Kelburn, Wellington)
- insulated to NZS 4218: 1996 minimum requirements, appropriate to the construction type
- naturally vented to a rate of five air changes per hour
- occupied by two people
- an overall (elemental-weighted) R-value of 1.5 m^2°C/W.

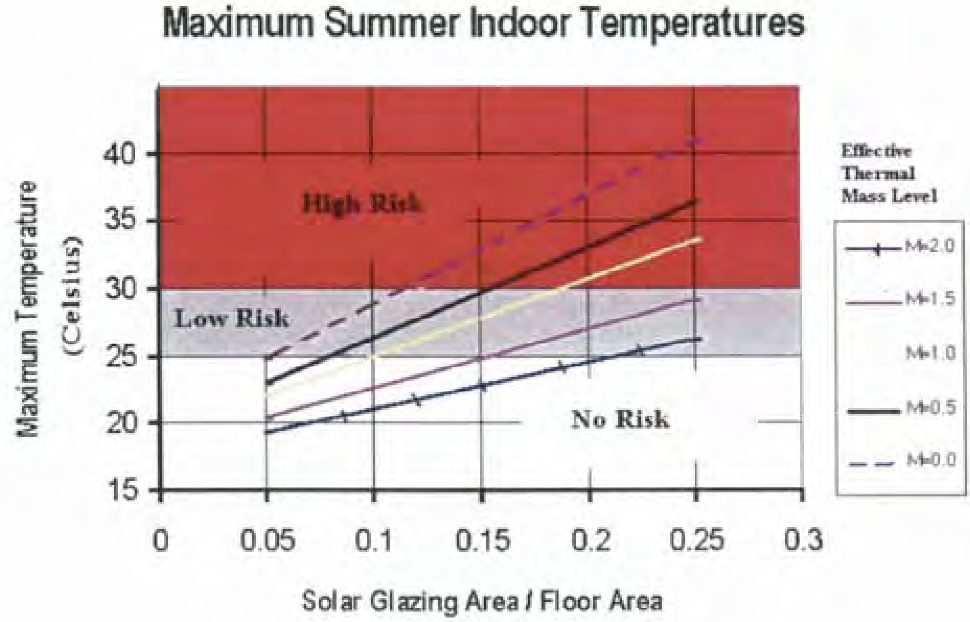

Figure 1: Estimation of maximum average indoor summertime temperature and associated risks of overheating

Three risk levels are given in Figure 1 to account for the likelihood of a particular house overheating. The overheating risk levels are determined simply by maximum temperature thresholds:

No Risk: where T_{max} is 25 °C or less
Low Risk: where T_{max} falls between 25 °C and 30 °C
High Risk: where T_{max} is above 30°C.

The previous single threshold level of overheating (i.e. 25°C) used to define the comfort threshold in the SUNCODE modelling for Part A: Parametric Study was further developed for its application here. It was felt that it was necessary to make a distinction between houses, which 'just' overheated, as opposed to those houses which had severe overheating problems. An extra echelon was therefore included to reflect this. The figure of 30°C was chosen to reflect this extra physiological stress, which would be incurred by the occupants, which is said to represent the extreme upper comfort bound (Humphreys, 1975).

6.4 Modelling Assumptions

The following details the variables used in the T_{max} equation, along with the assumptions made in the modelling of the 'base case' house.

$\mathbf{A_{sol}}$ is the solar glazing area – i.e. windows, which face east, north or west. For the 'base case' house considered, $A_{sol} = 35\ m^2$.

$\mathbf{Q_{sol}}$ is calculated from actual records of transmitted solar heat gain (Stoecklein and Bassett 1999), assuming a shading coefficient fraction of 0.55 due to losses from window grime, shading from external foliage and curtain netting. The per square metre solar heat gains were calculated for each of the three orientations (north, west, and east), summing hourly figures over the monitored time (6am to 3pm). It was found that there were very little differences between the solar heat gains irrespective of latitude, if averaged over the summer months (with Auckland, Wellington, Christchurch and Invercargill all about 450 kWh/m^2).

T_{set} (the interior set point temperature at start of warm-up) was calculated using the SUNCODE weather data files. It was found (based on SUNCODE simulations) that for Wellington, the lowest ambient air temperature was reached at about 6am (just before sunrise). Peak indoor temperatures are usually reached at around 3pm, thus the energy balance is calculated over these nine hours. $T_{set} = 15°C$.

Q_{int} is the amount of internal heat gain over the nine hours investigated. Assuming that there are two occupants in the house, using Bassett et al (1990) figures for occupant (about 300 kWh per season) and appliance (1300 kWh per season) heat gains, the total internal seasonal heat gains equal 1600 kWh per season. This converts to approximately 3 kWh per day (i.e. 9 hours out of 24 of a daily total of 1600 kWh/season).

UA, the overall building heat loss coefficient (W/°C), is made up of the elemental heat losses (i.e. the elemental surface areas divided by their respective R-values) plus the losses due to air leakage (i.e. the product of the air change rate per hour, the house volume and the heat capacity of the air).

T_{out} is calculated by the following equation, with the temperatures being taken from the New Zealand Meteorological Service data (1980). This is considered a good enough approximation, and saves averaging the daily 6am to 3pm temperatures for each of the three months. As for the Q_{sol} calculations, the T_{max} approximations were derived for each locality. T_{out} for Wellington = 16.5°C.

$$T_{out} = \text{T mean ambient} + \frac{\text{T average daily maximum} - \text{T mean ambient}}{2}$$

Equation 2: Average outdoor temperature calculation

The basis for calculating the **mCp** (or M, the effective heat capacity) is described in the ALF manual (Bassett et al, 1990) in some detail, and therefore will not be elaborated on here. Two examples of different material heat capacities are: for timber floors, plasterboard lined timber walls and ceiling, the effective thermal mass level is 0.2. For a concrete slab, with plasterboard walls and ceiling, the effective mass level is 1.0 (see Appendix G).

6.5 Model Interpretation

For houses in warmer or cooler climate zones, the resulting T_{max} will need to be adjusted (and therefore perhaps the resulting level of risk), based on mean ambient summertime temperatures (T_{mean}). Adjustments for different climate zones for T_{max} can be made using a 1:1 ratio – that is a 1°C higher T_{mean} for a non-Wellington region results in a 1°C higher T_{max}. For example, if the T_{max} for Auckland is required to be estimated, and the difference between the Auckland and Wellington T_{mean} is known to be 3°C, then the T_{max} for Auckland is Wellington's T_{max} plus 3°C.

For calculating the overheating risk for a particular building design, the following procedure should be applied:

1. Calculate the solar window area (sum the north, west and east-facing windows).
2. Calculate the floor area.
3. Calculate the solar glazing area to floor area ratio.
4. Estimate the Effective Mass Level (M) from Table 69 in Appendix G: Thermal Mass Levels.
5. Using Figure 1, find T_{max} and therefore the risk of overheating.

6. If the building location is in an area that differs from Wellington's climate, adjust the T_{max} by the difference in T_{mean} (refer Table 9).

Table 9: Correction factors for T_{max} graph for non-Wellington locations

Urban Location	T_{max} Correction
Auckland	+ 3.0 °C
Hamilton	+ 1.6 °C
Palmerston North	+ 0.9 °C
Christchurch	+ 1.0 °C
Dunedin	- 1.7 °C

6.6 Conclusions and Recommendations

1. Maximum summertime temperatures (and therefore comfort) can be determined from a small number of variables. These variables are: floor area, solar window area and effective thermal mass.

2. Figure 1 is based on Wellington ambient temperatures, and needs adjusting for more or less extreme climates. Table 9 provides T_{max} conversions for the main centres.

3. Figure 1 should be used as a guide only to the likelihood of summertime overheating, as it is based on a 'typical' design. Although a sensitivity analysis has been performed on some of the variables on which the graph was constructed, it is likely that T_{max} estimations derived from unusual designs/features (e.g. houses which are extremely well sheltered or heavily shaded) may be inaccurate. As eloquently stated by Auliciems and Szokolay (1997) in their notes on thermal comfort predictive tools, "*... the results of calculations and graphic analyses must be mitigated by human intelligence and not slavishly accepted in a mechanistic way*". It would be preferable if the predicted maximum temperatures in Figure 1 were field tested, to check for correlation. The BRANZ series of Household Energy End-Use Project (HEEP) houses could be used as a verification method.

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APPENDIX A: MEDIUM-SIZED 'BASE CASE' BUILDING FILE

SUNCODE

```
Medium Sized, Medium Weight House located in Wellington (Kelburn)
*
* ------------------------- RUNS -------------------------------------
RUNS
*     RUN LABEL      STATION    GROUND GROUND -START- -STOP-- SKYLINE  PAR.
*                     NAME       REFL.  TEMP. MON DAY MON DAY PROFILE  TYPE
*                               [FRAC]   [C]  [DATE]  [DATE]
*AAAAAAAAAAAAAAAA AAAAAAAAAA S.SSSS SSS.SS AAA XX. AAA XX. AAAAAA   AAAAAA
*mmbase           AUCKLAND   GRASS  GRD.AK JAN  1. DEC 31. <NONE>  <NONE>
 mmbase           KELBURN    GRASS  GRD.WG JAN  1. DEC 31. <NONE>  <NONE>
*mmbase           CHRIST     GRASS  GRD.CH JAN  1. DEC 31. <NONE>  <NONE>
*mmbase           INVERC     GRASS  GRD.IN JAN  1. DEC 31. <NONE>  <NONE>
*
* ------------------------- ZONES ------------------------------------
ZONES
*  ZONE       HVAC      FLOOR  HGT  INFIL.  SOLAR  SOLAR INTERNAL  LATENT
•  NAME       TYPE      AREA         RATE  TO AIR  LOST    GAIN     GAIN
•                       [SM]   [M]  [AC/H] [FRAC] [FRAC]   [KW]     [KW]
*AAAAAAAAAA AAAAAAAAAA XXXXX.X XX.X SSS.SSS X.XXX  X.XXX SSSS.SSS SSSS.SSS
 KIT.DIN    LIVING        33.3  2.4   1.     0.15   0.05 KIT-INT     0.000
 LOUNGE     LIVING        20.9  2.4   1.     0.15   0.05 LOUN-INT    0.000
 BED1       OTHER         24.0  2.4   1.     0.15   0.05 BED1-INT    0.000
 BEDS       OTHER         44.6  2.4   1.     0.15   0.05 BEDS-INT    0.000
 GARAGE     <NONE>        36.0  2.4   1.     0.15   0.05 GAR-INT     0.000
 ROOFSPACE  <NONE>       158.8  1.0   1.     0.15   0.          0.000    0.000
•
• ------------------------- WINDOWS ----------------------------------
WINDOWS
• INTERIOR   EXTERIOR   GLAZING      HEIGHT  LENGTH  ---LOCATION----
*   ZONE      SURFACE     TYPE                          HORZ.   VERT.
*                                      [M]     [M]      [M]     [M]
*AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA    XXXX.XX XXXX.XX XXXX.XX XXXX.XX
 KIT.DIN    WEST1      SNG1.M3          2.1     0.9     0.1     0.1
 KIT.DIN    NORTH2     SNG1.M3          1.1     1.4     2.6     0.1
 LOUNGE     WEST2      SNG1.M3          2.1     4.2     1.30    0.30
 LOUNGE     NORTH1     SNG1.M3          2.1     1.7     0.3     0.1
 BEDS       WEST3      SNG1.M3          1.5     1.8     1.3     0.1
 BEDS       SOUTH      SNG1.M3          1.5     1.2    10.3     0.10
 BEDS       SOUTH      SNG1.M3          1.2     0.6     9.3     0.1
 BEDS       SOUTH      SNG1.M3          1.5     1.6     6.8     0.1
 GARAGE     SOUTH      SNG1.M3          2.1     0.9     5.0     0.1
 GARAGE     SOUTH      SNG1.M3          1.2     1.9     3.9     0.10
*KIT.DIN    EAST1      SNG1.M3          2.1     1.5     0.00    0.00
 BED1       EAST1      SNG1.M3          1.5     1.5     1.30    0.20
 BED1       NORTH2     SNG1.M3          0.6     1.9     7.60    0.10
 BED1       NORTH2     SNG1.M3          1.1     0.8     5.50    0.10
*
* ------------------------- WALLS ------------------------------------
WALLS
*   WALL     --FRONT/INTERIOR SIDE--  --BACK/EXTERIOR SIDE---   WALL
•   TYPE        ZONE     SURF   SOLAR  ZONE OR    SURF  SOLAR    AREA
*               NAME     COEF   COEF.  SURFACE,   COEF  COEF.
*                        [W/C  [FRAC]  AMBIENT,   [W/C  [FRAC]   [SM]
*                        -SM]          GROUND     -SM]
*AAAAAAAAAA AAAAAAAAAA XX.XXX X.XXXX AAAAAAAAAA XX.XXX X.XXXX  XXXXX.X
 GIB.TIM.2  KIT.DIN     8.278 0.     NORTH2      22.73   .3        9.1
 GIB.TIM.2  KIT.DIN     8.278 0.     WEST1       22.73   .3        2.6
 GIB.TIM.2  LOUNGE      8.278 0.     NORTH1      22.73   .3        6.2
 GIB.TIM.2  LOUNGE      8.278 0.     WEST2       22.73   .3        5.1
 GIB.TIM.2  BEDS        8.278 0.     NORTH3      22.73   .3        3.8
 GIB.TIM.2  BEDS        8.278 0.     WEST3       22.73   .3        7.4
 GIB.TIM.2  BEDS        8.278 0.1    SOUTH       22.73   .3       16.7
 GIB.TIM.2  GARAGE      8.278 0.     SOUTH       22.73   .3       10.2
 GAR.DOOR   GARAGE      8.278 0.     EAST2       22.73   .3       11.5
 GIB.TIM.2  GARAGE      8.278 0.     EAST2       22.73   .3        8.6
 GIB.TIM.2  KIT.DIN     8.278 0.     EAST2       22.73   .3        1.7
 GIB.TIM.2  BED1        8.278 0.     SOUTH       22.73   .3        5.8
 GIB.TIM.2  BED1        8.278 0.     EAST1       22.73   .3        9.9
 GIB.TIM.2  BED1        8.278 0.     NORTH2      22.73   .3       12.9
 ROOF.MTL   ROOFSPACE   8.278 <AREA> ROOF        22.73   .7      158.8
 CON.COR    KIT.DIN     8.278 0.35   GROUND       8.278 0.        27.0
 CON.EDG    KIT.DIN     8.278 0.30   GROUND       8.278 0.         6.3
```

```
CON.COR     BED1        8.278 0.30   GROUND      8.278 0.          15.4
CON.EDG     BED1        8.278 0.20   GROUND      8.278 0.           8.6
CON.COR     LOUNGE      8.278 0.30   GROUND      8.278 0.          14.6
CON.EDG     LOUNGE      8.278 0.25   GROUND      8.278 0.           6.3
CON.COR     BEDS        8.278 0.40   GROUND      8.278 0.          33.8
CON.EDG     BEDS        8.278 0.25   GROUND      8.278 0.          10.8
CON.COR     GARAGE      8.278 <AREA> GROUND      8.278 0.          27.0
CON.EDG     GARAGE      8.278 <AREA> GROUND      8.278 0.           9.0
GIB.1       KIT.DIN     8.278 0.05   ROOFSPACE   8.278 <AREA>      33.3
GIB.1       LOUNGE      8.278 0.05   ROOFSPACE   8.278 <AREA>      20.9
GIB.1       BEDS        8.278 0.05   ROOFSPACE   8.278 <AREA>      44.6
GIB.1       GARAGE      8.278 <AREA> ROOFSPACE   8.278 <AREA>      36.0
GIB.1       BED1        8.278 0.05   ROOFSPACE   8.278 <AREA>      24.0
LOUN.DIN    LOUNGE      8.278 0.05   KIT.DIN     8.278 0.          11.3
GIB.GIB.2   LOUNGE      8.278 0.15   BEDS        8.278 0.          10.8
GIB.GIB.2   GARAGE      8.278 <AREA> BEDS        8.278 0.          14.4
GIB.GIB.2   GARAGE      8.278 <AREA> KIT.DIN     8.278 0.05        11.3
GIB.GIB.2   KIT.DIN     8.278 0.05   BED1        8.278 0.25        19.2
GIB.GIB.2   KIT.DIN     8.278 0.00   BEDS        8.278 0.           9.8
*
* ------------------------ SURFACES --------------------------------
SURFACES
* EXTERIOR  COMPASS  TILT  HEIGHT  LENGTH  OVERHANG    LEFT       RIGHT
* SURFACE   AZIMUTH                          TYPE     SIDEFIN    SIDEFIN
*            [DEG]  [DEG]   [M]     [M]
*AAAAAAAAAA  XXX.X   XX.X XXXX.XX XXXX.XX AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA
 NORTH2         0.    90.     2.40    10.5  EAVES0600  <NONE>     <NONE>
 NORTH1         0.    90.     2.40     4.1  EAVES0600  <NONE>     <NONE>
 NORTH3         0.    90.     2.40     1.6  EAVES0600  <NONE>     <NONE>
 WEST1        270.    90.     2.40     2.0  EAVES0600  <NONE>     <NONE>
 WEST2        270.    90.     2.40     5.8  EAVES      <NONE>     WALLS1
 WEST3        270.    90.     2.40     4.2  EAVES0600  <NONE>     <NONE>
 SOUTH        180.    90.     2.40    15.0  <NONE>     <NONE>     <NONE>
 EAST1         90.    90.     3.10     4.0  EAVES0600  <NONE>     <NONE>
 EAST2         90.    90      3.15     8.0  EAVES0600  <NONE>     <NONE>
 ROOF           0.     0.    15.00    10.7  <NONE>     <NONE>     <NONE>
*
* ------------------------ HVAC.TYPES ------------------------------
HVAC.TYPES
*   HVAC    HEATING  VENTING  COOLING  HEATING  VENTING  COOLING   COOLER
*   TYPE    SETPOINT SETPOINT SETPOINT CAPACITY CAPACITY CAPACITY   COIL
*             [C]      [C]      [C]      [KW]    [AC/H]    [KW]      [C]
*AAAAAAAAAA SSS.SSS  SSS.SSS  SSS.SSS  XXXX.XXX  XXX.XX  XXXX.XXX   XX.X
 LIVING     <NONE>    18.     <NONE>    <NONE>   10.     <ADEQ>     12.8
 OTHER      <NONE>    18.     <NONE>    <NONE>   10.     <ADEQ>     12.8
*
* ------------------------ WALL.TYPES ------------------------------
WALL.TYPES
*   WALL      LAYER      LAYER      LAYER      LAYER      LAYER      LAYER
*   TYPE       # 1        # 2        # 3        # 4        # 5        # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
* NZS4218:96 Wall -> R-1.5
 GIB.TIM.2  GIB.9.5    R-1.29     WEATH.19   <NONE>     <NONE>     <NONE>
* NZS4218:96 Ceiling -> R-1.9 (incl roofmetal and surface resistances)
 GIB.1      GIB.9.5    R-1.34     <NONE>     <NONE>     <NONE>     <NONE>
 ROOF.MTL   R-0.2      <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
* foil 100mm sag floor -> R-1.3 (incl perimeter wall, R-0.2 and surface
* resist. inside and external to peri. wall
* not in subspace assume allowed for in 0.2)
 PAR.1      PARTI.19   R-0.78     <NONE>     <NONE>     <NONE>     <NONE>
 GIB.GIB.2  GIB.9.5    R-0.18     GIB.9.5    <NONE>     <NONE>     <NONE>
 CON.COR    R-0.4     CONC.100    EARTH.C    <NONE>     <NONE>     <NONE>
 CON.EDG    R-0.4     CONC.100    EARTH.E    <NONE>     <NONE>     <NONE>
 LOUN.DIN   GAP.WALL   <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 GAR.DOOR   R-0.2      <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 EARTH      EARTH.E    <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
*
* ------------------------ MASS.TYPES ------------------------------
MASS.TYPES
*MASS TYPE   CONDUCTIVITY   DENSITY    SPECIFIC HEAT  THICKNESS   NODES
*               [W/M-C]      [KG/CM]      [KJ/KG-C]      [M]
*AAAAAAAAAA     X.XXXX      XXXX.XXX       X.XXXX       XX.XXXX     XX.
* 100mm concrete -> R-0.07
 CONC.100        1.43        2400.          .88            .1         2.
* 1.4m earth path for perimeter  -> R 0.93
 EARTH.E         1.5         1940.          .836          1.4         3.
* 5.9m earth sink for core   -> R 3.93
 EARTH.C         1.5         1940.          .836          5.9         5.
```

```
* Wall between lounge and dining: (gap of R 0.015) -> R 0.042
 GAP.WALL        0.43        800.         0.62          .018      1.
* GibBoard R-0.059
 GIB.9.5          .16        800.         1.34          .0095     1.
* Particle board R-0.14
 PARTI.19         .14        700.         1.17          .019      1.
* Weatherboard R-0.15
 WEATH.19         .13        630.         1.17          .019      1.
*
* ------------------------ GLAZING.TYPES ----------------------------
GLAZING.TYPES
* GLAZING    GLAZING    SHADING EXTINCTION  INDEX OF  THICKNESS  NUMBER
*  TYPE      U VALUE     COEF.     COEF.   REFRACTION OF LAYER     OF
*           [W/SM-C]    [FRAC]    [1/MM]     [NONE]     [MM]     LAYERS
*AAAAAAAAAA  SS.SSSSS  SS.SSSSS  X.XXXX     X.XXXX    X.XXXX      XX.
 SNG1.M3       5.6        .55      .0197     1.526     3.           1.
*
* ------------------------ OVERHANG.TYPES ---------------------------
OVERHANG.TYPES
* OVERHANG   VERTICAL  HORIZONTAL
*   TYPE      OFFSET   PROJECTION
*              [M]        [M]
*AAAAAAAAAA   XX.XX      XX.XX
 EAVES         0.0        2.0
 EAVES0600     0.0        0.60
*
* ------------------------ SIDEFIN.TYPES ----------------------------
SIDEFIN.TYPES
* SIDEFIN     OFFSET   LENGTH OF
*  TYPE       TO SIDE  PROJECTION
*              [M]       [M]
*AAAAAAAAAA   XX.XX     XX.XX
 WALLS1        0.0       1.6
*
* ------------------------ OUTPUTS ----------------------------------
OUTPUTS
* OUTPUT    TIME    UNITS    OUTPUT    BUILDING    OUTPUT    FORMAT?
*  TYPE    PERIOD            SEASON    ELEMENT     SECTION
*         [H/D/M]  [E/M]                                     [Y/N]
*AAAAAAAA    A        A     AAAAAAAA     XXXX.      XXXX.      A
 ZONES       H        M     SUM          <ALL>        6.       Y
*
* ------------------------ SCHEDULES --------------------------------
SCHEDULES
*SCHEDULE  SEASON   HR   VALUE     HR   VALUE     HR   VALUE     HR   VALUE
*AAAAAAAA AAAAAAAA XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX
 OTHER    YEAR      1.   14.
 LOUN-INT YEAR      7.     .312  23.     .040
 KIT-INT  YEAR      7.     .250  23.     .040
 BEDS-INT YEAR      7.     .230  23.     .215
 BED1-INT YEAR      7.     .040  23.     .155
 GAR-INT  YEAR      7.     .00   23.     .00
 GRASS    YEAR      1.     .2
 GRD.AK   YEAR      1.   18.6
 GRD.WG   YEAR      1.   17.3
 GRD.CH   YEAR      1.   18.4
 GRD.IN   YEAR      1.   13.6
*
* ------------------------ SEASONS ----------------------------------
SEASONS
* SEASON      START DATE     STOP DATE     DAY OF WEEK
*  NAME        MON DAY        MON DAY    [ALL/M-F/S-S]
*AAAAAAAA      AAA XX.        AAA XX.         AAA
 YEAR          JAN  1.        DEC 31.         ALL
 SUM           OCT  1.        DEC 31.         ALL
*
* ------------------------ STATIONS ---------------------------------
STATIONS
* STATION     LAT.  LONG.  ELEV.  FILENAME   DATA  UNITS  -START-  -STOP--
*  NAME      [DEG]  [DEG]  [M]               TYPE  [E/M]  MON DAY  MON DAY
*AAAAAAAAAA XXX.X  XXX.X  XXXXX. AAAAAAAAAA  XX.     A    AAA XX.  AAA XX.
*AUCKLAND   -36.6  174.5     4. WSWH63AV     2.      M    JAN  1.  DEC 31.
 KELBURN    -41.2  173.1     2. WSKL73AV     2.      M    JAN  1.  DEC 31.
*CHRIST     -43.3  172.3    30. WSCH64AV     2.      M    JAN  1.  DEC 31.
*INVERC     -46.6  168.2     0. WSIN73AV     2.      M    JAN  1.  DEC 31.
```

APPENDIX B: MEDIUM-SIZED 'BASE CASE' HOUSE PLANS

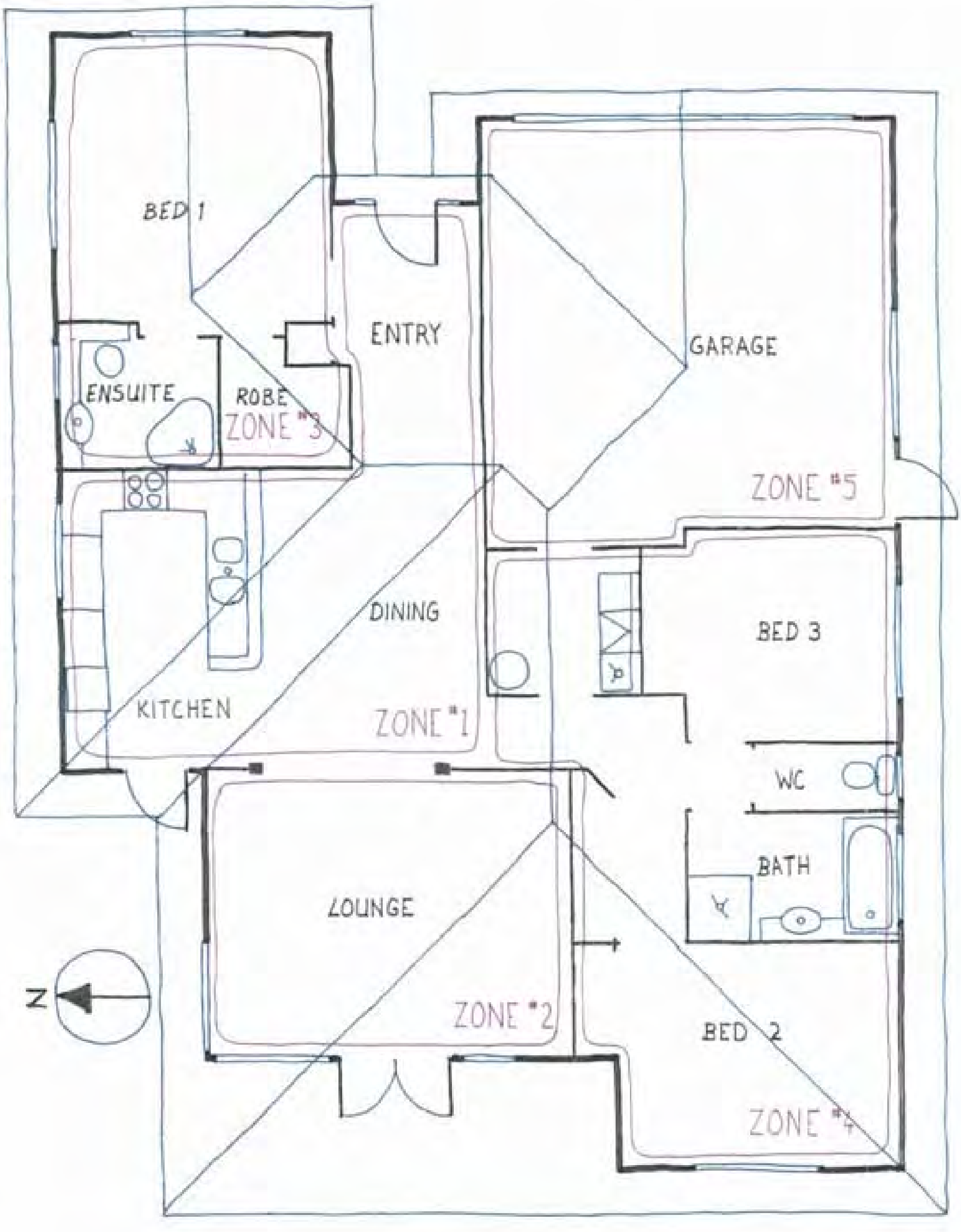

Figure 2: Schematic plan of medium sized house with total floor area 120 m^2 excluding garage. The lounge, dining and kitchen rooms are treated as the most important living areas. The house is modelled as having six different temperature zones (including the garage and roofspace).

APPENDIX C: LARGE AND SMALL 'BASE CASE' HOUSE PLANS

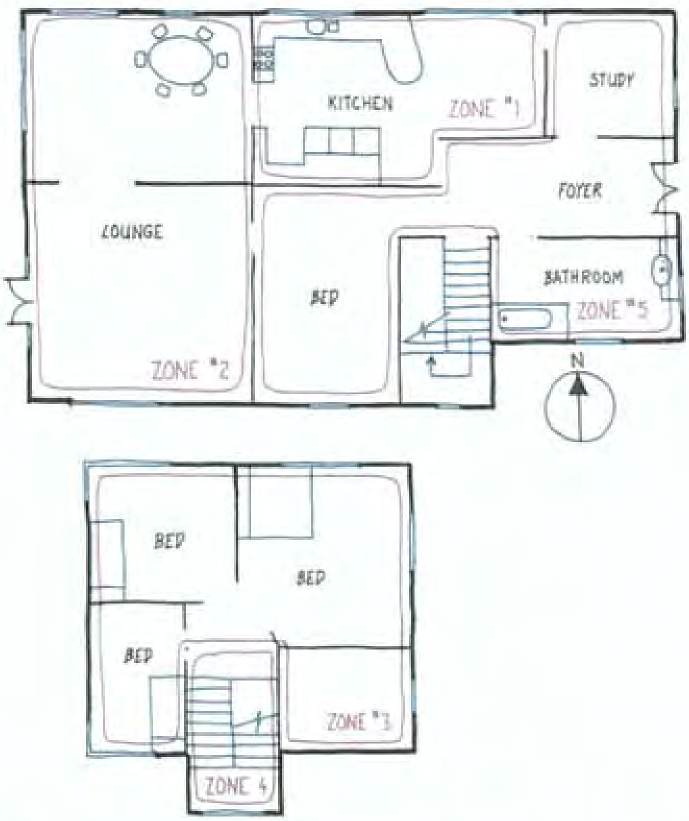

Figure 3: Schematic of the large house. The total floor area is 245 m^2. The lounge/dining, kitchen and upper storey bedroom were considered to be the most important rooms in terms of overheating. The house is modelled as having seven different temperature zones (including two roof spaces).

Figure 4: Schematic of the small house. The total floor area is 81 m^2. The lounge, kitchen and dining rooms are the most important living spaces in terms of overheating. The house is modelled as having seven different temperature zones (including the roof space).

APPENDIX D: RESULT TABLES FOR SMALL SIZED HOUSE

INTRODUCTION

For the purposes of this study, months which have 'significant' overheating – that is, they achieve more than two hours (i.e. more than 8%) of temperatures above 25 °C per day – will be highlighted. Highlighting is performed so that a quick visual representation of the impact (resulting from the physical- or climate-related variations) can be made for comparative purposes. The units are in 'percentage of time per day'. That is, 1% represents about 14 minutes, 5% equates to 1 hour 12 minutes (1.2 hours), 10% equates to 2 hours 24 minutes (2.4 hours) etc.

It should be noted that where the 'number of *months* to experience some or significant overheating' is counted, it is actually a tally of 'events' (i.e. an aggregate of the number of months for each of the rooms). Thus, if each room is overheated for every month, there are up to 21 overheating events possible, over the seven months examined.

A: SMALL HOUSE LOCATED IN WELLINGTON (BASE CASE)

Action

No action for 'base case'.

Analysis

- The warmest room (the dining) experiences 2.9 hours daily overheating, on average for February.
- Between the three spaces examined, there is *some* overheating occurring for a total of twelve months.
- *Significant* overheating is experienced by all three examined rooms for one month (February) of the summer period.

Table 10: Base case daily percentage of overheating

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	5	3	11	3	0	*Lounge*
	0	0	6	7	12	5	0	*Dining*
	0	0	6	7	10	3	0	*Bed 2*

B: 20% VENTILATION REDUCTION

Action

The ventilation rate in the Base Case house was reduced by 20%.

Analysis

Comparing the base case with Table 11 shows that:

- There is an increase in overheating.
- The warmest room (the dining) experiences now 3.8 hours daily overheating, on average, for February, compared to 2.9 hours previously (i.e. a 31% increase).
- The number of months which have *some* overheating has increased by two.
- The number of months which experience *significant* overheating has increased by two.

Table 11: Reducing ventilation by 20% (8 air changes per hour)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	7	5	13	5	1	*Lounge*
of time	0	0	8	9	16	7	1	*Dining*
uncomfortable	0	0	7	9	13	4	0	*Bed 2*

C: 50% VENTILATION REDUCTION

Action

The base case house ventilation levels were reduced by half, so that there are only five air changes per hour.

Analysis

Comparing the base case with Table 12 shows that:

- There is an increase in the number of overheating hours, overall.
- The warmest room experiences now 5.3 hours daily overheating, on average for February, compared to 2.9 hours previously (i.e. a 83% increase).
- The number of months which have *some* overheating has increased by two months.
- The number of months which experience *significant* overheating has increased by eight.

Table 12: Reducing ventilation by 50% (5 air changes per hour)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	12	10	19	9	2	*Lounge*
of time	0	0	15	16	22	11	3	*Dining*
uncomfortable	0	0	12	14	17	7	0	*Bed 2*

D: 100% VENTILATION REDUCTION

Action

The ventilation rate in the Base Case house was reduced by 100%, to model temperatures, which the building would get to if the house was shut up all day.

Analysis

Comparing the base case with Table 13 shows that:

- There is a massive increase in overheating.
- The warmest room experiences 9.8 hours daily overheating, on average, for February compared to only 3.8 hours previously (i.e. a 158% increase).
- The number of months that experience *some* overheating has extended to all those examined, and probably extends further.
- All the examined spaces suffer from *significant* overheating.

Table 13: Reducing ventilation by 100% (no air changes)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	4	24	28	32	15	3	*Lounge*
	13	17	14	39	41	27	12	*Dining*
	0	2	23	27	28	28	1	*Bed 2*

E: 20% INCREASE IN WINDOW AREAS

Action

All window areas were increased by 20%, to give a window/wall ratio of 0.35.

Analysis

Comparing the base case with Table 14 shows that:

- There is some increase in overheating.
- The warmest room experiences 3.6 hours daily overheating, on average, for February, compared to only 2.9 hours previously (i.e. a 24% increase).
- The number of months which experience *some* overheating has increased by two.
- The number of months which experience *significant* overheating has increased by two.

Table 14: Increasing all window areas by 20%

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	7	4	13	4	1	*Lounge*
	0	0	8	9	15	7	1	*Dining*
	0	0	7	9	13	4	0	*Bed 2*

F: REMOVE ALL CARPET

Action

All carpet was removed from the house, which had been previously carpeted throughout (excluding the garage).

Analysis

Comparing the base case with Table 15 shows that:

- There is a large decrease in the number of overheating hours.
- The warmest room experiences now only 1.4 hours daily overheating, on average, for February, compared to 2.9 hours previously (i.e. a 52% decrease).
- The number of months that the lounge experiences *some* overheating has reduced by one.
- No rooms experience *significant* overheating.

Table 15: Removing all carpet

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	1	1	3	1	0	*Lounge*
	0	0	1	1	6	1	0	*Dining*
	0	0	0	1	4	1	0	*Bed 2*

G: REMOVE ALL EAVES

Action

The base case house had all the overhangs removed from every side of the house.

Analysis

Comparing the base case with Table 16 shows that:

- There is a large increase in the number of overheating hours.
- The warmest room experiences now 4.1 hours daily overheating, on average for February, compared to 2.9 hours previously (i.e. a 41% increase).
- The number of months that experience *some* overheating has increased by two.
- The number of months which experience *significant* overheating hours has increased by four.

Table 16: Removing all eaves from house

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	10	8	16	5	1	*Lounge*
	0	0	10	11	17	7	1	*Dining*
	0	0	8	9	13	3	0	*Bed 2*

H: CHANGING ORIENTATION (+ 90°)

Action

The base case house was rotated by 90 degrees, clockwise, so the north becomes east, and east becomes south etc.

Analysis

Comparing the base case with

Table 17 shows that:

- There is a marked decrease in the number of overheating hours.
- The warmest room experiences now 1.4 hours daily overheating, on average for February, compared to 2.9 hours previously (i.e. a 52% decrease).
- The number of months that experience *some* overheating has remained constant, for the rooms examined.
- None of the rooms examined experience any *significant* overheating.

Table 17: Rotating house by 90 degrees clockwise

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	4	2	6	2	0	*Lounge*
	0	0	3	2	8	3	0	*Dining*
	0	0	1	1	4	2	0	*Bed 2*

I: CHANGING ORIENTATION (– 90°)

Action

The base case house was rotated by 90 degrees, anti-clockwise, so the north becomes west, and east becomes north etc.

Analysis

Comparing the base case with Table 18 shows that:

- There is very little change in the extent of overheating.
- The warmest room experiences now 2.6 hours daily overheating, on average for February, compared to 2.9 hours previously (i.e. a 10% decrease).
- The number of months which experience *some* overheating has remained the same.
- The number of months which have *significant* overheating has remained the same. However, Bed 2 now experiences no overheating during the entire summer period.

Table 18: Rotating house by 90 degrees anticlockwise

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	8	9	16	8	2	*Lounge*
	0	0	7	7	11	3	0	*Dining*
	0	0	1	1	2	0	0	*Bed 2*

J: INCREASING MASS

Action

The base case house mass was increased, by replacing the plasterboard and timber walls with concrete block walls. The roofing material was kept the same.

Analysis

Comparing the base case with Table 19 shows that:

- There is a marked decrease in the number of overheating hours.
- The warmest room experiences about an hour daily overheating, on average, for February, compared to 2.9 hours previously (i.e. an 66% decrease).
- The number of months that experience *some* overheating has reduced by five, over all the rooms examined.
- The number of months which experience *significant* overheating, has reduced to zero.

Table 19: Increasing amount of mass in structure

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	0	0	1	1	0	*Lounge*
of time	0	0	0	1	4	1	0	*Dining*
uncomfortable	0	0	0	1	1	0	0	*Bed 2*

K: REDUCE THE AMOUNT OF INSULATION

Action

The base case insulation levels (which are at current NZBC required levels) were altered to represent those of an uninsulated house.

Analysis

Comparing the base case with Table 20 shows that:

- There is a marked increase in the number of overheating hours, overall.
- The warmest room experiences now 4.3 hours daily overheating, on average for February, compared to 2.9 hours previously (i.e. a 48% increase).
- The number of months which have *some* overheating has increased by two.
- The number of months which experience *significant* overheating has increased by four.

Table 20: Base case with insulation removed

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	8	7	15	5	1	*Lounge*
of time	0	0	9	12	18	7	1	*Dining*
uncomfortable	0	0	11	11	15	5	0	*Bed 2*

L: INSTALL EXTERNAL SHADING DEVICES

Action

The base case house had external shading devices installed, which effectively reduced the incident light on the windows by 20%.

Analysis

Comparing the base case with Table 21 shows that:

- There is a small decrease in the number of overheating hours, overall.
- The warmest room experiences now 2.4 hours daily overheating, on average for February, compared to 2.9 hours previously (i.e. a 17% decrease).
- The number of months which have *some* overheating has stayed constant.
- The number of months which experience *significant* overheating has decreased by two.

Table 21: External shading devices installed to the windows

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	3	1	7	3	0	*Lounge*
	0	0	5	4	10	3	0	*Dining*
	0	0	3	4	8	2	0	*Bed 2*

M: RELOCATE TO AUCKLAND

Action

The base case house was transferred to Auckland, without any changes.

Analysis

Comparing the base case with Table 22 shows that:

- There is a dramatic increase in number overheating hours
- The dining room experiences now 7.4 hours daily overheating, on average, for February, compared to only 2.9 hours previously (i.e. a 155% increase).
- The number of months that experience *some* overheating has increased by six, for all the rooms examined.
- The number of months that experience *significant* overheating, has increased by nine.

Table 22: Transferring BASE CASE house to Auckland

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	3	10	35	33	23	3	*Lounge*
	0	3	11	31	31	22	3	*Dining*
	0	2	9	35	32	16	1	*Bed 2*

N: RELOCATING TO CHRISTCHURCH

Action

The base case house was transferred to Christchurch, without changing any other parameters.

Analysis

Comparing the base case with Table 23 shows that:

- There is a marked increase in the number of overheating hours
- The warmest room experiences now 3.8 hours daily overheating, on average for February, compared to 2.9 hours previously.
- The number of months that experience *some* overheating has increased by six, for all the rooms examined.
- The number of months that experience *significant* overheating has increased by seven over the rooms examined.

Table 23: Transferring BASE CASE house to Christchurch

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	5	13	11	9	6	1	*Lounge*
of time	1	6	14	16	12	9	1	*Dining*
uncomfortable	0	4	11	13	10	6	0	*Bed 2*

O: RELOCATING TO INVERCARGILL

Action

The base case house was transferred to Invercargill, without changing any other parameters.

Analysis

Comparing the base case with TABLE 24 shows that:

- There is a very little change in the number of overheating hours, overall.
- The warmest room experiences now 1.7 hours daily overheating, on average for February, compared to 2.9 hours previously (i.e. a 41% decrease).
- The number of months which have *some* overheating has increased by four.
- The number of months that experiences *significant* overheating has decreased by three months.

Table 24: Transferring BASE CASE house to Invercargill

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	1	3	2	6	2	1	*Lounge*
of time	0	1	4	4	7	4	1	*Dining*
uncomfortable	0	0	3	4	6	3	0	*Bed 2*

P: 'HIGH' CLIMATE CHANGE SCENARIO FOR 2030

Action

The base case house was subjected to the predicted climate resulting from the high-case (a rise in average temperature of 0.9° C) scenario for the year 2030.

Analysis

Comparing the base case with Table 25 shows that:

- There is a marked increase in the number of overheating hours, overall.
- The warmest room experiences now 4.1 hours daily overheating, on average for February, compared to 2.9 hours previously.
- The number of months which have *some* overheating have increased by two.
- The number of months which have *significant* overheating has increased by three.

Table 25: Base case with high climate change scenario for 2030

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	8	6	14	5	1	*Lounge*
	0	0	9	10	17	7	1	*Dining*
	0	0	8	10	14	5	0	*Bed 2*

Q: 'HIGH' CLIMATE CHANGE SCENARIO FOR 2070

Action

The base case house was subjected to the predicted climate resulting from the extreme-case (a rise in average temperature of 2.7°C) scenario for the year 2070.

Analysis

Comparing the base case with Table 26 shows that:

- There is a large increase in the number of overheating hours, overall.
- The dining room now experiences 6 hours daily overheating, on average for February, compared to 2.9 hours previously (i.e. a 107% increase).
- The number of months which have *some* overheating has increased by four.
- The number of months which experiences *significant* overheating is increased by eight.

Table 26: Base case with high climate change scenario for 2070

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	1	19	16	24	12	3	*Lounge*
	0	0	18	18	25	13	4	*Dining*
	0	0	16	16	20	8	1	*Bed 2*

R: 'MEDIUM' CLIMATE CHANGE SCENARIO FOR 2070

Action

The base case house was subjected to the predicted climate resulting from the medium-case (a rise in average temperature of 1.7 °C) scenario for the year 2070.

Analysis

Comparing the base case with Table 27 shows that:

- There is a marked increase in the number of overheating hours, overall.
- The warmest room experiences now 5 hours daily overheating, on average for February, compared to 2.9 hours previously (i.e. a 72% increase).
- The number of months which have *some* overheating has increased by two.
- All rooms experience *significant* overheating for an extra two months, over the assessed period.

Table 27: Base case with moderate climate change scenario for 2070

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	12	9	18	8	2	*Lounge*
of time	0	0	13	15	21	8	2	*Dining*
uncomfortable	0	0	11	12	16	7	0	*Bed 2*

S: 'MEDIUM' CLIMATE CHANGE SCENARIO FOR 2030

Action

The base case house was subjected to the predicted climate resulting from the high-case (a rise in average temperature of 0.5°C) scenario for the year 2030.

Analysis

Comparing the base case with Table 28 shows that:

- There is an increase in the number of overheating hours overall.
- The warmest room experiences now 3.4 hours daily overheating, on average for February, compared to 2.9 hours previously.
- The number of months which have *some* overheating has increased by two.
- The number of months which experience *significant* overheating has increased by two.

Table 28: Base case with moderate climate change scenario for 2030

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	6	5	10	4	1	*Lounge*
of time	0	0	8	9	14	6	1	*Dining*
uncomfortable	0	0	7	9	12	4	0	*Bed 2*

APPENDIX E: RESULT TABLES FOR MEDIUM-SIZED HOUSE

A: MEDIUM-SIZED HOUSE LOCATED IN WELLINGTON (BASE CASE)

Action

No action for 'Base Case'.

Analysis

Table 29 shows that:

- The warmest room (the lounge) experiences 3.8 hours daily overheating, on average, for February.
- Between the three spaces examined, there is *some* overheating occurring for a total of thirteen months.
- *Significant* overheating is contained to one room (the lounge), for three months of the summer period.

Table 29: Base case daily percentage of overheating

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	1	1	5	1	0	*Dining*
of time	0	0	9	10	16	7	1	*Lounge*
uncomfortable	0	0	2	1	6	1	0	*Zone #4*

B: 20% VENTILATION REDUCTION

Action

The ventilation rate in the Base Case house was reduced by 20%.

Analysis

Comparing the base case with Table 30 shows that:

- There is an increase in overheating by between 19% and 56%.
- The warmest room experiences now 4.6 hours daily overheating, on average, for February, compared to 3.8 hours previously (i.e. a 21% increase).
- There is no increase in the number of months that experience significant overheating.
- *Significant* overheating is still contained to one room (the lounge).

Table 30: Reducing ventilation by 20% (8 air changes per hour)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	0	1	6	1	0	*Dining*
of time	0	0	14	13	19	7	1	*Lounge*
uncomfortable	0	0	2	2	6	1	0	*Zone #4*

C: 50% VENTILATION REDUCTION

Action

The base case house ventilation levels were reduced by half, so that there is only five air changes per hour.

Analysis

Comparing the base case with Table 31 shows that:

- There is an increase in the number of overheating hours, overall.
- The warmest room experiences now 5.8 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 53% increase).
- The number of months which have *some* overheating has kept constant.
- The number of months which *experience* significant overheating has increased by three.

Table 31: Reducing ventilation by 50% (5 air changes per hour)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	5	4	10	2	0	*Dining*
of time	0	0	18	19	24	13	3	*Lounge*
uncomfortable	0	0	5	4	9	2	0	*Zone #4*

D: 100% VENTILATION REDUCTION

Action

The ventilation rate in the base case house was reduced by 100%, to model temperatures which the building would get to if the house was shut up all day.

Analysis

Comparing the base case with Table 32 shows that:

- There is a massive increase in overheating.
- The warmest room experiences 9.8 hours daily overheating, on average, for February compared to only 3.8 hours previously (i.e. a 158% increase).
- The number of months that experience *some* overheating has increased by (at least) six extra months.
- All the examined spaces suffer from *significant* overheating.

Table 32: Reducing ventilation by 100% (no air changes)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	4	24	28	32	15	3	*Dining*
of time	13	17	34	39	41	27	12	*Lounge*
uncomfortable	0	2	23	27	28	12	1	*Zone #4*

E: 20% INCREASE IN WINDOW AREAS

Action

All window areas were increased by 20%, to bring the window/wall ratio to just above 0.3.

Analysis

Comparing the base case with Table 33 shows that:

- There is only a small increase in overheating hours.
- The warmest room experiences 4.6 hours daily overheating, on average, for February, compared to only 3.8 hours previously (i.e. a 21% increase).
- The number of months that the lounge space experiences *some* overheating has remained the same.
- The lounge is still the only room to experience *significant* overheating.

Table 33: Increasing all window areas by 20%

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	2	2	6	1	0	*Dining*
of time	0	0	11	13	19	8	2	*Lounge*
uncomfortable	0	0	2	1	6	1	0	*Zone #4*

F: REMOVE ALL CARPET

Action

All carpet was removed from the house, which had been previously carpeted throughout (excluding the garage).

Analysis

Comparing the base case with Table 34 shows that:

- There is a large decrease in the number of overheating hours.
- The warmest room experiences now only 1.9 hours daily overheating, on average, for February, compared to 3.8 hours previously (i.e. a 50% decrease).
- The number of months that the lounge experiences *some* overheating has reduced by one.
- No rooms experience *significant* overheating.

Table 34: Removing all carpet

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	0	0	0	0	0	*Dining*
of time	0	0	3	2	8	2	0	*Lounge*
uncomfortable	0	0	0	0	0	0	0	*Zone #4*

G: REMOVE ALL EAVES

Action

The base case house had all the overhangs removed from every side of the house.

Analysis

Comparing the base case with Table 35 shows that:

- There is a increase in the number of overheating hours
- The warmest room experiences now 5.5 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 45% increase).
- The number of months that experience *some* overheating has increased by one, for all the rooms examined.
- The number of months which experience *significant* overheating hours in the lounge has increased by one.

Table 35: Removing all eaves around house

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	3	1	8	1	0	*Dining*
	0	1	17	19	23	10	2	*Lounge*
	0	0	3	1	6	1	0	*Zone #4*

H: REDUCING WEST GLAZING

Action

The base case's west wall glazing was reduced by 50%, so that the lounge wall/window area was similar to the other rooms analysed.

Analysis

Comparing the base case with Table 36 shows that:

- There is a marked decrease in the number of overheating hours.
- The warmest room experiences 2.2 hours of daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 42% decrease).
- The number of months that experience *some* overheating has reduced by one, for all the rooms examined.
- The lounge experiences *significant* overheating for only one month, instead of three.

Table 36: Reducing west glazing

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	1	1	4	1	0	*Dining*
	0	0	3	2	9	3	0	*Lounge*
	0	0	1	1	4	1	0	*Zone #4*

I: CHANGING ORIENTATION (+ 90°)

Action

The base case house was rotated by 90 degrees, clockwise, so the north becomes east, and east becomes south etc.

Analysis

Comparing the base case with Table 37 shows that:

- There is a marked decrease in the number of overheating hours.
- The warmest room experiences now 1.7 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 55% decrease).
- The number of months that experience *some* overheating has reduced by one, for all the rooms examined.
- The lounge does not experience any *significant* overheating.

Table 37: Rotating house by 90 degrees clockwise

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	1	1	3	1	0	*Dining*
of time	0	0	5	3	7	3	0	*Lounge*
uncomfortable	0	0	3	0	3	8	1	*Zone #4*

J: CHANGING ORIENTATION (- 90°)

Action

The base case house was rotated by 90 degrees, anti-clockwise, so the north becomes west, and east becomes north etc.

Analysis

Comparing the base case with Table 38 shows that:

- There is a decrease in the number of overheating hours.
- The warmest room experiences now 2.6 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 32% decrease).
- The number of months that experience *some* overheating has remained unchanged, for all the rooms examined.
- The lounge experiences *significant* overheating for two less months.

Table 38: Rotating house by 90 degrees anticlockwise

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	1	1	5	1	0	*Dining*
of time	0	0	8	8	11	3	1	*Lounge*
uncomfortable	0	0	1	1	3	1	0	*Zone #4*

K: INCREASING MASS

Action

The base case house mass was increased, by replacing the plasterboard and timber walls with concrete block walls. The roofing material was kept the same.

Analysis

Comparing the base case with Table 39 shows that:

- There is a decrease in the number of overheating hours.
- The warmest room experiences now 3.4 hours daily overheating, on average, for February, compared to 3.8 hours previously (i.e. an 11% decrease).
- The number of months that experience *some* overheating has reduced by three, for all the rooms examined.
- The number of months which experience *significant* overheating hours in the lounge is reduced by one.

Table 39: Increasing amount of mass in structure

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	0	1	3	1	0	*Dining*
of time	0	0	7	9	14	6	0	*Lounge*
uncomfortable	0	0	0	1	2	1	0	*Zone #4*

L: REDUCE THE AMOUNT OF INSULATION

Action

The base case insulation levels (which are at current NZBC required levels) were altered to represent those of an uninsulated house.

Analysis

Comparing the base case with Table 40 shows that:

- There is an increase in the number of overheating hours, overall.
- The warmest room experiences now 5.0 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 32% increase).
- The number of months which have *some* overheating has kept constant.
- The number of months which experience *significant* overheating has increased by two.

Table 40: Base case with extra insulation removed

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	7	6	11	3	0	*Dining*
of time	0	0	14	15	21	8	1	*Lounge*
uncomfortable	0	0	7	5	10	3	0	*Zone #4*

M: INSTALL EXTERNAL SHADING DEVICES

Action

The base case house had external shading devices installed, which effectively reduced the incident light on the windows by 20%.

Analysis

Comparing the base case with Table 41 shows that:

- There is a dramatic decrease in number of overheating hours, overall.
- The warmest room experiences now 3.4 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 6% decrease).
- The number of months which have *some* overheating have decreased by four.
- The number of months which experience *significant* overheating has decreased by two.

Table 41: External shading devices installed to the windows

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	0	0	4	1	0	*Dining*
of time	0	0	6	7	14	5	0	*Lounge*
uncomfortable	0	0	0	1	3	1	0	*Zone #4*

N: RELOCATE TO AUCKLAND

Action

The base case house was transferred to Auckland without any changes.

Analysis

Comparing the base case with Table 42 shows that:

- There is a large increase in the number of overheating hours.
- The warmest room experiences now 8.4 hours daily overheating, on average, for February, compared to only 3.8 hours previously (i.e. a 121% increase).
- The number of months that experience *some* overheating has increased by two, for all the rooms examined.
- All rooms now experience *significant* overheating, instead of just the lounge.

Table 42: Transferring BASE CASE house to Auckland

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	2	20	17	13	0	*Dining*
of time	1	5	16	35	35	25	5	*Lounge*
uncomfortable	0	0	3	20	17	11	0	*Zone #4*

O: RELOCATING TO CHRISTCHURCH

Action

The base case house was transferred to Christchurch, without changing any other parameters.

Analysis

Comparing the base case with Table 43 shows that:

- There is a marked increase in the number of overheating hours.
- The warmest room experiences now 3.6 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 5% decrease).
- The number of months that experience *some* overheating has increased, for all the rooms examined.
- The lounge experiences *significant* overheating for an extra month.
- The month with the greatest amount of overheating is January, shifted from February.

Table 43: Transferring BASE CASE house to Christchurch

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	2	6	7	4	3	0	*Dining*
of time	1	6	17	20	15	10	2	*Lounge*
uncomfortable	0	2	6	7	4	3	0	*Zone #4*

P: RELOCATING TO INVERCARGILL

Action

The base case house was transferred to Invercargill, without changing any other parameters.

Analysis

Comparing the base case with Table 44 shows that:

- There is a marked decrease in the number of overheating hours.
- The warmest room experiences now 2.4 hours daily overheating, on average for February, compared to 3.8 hours previously.
- The number of months which have *some* overheating has increased.
- The lounge experiences *significant* overheating for only one month, instead of three.

Table 44: Transferring BASE CASE house to Invercargill

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	2	1	4	1	0	*Dining*
of time	0	1	6	7	10	7	1	*Lounge*
uncomfortable	0	0	2	1	4	1	0	*Zone #4*

Q: 'HIGH' CLIMATE CHANGE SCENARIO FOR 2030

Action

The base case house was subjected to the predicted climate resulting from the high-case (a rise in average temperature of 0.9°C) scenario for the year 2030.

Analysis

Comparing the base case with Table 45 shows that:

- There is a marked increase in the number of overheating hours overall.
- The warmest room experiences now 5.0 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 32% increase).
- The number of months which have *some* overheating has stayed constant.
- There is no change in the number of months which have *significant* overheating.

Table 45: Base case with high climate change scenario for 2030

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	3	2	8	2	0	*Dining*
of time	0	0	13	14	21	8	2	*Lounge*
uncomfortable	0	0	3	2	7	2	0	*Zone #4*

R: 'HIGH' CLIMATE CHANGE SCENARIO FOR 2070

Action

The base case house was subjected to the predicted climate resulting from the extreme-case (a rise in average temperature of 2.7°C) scenario for the year 2070.

Analysis

Comparing the base case with Table 46 shows that:

- There is a large increase in the number of overheating hours overall.
- The warmest room experiences now 6.7 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 76% increase).
- The number of months which have *some* overheating has increased by one.
- The lounge experiences *significant* overheating for one extra month, with the dining and bedrooms experiencing an extra two and three months significant overheating respectively.

Table 46: Base case with high climate change scenario for 2070

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	9	8	14	4	0	*Dining*
of time	0	2	23	23	28	16	5	*Lounge*
uncomfortable	0	0	10	9	13	4	0	*Zone #4*

S: 'MEDIUM' CLIMATE CHANGE SCENARIO FOR 2070

Action

The base case house was subjected to the predicted climate resulting from the medium-change (a rise in average temperature of 1.7°C) scenario for the year 2070.

Analysis

Comparing the base case with Table 47 shows that:

- There is a marked increase in the number of overheating hours overall.
- The warmest room experiences now 5.7 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 50% increase).
- The number of months which have *some* overheating has kept constant.
- All rooms experience *significant* overheating for one extra month, over the assessed period.

Table 47: Base case with moderate climate change scenario for 2070

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	6	4	10	3	0	*Dining*
of time	0	0	17	17	24	12	3	*Lounge*
uncomfortable	0	0	6	5	10	3	0	*Zone #4*

T: 'MEDIUM' CLIMATE CHANGE SCENARIO FOR 2030

Action

The base case house was subjected to the predicted climate resulting from the medium-change (a rise in average temperature of 0.5°C) scenario for the year 2030.

Analysis

Comparing the base case with Table 48 shows that:

- There is an increase in the number of overheating hours overall.
- The warmest room experiences now 4.3 hours daily overheating, on average for February, compared to 3.8 hours previously (i.e. a 13% increase).
- The number of months which have *some* overheating has stayed constant.
- The number of months which experience *significant* overheating are kept constant.

Table 48: Base case with moderate climate change scenario for 2030

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	2	1	7	1	0	*Dining*
of time	0	0	12	13	18	8	1	*Lounge*
uncomfortable	0	0	2	2	6	1	0	*Zone #4*

APPENDIX F: RESULT TABLES FOR LARGE SIZED HOUSE

A: LARGE SIZED HOUSE LOCATED IN WELLINGTON (BASE CASE)

Action

No action for 'base case'.

Analysis

Table 49 shows that:

- The warmest room (the lounge) experiences 2.2 hours daily overheating, on average, for February.
- Between the three spaces examined, there is *some* overheating occurring for a total of twelve months.
- *Significant* overheating is contained to one room (the lounge) for one summer month.

Table 49: Base case daily percentage of overheating

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	2	1	5	2	0	*Kitchen*
	0	0	4	3	9	2	0	*Lounge*
	0	0	4	2	8	3	0	*Zone #3*

B: 20% VENTILATION REDUCTION

Action

The ventilation rate in the base case house was reduced by 20%.

Analysis

Comparing the base case with Table 50 shows that:

- There is a slight increase in overheating experienced in the rooms monitored.
- The warmest room experiences an average of 2.6 hours daily overheating for February, compared to 2.2 hours previously (i.e. a 18% increase).
- There is no increase in the number of months that experience *some* overheating.
- *Significant* overheating now occurs in two rooms during the month of February.

Table 50: Reducing ventilation by 20% (8 air changes per hour)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	2	1	6	2	0	*Kitchen*
	0	0	6	6	11	4	0	*Lounge*
	0	0	5	4	10	3	0	*Zone #3*

C: 50% VENTILATION REDUCTION

Action

The base case house ventilation levels were reduced by half, so that there are only five air changes per hour.

Analysis

Comparing the base case with Table 51 shows that:

- There is an increase in the number of overheating hours.
- The warmest room experiences now 4.1 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 86% increase).
- The number of months which have *some* overheating has increased by three.
- The number of months which experience *significant* overheating has increased by six.

Table 51: Reducing ventilation by 50% (5 air changes per hour)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	4	3	9	3	1	*Kitchen*
of time	0	0	10	12	17	7	1	*Lounge*
uncomfortable	0	0	9	9	14	5	1	*Zone #3*

D: 100% VENTILATION REDUCTION

Action

The ventilation rate in the base case house was reduced by 100%, to model temperatures which the building would get to if the house was shut up all day.

Analysis

Comparing the base case with Table 52 shows that:

- There is a massive increase in overheating.
- The warmest room experiences 9.8 hours daily overheating, on average for February, compared to only 3.8 hours previously (i.e. a 158% increase).
- The number of months that experience *some* overheating has extended to all those examined, and probably extends further.
- All the examined spaces suffer from *significant* overheating.

Table 52: Reducing ventilation by 100% (no air changes)

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	4	24	28	32	15	3	*Kitchen*
of time	13	17	14	39	41	27	12	*Lounge*
uncomfortable	0	2	23	27	28	28	1	*Zone #3*

E: 20% INCREASE IN WINDOW AREAS

Action

All window areas were increased by 20%, to give a window/wall ratio of 0.32.

Analysis

Comparing the base case with Table 53 shows that:

- There is a small increase in overheating hours.
- The warmest room experiences 2.6 hours daily overheating, on average for February, compared to only 2.2 hours previously (i.e. a 18% increase).
- The number of months that the lounge space experiences *some* overheating has remained the same.
- Both the lounge and bedrooms now experience *significant* overheating, with the number of months which experience overheating increasing by two.

Table 53: Increasing all window areas by 20%

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	2	1	6	2	0	*Kitchen*
of time	0	0	9	6	11	3	0	*Lounge*
uncomfortable	0	0	4	3	9	3	0	*Zone #3*

F: REMOVE ALL CARPET

Action

All carpet was removed from the house, which had been previously carpeted throughout (excluding the garage).

Analysis

Comparing the base case with Table 54 shows that:

- There is a large decrease in the number of overheating hours.
- The lounge experiences now only 1.4 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 36% decrease).
- The number of months that the lounge experiences *some* overheating has reduced by five.
- No rooms experience *significant* overheating.

Table 54: Removing all carpet

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	0	0	0	0	0	*Kitchen*
of time	0	0	0	1	3	1	0	*Lounge*
uncomfortable	0	0	3	2	8	2	0	*Zone #3*

G: REMOVE ALL EAVES

Action

The base case house had all the overhangs removed from every side of the house.

Analysis

Comparing the base case with Table 55 shows that:

- There is a increase in the number of overheating hours.
- The warmest room experiences now 2.6 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 18% increase).
- The number of months that experience *some* overheating has remained constant, for all the rooms examined.
- The number of months which experience *significant* overheating has increased by two.

Table 55: Removing all eaves around house

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	3	2	9	2	0	*Kitchen*
of time	0	0	6	6	11	3	0	*Lounge*
uncomfortable	0	0	5	3	9	3	0	*Zone #3*

H: REDUCING WEST GLAZING

Action

The base case's west wall glazing was reduced by 50%, so that the lounge wall/window area was similar to the other rooms analysed.

Analysis

Comparing the base case with
Table 56 shows that:

- There is a similar number of overheating hours.
- The warmest room experiences 1.9 hours of daily overheating, on average for February.
- The number of months that experience *some* overheating has remained unchanged, for all the rooms examined.
- No significant overheating is experienced.

Table 56: Reducing west glazing

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	1	1	4	1	0	*Kitchen*
of time	0	0	2	1	7	2	0	*Lounge*
uncomfortable	0	0	3	2	8	2	0	*Zone #3*

I: CHANGING ORIENTATION (+ 90°)

Action

The base case house was rotated by 90 degrees, clockwise, so the north becomes east, and east becomes south etc.

Analysis

Comparing the base case with Table 57 shows that:

- There is a marked decrease in the number of overheating hours.
- The lounge experiences now 1.7 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 30% decrease).
- The number of months that experience *some* overheating has remained constant, for all the rooms examined.
- The lounge does not experience any *significant* overheating.

Table 57: Rotating house by 90 degrees clockwise

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	4	1	3	1	0	*Kitchen*
	0	0	2	1	7	2	0	*Lounge*
	0	0	4	2	8	2	0	*Zone #3*

J: CHANGING ORIENTATION (- 90°)

Action

The base case house was rotated by 90 degrees, anti-clockwise, so the north becomes west, and east becomes north etc.

Analysis

Comparing the base case with Table 58 shows that:

- There is a marked decrease in the number of overheating hours.
- The lounge experiences now 1.4 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 57% decrease).
- The number of months that experience *some* overheating has remained unchanged, for all the rooms examined.
- The lounge experiences only one month of *significant* overheating.

Table 58: Rotating house by 90 degrees anticlockwise

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage of time uncomfortable	0	0	4	3	8	2	0	*Kitchen*
	0	0	3	2	6	2	0	*Lounge*
	0	0	3	3	9	3	0	*Zone #3*

K: INCREASING MASS

Action

The base case house mass was increased, by replacing the plasterboard and timber walls with concrete block walls. The roofing material was kept the same.

Analysis

Comparing the base case with Table 59 shows that:

- There is a decrease in the number of overheating hours.
- The warmest room experiences now 1.4 hours daily overheating, on average, for February, compared to 2.2 hours previously (i.e. a 57% decrease).
- The number of months that experience *some* overheating has reduced by one, over all the rooms examined.
- The rooms experience no *significant* overheating.

Table 59: Increasing amount of mass in structure

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	0	1	2	1	0	*Kitchen*
of time	0	0	2	2	6	1	0	*Lounge*
uncomfortable	0	0	4	2	8	2	0	*Zone #3*

L: REDUCE THE AMOUNT OF INSULATION

Action

The base case insulation levels (which are at current NZBC required levels) were altered to represent those of an uninsulated house.

Analysis

Comparing the base case with Table 60 shows that:

- There is a marked increase in the number of overheating hours overall.
- The warmest room experiences now 2.9 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 24% increase).
- The number of months which have *some* overheating has kept constant.
- The number of months which experience *significant* overheating has increased by three.

Table 60: Base case with extra insulation removed

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	4	3	9	3	0	*Kitchen*
of time	0	0	8	7	12	4	0	*Lounge*
uncomfortable	0	0	8	10	15	4	0	*Zone #3*

M: INSTALL EXTERNAL SHADING DEVICES

Action

The base case house had external shading devices installed, which effectively reduced the incident light on the windows by 20%.

Analysis

Comparing the base case with Table 61 shows that:

- There is a marked decrease in number of overheating hours overall.
- The warmest room experiences now 1.9 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 32% decrease).
- The number of months which have *some* overheating remained constant.
- The rooms experience no *significant* overheating.

Table 61: External shading devices installed to the windows

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	1	1	3	1	0	*Kitchen*
of time	0	0	3	2	8	2	0	*Lounge*
uncomfortable	0	0	3	1	7	2	0	*Zone #3*

N: RELOCATE TO AUCKLAND

Action

The base case house was transferred to Auckland without any changes.

Analysis

Comparing the base case with Table 62 shows that:

- There is a large increase in the number of overheating hours.
- The warmest room experiences now 6 hours daily overheating, on average for February, compared to only 2.2 hours previously (i.e. 173 % increase).
- The number of months that experience *some* overheating has increased by five for all the rooms examined.
- The number of months that experience *significant* overheating has increased by eight.

Table 62: Transferring BASE CASE house to Auckland

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	2	10	19	14	1	*Kitchen*
of time	0	2	8	26	25	19	1	*Lounge*
uncomfortable	0	2	7	26	22	18	1	*Zone #3*

O: RELOCATING TO CHRISTCHURCH

Action

The base case house was transferred to Christchurch, without changing any other parameters.

Analysis

Comparing the base case with Table 63 shows that:

- There is a marked increase in the number of overheating hours.
- The warmest room experiences the same amount of daily overheating, on average for February. However, the warmest month is now January.
- The number of months that experience *some* overheating has increased by three.
- The number of months that experience *significant* overheating has increased by four.

Table 63: Transferring BASE CASE house to Christchurch

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	3	6	5	4	4	0	*Kitchen*
of time	0	4	11	12	9	5	0	*Lounge*
uncomfortable	0	5	11	11	7	5	0	*Zone #3*

P: RELOCATING TO INVERCARGILL

Action

The base case house was transferred to Invercargill, without changing any other parameters.

Analysis

Comparing the base case with Table 64 shows that:

- There is a marked decrease in the number of overheating hours.
- The warmest room experiences now 1.2 hours daily overheating, on average for February, compared to 2.2 hours previously.
- The number of months which have *some* overheating has remained constant.
- There are no *significant* overheating periods.

Table 64: Transferring BASE CASE house to Invercargill

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	2	1	4	1	0	*Kitchen*
of time	0	0	3	3	5	2	0	*Lounge*
uncomfortable	0	0	3	3	6	2	0	*Zone #3*

Q: 'HIGH' CLIMATE CHANGE SCENARIO FOR 2030

Action

The base case house was subjected to the predicted climate resulting from the high-case (a rise in average temperature of 0.9°C) scenario for the year 2030.

Analysis

Comparing the base case with Table 65 shows that:

- There is a small increase in the number of overheating hours overall.
- The warmest room experiences now 2.6 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 15% increase).
- The number of months which have *some* overheating have kept constant.
- *Significant* overheating occurs for one extra month.

Table 65: Base Case with high climate change scenario for 2030

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	3	2	8	3	0	*Kitchen*
of time	0	0	6	6	11	4	0	*Lounge*
uncomfortable	0	0	6	4	11	3	0	*Zone #3*

R: 'HIGH' CLIMATE CHANGE SCENARIO FOR 2070

Action

The base case house was subjected to the predicted climate resulting from the extreme-case (a rise in average temperature of 2.7°C) scenario for the year 2070.

Analysis

Comparing the base case with Table 66 shows that:

- There is a large increase in the number of overheating hours overall.
- The warmest room experiences 6 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 173% increase).
- The number of months which have *some* overheating has increased by three.
- The number of months which experience *significant* overheating has increased by seven.

Table 66: Base Case with high climate change scenario for 2070

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	9	8	14	6	1	*Kitchen*
of time	0	0	14	15	20	8	2	*Lounge*
uncomfortable	0	0	12	13	18	7	1	*Zone #3*

S: 'MEDIUM' CLIMATE CHANGE SCENARIO FOR 2070

Action

The base case house was subjected to the predicted climate resulting from the medium-case (a rise in average temperature of 1.7°C) scenario for the year 2070.

Analysis

Comparing the base case with Table 67 shows that:

- There is a marked increase in the number of overheating hours overall.
- The warmest room experiences 3.6 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 64% increase).
- The number of months which have *some* overheating has increased by three.
- The number of months that experience *significant* overheating has increased by five.

Table 67: Base Case with moderate climate change scenario for 2070

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	5	3	10	3	1	*Kitchen*
of time	0	0	10	11	15	6	1	*Lounge*
uncomfortable	0	0	9	8	14	4	1	*Zone #3*

T: 'MEDIUM' CLIMATE CHANGE SCENARIO FOR 2030

Action

The base case house was subjected to the predicted climate resulting from the medium-case (a rise in average temperature of 0.5°C) scenario for the year 2030.

Analysis

Comparing the base case with Table 68 shows that:

- There is an increase in number of overheating hours overall
- The warmest room experiences 2.6 hours daily overheating, on average for February, compared to 2.2 hours previously (i.e. a 18% increase).
- The number of months which have *some* overheating has kept constant.
- The number of months that experience *significant* overheating has increased by one.

Table 68: Base Case with moderate climate change scenario for 2030

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Room
Percentage	0	0	2	1	6	2	0	*Kitchen*
of time	0	0	6	6	11	3	0	*Lounge*
uncomfortable	0	0	5	4	10	3	0	*Zone #3*

APPENDIX G: THERMAL MASS LEVELS

Table 69: Effective thermal mass level, based on construction type (after Bassett et al, 1990)

Northerly ❐ floor finish	Walls	Ceiling	Effective Thermal mass level (M)
all slab (or tiles✣ over slab)	plasterboard	plasterboard	1.0
all slab (or tiles over slab)	plasterboard ▲	plasterboard	1.2
all slab (or tiles over slab)	masonry (exterior) † plasterboard (interior)	plasterboard	1.5
all slab (or tiles over slab)	masonry †	plasterboard	1.9
all slab (or tiles over slab)	masonry †	concrete	2.2
2/3 slab (or tiles over slab)⁂	plasterboard	plasterboard	0.8
2/3 slab (or tiles over slab) ⁂	plasterboard ▲	plasterboard	1.0
½ slab (or tiles over slab) ⁂	plasterboard	plasterboard	0.7
1/3 slab (or tiles over slab) ⁂	plasterboard	plasterboard	0.5
1/3 slab (or tiles over slab) ⁂	plasterboard ▲	plasterboard	0.7
timber	plasterboard	plasterboard	0.2
timber	plasterboard ▲	plasterboard	0.5
carpeted ❖	plasterboard	plasterboard	0.0
carpeted ❖	plasterboard ▲	plasterboard	0.4
carpeted ❖	masonry † plasterboard (interior)	plasterboard	1.0
carpeted ❖	masonry †	plasterboard	1.5
carpeted ❖	masonry †	concrete	2.0

❐ Effective thermal storage will be in areas, which receive direct sun in the summer. This will be in rooms with north, west or east-facing windows.

✣ Vinyl tiles or PVC sheet

❖ Including a carpeted slab floor, which is no more effective as thermal mass than a carpeted timber floor

⁂ Balance of floor surface finished in carpet or timber (including tiled timber)

† Externally insulated masonry walls

▲ With feature interior brick wall 1/3 house length on northerly facing rooms

Notes on Table 69

1. Slate, ceramic tiles, vinyl tiles or sheet flooring over a slab floor do not affect its effective thermal mass level. Cork floor tiles reduce the effective thermal mass level of a slab or timber floor by 0.1.

2. Carpet over a floor slab causes that portion of the slab to lose its effectiveness, and the carpeted portion is subtracted from the balance of the slab for use in the table above.

3. This table is based on the Los Alamos approach (Balcomb, 1983) and is not very sensitive to small changes in interior construction (Bassett et al, 1990). The effective heat capacity is calculated by summing the product of the areas of each interior surface with the effective heat capacity of its materials. To this, a factor is added for furniture. As stated in Bassett et al (1990), "*The heat capacity of floors...in rooms without significant solar gain is counted as zero, due to the difficulty of convection charging of floors. Heat capacities of elements receiving direct beam solar radiation were increased by 10% to account for more effective charging.*"

4. The effective thermal mass levels (M) are adapted from Bassett et al (1990). It is known that thermal mass in houses can become a liability due to its need for heating in the morning (when night-time temperatures are uncontrolled) to bring it up to a comfortable temperature. This has been taken into consideration in this summertime overheating study by starting the set-point temperature when the house is at its lowest temperature, that is, just before the sun rises, in summertime. For more information on effective heat capacities, Balcomb (1983) should be consulted.

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