

APPENDICES A – D

THE APPLICATION OF NATHERS SOFTWARE IN NORTHERN AUSTRALIAN CLIMATES

APPENDIX A: TOOLS USED

1.1 ACCUBATCH

The **AccuBatch utility** allows the user to run many simulations with a wide variety of occupant behaviour assumptions (including no heating and cooling) over several climates. The results are written to a file which is easily opened by Excel. Tony Isaacs Consulting developed this tool for the former Department of Climate Change and Energy Efficiency (DCCEE), and it is now maintained and distributed through CSIRO. This tool has been used for this project.

Using AccuBatch has several time saving and analysis benefits:

- It eliminates transcribing results,
- It allows free running mode to be invoked without the need for a separate simulation in the NatHERS tool,
- It can analyse the frequency distribution of temperatures in all zones – this would otherwise require the temperature file to be cut and paste into a spread sheet for each simulation,
- It can change occupant heating and cooling hours of use and thermostats to represent a more average condition and so give a better indication of actual energy savings,
- It allows solutions developed for a particular location to be tested across the various NatHERS reference locations in the same BCA climate zone for very little additional effort,
- It can automatically save hourly energy and temperature files for later analysis, and
- It can analyse the frequency distribution of heating and cooling loads to provide a peak load for the house or a particular room.

1.2 TICTOOL

Tony Isaacs Consulting (TIC) has also developed an extensive range of **free running temperature analysis spread sheets** which facilitate easy analysis of hourly temperature files. These were developed through other similar projects and through the TIC NatHERS assessor practice where they are used to offer extended rating services. The current 69 climate data files have been analysed to identify 17 different climate periods useful for the evaluation of temperatures under critical conditions:

- i) 1a Day of highest maximum temperature
- ii) 1b Day of highest average temperature put in 1a 1b etc.
- iii) 1c Day of lowest minimum temperature
- iv) 2a Day of lowest average temperature
- v) 2b 3 day period of highest average temperature
- vi) 2c 3 day period of lowest average temperature
- vii) 3a Largest increase in maximum over previous day
- viii) 3b Largest decrease in maximum over previous day
- ix) 4a Day of highest solar radiation
- x) 4b Day of lowest solar radiation
- xi) 4c Day of highest solar in 'summer' months DJF
- xii) 4d Day of lowest solar in 'summer' months DJF
- xiii) 4e Day of highest solar in 'winter' months MJJ
- xiv) 4f Day of lowest solar in 'winter' months MJJ
- xv) 5a Hot Sticky Day – high temperature and humidity
- xvi) 5b Windy cool day
- xvii) 5c Windy hot day

These spread sheets are used to illustrate the extent of change the various design strategies produce in internal temperatures under critical climatic conditions. They will be modified to report the extent of window opening and ceiling fan usage and to show the impact of air movement on comfort.

1.3 CHENATH AND THE ACCURATE SUSTAINABILITY TOOL

The Chenath engine is used as the benchmark in all three of the accredited NatHERS software tools: AccuRate Sustainability, BERSPro and FirstRate5. It is one of the best credentialed thermal simulation software tools in the world. Chenath has passed the BESTEST protocol (CSIRO, 2005), which is used internationally to ensure that thermal simulation tools correctly model heat flows, accurately predict energy loads (cooling and heating) and can model 'free running' (i.e. no air conditioning) temperatures (see Section 3.5.3). BESTEST found Chenath predictions were in the same range as the best house energy assessment programs in the world, such as the USA's Department of Energy's 'Energy Plus' and the UK's 'ESP-r' software engines.

AccuRate Sustainability (version 1.1.4.1) was the software tool used to determine the extent of modifications required to achieve regulatory compliance and was the latest version available at the time of undertaking the assessments. It should be noted at that time the BERSPro software had a bug which required all permanent openings to be treated as 'controlled openings'. This bug affected the zoning of house designs, where rooms connected to a large permanent opening needed to be combined into one zone e.g. a kitchen and an adjacent living area. However because air movement is critical to the performance of houses in hot climates, for this study all analysis of air speed, affected temperatures and window openings were performed using a pre-release version of the latest Chenath engine that addressed permanent opening. Consequently, the findings in this report will not be able to be reproduced exactly with the current NatHERS tools that are now aligned.

The predicted temperatures modelled by Chenath have been compared to a range of real houses and test cells in Australia, and have been found to replicate real temperature conditions very well. These comparisons with reality were at the heart of software development by CSIRO. The initial algorithms were developed and tested by constructing and monitoring a house on their Highett campus (Melbourne, Victoria) in the 1970's. While the testing and validation of the software engine to date generally means that the predictions of the engine should be accurate, the real house tests have been conducted on only a limited range of designs, including a range of three different designs in Darwin, but have not focussed specifically on house ventilation in tropical and hot climates. This project therefore focuses on explaining how the Chenath engine employs ventilation for house designs in these climates.

APPENDIX B: HOW THE CHENATH ENGINE MODELS THERMAL COMFORT

The Chenath engine was upgraded in response to industry and jurisdictional concerns regarding the inability of 1st generation NatHERS software to appropriately model the impact of air movement on thermal comfort. It is therefore important to explain the way Chenath models thermal comfort for 2nd generation NatHERS tools.

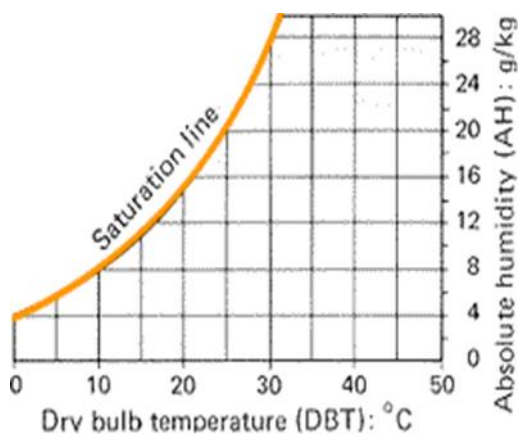
Houses are heated and cooled to maintain occupant comfort. Table 1 describes the various factors that can influence occupant comfort and how Chenath models these factors:

Table 1 Effect of various factors on thermal comfort and how Chenath models these factors

Factor	Effect on Comfort	Modelled in Chenath
Air temperature	Our bodies lose heat by contact with the air	The Chenath engine predicts internal air temperature
Temperature of surrounding objects, or radiant temperature	If objects are warmer than us they make us feel warmer	Chenath engine combines air temperature and radiant temperature into the 'environmental temperature' to better reflect human perception of comfort
Amount of moisture in the air or humidity	We lose heat by sweating. At higher humidity levels the amount of heat we can lose through the evaporation of sweat is reduced. However, a large range of humidity provides adequate heat loss and discomfort is generally only felt at high humidity when combined with higher air temperatures.	Chenath engine will turn on cooling if the air becomes too humid, typically at a humidity over 50% if the air is at 30 degrees. If there is air movement provided by opening windows or ceiling fans Chenath will not cool to reduce humidity until the humidity exceeds 90%.
Air movement	With higher air speeds the body's ability to lose heat by evaporation of sweat is increased	Chenath engine calculates the wind speed through each room of the house if windows are opened. It then calculates the additional comfort this air movement provides as a reduction in perceived temperature. Effects of ceiling fans are also allowed for.
Activity and clothing	As the body is more active it generates heat and the amount of clothes affect the body's ability to lose heat by providing insulation e.g. with appropriate clothing it can feel hot while skiing at sub zero temperatures.	Thermostat temperatures are set with household activity levels and clothing in mind. Bedroom heating temperatures overnight are set to lower levels because bedding provides insulation and the lower metabolic rate during sleep means a lower temperature is comfortable.

Factor	Effect on Comfort	Modelled in Chenath
Personal preference	Each body's ability to lose or gain heat from the environment is different, and each person has a preference for the rate of heat loss to the environment they consider comfortable. The ranges of conditions which will keep most people comfortable have been evaluated in many studies.	Those temperatures which satisfy the greatest proportion of people have been used as thermostat settings. These take into account adaptation to climate as discussed below. Note that cooling is switched on when it is 2.5 degrees above the thermostat setting i.e. when it becomes uncomfortable.
Acclimatisation	Simply put, if you live in a hot place you will feel comfortable at higher temperatures than a person who lives in a cold place. This is thought to be in part because people wear lighter clothes in warmer climates and in part human adaptation.	Cooling thermostat temperatures are set according to the comfort conditions relevant to the climate. This is based on Australian studies of acclimatisation.

Figure 1 Occupant comfort with humidity and temperature



The range of temperatures and humidity's that will produce thermal comfort can also be shown on a psychrometric chart, as shown in Figure 1. This chart plots temperature on the horizontal axis against the moisture content of the air on the vertical axis. The ability of air to hold moisture depends on its temperature. Warmer air can contain much higher levels of moisture than cold air. Once the moisture content gets high enough it starts to rain, so there is an upper limit on how much moisture air at a certain temperature can contain. Because of this phenomenon there is a curved line on the psychrometric chart that indicates the maximum moisture content of air for that temperature. This is also known as the saturation line.

Section 2.2. explains how the Chenath engine responds to humidity in more detail.

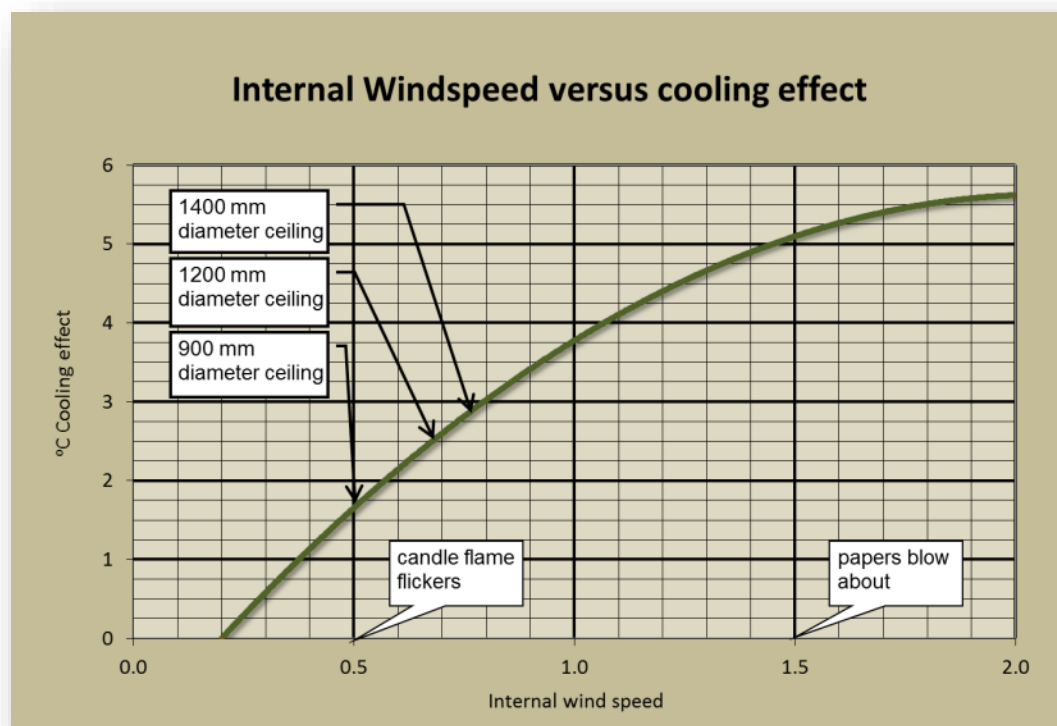
1.4 FACTORS AFFECTING INTERNAL AIR MOVEMENT

Air movement can allow people to tolerate higher temperature and humidity with less discomfort. Houses which can promote better air movement through windows and other openings, as well as fans, will be able to reduce the amount of time where air conditioning is needed to provide comfort.

Ceiling fans are available in Chenath which can artificially provide air movement and make conditions comfortable when temperatures are higher outside. The way in which Chenath models this air movement is based on research undertaken by Dr. Steven Szokolay, one of Australia's leading experts in the thermal performance of tropical housing design.

The comfort effects of air movement as modelled in AccuRate are shown in Figure 2.

Figure 1 Air movement and perceived comfort in Chenath



This comfort effect due to air movement is allowed for in the calculation in Chenath and it affects the way it activates air conditioning. Chenath checks at each hour whether temperatures could be made comfortable simply by opening windows. It considers comfortable conditions to be no more than the neutral temperature plus 2.5°C, that is, when the occupants start to feel some discomfort. If the room can be made more comfortable by opening windows no air conditioning will be used. If windows are opened in 'free-running' (non-conditioned) mode Chenath assumes they will be left open for a minimum of 3 hours to reflect the fact that occupants will not go through the assessment of comfort as rigorously as a computer model.

Chenath will also turn on air conditioning if the air is too humid, generally at around 50% Relative Humidity. If air movement is provided by opening windows this is relaxed to 90%. If Chenath is correctly predicting internal air movement this comfort effect should substantially reduce cooling loads in well-ventilated houses.

Unless otherwise stated, the temperatures referred to in this paper refer to Chenath's 'environmental temperature', which is the combination of air and radiant temperatures. The environment temperature is

reduced by the perceived temperature benefit as a result of air movement. The extent of the improvement in occupant comfort will depend on the effectiveness of the design in generating potential internal air movement. This can depend on several factors, as shown in Table 2.

Table 2 Factors influencing air movement through houses and how these are modelled by Chenath

Factor	Influence on air movement
Direction and Speed of external wind	The higher the external wind speed the higher the internal wind speed if the house has openings facing the wind. If openings are also on the opposite side internal air speeds are higher.
Location and size of openings	Larger openings generally allow greater air movement, however, the distribution around the building also has an effect. Smaller openings on the side facing the wind and larger openings on the opposite side will promote greater air movement. Openings only on adjacent sides will generally provide less cross ventilation. The nature of the opening e.g. awning vs sliding vs casement, determines the net openable area. For example, the opened sash in an awning window blocks some air flow. This is modelled by Chenath.
Ventilation path through the building	Each time the wind goes through an opening before exiting the house the internal wind speed is reduced. Houses which are 1 room deep facing the prevailing cooling wind will have higher internal wind speeds than houses with complex plans. Houses with larger openings between rooms will allow greater air movement. This is modelled by Chenath.

1.4.1 CEILING FANS

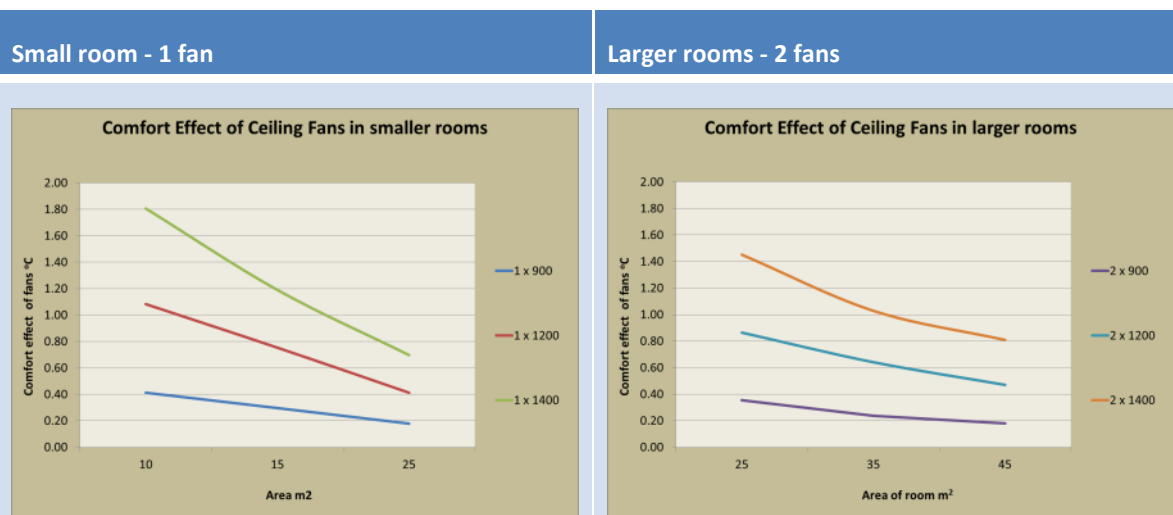
Ceiling fans are assumed to provide air speeds and comfort effects as shown in Table 3:

Table 3 Impact of ceiling fans assumed by Chenath when directly below the fan

Fan size (mm)	Air speed (m/second)	Comfort effect (°C)
900	0.5	1.7
1200	0.66	2.4
1400	0.77	2.9

The air speed is assumed to be fully effective over twice the swept area of the fan. If a room is larger than this area, the impact of the ceiling fan is reduced according to the proportion of the room area and the effective swept area of the fan. Table 4 shows how the comfort effect of a fan varies with room area and number of fans.

Table 4 Impact of ceiling fan size and number of fans on comfort in rooms of various sizes

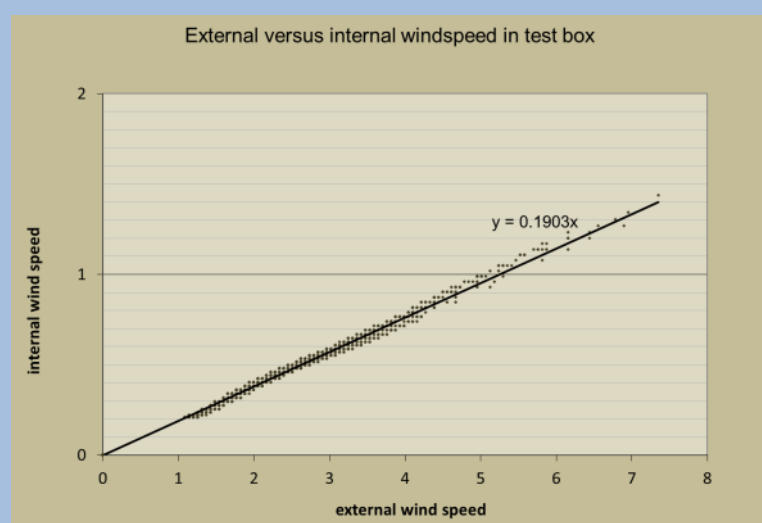


1.4.2 PREDICTING INTERNAL AIR SPEED

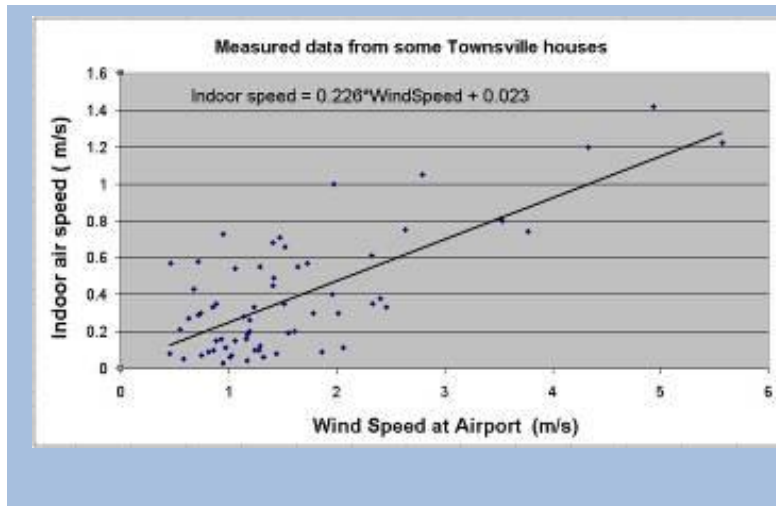
In an earlier report for the NT Government (Isaacs, 2006) the air speed through a simple test box was evaluated. The test box was a 5m x 5m square with equal sized openings on the north and south. The internal air speed in a box such as this will have a very simple relationship to external wind speed. The graphs below show that the internal wind speed is around 20% of external wind speed for the east/west facing 90% openable case window and appears to at least be an indicative figure. Measurements of a real house by Prof. Dick Ainslie in Townsville showed this to be in the average range of observed internal wind speeds shown in second graph.

Figure 2 Comparison of Chenath predicted wind speeds in a simple test box compared to actual recorded internal wind speeds for houses in Townsville

Simulated internal versus external windspeed: test box



Monitored internal versus external windspeed: real house



Source: NT Government report by Isaacs and personal communication Angelo Delsante CSIRO

1.5 CHENATH SPACE CONDITIONING PROCEDURE

The following section is based on the AccuRate Sustainability help file.

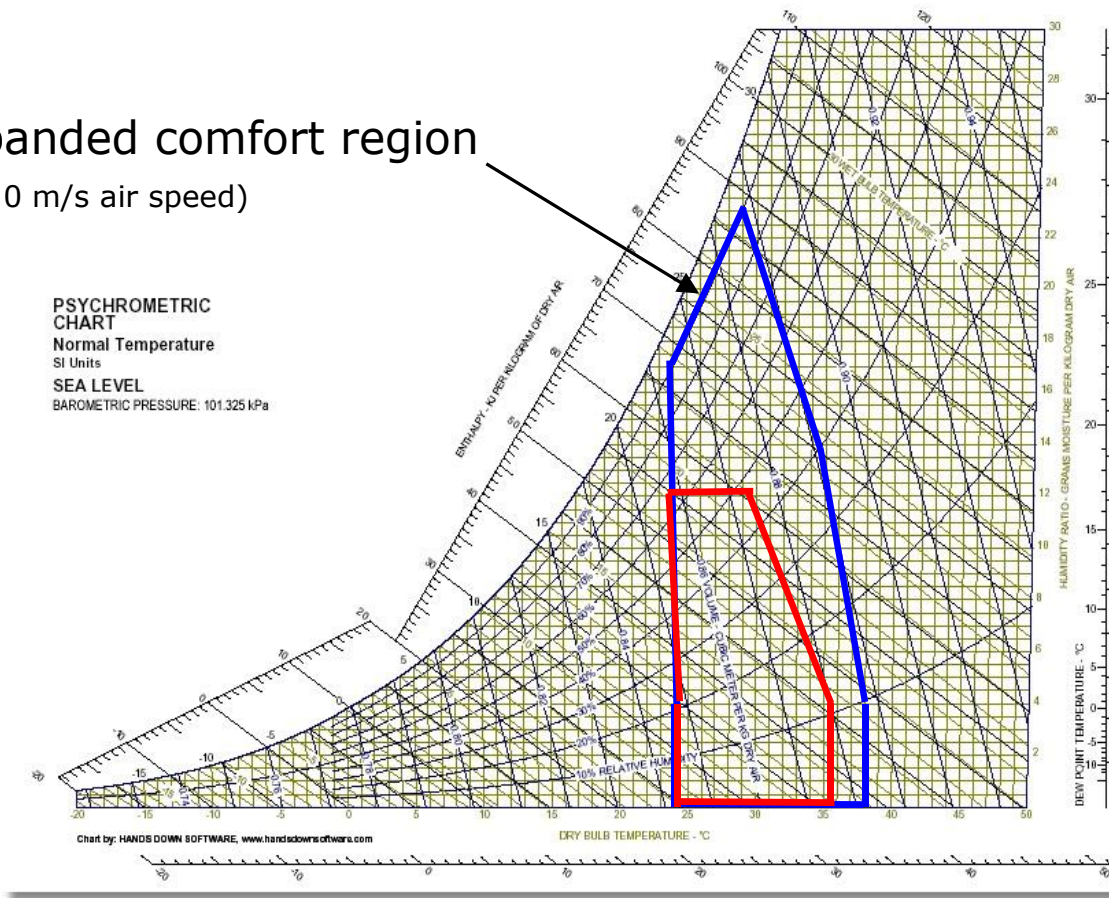
In zones designed as 'Living', 'Living/Kitchen', and 'Other', heating and cooling are available from 0700 to 2400. In zones designed as 'Bedroom', heating and cooling are available from 1600 to 0900. Although heating and cooling are available between these times, they are not invoked unless required, as described below.

Heating is applied if the zone temperature at the end of the hour without heating is below the prescribed heating thermostat setting in Chenath. Additional heating is supplied so that the temperature for the particular zone at the end of the hour equals the thermostat setting.

Cooling is invoked in a more complicated way. The boundaries of the comfort region on the psychrometric chart are shown in

Figure 4 Chenath comfort zone with and without air movement

Expanded comfort region (at 1.0 m/s air speed)



The psychrometric chart shows that when air movement is provided the range of conditions that can be considered comfortable increases significantly i.e. the expanded blue area (and the red area is for no air movement). This allows not only higher temperatures to be tolerated but also much higher humidity to be tolerated as well.

Guide to figure

Top	Absolute moisture content = 12 g/kg
Bottom	Absolute moisture content = 0 g/kg (normally it is 4 g/kg but Chenath will not invoke cooling merely because the air is too dry)
Right	Effective air temperature allowing for air movement (ET*) line passing through the point corresponding to (Cooling Thermostat + 2.5) degrees and 50% relative humidity (RH)
Left	Not relevant

Notes

1. If at the end of the hour the zone temperature without cooling or ventilation is greater than a trigger temperature and greater than the outdoor air temperature -4°C , ventilation is switched on (i.e. windows and other controlled openings in this zone are opened). The trigger temperature is generally 0.5°C below the cooling thermostat temperature, but with an upper limit of 26°C .
2. The new zone condition (i.e. temperature and moisture content) is calculated and an indoor air speed is estimated. If the indoor air speed is above 0.2 m/s, the comfort region described above is extended in

two ways:

- i. the top boundary becomes the 90% RH line, and
- ii. the right boundary becomes an ET* line passing through the point corresponding to (Cooling Thermostat + 2.5 + dT) and 50% RH, where:
 - dT (Impact of temperature of air movement) = $6 \times (v - 0.2) - 1.6 \times (v - 0.2)^2$, and
 - v is the indoor air speed (m/s). An upper limit of 1.5 m/s is imposed on the indoor air speed.

If the zone condition with natural ventilation is within the extended comfort region, cooling is not invoked.

3. If the zone condition with natural ventilation remains outside the extended comfort region, and ceiling fans are available in that zone, the indoor air speed calculated from natural ventilation is replaced by an indoor air speed appropriate to the number of fans and zone floor area (based on the cooling benefit of the ceiling fans). If the zone condition with ceiling fans and natural ventilation is within the extended comfort region, cooling is not invoked.
4. If the zone condition with ceiling fans and natural ventilation is still outside the extended comfort region, the zone openings are closed, ceiling fans (if any) are switched off, and sufficient cooling is applied so that the zone temperature at the end of the hour is the cooling thermostat setting.

Note that the cooling calculations include a generic model of a residential air conditioner cooling coil, so that dehumidification occurs when cooling is invoked i.e. moisture condensing due to the cooling of the air. The energy extracted from the air to reduce its humidity is reported as the latent cooling energy.

APPENDIX C: WIND SPEED AND DIRECTION ANALYSIS FOR SELECTED CLIMATES

Wind directions which have both wind speeds >3 m/s (measured at weather station – may be as low as 1 m/s through house) and temperatures between 20 and 30°C will provide the best cross ventilation and should have windows with the largest openable areas on this orientation.

The wind speeds and directions for the locations used in this study are shown in Figure 5 to 10.

Figure 5 Darwin wind analysis (NatHERS climate file 1)

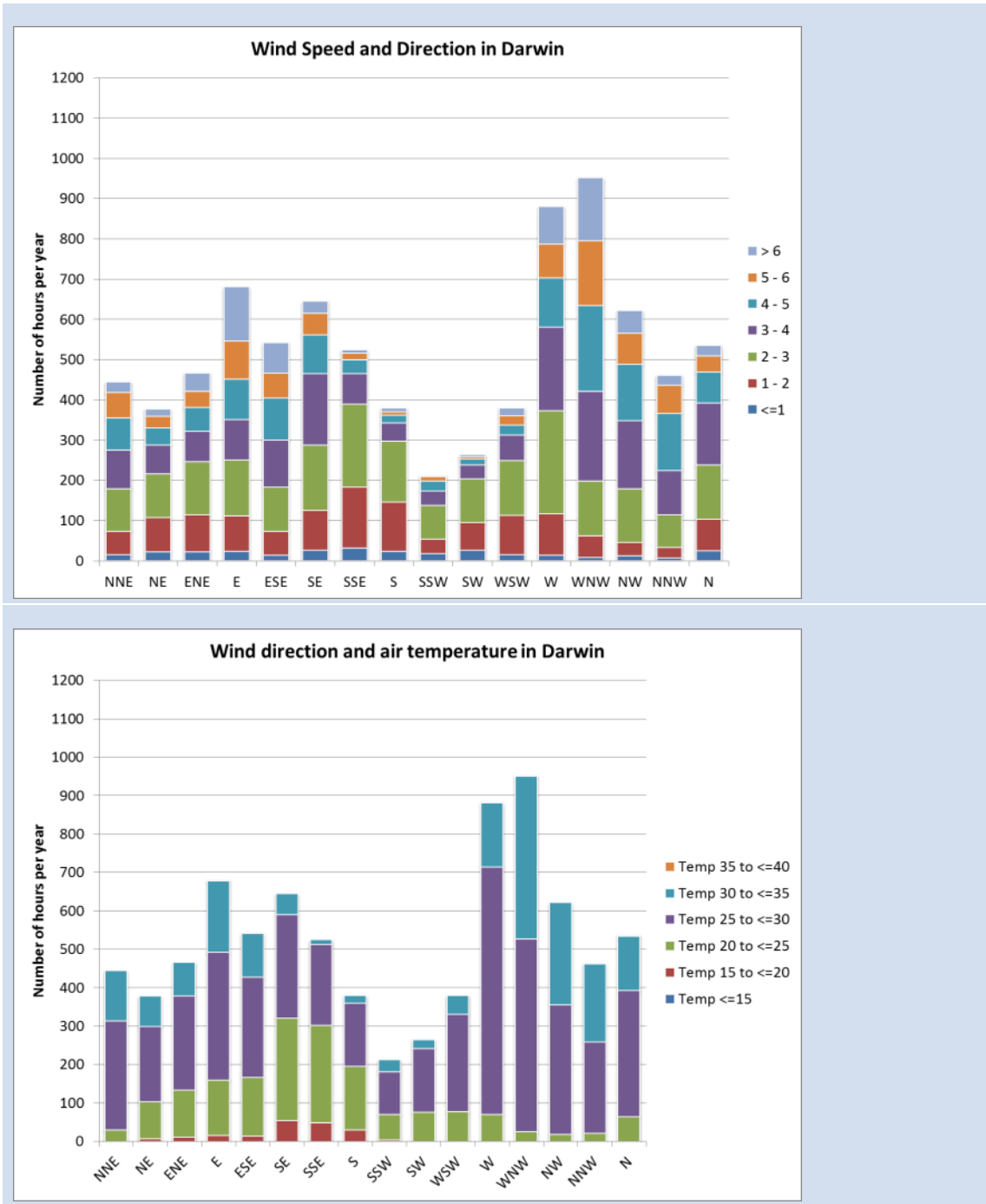


Figure 6 Townsville wind analysis (NatHERS climate file 5)

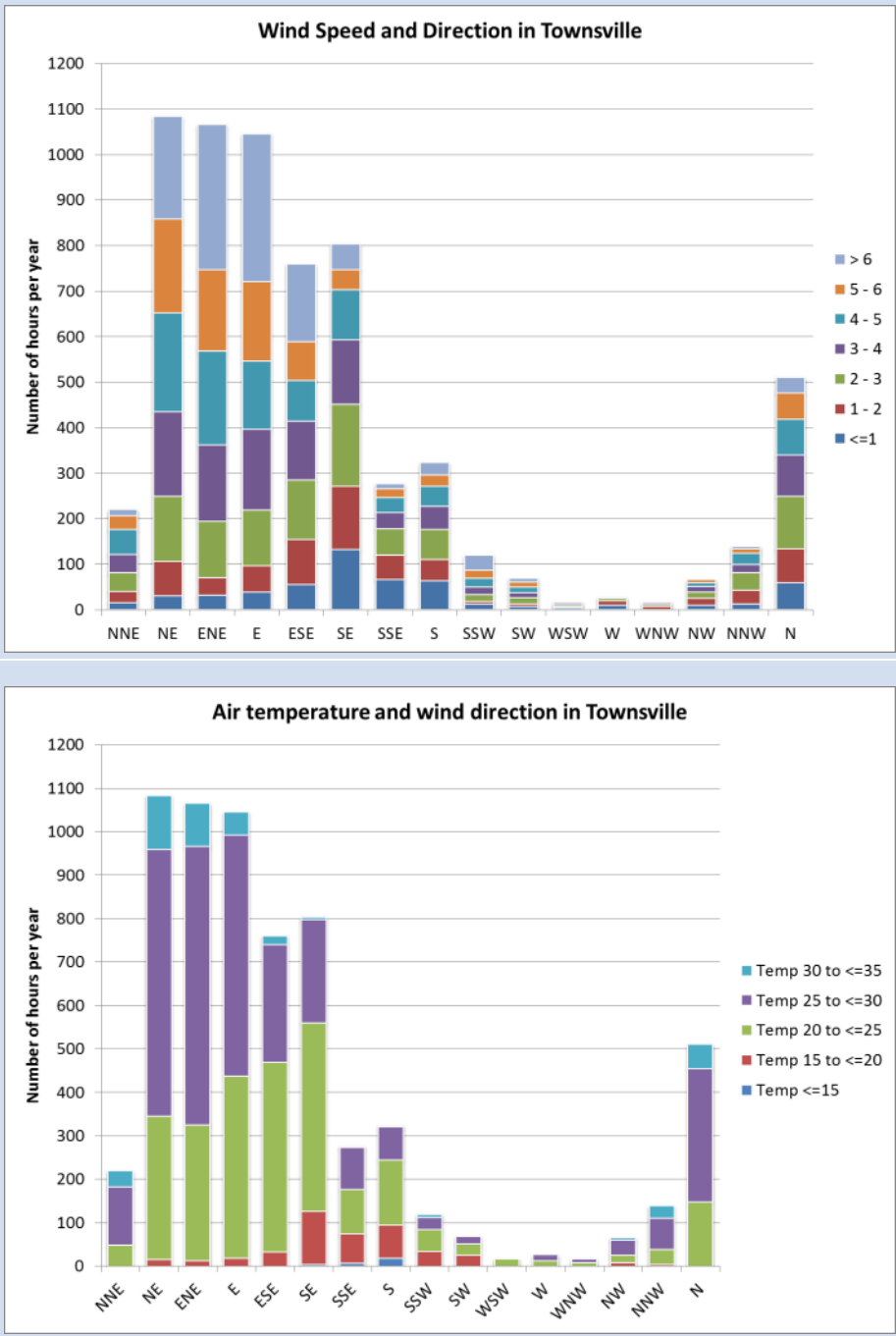


Figure 7 Brisbane wind analysis (NatHERS climate file 10)

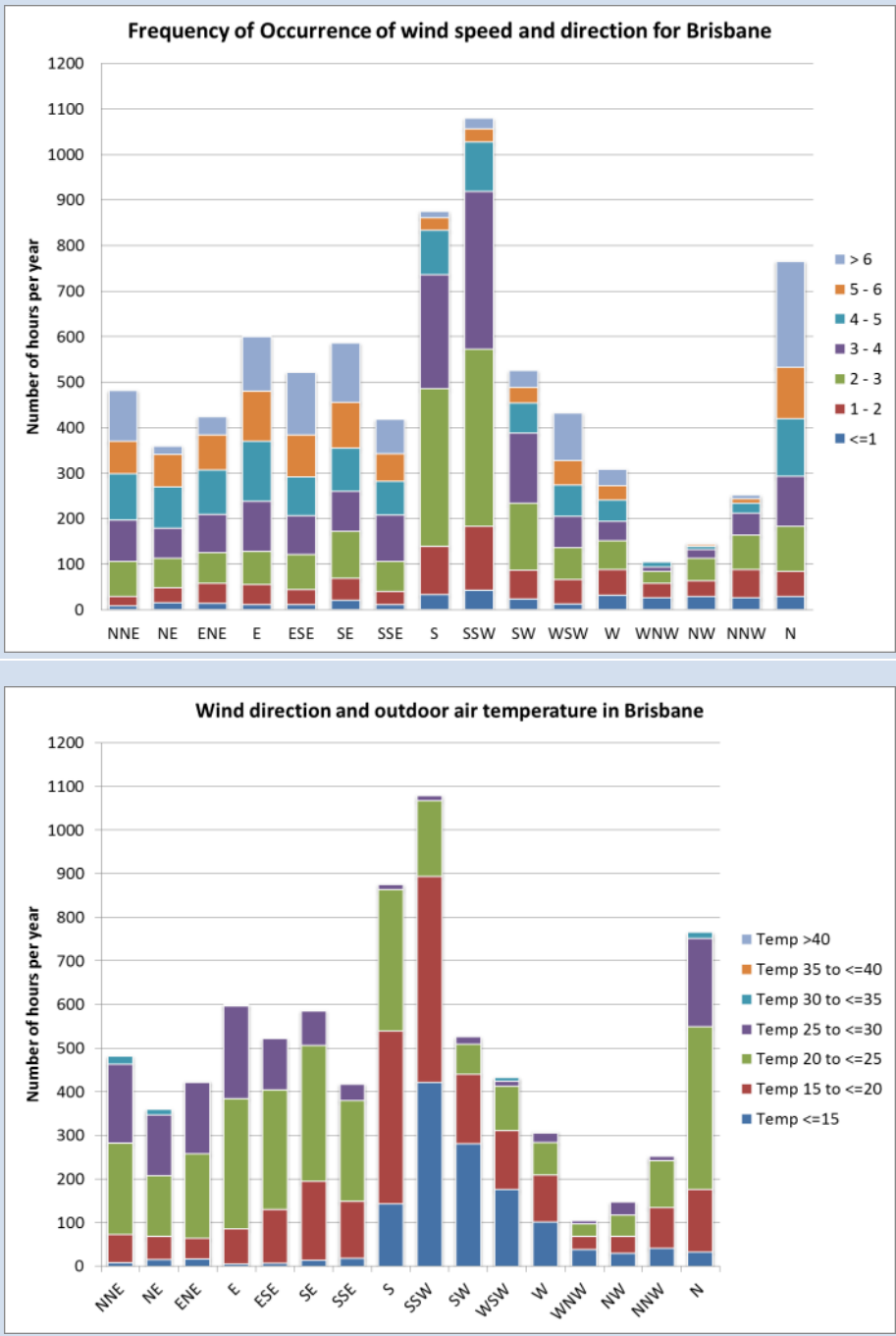


Figure 8 Alice Springs wind analysis (NatHERS climate file 6)

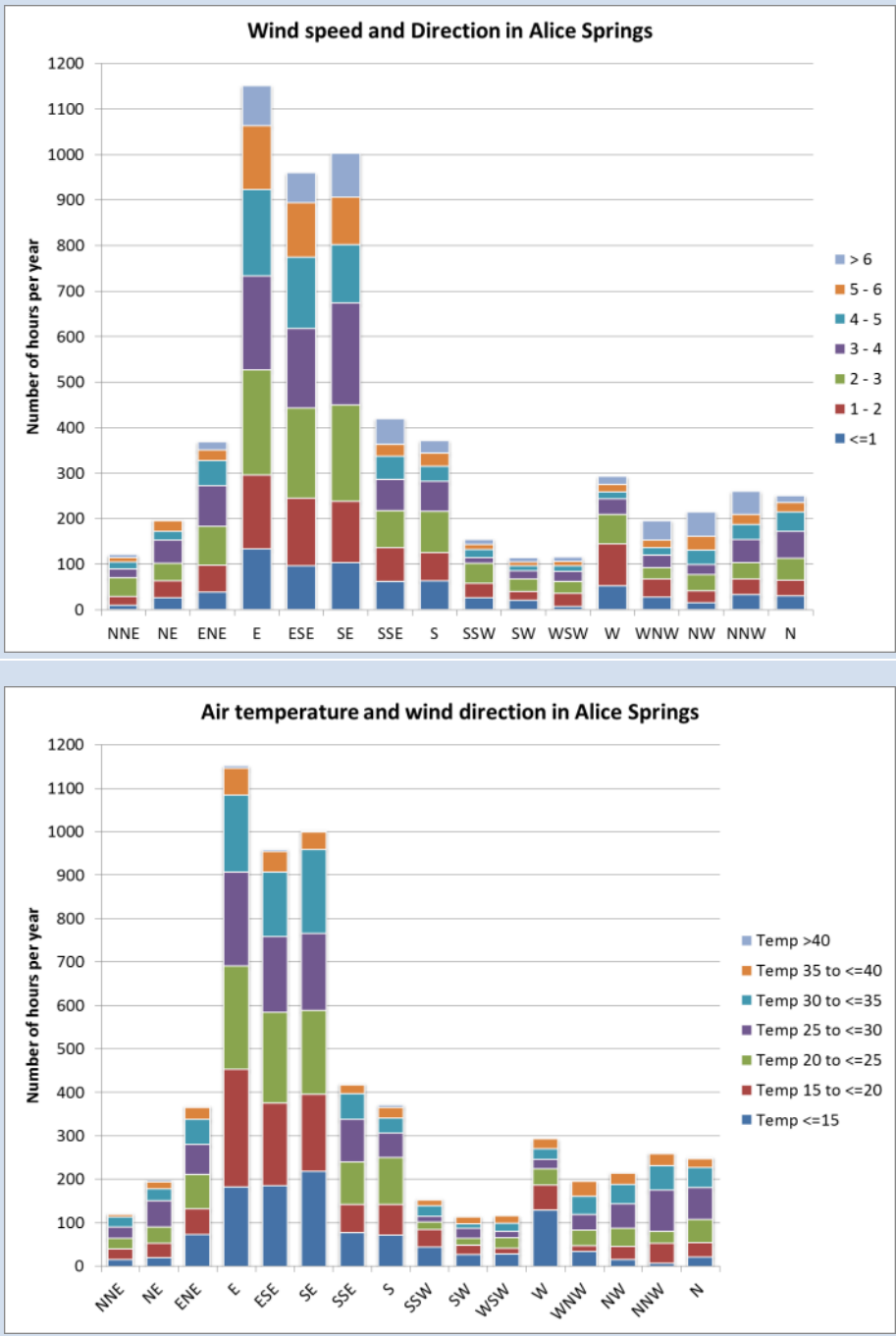


Figure 9 Emerald wind analysis (for Charleville NatHERS climate file 19)

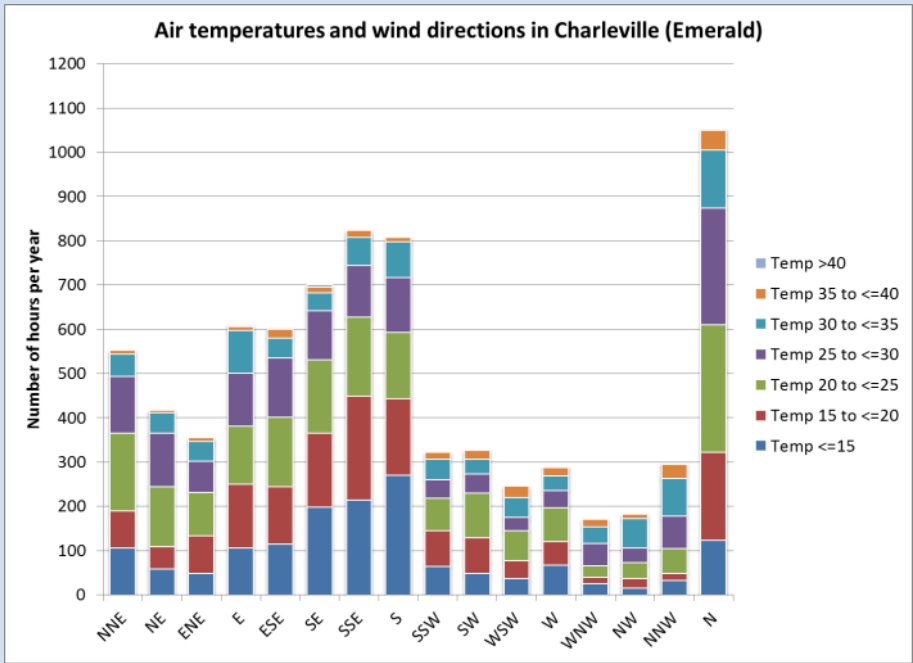
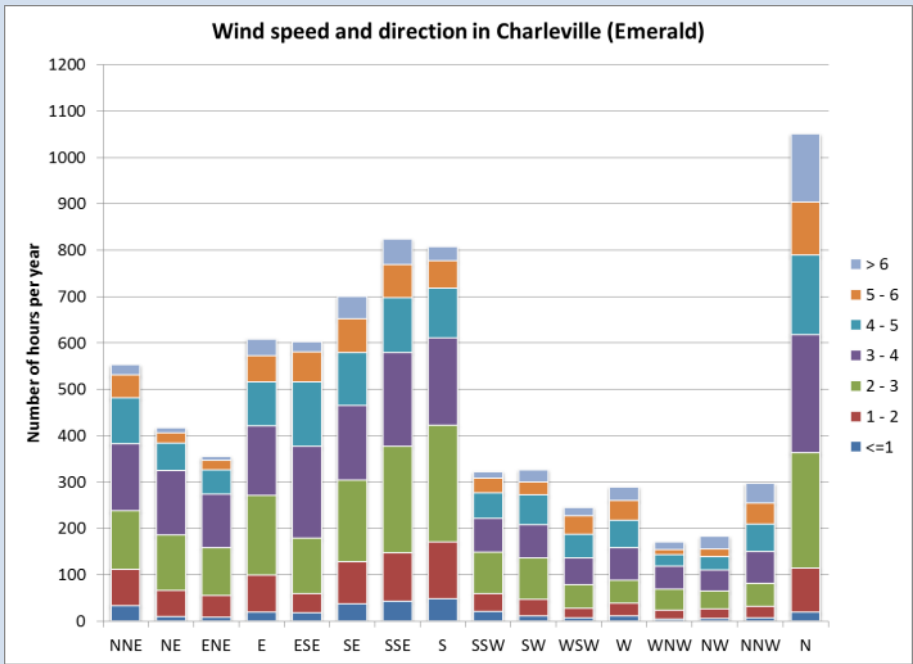
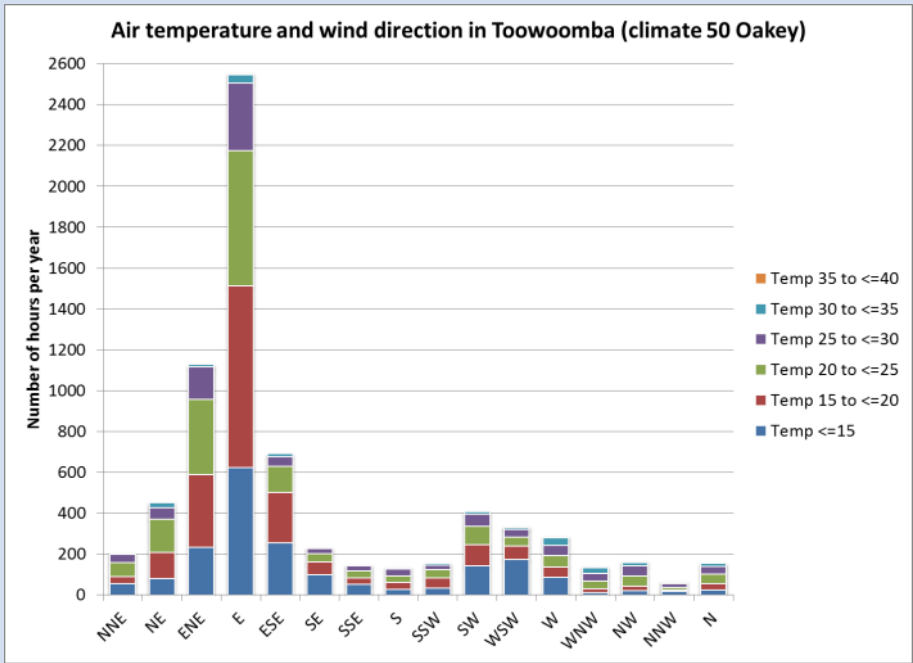
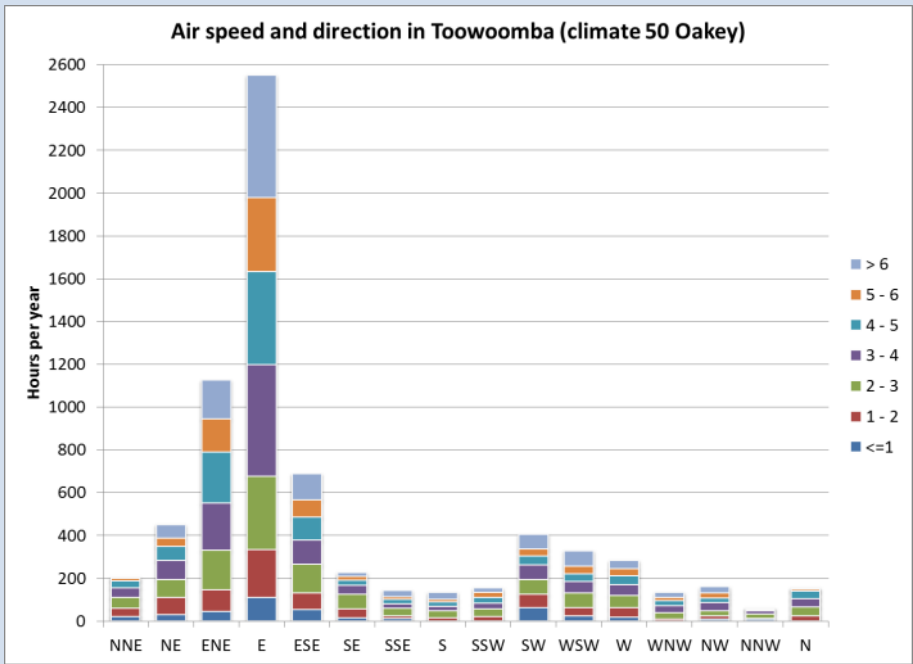


Figure 10 Toowoomba wind analysis (for Oakey NatHERS climate file 50)



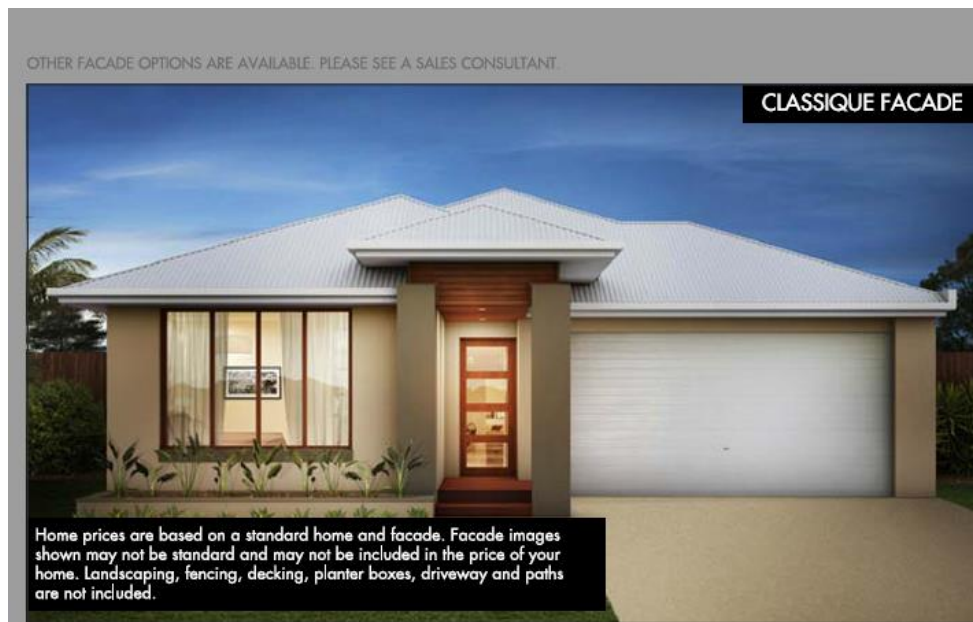
APPENDIX D: HOUSE SELECTION & ASPECTS OF METHODOLOGY

1.5.1 STANDARD HOUSES

Two house designs were selected to be typical of market-led housing in Northern Australian climates. The houses were selected to:

- Be typical of spec house designs being constructed throughout the climate zones evaluated. Both houses are built in reasonable volume by the housing companies who provided the designs. Similar houses can be seen in the portfolio of most of the volume housing suppliers who operate in these climates.
- Provide a range of typical house sizes: a smaller single-storey 4 bedroom house and a larger two-storey 4 bedroom house were selected. The use of a two-storey house design is particularly important to evaluate as upper floor bedrooms may not perform very well and two-storey construction is being used increasingly in these regions.
- Be as different to the traditional climatic design as possible. The standard houses use slab floors, are not particularly well designed to promote cross ventilation, provide minimal fixed shading and use small sliding or awning windows.

1.5.2 HENLEY LUNA 4



Cross ventilation paths (from one external side of the house to the other) are long and must pass through one or more openings. Only the Living/Kitchen area has openings on more than one side.

1.5.3 CLARENDON IV27



Cross ventilation paths are long and pass through multiple openings. The Living/Kitchen has openings on three sides which is a suitable feature for tropical housing. Window openability is also low with awning windows used.

1.5.4 REGULATORY COMPLIANCE OPTIONS ASSESSED

Each house was assessed and rated to achieve the minimum required level on 4 orientations in each of the 6 reference locations in northern Australia. The techniques used to achieve compliance focused on the market-led techniques for housing design:

1. Reducing heat flows through walls and ceilings by using high levels of insulation rather than light colours and shading,
2. Providing air movement with ceiling fans rather than promoting cross ventilation, and
3. Reducing solar gains from windows by using smaller windows with lower solar heat gain coefficients rather than using shade by verandahs and external screens.

In addition, it was assumed that houses have ceiling fans in all living areas and bedrooms. ABS 2008 found that in Queensland 66.1% of houses had ceiling fans (73.2% outside the mild Brisbane climate) and 86.3% of houses in the NT had ceiling fans. 60% of houses in Darwin had between 5 to 8 ceiling fans, and a further 27% had more than 8 ceiling fans (ABS, 2008). The use of ceiling fans has a substantial benefit in terms of the software star rating and it is generally cheaper to install fans than to make modifications to the building fabric in tropical climates. The use of ceiling fans can lower the cost of compliance which means that it is sensible to assume that houses in hot climates will typically install them.

1.5.4.1 USE OF OUTDOOR LIVING AREAS

In NCC climates 1 and 2 (Darwin, Townsville and Brisbane in this study) a 5 star rating for the building shell is allowed where it includes a compliant outdoor living area with ceiling fan. An optional credit of 1 star is available for an outdoor living area under 3.12.0.1 (a) with a Class 1 building in *climate zones* 1 or 2. The outdoor living area:

- (A) is fully covered with an impervious roof having a *Total R-Value* of at least 1.5 (for downward heat flow); and
- (B) has at least one permanently installed ceiling fan.

The outdoor living area must also be designed to meet the following criteria:

- (i) is directly adjoining, and directly accessible from, a general purpose living area of a Class 1 building such as a lounge, kitchen, dining or family room, which is not a room for sleeping or specialist tasks such as a study or home theatre; and
- (ii) has a *floor area* of not less than 12.0 m²; and
- (iii) has length and width dimensions of not less than 2.5 m each; and
- (iv) has an opening height above floor level of not less than 2.1 m; and
- (v) has one side permanently open with a second side either—
 - (A) permanently open; or
 - (B) readily openable.

The outdoor living area in each of the two designs selected for this study meet these requirements, and it was therefore assumed that the ceiling of the outdoor living area is insulated and that a ceiling fan was provided to gain the optional credit.

1.5.5 CONSTRUCTION MATERIALS

The house designs were assessed with the most common construction materials used in each location:

Table 5 Construction materials used for market-led housing

Location	Floor	Wall	Internal Wall	Roof/ceiling	Glazing*
Townsville	Slab	Concrete Block	Plasterboard	Attic, metal deck	Single clear / tinted as per rating
Darwin	Slab	Concrete Block	Concrete Block	Attic, metal deck	Single clear/tinted as per rating
Brisbane	Slab	Brick Veneer	Plasterboard	Attic, tiles	Single clear / tinted as per rating
Emerald	Slab	Concrete Block	Plasterboard	Attic, metal deck	Single clear / tinted as per rating
Alice Springs	Slab	Concrete Block	Concrete Block	Attic, metal deck	Single clear / tinted as per rating
Toowoomba	Slab	Brick Veneer	Plasterboard	Attic, metal deck	Single clear / tinted as per rating

* glazing is a mix of single clear and single tinted depending on the climate, house design and orientation of window

1.5.6 IMPACTS OF TRADITIONAL DESIGN TECHNIQUES ON STAR RATINGS

The project team distilled the traditional approach to tropical climate design to 8 basic design strategies:

1. Highly openable windows
2. Room placement and opening design to promote cross ventilation taking into consideration the direction of prevailing wind directions
3. Use of light colours
4. Use of heavily shaded design e.g. eaves, window awnings, verandahs, blinds and screens
5. Use of light-weight materials that allow the house to cool down rapidly at night in non-inland areas
6. Elevated house design to better capture breezes
7. Use of ceiling fans to provide air movement when there is little breeze
8. Use of high thermal mass building materials in hot inland areas.

Each of these strategies were applied to the worst rated orientation with a basic insulation and glazing specification i.e. generally lower than minimum regulatory compliance. The impact of each strategy on the star rating was reported and the most effective strategies were combined until regulatory compliance was achieved.

This provided a comparison case for free running temperatures with the market-led techniques used in section 1.5.4 above.

These strategies were applied to each of the two houses in the following manner:

Table 6 Application of traditional design strategies to market-led houses

Design Strategy	Henley Luna	Clarendon IV27
Openable windows	All windows louvres	All windows louvres
Room placement for cross ventilation	Not possible without redesign	Not possible without redesign
Light colours	Roof and walls to have 0.3 Solar Absorptance	Roof and walls to have 0.3 Solar Absorptance
Deep verandahs	1.8 m deep verandah on all sides except Garage	1.8 m deep verandah on all sides except Garage on ground floor, 900 eaves on upper floor
Lightweight materials	Timber framed fibre composite sheet clad walls and timber floor over an enclosed subfloor space	Timber framed fibre composite sheet clad walls and timber floor over an enclosed subfloor space
Elevated design	House increased in floor height by 2.4 m, garage moved under house	Not practical
Ceiling fans	Remove fans from base and compare to 1 x 1200 to all except Living: 3 x 1200*	Remove fans from base and compare to 1 x 1200 to all except Living: 3 x 1200*
High mass elements in inland areas	Change external walls to insulated reverse Block Veneer with internal block walls and slab floors to have ceramic tiles	Change external walls to insulated reverse Block Veneer with internal block walls and slab floors to have ceramic tiles

*In Tropical climates 1400 mm diameter fans may be more common, but because the effects are smaller in sub-tropical and hot arid climates there will be little benefit to be obtained through using 1400 mm diameter fans. 1200 mm diameter fans have been used throughout to provide consistency of results.

1.6 TRADITIONAL HOT CLIMATE HOUSE SELECTION

Demonstrating how climatically appropriate design strategies may benefit volume market-led housing design is important to show that the traditional techniques are appropriately assessed by software. However, an assumption used for this study is that the benefits of these techniques may be much greater in houses which facilitate cross ventilation through good window design and room placement. To investigate this theory, one house design which demonstrated traditional hot climate design strategies was assessed in each of the four climate zones (Tropical, Sub Tropical, Warm Temperate and Hot Arid).

Each house was optimised to achieve minimum regulatory compliance in the two climate zones which it was designed for. Because some of the houses were designed prior to the current regulatory requirement of 6-stars some significant modifications were required. However, changes were undertaken with a view to maintaining as many of the core design features as possible.

1.6.1 C19 STYLE HOUSE

This design was developed by Tony Isaacs based on the C19 public housing unit design. It is an elevated design similar to the government public housing design known as the C19. This house has often been held up as a model of good tropical design. In the C19 Style house each room has windows on two sides to facilitate cross ventilation and the design uses deep eaves, verandahs and screens to provide shade.

This house was selected because of its classic cross ventilation design. The house is only one room deep so air movement is not slowed because it has to pass through internal openings in other rooms. While bedrooms open directly to the hall, windows in the hall are only a metre away and are directly adjacent with the bedroom doors.

View from north



Upper Level Plan



Lower Level Plan



1.6.2 REDLYNCH HOUSE

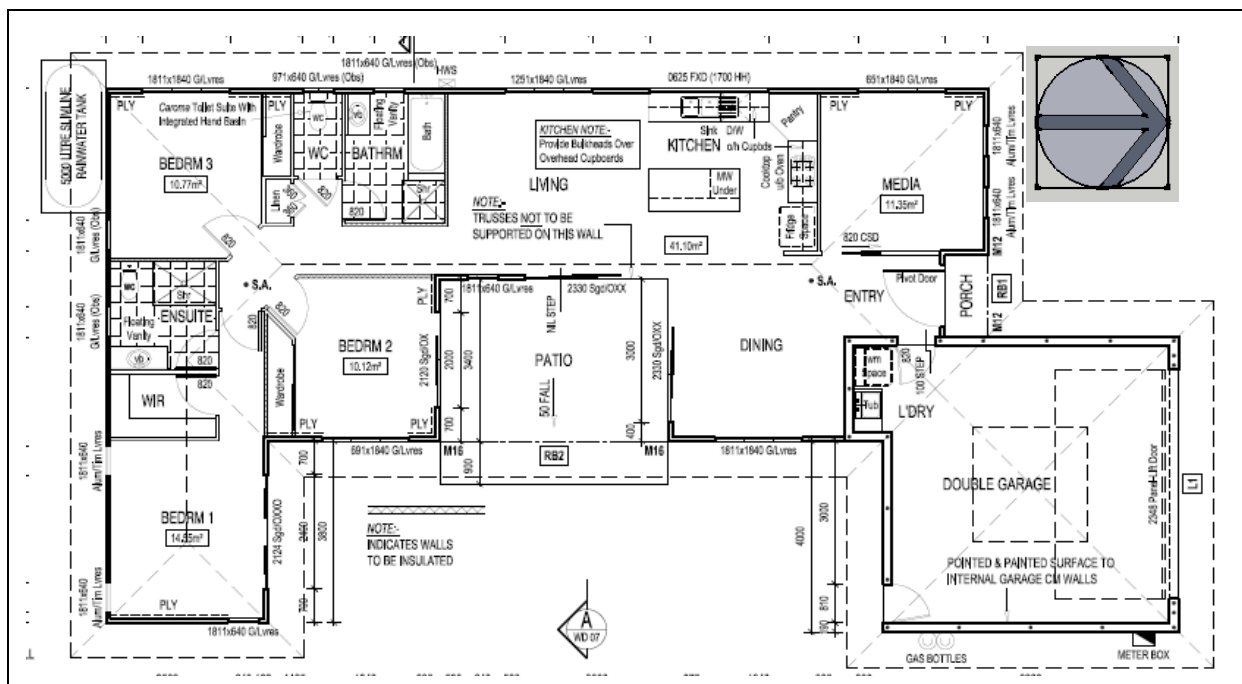
The design for Redlynch House gained a very high NatHERS star rating in its location of Cairns. It uses louver windows, has an outdoor living area and has reasonable cross ventilation to most rooms. This house is an example of 'hybrid design' as it combines features of both energy efficient and free running design. It was selected to provide an interesting contrast to the more traditional tropical design.

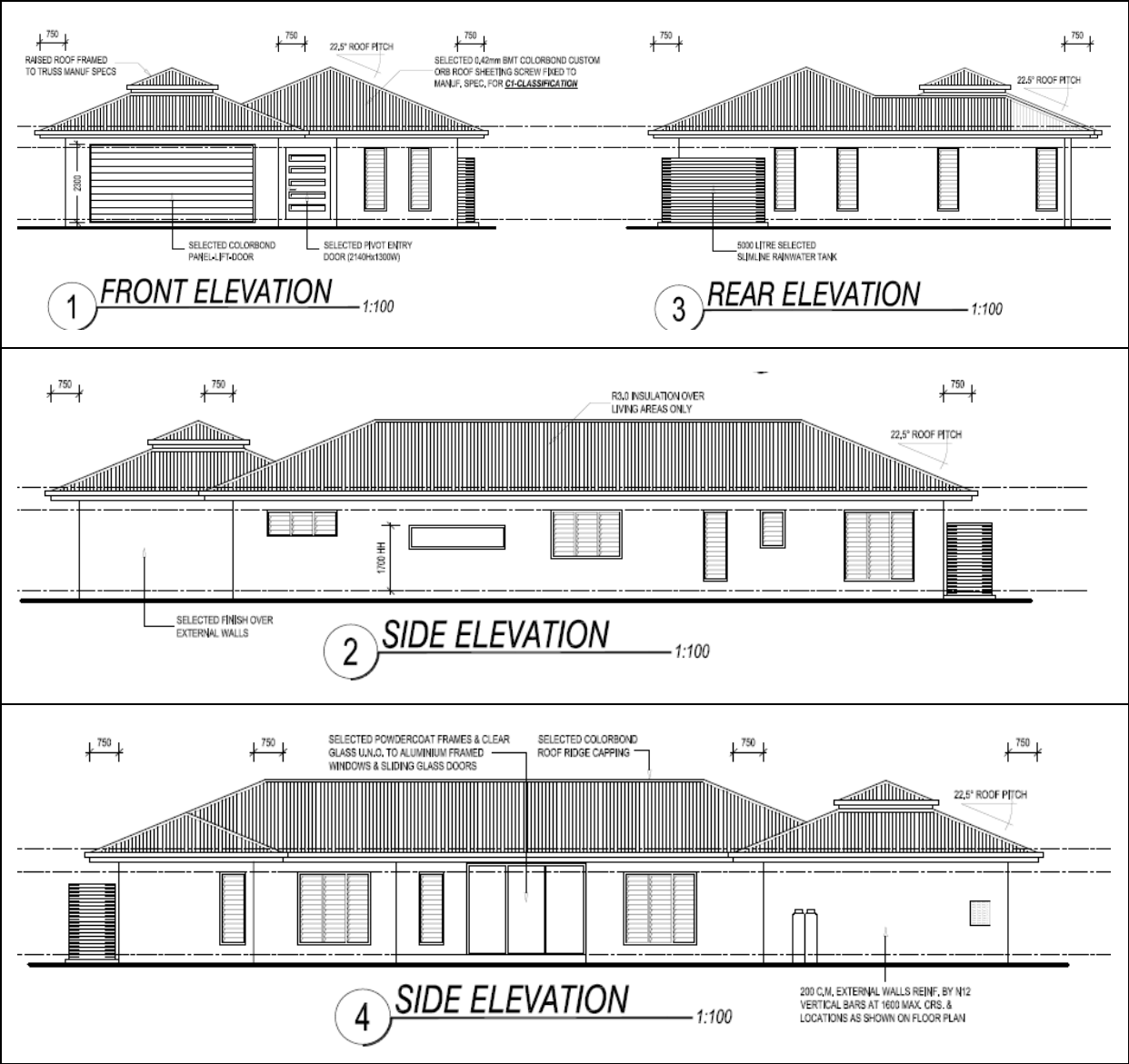
It obtained a rating in excess of 9 stars when assessed in the tropical climate zone, where it was originally designed for. For Darwin it gained a 7 star rating and in Townsville it was 8 stars. It has a larger area of windows than usually seen in market-led housing, including highly openable and heavily tinted louvers. Hard floor surfaces are used throughout to maximise the benefits of the slab floor during the day. All but one room has windows on two sides to promote cross ventilation. It also has an extensive outdoor living area adjacent to the main living area and bedroom (identified as 'patio' in the drawing below).

While this house is not strictly a traditional hot climate well ventilated design it is closer to the traditional design than the market-led housing, except that it uses high mass floor and wall materials. It will provide an interesting contrast to both the traditional and market-led housing, particularly in terms of free running performance.

Note that the house is not oriented ideally to the north, resulting in the longer sides facing east and west instead of north and south. This reflects the positioning of the house as built on the property. In its actual location the house received some beneficial shading by adjacent structures to the west, while the covered patio provided significant shade on the eastern side. It responded to the less than ideal orientation by using heavily tinted glazing and external blinds on the western side.

For the purposes of this study, at a 5 star level the kitchen and living areas were re-orientated to the south so that the design almost achieved 6 stars and then was de-specified down to the 5 stars regulatory compliant version.





1.6.3 SUB-TROPICAL AND WARM TEMPERATE HOUSE DESIGN: INNOVATION HOUSE (BRISBANE AND TOOWOOMBA)

This house was constructed on the Gold Coast as a display home by the developer and Gold Coast City Council about the benefits of good design and innovative technologies for the residential sector. It included well ventilated sub-tropical design.

As it was designed in 2004 and constructed in 2005, it was not required to meet the current minimum regulatory rating requirement of 6-stars.



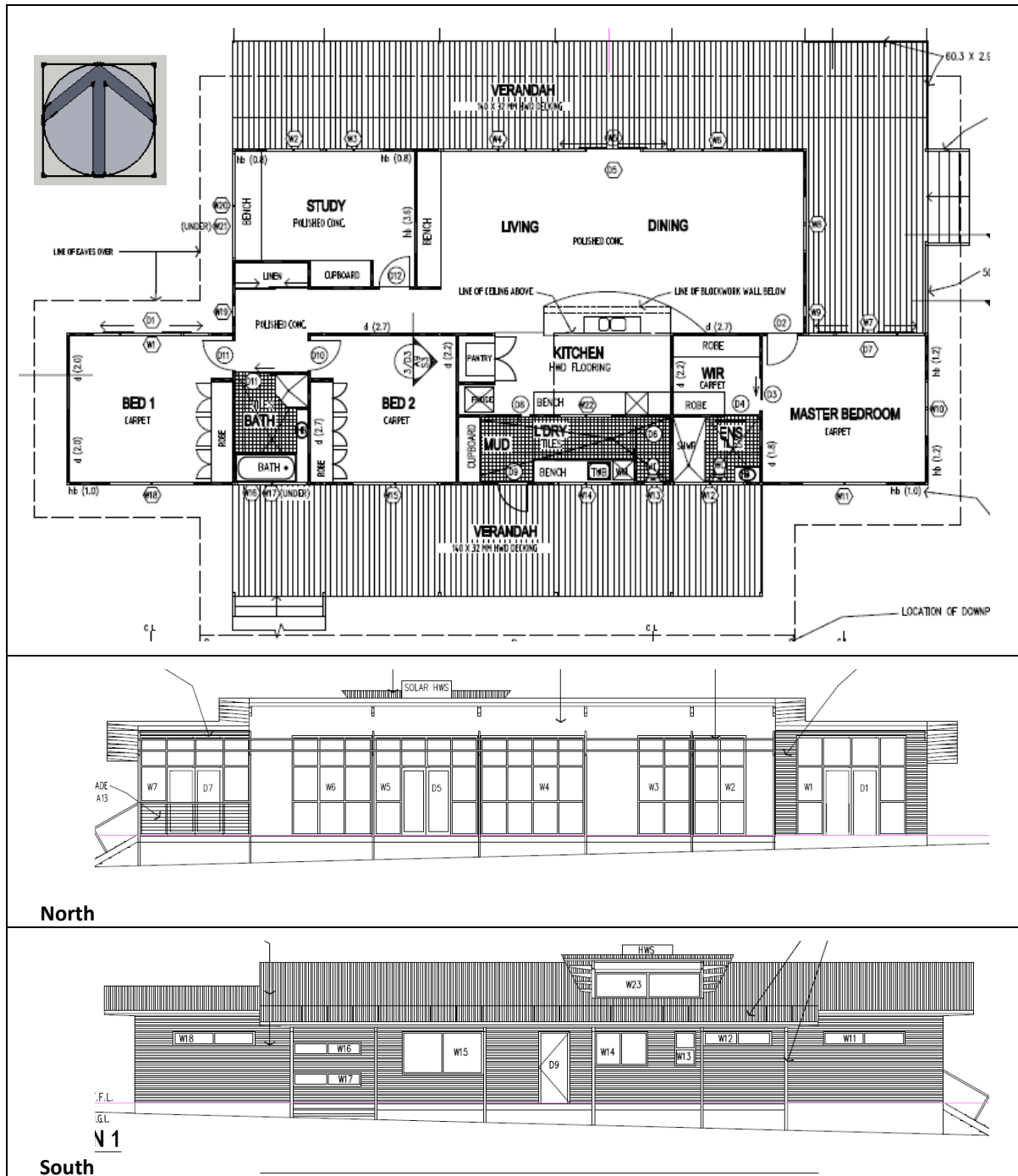
This design for Brisbane received a little under 3 stars. While it performed very well in summer, the large areas of well shaded glass increased heating requirements significantly for winter, and this is the principle reason for the low rating.

Note that part of the house was constructed on a timber floor due to the slope of land on the block at the Gold Coast. For this project the whole house was assumed to be constructed on a slab and this was a better test of the design concept.

1.6.4 HOT ARID HOUSE DESIGN: SHAYNE'S HOUSE (ALICE SPRINGS AND EMERALD)

This house was designed by Build-Up Designs in the Northern Territory and was used by the Northern Territory Government as an example of good hot arid housing for a research project in 2006 (Isaacs, 2006). It has a classic passive solar plan form and uses deep verandahs to provide shade.

While this house was designed before the introduction of minimum regulatory requirements in the Northern Territory, it achieved a 5 star rating. The house has a large glass area, however, all windows were double glazed. Because double glazing is rarely used in Alice Springs, for this study a single glazed version was developed with a reduced glass area.



1.7 COMPARISON OF HOUSE DESIGN FEATURES

Table 7 shows the key design and construction features of each of the houses used in this study.

Table 7 Construction and areas of key design features of the houses

Specification Element		Henley Luna	Clarendon IV 27	Redlynch	Innovation	Shayne's	C19 (Tropical)
Floor area:	Total (excl garage)	133.5 m ²	174.7 m ²	115.4 m ²	222.8 m ²	170.6 m ²	120.3 m ²
Note: Figures after the '/' indicate the size of this element relative to the total floor area of the house	Net Conditioned Floor Area (NCFA)	121.7/0.912	140.0/0.802	103.1/0.893	184.4/0.828	150.2/0.88	99.9/0.83
	Hard floor	59.2/0.443	22.7/0.13	115.4/1	22.1/0.099	100.2/0.587	29.2/0.243
	Hard floor in Rooms	Kit/Din/Liv & wet areas	Kitchen + wet areas	All	Wet areas (timber on slab not counted)	Only bedrooms carpeted	Lower floor on uncovered slab
	Lower Level area 1	133.5	84.5	115.4	152.9 (slab)	170.6	29.2
	Lower Level area 2	NA	0	0	65.3 (timber)	0	NA
	Upper Level area	NA	90.15	NA	NA	0	91.1
	Conditioned day/proportion house day cond.	72/0.539	100.3/0.574	63.14/0.547	123.97/0.556	92.8/0.544	51/0.424
	Conditioned Night	47.8/0.358	49.95/0.286	39.96/0.346	60.43/0.271	52.2/0.306	48.9/0.406
	Unconditioned * excl.	13.7/0.103	24.4/0.14	12.33/0.107	33.71/0.151	25.6/0.15	20.4/0.17
External Wall: Area relative to floor area	Type	As per climate	As per climate	Concrete block	Framed, polystyrene clad	Framed, metal clad	Framed, metal clad, concrete block on lower floor
	Area	122.79/0.92	193.76/1.109	167.11/1.448	243.97/1.095	204.75/1.2	258.68/2.15
Internal Wall: Area/	Type	0	0	0	0	0	0
	Area	139.3/1.043	146.98/0.842	108.73/0.942	161.51/0.725	145.32/0.852	62.1/5.8/0.56

4.2 Attachment D

Specification Element		Henley Luna	Clarendon IV 27	Redlynch	Innovation	Shayne's	C19 (Tropical)
relative to floor area							
Internal wall to garage: Area/relative to floor area	Type	Plasterboard	Plasterboard	Concrete Block	Plasterboard	NA	NA
	Area	21.18/0.159	26.16/0.15	9.84/0.085	25.56/0.115	NA	NA
Ceiling	Type	Plasterboard	Plasterboard	Plasterboard	NA	NA	NA
Attic	Yes	Yes	Yes	Yes	Yes/Cathedral ceiling over living areas	Yes/Cathedral ceiling over living areas	No
	Roof ventilators	No	No	No	No	No	NA
Roof	Type	As per climate Zone	As per climate Zone	Metal	Metal	Metal	Metal
	Surface Area	166.6 (incl. garage)	185.6	261.8	261.2	172	97.7
Ceiling Fans	Number	7	9	6	5	3	6
	Location	Bed & Living rooms	0	Bed & Living rooms	Media & bedrooms	Liv/Din/Kit	All living/bed rooms
Windows: Area/ relative to floor area	Total area	32.1/0.24	40.19/0.23	44.44/0.385	117.02/0.525	75.77/0.444	68.86/0.572
	Type	Aluminium frame single glazed sliding	Aluminium frame single glazed sliding	Aluminium frame single glazed louvre	Aluminium frame single glazed sliding	Timber frame single glazed sliding/awning	Aluminium frame single glazed louvre
	Living Area	22.1/0.166	24.58/0.141	23.29/0.202	85.5/0.384	43.84/0.257	32.47/0.27
	Bedrooms Area	7.9/0.059	8.15/0.047	18.21/0.158	20.13/0.09	28.19/0.165	36.47/0.303
	Unconditioned	2.1/0.016	7.46/0.043	2.94/0.025	11.39/0.051	3.7/0.022	4.1/0.034
North: Area/ relative to floor area	Area	4.8/0.036	10.2/0.058	9.2/0.08	41.9/0.188	56.4/0.331	37.5/0.312
	Eave	0.45	0.5 upper 3.5 lower outdoor room	0.75	0.6/3.2	3	1.1/3.2
East: Area/ relative to floor area	Area	10.2/0.076	12.2/0.07	15.9/0.138	8.0/0.036	4.8/0.028	2.9/0.024
	Eave	0.45	0.5 upper 4.0 lower outdoor room	0.75+OOA	0.6	0.9	0.9
South: Area/	Area	10.1/0.076	8.6/0.049	9.2/0.08	41.5/0.186	11.4/0.067	23.0/0.192

4.2 Attachment D

Specification Element		Henley Luna	Clarendon IV 27	Redlynch	Innovation	Shayne's	C19 (Tropical)
relative to floor area	Eave	2.8 (av)	0.5 upper	0.75	0.6	4.2	1.1
West: Area/ relative to floor area	Area	7.0/0.052	9.3/0.053	10.1/0.088	25.6/0.115	3.1/0.018	5.4/0.045
	Eave	0.45	0.5 upper	0.75	0.6/3.4	0.6/4.3	0.9
Weather seals	Doors	Yes	Yes	Yes	Yes	Yes	Yes
	Windows	Yes	Yes	Yes	Yes	Yes	Yes
	Exhaust Fans	Yes	Yes	Yes	Yes	Yes	Yes

The most striking differences in the houses which use traditional well ventilated/passive solar design principles and the market-led houses are in the wall and window areas. The window areas for the market-led houses are on average around half the window area per square metre of floor area of the traditional designs. Further, the traditional designs have much higher wall areas at an average of around 40% more wall area per square metre of floor area. The traditional designs also concentrate a much higher proportion of window area on the north and south than the market-led designs which have a fairly random window orientation. Deeper shading is more prevalent with the traditional designs than the market-led designs and they have light weight walls in all climates.

1.8 EVALUATION OF BEDROOM PERFORMANCE AND ALTERNATIVE USER BEHAVIOUR

The performance of bedrooms at night in summer has been found to be critical aspect of the thermal performance of housing by several studies (e.g. NEEHA, 1991). Studies have shown households in hot climates use air conditioning in bedrooms more frequently than living rooms despite the fact that night time temperatures are cooler than daytime. This makes intuitive sense as occupants can tolerate discomfort during the day, but discomfort during the night may mean going without or disturbed sleep.

For this study the energy loads in bedrooms and living rooms were reported separately. This facilitated analysis of how well bedroom performance correlated with the software assessment.

In 2006, the Northern Territory House Energy Rating Industry Reference Group (HER IRG) undertook a study of the impacts of compliance with NatHERS at 5 stars (Isaacs, 2006). This study showed that bedroom energy use represented between 18 and 23 per cent of the total predicted cooling loads of houses in Darwin and that houses constructed with concrete block walls had superior ratings to houses constructed with lightweight walls. This study also showed that free running temperatures in houses with concrete block walls remained at higher temperatures overnight, even when they had higher star ratings than the houses with lightweight construction.

Houses with concrete blockwork as their external walls often receive higher star ratings than houses with light weight walls. Isaacs (2006) found that the advantage of blockwork wall construction in terms of energy rating occurs during the day. This is because blockwork walls absorb heat during the day and lower the required cooling load at that time, but given the thermal lag effect of stored heat being re-released into the evening and night time it results in higher cooling loads. This caused concerns that the software was not delivering optimal outcomes for housing in tropical climates:

The HER ERG is concerned that, with the current AccuRate occupancy profiles and settings, this mid-day advantage of blockwork is having a disproportionately large effect on houses' relative final star ratings. It is thought that blockwork housing is generally rating better than it should compared to lightweight housing. (Kieboom, 2007)

The market research of Northern Territory households found that when bedrooms are occupied during the wet season (October to April), air conditioning is generally turned on. By contrast, even when living areas are occupied a significant proportion of households do not use air conditioning. Table 8 shows the occupancy and use of air conditioning for the main living room and bedroom 1 on weekends during the wet season for households in the Northern Territory:

Table 8 Occupancy and use of air-conditioning on weekends during the wet season in the living room and bedroom 1 for Northern Territory households

Living Room				Bedroom 1		
Period	Occupied (%)	Air Con on (%)	% occupied time with AC	Occupied (%)	Air Con on (%)	% occupied time with AC
12mn - 6am	10	4	40	96	67	70
6am - 9am	85	18	21	53	30	57
9am - 12md	85	18	21	7	5	71
12md - 3pm	84	31	37	11	9	82
3pm - 6pm	86	40	47	9	4	44
6pm - 9pm	93	45	48	12	14	117
9pm - 12mn	71	33	46	79	61	77
Average			37			74

On average the living room is only conditioned for 37 per cent of occupied time, while Bedroom 1 is air conditioned for 74 per cent of the time it is occupied. In the living room households preferred to keep cool by using ceiling fans and opening windows far more often than they did in bedrooms. This is consistent with the theory of human comfort as it is more difficult to maintain comfort while sleeping because half of the body is insulated by bedding.

The market research also asked households which temperature was used for their air conditioning thermostat. As would be expected – human perception of comfort varies widely between individuals. Responses varied from below 20°C to as high as 28°C, with an average of 23°C. This is substantially lower than the 26.5°C used by the NatHERS scheme. The NatHERS thermostats were developed by calculating free running thermal neutrality for the hottest 3 months for each climate. It is understood, however, that thermal neutrality in air conditioned buildings is lower than in free running buildings.

The households surveyed rely much more on air conditioning to provide comfort in bedrooms overnight than they do in living rooms during the day. This suggests that it could be appropriate to lower the thermostat setting in the NatHERS behaviour assumptions for these areas, particularly at night. Lowering the thermostat setting for bedrooms alone would significantly increase the proportion of total NatHERS loads in bedrooms and hence the potential impact of their performance on the star rating. This change would address a key concern of the HER IRG.

The market research also found that the hours of use for cooling were much lower than the potential 17 hours per day of the NatHERS user assumptions (5.8 hours per day in living room and 7.7 hours per day in bedroom 1 during the wet season). However, just because cooling is available for use does not necessarily mean it is used. This study evaluated how many hours per day cooling was used in the wet season and then compared this to the reported hours of use observed in the market research before considering any change to the hours of use in the NatHERS behaviour assumptions.

Limiting the hours of use may have other less desirable outcomes. For instance, if air conditioning is not used during some hours then the performance of the house is not valued at this time. The market research showed little use of air conditioning in living areas before mid-day. If these hours were excluded from the NatHERS behaviour assumptions it is conceivable that a house with large areas of eastern facing windows could meet the scheme's target despite significant over-heating during the early hours of the day. In houses which

reported using air conditioning before mid-day, it may be that this was due to solar gains through eastern facing windows. Therefore there is less reason for changing the hours of use than in the NatHERS thermostat settings.

This study investigated lowering the bedroom's thermostat settings. It observed whether the hours of use of cooling corresponded with the findings of the market research, and then evaluated whether a change may need to be made to the hours of cooling use in the NatHERS scheme.

Importantly, it should be noted that care must be taken in applying the findings of this market research. It only surveyed people in Darwin and Alice Springs, and therefore may not be applicable to other tropical climates. Further, it is not known whether this sample was a statistically representative sample of households in the climates where it was undertaken. However, its findings point to a potential solution of the HER IRG's concerns regarding the NatHERS assessment outcomes. Lower thermostat settings in bedrooms would increase the proportion of energy loads in bedrooms and potentially make it easier for lightweight housing design - which have traditionally been found to be most appropriate for tropical climates – to achieve compliance. However, such a change may inherently result in further issues. Concrete block construction is now prevalent for new housing across much of northern Australia because it is cheaper than other forms of construction and also for ease of meeting NCC building requirements for high wind speeds in cyclonic areas. If amending the NatHERS behaviour assumptions improves the ratings of lightweight buildings it may add significant cost to concrete block houses. This may have significant impacts on the benefit-cost ratios in these climate zones and any potential changes that could impact on the energy efficiency stringency under the NCC would expected to be subject to a Regulatory Impact Statement.