Thermal Sensitivity of Australian Houses to Variations in Building Parameters

H. Willrath
Department of Architecture University of Queensland
and Solar Logic
162 Blackwood St Mitchelton Qld 4053 AUSTRALIA
Telephone/Facsimile : +61 (0)7 33552608
E-mail : holgerw@www.ats.au.com

Abstract

This paper looks at the relative effects that variations in the values of major building parameters have on the thermal performance of houses across the Australian climatic spectrum. Thousands of variations of house types in each of 15 locations have been examined using the Solar Logic BERS computer program incorporating the CSIRO CHENATH thermal simulation engine. Presented here is a summary of the more important factors which influence the thermal performance of these houses. Indices which quantify the sensitivity of the performance of a building to a variation in one of its parameters are defined and presented in graph form.

1 INTRODUCTION

Most of the conventional wisdom used by designers of energy efficient houses still comes from Europe and North America. Australia has a large range of climates which include those to which these conventional rules of thumb apply. There are several climate types in Australia, however, which are not found in these colder northern hemisphere locations.

There have been some simulation studies of the thermal performance of houses in Australian climates, but most of these studies are limited to specific regions of Australia. The one study which does cover a good range of climates, the CSIRO Thermal Mass Study, is only concerned with the usefulness of thermal mass, (Walsh, Gurr and Ballantyne 1982). The purpose of study which is being reported here was to simulate a large range of house variation over the entire spectrum of Australian climate types and to analyse the results from a building parameter perspective.

The thermal performances of over 2000 variations of a simple rectangular house were simulated for 15 different locations. The software used was BERS, (Willrath 1995,1996), which incorporates the computer simulation engine, CHENATH 4.01a, (Delsante 1995). The energy required to maintain year round comfort in the living and sleeping areas was calculated for each of these house variations. The parameters which had the greatest effect on thermal performance were identified and thermal indices were defined and calculated for each location.

2 STANDARD HOUSE

A simple rectangular house was modelled as the standard or "base house". Variations of this house were simulated for this study. The floor plan is shown in Figure 1. Tables 1 and 2 describe the main features found in the base house.

Two different base window areas were used depending on whether variations in glazing areas and orientations or other aspects of the house were being investigated.

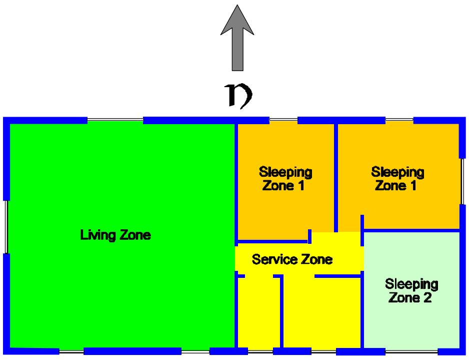

Figure 1. Floor plan of the base-case house.

DESCRIPTION

Window variation simulations assumed a base window area equal to 10% of the floor area in habitable rooms, (9% overall), to which extra glazing was added to, one orientation at a time. Variations of other parameters were modelled with a constant glazing area which was twice the base window area used for the glazing variations.

The following abbreviations have been used:

BV-Brick veneer CB-Cavity brick SOG-Slab on ground RFL-Reflective foil laminate

In some cases three mass levels were simulated. They are abbreviated as follows :

LM	Low mass: BV external walls, plasterboard internal walls, timber floor
SM	Standard mass: BV external walls, plasterboard internal walls, SOG floor
HM	High mass: CB external walls, brick internal walls, SOG floor

Two levels of insulation were sometimes simulated for each mass level. They are abbreviated as follows :

NI	No insulation
SI	Standard insulation: RFL in external walls, R2.5 in ceiling, no floor insulation

Table 1. Base case house description.

External walls	Brick veneer, reflective foil or R1.0
Internal walls	Plasterboard cavity
Roof	Tiles with RFL underneath, 190 m² of roof area
Roof cavity	Ventilated at 10 AC/h at 3.5 m/s wind speed, 160 m^3 of volume
Ceiling	Plasterboard with R2.5 bulk insulation
Standard floor	Concrete slab on ground, uninsulated, Carpet in bedrooms and living areas, Floor tiles in the service zone, laundry, WC and bathroom
Timber floor variation	Under floor cavity 0.5 m high, walls same as base house Ventilated at 5 AC/h at 3.5 m/s wind speed.
Windows	Single glazed in aluminium frames directly below 450 mm eaves
Infiltration rate	0.6 AC/h at a wind speed of 3.5 m/s.
Floor plan	Rectangular, 18 m x 9 m excluding wall footprint
Floor area	Total 162 m²
	Living zone 81 m²
	Bedroom zone 1 39 m² (2 bedrooms)
	Bedroom zone 2 20 m²
	Service zone 22 m²
Orientation	Long axis East-West
Window area	Non window investigations have window area evenly distributed in proportion to wall area.

Table 2. Window areas (m^2) of the base house.

Window area m²	**N**	**E**	**S**	**W**	**Total**
window investigations	4.8	2.4	4.8	2.4	9%
non window investigations	9.0	4.5	9.1	4.5	17%

3 PARAMETRIC INDICES

Tables 3 and 4, define the indices which are used in this chapter. These indices give the percentage differences in energy requirements of two variations of the same house when simulated using the same climate data.

ie ((Energy required by first case / Energy required by second case) - 1) x 100

A negative index indicates that the first case is more efficient than the second in that climate. These indices have been calculated for each location and are presented as graphs.

Table 3. Definitions of the non-glazing parametric indices used in this chapter.

Thermal Mass Index	LMSI cf HMSI
General Insulation Index	SMSI cf SMNI
Wall Type Index	SMSI no wall insulation cf HMSI
Ceiling Insulation Index	SMSI No ceiling insulation cf SMSI R2.5 ceil ins
Floor Type Index	Worst floor cf Best floor
Timber floor Carpet Index	LMSI floor with carpet cf LMSI no carpet
Suspended Slab Carpet Index	SMSI suspended slab floor with carpet cf no carpet
Slab on Ground Carpet Index	SMSI floor with carpet cf SMSI no carpet
Timber floor Insulation Index	LMSI carpet, R1.0 under floor cf no under floor insulation
Suspended Slab Insulation Index	SMSI suspended slab floor, carpet, R1.0 underfloor insulation cf no underfloor insulation
Slab on Ground Insulation Index	SMSI carpet, R1.0 under floor cf no underfloor insulation
Infiltration Index	SMSI 6.4 AC/h cf Well sealed, 0.6AC/h
Roof Ventilation Index	SMSI 1 AC/h cf 22 AC/h
Under Floor Ventilation Index	LMSI 25 AC/h cf 0.5 AC/h
Cross Ventilation Index	SMSI 2 AC/h cf 10 AC/h
External Colour Index	SMSI Dark cf Light

Table 4. Definitions of the glazing parametric indices used in this chapter.

Glazing Index	SMSI SG Al frame cf SMSI DG timber frame
LM North Window area Index	LMSI 12 m^2 N window cf LMSI Zero N window
LM East Window area Index	LMSI 12 m^2 E window cf LMSI Zero E window
LM South Window area Index	LMSI 12 m^2 S window cf LMSI Zero S window
LM West Window area Index	LMSI 12 m^2 W window cf LMSI Zero W window
SM North Window area Index	SMSI 12 m^2 N window cf SMSI Zero N window
SM East Window area Index	SMSI 12 m^2 E window cf SMSI Zero E window
SM South Window area Index	SMSI 12 m^2 S window cf SMSI Zero S window
SM West Window area Index	SMSI 12 m^2 W window cf SMSI Zero W window
HM North Window area Index	HMSI 12 m^2 N window cf HMSI Zero N window
HM East Window area Index	HMSI 12 m^2 E window cf HMSI Zero E window
HM South Window area Index	HMSI 12 m^2 S window cf HMSI Zero S window
HM West Window area Index	HMSI 12 m^2 W window cf HMSI Zero W window
Retractable North Shading Index	SMSI 12 m^2 N window cf SMSI 12 m^2 N window retract N shading
West Eaves Index	SMSI 12 m^2 W win Zero Eaves cf SMSI 12 m^2 W win 1350 Eaves
North Eaves Index	SMSI 12 m^2 N win Zero Eaves cf SMSI 12m^2 N win 900 Eaves
Winter Obstruction Index	SMSI 6m obstruction 12 m^2 N win cf SMSI no obstruction 12 m^2 N win

4 THERMOSTAT SETTINGS AND ENERGY CONSUMPTION

The graph of Figure 2 shows the heating and cooling requirements of the base house when situated in each of the 15 locations used to typify Australia’s range of climates. There is a difference of a factor of 4 between the energy used by the base house in the mildest climates compared with the most severe.

Thermostat settings used for these calculations are shown in Figure 2. They were derived by calculating the average thermal neutrality for the three hottest months and for the three coldest months using the method Auliciems, (1983).

5 INSULATION AND THERMAL MASS

Examination of the data presented in Figures 4 to 13 indicates quite clearly that insulation is the one most important factor which determines the thermal performance of houses throughout Australia. The graph of Figure 4 shows that the houses in moderate and colder climate locations are able to achieve the greatest increase in performance by **insulating ceilings** and **walls**. In fact uninsulated houses use between 120 and 340% more energy to maintain comfort.

Thermal mass effects can also be significant in moderate climates, but to a lesser extent than insulation. Lightweight houses require between 15 and 90% more energy than heavyweight houses. Houses situated in very hot or very cold climates are least able to benefit from thermal mass.

6 CEILING, WALL, FLOOR, GLAZING TYPES AND COLOUR

The importance of ceiling insulation, wall type, floor type, glazing type and external surface colour are shown in Figure 4. **Ceiling insulation** dominates in its ability to moderate energy consumption in all parts of Australia. Houses with uninsulated ceilings require between 100 and 300% more energy than houses with R2.5 in the ceiling space. The energy reduction potential of ceiling insulation is generally greater than the combined potential of wall type, floor type, glazing type and external colour.

The thermal performance of buildings in all locations can be improved by using **walls** which provide externally insulated mass. The energy consumption of houses with light, uninsulated walls is greater by between 30 and 110%.

Slab on ground **floors** also provide mass. In addition to this the thermal contact with the ground provides a thermal advantage to houses in all but extreme climates. Houses with suspended floors require 20 to 100% more energy to maintain comfort.

The thermal advantage of using low frame conductance double **glazing** instead of aluminium framed single glazing is between 21 and 44%.

The difference in performance in houses with light and dark **external colours** can be as great as 30% in places like Brisbane. In climates colder than Canberra it is an advantage to have a dark external surface to the building.

7 INFILTRATION AND VENTILATION

The graphs of Figure 4 present data relating to ventilation issues. There are large thermal gains to be made by minimising **infiltration**, particularly in the temperate and cooler regions. Well sealed houses always perform better than leaky houses, the latter requiring 24 to 90% more energy to maintain comfort, depending on location. The use of doors and windows with good seals, and the control and sealing of all external vents allows the ventilation rate to be maintained in the range between what is adequate for health and what is required to cool down the internal mass of the house at night.

The potential to cool buildings using **cross ventilation** was never more than 10% in any of the locations simulated. These simulations did not take into account the physiological comfort obtained from air movement past the occupants as the inside air was being exchanged with cooler air from outside.

There seems to be a mismatch between when cooling breezes are available and when they are needed to cool the building at night, particularly in the hotter locations. Exhaust fans with low energy consumption can provide the air movement through the house required to cool the mass at night in summer when insufficient natural ventilation is available.

High **under floor ventilation** rates can reduce the performance of houses with uninsulated suspended floors by about 10% in the hottest locations to about 40% from the temperate to coldest locations. The ventilation rate can be dramatically reduced by enclosing the floor space between the suspended floor and the ground, making the performance of the house closer to one which has a slab on ground floor. In colder climates it is an advantage to insulate a suspended floor, so these houses are not as sensitive to under floor air rate changes.

Roof space ventilation rate has very little influence over the performance of a house, if the ceiling has R2.5 insulation installed, as was the case here.

8 FLOOR TYPE, UNDERFLOOR INSULATION AND CARPETS

The rather more complex relationships between **floor types, under floor insulation and carpets** are shown in the graphs of Figures 7-9. Whether insulation and carpets are a help or a hindrance to thermal performance is very much dependent on location and the type of floor.

The **slab on ground floor**, (Figure 7), performs best without carpet, and without any insulation, for all locations warmer than Melbourne. Carpet appears to degrade performance more than insulation for these locations. The energy of Brisbane houses with slab on ground floors can be reduced by 75% if hard floors are installed rather than carpets. This rather large energy saving appears to be due to the carpet thermally isolating the mass of the slab from the rest of the house, and at the same type isolating the house from the mass of the ground beneath. Carpeting floors in Melbourne or Canberra makes no difference while insulating the slab improves performance. In Hobart and the Alpine regions, the use of carpets benefits performance to about the same extent as does R1.0 insulation, ie about 10%.

Regardless of location, removing carpet from **suspended timber floors** has about the same effect as removing insulation from under these floors. The timber in the floor provides only a small amount of thermal mass, so it makes little difference which side of it is insulated. The use of carpet or underfloor insulation is detrimental to the performance of houses in locations warmer than Mildura. In cooler locations than Adelaide, houses benefit from carpets and under floor insulation, although the combined energy saving is only between 20 and 35%.

Houses with **suspended slab floors** in temperate and cool climates are able to benefit from under slab insulation. Carpets can also be of benefit in locations which are no warmer than Melbourne. Houses in locations warmer than Perth can achieve a 10 **-** 20% energy saving by removing floor coverings to give better access to the mass of the slab. (This saving is not as great as is achievable by removing the carpets from slab on ground floors because there is no direct heat transfer from the suspended slab to the mass of the ground.)

9 SHADING OF GLAZING

The graph of Figure 10 shows the relative effects of making changes which involve shading the glazing of windows from the beam component of irradiance. These changes relate to the SMSI base house.

Houses in climates warmer than Mildura are able to achieve significant thermal gains by controlling entry of direct sunlight. **Retractable north shading devices** allow sunlight in through the windows when conditions are cool and substantially shade the windows in hot weather. In all but the colder climates these shading devices can reduce the energy load by between 20 and 50%. **Wide west facing eaves** can reduce energy consumption by between 10 and 20% in climates warmer than Melbourne.

Fixed north facing eaves can provide a 10% reduction in energy requirements compared to not having any eaves, in all locations warmer than Mildura. In the cooler locations partial blocking of the winter sky by eaves more than offsets any gains in summer performance.

The results of the simulations which investigated the effects of **winter shading** by an identical house 6 m to the north, showed that this effect was never more than 15%, (in Hobart), and not more than 10% in other cool and temperate regions. Winter overshadowing was found not to be an issue in warmer climates.

10 ORIENTATION OF GLAZING

The graphs of Figures 11 to 13 show the differences in energy consumption when **windows** are placed in walls which face the cardinal directions in the LMSI, the SMSI and the HMSI houses.

In all locations, and for all three house types, windows facing direction other than northerly are always a thermal liability. Energy requirements increase by between 40% and 120% when 12 m² of non north glazing is added to houses in warmer climates. In these climates, even north facing windows contribute to energy consumption.

High mass houses are able to utilise north glazing to advantage in temperate and cool climates. A maximum performance gain of 30% is possible when north glazing is used in the high mass house in Sydney. Standard mass and low mass houses are relatively insensitive to north glazing in cool and temperate climates.

11 CONCLUSION

- The dominant factor which affects the thermal performance of houses in all Australian climates is ceiling insulation.
- This is followed by wall type and insulation and floor type.
- Infiltration control is important in all climates, particularly in cooler locations.
- In the temperate and warm locations the amount of glazing area and how it is shaded is very important, because solar gain through any window reduces thermal performance.
- High mass houses perform better than houses of lower thermal mass in all locations. They are able to benefit from north glazing in cool to temperate climates.
- Retractable shading over the north windows improves performance in all but the coldest locations.
- The use of double glazing and low conductance frames reduces energy consumption by at least 20% in any location.
- Substantial eaves over west windows, and narrower eaves over north windows, can each increase performance by about 10% in locations warmer than Mildura.
- Reduction of the ventilation rate under houses with suspended floor, (by enclosing the underfloor space), can reduce energy consumption by at least 40% in climates cooler than Brisbane.
- Dark external colours degrade thermal performance except in cool locations.
- Underfloor insulation and carpets can reduce performance in warmer locations but enhance performance in cool climates.
- Other parameters which were investigated have only a minor effect on thermal performance. These include roof space ventilation rate and cross ventilation potential.

12 REFERENCES

Auliciems, A. (1983) P*sycho-physiological criteria for global thermal zones of building design*. International Journal of Biometeorology, Vol 26, 69-86.

Delsante, A. E. (1995) *A comparison of CHENATH, the National House Energy Rating Scheme simulation engine, with measured test cell data*. Proc. ANZSES Solar 95 Conference. (29 Nov - 1 Dec). Hobart, Australia. 441-446.

Walsh, P.J., Gurr, T.A. and Ballantyne, E.R. (1982) *A Comparison of the Thermal Performance of Heavyweight and Lightweight Construction in Australian Dwellings*. TP44. CSIRO Division of Building Research.

Willrath, H. (1995) *Rating the thermal performance of houses*. Solar Progress 16(4).

Willrath, H. (1996) *BERS - A User Friendly Building Energy Rating Scheme.* Proceedings of Simulation Tools for Design, International Building performance Simulation Association., pp. 39-42. Sydney.

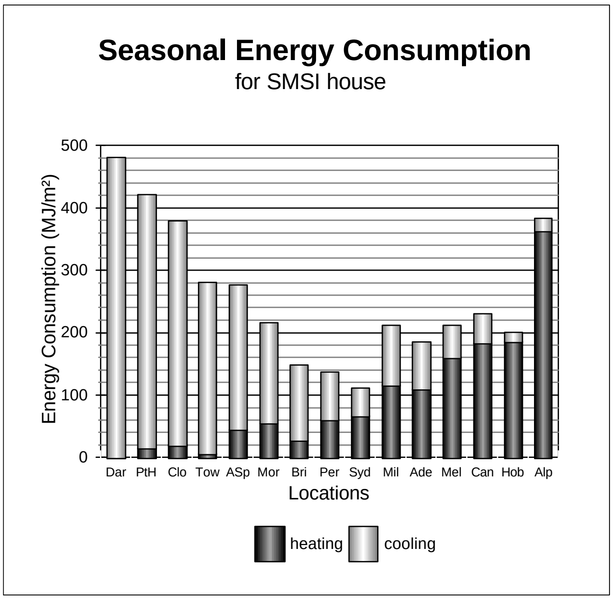

Figure 2 Heating and cooling requirements for Australian locations

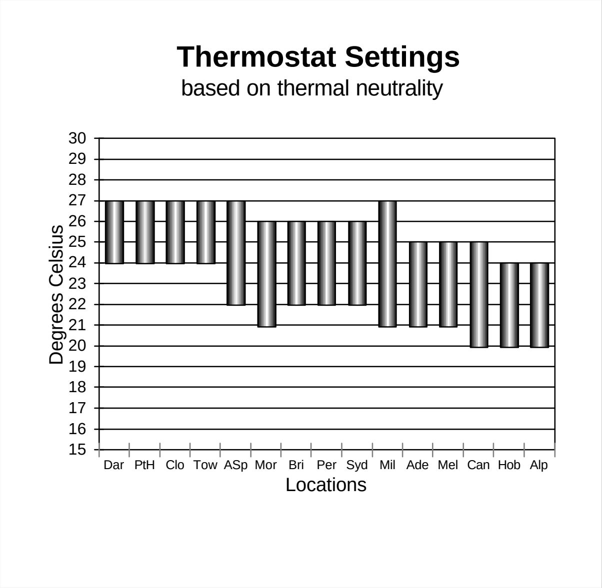

Figure 3 Thermostat settings used to calculate the heating and cooling requirements.

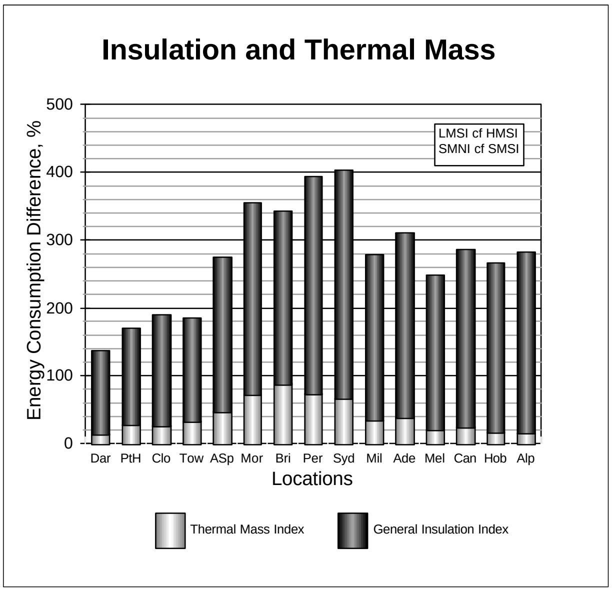

Figure 4 Energy consumption differences attributed to by insulation and thermal mass effects.

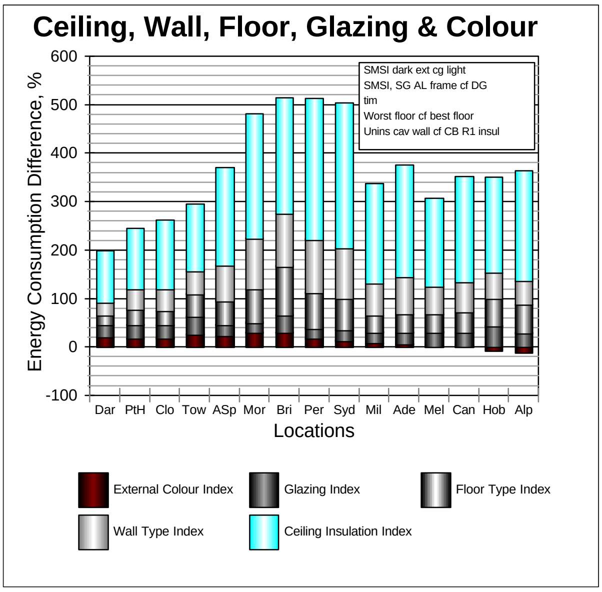

Figure 5 Consumption differences attributed to by ceiling, wall, floor, glazing and frame type and colour effects.

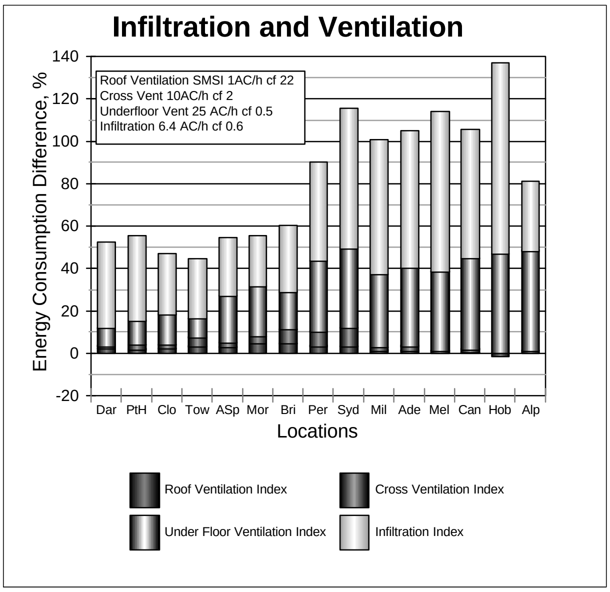

Figure 6 Energy consumption differences attributed to by infiltration and ventilation effects.

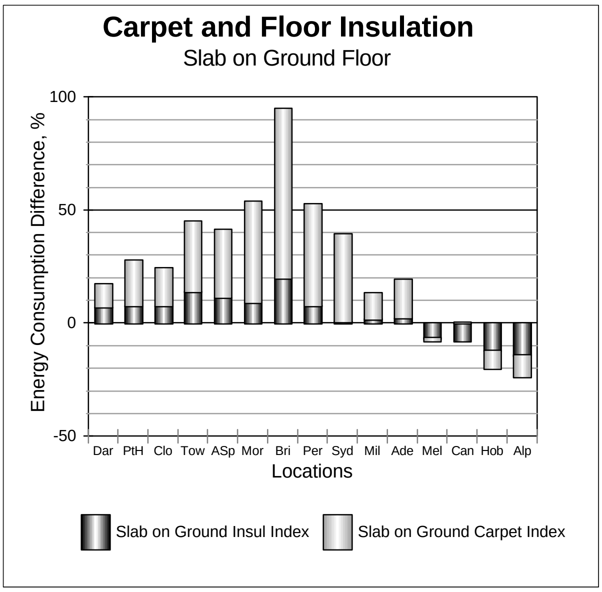

Figure 7 Energy consumption differences due to carpets and underfloor insulation. in houses with concrete slab on ground floors

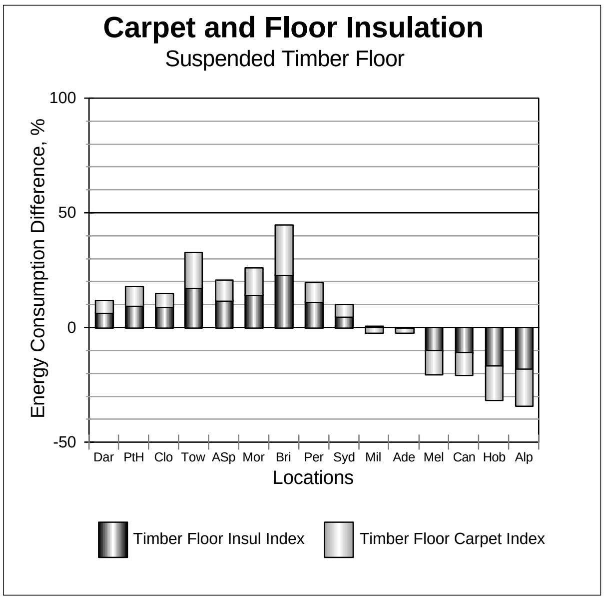

Figure 8 Energy consumption differences due to carpets and underfloor insulation. in houses with suspended timber floors.

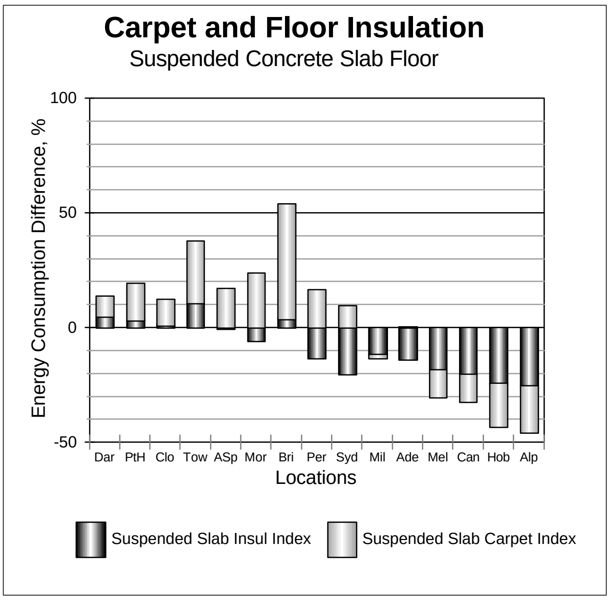

Figure 9 Energy consumption differences due to carpets and underfloor insulation in houses with suspended slab concrete floors.

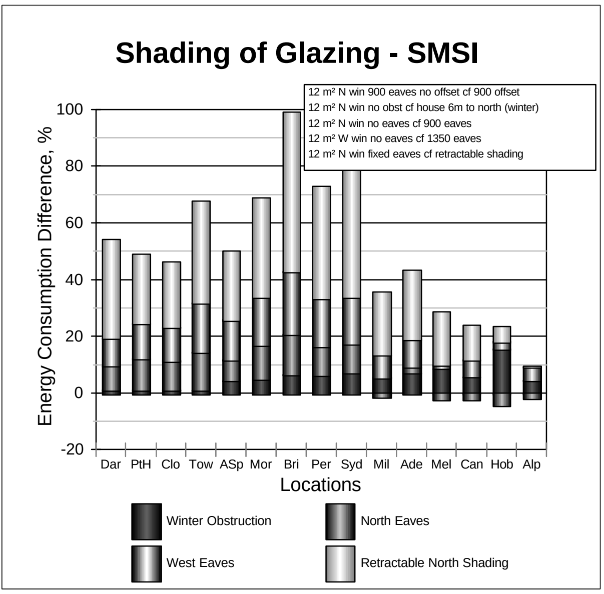

Figure 10 Energy consumption contributed to by shading the glazing of the SMSI house.

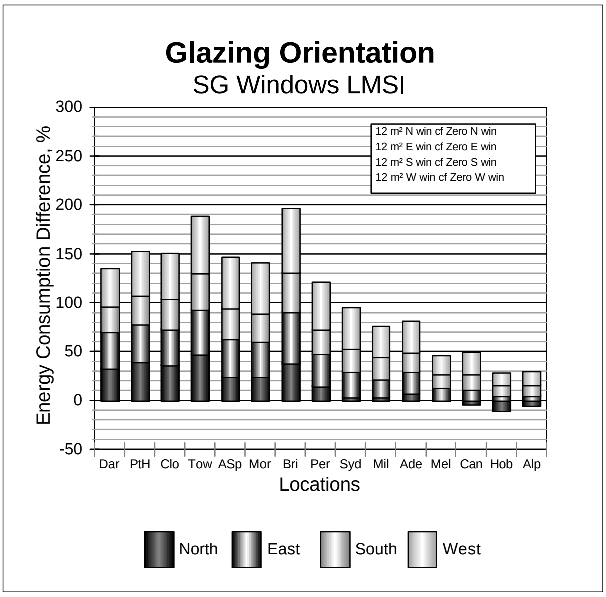

Figure 11 Energy consumption contributed to by glazing area and orientation in the LMSI house.

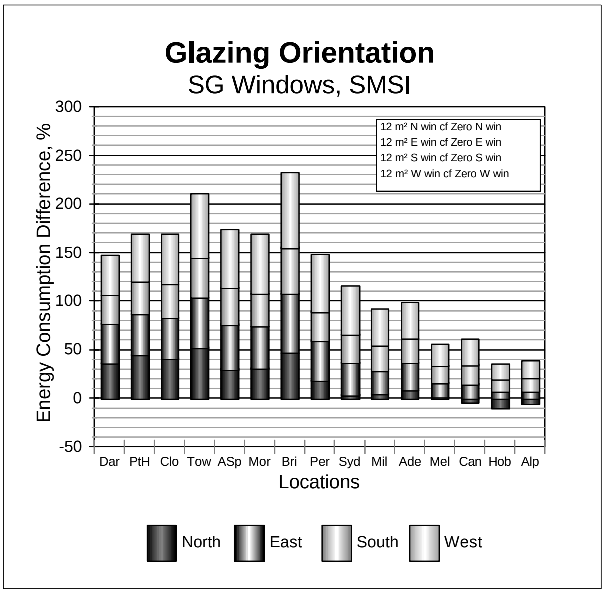

Figure 12 Energy consumption contributed to by glazing area and orientation in the SMSI house.

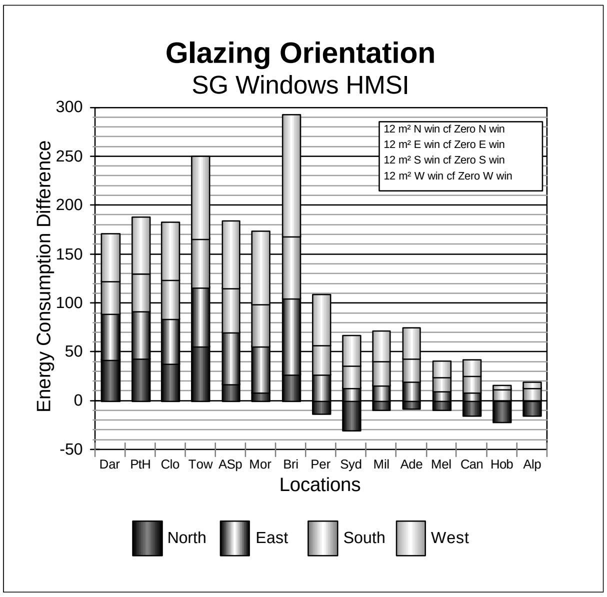

Figure 13 Energy consumption contributed to by glazing area and orientation in the HMSI house.