Comparison of the Thermal Performance of Free Running and Conditioned Houses in the Brisbane Climate

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SUMMARY

This paper looks at the apparent differences in thermal design requirements of houses which are thermally conditioned to remain comfortable, with the requirements of houses which are allowed to free run with no heating or cooling inputs. The results of a series of thermal computer simulations using BERS and CHENATH are reported which examine the effects of changes in building parameters on the thermal performance of houses run in both the conditioned and free running modes. A simple rectangular house was modelled as the standard for comparing the thermal effects of variations in building materials and design. The thermal performance of a house running in the conditioned mode has been quantified in terms of the annual heating and cooling energy needed to maintain the sleeping and living zones within a fixed temperature band. The thermal performance of a house when free running has been quantified in terms of degree hours of discomfort in these zones, where allowances have been made for acclimatisation throughout the year and for variations in relative humidity.

INTRODUCTION

This paper looks at the thermal performance differences in response to parametric changes between houses which are heated and cooled to maintain comfort temperatures and the same houses when they are free running with no additional energy inputs. Four thousand house variations were simulated with BERS (from Solar Logic) which incorporates CHENATH (from CSIRO), using hourly climatic data from 1986.

The large range of climates experienced in Australia have lead to different ways of maintaining indoor comfort in various locations. In the colder southern regions most houses have an inbuilt heating system, ranging from an open fire or a slow combustion heater in one or two rooms to central heating. Cooling is generally available only if heating is provided by a heat pump which can be reverse cycled. In the Northern Territory, the northern coastal areas of Queensland and Western Australia, as well as many inland regions of Australia, cooling is often provided as a central ducted system or in just one or two rooms. Either refrigerated or evaporative cooling may be used, depending on the humidity of the location.

Much of the housing in northern New South Wales, Southern Queensland and within mild climate zones elsewhere, has neither heating nor cooling built into the dwellings. Here, small convection heaters or bar radiators are used if it gets too cold in the morning or evenings, and fans provide air movement when it gets too hot in summer. In these regions it may be considered to be inappropriate to measure the thermal performance of a house in terms of heating and cooling energy requirements. It may be more useful to look at the frequency and magnitude of temperature excursions outside of the comfort band, ie in terms of degree hours of discomfort.

MODELLING THE HOUSES

A simple rectangular house was modelled as the standard or "base house". The floor plan is shown in Figure 1.

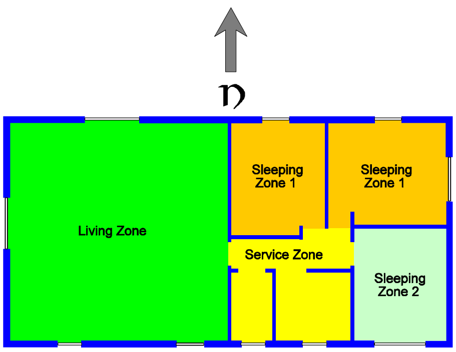


Figure 1. Floor plan of the base case house.

Variations of this house were simulated for this study. In some cases three mass levels and three levels of insulation were simulated.

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

The three levels of insulation were:
No insulation (NI)
Standard insulation (SI): RFL in external walls, R2.5 in ceiling, no floor insulation
High insulation (HI): R2 in external walls, R4 in ceiling, R2 under floor.

When the houses were modelled in the conditioned mode, the heating and cooling thermostat settings, 22 and 26 °C, were determined by calculating the thermal neutrality of the three hottest and three coldest months respectively.

When the houses were modelled as free running the methodology used to calculate the degree hours of underheating and overheating was as follows. A comfort zone is defined on a monthly basis as a 4 K wide band around the thermal neutrality temperature as determined by the method of Auliciems. This is shown in Figure 2. The upper limit of that band changes on an hourly basis in response to relative humidity. Higher than 50% RH will lower the upper limit while a lower RH will raise this limit in accordance with the ASHRAE standard effective temperature lines, (Figure 3). The yearly degree hours of discomfort within a zone of a house is calculated as the sum of the hourly Kelvin deviations outside of the comfort limits.

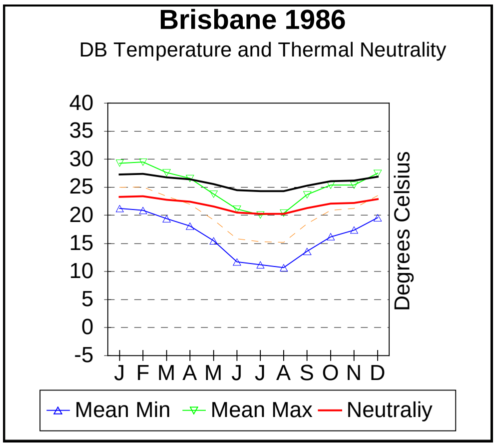
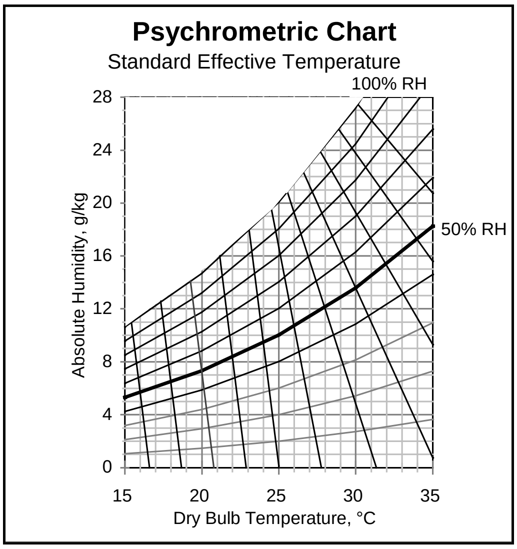


Figure 2. Dry bulb maximum and minimum temperatures and thermal neutrality comfort band.

Figure 3. Lines of effective humidity compensated temperature superimposed on a psychrometric chart.



The conditioned model calculates the heating and cooling energy requirements, (MJ/m²), of the living and sleeping areas of the house for the time period between 7 am and 12 pm. In order to be able to compare degree hours of discomfort with energy required to maintain comfort, a single pair of overheating and underheating degree hour figures were calculated for this same time period. Each living and sleeping zone was given a weighting in proportion to its area as a fraction of the total. The sums of the area weighted degree hours of discomfort of three zones provide the figures used.

No attempt has been made to account for the physiological cooling effects of air movement due to ventilation or fans. Whether or not breezes can be of benefit in this way depends on several factors:

- wind speed
- wind direction
- degree of air flow possible in the house when the wind comes from that direction
- the difference between the temperature of the breeze and the temperature in the house
- the position of the occupants relative to the air flow paths

Local wind speed and direction depend on topography which can vary greatly over a short distance, so data measured at airports, (which is where most of the Australian climate measurements used in simulations are made), particularly wind direction, may not be of use to determine the direction air should flow through the house when it is built on the side of a hill or in a gully. The occupants spend time in different parts of the house, so it is unlikely that they will be in an air stream at all times. Perhaps a way of dealing with this problem is to increase the upper comfort boundary by one to three Kelvin, depending on the presence of ceiling fans and an estimate of air flow through the house. This has not been attempted here.

SIMULATION RESULTS

This section examines the differences in the effects on thermal performance of changes in thermal building parameters when the houses are simulated in the free running mode rather than being simulated in the conditioned mode.

The right side graph of Figure 4 shows the results of simulations of the 9 house mass-insulation variations when conditioned to remain between 22 and 26°C. The left side shows the results for the houses in the free running mode when the comfort band is adjusted for thermal neutrality and

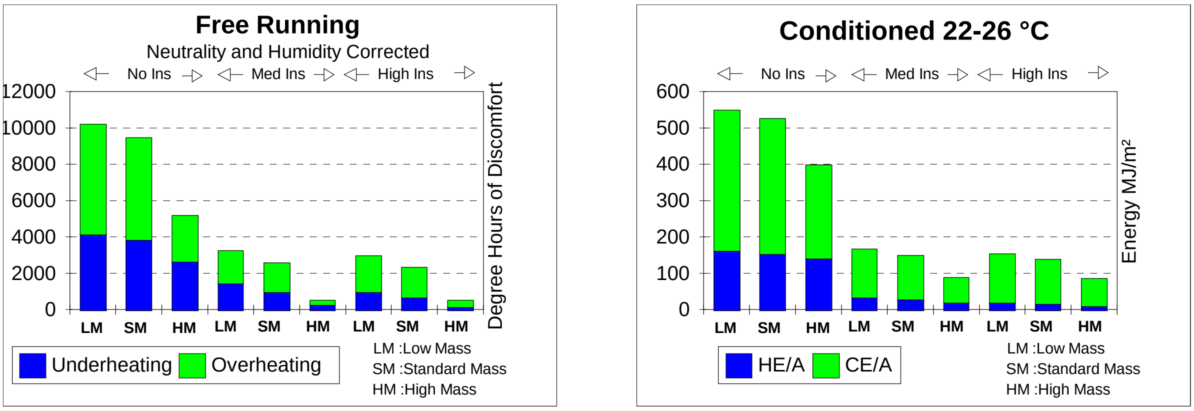


Figure 4. The effect of mass-insulation variations on performance when houses are free running and conditioned.

humidity. Clearly the ratio of heating to cooling energy is less than the ratio of underheating to overheating degree hours.

The graphical results which present comparisons of thermal performance when the houses are operated in the two different modes use a scale which has been chosen so that 100 MJ/m² on the graph of conditioned mode is equivalent to 2000 degree hours of discomfort on the graph of the free running mode. This makes the scale for the conditioned mode approximately 10% greater than for the free running mode, so when the graphs are compared, the height of the data points on the right hand side should be reduced by about one tenth.

Thermal Mass

The graphs of Figure 4 show that thermal mass is of more value to a house when it is free running than when it is conditioned. The main differences occur between the high mass house, (which has internal walls of brick, and brick on the inside of insulation or air gap of the external walls), and the standard or low mass version. When used in the free running mode, the performance of the uninsulated high mass house is twice as good as the uninsulated low mass house. In the conditioned mode however, this difference is halved.

The difference in performance between these two house types when the houses are insulated is even greater in the case of the free running mode than the conditioned mode. The degree hours of discomfort of the high mass house are only about a quarter that of low mass house, while energy use of the low mass house is about half that of the high mass house.

Most of the other performance differences between the two modes of operation which are discussed below can be linked to this difference in the way thermal mass is valued.

Ceiling and Roof Insulation

The two graphs of Figures 5 show the changes in performance of the SMSI house as the level of ceiling and roof insulation is varied. The curves are very similar which suggests that ceiling and roof insulation have the same effect on performance irrespective of whether the building is analysed as being conditioned or free running.

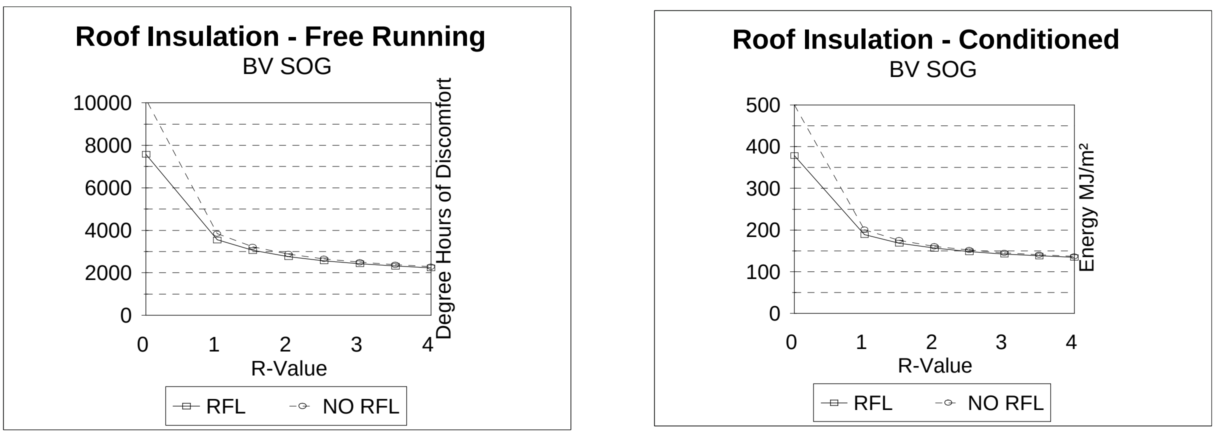
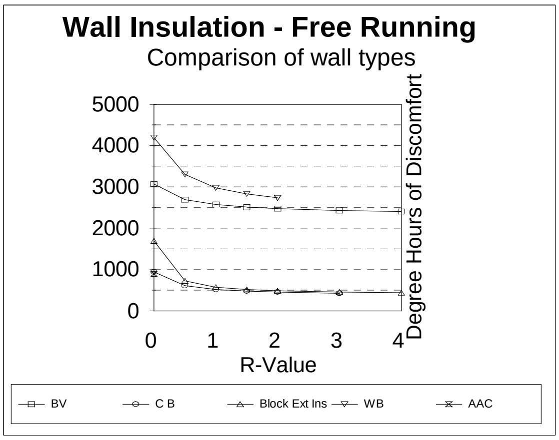


Figure 5. The effect of roof/ceiling insulation on the thermal performance of the standard mass house.



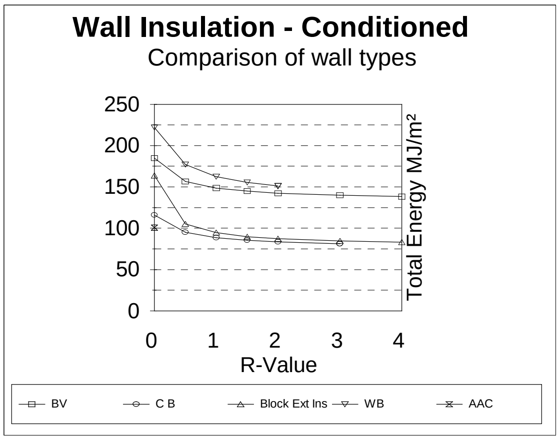


Figure 6. The effect of insulation on the thermal performance of houses incorporating a range of wall types.

Wall Insulation

Both graphs of Figure 6 show a marked separation between the performance of houses with high mass external walls and similar houses with low mass walls. The curves for the low mass walls are almost identical for the two modes of operation. Although a conditioned house with high mass walls performs better than the same house with light weight walls, the difference in performance is only about half as much as the difference between high mass and low mass walls when the house is analysed in the free running mode.

It appears that differences between the contribution of walls to the thermal performance of a conditioned house and their value to a free running house are due to any differences in thermal mass rather than insulation.

The effect on thermal performance of the relative positioning of mass and insulation when the mode of operation differs was examined. Tilt up concrete walls which are either externally or internally insulated, were compared with insulated cavity brick walls. As expected, the high mass external walls perform better when the house is free running rather than conditioned. Perhaps less obvious, but logically consistent, is that the difference in performance between externally and internally insulated mass walls is also much greater for free running houses than for conditioned dwellings.

Floor Insulation

The performance of houses with different types of floors which are all uncarpeted were simulated. When the floors are uninsulated, all three floor types appear to perform better when the house is in the free running mode than when it is conditioned. Both the slab on ground floor and the suspended slab floor have thermal mass that is immediately accessible to the air of the room above, so it is not surprising that the houses perform better in this mode.

A possible explanation for the better performance of the bare uninsulated timber floor when the house is free running is as follows. The timber floored house is modelled as having a 0.5 m high crawl space that is fully enclosed around the perimeter. This makes the mass of the ground partially available to the floor, and so even the timber floor would be valued more in this mode.

When the insulation under the timber floor is increased from zero, the performance rapidly decreases in the free running mode until it is similar to what it would be in the conditioned mode. This is to be expected as the insulation under the timber floor increasingly isolates the room from the mass of the ground. Both the suspended and on ground slabs have sufficient thermal mass so that even when considerable insulation is placed beneath, it is valued more when the house is analysed in the free running mode. The performance of the slab on ground approaches that of the suspended slab as the insulation beneath is increased, and the slab is increasingly isolated from the mass of the ground.

The effect of floor type, when carpeted, on performance for each of the two modes of operation was examined. As expected, the carpet partially isolates the thermal mass of the floor, and the ground beneath, from the room above. Consequently there is little difference in the performance of the different floor types when the building is operated in different modes.

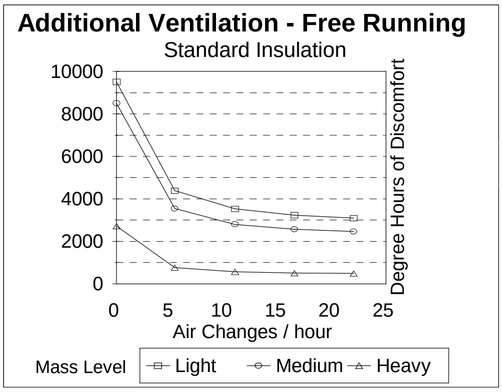
Infiltration and Ventilation

The effect of infiltration rate on the performance of 9 mass-insulation house combinations, when operated in both free running and conditioned modes, was investigated. There is very little difference in performance between the two modes of operation for the light and medium weight houses. The heavy weight houses, however, perform much better in the free running mode, as expected.

Variations in roof space ventilation rate seem to affect the performance of the SMSI house to the same degree irrespective of the mode of operation used. Thermal mass is not involved so variations due to different operating modes would not be expected.

The sensitivity of thermal performance to variations in under floor ventilation rate for the free running and conditioned modes of operation were examined for houses with timber floors. Although the performance is similar at low ventilation rates, as the rate increases, there is a greater reduction in performance when the building is free running than when it is conditioned. The under floor ventilation rate is important in determining the rate at which the heat or "coolth" stored in the ground under the floor is degraded. This in turn determines how effectively the ground provides thermal storage access to the room above. Since thermal mass is of more value to a house that is free running, it is to be expected that an increase in under floor ventilation rate will have greater consequences for buildings when they are operated in this mode.

The effect of additional ventilation on the performance of houses with different mass levels, when operated as free running or conditioned, is illustrated in the graphs of Figure 7. As expected, the heavy building performs better when in the free running mode than when conditioned.



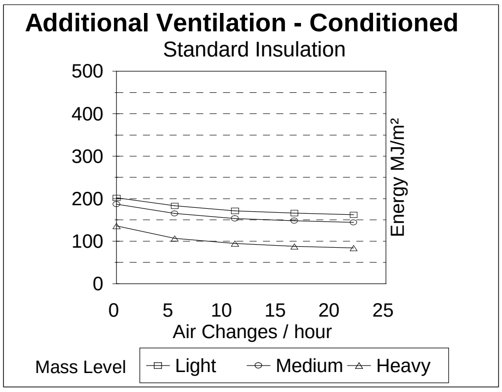


Figure 7. The effects of additional ventilation on the performance of houses with different thermal mass levels.

Houses of all three mass levels are able to utilise relatively small ventilation rates to lower the temperature of the building in the late afternoon and evening to a much greater extent when free running. This is primarily due to differences in opportunity. The conditioned house will have its doors and windows opened when the indoor temperature increases until it approaches the cooling thermostat setting. Ventilation will then stop and cooling begins. The overheated free running house will allow ventilation to occur at all times, provided that indoor temperatures exceed that that of the outside air. Consequently ventilation is more effective when the building is free running, particularly when the ventilation rate is less than 10 AC/h, (at wind speeds of 3.5 m/s).

External Colour

The only difference in performance between the conditioned and free running modes when three mass levels were simulated with different external colours, were due to mass being valued more, rather differences in external absorptance.

Glazing Type

The mode of operation does not seem to affect the performance of a range of glazing and frame combinations used in windows when no alterations were made to the window areas or eaves widths.

Glazing Area and Orientation

Extensive simulations were carried out to determine how the performance of different houses of three mass levels depend on the area and orientation of glazing, and the width of eaves. A subset of this data for variations to north facing windows in conditioned houses is presented graphically in Figure 8. Similar data is presented in the graphs of Figure 9 for the same glazing variations when the houses are analysed in the free running mode. The obvious difference between the two modes again relates to thermal mass, with the high mass house performing much better in the free running mode.

There is also a flattening in the curves of the performance of houses in the free running mode. This indicates that houses are less sensitive to increases in glazing areas, provided these areas are kept small. In the case of north facing windows, the flattening is actually a dip, which is most pronounced in the case of the high mass house. A significant increase in the performance of the high mass house is possible in the free running mode when a north glazing area of between 5 and 15 m² is provided. In the conditioned mode, the high mass house is insensitive to small areas of north glazing, but rapidly loses performance for glazing areas greater than about 5 m².

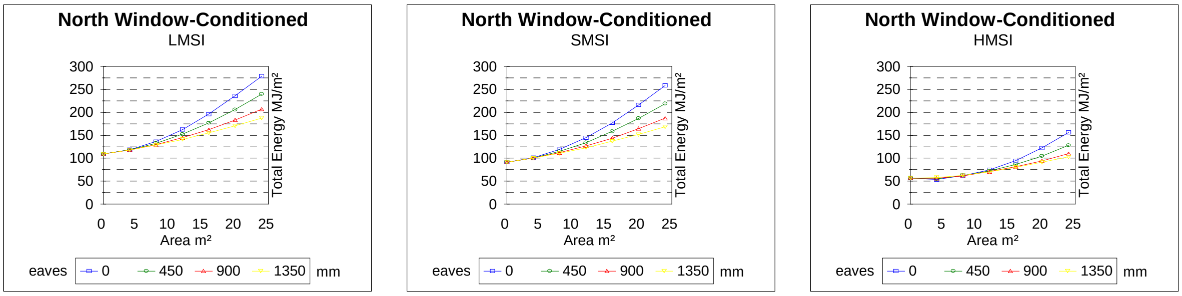


Figure 8. Comparative performance of north window variations in conditioned houses.

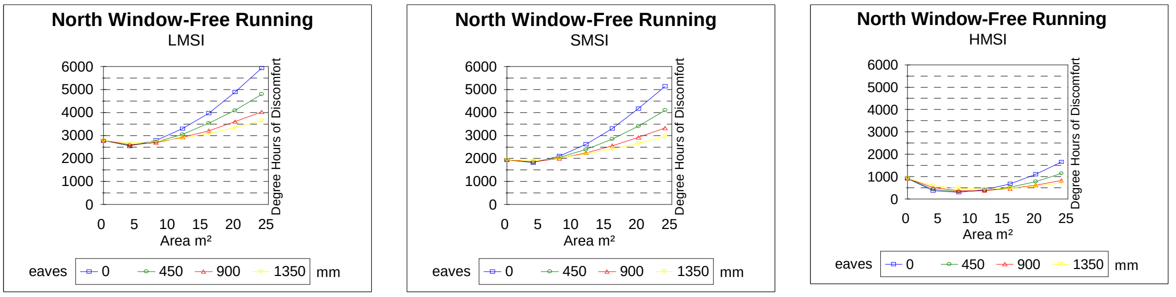


Figure 9. Comparative performance of north window variations in free running houses.

The graphs of Figure 10 show how the dip is produced for the free running version of the SMSI house when north window areas are varied. For relatively small areas of north glazing underheating occurs much more frequently than overheating. When the building is conditioned, the annual cooling load is considerably larger than the heating load, and the resulting curve continues to increase in height as the glazing area is increased.

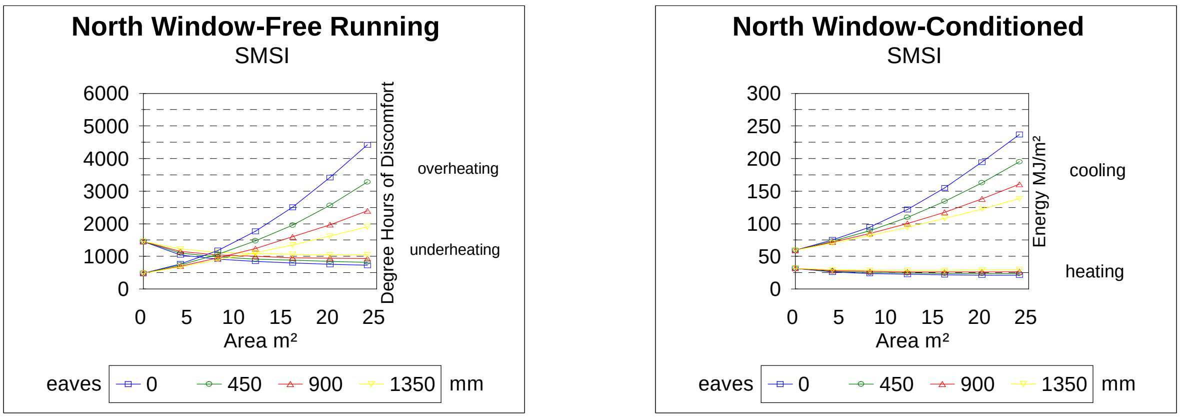


Figure 10. Seasonal thermal performance comparisons of north windows in the SMSI house.

CONCLUSION

The ratio of heating to cooling energy is less than the ratio of underheating to overheating degree hours. The best match for the neutrality and humidity corrected free running houses occurs for houses conditioned between 23 and 28 °C rather than the 22-26 °C comfort range calculated from the thermal neutrality of the three coldest and the three hottest months respectively.

Thermal mass is of more value to a house when it is free running than when it is conditioned. This is most likely due to the intermittent nature of the heating and cooling required in Brisbane. Most of the other variations between the two modes of operation can be linked to thermal mass.

There is a good correlation between the performance of a house in the free running mode and its performance in the conditioned mode when only the levels of insulation are varied.

Ventilation is more effective as a cooling strategy when the building is free running, particularly when the ventilation rate is less than 10 AC/h. The overheated free running house will allow ventilation to occur at all times, provided that indoor temperatures exceed that of the outside air. All ventilation stops, however, while the conditioned house is being cooled.

Houses are less sensitive to increases in glazing areas in the free running mode, provided these areas are kept small. This is primarily due to the ratio of under heating to over heating being greater than the ratio of heating to cooling in the conditioned mode.

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