The other story about glass in buildings

Having used NatHERS for several years to perform thermal modelling of residential buildings designed by our office and others, a story has been emerging that something isn't right with many architecturally designed houses. It's often the case that the modelling results are at odds with the thermal performance predicted by the architect. It's also often the case that these houses incorporate lots of glass for cross ventilation and lots of shading.

A common response to a poor NatHERS result is to question the adequacy of the modelling – the deficiencies of NatHERS having been widely publicised. The replacement for NatHERS is AccuRate. My experience using this new software shows that NatHERS was mostly right about the thermal performance of highly glazed buildings. The time has come for architects to question the perceived wisdom about the merits of highly glazed buildings.

A defining characteristic of many architecturally designed homes is lots of glass. To put this into perspective, a traditional project home has a ratio of glass to floor area of approximately 25 per cent whereas many of the buildings I have rated have a glass to floor area ratio of at least 70 per cent (the Farnsworth House is approximately 120 per cent).

The positive aspects of the use of glass in buildings, particularly the association with 'passive solar design' are frequently identified in awards entries and in the architectural media to the extent that highly glazed buildings have in a sense been accepted as 'green' or 'energy efficient'.

While we are all familiar with the potential benefits that glass can bring to a well-designed building there are many other characteristics of glass that are not commonly recognised by architects when describing the thermal performance of their buildings.

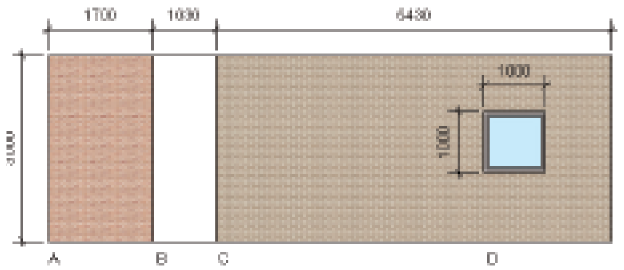
Glass has a very low insulation level

The thermal properties of glazing are by convention described in terms of a U value (the effectiveness of a building element to conduct heat), which is quite literally the inverse of an R value (the effectiveness of a building material to resist the flow of heat). It's possible to directly convert a U value into an R value by using the formula 1/U = R.

The U value of 3mm clear glazing is 5.9, which converts to an R value of only R0.17. To put this into perspective the R value of common construction materials are listed below.

6mm clear glazing = R0.17	10mm plasterboard sheet = R0.06
10mm clear glazing = R0.18	6mm fibre cement = R0.03
110mm masonry = R0.17	10mm render = R0.02

In comparison to individual materials, glass compares favourably. However, when construction elements (made from a combination of materials) are studied, glazed units are distinguished by their low R values compared with common wall systems.



Each of these wall areas transfers heat at the same rate
A = 5.2m² cavity brickwork
B = 3.1m² fibre cement on studwork
C = 18.3m² brick veneer walll with R1.5 insulation
D = 1m² aluminium framed clear glazed window

Aluminium framed window with 3mm clear glazing = R0.13
Cavity brickwork = R0.68
Fibre cement sheet on stud framing = R0.41
Brick veneer with R1.5 bulk insulation = R2.38

Both U and R values are measured relative to the area of a material, meaning that the amount of heat transferred through an equal area of a given material will be directly proportional to the U or R value of that material.

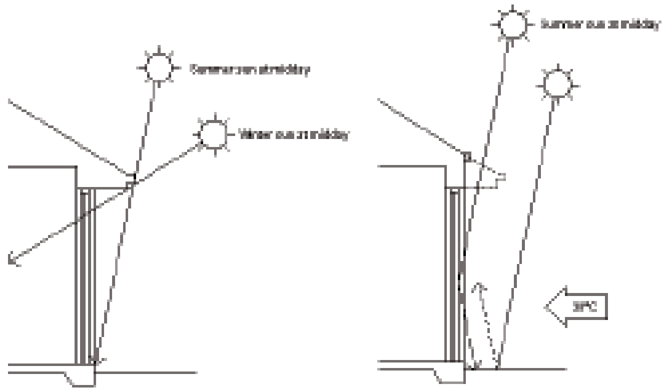
For example, 1 square meter of single glazing will transfer heat at a rate 3.1 times the equivalent area of an uninsulated FC clad stud wall or 18.3 times the equivalent area of a brick veneer wall with R1.5 insulation.

Clearly glass is not a good material to be building walls from if you're wanting to resist heat transfer into and out of a building.

Those lovely evening shots with the internal lights on and the building glowing in the landscape against a setting sun are similar in appearance to the images that would be taken with a thermal imaging camera (heat radiation is another form of light). It's a good rule of thumb that if light is escaping from a building then heat is also escaping or entering the building the same way.

Sunshading alone will not prevent excessive heat entering a building

I'll leave a discussion about what constitutes effective sunshading to another time, but a good test for the effectiveness of sunshading can be carried out in both NatHERS and AccuRate by applying operable external louvres to all windows of a building. In both cases the shading is going to be operated by the software on an hourly basis to optimise performance (clearly better than is achieved in most real situations).



Many architects rely upon solar geometry in terms of sun angles to calculate effective shading, often resorting to a diagram such as the one above at left to describe 'passive solar' principles – excluding summer sun and allowing winter sun to enter the building. Horizontal shading projections to the northern facade are sized to exclude direct sun from striking the glass facade at midday on the summer solstice. The sun then progressively strikes larger areas of glass as it moves towards the winter solstice so that a majority of the winter solstice sun enters the building.

But the diagram at left only tells part of the story about the performance of the window. The diagram above right is also happening. The poor insulation levels of the glass mean that if it's hot outside it will soon be hot inside. Thermal modelling tends to predict that, at best, a heavily glazed building will do little better than track external air temperatures. At worst, heavily glazed buildings are consistently cooler in winter and warmer in summer than external temperatures.

Few shading strategies take into account reflected sunlight. When you consider that even grass is about 10 per cent reflective and the sun is approx 1500W/m² at midday in summer you have a lot of potential for heat gain from sunlight reflecting under shading devices.

Even if no shading devices are present, summer midday sun is largely reflected from glazing as the reflectivity of glass increases dramatically as the angle at which the sun strikes the glass moves away from 90°.

Shading devices, and some window tints, that are heated by the sun can re-radiate their heat back into the building counteracting their benefit. Tinted glass also reduces performance in winter.

Double glazing is not significantly better than single glazing

While double glazing undoubtedly has higher insulation properties than single glazing (single 3mm clear float U = 5.9, double glazed 3/12/3 clear float U = 2.7, a 120 per cent improvement) the level of insulation offered by double glazing is still six times less than would be offered by a brick veneer wall with R1.5 insulation.

The relative difference between a double-glazed window and an insulated brick veneer wall is further decreased due to the impact the frame has on the performance of the window unit (framing materials are often highly conductive).

A useful reference for evaluating the relative thermal performance of complete window units is the Window Energy Rating Scheme (WERS) – it provides U values for glazed window and door units including their frames. WERS figures indicate that an aluminium-framed, clear single-glazed window will have a U value of 7.73, whereas an aluminium-framed, clear double-glazed window will have a U value of 5.0. This represents only a 50 per cent improvement when frames are included compared to a 120 per cent improvement if glass alone is considered.

Simply changing from aluminium to timber framing is almost as effective as double glazing – a single-glazed timber framed window has a U = 5.46, a 40 per cent improvement.

A thicker aluminium frame decreases a window's performance due to the higher proportion of highly conductive material used in the frame.

Double glazing is also not very effective at reducing the amount of direct sun entering a space. A useful reference for evaluating the shading effectiveness of different glazing options is to evaluate the solar heat gain coefficient (SHGC) values. 3mm clear float has a SHGC = 0.86, 3/12/3 clear float SHGC = 0.76. Therefore double glazing is only 13 per cent better at reducing direct sun infiltration than single glazing. If double glazing is used, it should be combined with effectively designed shading devices to avoid overheating.

Cross ventilation is not as effective as imagined

One of the big improvements in AccuRate (compared to NatHERS) is its ability to take into account the cooling benefit of air movement on skin, and its more sophisticated assessment of the potential benefits of cross ventilation. But is cross ventilation really of benefit?

Cross ventilation is assessed for its ability to reduce temperatures at times when conditions inside the building are outside the 'comfort zone'. If external temperatures at these times are high, then the software closes down the cross ventilation pathways and they are of no benefit to the rating.

If conditions within the building are already in the 'comfort zone' then cross ventilation is of limited use as the rating scheme does not distinguish between degrees of comfort in the 'comfort zone'.

Cross ventilation is in many ways a risky strategy as it:

- is reliant upon the vagaries of occupant behaviour
- is subject to requirements for security
- may impact occupant comfort levels through excess internal air speed (papers blow off a desk), increased environmental noise, dust, insects, limited internal privacy (doors must be open between rooms).

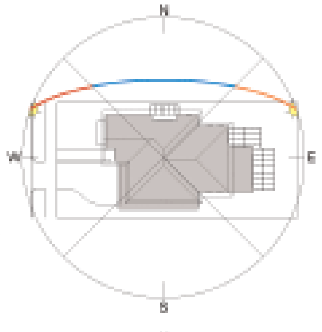
The pros and cons of this strategy should be seriously considered compared with other strategies such as the incorporation of well-shaded thermal mass. If the adoption of cross ventilation is contingent upon excessive areas of glazing, especially at times when cross ventilation is shut down due to high external temperatures, then it will be of limited benefit to a rating.

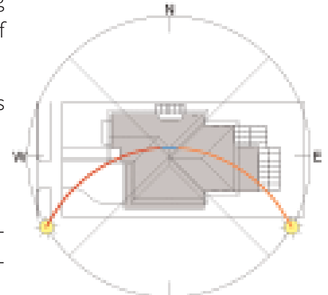
Western sun is not very powerful

The problem with western sun is not its intensity – it is often a fraction of the strength of the northern sun due to the greater distance that it travels through the atmosphere as a result of its low angle in the sky.

The problem with western sun is that it's available for more hours of the day in summer and only for a very limited period of the day in winter. Western sun also strikes glass at an angle closer to a right angle, meaning that more of it is transmitted into the glass at a time of day that happens to be the hottest.

Western sun is to be avoided, but not because it's stronger than northern sun.





Top
Winter solstice sun path for Sydney identifying the proportion of sun in each segment of the sky. The majority of the sun is in the northern segment. Eastern and western facades have very little solar exposure at this time.

Above
Summer solstice sun path for Sydney. The majority of the sun appears on the eastern and western segments.

Some strategies to consider

Used responsibly, glass has the potential to be of significant benefit. Maximise this potential by adopting the following design strategies.

Use passive solar design principles for placement of windows, but consider limiting the amount of glazing to 40 per cent of the floor area. This figure is still high and achieving good performance will be difficult unless the design is carefully handled. Bear in mind that a northern glazed facade can collect about six hours of energy from the sun in the middle of winter, but that must be balanced against the next 18 hours of heat loss.

Consider using higher performing combinations of glazing and framing, especially if glazed areas are extensive. The days of single-glazed aluminium-framed facades are numbered. Use WERS to compare the performance characteristics of window and door combinations.

When selecting a product based on a U value, choose the lowest one available as it has the highest R value. If aluminium framing is to be used, consider using a thinner framing section or even better using a thermally improved frame that has less conductivity.

Consider sunshading for times other than the summer solstice as there are other times that sunshading will be of benefit. Consider glazing with a low e coating or tint to improve summer performance.

If an area is to be excessively glazed, consider isolating it from other living areas so that at times of extreme temperature its influence will be limited. This won't help with its rating, as this is based upon whole of house performance, but it will make your client's life more comfortable.

Consider embracing the art of making openings in walls rather than designing for an absence of wall.

Anthony Nolan