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Converting Second-Generation NatHERS Tools to Use NFRC-based Window System Data

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EXECUTIVE SUMMARY

In 2006, Australian glass and window industry bodies introduced fenestration system product ratings that comply with the National Fenestration Rating Council (NFRC), assessing windows and skylights against a new fixed set of environmental conditions, NFRC 100-2001.

To use NFRC-based window system data, the engine of the Second-Generation NatHERS Tools and its window data files (WDFs) needed to be updated.

CSIRO, engaged at the time by the then Australian Greenhouse Office, investigated issues involved in converting second-generation NatHERS tools to use NFRC-based window system data.

The findings were reported in Delsante and Lyons (May 2007), which recommended implementation options for the conversion. On the basis of this study, CSIRO was engaged by the AGO, in November 2007, to further implement these recommendations and test the feasibility of a Performance Matrix (PM) approach for generating a manageable set of NFRC-based WDFs to cover the likely range of *U*-values and SHGCs.

The current study in this report accomplished the following deliverables:

1. The AccuRate engine has been modified to handle window system data at NFRC conditions.
2. A Delphi® application has been written to create NFRC WDFs for the AccuRate window library.
3. A window naming convention has been recommended for defining the frame material so as to achieve correct application of boundary conditions by the AccuRate engine.
4. Five pairs of window systems have been selected, with the windows in each pair having the same *U*-value and SHGC but differing with respect to glass type, frame material, vision fraction or specific solar aperture. The feasibility of a performance matrix approach was investigated by AccuRate modelling of four

different house types in eight different climates using the five window pairs. It was found that:

a. For all the five Window Pairs and four house types, the maximum differences of total annual energy were found almost exclusively in cooling-dominated climates and the minimum differences in heating-dominated climates, with the mixed climates in between;
b. Among all the combinations of window pairs, houses and climate zones investigated, the maximum percentage difference in total annual energy was found to be 19.7% for a Medium House in Brisbane (a cooling-dominated climate), which also has the maximum star rating difference of 0.5 star among all the combinations. Considering the large difference in star rating, this suggests that the PM approach with only *U*-value and SHGC as the performance indicators may be not suitable for cooling-dominated climates in Australia;
c. Assuming a star rating difference tolerance of 0.3 star, a PM approach with *U*-value, SHGC and with the addition of *specific solar aperture* as the performance indicators may be suitable for all climates in Australia.
d. For a PM approach using *U*-value, SHGC and specific solar aperture as the performance predictors, WDFs with a large set of PM windows, possibly 1000 ($10 \times 10 \times 10$) or more, may be required to cover the likely range of the three parameters in sufficiently fine steps.

Recommendations

Based on the current study, it is recommended that

1. With a 0.3-star difference tolerance, a PM approach using *U*-value, SHGC and specific solar aperture as the performance predictors may be suitable for all climates in Australia. However, to cover the likely ranges of these three parameters in sufficiently fine detail may require a large set of PM windows – possibly of the order of 1000. Unfortunately this reduces the attractiveness of the PM approach compared with using the full set (4000+) of custom windows, which will grow as more fenestration products become rated and certified. Consequently, a three-parameter PM approach is not recommended for implementation in the second-generation NatHERS tools at this stage;

2. WDFs for the NFRC-rated generic windows from the BCA generic table should be generated and made available in second-generation NatHERS tools. In this case, verification need only be visual (glass and frame type).

3. Further work is needed to establish whether a workable PM approach is possible.

4. Irrespective of whether a workable PM approach is possible, we recommend that WDFs for the current full set of custom windows be created. The Delphi® application developed in this project can be used to create the required NFRC WDFs for these windows. If a workable PM approach is not possible, these custom windows must be made available in second-generation NatHERS tools if no other alternative to the PM approach is found. If a PM approach is possible, the custom windows need not necessarily be made available.

1. BACKGROUND

In 2006 NFRC-compliant product ratings were introduced by the Australian glass and window industries, whereby windows and skylights are rated at a new fixed set of environmental conditions known as NFRC 100-2001. The NFRC 100-2001 winter condition, which is the ASHRAE Winter Condition, is used for *U*-value calculations and is an extreme condition, being far colder (-18°C) and windier (5.5 m/s) than most Australian outdoor conditions. However, whole-building simulation engines such as used in AccuRate need to model the effect of varying weather conditions over a year. The main effect of varying air temperatures and especially varying wind conditions is that the thermal transmittance of a glazing system changes from hour to hour. The solar heat gain also changes continually because apart from the obvious angular dependence, it also depends on convective effects which are a function of weather conditions.

The current link between fenestration product ratings and AccuRate is the Window (or Skylight) Data File, hereafter referred to as a WDF. WDFs have existed for over a decade and are based on fenestration products modelled at so-called Australian National Average Conditions (ANAC). An ‘average’, area-weighted, all-year-round *U*-value is determined for the frame and is passed to AccuRate via the WDF. Unlike the glazed part of the product, this ANAC frame *U*-value is not adjusted within the AccuRate engine for varying wind conditions. While this is an approximation, it is not a serious issue because ANAC are not extreme. The introduction of NFRC ratings means that the AccuRate engine must be modified to recalculate both glazing gap resistances and frame *U*-values at each hour.

The WDF is a text file, the format of which was developed by CSIRO to suit its AccuRate software. The change to NFRC conditions means that at the very least current WDFs must be re-created to contain NFRC data. The data in WDFs are assembled from the output of simulations done with the Window 5 and Therm 5 public-domain software from Lawrence Berkeley National Laboratory (LBNL), and a knowledgeable and experienced NFRC or AFRC-certified simulator is needed to create correct WDFs.

The change to NFRC conditions provides an opportunity to review WDFs, both in terms of their content and the need to create a WDF in the current (custom) format for any fenestration system that is to be listed in the user interface of second-generation tools.

A previous study documented in the CSIRO report to the then AGO on NFRC window data, by Delsante and Lyons (May 2007) presented the following conclusions and recommendations:

Conclusions from the May 2007 study

1. The use of the simple method for calculating frame *U*-values at conditions very different from NFRC-100 is likely to result in acceptable errors at the whole-house energy rating level, except possibly for very good glazing in a poor frame.
2. For very good glazing in a poor frame the errors involved in using the simple method may be of concern at the whole-house energy rating level, as they exceeded 5% for one test case, a well-insulated house in Canberra.
3. For a skylight with a near-zero projected frame dimension (PFD)[1], the error in the system *U*-value calculated within AccuRate can be in excess of 25%, because

[1] E.g. for a sill, PFD = frame height in millimetres.

the frame *U*-value is greatly underestimated. However even with three relatively large 1200 mm x 1200 mm skylights (used as roof windows) in a test house in Canberra, the error in the total annual energy was less than 1%. Thus the simple method for calculating frame *U*-values can also be used for skylights and roof windows as well as vertical windows.

4. If the simple method is used, the Window 5 detailed report contains almost enough performance data for the needs of AccuRate, although it does not provide enough space to describe the window system and glazing system properly.
5. Data missing from the Window 5 detailed report could easily be appended to the detailed report from Window 6, since there is still an opportunity for Window 6 (in the final stages of development by LBNL) to be modified as it is not yet approved for NFRC ratings.[2]
6. The Window 5 EnergyPlus report is technically flawed in its calculation of frame conductivity and is not suitable for frame calculations by AccuRate or any other whole-building energy simulation program.

Recommendations from the May 2007 study

1. For windows, skylights and roof windows the simple method should be used to calculate frame *U*-values in the AccuRate engine at each hour until an improved method is developed for calculating frame *U*-values at non-NFRC conditions.
2. The AccuRate engine be modified to implement the ISO 15099 equations for calculating gap resistances in multi-pane systems. As part of this project these equations have been implemented in a separate program that agrees well with the Window 5 software. The code can readily be inserted directly into the AccuRate engine. The incorporation of this code will need to be done in conjunction with the changeover to NFRC-based window system data, immediately after the Window Data File format has been established.
3. Further consultation, in particular with the AWA (Australian Window Association) and AGGA (Australian Glass & Glazing Association), is needed to decide on the future format of Window Data Files. The objectives are to provide adequate information but minimise any additional effort imposed on modellers and the window industry in general. This consultation has begun via both authors becoming members of the Technical Advisory Committee (TAC) of the Australian Fenestration Rating Council (AFRC), a body formed in 2006 which is licensed to apply NFRC technical procedures. The first meeting of the AFRC TAC was held in Melbourne on 20 March 2007, where the issues described in this report were discussed in detail and the various options for the future format of WDFs were discussed. Further work to test the viability of using a performance matrix approach will be undertaken by this committee as soon as possible.
4. At that stage, and subject to further consultation, the report (Delsante and Lyons, May 2007) recommended that WDFs in the current format, slightly modified as needed to deal with NFRC data, should be created for a limited number (perhaps 100) of 'performance matrix' (PM) fenestration systems that cover the likely range of *U*-values and solar heat gain coefficients, in reasonably small increments of

[2] A request has been made to LBNL and agreed to by their Windows & Daylighting Group on 6 August 2008 to include the additional information in the Detailed Report of Window 6 which still under development. This would enable facilitate improved implementation of frame conductivity calculations in the AccuRate engine.

each. However the robustness and viability of the PM concept needed to be confirmed.

The idea of the PM approach is to use *U*-value and SHGC (at normal solar incidence) as predictors of a glazing system's performance insofar as it affects a dwelling's annual heating and cooling energy. Instead of selecting a glazing system from a set containing thousands of specific, custom-rated windows with their associated data files, the AccuRate user need only specify a window parametrically by selecting a combination of *U*-value and SHGC from a table (the "Performance Matrix"). Each entry in the matrix is linked to a hypothetical, fully modelled window stored in AccuRate's window library, which has that particular combination of U and SHGC values. When the dwelling achieves a satisfactory star rating with the selected PM system, the user would source a 'real' window having an NFRC-certified performance that matches or exceeds that of the PM window used for the AccuRate simulation.

The Performance Matrix does not include any variability in air infiltration. While it is well understood that AccuRate's calculated annual energy also varies with window air infiltration, a separate study by Delsante and Lyons established that window air infiltration, up to 5 $L/m^2 \cdot s$, is much less influential than either *U*-value or SHGC. This is particularly true in cooling-dominated climates. Note that the benefits of natural ventilation are separately accounted for in AccuRate, via an occupant schedule for operable windows.

On the basis of the May 2007 study, the then AGO engaged CSIRO to carry out the current study to further implement these recommendations and to investigate the feasibility of the PM concept. The aims of the current project are:

1. Modify the AccuRate engine to handle window system data at NFRC conditions, including modifying the frame *U*-value at each hour.
2. Write software to read a Window 5 Detailed Report (W5DR) and an EnergyPlus Report (EPR) from which it outputs a binary file for use by the AccuRate user interface, and a separate binary file for the AccuRate simulation engine.
3. Establish a code for defining the frame material so as to achieve correct application of boundary conditions by the AccuRate engine[3].
4. Test the viability of the PM approach by selecting several pairs of window systems that have the same *U*-value and SHGC but differ with respect to glass type, frame material or vision fraction (one or more differences), and that cover the likely range of *U*-values and SHGCs, and assess the differences in annual energy calculated by AccuRate when run in say three different climates (e.g. Canberra, Sydney and Brisbane) for up to three different house types.
5. If step 4 results in acceptably small annual energy differences between nominally identical systems (i.e. having the same *U* and SHGC), develop a PM set of systems covering the expected range of *U*-values and SHGCs in small increments.
6. If step 5 is undertaken, provide the PM systems plus the BCA generic window systems as part of a new version of AccuRate.

This report presents the findings, conclusions and recommendations of this study.

[3] Boundary film coefficients for frames are material-dependent.

2. SOFTWARE TO CREATE NFRC WINDOW DATA FILES

For AFRC and NFRC rating purposes, windows and roof windows are modelled in Window 5, with frame performance parameters being first obtained using Therm 5. In both Therm 5 and Window 5 modelling, NFRC 100-2001 environmental conditions are used[4] which use the ASHRAE Winter condition for U-value and ASHRAE Summer for SHGC.

As pointed out in Section 1, the Window 5 detailed report (W5DR) contains almost enough performance data for the needs of AccuRate. However, it does not provide enough space to describe the window system and glazing system properly. In addition the W5DR lacks information required for gas conduction calculations in multiple glazing. This information is contained in the Window 5 EnergyPlus report (EPR). As shown in Figure 1, a Delphi® application has been written to extract the relevant information from both the W5DR and EPR, for each window system. This application furnishes the AccuRate window library files, which are binary-encoded for data security.

Window naming convention

In order for AccuRate to properly identify the window system and the dominant frame material (e.g. aluminium or timber), the following window naming convention is required when creating new windows in Window 5:

The first 20 characters of the system name must be unique to the set of systems being processed into one library file. Additionally, the last non-blank character within the first 20 characters of the window name is used as the code to identify the dominant window frame material, as shown in Table 1.

This window naming convention ensures that the correct Window 5 frame film coefficients, as shown in Table 2, are used in the AccuRate calculations. This also ensures that the assigned film coefficients are compliant with requirements of the NFRC Simulation Manual (2006).

Table 1 Codes for dominant window frame materials

Frame material	**Code**
Aluminium frame with no thermal break	A
Aluminium frame with thermal break	B
Thermally Improved Frame	I
uPVC or wooden frame	W

[4] In Window 5 under File | Preferences, the check box "Use Nominal Heights" is left unchecked, which means that the actual heights (for specific systems) are used to calculate the centre-of-glass U-values (U_{cog}).

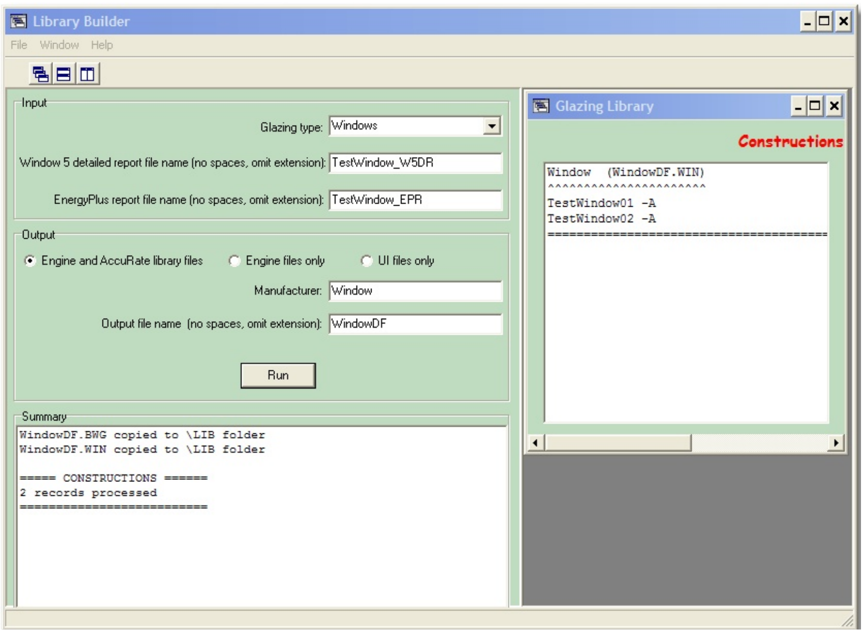

Figure 1. The Delphi® application that creates NFRC WDFs for AccuRate

Table 2 Window frame materials and the convection heat transfer coefficient (per NFRC Simulation Manual 2006, Table 6-3)

Boundary Condition	Radiation Model	Convective Film Coefficient			
		Tilt = 90°		Tilt = 20°	
		W/m²-°K	Btu/h-ft²-°F	W/m²-°K	Btu/h-ft²-°F
NFRC 100-2001 Exterior	Blackbody	26	4.578	26	4.578
Interior Aluminum Frame (convection only)	AutoEnclosure	3.29	0.579	4.94	0.869
Interior Thermally Broken Frame (convection only)	AutoEnclosure	3.00	0.528	4.38	0.771
Interior Thermally Improved Frame (convection only)	AutoEnclosure	3.12	0.549	4.60	0.81
Interior Wood/Vinyl Frame (convection only)	AutoEnclosure	2.44	0.429	3.38	0.595
WINDOW Glazing System boundary condition <filename>:<glazing system name> U-factor Inside Film	AutoEnclosure	Depends on the WINDOW calculations for the imported glazing system			

3. MODIFICATION OF ACCURATE ENGINE

The AccuRate engine has been modified to accept NFRC-based window information via NFRC WDFs. This section describes the modifications and improvements implemented in the AccuRate Engine.

3.1 Glazing System U-Value Implementation

Single glazing

The AccuRate engine has been modified to update the hourly *U*-value (U_{NEW}) of single glazing using the *U*-value at NFRC conditions (U_{NFRC}) as follows:

$$\frac{1}{U_{NEW}} = \frac{1}{U_{NFRC}} - \frac{1}{h_{o,NFRC}} - \frac{1}{h_{i,NFRC}} + \frac{1}{h_{o,NEW}} + \frac{1}{h_{i,NEW}} \qquad (1)$$

where h_o and h_i are the outdoor and indoor surface heat transfer coefficients at the condition indicated. The surface heat transfer coefficients at NFRC are supplied in the window data file. At other conditions, they are calculated by the AccuRate engine for all the window systems at each hour.

Multiple glazing

Multiple glazing includes gaps between panes containing air or argon/air mixtures (and potentially other gases in Australian-manufactured windows in future). The thermal resistances of such gaps depend on the temperatures of their bounding surfaces (as well as their emissivities and the glazing slope), which in turn are determined by the changing indoor and outdoor conditions.

The existing version of AccuRate uses fixed values for the gap resistances. This is an approximation and is only possible because ANAC conditions are not extreme. However, if gap resistances are provided at NFRC conditions, they will seldom be typical for general conditions anywhere, because the NFRC's ASHRAE Winter condition is an extreme design condition. Thus it was necessary for the simulation engine to re-calculate gap resistances at the conditions prevailing at each hour of the calculation.

The gap resistance is the inverse of the sum of the convective and radiative conductances. Equations for calculating the convective conductance are given in ISO Standard 15099:2003, section 5.3.3.

The AccuRate engine has been modified to calculate conductivity, density, specific heat and dynamic viscosity for any mixture of air, argon, krypton and xenon. Testing showed that the modified AccuRate engine gave very good agreement with the resistances calculated by Window 5 for a range of temperature differences, gap widths, tilts and surface emissivities[5].

3.2 Window Frame U-value Implementation

The convective coefficients for the frame (from Table 6-3 of the NFRC Simulation Manual) are specified as 26.0 W/m^2.K outdoors and values ranging from 3.29 W/m^2.K (Aluminium) to 2.44 W/m^2.K (timber) indoors (see Table 2). Because the radiative coefficients are not readily available in Window 5, they were estimated from the radiative glass coefficient as

$$h_{r,frame} = \frac{\varepsilon_{frame}}{\varepsilon_{glass}} h_{r,glass} \qquad (2)$$

where $h_{r,frame}$ and $h_{r,glass}$ are the radiative frame and glass coefficients, and ε_{frame} and ε_{glass} are the frame and glass emissivities respectively.

Because the frame data in the WDF are now at NFRC 100-2001 conditions, which are highly unrealistic for most Australian climates, it was necessary to modify the AccuRate engine so that at each hour the frame *U*-value, as well as the glass *U*-value, was re-calculated according to the prevailing conditions. As discussed in Delsante and Lyons (2007), this is very difficult to do precisely because frame heat flow is not one-dimensional. However that study did conclude that, while imperfect, estimating the frame *U*-value by simply subtracting the surface coefficients at NFRC-100 and adding the coefficients at the prevailing conditions would result in acceptable accuracy on a whole-building basis.

The AccuRate engine calculates surface coefficients for the glass according to temperature difference and air speed. It does not calculate the corresponding coefficients for the frame - in fact it would need a Therm 5 simulation to calculate the frame radiative heat transfer correctly. This would have to be repeated for all 8760 hours in an annual building simulation, which is not feasible. Instead, the indoor and outdoor frame coefficients were calculated in AccuRate at each hour by assuming that the convective coefficients are the same as the glass convective coefficients, and that the radiative coefficients are given by Eq. (2).

[5] Except for non-horizontal systems with heat flow down (a realistic example being a roof window in summer, where the outdoor temperature exceeds the indoor temperature). For such cases Window 5 appears to be in error as it does not agree with a hand calculation from the equations in ISO Standard 15099. However this error, even if confirmed, does not affect the use of Window 5 to calculate NFRC U-values, since they are calculated at a winter condition.

4. FEASIBILITY STUDY OF THE PERFORMANCE MATRIX APPROACH

4.1 Background of the Performance Matrix Approach

Although it is possible to use the Delphi® application described in Section 2 to generate WDFs for custom window systems, it will be time-consuming to do so for the thousands of custom windows and skylights that have appeared in the Australian market. The WDFs would need to be created and maintained by an experienced user, and updated and thoroughly checked frequently to accommodate additional window systems. This approach requires substantial resources and is obviously complicated and error-prone. Considering this, Delsante and Lyons (2007) recommended that a much simpler Performance Matrix (PM) approach be tested.

There appears to be a prevalent but untested assumption that if two window systems have the same *U*-value and solar heat gain coefficient (SHGC), then their performance, when installed in a real building subjected to time-varying indoor and outdoor conditions (and in particular varying angles of incidence for solar radiation), will be the same in terms of, for example, annual heating and cooling energy consumption. If this assumption is right, then a PM approach is feasible.

With the PM approach, a range of window systems is selected or developed to cover the full range of possible *U*-value and SHGC combinations, in reasonably small increments of *U*-value and SHGC. Perhaps a few hundred such 'Performance Matrix' (PM) systems - a relatively small number - might be needed, and their WDFs can be created manually, once.

With the PM approach, the only essential systems available in second-generation tools would be the limited number of PM systems, plus the generic systems listed in the Building Code of Australia. Custom window systems could also be made available but would no longer be essential. Buildings would be rated using either one of the generic systems or one of the PM systems. In the former case verification need only be visual (glass and frame type). In the latter case, when the building is to be built and an actual custom system must be chosen, the custom system need only match the *U*-value and SHGC (within specified tolerances) of the PM system used to obtain the rating. Thus suppliers of new (and existing) custom window systems need only provide the NFRC-compliant *U*-value and SHGC.

The PM approach will avoid the need to create a WDF (in any format) for every new or existing custom window system. This approach requires fewer resources for the modification and maintenance of the WDFs and is less error-prone. However, before the PM approach can be adopted, the robustness and viability of the PM concept need to be confirmed. In this section, the feasibility of the PM approach is investigated.

4.2 Specific Solar Aperture and Heat Gain from Window

The SHGC of a single-glazed window system can be calculated in a simplified way as

$$SHGC = f_v \tau(0) + \left[\frac{f_v \alpha(0) U_g}{h_0} + \frac{f_f \alpha_f U_f}{h_0} \right] \qquad (1)$$

where f_v is the vision fraction, f_f is the frame fraction (= 1- f_v), $\tau(0)$and $\alpha(0)$ are the glazing transmittance and absorptance at normal angle of incidence, U_g and U_f are the glass and frame *U*-values, h_o is the outdoor surface coefficient, and α_f is the frame absorptance. The term, $f_v\tau(0)$, is referred to as specific solar aperture in this report. For simplicity, edge-of glass effects are ignored.

In Eq.(1), the first term of the RHS represents the directly transmitted solar radiation into a room, which may be defined as the specific solar aperture of the window. As schematically shown in Figure 2, AccuRate assumes that all the directly transmitted solar radiation strikes the floor first. Some is reflected (according to the floor reflectance) and is then absorbed by other indoor surfaces (note that this is a simplified description). Due to the thermal mass of the floors, walls and ceilings etc, this directly transmitted solar gain is not immediately released to the indoor air, and the heat-release speed is determined by the thermal mass of the surfaces, the indoor surface convection coefficients, and the temperature differences between the indoor air and the indoor surfaces.

The second and third terms of the RHS in Eq. (1) represent the portion of the solar gain which is convected to the indoor air after being absorbed by the glazing and the frame of the window system. Consequently, this part of the solar gain directly and immediately impacts on the indoor air temperature.

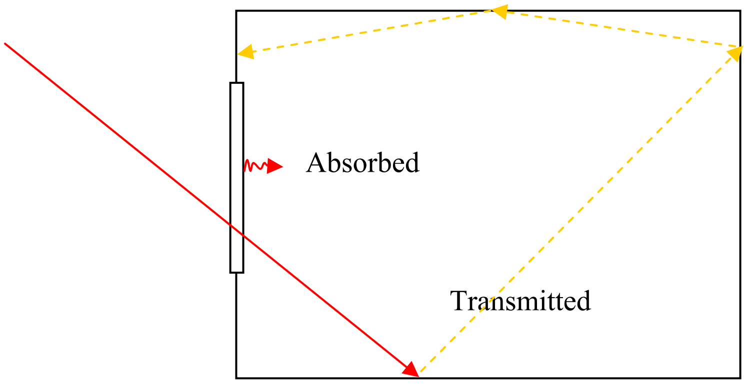

Figure 2. Schematic view of the heat gains from a window.

From the above discussion, it is clear that these two parts of the solar gain from a window system have different paths towards the final indoor heat gain. In order for two window systems to have similar performance in terms of heating and cooling energy requirements, the specific solar apertures of the two windows may need to be matched in addition to the *U*-values and SHGCs.

4.3 Window Systems for the Performance Matrix Study

In the current AccuRate WDFs at ANAC conditions, the *U*-values and SHGCs lie within the bands 0.97 - 5.97 W/m^2·K and 0.17 - 0.86 respectively. With the PM approach, the *U*-values and SHGCs would vary in discrete steps within these bands. In order to limit PM window selection set to, say, 100 windows, the step size for both the *U*-value and the SHGC would represent an approximately 20% increase between successive value points. If a PM window selection set of 400 windows is used, then the step increase for both the *U*-value and SHGC will be approximately 10% between successive value points.

To investigate the feasibility of the PM approach, five pairs of glazing systems were selected. Each pair was developed so its members had a marked difference in some or all of the following parameters: vision fraction, frame solar absorptance, centre-glass *U*-value, centre-glass SHGC and specific solar aperture. In this way, nominally equivalent windows in terms of overall *U*-value and SHGC, but having significantly different constructions and optical properties, could be compared in AccuRate.

Details of the five pairs of glazing systems are given in Table 3. Window 1a has a SHGC 4.8% less than that of Window 1b, while the system *U*-values differ only by 0.3%. All the remaining four window pairs have closely matched *U*-values and SHGCs except for pair 3 which has a *U*-value difference of 3.4%. Eight windows in Table 3 have aluminium frames, one has a composite aluminium/timber frame while one has a full timber frame.

Pair 1 differs greatly in total area, vision fraction, visible transmittance (VT) and glass transmittance. Their glazing systems have differing angular dependencies, defined by Window 1a having VT < 0.645 while Window 1b has VT >= 0.645 [6]. Window 1a has a much high frame absorptance of 0.80 compared with Window 1b of 0.20. It should also be noted that the specific solar aperture of Window 1a is significantly lower than that for Window 1b.

Pair 2 differs significantly in vision fraction, visible transmittance (VT) and glass transmittance. Like Pair 1, the two windows have different angular dependencies. Windows 2a and 2b have the same frame absorptance of 0.30. The specific solar aperture of Window 2a is significantly higher than that for Window 2b.

Pair 3 has similar angular dependencies but different combinations of glazing system *U*-value and frame *U*-value to give the same overall product *U*-value. They contrast a composite aluminium/timber frame with a full timber frame. Pair 3 windows have closely matched specific solar aperture.

Pair 4 contrasts single-glazed low-e in a composite aluminium/timber door with tinted double glazing in a timber window. Pair 4 windows have different angular dependencies and significantly different frame absorptances, but closely matched specific solar aperture.

Pair 5 contrasts air and argon-filled double glazing units, both in aluminium frames but with different product sizes (door versus window). The specific solar apertures of the two windows are closely matched.

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[6] VT = 0.645 is a threshold defined in ASHRAE Handbook, 2005 Edition, Chapter 31, Table 12. The curve-fit coefficients in Table 12 are applied by Window 5 when it calculates angular properties of coated and uncoated glazings and reported in Window 5 Detailed Report and EnergyPlus Report.

4.4 Houses for the Performance Matrix Study

Four well-insulated houses were used for the Performance Matrix Study. Descriptions of these houses are listed in Table 4. Houses No. 1, 2 and 4 are single-storey and House No.3 is a double-storey home. All the houses have no indoor window coverings or fixed shading in order to avoid masking any differences between the window systems. House No.4 (Medium House with 32% more glazing) is the same as House No.2 except that the window areas are 32% greater than those in House No.2 (Medium House).

4.5 Houses for the Performance Matrix Study

AccuRate simulations were carried out for the four houses using the five window pairs in eight climate zones, which can be grouped into cooling-dominated, heating-dominated and mixed (balanced) climate zones as listed in Table 5.

Tables 6-9 show the modelling results of the total annual energy for the four houses. In these tables, a negative value of percentage difference means that the annual total energy using window (a) is less than that using window (b) of the given window pair.

4.5.1 Cooling-Dominated Climates

From Tables 6-9, it can be seen that for each window pair, the maximum differences in total annual energy are almost exclusively in cooling-dominated climates and the minimum differences are in heating-dominated climates, with the mixed climates in between.

For all the four houses investigated, the maximum percentage differences and absolute differences in the total annual energy always occur in cooling-dominated climates by using Window Pair 1.

Among all the combinations of window pairs, houses and climate zones investigated, the maximum percentage difference in total annual energy was found to be 19.7% for House No.2 (Medium House) in Brisbane using Window Pair 1, which has a maximum star-rating difference of 0.5 star among all the combinations. Window Pair 1 also results in 0.5 star differences with House No.2 (Medium House) in Alice Springs and with House No.4 (Medium House 32%) in Brisbane.

It is noted that the window systems in Window Pair 1 and Window Pair 2 have different angular dependencies and a significant difference in specific solar aperture, while Window Pairs 3-5 have closely matched *U*-values, SHGC and specific solar aperture. If Window Pair 1 is excluded, the maximum percentage difference in total annual energy is 9.4% for House No.4 (Medium House 32%) in Brisbane by using Window Pair 2, which has a star rating difference of 0.3 star. If both Window Pair 1 and Window Pair 2 are excluded, the maximum percentage difference in total annual energy is 8.7% for House No.4 (Medium House 32%) in Alice Springs by using Window Pair 5a and 5b, which has a star rating difference of 0.3 star.

From Tables 6-9, it was found that the annual energy requirements using Window 4a and 4b have relatively small difference in all the climates and houses investigated, although Windows 4a and 4b have different angular dependencies in their glass transmittance. The maximum star rating difference for all the combinations of house and climate using Window 4a and Window 4b is 0.2 star. Consequently, it appears that different angular dependencies of the glass transmittance may have a relatively small impact on annual energy requirement.

From Tables 6-9, it was found that the total annual energy requirement for any house and climate combination using Window 1a is higher than that using Window 1b. This is unexpected for cooling-dominated climates considering that Window 1a has *a lower* SHGC than Window 1b. Table 10 shows the annual cooling and heating energy requirements for all the house and climate combinations using Window 1a and Window 1b. It is seen that for all the climates and houses, using Window 1a always results in higher annual cooling energy requirement compared with using Window 1b. For cooling-dominated and mixed-climates, the cooling energy requirement using Window 1a was found, in general, 10-30% higher than those using Window 1b. This much higher cooling energy requirement using Window 1a results in the higher total annual energy requirement in cooling-dominated and mixed-climates.

Such a significantly higher cooling energy requirement using Window 1a is likely to be caused by the significantly lower specific solar aperture compared with Window 1b as shown in Table 3.

In heating-dominated climates, cooling makes an insignificant contribution to the total annual energy requirement. As shown in Table 10, the heating requirements using Window 1a are generally higher than those using Window 1b, which is likely due to the smaller SHGC of Window 1a. However, the differences in the heating energy requirements are relatively small, being in the range of 1-2% for Window Pair 1.

Table 11 shows the annual cooling and heating energy requirements for all the houses and climates using Window Pair 2. It was found that using Window 2b always results in a higher annual cooling energy requirement in all climates and houses investigated. Similar to the results for Window 1a and Window 1b, this high cooling energy requirement using Window 2b is likely to be caused by the significantly lower specific solar aperture of Window 2b compared with Window 2a.

4.5.2 Heating-dominated Climates

For heating-dominated climates, the differences in annual total energy by using a given window pair are relatively small and the differences in star rating are less than 0.1 star except for Window Pair 1 which results in 0.2-star difference.

4.5.3 Mixed Climates

For mixed climates, the maximum star-rating difference of 0.4 star was found in Richmond for using Window Pair 1 for House No.2 (Medium House). If Window Pair 1 is excluded, the maximum star-rating difference of 0.2 star was found in Richmond using Window Pair 4 for Houses No.2 (Medium House) and No. 4 (Medium House 32%).

4.5.4 Summary of the Modeling Results

Table 12 is a brief summary of the modeling results of the maximum percentage differences and the maximum star rating differences for the four houses in the eight climate zones using the five Window Pairs. Based on the current study, a maximum star rating difference of around 0.5 star is possible in cooling-dominated climates using windows with identical *U*-values and SHGCs.

Assuming a star rating difference tolerance of ±0.3 star, then a line can be drawn based on this PM study as shown by the blue line in Table 12. Above the line, the 0.3-star tolerance is exceeded and below the line, the difference is smaller than 0.3 star. From Table 12, it is seen that with a 0.3-star tolerance, the PM approach with only *U*-value and SHGC as the performance predictors may be suitable for heating-dominated climate zones (BCA Climate Zones 6, 7, 8). For mixed climates and cooling-dominated climates (BCA 1, 2, 3, 4, 5), an additional parameter – specific solar aperture needs to be matched for the PM approach to be valid (assuming a star rating difference tolerance of 0.3 star).

Consequently, a PM approach with *U*-value, SHGC and specific solar aperture as the performance predictors may be appropriate for all the climates in Australia. With the PM approach, the windows specified for the real house construction need to closely match or exceed the SHGCs, *U*-values and specific solar apertures used in the AccuRate modelling using PM windows. It should be noted that the requirement for actual window selection will be different for different climates. In cooling-dominated climates, actual windows may be specified having *U*-values, SHGCs matching or lower than those of the PM window and with the specific solar aperture to be higher than that of the PM window. In heating-dominated climates, the requirement of specific solar aperture can be removed, the actual windows with matching or lower *U*-values and matching or higher SHGCs compared with those of the PM window should be used. In mixed climates it is likely to be on a case-by-case situation for individual climate.

For a three-parameter PM approach, WDFs with approximately 1000 ($10 \times 10 \times 10$) or more PM windows may be required to cover the possible range of three parameters. This could potentially make the PM system relatively unattractive, given the effort of constructing the 1000+ PM window systems and the fact that an AccuRate user would need to chose a PM window from a 1000+ PM window library.

It is noted that there are numerous possible combinations of window systems, houses and climate zones. The current study cannot cover all the possible scenarios and should be considered as a guide to the possible extent of differences in star rating and total annual energy in using the PM approach.

Table 3. Data for window pairs used for Performance Matrix Study

System no.	Glass	Frame material	Frame Absorptance	Height (mm)	Width (mm)	U (W/m^2.K)	System SHGC	U % Diff	SHGC % Diff	Visible Transmittance of Glass Centre	Visible Transmittance of Window	Glazing Solar Transmittance (Normal)	Vision Fraction	Specific Solar Aperture
			α_f							VT	VTw	$\tau(0)$	f_v	$f_v \times \tau(0)$
1a	tint	Al	0.80	1200	1500	6.415	0.565	0.3	-4.8	0.594	0.520	0.477	0.875	0.418
1b	lam	Al	0.20	600	1500	6.398	0.592			0.886	0.643	0.737	0.726	0.535
2a	clear	Al	0.30	1500	600	6.324	0.510	1.6	0.6	0.893	0.498	0.814	0.558	0.454
2b	tint lam	Al	0.30	1500	1200	6.224	0.507			0.412	0.346	0.426	0.840	0.358
3a	hi-sol LE, Ar	Composite Al/timber	0.40	600	1500	2.340	0.483	3.4	-0.2	0.753	0.490	0.588	0.651	0.383
3b	hi-sol LE, air	Cedar	0.30	600	1500	2.261	0.484			0.738	0.512	0.560	0.694	0.389
4a	tint, hi-sol LE, Ar	Al	0.30	2000	2000	2.748	0.347	-1.5	0.3	0.611	0.510	0.309	0.835	0.258
4b	tint, air	Al	0.75	1500	1200	2.790	0.346			0.667	0.483	0.355	0.724	0.257
5a	tint hard LE, air, clear	Al	0.45	2000	1000	3.661	0.291	-0.6	-0.3	0.501	0.352	0.266	0.703	0.187
5b	tint, hi-sol LE, Ar	Al	0.30	600	1500	3.682	0.292			0.611	0.390	0.309	0.638	0.197

Table 4. Details of the five houses used for Performance Matrix Study

House No.	**1. Small House**	**2. Medium House**	**3. Large House**	**4. Medium House 32% (with 32% more window area)**
Building Stories	Single	Single	Double	Single
Floor area (m^2)	113.1	188.6	265.6	188.6
Window area (m^2)	26.9	47.61	64.44	62.91
Window-to-floor area ratio (WFR)	23.8%	25.2%	24.3%	33.4%
Floor Construction	Concrete slab, no edge insulation	Concrete slab, no edge insulation	Concrete slab, no edge insulation	Concrete slab, no edge insulation
External Walls Construction	Brick Veneer R2.0 with outward reflective foil laminate (RFL)	Brick Veneer R2.0 with outward RFL	Brick Veneer R2.0 with outward RFL	Brick Veneer R2.0 with outward RFL
Ceiling Construction	Plasterboard 13mm + R5.0 bulk insulation	Plasterboard 13mm + R5.0 bulk insulation	Plasterboard 13mm + R5.0 bulk insulation	Plasterboard 13mm + R5.0 bulk insulation
Roof Construction	Tiles (concrete)	Tiles (concrete)	Metal deck flat roof with R2.0 and Tiles (terracotta)	Tiles (concrete)
House Facing	North	West	North	West
Blinds	None	None	None	None

Table 5. Climate zones used for Performance Matrix Study

Climate	**Locations used for PM study**
Cooling-Dominated	Darwin (NT), Alice Springs (NT), Brisbane (QLD)
Mixed (Balanced)	Adelaide (SA), Richmond (NSW)
Heating-Dominated	Canberra (ACT), Cabramurra (NSW), Tullamarine (VIC)

Table 6. Annual total energy and % difference with five window pairs for Small House (House No.1)

Climate	**Cooling-Dominated**						**Balanced**				**Heating-Dominated**					
Location	Darwin		Alice Springs		Brisbane		Adelaide		Richmond		Canberra		Cabramurra		Tullamarine	
Windows	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff
1a	**534.6**	6.5%	201.2	9.0%	76.1	**9.8%**	142.3	5.8%	126.3	7.9%	236.6	0.7%	543.4	1.2%	213.6	2.2%
1b	**501.8**		184.6		69.3		134.5		117.0		234.9		537.2		208.9	
2a	**472.4**	-3.2%	174.5	-2.3%	64.8	-4.3%	136.6	0.6%	116.7	-0.8%	247.4	3.3%	570.6	2.7%	222.7	2.5%
2b	**488.2**		178.6		67.7		135.8		117.6		239.4		555.6		217.3	
3a	423.6	0.5%	121.8	0.7%	49.2	0.6%	82.2	0.7%	75.8	0.4%	155.3	-0.2%	352.4	0.1%	125.6	0.0%
3b	421.3		120.9		48.9		81.6		75.5		155.6		352.1		125.6	
4a	376.8	-2.8%	103.6	-5.0%	42.5	-4.5%	83.7	-2.3%	75.4	-3.6%	175.1	0.6%	405.8	1.5%	147.8	0.6%
4b	387.5		109.1		44.5		85.7		78.2		174.1		400.0		146.9	
5a	375.2	3.8%	110.4	**6.3%**	45.1	4.4%	97.7	2.3%	86.2	1.2%	202.3	-1.0%	469.0	-0.5%	176.5	-0.5%
5b	361.3		103.9		43.2		95.5		85.2		204.4		471.2		177.4	

Notes:

Red bold – the maximum differences for all the eight locations with the five window pairs

Pink bold – the maximum differences for all the eight locations using all the window pairs except window pair 1a and 1b

Table 7. Annual total energy and % difference with five window pairs for Medium House (House No.2)

Climate	Cooling-Dominated						Balanced				Heating-Dominated					
Location	Darwin		Alice Springs		Brisbane		Adelaide		Richmond		Canberra		Cabramurra		Tullamarine	
Windows	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff
1a	**642.3**	8.6%	252.8	15.7%	129.2	**19.7%**	185.7	11.6%	177.6	15.9%	282.0	4.8%	602.7	1.5%	260.5	5.3%
1b	**591.6**		218.5		107.9		166.4		153.3		269.2		593.8		247.4	
2a	**559.8**	-4.2%	206.2	-6.4%	99.3	**-9.1%**	168.3	-3.4%	151.3	-5.3%	281.5	0.4%	630.8	2.4%	262.2	1.0%
2b	**584.5**		220.4		109.2		174.2		159.8		280.5		615.8		259.6	
3a	485.5	0.6%	138.1	1.5%	76.1	0.5%	101.7	0.6%	100.2	1.0%	179.2	0.1%	391.5	0.1%	150.0	0.3%
3b	482.6		136.1		75.7		101.1		99.2		179.1		391.1		149.6	
4a	426.7	-3.1%	117.9	-6.7%	63.1	-4.2%	103.5	-2.8%	96.9	-4.5%	198.4	-0.4%	451.5	1.6%	173.6	0.8%
4b	440.5		126.3		65.9		106.5		101.5		199.2		444.5		172.3	
5a	427.5	4.7%	128.6	8.5%	66.6	6.1%	121.1	2.8%	110.3	3.6%	230.0	-0.6%	521.2	-0.7%	207.5	-0.1%
5b	408.2		118.5		62.8		117.8		106.5		231.3		524.7		207.8	

Red bold – the maximum differences for all the eight locations with the five window pairs

Pink bold – the maximum differences for all the eight locations using all the window pairs except window pair 1a and 1b

Table 8. Annual total energy and % difference with five window pairs for Large House (House No.3)

Climate	**Cooling-Dominated**						**Balanced**				**Heating-Dominated**					
Location	Darwin		Alice Springs		Brisbane		Adelaide		Richmond		Canberra		Cabramurra		Tullamarine	
Windows	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff
1a	**532.9**	7.1%	236.3	8.3%	91.0	**10.6%**	171.6	6.2%	151.7	8.4%	241.4	2.6%	520.0	1.2%	229.3	3.2%
1b	**497.7**		218.1		82.3		161.6		140.0		235.2		513.9		222.2	
2a	473.1	-2.8%	209.6	-1.9%	78.8	-3.1%	164.3	0.1%	139.4	-1.2%	247.2	2.7%	**547.0**	3.1%	236.3	2.6%
2b	486.7		213.6		81.3		164.1		141.1		240.8		**530.7**		230.2	
3a	409.8	0.5%	140.4	1.2%	57.7	0.9%	97.7	0.5%	89.1	0.8%	145.6	0.3%	313.0	0.1%	126.4	0.5%
3b	407.9		138.8		57.2		97.2		88.4		145.2		312.6		125.8	
4a	363.5	-3.2%	122.5	-5.3%	51.3	-3.9%	98.5	-2.7%	86.9	-4.5%	162.2	-0.2%	365.1	1.5%	145.8	0.5%
4b	375.5		129.3		53.4		101.2		91.0		162.6		359.8		145.1	
5a	365.5	4.0%	133.3	**6.0%**	54.9	3.8%	115.0	2.5%	98.8	2.7%	191.8	-0.3%	431.9	-0.4%	177.2	0.0%
5b	351.5		125.8		52.9		112.2		96.2		192.4		433.8		177.2	

Red bold – the maximum differences for all the eight locations with the five window pairs

Pink bold – the maximum differences for all the eight locations using all the window pairs except window pair 1a and 1b

Table 9. Annual total energy and % difference with five window pairs for Medium House with 32% more window area (House No.4)

Climate	**Cooling-Dominated**						**Balanced**				**Heating-Dominated**					
Location	Darwin		Alice Springs		Brisbane		Adelaide		Richmond		Canberra		Cabramurra		Tullamarine	
Windows	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff	MJ/m^2	Diff
1a	**731.7**	9.3%	322.9	14.8%	155.8	**19.2%**	228.0	11.1%	222.9	16.9%	332.8	5.8%	688.0	2.0%	307.3	5.5%
1b	**669.4**		281.3		130.7		205.3		190.7		314.5		674.2		291.4	
2a	**632.4**	-4.1%	266.1	-5.9%	121.9	**-9.4%**	207.3	-2.9%	187.7	-5.7%	330.2	0.9%	719.1	2.6%	308.6	1.0%
2b	**659.5**		282.9		134.6		213.6		199.1		327.4		700.7		305.4	
3a	540.2	0.7%	177.5	1.1%	89.9	1.8%	121.2	1.1%	119.8	1.1%	195.5	0.2%	411.1	0.2%	164.8	0.4%
3b	536.7		175.5		88.3		119.9		118.5		195.2		410.2		164.1	
4a	470.1	-3.7%	150.9	-6.6%	73.7	-5.0%	121.2	-3.3%	114.1	-5.9%	217.1	-1.2%	480.3	1.5%	190.0	0.5%
4b	488.0		161.6		77.6		125.3		121.2		219.7		473.0		189.1	
5a	472.4	5.2%	164.7	8.7%	77.9	7.7%	143.3	3.7%	131.1	4.6%	256.8	0.3%	568.0	-0.4%	231.9	0.2%
5b	449.0		151.5		72.3		138.2		125.3		256.0		570.5		231.5	

Red bold – the maximum differences for all the eight locations with the five window pairs

Pink bold – the maximum differences for all the eight locations using all the window pairs except window pair 1a and 1b

Table 10. Annual cooling and heating energy requirement using Window Pair 1

Climate	**Cooling-Dominated**						**Balanced**				**Heating-Dominated**					
Location	Darwin		Alice Springs		Brisbane		Adelaide		Richmond		Canberra		Cabramurra		Tullamarine	
Houses (Window)	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2
No.1 (1a)	**0.0**	**534.6**	**23.1**	**178.1**	**11.8**	**64.3**	**68.1**	**74.2**	**53.4**	**72.9**	**202.0**	**34.6**	**536.7**	**6.7**	**185.2**	**28.4**
No.1 (1b)	0.0	501.8	24.5	160.1	12.1	57.2	68.5	66.0	56.1	60.9	205.7	29.2	531.9	5.3	183.6	25.3
No.2 (1a)	**0.0**	**642.3**	**32.8**	**220.0**	**18.6**	**110.6**	**86.6**	**99.1**	**70.4**	**107.2**	**230.8**	**51.2**	**592.6**	**10.1**	**215.8**	**44.7**
No.2 (1b)	0.0	591.6	32.3	186.2	18.3	89.6	85.4	81.0	71.4	81.9	231.9	37.3	586.9	6.9	212.5	34.9
No.3 (1a)	**0.0**	**532.9**	**35.4**	**200.9**	**20.0**	**71.0**	**81.9**	**89.7**	**63.7**	**88.0**	**201.0**	**40.4**	**515.3**	**4.7**	**191.6**	**37.7**
No.3 (1b)	0.0	497.7	36.5	181.6	20.2	62.1	81.3	80.3	65.8	74.2	201.9	33.3	509.9	4.0	189.0	33.2
No.4 (1a)	**0.0**	**731.7**	**42.5**	**280.4**	**24.7**	**131.1**	**103.3**	**124.7**	**84.6**	**138.3**	**264.0**	**68.8**	**673.2**	**14.8**	**249.2**	**58.1**
No.4 (1b)	0.0	669.4	42.2	239.1	24.1	106.6	101.3	104.0	85.4	105.3	263.4	50.9	664.2	10.0	244.3	47.1

Table 11. Annual cooling and heating energy requirement using Window Pair 2

Climate	**Cooling-Dominated**						**Balanced**				**Heating-Dominated**					
Location	Darwin		Alice Springs		Brisbane		Adelaide		Richmond		Canberra		Cabramurra		Tullamarine	
Houses (Window)	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2	Heating MJ/m^2	Cooling MJ/m^2
No.1 (2a)	**0.0**	**472.4**	**28.2**	**146.3**	**14.3**	**50.5**	**76.7**	**59.9**	**63.3**	**53.4**	**222.9**	**24.5**	**566.2**	**4.4**	**200.8**	**21.9**
No.1 (2b)	0.0	488.2	25.2	153.4	13.0	54.7	72.6	63.2	57.7	59.9	211.8	27.6	550.5	5.1	193.8	23.5
No.2 (2a)	**0.0**	**559.8**	**36.5**	**169.7**	**21.1**	**78.2**	**95.1**	**73.2**	**79.7**	**71.6**	**250.4**	**31.1**	**624.8**	**6.0**	**232.1**	**30.1**
No.2 (2b)	0.0	584.5	34.8	185.6	20.1	89.1	91.8	82.4	75.1	84.7	241.1	39.4	608.3	7.5	225.6	34.0
No.3 (2a)	**0.0**	**473.1**	**40.0**	**169.6**	**22.7**	**56.1**	**89.2**	**75.1**	**72.7**	**66.7**	**217.5**	**29.7**	**543.5**	**3.5**	**205.8**	**30.5**
No.3 (2b)	0.0	486.7	37.0	176.6	21.2	60.1	85.4	78.7	67.4	73.7	207.6	33.2	526.9	3.8	198.6	31.6
No.4 (2a)	**0.0**	**632.4**	**47.2**	**218.9**	**27.8**	**94.1**	**113.0**	**94.3**	**95.1**	**92.6**	**286.2**	**44.0**	**710.2**	**8.9**	**267.6**	**41.0**
No.4 (2b)	0.0	659.5	45.1	237.8	26.3	108.3	108.8	104.8	89.6	109.5	274.2	53.2	689.5	11.2	259.2	46.2

Table 12. A brief summary of maximum % difference in total annual energy and star rating

	Cooling Dominated Diff, total energy	Cooling Dominated Star Rating Diff	Balanced % Diff, total energy	Balanced Star Rating Diff	Heating Dominated % Diff, total energy	Heating Dominated Star Rating Diff
Window Pair 1a & 1b Window Pair with almost identical *U*-value, 4.8% difference in SHGCs and large difference in Specific Solar Aperture	19.7 %	0.5 stars	16.9%	0.4 stars	5.8%	0.2 stars
Window Pair 2a & 2b, Window Pairs with almost identical *U*-value and SHGC, but different in Specific Solar Aperture	9.4%	0.3 stars	5.7%	0.2 stars	3.3%	0.1 stars
Window Pair 3a & 3b, 4a & 4b, 5a & 5b Window Pair with closely matched *U*-value, SHGC and Specific Solar Aperture	8.7%	0.3 stars	5.9%	0.2 stars	0.5%	<0.1 stars

Note: Above the blue line, the 0.3-star tolerance is exceeded and below the blue line, the difference is smaller than 0.3 star.

5. CONCLUSIONS

This report presents the progress, findings and recommendations of the project to convert Second-Generation NatHERS Tools to using NFRC-based window system data.

1. The AccuRate engine has been modified to handle window system data at NFRC conditions, including modifying the frame *U*-value and the SHGC at each hour.
2. A Delphi® application has been written to create NFRC Window Data Files (WDFs) for the AccuRate window library. The Delphi® application reads a Window 5 Detailed Report (W5DR) and an EnergyPlus Report (EPR) from which it outputs a binary file for use by the AccuRate user interface, and a binary file for the AccuRate simulation engine.
3. A window naming convention has been recommended for defining the frame material so as to achieve correct, NFRC-compliant application of boundary conditions by the AccuRate engine.
4. Five pairs of window systems have been selected, with the windows in each pair having as close as possible to the same *U*-value and SHGC but where they differ with respect to glass type, frame material, vision fraction or specific solar aperture. The feasibility of a performance matrix approach was investigated by AccuRate modelling for four different house types in eight different climates using the five window pairs. It was found that:
    a. For all the five Window Pairs and four house types, the maximum differences of total annual energy were found almost exclusively in cooling-dominated climates and the minimum differences are in heating-dominated climates, with the mixed climates in between;
    b. Among all the combinations of window pairs, houses and climate zones investigated, the maximum percentage difference in total annual energy was found to be 19.7% for a Medium House in Brisbane (a cooling-dominated climate), which also has the maximum star rating difference of 0.5 star among all the combinations. Considering the large difference in star rating, this suggests that the PM approach with only *U*-value and SHGC as the performance predictors may be not suitable for cooling-dominated climates in Australia.
    c. Assuming a star rating difference tolerance of 0.3 star, a PM approach with *U*-value, SHGC and specific solar aperture as the performance predictors may be suitable for all climates in Australia. It should be noted that the requirement for actual window selection will be different for different climates. In cooling-dominated climates, actual windows may be specified having *U*-values and SHGCs matching or lower than those of the PM window and with the specific solar aperture to be higher than that of the PM window. In heating-dominated climates, the requirement of specific solar aperture can be removed. The actual windows with matching or lower *U*-values and matching or higher SHGCs compared with those of the PM window should be used. In mixed climates the requirement is likely to be on a case-by-case basis for each individual climate.
    d. For a PM approach using *U*-value, SHGC and specific solar aperture as the performance predictors, WDFs with a large set of PM windows, possibly 1000 ($10 \times 10 \times 10$) or more, may be required to cover the

likely range of the three parameters in sufficiently fine steps. Unfortunately, this could potentially make the PM system relatively unattractive, given the effort of constructing the 1000+ PM window system and the fact that an AccuRate user would need to chose a PM window from the 1000+ PM window library.

6. RECOMMENDATIONS

Based on the current study, it is recommended that

1. With a 0.3-star difference tolerance, a PM approach using *U*-value, SHGC and specific solar aperture as the performance predictors may be suitable for all climates in Australia. However, to cover the likely ranges of these three parameters in sufficiently fine detail may require a large set of PM windows – possibly of the order of 1000. Unfortunately this reduces the attractiveness of the PM approach compared with using the full set (4000+) of custom windows. Consequently, a three-parameter PM approach is not recommended for implementation in the second-generation NatHERS tools at this stage;
2. WDFs for NFRC-rated generic (default) windows from the BCA generic table need to be generated as soon as possible and made available in second-generation NatHERS tools and in the Building Code of Australia. In this case, verification need only be visual (glass and frame type). The performance of these default windows needs to be punitive (conservative) so their use does not undermine custom-rated window ratings.
3. Further work is needed to establish whether a workable PM approach is possible.
4. Irrespective of whether a workable PM approach is possible, we recommend that WDFs for the current full set of custom windows be created. The Delphi® application developed in this project can be used to create the required NFRC WDFs for these windows. If a workable PM approach is not possible, these custom windows must be made available in second-generation NatHERS tools if no alternative to the PM approach is found. If a PM approach is possible, the custom windows need not necessarily be made available.

REFERENCES

Delsante, A.E. and Lyons, P. (2007), The Issues Involved in Handling NFRC-Rated Glazing Systems in Second-Generation NatHERS Tools, CSE USP 2007/003.

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