AFRC 200-01-1.3

AFRC Skylight Simulation Manual: NFRC harmonised

Version 1.3
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1. FOREWORD

This document sets out procedures for the energy rating of skylights under the skylight module of the Window Energy Rating Scheme (WERS). The procedures form the basis of WERS for Skylights. The scheme provides for roof windows[1], skylights with shafts, and tubular skylights[2]. The same algorithms are used in AccuRate, the reference house rating software under Second Generation NatHERS.

With the establishment of the Australian Fenestration Rating Council (AFRC) in 2007, NFRC [3] technical procedures became mandatory in Australia for energy rating of those products already covered by NFRC procedures. However WERS for Skylights includes additional products not currently covered by the NFRC. This document updates the previous WERS for Skylights procedure (2005) to take account of AFRC adherence to the NFRC system wherever possible, and has three objectives:

For roof windows, this procedure follows those of NFRC exactly.

For tubular skylight static ratings this document follows NFRC procedures exactly for U-value and uses CSIRO-AccuRate algorithms to calculate solar heat gain coefficient (SHGC) and visible transmittance (VT). These algorithms are also largely identical to those already in the public domain and implemented by EnergyPlus, which is employed worldwide by building energy simulators (www.energyplus.gov).

For convex, rectangular skylight static ratings (with or without a light well and bottom diffuser) there is no existing NFRC modelling procedure. This document presents an NFRC-like procedure for such products for calculating U-value which was developed by analogy with that for tubular products and with actual NFRC modelling methods for tubular products. It uses the CSIRO-AccuRate algorithms to calculate SHGC and VT.

For dynamic modelling in AccuRate, for tubular or rectangular skylights, this procedure sets out detail that goes far beyond existing NFRC procedures and algorithms. Equations are implemented which deal with separate 'component' information for the top glazing assembly, tube (or shaft) plus bottom diffuser. This information is required because like EnergyPlus, AccuRate performs an annual, dynamic, heat balance on the skylight system in order to estimate the contribution of the skylight system to the annual energy performance of the whole building. This is an integral part of the house's AccuRate star rating on a scale of 0 – 10 stars.

The procedure accounts correctly for top dome centre-of-glazing, edge-of-glazing and frame heat transfer. It also accounts separately for diffuser centre-of-glazing, edge-of-glazing and frame heat transfer. This flexibility is necessary for modelling a variety of products including those where the top dome projects beyond the throat (internal size) of the tube. This also accounts for the fact that the thermal aperture and solar/optical aperture may be different.

Full documentation of algorithms referenced by this simulation manual may be found in Lyons & Bennie (2010).[4] All WERS for Skylights algorithms are based on basic heat-transfer physics, or drawn from peer-reviewed, open literature or from established modelling techniques published by NFRC. As with AFRC procedures for vertical windows, WERS for Skylights uses the WINDOW and THERM fenestration modelling tools as employed by AFRC Certified Simulators.

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[1] Roof windows are termed 'skylights' in the NFRC system; see NFRC Simulation Manual (2010) (*http://windows.lbl.gov/software*).
[2] Known as tubular daylighting devices (TDDs) in the NFRC system; see NFRC Simulation Manual (2010).
[3] U.S. National Fenestration Rating Council, *www.nfrc.org*
[4] Skylight Industry Association, Inc. *WERS for Skylights Operational Manual: NFRC Harmonised - Version 3.6* (June 2010). Peter Lyons & Associates and Ian Bennie & Associates.

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WERS for Skylights provides comparative values for skylight systems for:

- U-value (thermal transmittance, U-Factor)
- Solar heat gain coefficient (SHGC)
- Visible transmittance (VT)
- Luminous efficacy (‘cool daylight rating’) (k_e = VT / SHGC)

2. TUBULAR SKYLIGHT RATING PROCEDURE

2.1 *Determination of whole product U-Factor*

The procedure to follow is detailed in the NFRC Simulation Manual Section 8.6, except that the AFRC Skylight Rating Spreadsheet, worksheet *AFRC Tubes_keff*, is to be used in place of the standalone NFRC spreadsheet, *Tubes_Keff.*

The required inputs and outputs in *AFRC Tubes_keff* are shown in Table 1 below. This worksheet should be run to obtain *keff* as an input to the simulation procedure in Section 8.6.

Rated diameter:	350mm	=	0.35m	
Rated length:	1041mm	=	1.041m	for hemispherical or convex domes
	750mm	=	0.750m	for flat or near-flat domes (<10% convexity/width)

Table 1. *AFRC Tubes_keff:* example calculation of tubular skylight effective conductivity of air column. Inputs shown in yellow cells; *keff* output shown in separate box.

Height, L [m]	**1.041**	***<- Note: This should be changed only if flat or near-flat dome***
Diameter, D [m]	0.350	
T warm	2.500	**keff [W/mK]**
T cold	-17.200	**4.425**
emiss - hot side	**0.9**	
emiss - cold side	**0.9**	

For dynamic modelling in AccuRate, EnergyPlus and other whole-building simulation tools, that software requires input data calculated at NFRC conditions. Separate calculations must be performed to derive two component quantities required for the AccuRate skylight data file (SDF):

- U-value of top dome and frame assembly;
- U-value of bottom diffuser and frame assembly.

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2.2 *Determination of whole product SHGC, VT, luminous efficacy and tube mean air temperature*

2.2.1 Modelling steps and required THERM inputs and outputs

The process outlined below is identical for tubular and rectangular skylights. Separate worksheets in *AFRC Skylight Rating Spreadsheet, v1.0.xls* are provided for the two cases. These differ only in the area-weighting algorithms used to calculate dome and diffuser U-values.

Follow these steps:

1. Define new boundary conditions. ***See Figures 1, 2, 3 immediately below***.

   Skylight dome exterior (Figure 1): same as standard NFRC exterior boundary condition, with h_c = 26 W/m^2.K.

   Skylight shaft interior (Figure 2): temperature incremented from -5C to -18C in 1K increments for both Convection "Temperature" and Black Body Radiation "Ti" (see example below for -10C). Follows standard method for defining boundary condition but with black body radiation where Ti = <temperature inside shaft or tube>, Ei = <emissivity of room interior surfaces> = 1, View Factor = 1. *Note:* h_c = 3.09 (WINDOW 6.3 onwards; refer to NFRC Simulation Manual 2010, Table 6-4).

   Skylight diffuser (underside facing room) (Figure 3): per NFRC Simulation Manual 2010, Section 8.6.6. Note - condition named *Tubes Indoor*, per NFRC.

Figure 1.

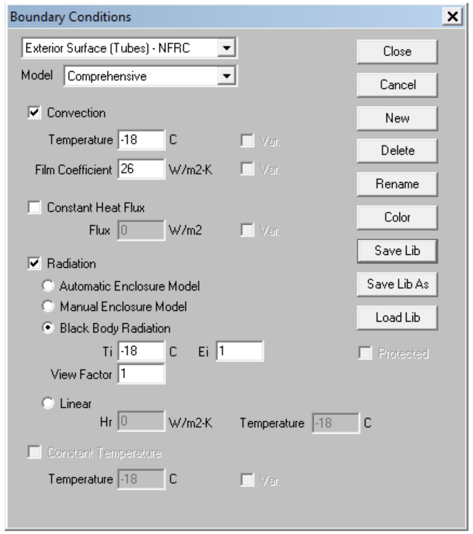


Figure 2.

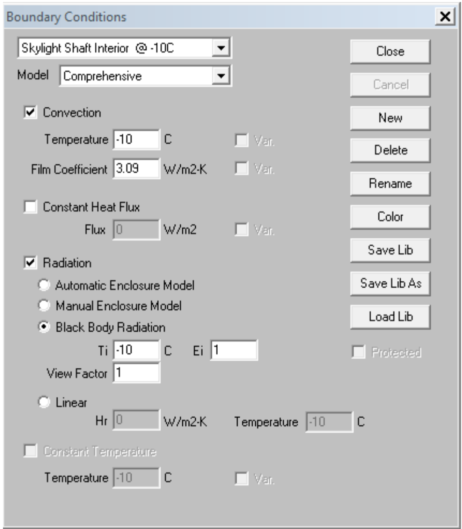
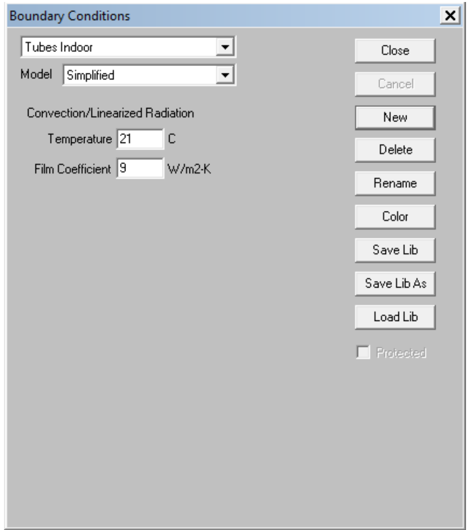


Figure 3.



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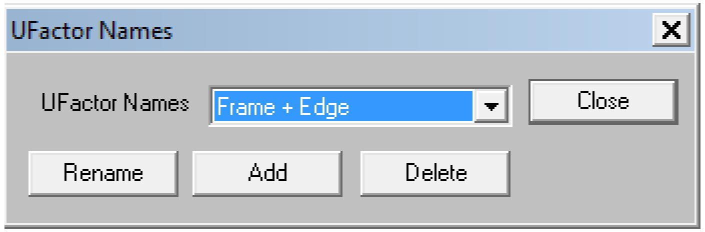
2. Define new U-Factor tags: Frame + Edge, Centre of Dome, Centre of Diffuser. These tag names must be used *exactly*. See example in Figure 4:

Figure 4. Example definition of U-Factor tag names.



3. Model skylight top dome assembly in THERM using -14°C for air temperature in tube/shaft for interior boundary condition. Model half the top dome assembly in THERM, from centreline to outermost point of dome or frame (as applicable). This is shown in **Figure 7**. Note that the *rated* tube radius (or rectangular shaft half-width) shall strictly be 175mm (or 450mm) respectively. If the actual tube (or shaft) dimension is less than 175mm (or 450mm), artificially extend it to the rating dimension. If the product centreline is more than 175mm / 450mm, trim the dome back to the required width. Model the dome collar (flashing) down to the roof plane. However, because most roofs are sloping, the collar height will not be constant. Therefore the *average* collar height should be modelled, which will generally occur at the sides of a TDD, rather than on the lower or upper sides of the dome. If the glazing extends beyond the tube (i.e. has a diameter greater than the tube diameter) the 'Frame + Edge' tag must extend a projected X-distance of 63.5mm into the tube. **See Figure 6.** The *Custom length* in the THERM U-Factor results box must be set to 63.5mm (see Figure 7) and the distance from dome sightline to inside of tube wall (cell G19) must be set to zero in the spreadsheet. However, if the frame /dome assembly is wholly within the tube (i.e. tube diameter bigger than dome diameter, **Figure 5**), the 'Frame + Edge' tag must extend 63.5mm into the tube with the custom length set to 63.5mm + projection into tube ('X' in Figure 5), and G19 must equal the projection of the frame into the tube. Use the same taping rules as for NFRC TDDs.

4. Model skylight diffuser assembly in THERM using -14°C for air temperature in tube/shaft for interior boundary condition. Model half the diffuser assembly in THERM, from centreline to outermost point of the diffuser frame. This is shown in **Figure 8.** As for the top dome, the tube radius (or rectangular shaft half-width) shall be 175mm (or 450mm) respectively. Include the bottom 250mm of the tube (or shaft) which is assumed to be adiabatic and surrounded by ceiling insulation. If the glazing extends beyond the tube (as in **Figure 6**), the 'frame + edge' tag must extend a projected X-distance of 63.5mm into the tube. The custom length in the THERM U-Factor results box must be set to 63.5mm and the distance from diffuser sightline to inside of tube wall (cell G27) must be set to zero in the spreadsheet. However, if any of the frame projects into the tube, the 'Frame + Edge' tag must extend a further 63.5mm into the tube with the custom length set to 63.5mm + projection into tube, and G27 must equal the projection of the frame into the tube. Refer also to **Figure 5**. Use the same taping rules as for NFRC TDDs.

5. Input THERM U-Factors from steps 1 and 2 into spreadsheet, which will automatically estimate the mean temperature of the air column in the tube (cell E8). If the estimated mean air temperature differs from -14°C by more than 1 degree (1K), repeat steps 1 and 2 above using a new boundary condition with the estimated mean air temperature.

6. Repeat step 3 until successive iterations yield a temperature difference of < 1K. Note that it may be necessary to increase the *Quad Tree Mesh Parameter* or failing that, the *Maximum Iterations* in THERM, under Options | Preferences | Preferences.
7. Extract contents of indicated cells for use in AccuRate and contents of tan cells for WERS for Skylights rating.

NOTE: Only AFRC-approved optical and thermophysical data shall be used in all THERM modelling and spreadsheet calculations.

Figure 5. Dome wholly within tube.

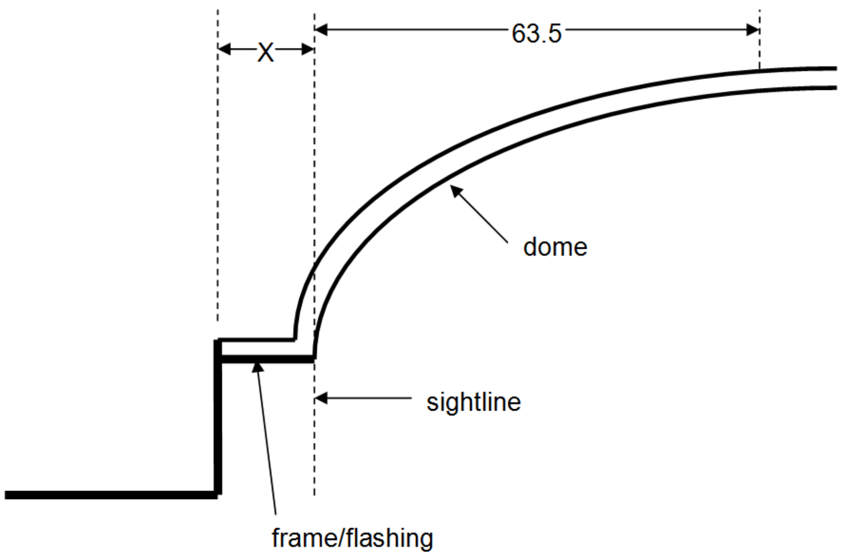
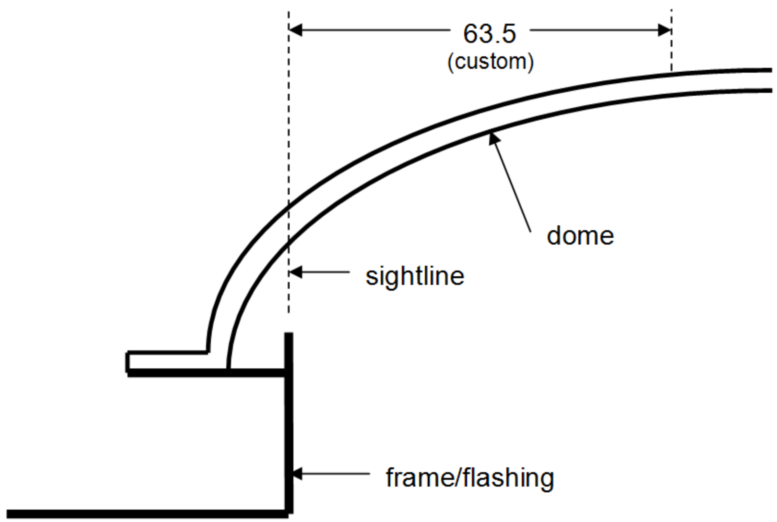


Figure 6. Dome overhanging tube



2.2.2 Skylight rating spreadsheet

Table 2. Inputs and outputs for skylight rating calculation (tubular case shown). Derivation of parameters described in Section 2.2.2. Variables in yellow cells input by user; variable in green cell is used in THERM iterations; variables in tan cells are used in WERS for Skylights report. AccuRate inputs are also identified. Tubular worksheet uses annular area-weighting algorithms. Note: Set ΔR_{tube} = zero unless additional insulation is fitted to tube or shaft of product at time of manufacture. If the latter, manufacturer shall supply specifications of insulation.

AFRC Skylight Rating Spreadsheet, v1.0.xls **31-Aug-10**

TUBULAR SKYLIGHT (NFRC: *TUBULAR DAYLIGHTING DEVICE)* ***Example calculations***

Calculation of SHGC, VT, luminous efficacy and mean tube air temperature

INPUTS	**Input data: only in yellow highlighted fields**			
OUTPUT	**Output data: mean temperature of air in tube for Therm modelling iteration =**	**-11.15**	**degC**	
OUTPUT	**Output data: exported to WERS for Skylights report**			

Variable	Description	Value	Unit	AccuRate
$U_{centre\ of\ dome}$	U-value of centre-of-glazing region of dome (obtained from Therm)	5.3566	W/m^2.K	
$U_{dome\ frame+edge}$	U-value of frame within throat + 63.5mm edge (obtained from Therm)	16.0628	W/m^2.K	
$L_{dome\ sight\ line\ to\ tube\ wall}$	distance from dome sight line to inside of tube wall (zero if sight line extends beyond tube)	0.00	mm	
U_{top}	area-weighted overall U-value of top glazing and frame	11.7166	W/m^2.K	*Input to AccuRate*
$U_{centre\ of\ diffuser}$	U-value of centre-of-glazing region of diffuser (obtained from Window, using specular glazing layers)	2.3711	W/m^2.K	
$U_{edge\ of\ diffuser\ +\ frame\ within\ throat}$	U-value of diffuser frame within throat + 63.5mm edge (obtained from Therm)	4.8163	W/m^2.K	
$L_{diffuser\ sight\ line\ to\ tube\ wall}$	distance from diffuser sight line to inside of tube wall (zero if sight line extends beyond tube)	20.655	mm	
$U_{diffuser}$	area-weighted overall U-value of whole diffuser	4.1574	W/m^2.K	*Input to AccuRate*
k_{tube}	thermal conductivity of tube wall material	160.00	W/m.K	
$thick_{tube}$	thickness of tube wall	0.60	mm	
ΔR_{tube}	thermal resistance added to non-adiabatic tube wall above ceiling insulation (now adjustable in AccuRate)	1.0	m^2.K/W	
t_{stg}	solar transmittance of top glazing	0.846		*Input to AccuRate*
t_{vtg}	visible transmittance of top glazing	0.922		
$r_{wall,s}$	solar reflectance of tube wall	0.800		
$r_{wall,v}$	visible reflectance of tube wall	0.800		
t_{ds}	solar transmittance of diffuser	0.750		*Input to AccuRate*
t_{dv}	visible transmittance of diffuser	0.750		
a_{ds}	solar absorptance of diffuser	0.250		

SOLAR PERFORMANCE

SHGC	**solar heat gain coefficient of overall TDD system**	**0.454**

VISIBLE PERFORMANCE

t_{vis} = *VT*	**visible transmittance of overall skylight system**	**0.425**
LSG	**light-to-solar gain ratio (luminous efficacy)**	**0.934**

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Figure 7. ***Dome frame & edge combined U-value; centre-of-dome U-value.***

Note: edge region of dome glazing is 63.5mm wide, projected in horizontal plane. U-Factors (bottom right) are entered into spreadsheet cells G17, G18.

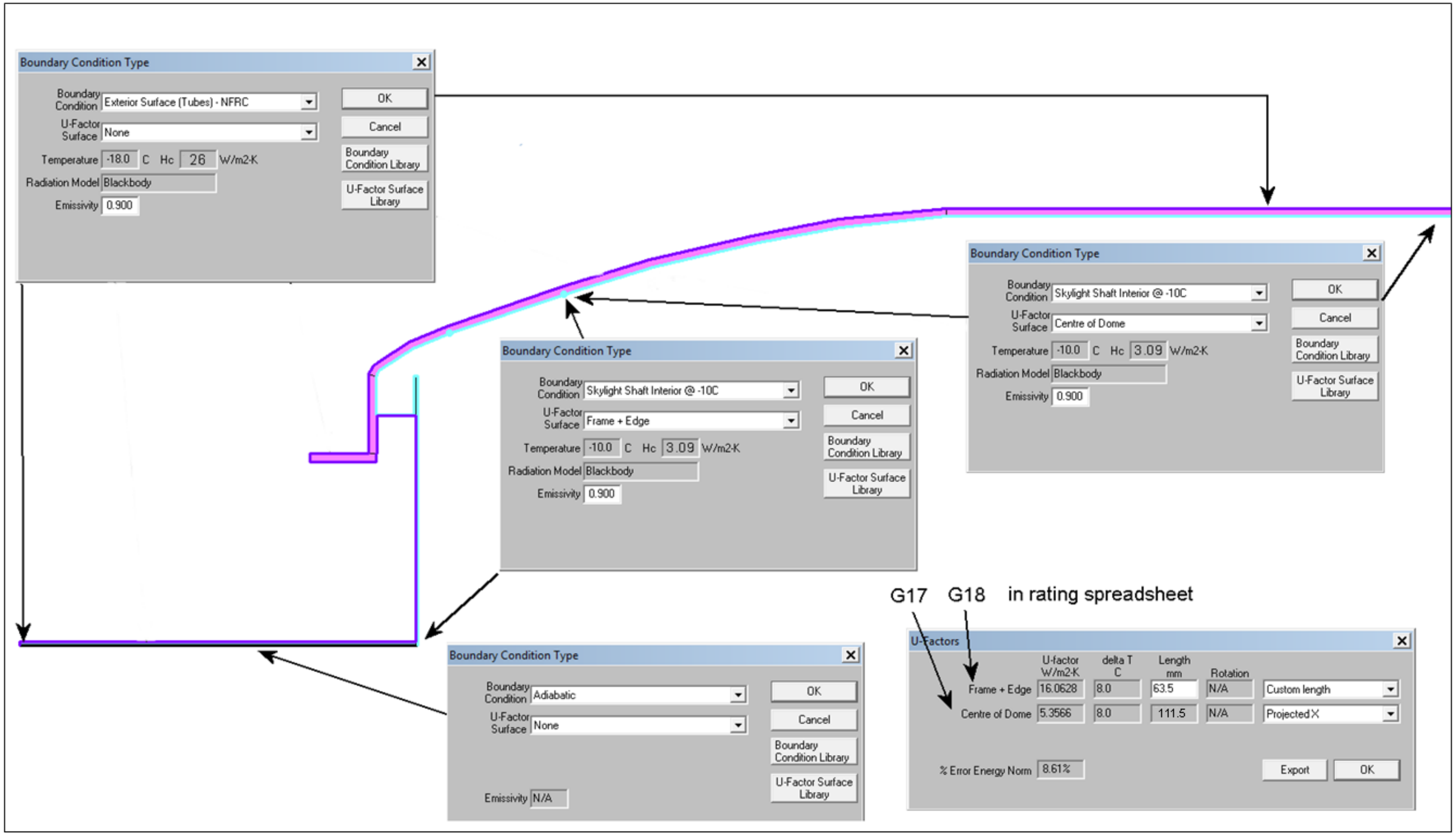

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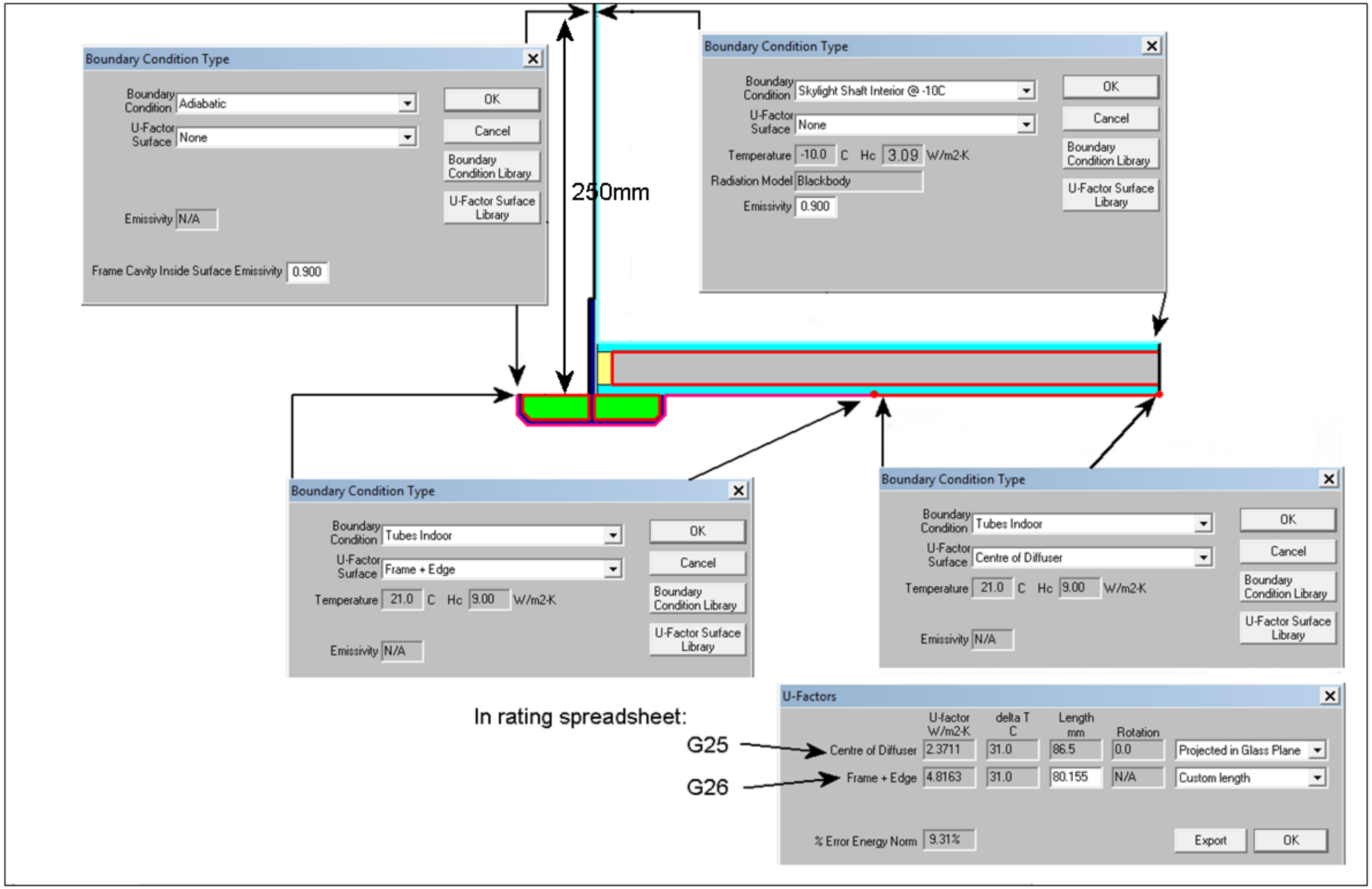
Figure 8. Centre-of-diffuser U-value; edge-of-diffuser and diffuser frame U-values.

Note: edge region of diffuser glazing is 63.5mm wide, projected in horizontal plane. U-Factors (bottom right) are entered into spreadsheet cells G25, G26. Modelling



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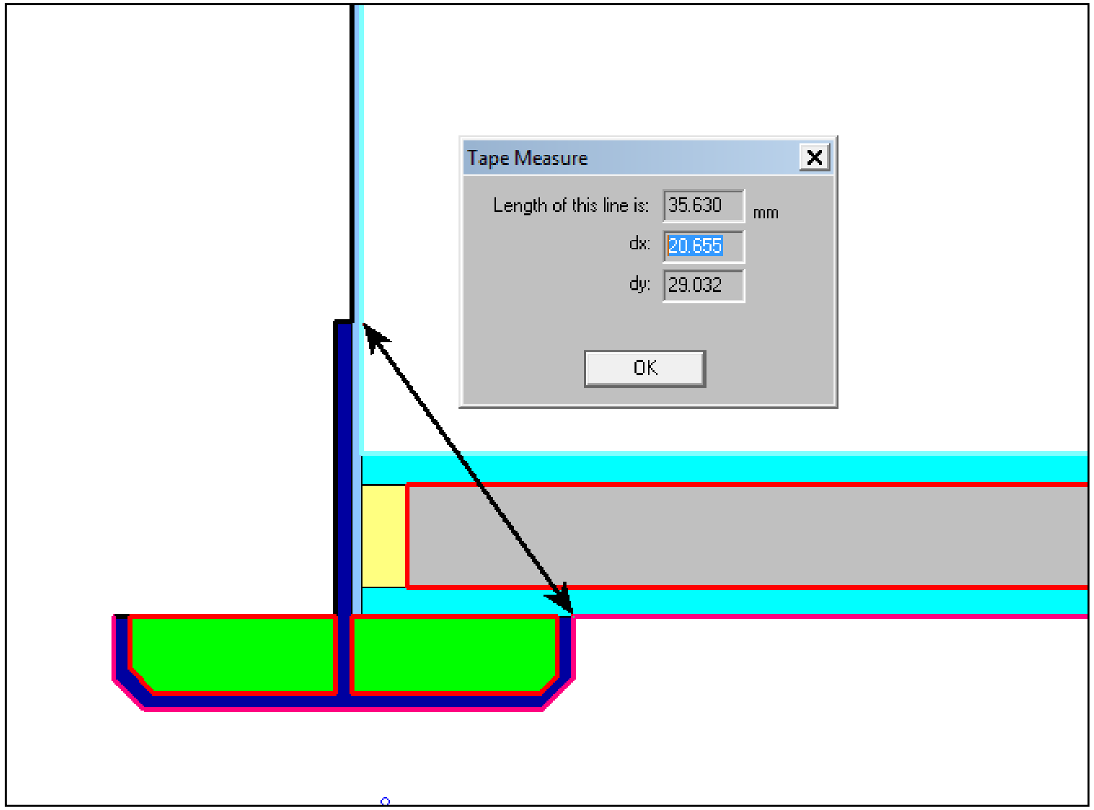
must extend 250mm up the tube wall, measured from underside of diffuser.

Figure 9. Measurement of diffuser frame width inside of tube internal diameter (cell G27 in AFRC Skylight Rating Spreadsheet, v1.0.xls).



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3. RECTANGULAR SKYLIGHT RATING PROCEDURE

3.1 *Determination of whole product U-Factor*

The procedure to follow is similar to that detailed in the NFRC Simulation Manual Section 8.6, except that the AFRC Skylight Rating Spreadsheet, worksheet *AFRC Rectangular shafted_Keff*, is to be used in place of the standalone NFRC spreadsheet, *Tubes_Keff.*

The required inputs and outputs in *AFRC Rectangular shafted_Keff* are shown in Table 3 below. This worksheet should be run to obtain *keff* as an input to the simulation procedure in Section 8.6.

Rated X-dimension:	900mm	=	0.90m
Rated Y-dimension:	900mm	=	0.90m
Rated shaft length:	1041mm	=	1.041m for hemispherical or convex domes
	750mm	=	0.750m for flat or near-flat domes (<10% convexity/width)

Table 3. *AFRC Rectangular shafted_Keff:* example calculation of shafted, rectangular skylight effective conductivity of air column. Inputs shown in yellow cells; *keff* output shown in separate box.

Height, L [m]	**1.041**	***<- Note: This should be changed only if flat or near-flat dome***
horizontal internal X dimension, L [m]	0.900	
horizontal internal Y dimension, W [m]	0.900	
square root of horizontal area LW [m]	0.900	**keff [W/mK] 4.781**
T warm	**2.5**	
T cold	**-17.2**	
emiss - hot side	**0.9**	
emiss - cold side	**0.9**	

For dynamic modelling in AccuRate, EnergyPlus and other whole-building simulation tools, that software requires input data calculated at NFRC conditions. Separate calculations must be performed to derive two component quantities required for the AccuRate skylight data file (SDF):

- U-value of top dome and frame assembly;
- U-value of bottom diffuser and frame assembly.

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3.2 Determination of whole product SHGC, VT, luminous efficacy and shaft mean air temperature

3.2.1 Summary of required inputs and outputs

Table 4. Inputs and outputs for skylight rating calculation (rectangular case shown). Derivation of parameters described in Section 2.2.2. Variables in yellow cells input by user; variable in green cell is used in THERM iterations; variables in tan cells are used in WERS for Skylights report. AccuRate inputs are also identified. Worksheet uses rectangular area-weighting algorithms. Note: Set ΔR_{tube} = zero unless additional insulation is fitted to tube or shaft of product at time of manufacture. If the latter, manufacturer shall supply specifications of insulation.

AFRC Skylight Rating Spreadsheet, v1.0.xls		**31-Aug-10**			
RECTANGULAR SKYLIGHT WITH SHAFT		***Example calculations***			
Calculation of SHGC, VT, luminous efficacy and mean tube air temperature					
INPUTS	**Input data: only in yellow highlighted fields**				
OUTPUTS	**Output data: mean temperature of air in shaft for Therm modelling iteration**	**=**	**-9.30**	**degC**	
OUTPUT	**Output data: exported to WERS for Skylights report**				
	$U_{centre\ of\ dome}$	U-value of centre-of-glazing region of dome (obtained from Therm)	**5.3566**	W/m².K	
	$U_{dome\ frame+edge}$	U-value of frame within throat + 63.5mm edge (obtained from Therm)	**16.063**	W/m².K	
	$L_{dome\ sight\ line\ to\ shaft\ wall}$	distance from dome sight line to inside of shaft wall (zero if sight line extends beyond shaft)	**0.00**	mm	
	U_{top}	area-weighted overall U-value of top glazing and frame	**6.8141**	W/m².K	***Input to AccuRate***
	$U_{centre\ of\ diffuser}$	U-value of centre-of-glazing region of diffuser (obtained from Window)	**2.3711**	W/m².K	
	$U_{diffuser\ frame+edge}$	U-value of diffuser frame within throat + 63.5mm edge (obtained from Therm)	**4.8163**	W/m².K	
	$L_{diffuser\ sight\ line\ to\ shaft\ wall}$	distance from diffuser sight line to inside of shaft wall (zero if sight line extends beyond shaft)	**20.655**	mm	
	$U_{diffuser}$	area-weighted overall U-value of whole diffuser	**2.8070**	W/m².K	***Input to AccuRate***
	k_{tube}	thermal conductivity of shaft wall material	**0.14**	W/m.K	
	$thick_{tube}$	thickness of shaft wall	**4.0**	mm	
	ΔR_{tube}	thermal resistance added to non-adiabatic shaft wall above ceiling insulation (now adjustable in AccuRate)	**1.0**	m².K/W	
	t_{stg}	solar transmittance of top glazing	**0.846**		***Input to AccuRate***
	t_{vtg}	visible transmittance of top glazing	**0.922**		
	$r_{wall,s}$	solar reflectance of shaft wall	**0.800**		
	$r_{wall,v}$	visible reflectance of shaft wall	**0.800**		
	t_{ds}	solar transmittance of diffuser	**0.750**		***Input to AccuRate***
	t_{dv}	visible transmittance of diffuser	**0.750**		
	a_{ds}	solar absorptance of diffuser	**0.250**		
SOLAR PERFORMANCE					
	SHGC	**solar heat gain coefficient of overall skylight system**	**0.425**		
VISIBLE PERFORMANCE					
	t_{vis}	**visible transmittance of overall skylight system**	**0.397**		
	LSG	**light-to-solar gain ratio (luminous efficacy)**	**0.934**		

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4. CREATION OF ACCURATE SKYLIGHT DATA FILES

In addition to a static rating report, WERS for Skylights supplies skylight data files (SDFs) as input to the AccuRate simulation engine. SDFs are compiled into binary files and added to the subdirectory *AccuRate\Lib* as part of a regular support cycle provided to the developers of AccuRate by the Australian Fenestration Rating Council (AFRC). In this way, windows and skylights are added to other building façade products to provide the simulator with a very wide choice of data for house energy ratings.

For each unique skylight, performance data must be input to a skylight data file according to a format that is yet to be defined, in consultation with CSIRO and DCCEE. For this reason, this release of the WFS Simulation Manual cannot define the content and format of AccuRate SDFs.

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