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Benchmarking of DR AS 5389:2016 TRNSYS Domestic Building Model and Reference Air-Conditioner Against AccuRate

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Abstract

DR AS 5389:2016 Space heating and cooling and ventilation systems – Calculation of energy consumption was released for public comment on 24 June 2016, and aims to provide manufacturers, regulators and conformity assessment bodies with a means of evaluating the annual energy performance of solar innovative heating, cooling and ventilation system for domestic and commercial buildings.

In order for this new standard to be well accepted in the Building, HVAC and Energy Savings Industries, and successfully implemented as a methodology for estimating both energy consumption and building comfort, it is expected that there needs to be good agreement between the AS 5389 models and those of the same building in AccuRate (Delsante, 2005b). AccuRate is a well-established NatHERS rating tool developed by CSIRO.

Initial simulations showed this not to be the case, requiring significant investigation into both models, both in terms of their sensitivity to user inputs and to their core differences. This paper demonstrates the value of both models in terms of their specific roles (building rating vs new appliance rating), highlights the key inputs that must be aligned in order to get good agreement in results, and summarises the main sources of the remaining differences.

In completing this analysis, several suggested changes to DR AS 5389 were identified, and provided to the CS-028 Standards Committee via public comment.

1. Introduction

DR AS 5389: 2016 Space heating and cooling and ventilation systems – Calculation of energy consumption has been developed with the objective of providing manufacturers, regulators and conformity assessment bodies with a means of evaluating the annual energy performance of solar heating and cooling systems and ventilation systems for domestic and commercial buildings. The standard provides a test methodology for characterising the performance of Desiccant wheel-based space heating and cooling systems; Solar air heating systems; Occupied space and roof ventilator systems; and Evaporative cooling systems. The performance calculation then compares the annual energy use of representative buildings with conventional reference appliances to the same building with the nominated appliances. The performance is determined for a range of climatic conditions using the TRNSYS 17 simulation program (Klein, 2010). TRNSYS enables the user to program detailed numerical models of appliance behaviour and control systems in a way which is not currently available in building rating tools such as AccuRate.

DR AS 5389, and the related TRNSYS files, were released for public comment on 24 June 2016, enabling industry to review the standard, and to benchmark the related TRNSYS domestic building model against a similar building model created with the building industry accepted energy rating program, AccuRate.

It was viewed that, in order for this standard to be accepted by the building and HVAC services industries, it would be important that the modelled energy loads are in good agreement with the current benchmarks for building energy assessments: AccuRate and/or IES. AccuRate is a well-established building modelling and rating tool, for the purpose of determining heating and cooling loads, and is widely used and accepted by the building industry in Australia.

Initially the content of the standard alone was used to develop an equivalent reference building model in AccuRate, despite many items not being specified in detail, in order to compare the heating and cooling loads predicted by TRNSYS with those predicted by AccuRate. It was expected that the two models should achieve similar outcomes in terms of total heating and cooling loads, for the same location and building construction. However, several assumptions needed to be made regarding construction, and there were significant differences in the results, with the AccuRate model resulting in a much hotter building with higher cooling and lower heating loads, compared to the TRNSYS results.

The TRNSYS Type 56 building model (TRNBuild file) and related files were then reviewed in more detail in order to better specify the AccuRate building, highlighting minor inconsistencies in geometry, and differences in the construction and boundary specifications provided in the text of the standard. These differences included the thermal properties of the surfaces, the thermal capacity of each construction element (wall, floor, etc.), the details of the window frames and shading, and the slab to ground temperature boundary condition. The AccuRate model was then revised with this new information, but the results were still far apart, both in terms of energy requirements, and star ratings (bands), as shown in Figure 1.

At this point, a detailed investigation into variations between the two models was initiated, the results of which are described in this paper, along with a comparison of their estimated heating and cooling loads.

2. Investigation

In general, building energy models are made up of:

- Building geometry and construction, including bulk and surface thermal properties;
- Internal loads, both sensible and latent, from the appliances and occupants;
- Weather files, particularly solar radiation, air temperature and air humidity;
- Heating and cooling models, including their control algorithms;
- Mathematical models of geometry and heat transfer, including night sky, ground coupling and infiltration models;
- Numerical solution algorithm or engine.

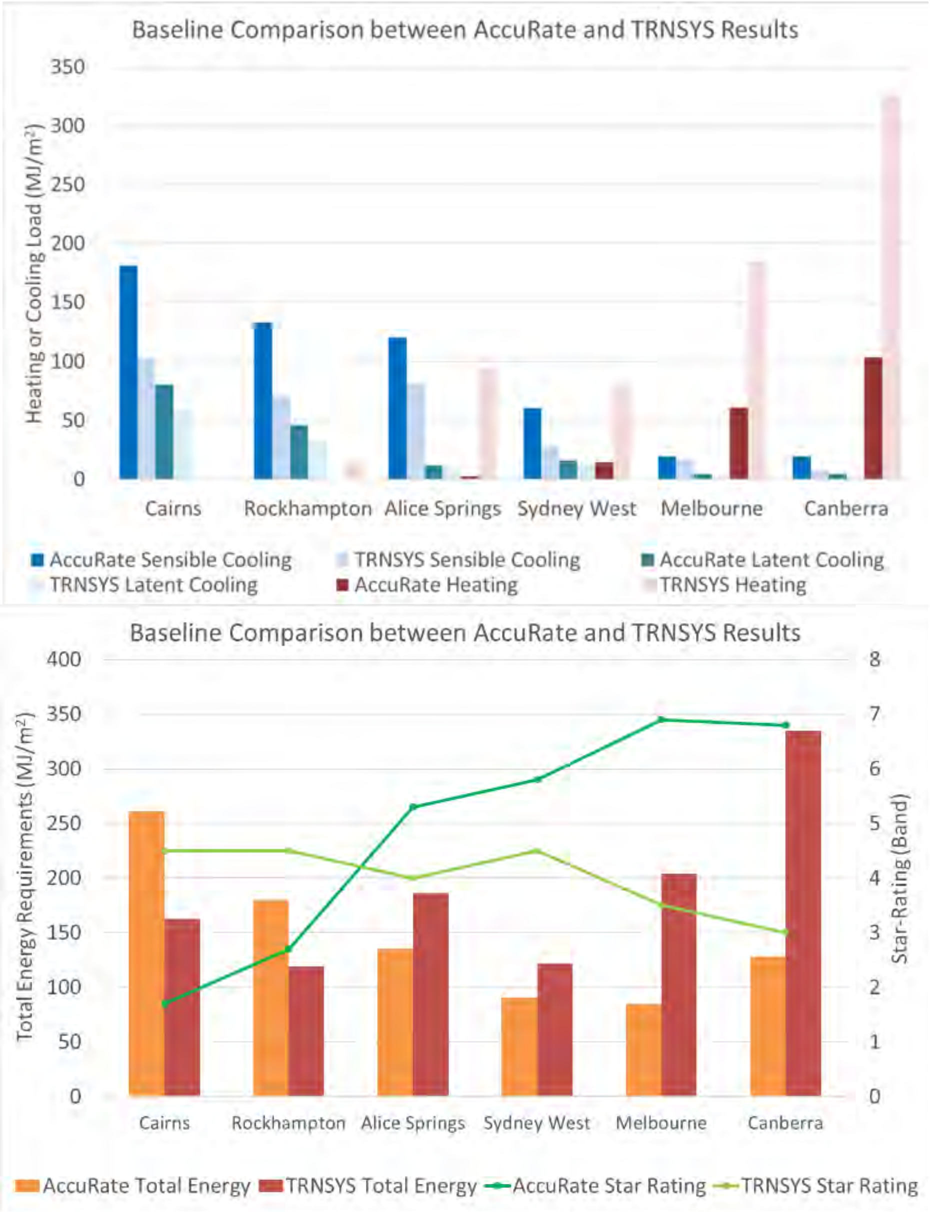

Figure 1: Baseline Comparison between TRNSYS and AccuRate Results

When significant differences between the AccuRate and TRNSYS results were identified, for what appeared to be the same geometry and construction, in the same locations, each of the other components of the building models were investigated as described in the following sections. In some cases it was possible to change one or other of the models in order to align them, but not in all.

Working through this level of detail in both the simulation programs highlighted that it is quite likely that non-expert users can obtain significantly different results for what appears to be the same building if they are not aware of the finer details which need to be aligned, and that even for more expert users, some areas of the models are unclear or not able to be adjusted.

2.1. *Building Geometry and Construction*

The building model created in AccuRate was limited by the available construction materials provided in AccuRate; the need to create both a kitchen/living zone and a bedroom zone as separate rooms with a dividing wall in order to match the internal heating loads specified in DR AS 5389; and the default blind specifications. In most cases, materials that were relatively close to those specified in DR AS5389 were available, and in some cases the thickness of the material was adjusted to achieve the same U-value.

A simple plasterboard on stud wall was used to separate the two zones with a permanent opening of 49m^2 out of 50m^2. This was considered to be the closest approximation available to the single room construction specified in DR AS 5389, and was intended to result in a relatively well mixed volume. Unfortunately, this did not always result in the two zones being maintained at the same temperature, particularly when only one of them was actively controlling heating or cooling, which is likely to be one source of variation in the heating and cooling loads predicted.

In rating mode, the AccuRate model contains Holland blinds which open and close on a defined schedule (7am Open, 6pm Close), and due to room temperature (Cooling thermostat setpoint) and sunlight (200 W/m^2) (NatHERS, 2012, App B.4). The thermal properties of the Holland blinds in AccuRate appear to be those of "Curtain 6" in the scratch file with Transmissivity = 0.2, Absorptance = 0.3 and Thermal Resistance, R = 0.03. In the DR AS 5389 TRNSYS model, the external shading device is set to zero, and the internal shading device is 70%. The internal shading device is then closed when sunlight exceeds 140 W/m^2 and opened again when sunlight drops below 120 W/m^2.

In order to align the two models, a blind schedule which is open from 7am to 6pm and closed from 6pm to 7am was implemented. This was considered to be a very common household behaviour and more straightforward to implement in TRNSYS than the combined time, temperature and radiation control which is standard in AccuRate. This was achieved in AccuRate by manually editing the scratch files to change the temperature and radiation limits to 40°C and 900 W/m^2, and then running them directly using the AccuRateengine.exe from the command prompt. Scratch files are text files generated by AccuRate which contain the detailed building construction information, and automatically run using the Chenath engine.

2.2. *Internal Loads*

The internal loads in AccuRate are defined by zone type and floor area (Delsante, 2005a). It was originally intended that the DR AS 5389 internal loads should match those of an AccuRate building of the same floor area, with 50% kitchen/living area and 50% bedroom, however, the floor area adjustment was not included, and the loads for a 160m^2 building were used as per Appendix B.1 of the NatHERS Software Accreditation Protocol (NatHERS, 2012). Once this was recognised, the internal loads specified for AS 5389 were updated to match those of AccuRate.

2.3. *Weather Files*

The weather files supplied with DR AS 5389 are only for a selected number of cities, and in a different format to other commonly used weather files that are available for a wide range of locations. There are also significant differences between the DR AS 5389 weather files and those supplied with AccuRate, particularly for Sydney, which is a single file for DR AS 5389, and divided into Sydney East (Tcool = 25.5°C) and Sydney West (Tcool = 24.5°C) for

AccuRate. In order to remove the variations due to weather files, for the purposes of this analysis the AccuRate weather files were pre-processed to be similar to the DR AS 5389 weather file format and the weather file reader and psychrometric calculator updated to use the AccuRate data.

2.4. Heating and Cooling Models

In both programs heating and cooling models are used to determine the required heating and cooling loads to maintain comfort. While the controls used in DR AS 5389 are clearly defined in the TRNSYS files, AccuRate's control equations, in particular for dehumidification and/or latent cooling, are less clear.

The heating control algorithms are slightly different in AccuRate to those specified in DR AS 5389. In DR AS 5389 heating is to a setpoint of 17°C from Midnight until 6am, with a deadband of 2°C (turn on at 15°C, heat until 17°C), and to a setpoint of 20°C from 6am until Midnight, with a deadband of 2°C. In AccuRate, heating is to a setpoint of 15°C from Midnight until 7am, and to a setpoint of 20°C from 7am to Midnight (NatHERS, 2012, App B.3). There is no deadband in AccuRate for heating, but rather at the end of each hour, the heating required to bring the temperature up to its setpoint is calculated and provided. To complicate matters further, in AccuRate the kitchen/living and bedroom zones actually have two separate heating thermostats, and the above is the maximum of the two, so there are times where one zone or the other drops below these levels.

The sensible cooling algorithms appear to be equivalent, with both programs using setpoints that vary with location but not with time of day overall (either the kitchen or the bedroom zone does turn off at times in AccuRate). It is important to note that in AccuRate the Sydney East (Climat17) cooling setpoint is 25.5°C, but the Sydney West (Climat28) cooling setpoint is 24.5°C (NatHERS, 2012, App B.2). A deadband of 2.5°C is used in all cases, with the temperature being allowed to increase to 2.5°C above the setpoint before cooling turns on, and then cooling occurs until the temperature is brought down to the setpoint.

The latent cooling algorithms were not investigated fully to determine if they are equivalent.

It is expected that the differences in these heating and cooling controls significantly contribute to differences in the final heating and cooling loads estimated by the two programs.

2.5. Mathematical Models

Both programs are built on underlying mathematical models for heat transfer, including conduction, convection and radiation, all of which are typically expected to vary by about 20%, depending on the specific correlations selected and approximations made in order to enable efficient calculations. In addition to these, there are also mathematical models for psychrometric calculations, radiation transfer with the sky and surroundings, and heat transfer into the ground (ground coupling). AccuRate has built-in default values for many of the convective and radiative heat transfer coefficients and effective sky temperature, some of which are not visible to the user and/or not able to be changed, and may be significantly contributing to differences in the estimated heating and cooling loads.

2.5.1. Ground Coupling

DR AS 5389 implemented a very low convection coefficient at the boundary between the building and the ground, essentially insulating the concrete slab from the ground temperature. While the equivalent could be implemented in AccuRate by adding insulation below the concrete slab, this is not considered a common construction method for the average domestic building. In order to demonstrate the important effect that ground coupling plays on building performance, the ground boundary temperatures were extracted from AccuRate and then applied as a boundary temperature condition to the TRNSYS model. This was sufficient to represent ground coupling for this specific building, with these heating and cooling controls, however it is not a long-term solution in TRNSYS as the ground boundary temperature varies significantly with building construction, weather and heating and cooling controls. An approximate steady state ground coupling model (Davies, 1993, Chen, 2013a) is likely to be incorporated into the AS 5389 building model before the standard is published.

2.5.2. *Sky Radiation*

The sky temperature calculated in the DR AS 5389 building model did not take into account cloud coverage and/or local shielding, and appeared to be creating excessive night time cooling. For simplicity, a weighted average of the calculated sky temperature and the ambient temperature was used for the purposes of this paper. For the future, a sky temperature calculation including cloud coverage will be used. The sky radiation model used in AccuRate was unclear, and could be a significant source of difference between the two models.

2.5.3. *Infiltration Rates*

In the DR AS 5389 model files the infiltration rates are set to 1 air change per hour (ACH) for both the occupied space and the roof cavity, for all locations. AccuRate uses the wind speed data provided in the weather file to calculating infiltration rates based on a wind shielding factor, f, (0.48 for this model) and A and B values specific to the building construction, according to the following equation (Chen, 2013b):

$$\text{Infiltration rate (air changes per hour)} = A + B(f \times \text{wind speed})$$

For this building the A and B values provided in the AccuRate scratch file are:

- Occupied space: A = 0.16 and B = 0.05
- Roof cavity: A = 2.00 and B = 1.00

The infiltration rates are therefore calculated based on the wind speed, V, from the following equations:

- Occupied space: Infiltration = 0.16 + 0.024V
- Roof cavity: Infiltration = 2 + 0.48V

Wind speeds are often around 4 m/s, resulting in an infiltration rate of about 0.26 ACH for the occupied space and 3.9 ACH for the roof cavity. This results in significantly lower air change rates in the occupied space, and much higher air change rates in the roof cavity, particularly compared with the 1 ACH applied in the original DR AS 5389 model.

Existing studies have suggested that an average value for ACR(50) of 26.3 is reasonable for the occupied space, which corresponds to an infiltration rate of 1.32 air changes per hour (Biggs et al, 1986). Maintaining the existing ratio A/B = 3.2, the wind data in the weather files can be used to determine the values of A and B which will results in an average air change rate, over the year, of 1.32. The A and B values will vary with location, due to the variation in wind speeds, and are provided in Table 1. This methodology allows the seasonal and diurnal variations in wind-driven infiltration to be maintained, while also achieving an appropriate average infiltration rate.

Table 1. Infiltration Coefficients

Location	A	B	F
Cairns	0.81	0.25	0.48
Rockhampton	0.93	0.29	0.48
Alice Springs	0.98	0.31	0.48
Sydney West	1.04	0.33	0.48
Melbourne	0.88	0.27	0.48
Canberra	1.01	0.32	0.48

The infiltration coefficients listed in Table 1 were implemented in both building models. In order to implement these in AccuRate the values of A and B for the kitchen/living and bedroom zones were edited manually in the scratch files, and then run directly using the AccuRateengine.exe from the command prompt.

2.6. *Numerical Solution Algorithms*

The Chenath engine for AccuRate, and TRNSYS's solution algorithm will both have their own set of assumptions and approximations required to achieve numerical solution efficiently, which could contribute to any differences in their final results. Neither of these were investigated as part of this scope of work.

3. Comparison of Results

After completing the above investigation, despite many adjustments being made, the following items were still not aligned, and expected to contribute to differences in the results:

- Two separate zones (Kitchen/Living and Bedroom) with separate temperature controls in AccuRate, compared to one occupied space in TRNSYS.
- Heating and Cooling Models, particularly dehumidification / latent cooling.
- Sky radiation, and underlying heat transfer and numerical solution algorithms.

The results provided in Table 2 and Figure 2 are based on:

- Construction as per DR AS 5389 TRNSYS files with AccuRate Internal Loads and Weather Files, and shades drawn from 6pm to 7am only.
- Ground temperature boundary condition specified in TRNSYS based on AccuRate output temperatures.
- Wind-driven infiltration model as per AccuRate, but with average occupied space ACH = 1.32, based on coefficients listed in Table 1.

With these changes in place there was a significant improvement in agreement between the two models, particularly for heating and sensible cooling loads.

- Heating loads are within 10%, with the exception of Rockhampton, with its very small heating load of 0.2-0.4 MJ/m^2.
- Sensible cooling loads are within 25% with the exceptions of Alice Springs and Canberra. Canberra is a relatively small cooling load of 16.4-22.0 MJ/m^2, while Alice Springs' significant sensible cooling load may be affect by differences in both the sensible cooling and latent cooling (or dehumidification) models.

- There are significant differences in the latent cooling loads.
- The combined effect is that total energy loads are within 11% for the cooler climates and large population centres of Sydney, Melbourne and Canberra, but further apart (within 30%) for the hotter and often more humid cities of Alice Springs, Rockhampton and Cairns.

Table 2. Revised Comparison between AccuRate and TRNSYS Results

Location	Heating Required (MJ/m^2)	Cooling (Sensible) Required (MJ/m^2)	Cooling (Latent) Required (MJ/m^2)	Total Energy Required (MJ/m^2)
AccuRate				
Cairns	0.0	186.3	134.5	320.8
Rockhampton	0.2	128.6	69.2	197.9
Alice Springs	21.0	130.2	12.3	163.5
Sydney West	56.4	51.3	17.6	125.3
Melbourne	135.3	22.7	3.6	161.6
Canberra	223.3	16.4	2.4	242.1
TRNSYS				
Cairns	0.0	156.9	83.1	240.0
Rockhampton	0.4	108.3	36.5	145.2
Alice Springs	22.5	179.0	4.0	205.5
Sydney West	57.8	60.1	15.1	133.0
Melbourne	122.7	27.9	2.2	152.8
Canberra	246.1	22.0	0.8	269.0
Difference in Energy Requirement				
Cairns	0.0	-29.3	-51.4	-80.7
Rockhampton	0.2	-20.2	-32.7	-52.7
Alice Springs	1.6	48.8	-8.4	42.0
Sydney West	1.4	8.8	-2.5	7.7
Melbourne	-12.6	5.2	-1.5	-8.8
Canberra	22.8	5.6	-1.6	26.8

In general, when using heat transfer correlations and numerical models, variations of 10-20% are to be expected, but this does not explain the larger variations in latent cooling loads.

Star-band ratings were also calculated for each location based on the total energy requirement (NatHERS, 2012, App D), to the nearest 0.5, and similarly were found to be in good agreement for Sydney, Melbourne and Canberra, and 1 to 1.5 stars apart for Cairns, Rockhampton and Alice Springs.

In order to investigate these differences further, the output temperature profiles from both programs were compared for Cairns. Unfortunately, AccuRate only outputs hourly data, which is often not sufficient resolution to see how the cooling appliances are actually operating, but it still provides us with some helpful information.

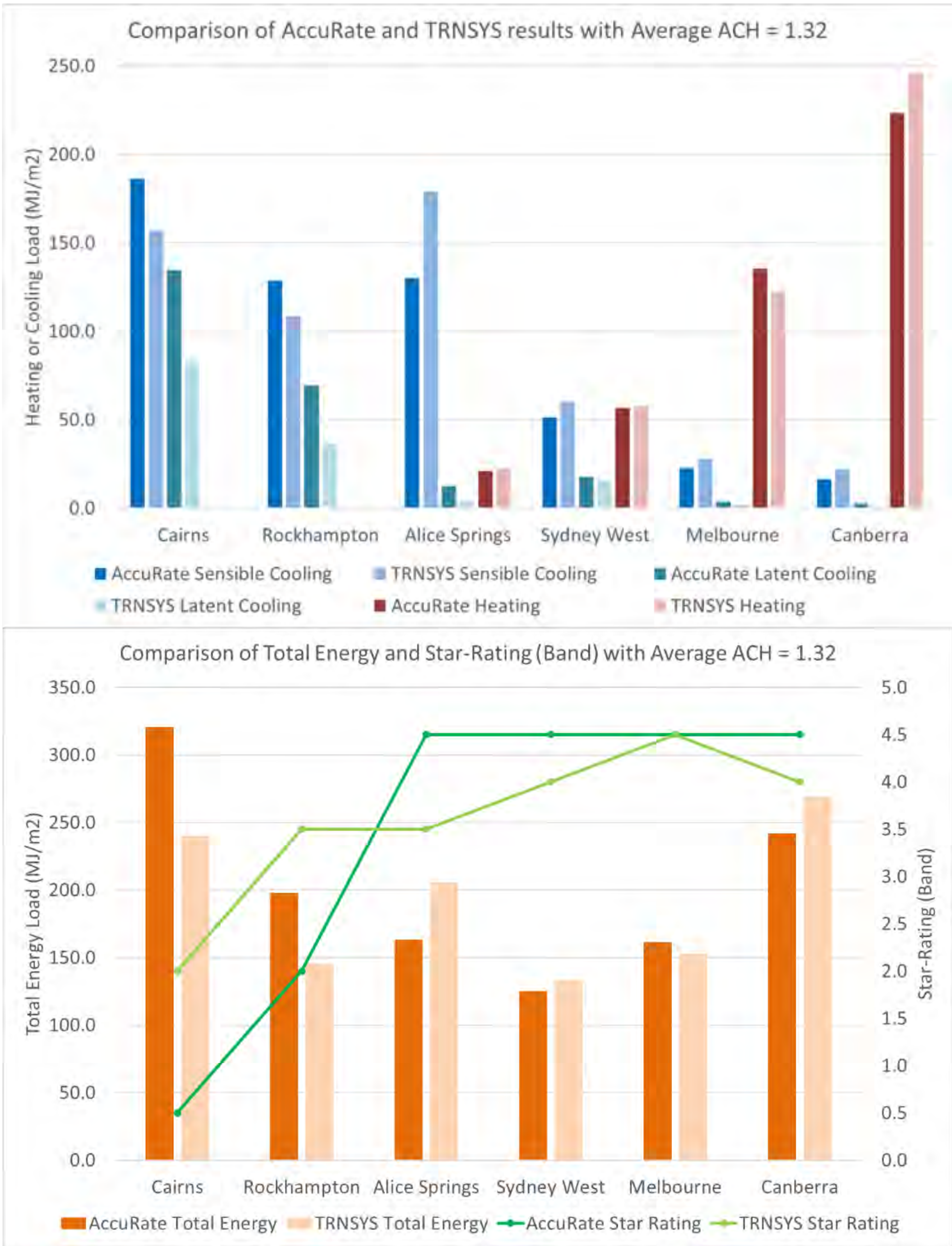

Figure 2: Revised Comparison of AccuRate and TRNSYS Results

Comparing the ambient and occupied space temperatures for Cairns, in both Summer and Winter, as shown in Figure 3, we can observe that:

- The ambient and outside temperatures match, as they should, and the occupied space temperature generated by TRNSYS, Troom, is in good general agreement with the AccuRate room temperature, particularly when they are not being actively controlled.
- The TRNSYS occupied space temperature behaves as we would expect from the cooling algorithm, being bounded between 26.5°C and 29°C during active cooling.
- The AccuRate temperatures are allowed to exceed the cooling setpoint + 2.5°C at some times, yet at others time are held tightly to the cooling setpoint, potentially indicating differences in the way this control is implementing, and the resulting cooling loads.

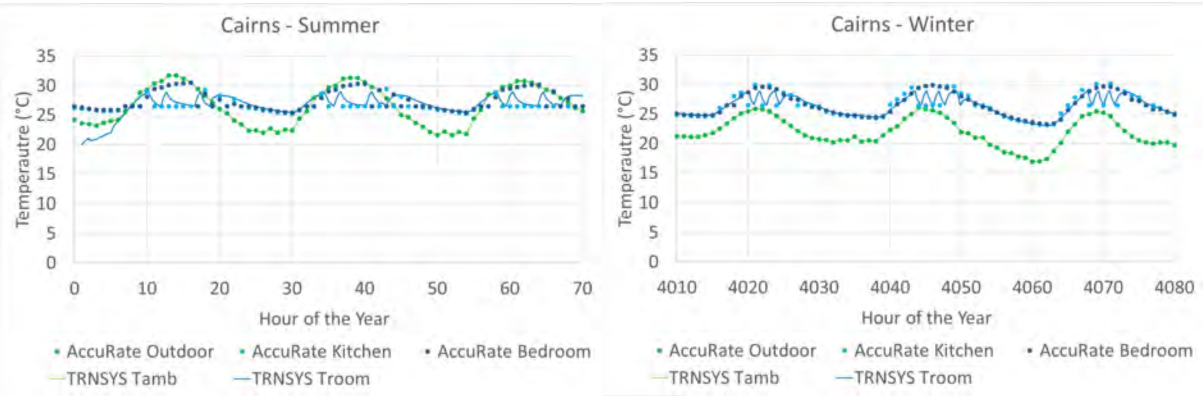

Figure 3: Cairns Occupied Space Temperatures

Similar plots of room temperature for Rockhampton are provided in Figure 4 and show the TRNSYS model requiring much less active cooling than AccuRate to maintain temperature in Summer, and again the AccuRate controller generally holding the room temperature tightly to the cooling setpoint. In Winter, Rockhampton requires very little active heating or cooling, and the room temperatures are all in very close agreement.

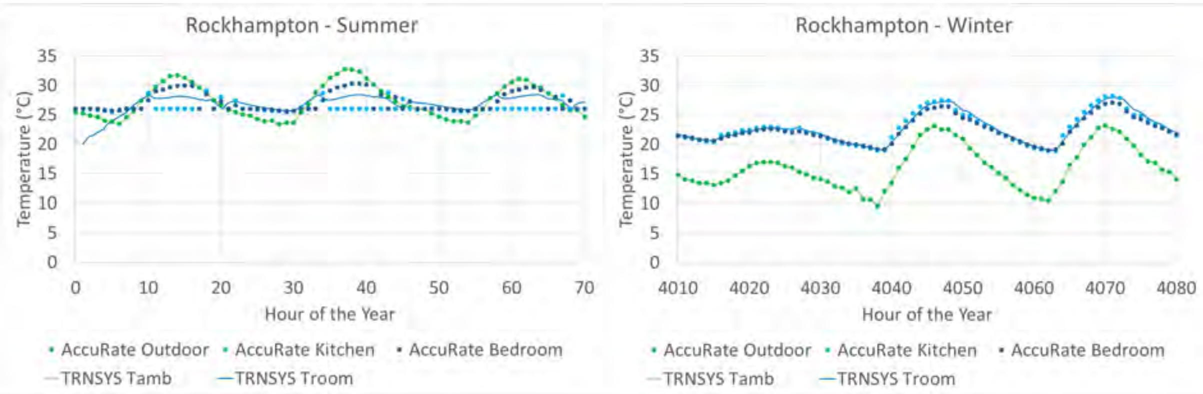

Figure 4: Rockhampton Occupied Space Temperatures

These results would seem to indicate that the differences in cooling results may be due to differences in the implementation of the cooling algorithms (both sensible and latent).

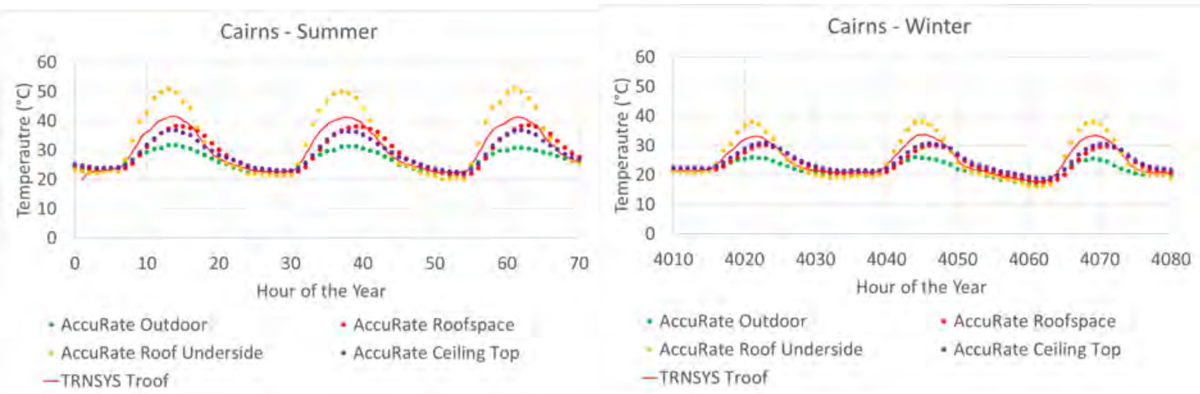

Figure 5: Cairns Roof Space Temperatures

The roof temperatures for Cairns were also plotted, as shown in Figure 5. The TRNSYS roof space temperature (TRNSYS Troof) generally sits in between the AccuRate roof cavity temperature (Roofspace) and the AccuRate Underside of Roof temperature, showing good general agreement.

4. Conclusion

Once the full details of the DR AS5389 reference building specification were understood, and the details of some of the AccuRate algorithms investigated, relatively good agreement was able to be achieved between AccuRate and TRNSYS. The remaining differences appear to be partly due to differences in the cooling (particularly latent cooling) algorithms, but details of the AccuRate latent cooling algorithm were unable to be obtained in order to confirm this. The underlying differences in the heat transfer, sky radiation and numerical solution algorithms, and the use of two zones, may also be contributing to these differences.

In order to align the results, the shade controls, internal loads, weather files, ground boundary condition and infiltration rates of the TRNSYS model were adjusted, and recommendations for these implementations have been provided to the CS-028 committee via the public comment process. The combined effect is that the total energy loads were within 11% for the cooler climates and large population centres of Sydney, Melbourne and Canberra, and within 30% for the hotter cities of Alice Springs, Rockhampton and Cairns, which hopefully will assist in industry acceptance of the standard.

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