CONVERGING ON A RECOMMENDED SET OF INTERPRETATIONS AND ASSUMPTIONS IN APPLYING STANDARD TESTS TO ENERGY ANALYSIS TOOLS

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ABSTRACT

The authors, having individually applied ANSI/ASHRAE Standard 140-2001 to the simulation program TRNSYS in a previous project, compare their results, simulation assumptions, and interpretations of the Standard's test cases to arrive at a conformed set of recommended practices. Sensitivities to individual assumptions are investigated and results of applying the conformed set of assumptions are presented.

INTRODUCTION

Increasingly, obtainment of energy efficiency certification requires the use of simulation packages and standardized energy codes to insure that a proposed building will meet minimum energy performance guidelines. A number of standards have been developed in an effort to assist end users in choosing an appropriate tool and to guide software developers in implementing common and accepted practices. However, the complexity of building energy simulation and the flexible nature of many of these tools mean that there is a range of acceptable answers to a given problem. In a recent project [1], three people with differing simulation backgrounds (a user, a user/developer, and a developer) individually applied the ANSI/ASHRAE 140-2001 Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs [2] to the software package TRNSYS (version 15.3) [3], developed by the University of Wisconsin – Madison in conjunction with the Centre Scientifique et Technique du Bâtiment in Nice, France, and Transsolar Energietechnik in Stuttgart, Germany. In comparing their results, intriguing and completely justifiable differences were noted in simulation technique, in base level assumptions and, not unexpectedly, in results. This paper describes the process by which the three authors converged upon a "recommended" set of interpretations and assumptions for the building configurations that are embodied in the ASHRAE 140 Standard as applied to TRNSYS and explores the effect of each major assumption and interpretation difference on annual simulation results. It further seeks to present some rudimentary results of applying TRNSYS v. 15.3 to Standard 140.

TRNSYS, commercially available since 1975 is a modular simulation program designed to model the energy transfers in any time dependent system. While this paper focuses on one aspect of TRNSYS's capabilities: that of building energy analysis, TRNSYS is by no means limited to these types of system. In fact each component of a given system is modeled in TRNSYS as a Fortran subroutine refered to as a Type. Types have a completely generic form such that from the user's perspective, there is no conceptual difference between the Type that models a building and the Type that models a pump, or a photovoltaic panel or a geothermal heat pump. The Type that models a multizone building is one of the more complex models in TRNSYS and the user is often given the choice between modeling a particular aspect within the building model or external to the building model. For example, occupancy can either be scheduled completely within the scope of the building model or the user can define an external model to define the same driving function. External models are not external to TRNSYS, only external to the building model for the purposes of this project and paper.

ASHRAE STANDARD 140

ASHRAE Standard 140 is divided into five series of test cases. These are 600-650, 900-960, 195-320, 395-440, and 800-810. Each series begins with a base case (600, 900, 220, 400, and 800 respectively) on which subsequent cases are built. Each subsequent case in a given series tests the software's ability to model a specific change in building configuration (addition of a night setback thermostat, addition of south shading, modification of window orientation, etc.). Each series of cases seeks to apply the same set of changes to fundamentally different buildings (low mass and high mass, for example). The 220, 400 and 800 series cases seek to isolate the effect of or sensitivity to one

particular variable or algorithm in the software. This paper deals primarily with the results from the 600 series of cases (low mass building), the 900 series of cases (high mass building), and a series of sensitivity tests in which results from one test are subtracted from the results of another to isolate the software's sensitivity to a particular modification. In many cases the sensitivity tests (difference between case results) are more elucidating than the actual values from a given case because the effects of base level assumption differences are subtracted out. ASHRAE Standard 140 primarily uses four figures of merit in assessing tool capability: annual heating load, annual cooling load, peak heating load and peak cooling load. Individual cases often have specific output reporting requirements. All cases specified in ASHRAE Standard 140 were run as part of this project and of the precursor project.

For each case, the Standard reports an acceptable range of answers. The answers forming the range are the result of the same simulations having been carried out using a selection of the most commonly used building energy simulation tools available on the market. TRNSYS 13 (the current version when the original work was performed) was one of the tools used in setting the range of acceptability.

The building at the heart of all case series is a 6m x 8m x 2.7m box as shown in Figure 1. The box is modified in various cases by shifting windows, by adding overhangs and wing walls, by adjusting heating and cooling set points, by adding night time ventilation and by making similar, targeted modifications. The most complex modification involves the addition of an unconditioned "sunspace" zone to the south side of the building.
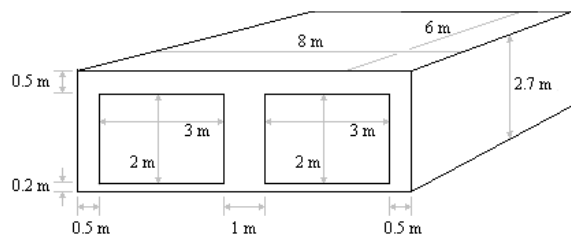

Figure 1: Base Level ASHRAE Standard 140 Building Configuration

METHODOLOGY AND ASSUMPTIONS

During the precursor project, the three authors applied ASHRAE Standard 140 to TRNSYS 15.3 individually. Those simulations and their results are referred to in this paper as the preliminary or independent runs. As might be expected when three people independently model a building, the authors' assumptions and results differed although their results all fell within the Standard's range of acceptability. Following the precursor project, the authors discussed their assumptions and interpretations and came to agree on a conformed set of suggested assumptions based on two factors.

- How would a normal TRNSYS user model a given case? The authors wanted to minimize the effects of their knowledge as developers and/or power users.

- What does the language of the Standard seem to intend?

They then designated two of the three authors to rerun all the cases with the conformed assumptions. The following sections of this paper present the differing assumptions, seek to address TRNSYS's sensitivity to those assumptions, and then present the authors' assumption recommendation.

Diffuse Sky Model

In TRNSYS, the user is allowed the choice between four correlations that estimate the amount of diffuse solar radiation incident on a surface of given orientation (slope and azimuth). The two most commonly used correlations are the Reindl and Perez models, which both account for isotropic diffuse, circumsolar diffuse and horizon brightening [4]. The TRNSYS documentation suggests that the Perez, and Reindl correlations are largely comparable but that Perez is more computationally complex. During conversations with the correlation developers, however, the authors were told that the Reindl model had been optimized for solar thermal applications (non vertical, south facing, tilted surfaces) and that the Perez model had been optimized over the entire range of possible surface orientations. In their independent runs, one author chose to accept computational complexity and use the Perez model while the two others used the Reindl correlation. Among their justifications for using the Reindl correlation, both of these authors stated that they felt it was the default correlation because in the TRNSYS front end, the default solar radiation processing mode is set to employ the Reindl correlation. The third author, who did not use of the front end but wrote the input files by hand found no indication of a default value in the documentation and chose a correlation based on the developers' oral recommendation. In their conformed simulation reruns, the Perez model was employed.

Table 1 shows results for three cases run under each of the two competing sky models (Reindl and Perez). The

three cases in question are the low mass base case, the low mass case with shaded south façade and the low mass case with east / west oriented shaded windows. These three cases were deemed likely to be most sensitive to changes in sky model. The most sensitive measure was found to be annual cooling and the most sensitive case was found to be the unshaded base case (600). Modification of the sky model results in a 2.3 % change annual cooling for this case.

Table 1: Sensitivity to Sky Model

VERSION	ANNUAL HEATING	ANNUAL COOLING	PEAK HEATING	PEAK COOLING
	[MWh]	[MWh]	[kW]	[kW]
Case 600 Perez	5.2595	6.1935	3.9158	6.4031
Case 600 Reindl	5.2123	6.3382	3.9158	6.5067
Case 610 Perez	5.3835	4.2280	3.9158	5.8133
Case 610 Reindl	5.3788	4.2261	3.9158	5.8092
Case 630 Perez	6.0054	2.2501	3.9208	3.4283
Case 630 Reindl	6.0012	2.2505	3.9208	3.4233

Time Varying Convective Heat Transfer Coefficients

A significant number of possibilities exist for treating interior and exterior heat transfer coefficients on building walls in TRNSYS. These include (but are not limited to) setting constant values, using simple equations to determine the coefficiencts based on wind speed, surface temperature, or any other combination of avaliable output variables, or calculating time dependent coefficients using a model external to the building model.

The TRNSYS building model separates convection and radiation, requiring the user to input convection coefficients but calculating the radiation portion internally. The user is unable to affect the radiation coefficient. ASHRAE Standard 140 provides combined coefficients in its main body and provides split convection and radiation coefficients in an Informative Annex.

The TRNSYS building model developer recommends that the average radiative coefficient for surface temperatures between 0 and 100 ºC be taken as 5 W/m2.K and that the convective portion of the combined coefficient be calculated as the difference between the values reported in the Standard and the

average radiative coefficient value. This is not the same split as is provided in the Informative Annex.

As an additional option, TRNSYS is equipped with a detailed external model (external to the building model but part of standard TRNSYS) that calculates convection coefficients for interior vertical or horizontal surfaces. The convection coefficients for these surfaces can be dependent upon the instantaneous surface/air temperature difference instead of being set to constants. In the precursor project one of the three authors made use of the detailed external model for convection on interior surfaces. For exterior surfaces, he employed equations that compute convection coefficients as a function of wind speed (also suggested in an Informative Annex of the Standard). The second author used constant convective heat transfer coefficients from the ASHRAE Standard 140 Annex for both interior and exterior surfaces. The third author used constant coefficients (interior and exterior) based on the building model developer's convective / radiative split recommendations.

In their conformed assumptions, the authors came to the conclusion that the preferred method would be to use wind speed dependent equations for exterior surfaces since they were clearly referenced in the Standard. For interior surfaces, they used a hybrid method in which the constant coefficient values from the Standard were used along with the detailed external model to determine the direction of heat transfer (whether the surface or the air was warmer). The resulting heat transfer direction was used to pick between the "heat transfer up" and the "heat transfer down" values supplied in the Standard for horizontal surfaces with the split fractions for the convective portion taken from the Informational Annex. Interior vertical surface were assigned constant values.

Table 2 below compares annual heating and cooling, peak heating and cooling for four different modeling assumptions as applied to Case 600 (light weight base case) and to Case 900 (heavy weight base case). In the table, the exterior convection coefficients were always computed using wind speed dependent equations. The following abbreviations apply:

-01: external component used to switch between upward and downward heat transfer on horizontal surfaces; constant coefficients provided by the Standard. Constant values for walls as provided in the Standard.

-02: constant coefficients on all interior surfaces (recommended by the Standard if values cannot be variable)

-03: external component used not only to switch between upward and downward heat transfer but to calculate time dependent coefficient values for all interior surfaces (vertical and horizontal).

Table 2: Sensitivity to Convection Coefficient Calculation Method

VERSION	ANNUAL HEATING [MWh]	ANNUAL COOLING [MWh]	PEAK HEATING [kW]	PEAK COOLING [kW]
600-01	5.241	6.284	3.930	6.473
600-02	5.325	6.480	4.009	6.683
600-03	5.099	6.165	3.961	6.536
900-01	1.732	2.048	3.413	3.307
900-02	1.719	2.104	3.536	3.445
900-03	1.680	1.968	3.431	3.228

Of the three assumptions, the second (all constant coefficients) results in the highest energy use estimates in the light weight case and in the highest estimates except for annual heating in the heavyweight case. The completely variable coefficient assumption (-03) results in the lowest energy use estimates for both annual measures in both cases but does not for peak values. It is difficult to draw any meaningful conclusion from the results shown in Table 2 except to note that the method of calculating interior convection coefficient has a fairly significant effect upon whole building results (5% for annual heating and cooling in the light weight case). It was felt by the authors that the information available in the Standard did not correspond enough to the information required by the detailed external model or that the detailed external model did not provide enough guidelines on how to choose appropriate coefficient multipliers and exponent values based on the information that was available in the standard. The authors were unable to further research the detailed external model as it is based upon a paper written in German. The gap between available information sources was such that the detailed external model could not be used to its full extent but that it could be used as a switch to determine whether heat transfer was "upward" or "downward." In the conformed case reruns therefore, assumption – 01 was used throughout.

Shading

The TRNSYS building model is not a geometrical model, which means that there is no information entered about the position of walls with respect to one another. Consequently, shading of surfaces is most often handled by a model external to the building model that calculates the net effect of wing walls and overhangs on an aperture. In Cases 610 and 910, a 1m wide overhang is applied along the roofline of the entire south façade of the building. In Cases 630 and 930, the south facing windows are moved to the east and west façades and each window is outfitted with an overhang above and wing walls on either side. When faced with such shading configurations, it is not uncommon to assume that the effect of shading on the opaque portions of the façade (the walls) is negligible in comparison to the effect of shading on the windows themselves. In their original work, two authors accounted for shading on walls as well as on windows. The third author made the simplifying assumption that the energy transfer through the wall would be goverend more by the temperature difference across the wall than by the solar induced boundary condition of the outer surface and so defined shading devices only for the windows, allowing opaque surfaces to see unshaded radiation values. No specific test was made to determine the effect of this shading assumption. In the conformed runs, all three authors agreed that the more correct approach is to apply shading by overhangs and wing walls not only to the window but also to opaque wall surfaces.

Ground Coupling

Ground coupling remains at the forefront of building simulation research. One of the key differences between the ASHRAE Standard 140 and IEA BESTEST [5] upon which Standard 140 is heavily based, is in ground coupling tests. BESTEST contains a number of additional cases in the 900 series that seek to test a software package's ability to model ground coupling. These cases are largely absent from ASHRAE 140, suggesting that there is not, as yet, consensus among building energy simulation methodology developers as to how best to model such effects. Ground coupling effects are set in the 600 base case and are not modified in any of the subsequent cases. However, there is still some leeway as to how one defines the base case ground coupling. Standard 140 states that "to reduce uncertainty regarding testing the other [non ground coupling] aspects of simulating the building envelope, the floor insulation has been made very thick to effectively decouple the floor thermally from the ground." Using one of the three methods available in TRNSYS, it is possible to completely decouple the ground and building not by inserting large amounts of insulation but by specifying that the temperature at the slab/soil interface is the identical to the slab/zone temperature and that therefore, the slab is adiabatic although it still contributes to the thermal capacitance of the building. In their independent runs, two of the authors decided to interpret Standard 140 to mean that complete decoupling of the building and ground was intended where possible; the Standard states in its introduction

that advanced features from the software package should be used if available. Consequently, both made the adiabatic slab assumption when applying the Standard in TRNSYS. The third author included the effective insulation layer and followed the suggestion in the Standard that "for software that requires input of ground properties … the ground in the vicinity of the building is dry packed soil with the following characteristics: deep ground temperature = 10 ºC"

The third method available to TRNSYS users for estimating ground coupling effects is to make use of an external three dimensional finite difference ground model that divides the ground surrounding the building into two zones [6]. The first is the "near field" zone, in which ground temperatures are affected by energy transferred from the slab, by time of year, and by depth beneath the surface. In the second "far field" zone, ground temperatures are only affected by depth and time of year.

It was decided between the authors that the effective decoupling method would be recommended for applying Standard 140. The adiabatic slab assumption was thought to be an overly liberal interpretation of the Standard's text and the external model is not part of the standard TRNSYS package but is available only as an add on. However, all three alternatives were tested. The results are summarized in Table 3 below.

Table 3: Sensitivity to Ground Coupling Assumption

VERSION	ANNUAL HEATING [MWh]	ANNUAL COOLING [MWh]	PEAK HEATING [kW]	PEAK COOLING [kW]
Effective Decoupling	5.260	6.194	3.916	6.403
Adiabatic Slab	5.188	6.296	3.908	6.448
External model	5.258	6.198	3.921	6.408
External Model (with 5yr preheat)	5.256	6.199	3.916	6.408

Comparing only the first two rows of table entries, it is evident that the two original assumptions made by the authors are not entirely equivalent. Assuming that the slab is adiabatic reduces annual heating load and increases annual cooling load by approximately 1.5 % (at least given the assumption of a constant 10 ºC ground temperature). Results from the external, three-dimensional conduction model and from the effective decoupling method suggested in the Standard correspond well. While this gives some confidence through corroboration that the assumption is

reasonable it does not mean that either assumption is a particularly realistic. It should be stated that the external model is currently being verified as part of an International Energy Agency (IEA) Task.

Time Step

TRNSYS uses a constant, user defined time step throughout a given simulation. Once again in their preliminary runs, the authors chose different time steps for their work. One author used a time step of 1 hour for all cases except 640 and 940. In those two cases, he used a time step of 0.1 hour. Cases 640 and 940 involve a thermostat night set back in which the heating set point in the building jumps from 10 ºC to 20 ºC each morning at 7AM (and back again at 11PM). In order to model such a step change, TRNSYS would have to allow for there to be two simultaneous set point temperatures (10 ºC for the time step ending at 7AM and 20 ºC for the time step beginning at 7 AM.) Since this is not possible in TRNSYS, the software in fact does not register that the set point temperature has changed until one time step later. When using a one hour time step, this delay causes significantly low peak heating loads; more time step precision was required in order to alleviate the problem. The other two authors used a 0.25 hour time step throughout their simulations.

In their post independent run discussions, the authors decided that it would be preferable to be consistent with the simulation time step from one run to another so as to eliminate it as a source of difference when it came to making later comparisons between cases. The authors also decided that "best practice" dictates that the wall time base (the time step used to precalculate a wall, roof, or floor's transfer function coefficients) should match the simulation time step when possible. Case 900 was run using various time step / time base pairs ranging from 1 hour to 1/8th hour and bearing in mind that the simulation time step cannot exceed the wall time base.

Table 4: Sensitivity to Time Step and Wall Time Base

Time Step	1	1	1	1
Time Base	1	0.5	0.25	0.125
	[MWh]	[MWh]	[kW]	[kW]
Annual Heat	1.775	1.771	1.765	1.763
Annual Cool	1.963	1.971	1.965	1.963
Peak Heat	3.406	3.409	3.405	3.403
Peak Cool	3.174	3.188	3.194	3.203
Time Step	0.5	0.5	0.25	0.25
Time Base	0.5	0.25	0.25	0.125
	[MWh]	[MWh]	[kW]	[kW]
Annual Heat	1.778	1.774	1.772	1.778

Annual Cool	1.98	1.979	1.977	1.986
Peak Heat	3.409	3.406	3.404	3.408
Peak Cool	3.228	3.227	3.228	3.25

Time Step	0.5	0.5
Time Base	0.5	0.25
	[MWh]	[MWh]
Annual Heat	1.776	1.777
Annual Cool	1.986	1.99
Peak Heat	3.408	3.409
Peak Cool	3.243	3.254

Since no comparison can be made between simulated results and measured results, the choice of time step and time base must be somewhat arbitrary. As can be seen from Table 4 above, little sensitivity was seen based on modification of these two values. The maximum deviation from the average result was 1.3 % and ocurred in peak cooling with a time step and time base of 1 hour. Case 900 does not include any modification to the thermostat setting. Consequently the deviation cannot be attributed to the late registration of thermostat set back or set up discussed earlier in this section. In the conformed runs, a time step and wall time base of 0.25 hours were used throughout.

Schedules

In their original work, the authors used two different methods for specifying schedules such as the thermostat night setbacks in cases 640 and 940 or the night ventilation schedules in cases 650 and 950. In the TRNSYS building model, it is always possible to define a given aspect of the model (thermostat setting for example) as an internal schedule or as an external input. When set to be an internal schedule, the user is required to create a 24-hour repeating step change schedule for the variable at hand. When set to be an external input, the user must make use of a component in the TRNSYS simulation to generate the required value. This component interpolates between values but can be set to create step changes in value as well. It was difficult for the authors to imagine how the difference between internal and external schedules would have had a bearing on and indeed testing of only that modification showed that the methods were completely equivalent. In discussions following the original simulation work it was decided to use internal schedules since this is the method most commonly taught to new TRNSYS users during training workshops.

Weather File Format

The authors employed two different methods of dealing with the TMY [7] format weather data supplied with ASHRAE Standard 140. In its commercially available form, TRNSYS 15.3 does not include a component for directly reading TMY format weather files. One of the three authors found a freely available program available on the internet that converts TMY format to EnergyPlus [8] format weather data, which TRNSYS can read directly. That author preprocessed the supplied weather data then read the resulting file using a standard TRNSYS component. The other two authors modified the weather data supplied with the Standard, extracting the necessary data columns and placing them in a data file readable by another standard TRNSYS component. It was decided that the later method was the more accessible course of action to a standard user and thus was employed by both authors in their conformed runs. It was assumed that the the two methods (hand modification and preprocessing with a weather converter program available as part of the EnergyPlus distribution [9]) were identical and that the resulting data files would be largely similar.

Sky Temperature Model and Cloudiness Factor

Sky temperature provides a simplified method for calculating the radiative heat transfer between a surface (such as a building façade) and the sky. It assigns an effective temperature to the sky, which is lower than the ambient air temperature by an amount that depends upon the current cloud cover and on the time of day (black night sky, for example, has a lower effective temperature than a clouded day time sky). The TMY data includes a column for "opaque sky cover," a value that indicates the percentage of sky that is covered by opaque clouds during a given hour. Examination of the raw data shows that for portions of the file, only one hour in three was recorded; the two intervening hours were set to values of 99 indicating that data was unavailable. The provided data file was modified by replacing the missing values with values interpolated between existing values.

Two methods for calculating the sky temperature exist in TRNSYS [10]. In the first, cloud cover is provided as an input; in the second, cloud cover is calculated by the model based upon ambient temperature, dew point temperature, atmospheric pressure, and solar radiation incident on a horizontal surface. The TRNSYS manual recommends that cloudiness data be read from a data file when available. Once an estimation of the cloudiness factor has been made, the actual calculation of the sky temperature does not differ from one method to the other. Where the first author used sky

temperature based on corrected data file cloudiness, the other two authors chose to allow the sky temperature model to calculate its own cloudiness factor. A comparison of the two methods for calculating sky shows some significant differences as can be seen in Figure 2.
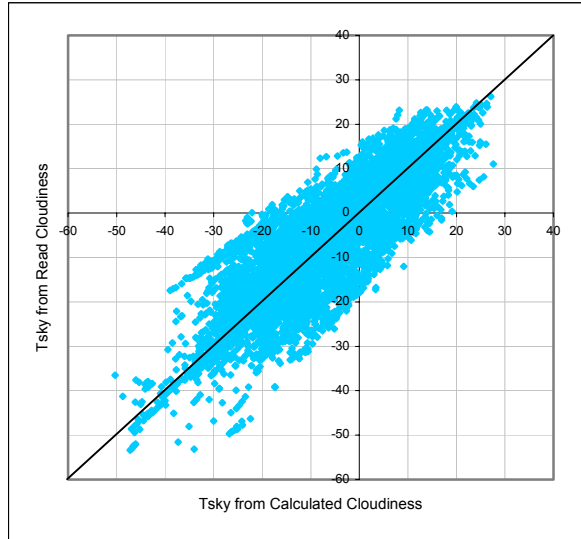

Figure 2: Sky Temperature Based on Calculated versus Read Cloudiness

The difference in annual heating, annual cooling, peak heating and peak cooling, however was not significantly affected by the choice of sky temperature assumption as can be noted in Table 5.

Table 5: Sensitivity to Sky Temperature Assumption for Case 600

VERSION	ANNUAL HEATING	ANNUAL COOLING	PEAK HEATING	PEAK COOLING
	[MWh]	[MWh]	[kW]	[kW]
Cloudiness from data file	5.260	6.194	3.916	6.403
Calculated cloudiness	5.274	6.169	3.896	6.412

It is the authors' recommendation that in accordance with the TRNSYS documentation, the cloudiness factor be read from the corrected TMY data file and that this value be passed to the sky temperature model as an input.

CONFORMED RESULTS

The following section summarizes the results of rerunning all cases using the conformed assumption set described above. Minor differences were still seen between the results obtained by the two authors who reran the cases. However, none were particularly significant. The duplication served to highlight and resolve any errors in the two authors' final results.

Figure 3 shows the annual heating results for all cases in the 600 and 900 series. The building configurations in Cases 650 and 950 do not include any heating equipment.
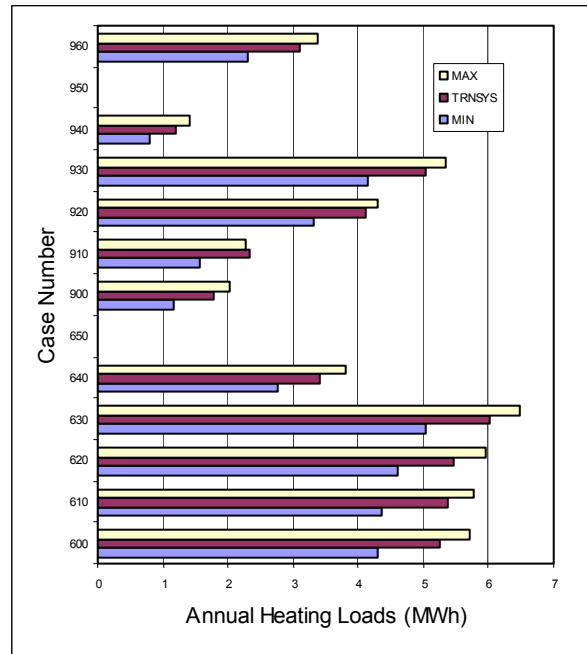

Figure 3: Annual Heating Results (Series 600 and 900)

In the lightweight series of cases (600-640) TRNSYS lies well within the range of acceptability as defined by Standard 140. In the heavyweight case (900-950), however, TRNSYS lies nearer to the maximum end of the range and in fact gave an annual heating result slightly above the range for case 910. The fact that the results lie at different places in the range could be an indication that TRNSYS does not react to mass changes in the same way that its peer software does. Such conclusions can be verified or invalidated by use of sensitivity tests in which the results of a case from one series are subtracted from the corresponding case in the other series. If the difference (or delta) between the two cases falls outside the acceptability range of deltas then one can conclude with more conviction that the program in question is sensitive, perhaps inappropriately so, to the modeling assumption at hand. Figure 4 shows the annual heating results of Case 600 subtracted from the same results of Case 900. As can be seen in the figure, the delta between the two

cases falls nearly perfectly in the middle of the range suggesting that TRNSYS is not inappropriately sensitive to mass change.
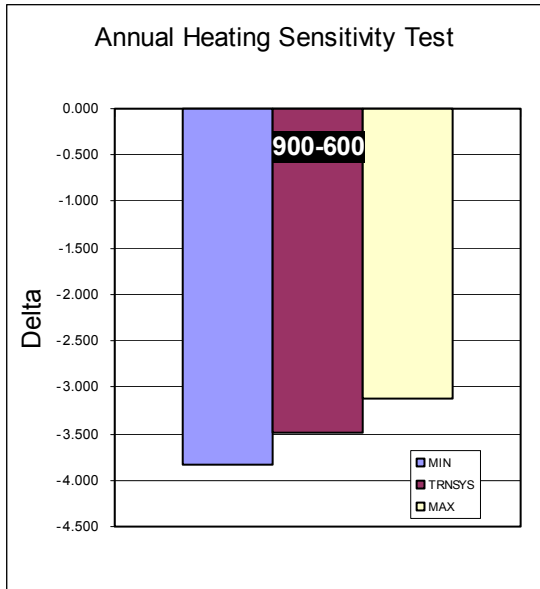

Figure 4: Sensitivity to Mass Change

Figure 5 presents the annual cooling results for all cases in the 600 and 900 series. Without exception, TRNSYS falls at the low end of the ranges in annual cooling, sometimes slightly below the acceptability range. Sensitivity test results did not raise any alarms.
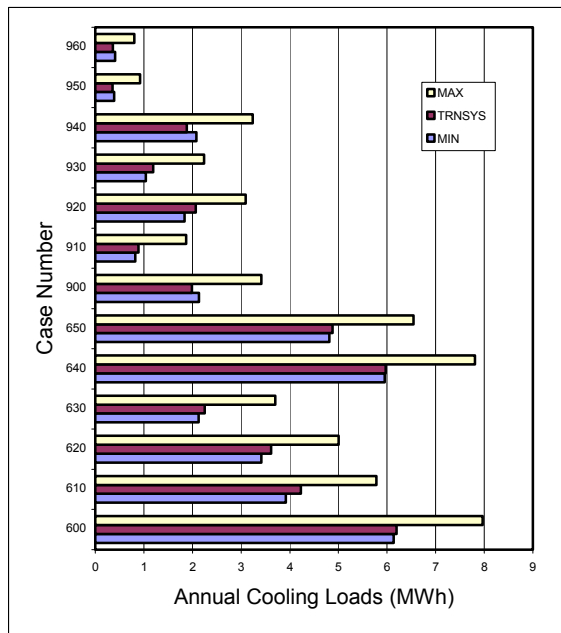

Figure 5: Annual Cooling Results (Series 600 and 900)

In investigating the causes for the low cooling estimates, it was noted that TRNSYS uses a different algorithm for calculating sky temperature than does one of its peer software packages. Both correlations are conceptually the same and return nearly identical average sky temperatures. However, the sky temperature correlation used in TRNSYS has a higher amplitude than does the correlation used in EnergyPlus. It is also worth noting that at least in the original TRNSYS work (version 13, which helped to set the acceptability range) convection and radiation coefficients were not split in the building model: combined coefficients were used instead. Given the sensitivity to interior heat transfer coefficients noted earlier, this algorithmic change could explain the shift in annual cooling results.

Figure 6 shows the peak heating load results for all cases in the 600 and 900 series. These, as well as the peak cooling load results shown in Figure 7 mostly fall near the middle of their respective ranges.
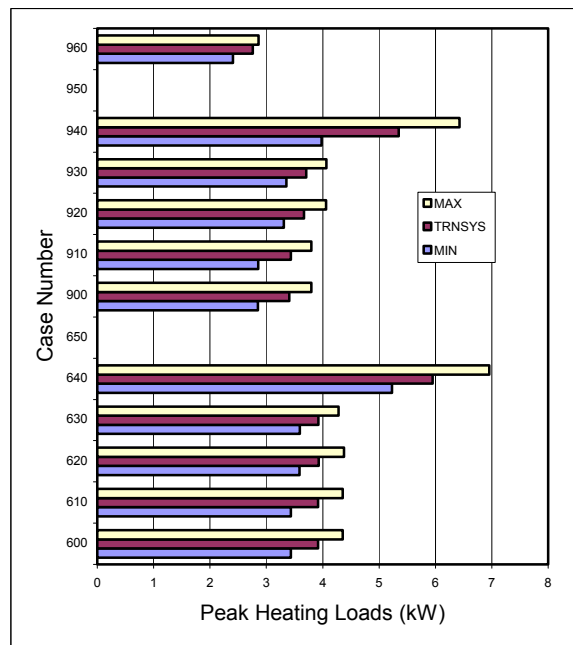

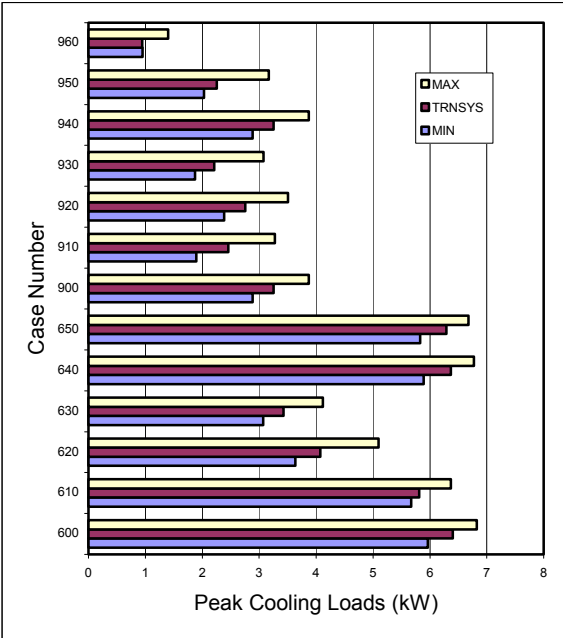*Figure 6: Peak Heating Loads (Series 600 and 900)*

Figure 7: Peak Cooling Load (Series 600 and 900)

CONCLUSIONS

It is clear from the work involved in this project as well as its precursor that there are a great many valid assumptions that the user of a given building energy simulation tool can make and still fall well within a range of acceptable answers. It is also clear that comparatively minor interpretational differences as well as a user's habits and standard practices can have a significant effect upon the annual results of a given simulation. Of those examined in the scope of this project, probably the most significant was found in the application of interior convection coefficients. In practice, these values are difficult to come by and numerous methods exist for estimating them. The authors researched the available literature and found differences between the method called for in the Standard and the methods recommended in more recent literature. While a detailed investigation of the merits of the various available heat transfer function coefficient calculation methods was outside the scope of this project, TRNSYS does show a high sensitivity not only to different constant values of these coefficients but also to constant versus varrying values.

The second most significant sensitivity was found in the treatment of ground coupling, an effect that is modeled using a wide range of assumptions and estimations that depend largely on software capabilities. In addition to dependence on slab assumption, TRNSYS was also shown to be sensitive to modifications of ground temperature slab insulation level. The ASHRAE 140 Standard clearly states its

intended assumption concerning ground coupling; whether this assumption is an accurate representation of reality is beyond the scope of this project to verify. One would assume that because other software packages employ many of the same algorithms that they would show similar sensitivities to ground coupling.

Given such sensitivities, one might conclude that it would be difficult to obtain a consistent set of assumptions that would cause a software package to pass the entire series of ASHRAE tests. Much the opposite was shown to be true, however. TRNSYS did acceptibly pass all the tests using the conformed assumption set described in this paper. Through discussions and result comparison, the authors progressed from their individual assumptions to a recommended set of assumptions and interpretations that can be used by other users in applying TRNSYS to ANSI/ASHRAE Standard 140 and IEA BESTEST and which can also give guidance as to "best practice" in other building modeling exercises.

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