Tests performed on ApacheSim in accordance with ANSI/ASHRAE Standard 140-2001

ApacheSim Version 5.2
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1 Introduction


This standard method of test (SMOT) which has its origin in the IEA 12B/21C ‘BESTEST’ diagnostic tests\(^2\), requires the simulation of a number of variants of a test building. The test cases increase in complexity from a simple building shell without glazing, infiltration or internal gains to comparatively realistic building types.

The aim of the tests is to identify and diagnose differences in predictions that may be caused by software errors. The ways in which they can be used are listed in Standard 140-2001:

(a) comparing the predictions from other building energy programs to the example results provided in the informational Annex B8 and/or to other results that were generated using this SMOT,

(b) checking a program against a previous version of itself after internal code modifications to ensure that only the intended changes actually resulted,

(c) checking a program against itself after a single algorithmic change to understand the sensitivity between algorithms,

(d) diagnosing the algorithmic sources of prediction differences; diagnostic logic flow diagrams are included in the informational Annex B9.

While the text of the Standard emphasises that all building models are simplifications of reality, and full validation cannot be achieved by a single series of tests, the ASHRAE 140 tests provide a valuable benchmark by which the predictions of a simulation program may be compared with those of its peers, as means to establishing a degree of confidence in the correctness of its algorithms and their implementation.

This report presents the results of these tests applied to the simulation program ApacheSim\(^3\), as required by ASHRAE Standard 90.1-2001, Addendum p\(^4\).

A brief outline of the tests is provided. This is followed by a description of the modelling assumptions and settings used to run the tests in the ApacheSim program. The ApacheSim results are then presented and discussed.

2 Description of tests

A full description of the tests, including input data, output reporting conventions and terminology, is provided in the ASHRAE Standard. Here it will suffice to enumerate and briefly describe the cases.

Figure 1 shows a sketch of the building which forms the subject of Case 600. This is referred to in the Standard as the ‘Base Case’, of which all other cases are variants.
The building is a cuboid with one of its longer sides facing south. In Case 600 it has two south-facing windows each of area 6m².

Two groups of cases are identified: ‘basic tests’ (cases 600-650 and 900-960) and ‘in-depth’ tests (the remainder).

Each case consists of simulating a variant of the test building over a year using a Denver, Colorado weather dataset. The cases explore different combinations of the following parameters and settings:

- **Glazing:** none, high conductance opaque panel or double glazed window
- **Glazing orientation:** south or east/west
- **Glazing shading devices:** none, overhang (south), overhang + side-fins (E/W)
- **Fabric:** low-mass or high-mass construction
- **Infra-red emissivity of internal (ε_i) and external (ε_e) surfaces:** 0.1 or 0.9
- **Solar-spectrum absorptance of internal (α_i) and external (α_e) surfaces:** 0.1, 0.6, 0.9
- **Internal gains:** 0 or 200W
- **Infiltration:** 0.0, 0.5 or 1.0 ach
- **Heating and cooling:** different setpoint combinations or no heating/cooling
- **Venting:** an option using night ventilation and free cooling
- **Sunspace:** Case 960 examines the effect of an attached sunspace

The following simulation variables are specified for output:

- Heating load
- Cooling load
- Air temperature
- Incident solar gain on the various surfaces
- Direct transmitted solar gain

**Figure 1 – Case 600 geometry**
In all the tests the issue of heat transfer with the ground is largely eliminated by the inclusion of a thick layer of insulation in the floor construction.

Table 1 provides a summary of the test cases. The ‘basic’ cases are indicated by underlining. Bold text indicates salient differences from previously listed cases. The table is divided into sections covering different heating and cooling control regimes. For example, ‘Setpoints 20, 27’ means heating to 20°C and cooling to 27°C. ‘Setback’ means heating to 10°C overnight (2300-0700) and to 20°C at other times, with cooling to 27°C. ‘Venting’ means continuous night ventilation between 1800 and 0700, cooling to 27°C during the rest of the day, and no heating.

Cases including the letters ‘FF’ test free-floating conditions with no heating or cooling.

Case 960 is a version of Case 600 with an attached sunspace. The outputs tested are heating and cooling loads in the room and the temperature in the sunspace.
<table>
<thead>
<tr>
<th>Case</th>
<th>Glazing Type</th>
<th>Emissivity $\varepsilon_i$</th>
<th>Absorptance $\varepsilon_e$</th>
<th>Internal Gains $\alpha_i$</th>
<th>Infiltration (ach)</th>
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</table>
3 ApacheSim Models

Modelling options used in ApacheSim are set out in Appendix A, using the format specified in the Standard.

4 ApacheSim Results

The ApacheSim results are presented graphically in Figures 1-326, alongside the results for other programs reported in ANSI/ASHRAE Standard 140-2001[1]. Results provided for other programs in the earlier BESTEST report[2] but omitted from the ANSI/ASHRAE Standard are indicated with a striped fill pattern. Results from the program EnergyPlus version 1.1.0.020[6] are also included.

The results are presented in tabular form in the file ‘ASHRAE 140 ApacheSim.xls’, as required by the Standard. This file contains certain additional data not included in this report, including time series comparisons and binned temperature data for Case 900FF.

5 Observations on ApacheSim Results

One way to assess ApacheSim’s performance with respect to the other 9 programs for which results are available is to see whether its predictions lie within the spread of results obtained from those programs. The results are now examined on this basis.

Heating load

Refer to Figures 1-70.

In all but 3 of the 35 cases, the annual heating loads calculated by ApacheSim lie within the range of values calculated by the other 9 programs.

There is a tendency for ApacheSim’s heating loads to lie towards the upper end of the distribution of predicted values, and in three instances (cases 210, 910 and 920) ApacheSim’s annual heating load exceeds that of the other programs. Three possible reasons for this can be identified.

ApacheSim models the participation of the room air in radiant exchanges, an effect which we shall refer to as air emissivity. This is a small but significant effect which is ignored by the other programs for which results are presented in the Standard. One of the consequences of this mechanism is an increase in the thermal coupling between the room air and the internal surfaces of the room, and this tends to increase heating load.

A second possible reason for higher than average heating loads is the algorithm used by ApacheSim for the calculation of long-wave radiation from the sky. ApacheSim uses the
CIBSE Guide A\textsuperscript{[5]} algorithm for this process, which gives somewhat cooler sky temperatures than some other methods.

Finally, in case 920, where the windows have shading devices, ApacheSim heating loads will have been increased by the inclusion of diffuse shading in ApacheSim's solar calculations. ApacheSim, unlike most of the programs involved in the study, performs a calculation of the obscuration of both short-wave and long-wave sky radiation by shading objects. The inclusion of diffuse shading will have reduced the solar gain, causing an increase in heating load.

The comparison of peak heating loads shows that ApacheSim's predictions fall consistently within the range of values calculated by the other programs.

**Cooling load**

Refer to Figures 71-140. In all cases, ApacheSim's predictions of both annual and peak cooling loads fall within the range of values calculated by the other programs.

**Annual free-floating temperature output**

Refer to Figures 141-155. These tests look at the prediction of free-floating temperatures for a range of basic cases. The ApacheSim predictions lie within the range of the other program's results, with the exception of the average annual temperature for cases 900FF and 950FF, where ApacheSim has (by margins of less than 0.2K) the lowest prediction.

**Basic sensitivity tests – cases 600-960**

Refer to Figures 156-199. These tests examine, for the basic cases (both low-mass and high-mass), the sensitivity of heating and cooling loads to:

- glazing orientation and shading
- control setpoint setback and venting
- addition of a sunspace

The results show the change in heating or cooling load (both annual and peak) that occurs in moving between two of the test cases.

ApacheSim's results are in every case within the spread of values calculated by the other programs.

The comparison between cases 630 and 620 is worthy of mention. Perhaps unexpectedly, the ApacheSim results show a small reduction in peak heating load when the shading devices are added. The reason is that the peak heating load occurs during the night, and the shading devices partially shield the windows from the cold night sky. This mechanism
is taken into account by ApacheSim's diffuse shading algorithm as applied to long-wave sky radiation.

**Low-mass in-depth sensitivity tests – cases 195-320**

Refer to Figures 200-255.

These tests examine, for in-depth cases 195-310 (low-mass, setpoints 20, 20) and 320 (low-mass, setpoints 20, 27), the sensitivity of heating and cooling loads to:

- addition of a high-conductance opaque panel
- internal and external infra-red emissivity
- internal and external solar absorptance
- infiltration
- internal gains
- glazing (in two orientations)
- shading
- cooling setpoint

In all but 5 of the 56 comparisons, the ApacheSim results lie within the spread of predicted values.

The comparison between cases 290 and 270 shows the same effect as that between cases 630 and 620: the small reduction in peak heating load that occurs when the shading device is added can be attributed to long-wave sky shading.

There is one other instance – the comparison between cases 230 and 220 – where ApacheSim predicts the lowest increase in peak heating load. This comparison, which is a test of the effect of air infiltration, also shows ApacheSim predicting the largest increase in annual cooling. Both these results can be attributed to somewhat artificial circumstances that arise in case 220 in relation to ApacheSim's air emissivity modelling.

Case 220 has no infiltration. Consequently the moisture content of the air in the building remains fixed at its initialisation value, which ApacheSim sets to the external air moisture content. In case 230, one air change per hour of infiltration is introduced, which causes the room moisture content for this case to follow the external air moisture content. Room moisture content is one of the variables affecting the calculation of air emissivity in ApacheSim: higher humidity is linked to higher air emissivity. At the time of the peak heating loads (January 4) the external moisture content, and consequently the room moisture content in case 230, is lower than the fixed value applying in case 220. Consequently at this time case 230 has a lower air emissivity than case 220. This translates to less thermal coupling between the air and the room surfaces, and a reduction in the differential between the peak heating loads for cases 230 and 220.

During the summer when most cooling demand occurs, external moisture content, and therefore room moisture content in case 230, tends to be high. This strengthens air-surface coupling by the air emissivity effect, and this in turn increases conduction gain and
solar heat transfer to the air point. The result is a small increase in annual cooling load for case 230, but not for case 220, which has a fixed, and low, room moisture content. These effects would of course not occur in realistic modelling situations where there is always some degree of infiltration. ApacheSim predicts the highest figure for the increase in annual cooling load between cases 250 and 220. Case 250’s annual cooling load has already been discussed. The only other extreme ApacheSim value is that for the difference in peak cooling load between cases 220 and 270, where, in a closely grouped set of results, ApacheSim predicts the lowest increase by a small margin.

**Low-mass in-depth sensitivity tests – cases 395-440**

Refer to Figures 256-279. These tests examine, for in-depth cases 395-440 (low-mass, setpoints 20, 27), the sensitivity of heating and cooling loads to:

- addition of a high-conductance opaque panel
- internal and external solar absorptance
- infiltration
- internal gains
- glazing (south orientation)
- shading

In only two of the 24 results in this group does the ApacheSim result lie outside the range covered by the other programs: ApacheSim predicts the greatest reduction in peak heating load and the greatest increase in peak cooling load between cases 410 and 400. This comparison explores the effect of infiltration, and the reason for the ApacheSim behaviour is the same as in the comparison between cases 230 and 220. It is down to an artificial effect related to the modelling of humidity ratio under conditions of zero infiltration.

**High mass in-depth sensitivity tests – cases 800-950**

Refer to Figures 280-309. These tests examine, for in-depth cases 800-950 (high-mass, setpoints 20, 27), the sensitivity of heating and cooling loads to:

- thermal mass (for various glazing options)
- internal solar absorptance
- glazing (south orientation)

In each of the 30 results from these tests, ApacheSim’s predictions lie within the spread of values from the other programs.
Solar radiation tests

Refer to Figures 310-326.

The ApacheSim results relating to incident and transmitted solar flux all lie within the spread of values predicted by the other programs.

ApacheSim’s value for annual incident solar radiation on the horizontal is a fraction less than the sum of the hourly horizontal irradiance values. This is explained by interpolation of direct and diffuse flux values at sub-hourly time-steps.

ApacheSim predicts the greatest shading effect from the side-fins and overhangs attached to the east and west windows in case 930 (as compared with case 920). This reflects ApacheSim’s accounting for diffuse sky shading. A similar effect is seen in the case of overhangs attached to the south window (cases 910 and 900), where ApacheSim ranks second in its prediction of shading effect.

6 Conclusions

The tests set out in ANSI/ASHRAE Standard 140-2001 have been applied to the program ApacheSim. The ApacheSim results are in good agreement with those from the reference programs. Out of 326 tests, Apache predicted a value outside the range set by the other programs in only 13. In each of these cases a satisfactory explanation has been found for the difference. In most of these the difference can be accounted for in terms of modelling refinements incorporated in ApacheSim’s algorithms. The tests did not reveal any bugs in the software.

References


3. ApacheSim Building Thermal Simulation Program. IES Ltd. 141 St James Road, Glasgow G4 0LT, [www.iesve.com](http://www.iesve.com)


Appendix A. Apache simulation settings

STANDARD 140 OUTPUT FORM - MODELING NOTES

INSTRUCTIONS: See Annex A2.

SOFTWARE: ApacheSim

VERSION: 5.2

DOCUMENT BELOW THE MODELING METHODS USED IF ALTERNATIVE MODELING METHODS OR ALGORITHMS ARE AVAILABLE IN THE SOFTWARE BEING TESTED. (See Annex A2 for examples.)

**Simulated Effect:**
*Solar radiation model.*

Optional Settings or Modeling Capabilities:
*Off, Anisotropic (default), Isotropic.*

Setting or Capability Used:
*Anisotropic.*

Physical Meaning of Option Used:
*Anisotropic short-wave sky model.*

**Simulated Effect:**
*Internal Heat Transfer*

Optional Settings or Modeling Capabilities:
*CIBSE fixed values (default), Alamdari & Hammond, CIBSE variable values*

Setting or Capability Used:
*CIBSE fixed values*

Physical Meaning of Option Used:
*Internal convection coefficients are fixed at values given in CIBSE Guide A. Note: external convective heat transfer is treated using a wind-speed dependent algorithm.*

**Simulated Effect:**
*Initial temperature*

Optional Settings or Modeling Capabilities:
*Any temperature (default 18 °C)*
Setting or Capability Used:
18 °C

Physical Meaning of Option Used:
*Temperature at which building is initialised before simulation. Has minimal effect provided there is sufficient preconditioning.*

**Simulated Effect:**
*Time step*

Optional Settings or Modeling Capabilities:
1, 2, 6, 10 or 30 minutes

Setting or Capability Used:
2 minutes

Physical Meaning of Option Used:
*Simulation time step. A small time step was used for optimal accuracy.*

**Simulated Effect:**
*Reporting interval*

Optional Settings or Modeling Capabilities:
6, 10, 30 or 60 minutes

Setting or Capability Used:
60 minutes

Physical Meaning of Option Used:
*Time interval over which simulation results are averaged for output. 60 minutes was chosen in accordance with the reporting instructions.*

**Simulated Effect:**
*Preconditioning period*

Optional Settings or Modeling Capabilities:
*Between 0 and 365 days (default 10 days)*

Setting or Capability Used:
10 days

Physical Meaning of Option Used:
*Number of days simulated in the run-up to the start of the specified simulation period. Has minimal effect, provided the number of days is sufficiently large in relation to the response time of the building.*
Simulated Effect:
Direct solar shading and internal solar tracking calculated by the SunCast program

Optional Settings or Modeling Capabilities:
SunCast shading can be included or not, at the user’s option

Setting or Capability Used:
SunCast direct solar shading and internal solar tracking was used for all cases with glazing.

Physical Meaning of Option Used:
SunCast direct shading and internal solar tracking calculates the effect of shading of the external surfaces of the building from the solar beam, and traces the solar beam through glazing elements onto internal building surfaces. This is the method used to simulate the direct shading effect of overhangs and side-fins. Solar tracking is an important feature of Case 960 (sunspace).

Simulated Effect:
Diffuse shading calculated by the SunCast program

Optional Settings or Modeling Capabilities:
SunCast diffuse shading can be included or not, at the user’s option

Setting or Capability Used:
SunCast diffuse solar shading was used for all cases with glazing.

Physical Meaning of Option Used:
SunCast diffuse shading calculates the effect of shading of the external surfaces of the building from short-wave radiation emanating from the sky vault. This is the method used to simulate the diffuse shading effect of overhangs and side-fins.

Simulated Effect:
Infiltration

Optional Settings or Modeling Capabilities:
Room air exchanges, MacroFlo natural ventilation simulation program

Setting or Capability Used:
Room air exchanges

Physical Meaning of Option Used:
The infiltration rates were adjusted for the altitude of the site using the method described in the Standard.
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- MWH
- ESP
- BLAST
- DOE2
- SRES
- SERIRIS
- S3PAS
- TRNSYS
- TASE
- EnergyPlus
- APACHE

Figure 257: Low Mass In-Depth Sensitivity Tests: Annual Heating - Cases 410-410 (infiltration)

- MWH
- ESP
- BLAST
- DOE2
- SRES
- SERIRIS
- S3PAS
- TRNSYS
- TASE
- EnergyPlus
- APACHE

Figure 258: Low Mass In-Depth Sensitivity Tests: Annual Heating - Cases 420-410 (internal gains)

- MWH
- ESP
- BLAST
- DOE2
- SRES
- SERIRIS
- S3PAS
- TRNSYS
- TASE
- EnergyPlus
- APACHE

Figure 259: Low Mass In-Depth Sensitivity Tests: Annual Heating - Cases 430-420 (external solar absorptance)

- MWH
- ESP
- BLAST
- DOE2
- SRES
- SERIRIS
- S3PAS
- TRNSYS
- TASE
- EnergyPlus
- APACHE

Figure 260: Low Mass In-Depth Sensitivity Tests: Annual Heating - Cases 440-430 (south window replaces opaque panel)

- MWH
- ESP
- BLAST
- DOE2
- SRES
- SERIRIS
- S3PAS
- TRNSYS
- TASE
- EnergyPlus
- APACHE

Figure 261: Low Mass In-Depth Sensitivity Tests: Annual Heating - Cases 450-440 (internal solar absorptance)

- MWH
- ESP
- BLAST
- DOE2
- SRES
- SERIRIS
- S3PAS
- TRNSYS
- TASE
- EnergyPlus
- APACHE
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