

TESTING AND VALIDATING AN EQUATION-BASED DYNAMIC BUILDING PROGRAM WITH ASHRAE STANDARD METHOD OF TEST

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ABSTRACT

This paper applies ASHRAE Standard 140-2004 to test an equation-based dynamic building model written in Modelica. Unlike other building energy simulation programs such as EnergyPlus and DOE-2, there is a class of simulation programs that is developed to study the dynamics of a building and design control strategies for HVAC equipment. These programs may share the following features: 1) employing a variable simulation time step, which may be down to a fraction of second; 2) not calculating heating/cooling loads directly; 3) a feedback control scheme has to be explicitly modeled. The Modelica-based program in this paper belongs to the above class. Evaluating these programs with ASHRAE Standard 140 requires implementing the standard's thermostat control scheme, and computing loads compatible with the standard. This paper describes the technical challenges we encountered in this testing work and methods we adopted to resolve them. After analyzing the results of a series of comparative tests applied to the Modelica model, we conclude that studied model is capable of predicting the thermal performance of building envelopes and delivering comparable results with respect to prevailing building simulation programs.

INTRODUCTION

ANSI/ASHRAE Standard 140 (ANSI/ASHRAE 2004), *Method of Test for the Evaluation of Building Energy Analysis Computer Programs*, sets forth procedures for testing building energy simulation software. ASHRAE Standard 90.1 (ASHRAE 2007), *Energy Standard for Buildings Except Low-Rise Residential Buildings*, requires that "simulation program shall be tested according to ANSI/ASHRAE Standard 140, and the results shall be furnished by the software provider." In this paper the ANSI/ASHRAE Standard 140-2004 will be called the Standard for simplicity. We have developed an extensive library of models of building and HVAC components using a programming language called Modelica, which contains models of chiller, coil,

fan, pump, valve, controls, flow pipe, building envelope, etc. These models have been used in many studies such as whole building energy analysis and hydronic system control design.

The Standard prescribes two sets of tests: the comparative tests that are used to evaluate building thermal envelope models, and the analytical tests for HVAC equipment. This paper focuses on testing building envelope models in the library (Wetter 2006).

MODELICA MODELS

Modelica (www.modelica.org) is an object-oriented programming language designed for modeling large-sized, structurally complex, multi-engineering systems. A Modelica model is a set of differential and algebraic equations, and/or discrete events. A user can build a Modelica model by defining equations or extending existing models. There are several commercial Modelica-based programs that provide a graphical interface for users to build, manage, and run models. In this study, we used *Dymola* version 6.1 (www.dynasim.se).

Here we present a Modelica model example. This is a simplified model of air in a zone with humidity and infiltration ignored. The model was built based on sensible heat balance of air, which is shown in Equation (1). The "SimplifiedZoneAir" Modelica code is shown below, and definitions of variables can be found in the body of the code. In the Modelica model the variables and parameters as well as governing equations are defined.

$$C \frac{dT}{dt} = UA(T_{sol,air} - T) + \dot{m}_{vent} c_{pa} (T_{vent} - T) + Q_{int} \quad (1)$$

```

model SimplifiedZoneAir
  import SI = Modelica.SIunits;
  constant SI.SpecificHeatCapacity cpa = 1.006
  parameter Real C (unit="J/K") "capacity of
  zone air";
  parameter SI.ThermalConductance UA "overall
  heat transfer coefficient of zone envelope
  times area";
  SI.ThermaldynamicTemperature T "zone air
  temperature";
    
```

```

SI.ThermaldynamicTemperature Tsolair
"effective temperature of outdoor air";
SI.ThermaldynamicTemperature Tvent
"temperature of air supplied by HVAC
system";
SI.MassFlowRate mvent "mass flow rate of
air supplied by HVAC system";
SI.Power Qint "internal heat gains"
equation
C*der(T)=UA*(Tsolair-T)+mvent*cpa*(Tvent
-T)+Qint;
end SimplifiedZoneAir;

```

Suppose we have a simple HVAC system model, "SimpleHVAC", we can put this model with zone air model into a higher-level model to simulate the whole system called "SimpleSystem". Modelica code for this case is shown below.

```

model SimpleSystem
SimplifiedZoneAir AirInstance
(C=<input>, UA=<input>, Qint=<input>, ...);
SimpleHVAC HVACInstance;
equation
AirInstance.Tvent=HVACInstance.Tair;
AirInstance.mvent=HVACInstance.mair;
end SimpleSystem;

```

The major work of Modelica users is to define equations that describe the behavior of components and their relationships, they do not need to consider the causality within a given system because all the equations are internally expressed as a set of differential algebraic equations (DAE) and discrete events by Modelica during compilation and solved simultaneously with a numerical solver. There are many numerical algorithms that can solve DAE. We used DASSL, a variable-step-size solver with a tolerance of 10^{-6} in Dymola.

The Modelica building model used in our study was discussed in detail by Wetter (2006). Figure 1 shows a snapshot of the model in Dymola including the icon, source code, and diagram. This thermal zone model can be used to model zones with an arbitrary number of surface constructions and windows. A one-dimensional finite difference scheme is used to compute heat conduction through opaque surface. A multizone building model is constructed by connecting individual thermal zone models together. The air in each zone is assumed to be well mixed. The version of the model explored in this paper requires users to provide information on weather and heat gains such as sky temperature, solar irradiation on external opaque surfaces, solar irradiation transmitted through windows, and internal heat gains in a format of time series. We used EnergyPlus (2007) to generate the needed data. A simple window model with inputs of transmitted irradiation is adopted. Window panes, along with the air in between, are treated as a block of solid material that absorbs heat from transmitted irradiation and conducts

heat due to the temperature difference between exterior and interior surfaces.

When testing the Modelica model's performance against the Standard, we found that it has three complications: 1) employing a variable simulation step, which may be down to a fraction of second; 2) not calculating heating/cooling loads automatically; 3) requiring an explicit implementation of feedback controls. To the authors' knowledge, some other building/HVAC simulation programs such as SIMBAD (2007) share the same complications. These kinds of programs are powerful for studying dynamic behavior of a system and developing control strategies, but evaluating these programs with the Standard requires implementing the particular control strategy and post-processing outputs to compute loads. These two points will be discussed later in the section of methodology.

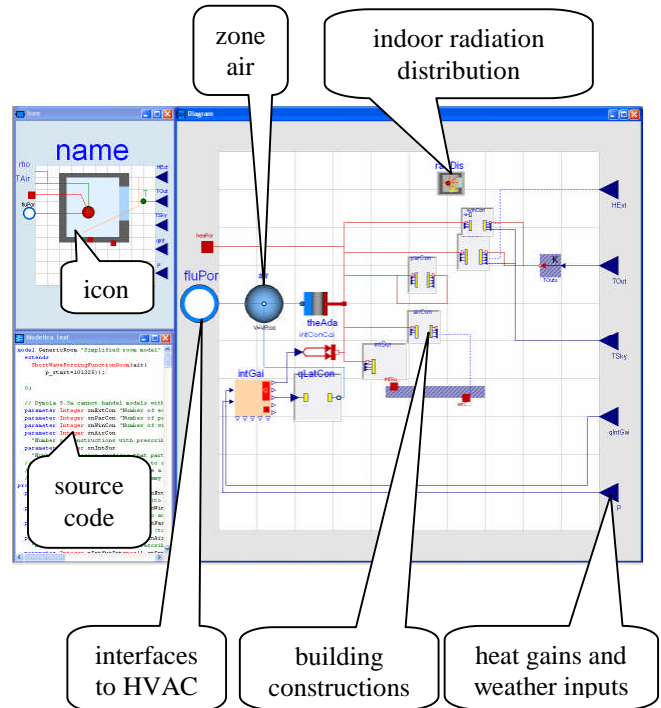


Figure 1 Graphical view of room model in Dymola

This paper describes our methods and results in testing the Modelica building model according to the Standard, and interprets the test results and explores the effects of major assumptions.

ASHRAE STANDARD 140

The Standard "can be used for identifying and diagnosing difference in predictions for whole building energy simulation software that may possibly be caused by algorithmic differences, modeling limitations, input

differences or coding errors” (ASHRAE 2004). The Standard specifies a series of test cases, each of which aims to evaluate one aspect of the examined program. For each test case the Standard provides sample test results generated by several software programs considered to represent state-of-the-art for building energy performance simulation. For the building envelope load calculations, the reference programs are ESP, BLAST, DOE2, SRES/SUN, SERIRES, S3PAS, TRNSYS and TASE. Four figures of merit are used to assess a simulation program: annual heating load, annual cooling load, hourly peak heating load and hourly peak cooling load.

There are two categories of tests specified in the Standard: basic tests and in-depth tests. Basic tests include low mass cases 600–650 and high mass cases 900–960. In-depth tests include cases 195–320, 395–440, and 800–810. Each series begins with a base case on which subsequent cases are built by adjusting building configurations. For each test case, the Standard provides a range of results produced by reference programs mentioned above. If test results fall within or close to this range, the subject software is considered to yield acceptable accuracy. The Standard also points out that it does not necessarily indicate that anything is incorrect if a tested program produces a result that falls outside of the provided range. However, it is worthwhile to investigate results to find the causes. The Standard does not prescribe a clear-cut criterion to judge whether a program passes or fails, instead, “...determination of when results agree or disagree is left to the user...”

The basic test building is a simple single zone (L 6 m × W 8 m × H 2.7 m) without furniture, plenum and partitions, as shown in Figure 2. Two identical windows (W 3 m × H 2 m) are installed on the south facing wall. This basic building is modified in subsequent cases by shifting windows, by adding an overhang, by adjusting heating and cooling setpoints, by adding night time ventilation, and by adding an unconditioned “sunspace” zone to the south side of the building.

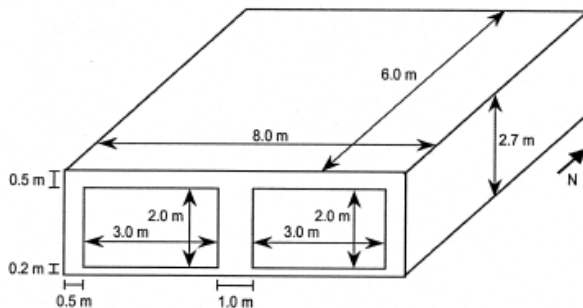


Figure 2 ASHRAE Standard 140 base case configuration (ASHRAE 2004)

METHODOLOGY

This study focused on the 600 series of cases (low mass tests) and the 900 series of cases (high mass tests):

- Base test:
 - Case 600
- Basic test:
 - Case 620, 640 and 650 (low mass tests)
 - Case 900, 920, 940, 950, and 960 (high mass tests)
 - Cases 600FF, 650FF, 900FF and 950 FF (free float tests)

Since no shading elements were modeled in Modelica, Cases 610, 630, 910, and 930 were not simulated.

Figure 3 shows a graphical view of Case 600 in Dymola, in which an instance of the room model shown in Figure 1 is used.

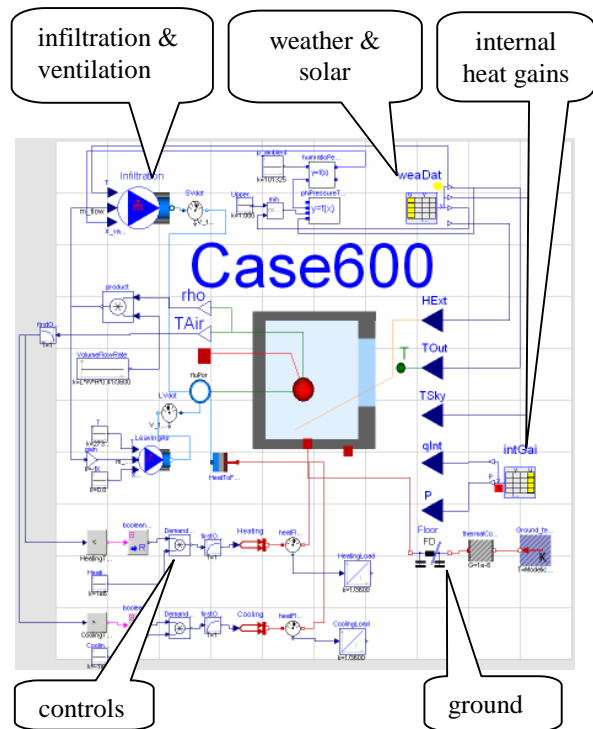


Figure 3 Graphical view of room model in Dymola

Implementation of thermostat control strategy

The thermostat control strategy for the basic case is specified in the Standard:

- Thermostat senses zone air temperature only
- Thermostat is non-proportional
- Thermostat has dual setpoint with deadband
 - Heat = on if temperature < 20°C; otherwise heat = off

- Cool = on if temperature >27°C;
otherwise cool = off

The Standard specifies the equipment capacity to be ± 1000 kW, and the equipment is supposed to operate at the maximum capacity when the temperature is below 20°C (heating mode) or above 27°C (cooling mode), otherwise, the temperature is free floating and HVAC equipment is turned off. Figure 4 is the diagram of the thermostat control strategy implemented in our study.

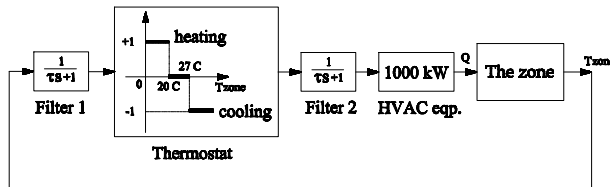


Figure 4 The thermostat control scheme

Such a closed-loop control scheme has to be modeled explicitly in Modelica. The *if-then* logic is treated as a discrete event. For instance, if the zone air temperature is higher than 27°C, a discrete event occurs. In order to solve DAEs correctly, the DAE solver needs to calculate integrals and update the integrated variables each time when a discrete event occurs in the progress of a simulation. The HVAC equipment specified in the Standard has a capacity far greater than the zone loads, which means it only needs to operate a very brief period to bring the temperature back to its setpoint. Once the temperature reaches its setpoint, the HVAC equipment should be turned off, and then temperature tends to deviate from the setpoint, and the equipment starts again. Therefore, the bang-bang control turns the HVAC equipment on and off at an extremely fast frequency, and the temperature seems to be maintained perfectly at its setpoint. However, this kind of thermostat controls leads to a very large number of discrete events per unit time, which in turn causes the solver to spend significant amount of time on integration updates. From the user standpoint, such simulations are extremely slow and in many cases seem frozen. One solution, which was adopted in this study, is to reduce the occurrences of discrete events with filters. As shown in Figure 4, two first-order filters were added before and after the controls block. In this way, the response of closed-loop controls is intentionally slowed down so that fewer discrete events are generated per unit time. The larger the time constant τ is, the smaller number of events and the faster simulation speed we will have. The trade-off is that the temperature control gets worse as larger time constants are used. Table 1 shows how time constant τ affects the simulation time. All the simulations were run on a PC

with an Intel® Pentium® M 1.73GHz processor and 2GB RAM. In this study, the choice of τ also affected the accuracy of simulation results and in turn the calculation of loads. We will discuss it later in the section of results and analysis.

Table 1. Simulation time consumption vs. time constant

τ (sec)	Simulation Duration (h)	num. of events	Integration Time (sec)	est. time for 1-yr simu. (h)
3	24	1066	67.3	~5
2	24	1506	101	~7
1	24	2816	180	~14

The design day temperatures in Case 600 with time constant τ set to 1 second are shown in Figure 5.

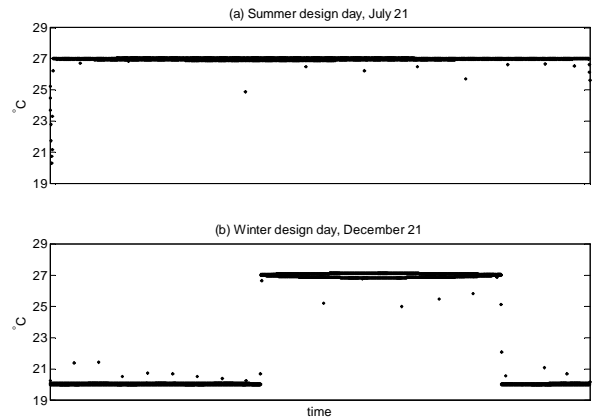


Figure 5 Temperature in Case600 on winter and summer design days with time constant of 1 second

Load calculation

The Modelica model does not calculate heating or cooling loads during the simulation. In this study we had Dymola output the selected simulation data of each test to a file. Then we wrote a program in Matlab to process the data and calculate loads.

There exists a heating or sensible cooling load only when a zone is in a thermally equilibrium state, i.e. the zone temperature is intentionally maintained at a given value. Equation (2) was used in this study to calculate loads.

$$Q_L = \sum_j Q_j + Q_c + i_{in} \dot{m} - i_a \dot{m} \quad (2)$$

Where:

Q_L : heating load (-) or sensible cooling load (+), kW

Q_j : heat flow from opaque walls, floor, ceiling, and windows to air by convection, kW

Q_c : convective portion of internal heat gain, kW

i_{in} : specific enthalpy of infiltration, kJ/kg

i_a : specific enthalpy of room air, kJ/kg

\dot{m} : mass flow rate of infiltration, kg/sec

We ran into two issues about load calculation in this study. One issue is that each of the four terms on the right side of Equation (2) is a continuous function of time, so we need to determine the conditions at which they are counted as a part of load. According to the definition of load, we should use the data at the times when the room temperature is at either 20°C or 27°C to calculate the load. However, it is impossible to achieve an ideal temperature control in the Modelica model since the two first-order filters were used to speed up the simulation, i.e. the actual temperature always varies around the setpoint rather than being perfectly kept at the setpoint. Therefore, we had to use the data at the moments when the zone temperature was within a region of the setpoint, i.e. 20°C ± ΔT or 27°C ± ΔT. ΔT should not be too small, otherwise many valid data would be excluded so that the calculated loads would be very small. Furthermore, ΔT is related to the magnitude of τ. The smaller τ is used, the smaller ΔT is allowed due to a better temperature control. A set of experiments showed that ΔT should be no less than 0.1°C. We set ΔT to be 0.1°C in this study.

The other issue about load calculation is that we need hourly load results but the Dymola simulations were of variable time step, which could be less than one second. When applying Equation (2), we summed up all the products of Q_L 's and their duration periods within an hour, and then had the sum divided by 3600 seconds to find the average load of that hour, as expressed in Equation (3).

$$Q_{L_hour} = \frac{1}{3600} \sum_i Q_L(i)\Delta t(i) \quad (3)$$

Where:

Q_{L_hour} : hourly heating/cooling load, kW

$Q_L(i)$: i^{th} instant load in an hour calculated with Equation (2) when zone temperature is within either 20°C ± ΔT or 27°C ± ΔT, kW

$\Delta t(i)$: time duration period of $Q_L(i)$, sec

MODEL SPECIFICATIONS

The Modelica model used the parameters of opaque walls, windows and ground specified by the Standard, but some specifications provided in the Standard are redundant for different degree of modeling complexity or can not be used directly in the Modelica model. This section addresses the parameters that influence the load calculation.

U-value of double panes and air in between

Since the window model in the version of studied Modelica model (Wetter, 2006) was a simplified optical model, most of the parameters given in the Standard can not be used, and the U-value of double panes and air in between is not available. Equation (4) was used to find U_w .

$$\frac{1}{U_w} + \frac{1}{h_o} + \frac{1}{h_i} = \frac{1}{U_{a-a}} \quad (4)$$

Where:

U_w : U-value of double panes and air in between, W/m²·K

h_o = 21 W/m²·K, exterior combined surface coefficient, given in the Standard

h_i = 8.29 W/m²·K, interior combined surface coefficient, given in the Standard

U_{a-a} = 3 W/m²·K, overall U-value from interior air to ambient, given in the Standard

Angular-dependent optical properties

The absorptance magnitudes of inner panes α_i , absorptance of outer pane α_o , and the transmittance τ_w are supposed to be dependent on solar incident angle, but in the Modelica model they are fixed. In this study we used $\alpha_i = 0.055$, $\alpha_o = 0.065$, and $\tau_w = 0.7$.

Shortwave absorptance of interior surface of inner pane

The Modelica model used this parameter to calculate the amount of internally distributed shortwave radiation absorbed by windows, which is not specified by the Standard. We set it to be a typical value of 0.054.

Convective heat transfer coefficients

Convection and radiation of interior and exterior surfaces are calculated separately in the Modelica model. Users are required to input the convective coefficients while the models calculate the radiation portion internally. The convective portion of surface coefficients applicable to all the cases in this study are listed in Table 2. The data are from Annex B5 of the Standard.

Table 2 Film convective coefficients

CONVECTIVE PORTION OF SURFACE COEFFICIENT	VALUE
Interior surface of window	3.16 W/m ² ·K
Exterior surface of window	16.37 W/m ² ·K
Interior surface of opaque wall	3.16 W/m ² ·K
Exterior surface of opaque wall	24.67 W/m ² ·K

Opaque surface radiative properties

For the infrared radiation, the Modelica model used absorptance rather than emittance specified in the Standard. In this study we assumed that the absorptance is equal to the emittance. The Modelica window model also has parameters of interior/exterior infrared absorptance, which uses the same values as for opaque walls as shown in Table 3.

Table 3 Opaque surface radiative properties

	INTERIOR SURFACE	EXTERIOR SURFACE
Infrared absorptance	0.9	0.9

RESULTS AND ANALYSIS

Three types of indexing quantities, i.e. annual heating/cooling load in kWh, hourly peak heating/cooling load in kW, and annual max/min/mean zone temperature in °C, were calculated. Both absolute values from basic tests (e.g. Case 600 & 620) and sensitivity values (e.g. differences between Case 620 and Case 600) were compared to the example results provided by the Standard. The example results come from eight selected whole building energy simulation programs, which set up an upper and a lower bound for each indexing quantity. We had the lower and upper bounds normalized to 0.0 and 1.0. The results from the Modelica model were normalized by using Equation (5).

$$\text{Normalized} = \frac{\text{Original quantity} - \text{Lower Bound}}{\text{Upper Bound} - \text{Lower Bound}} \quad (5)$$

We plotted the results of basic tests in Figure 6 and sensitivity tests in Figure 7. There are 47 indexing quantities from the basic tests and 42 quantities from the sensitivity tests. For instance, the marked axis in Figure 6 represents the annual hourly peak heating load from Case 600. The upper bound and lower bound provided by the Standard are 4.354 kW and 3.437 kW respectively, which are normalized to 1.0 and 0.0. The result of the Modelica model is 3.750 kW, which is normalized to 0.3413. In Figure 6 the outer circle represents the normalized upper bound, the inner circle denotes the lower bound, and the red dots are the results of the Modelica model.

The overall results are summarized in Table 4. In the basic tests there are 3 out of 47 quantities, which are out of the range. It is shown in Figure 6 that most of the quantities are closer to the lower bound than to the upper bound, all the 3 out-of-range quantities are below the lower bound. The largest relative error is 2.41%, which is defined as:

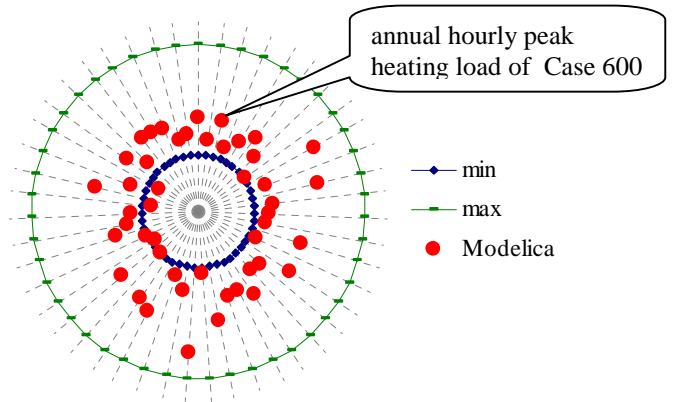


Figure 6 Normalized results of basic tests

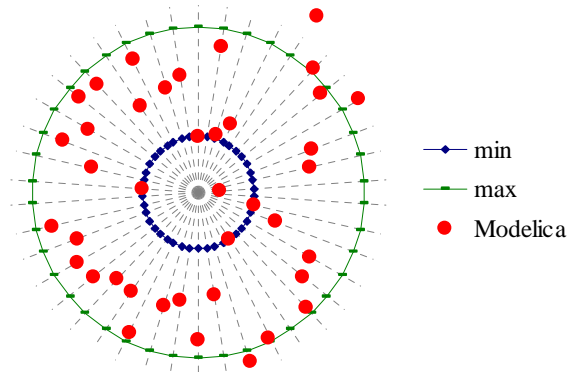


Figure 7 Normalized results of sensitivity tests

$$\text{Relative error} = \frac{|\text{out of range quantity} - \text{closer bound}|}{\text{closer bound}} \quad (6)$$

Table 4 Number of out-of-bound quantities

	BASIC	SENSITIVITY	TOTAL
Num. of out-of-bound quantities	6.38% (3 of 47)	16.6% (7 of 42)	11.2% (10 of 89)

In our opinion, the results are acceptable because most of the quantities are within the bound and only a small portion slightly deviates from the range. The results show that the Modelica model can be used for whole building energy simulations and delivers comparable results with respect to prevailing programs.

On the other hand, in-depth studies have revealed two major sources that caused the bias and disagreements.

- Modeling limitation
- Implementation of the thermostat control scheme

We used EnergyPlus (2007) as a reference for our in-depth analysis due to two reasons: 1) the internal/external heat gain profiles used by the Modelica model were generated with EnergyPlus, i.e. these two

programs share the same thermal boundary conditions, so the differences in their simulation results are caused only by the model differences; 2) the results of the Modelica model is closer to the lower bound of the range while EnergyPlus's results are relatively more evenly distributed within the range. Data used in this analysis were taken from the basic test Case 600.

Modeling limitation

The Modelica models adopted a simplified model of window that had a similar structure as the model of opaque wall except that there is solar radiation transmission through it and part of solar radiation is absorbed by the glass. The other programs such as EnergyPlus use a much more sophisticated window model. The simplified model for a double pane in Modelica uses the transmitted solar radiation per unit area through window as an input to a heat balance model (Wetter 2006). This transmitted solar radiation can be obtained from building energy simulation program like EnergyPlus. This simplification led to a large difference in the amount of net heat flow entering a zone through a window as shown in Figure 8.

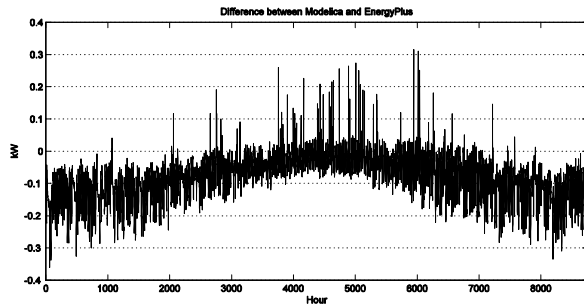


Figure 8 Net heat flow through one window over a year

Figure 8 shows differences between the Modelica model and EnergyPlus. The net heat flow in Modelica is 16.6% less than that in EnergyPlus on average. We also did other root-cause analysis such as comparisons of heat transfer rate wall by wall. We found that among all the causes, the simplified window model is the primary reason that the building loads calculated from the Modelica model were closer to the lower bound and smaller than those from EnergyPlus.

Implementation of the thermostat control scheme

To reduce the occurrences of discrete events, the Modelica model used two first-order filters, which kept simulations running slowly and reduced the simulation time. However, this method can adversely affect the calculation of load. Table 5 lists the loads from Case 600 simulations using different filter time constants τ . For each of the four indexing quantities, there is an

upper bound, Max, and a lower bound, Min, provided by the Standard. It can be seen that: 1) when $\tau=1$ sec, all the quantities fall within the range; 2) when $\tau=2$ sec, two cooling quantities are out of the range; 3) when $\tau=3$ sec, all the quantities are below the lower bound. As τ decreased, the calculated load increased.

Table 5 Sensitivity of loads to time constant

Time constant (sec)	3	2	1	Min	Max
Annual heating (MWh)	4.017	4.356	4.769	4.296	5.709
Annual sensible cooling (MWh)	5.612	5.969	6.386	6.137	7.964
Peak heating (kW)	3.320	3.522	3.750	3.437	4.354
Peak sensible cooling (kW)	5.547	5.797	6.072	5.965	6.827

The reason that the filter time constant τ has an impact on load calculation is discussed here. Convection heat flow between building envelope and air, Q_j , can be found by:

$$Q_j = h_{ij} A_j (T_{jsur} - T_a) \quad (7)$$

Where:

h_{ij} : convective film coefficient of j^{th} construction interior surface, W/m^2K

A_j : area of j^{th} construction interior surface, m^2

T_{jsur} : temperature of j^{th} construction interior surface $^{\circ}C$

T_a : temperature of room air, $^{\circ}C$

Equation (7) shows that the calculation of Q_j is affected by surface temperature T_{jsur} , and room air temperature T_a . Taking a partial derivative of Q_j with respect to T_{jsur} and T_a , we have:

$$\left. \frac{\partial Q_j}{\partial T_{jsur}} \right| = \left. \frac{\partial Q_j}{\partial T_a} \right| = h_{ij} A_j \quad (8)$$

Let us take the east wall in Case 600 as an example. Knowing $h_{ij}=3.16 W/m^2K$ for all interior surfaces from Table 2 and $A_j = 16.2 m^2$ for the interior surface of the east wall, we have the absolute values of the two derivatives to be $51.2 W/K$. If T_{jsur} or T_a varies by $1^{\circ}C$, the variation in Q_j will be $0.0512 kW$. Since the zone has six interior surfaces, the total change in $\Sigma Q_j = \Sigma h_{ij} A_j$ will be $0.542 kW$ if T_{jsur} of each wall or T_a has a change of $1^{\circ}C$. This is significant for load calculation in our study.

We compared T_{jsur} and T_a with $\tau = 1$ sec to those with $\tau = 3$ sec in Case 600. Then we found that the differences in T_a were on the order of $0.01^{\circ}C$ and the differences in T_{jsur} were as large as $1^{\circ}C$. Thus, we concluded that τ influences the load calculation through T_{jsur} . Further

study of the DASSL algorithm's effects is beyond the scope of this work. However, we think it is worthy of investigations in the future. Figure 9 shows $\Delta T_{j\text{sur}}$ of the east wall under two τ 's from March to April. The largest difference is 0.96°C and the average is 0.40°C.

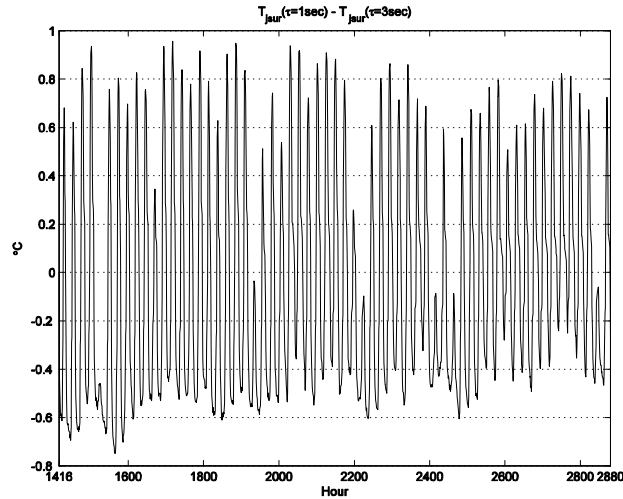


Figure 9 East wall interior surface temperature difference between different time constant τ

CONCLUSIONS

Comparative tests, specified in ASHRAE Standard 140-2004, were conducted in this study to evaluate the capability of the Modelica model (Wetter, 2006).

We conclude that the Modelica building model is capable of predicting the thermal performance of building envelopes because:

- 88.8% of the indexing quantities of the simulations are in the range of example results from the Standard.
- The out-of-range quantities are close to the range of example results. In the worst case from basic tests, the result is only below the bound by 2.41%.
- The current results can be further improved by adopting tighter temperature controls, i.e. reducing the time constants τ of the first-order filters.

The current version of the Modelica model uses a simplified window, which transferred less heat flow than the window model in EnergyPlus in our tests (by 16.6% in Case 600).

Modelica is a programming language to model complex engineering dynamic systems by establishing a set of differential and algebraic equations and discrete events. The thermostat control scheme in the Standard has to be implemented explicitly, which may generate so many

discrete events that can significantly slow down or freeze a simulation. A careful tradeoff must be made between simulation speed and accuracy. The Modelica model does not directly calculate loads. The user must postprocess the simulation data to calculate loads.

To enhance the capability of the Modelica model (Wetter, 2006), this study suggests using a more sophisticated window model and building a model to process raw weather data.

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NOMENCLATURE

- A_j : area of j^{th} construction interior surface, m^2
- h_i : interior combine surface coefficient, $\text{W}/\text{m}^2\text{K}$
- h_{ij} : convective film coefficient of j^{th} construction interior surface, $\text{W}/\text{m}^2\text{K}$
- h_o : exterior combine surface coefficient, $\text{W}/\text{m}^2\text{K}$
- i_a : specific enthalpy of room air, kJ/kg
- i_m : specific enthalpy of infiltration, kJ/kg
- \dot{m} : mass flow rate of infiltration, kg/sec
- Q_L : heating load (-) or sensible cooling load (+), kW
- Q_j : heat flow from opaque walls, floor, ceiling, and windows to air by convection, kW
- Q_c : convective portion of internal heat gain, kW
- T_a : temperature of room air, $^{\circ}\text{C}$
- $T_{j\text{sur}}$: temperature of j^{th} construction interior surface $^{\circ}\text{C}$
- U_{a-a} : overall U-value from interior air to ambient
- U_w : U-value of double panes and air in between