Testing and Validating an Equation-Based Dynamic Building Program with ASHRAE Standard Method of Test

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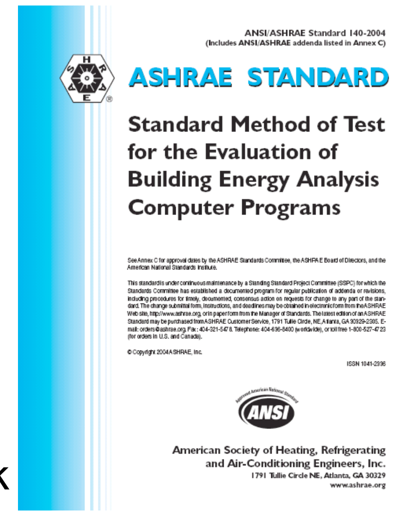
SimBuild 2008

Agenda

- Overview
- BESTEST results
- Issues and solutions

Overview – ASHRAE Standard 140

- ASHRAE Standard 140-2004 – "Used for identifying and diagnosing predictive differences from whole building energy simulation software"
  - Comparative tests for evaluating building thermal envelope models
    - Basic and in-depth tests on a simple building model
      - Basic tests: test the modeling ability
      - In-depth: for diagnosis purposes
    - Figures of merit: annual heating/sensible cooling loads, hourly peak heating/sensible cooling load, hourly zone temperature
    - Example results from 8 representative simulation programs
    - "No formal criteria for when results agree or disagree." Determination is left to the user.
  - Analytical verification tests for mechanical equipment performance
    - Model a simple unitary split cooling system using manufacture design data
    - Not conducted in this study



Overview – Modelica

- Modelica – an equation-based modeling language
  - Models are described with a set of differential, algebraic, and discrete equations.
  - Attractive features including: retaining original physical structure and reusability.
    - Block-oriented programs require: $f(t, x, \dot{x}, u, y) = 0 \;\Rightarrow\; \dot{x} = g(t, x, u),\ y = h(t, x, u)$
    - The physical structure may lose, and it's not easy to maintain models.
    - Reusability: a model can be used for different scenarios and for developing new models

example 1:

centrifugal fan
$f(RPM, dp, flowrate)=0$

→ $dp=f_1(RPM, flowrate)$

→ $flowrate=f_2(RPM, dp)$

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example 2:

```
partial connector HeatPort
  Temperature T;
  flow HeatFlowRate Q_flow
end HeatPort;
```

⇨

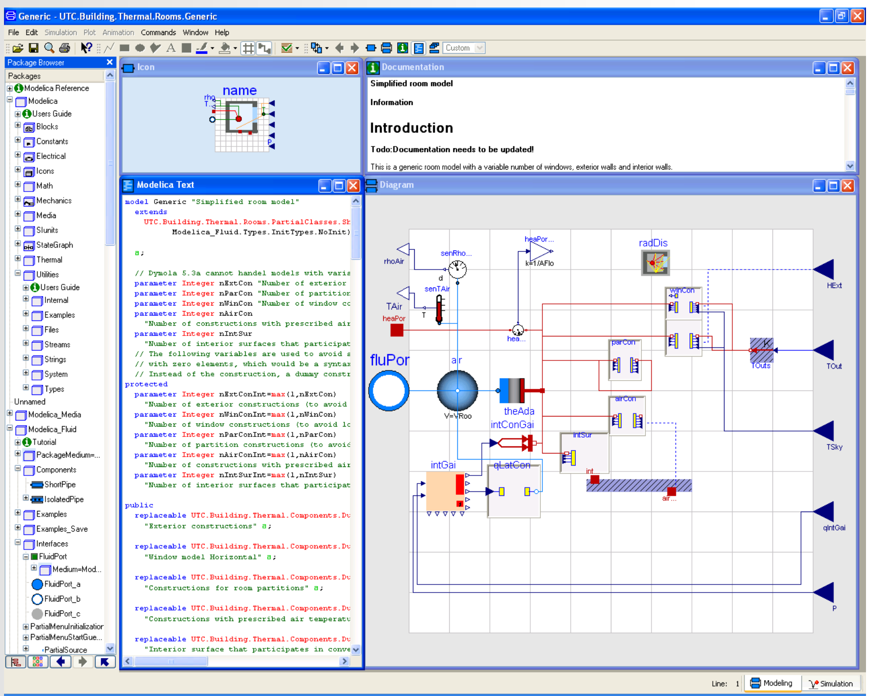
```
partial model Element1D
  HeatPort_a port_a;
  HeatPort_b port_b;
  HeatFlowRate Q_flow;
  TemperatureDifference dT;
equation
  dT = port_a.T - port_b.T;
  port_a.Q_flow = Q_flow;
  port_b.Q_flow = -Q_flow;
end Element1D;
```

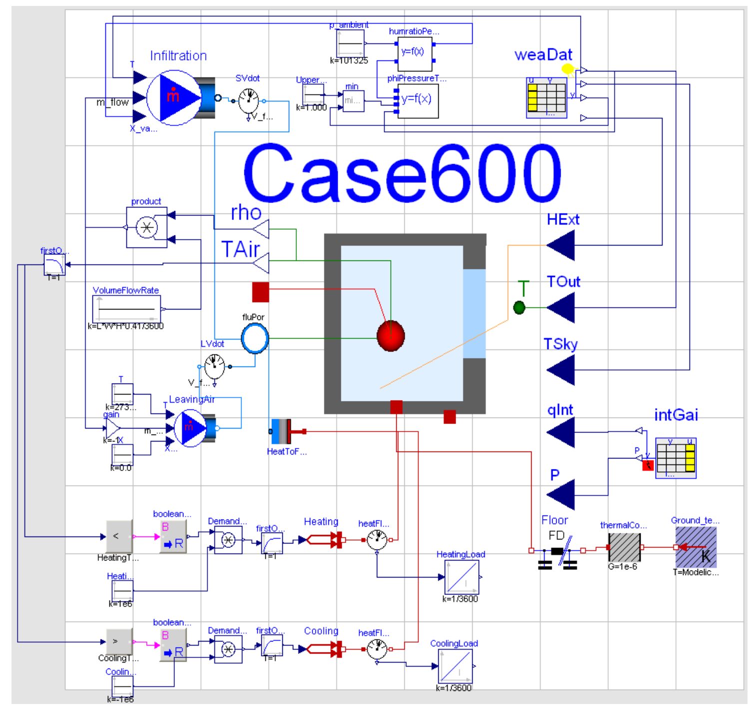
⇨

```
model ThermalConductor
  extends Interfaces.Element1D;
  parameter ThermalConductance G;
equation
  Q_flow = G*dT;
end ThermalConductor;
```

Overview – Dymola

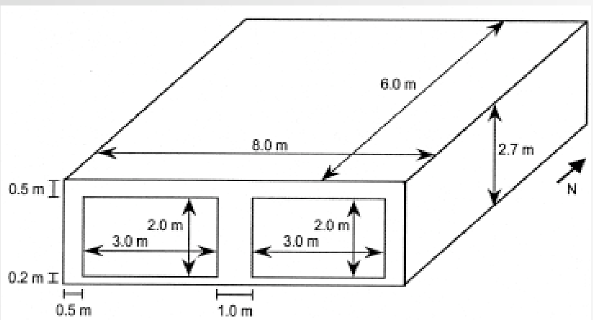
- Dymola – an integrated Modelica-based modeling/simulation environment
  - Composed of a model editor, a Modelica translator, compilers and solvers.
  - A library of building envelope and HVAC components developed using Dymola v6.1

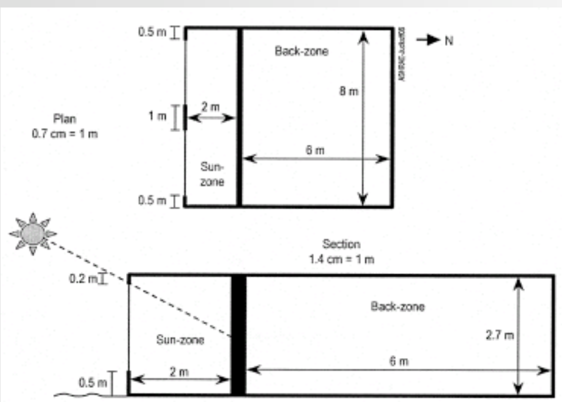




BESTEST results

- Tests
  - Basic tests – 8 low mass cases: 600,610,620,630,640,650,600FF,650FF
  - Basic tests – 9 high mass cases: 900,910,920,930,940,950,960,900FF,950FF
  - Sensitivity results: differences between 2 basic/in-depth cases





ANNUAL LOADS

ANNUAL HEATING [MWH] CASE	ESP UK-DMU	BLAST US/IT	DOE2 USA	SRES/SUN USA	SERIRES* UK-BRE	S3PAS SPAIN	TRNSYS BEL/UK	TASE FINLAND	SUMMARY FOR ALL RESULTS MIN	MAX	MAX/MIN	MEAN
600	4.296	4.773	5.709	5.226	5.596	4.882	4.872	5.362	4.296	5.709	1.329	5.090
610	4.355	4.806	5.786	5.280	5.620	4.971	4.970	5.363	4.355	5.786	1.329	5.146
620	4.613	5.049	5.944	5.554	5.734	5.564	5.073	5.728	4.613	5.944	1.289	5.407
630	5.050	5.359	6.469	5.883	6.001	6.095	5.624		5.050	6.469	1.281	5.783
640	2.751	2.888	3.543	3.255	3.803	3.065	3.043	3.309	2.751	3.803	1.382	3.207
650	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	ERR	0.000
900	1.170	1.610	1.872	1.897	1.988	1.730	1.655	2.041	1.170	2.041	1.744	1.745
910	1.575	1.862	2.254	2.174	2.282	2.063	2.097	2.220	1.575	2.282	1.449	2.066
920	3.313	3.752	4.255	4.093	4.058	4.235	3.776	4.300	3.313	4.300	1.298	3.973
930	4.143	4.347	5.335	4.755	4.728	5.168	4.740		4.143	5.335	1.288	4.745
940	0.793	1.021	1.239	1.231	1.411	1.179	1.080	1.323	0.793	1.411	1.779	1.160
950	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	ERR	0.000
960	2.311	2.664	2.928	2.884	2.851	2.943	3.373	2.816	2.311	3.373	1.460	2.846

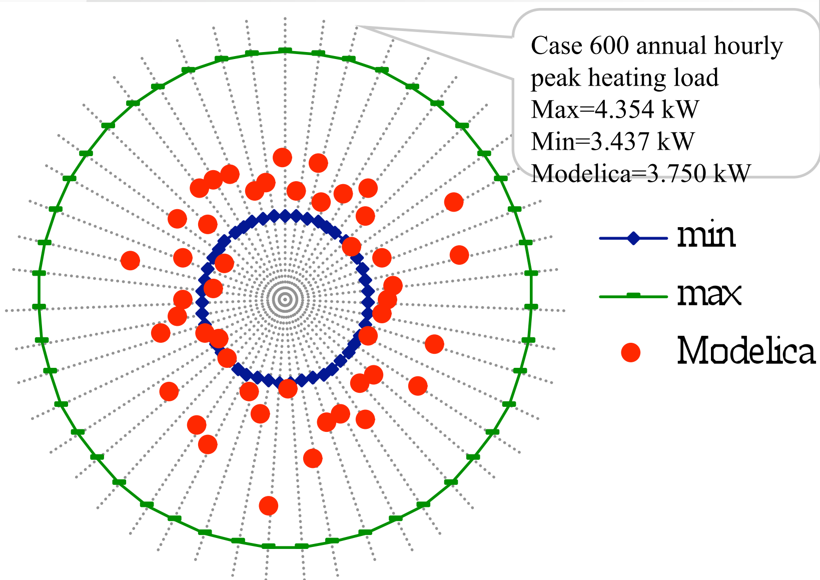
LOW MASS BASIC SENSITIVITY TESTS

ANNUAL HEATING [MWH] CASES	ESP UK-DMU	BLAST US/IT	DOE2 USA	SRES/SUN USA	SERIRES UK-BRE	S3PAS SPAIN	TRNSYS BEL/UK	TASE FINLAND	SUMMARY FOR ALL RESULTS MIN	MAX	MAX/MIN	MEAN
610-600	0.059	0.033	0.077	0.054	0.024	0.089	0.098	0.021	0.021	0.098	4.667	0.057
620-600	0.317	0.276	0.235	0.328	0.138	0.682	0.201	0.366	0.138	0.682	4.942	0.318
630-620	0.437	0.310	0.525	0.329	0.267	0.531	0.551		0.267	0.551	2.064	0.421
640-600	-1.545	-1.885	-2.166	-1.971	-1.793	-1.817	-1.829	-2.053	-2.166	-1.545	0.713	-1.882

ANNUAL SENSIBLE COOLING [MWH] CASES	ESP UK-DMU	BLAST US/IT	DOE2 USA	SRES/SUN USA	SERIRES UK-BRE	S3PAS SPAIN	TRNSYS BEL/UK	TASE FINLAND	SUMMARY FOR ALL RESULTS MIN	MAX	MAX/MIN	MEAN
610-600	-2.222	-1.582	-2.227	-1.830	-2.186	-1.728	-1.891	-1.272	-2.227	-1.272	0.571	-1.867
620-600	-2.720	-2.341	-2.745	-2.645	-2.960	-2.481	-2.591	-2.427	-2.960	-2.341	0.791	-2.614
630-620	-1.268	-0.984	-1.845	-1.140	-1.303	-1.522	-1.485		-1.845	-0.984	0.533	-1.367
640-600	-0.185	-0.250	-0.320	-0.252	-0.153	-0.245	-0.246	-0.270	-0.320	-0.153	0.478	-0.240
650-600	-1.321	-1.293	-1.284	-1.384	-1.419	-1.404	-1.373	-1.322	-1.419	-1.284	0.905	-1.350

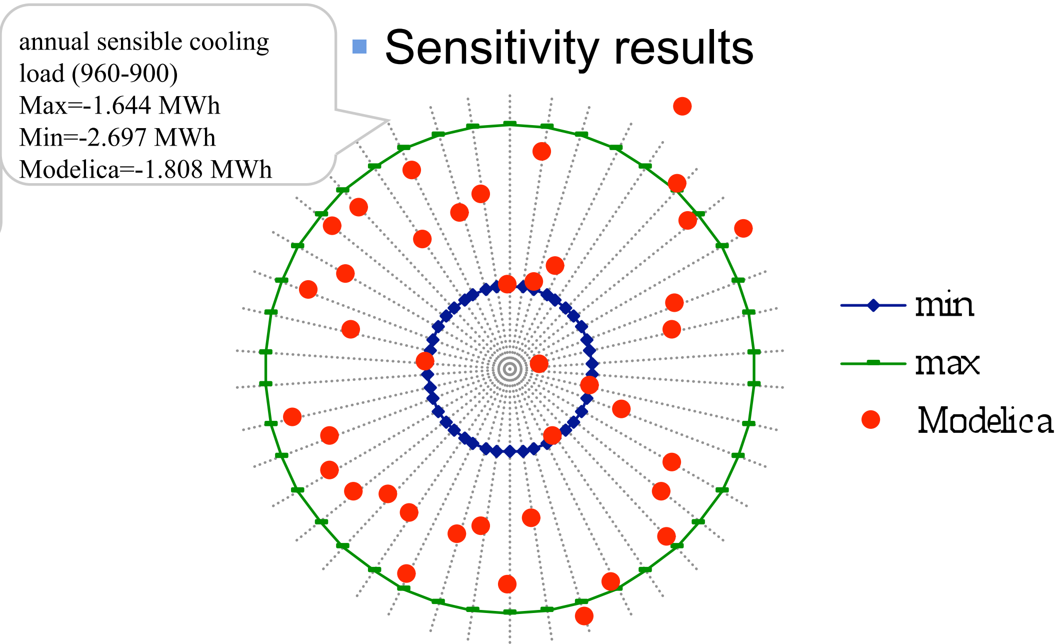
BESTEST results

- Results of basic tests



Note: Each axis represents a normalized figure of merit.

- Sensitivity results



Note: Each axis represents a normalized difference between 2 test cases.

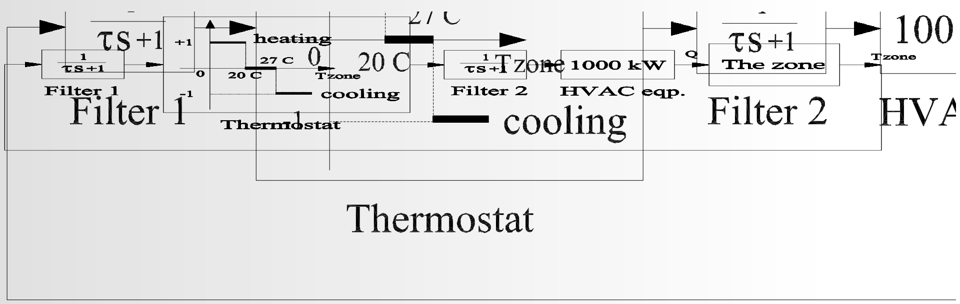
	BASIC	SENSITIVITY	TOTAL
Num. of out-of-bound quantities	6.38% (3 of 47)	16.6% (7 of 42)	11.2% (10 of 89)

- Conclusion:

The Modelica models are capable of predicting the thermal performance of building envelope and delivering comparable results with respect to representative programs.

Issues and solutions

- Three issues encountered in this study
  - Implementation of on-off control
  - Load calculation
  - Biased results caused by controls and window model
- On-off thermostat control
  - Capacity=1000kW; heat=on if T_{zone}<20°C; cool=on if T_{zone}>27°C; otherwise, off
  - Has to be implemented explicitly in Dymola
  - Significantly slows down a simulation
  - 1st-order filter added to reduce the occurrences of discrete events



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

United Technologies Research Center

Issues and solutions

- Load calculation

$$Q_L = \sum_j Q_j + Q_c + i_{in}\,\dot{m} - i_a\,\dot{m}$$

Q_j – heat flow from opaque walls

by convection (+heating – cooling), kW

Q_c – convective internal heat gain, kW

i_{in} – specific enthalphy of infiltration, kJ / kg

i_a – specific enthalphy of room air, kJ / kg

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

  - Should use the data when T_{zone} = 20°C or 27°C
  - Actual valid data: when T_{zone} = 20°C ± ΔT or 27°C ± ΔT
  - The lower bound of ΔT depends on time constant of added filters
    - The smaller τ, the smaller ΔT allowed due to tighter temperature controls
    - ΔT was set to 0.1°C in this study

Issues and solutions

- Biased results from basic tests
  - Compared with the results of EnergyPlus ver 2.0
  - Primary causes:
    - A simplified window model – the net heat flow through windows is 16.6% less than that in EnergyPlus
    - The time constant of the low pass filters affects the calculation of T_{sur}

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

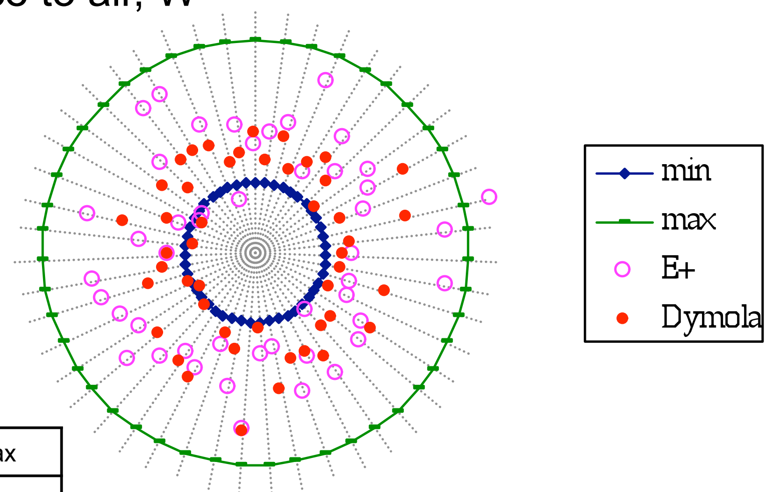
Q_j – convective heat flow from interior surface to air, W

h_{ij} – convective film coefficient, W/m^2K

A – area, m^2

T_{jsur} – surface temperature, °C

T_a – zone temperature, °C



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

Summary

- The Modelica-based building envelope models can be used for whole-building energy simulations.

- The simple window model caused the bias, and a more complex window has been implemented and needs to be evaluated.

THANK YOU