CONTRASTING THE CAPABILITIES OF BUILDING ENERGY PERFORMANCE SIMULATION PROGRAMS

Drury B. Crawley[1], Jon W. Hand[2], Michaël Kummert[3], and Brent T. Griffith[4]

[1]U S Department of Energy, Washington, DC, USA
[2]Energy Systems Research Unit, University of Strathclyde, Glasgow, Scotland, UK
[3]University of Wisconsin-Madison, Solar Energy Laboratory, Madison, Wisconsin, USA
[4]National Renewable Energy Laboratory, Golden, Colorado, USA

ABSTRACT

For the past 50 years, a wide variety of building energy simulation programs have been developed, enhanced and are in use throughout the building energy community. This paper is an overview of a report which provides up-to-date comparison of the features and capabilities of twenty major building energy simulation programs. The comparison is based on information provided by the program developers in the following categories: general modeling features; zone loads; building envelope and daylighting and solar; infiltration, ventilation and multizone airflow; renewable energy systems; electrical systems and equipment; HVAC systems; HVAC equipment; environmental emissions; economic evaluation; climate data availability, results reporting; validation; and user interface, links to other programs, and availability.

INTRODUCTION

Over the past 50 years, literally hundreds of building energy programs have been developed, enhanced and are in use. The core tools in the building energy field are the whole-building energy simulation programs which provide users with key building performance indicators such as energy use and demand, temperature, humidity, and costs.

During that time, a number of comparative surveys of energy programs have been published, ranging from comprehensive surveys of building energy simulation programs to reviews of single topics such as daylighting tools or energy auditing. Yet in our study we found that no comprehensive comparative survey of tools had been conducted in the past ten years.

This paper provides a small excerpt from a much longer report which compares the features of twenty major building energy simulation programs: BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS. The developers of these programs provided initial detailed information about their tools. This report by Crawley, Hand, Kummert, and Griffith (2005) includes more than five pages of detailed references for the surveys mentioned above as well as for the 20 tools. The report contains detailed tables comparing the features and capabilities of the programs in the following 14 categories: General Modeling Features, Zone Loads, Building Envelope and Daylighting, Infiltration, Ventilation and Multizone Airflow, Renewable Energy Systems, Electrical Systems and Equipment, HVAC Systems, HVAC Equipment, Environmental Emissions, Economic Evaluation, Climate Data Availability, Results Reporting, Validation, and User Interface, Links to Other Programs, and Availability. The detailed report is available on the web: www.energytoolsdirectory.gov/pdfs/comparative_paper.pdf

OVERVIEW OF THE TWENTY PROGRAMS

BLAST Version 3.0 Level 334, August 1998

www.bso.uiuc.edu/BLAST

The Building Loads Analysis and System Thermodynamics (BLAST) system predicts energy consumption and energy system performance and cost in buildings. BLAST contains three major subprograms: Space Loads Prediction, Air System Simulation, and Central Plant. Space Loads Prediction computes hourly space loads given hourly weather data and building construction and operation details using a radiant, convective, and conductive heat balance for all surfaces and a heat balance of the room air. This includes transmission loads, solar loads, internal heat gains, infiltration loads, and the temperature control strategy used to maintain the space temperature. BLAST can be used to investigate the energy performance of new or retrofit building design options of almost any type and size.

BSim Version 4.4.12.11

www.bsim.dk

BSim provides user-friendly simulation of detailed, combined hygrothermal simulations of buildings and constructions. The package comprise several modules: SimView (graphic editor), tsbi5 (building simulation), SimLight (daylight), XSun (direct sunlight and shadowing), SimPV (photovoltaic power), NatVent (natural ventilation) and SimDxf (import from CAD). BSim has been used extensively over the past 20 years, previously under the name tsbi3. Today BSim is the most commonly used tool in Denmark, and with increasing interest abroad, for energy design of buildings and for moisture analysis.

DeST Version 2.0, 2005
www.dest.com.cn (Chinese version only)

DeST (Designer's Simulation Toolkits) allows detailed analysis of building thermal processes and HVAC system performance. DeST comprises a number of different modules for handling different functions: Medpha (weather data), VentPlus (natural ventilation), Bshadow (external shading), Lighting (lighting), and CABD (CAD interface). BAS (Building Analysis & Simulation) performs hourly calculations for indoor air temperatures and cooling/heating loads for buildings, including complicated buildings of up to 1000 rooms.

There are five versions in the DeST family: DeST-h (residences), DeST-c (commercial), DeST-e (building evaluation), DeST-r (building ratings) and DeST-s (solar buildings). DeST has been widely used in China for various prestige large structures such as the State Grand Theatre and the State Swimming Centre.

DOE-2.1E Version 121, September 2003
simulationresearch.lbl.gov

DOE-2.1E predicts the hourly energy use and energy cost of a building given hourly weather information, a building geometric and HVAC description, and utility rate structure. DOE-2.1E has one subprogram for translation of input (BDL Processor), and four simulation subprograms (LOADS, SYSTEMS, PLANT and ECON). LOADS, SYSTEMS and PLANT are executed in sequence, with the output of LOADS becoming the input of SYSTEMS, etc. The output then becomes the input to ECONOMICS. Each of the simulation subprograms also produces printed reports of the results of its calculations.

DOE-2.1E has been used extensively for more than 25 years for both building design studies, analysis of retrofit opportunities, and for developing and testing building energy standards in the U.S. and around the world. The private sector has adapted DOE-2.1E by creating more than 20 interfaces that make the program easier to use.

ECOTECT Version 5.50, April 2005
www.ecotect.com

Ecotect is a highly visual architectural design and analysis tool that links a comprehensive 3D modeller with a wide range of performance analysis functions covering thermal, energy, lighting, shading, acoustics and cost aspects. Whilst its modelling and analysis capabilities can handle geometry of any size and complexity, its main advantage is a focus on feedback at the earliest stages of the building design process.

In addition to standard graph and table-based reports, analysis results can be mapped over building surfaces or displayed directly within the spaces. This includes visualisation of volumetric and spatial analysis results, including imported 3D CFD data. Real-time animation features are provided along with interactive acoustic and solar raytracing that updates in real time with changes to building geometry and material properties.

Ener-Win Version EC, June 2005
members.cox.net/enerwin

Ener-Win, originally developed at Texas A&M University, simulates hourly energy consumption in buildings, including annual and monthly energy consumption, peak demand charges, peak heating and cooling loads, solar heating fraction through glazing, daylighting contribution, and a life-cycle cost analysis. Design data, tabulated by zones, also show duct sizes and electric power requirements.

The Ener-Win software is composed of several modules — an interface module, a weather data retrieval module, a sketching module, and an energy simulation module. The interface module includes a rudimentary building sketching interface. Ener-Win requires only three basic inputs: (1) the building type, (2) the building's location, and (3) the building's geometrical data.

Energy Express, Version 1.0, February 2005
www.ee.hearne.com.au

Energy Express is a design tool, created by CSIRO, for estimating energy consumption and cost at the design stage. The user interface allows fast and accurate model creation and manipulation. Energy Express includes a dynamic multi-zone heat transfer model coupled to an integrated HVAC model so that zone temperatures are impacted by any HVAC shortcomings.

Energy Express for Architects provides graphic geometry input and editing, multiple report viewing, comparison of alternative designs and results, simplified HVAC model, and detailed online help. Energy Express for Engineers provides those capabilities along with peak load estimating, and detailed HVAC model, graphic editing of air handling system and thermal plant layouts.

Energy-10 Version 1.8, June 2005
www.nrel.gov/buildings/energy10

Energy-10 was designed to facilitate the analysis of buildings early in the design process with a focus on providing a comprehensive tool suited to the design-team environment for smaller buildings. Rapid presentation of reference and low-energy cases is the hallmarks of Energy-10. Since Energy-10 evaluates one or two thermal zones, it is most suitable for smaller, 10,000 ft^2 (1000 m^2) or less, simpler, commercial and residential buildings.

Energy-10 takes a baseline simulation and automatically applies a number of predefined strategies ranging from building envelope (insulation, glazing, shading, thermal mass, etc.) and system efficiency options (HVAC, lighting, daylighting, solar service hot water and integrated photovoltaic electricity generation). Full life-cycle costing is an integral part of the software.

EnergyPlus Version 1.2.2, April 2005
www.energyplus.gov

EnergyPlus is a modular, structured code based on the most popular features and capabilities of BLAST and DOE-2.1E. It is a simulation engine with input and output of text files. Loads calculated (by a heat balance engine) at a user-specified time step (15-minute default) are passed to the building systems simulation module at the same time step. The EnergyPlus building systems simulation module, with a variable time step, calculates heating and cooling system and plant and electrical system response. This integrated solution provides more accurate space temperature prediction—crucial for system and plant sizing, occupant comfort and occupant health calculations. Integrated simulation also allows users to evaluate realistic system controls, moisture adsorption and desorption in building elements, radiant heating and cooling systems, and interzone air flow.

eQUEST Version 3.55, February 2005
www.doe2.com/equest

eQUEST is a easy to use building energy use analysis tool which provides high quality results by combining a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical results display module with an enhanced DOE-2.2-derived building energy use simulation program.

The building creation wizard walks a user through the process of creating a building model. Within eQUEST, DOE-2.2 performs an hourly simulation of the building based on walls, windows, glass, people, plug loads, and ventilation. DOE-2.2 also simulates the performance of fans, pumps, chillers, boilers, and other energy-consuming devices. eQUEST allows users to create multiple simulations and view the alternative results in side-by-side graphics. It offers energy cost estimating, daylighting and lighting system control, and automatic implementation of energy efficiency measures (by selecting preferred measures from a list).

ESP-r Version 10.1, February 2005
www.esru.strath.ac.uk/Programs/ESP-r.htm

ESP is a general purpose, multi-domain—building thermal, inter-zone air flow, intra-zone air movement, HVAC systems and electrical power flow—simulation environment which has been under development for more than 25 years. It follows the pattern of `simulation follows description` where additional technical domain solvers are invoked as the building and system description evolves. Users control the complexity of the geometric, environmental control and operations to match the requirements of particular projects. It supports an explicit energy balance in each zone and at each surface.. ESP-r is distributed under a GPL license. The web site also includes an extensive publications list, example models, source code, tutorials and resources for developers.

HAP Version 4.20a, February 2004
www.commercial.carrier.com

Hourly Analysis Program (HAP) provides two tools in one package: sizing commercial HVAC systems and simulating hourly building energy performance to derive annual energy use and energy costs. Input data and results from system design calculations can be used directly in energy studies.

HAP is designed for the practicing engineer, to facilitate the efficient day-to-day work of estimating loads, designing systems and evaluating energy performance. Tabular and graphical output reports provide both summaries of and detailed information about building, system and equipment performance.

HAP is suitable for a wide range of new design and retrofit applications. It provides extensive features for configuring and controlling air-side HVAC systems and terminal equipment. Part-load performance models are provided for split DX units, packaged DX units, heat pumps, chillers and cooling towers. Hydronic loops can be simulated with primary-only and primary/secondary configurations, using constant speed or variable speed pumps.

HEED Version 1.2, January 2005
www.aud.ucla.edu/heed

The objective of HEED is to combine a single-zone simulation engine with an user-friendly interface. It is intended for use at the very beginning of the design process, when most of the decisions are made that ultimately impact the energy performance of envelope-dominated buildings.

HEED requires just four project inputs: floor area, number of stories, location (zip code), and building type. An expert system uses this information to design two base case buildings: scheme 1 meets California's Title 24 Energy Code, and a scheme 2 which is 30% more energy efficient. HEED automatically manages up to 9 schemes for up to 25 different projects.

HEED's strengths are ease of use, simplicity of input data, a wide array of graphic output displays, computational speed, and the ability to quickly compare multiple design alternatives. Context specific Help, Advice, and a FAQ file are included. A full Spanish language version is also included. HEED is free, and can be downloaded from www.aud.ucla.edu/heed.

IDA ICE Version 3.0, build 15, April 2005
www.equa.se/ice

IDA Indoor Climate and Energy (IDA ICE) is based on a general simulation platform for modular systems, IDA Simulation Environment. Physical systems from several domains are in IDA described using symbolic equations, stated in either or both of the simulation languages Neutral Model Format (NMF) or Modelica. IDA ICE offers separated but integrated user interfaces to different user categories:

- Wizard interfaces lead the user through the steps of building a model for a specific type of study. The Internet browser based IDA Room wizard calculates cooling and heating load.
- Standard interface for users to formulate a simulation model using domain specific concepts and objects, such as zones, radiators and windows.
- Advanced level interface – where the user is able to browse and edit the mathematical model of the system.
- NMF and/or Modelica programming – for developers.

IES <VE> Version 5.2, December 2004
www.iesve.com

The IES <Virtual Environment> (IES <VE>) is an integrated suite of applications linked by a common user interface and a single integrated data model. <Virtual Environment> modules include:

- ModelIT – geometry creation and editing
- ApacheCalc – loads analysis
- ApacheSim – thermal
- MacroFlo – natural ventilation
- Apache HVAC – component based HVAC
- SunCast – shading visualisation and analysis
- MicroFlo – 3D computational fluid dynamics
- FlucsPro/Radiance – lighting design
- DEFT – model optimisation
- LifeCycle – life-cycle energy and cost analysis
- Simulex – building evacuation

The program provides an environment for the detailed evaluation of building and system designs, allowing them to be optimized with regard to comfort criteria and energy use.

PowerDomus Version 1.5, September 2005
www.pucpr.br/lst

PowerDomus is a whole-building simulation tool for analysis of both thermal comfort and energy use. It has been developed to model coupled heat and moisture transfer in buildings when subjected to any kind of climate conditions, i.e., considering both vapor diffusion and capillary migration. Its models predict temperature and moisture content profiles within multi-layer walls for any time step and temperature and relative humidity for each zone.

PowerDomus allows users to visualize the sun path and inter-buildings shading effects and provides reports with graphical results of zone temperature and relative humidity, PMV and PPD, thermal loads statistics, temperature and moisture content within user-selectable walls/roofs, surface vapor fluxes and daily-integrated moisture sorption/ desorption capacity.

SUNREL Version 1.14, November 2004
www.nrel.gov/buildings/sunrel

SUNREL is an hourly building energy simulation program that aids in the design of small energy-efficient buildings where the loads are dominated by the dynamic interactions between the building's envelope, its environment, and its occupants.

SUNREL has a simplified multizone nodal airflow algorithm that can be used to calculate infiltration and natural ventilation. Windows can be modeled by one of two methods. Users can enter exact optical interactions of windows with identical layers of clear or tinted glass and no coatings on the layers. Thermal properties are modeled with a fixed U-value and fixed surface coefficients. For the second method, a user imports data from Window 4 or 5. SUNREL only models idealized HVAC equipment. The equipment and loads calculations are solved simultaneously, and the equipment capacities can be set to unlimited. Fans move a schedulable fixed amount of air between zones or from outside.

Tas Version 9.0.7, May 2005
www.edsl.net

Tas is a suite of software products, which simulate the dynamic thermal performance of buildings and their systems. The main module is Tas Building Designer, which performs dynamic building simulation with integrated natural and forced airflow. It has a 3D graphics based geometry input that includes a CAD link. Tas Systems is a HVAC systems/controls simulator, which may be directly coupled with the building simulator. It performs automatic airflow and plant sizing and total energy demand. The third module, Tas Ambiens, is a robust and simple to use 2D CFD package which produces a cross section of micro climate variation in a space.

Tas combines dynamic thermal simulation of the building structure with natural ventilation calculations which include advanced control functions on aperture opening and the ability to simulate complex mixed mode systems. The software has heating and cooling plant sizing procedures, which include optimum start. Tas has 20 years of commercial use in the UK and around the world.

TRACE 700 Version 4.1.10, November 2004
www.tranecds.com

TRACE is divided into four distinct calculation phases: Design, System, Equipment and Economics. During the Design Phase the program first calculates building heat gains for conduction through building surfaces as well as heat gains from people, lights, and appliances and impact of ventilation and infiltration. Finally, the program sizes all coils and air handlers based on these maximum loads.

During the System Phase, the dynamic response of the building is simulated for an 8760-hour (or reduced) year by combining room load profiles with the characteristics of the selected airside system to predict the load imposed on the equipment. The Equipment Phase uses the hourly coil loads from the System Phase to determine how the cooling, heating, and air moving equipment will consume energy. The Economic Phase combines economic input supplied by the user with the energy usage from the Equipment Phase to calculate each alternative's utility cost, installed cost, maintenance cost and life cycle cost.

TRNSYS Version 16.0.37, February 2005
sel.me.wisc.edu/trnsys

TRNSYS is a transient system simulation program with a modular structure that was designed to solve complex energy system problems by breaking the problem down into a series of smaller components. TRNSYS components (referred to as "Types") may be as simple as a pump or pipe, or as complicated as a multi-zone building model.

The components are configured and assembled using a fully integrated visual interface known as the TRNSYS Simulation Studio, and building input data is entered through a dedicated visual interface (TRNBuild). The simulation engine then solves the system of algebraic and differential equations that represent the whole system. In building simulations, all HVAC-system components are solved simultaneously with the building envelope thermal balance and the air network at each time step. In addition to a detailed multizone building model, the TRNSYS library includes components for solar thermal and photovoltaic systems, low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells, etc.

The modular nature of TRNSYS facilitates the addition of new mathematical models to the program. In addition to the ability to develop new components in any programming language, the program allows to directly embed components implemented using other software (e.g. Matlab/Simulink, Excel/VBA, and EES). TRNSYS can also generate executables that allow non-expert to run parametric studies.

COMPARISON AMONG THE TOOLS

Readers of the report who have specific simulation tasks or technologies in mind should be able to quickly identify likely candidate tools. The web sites and detailed references and footnotes included in the report would then allow a potential user to confirm that the programs indeed have the capabilities.

From our experience, many users are relying on a single simulation tool when they might be more productive having a suite of tools from which to chose. Early design decisions may not require a detailed simulation program to deal with massing or other early design problems. We encourage users to consider adopting a suite of tools which would support the range of simulation needs they usually see in their practice.

Because the 14 tables comprise 30 pages with more than 250 footnotes in the full comparison report, this paper provides only a glimpse of the wealth of information in the tables. Here we present portions of Tables 2, 3, and 11, a summary of Tables 5, 7 and 8, as well as the complete Table 4 to demonstrate the variety of approaches and solutions represented by these programs. For example in Table 2, note that almost all the programs deal with internal thermal mass; yet most tools only perform design sizing calculations using dry bulb temperature.

While the tables may indicate a tool has a capability, note that there are many nuances of ‘capability’ that the developers found difficult to communicate. For example, there are several levels of resolution here—one tool may do a simplified solution while another may have multiple approaches for that feature.

The tables attempt to resolve this by providing more depth than a simple **X** (has capability) by including **P** (partially implemented), **O** (optional), **R** (research use), **E** (expert use), or **I** (difficult to obtain input data) or through extensive explanatory footnotes. In many tables, many tools allow user-specified correlations, solution methods, or convergence criteria.

CONCLUSIONS

As we began working on this paper, we found that even among the 'mature' tools, there was not quite a common language to describe what the tools could do. There was much ambiguity which will continue to require additional work to resolve in the future.

This report does not attempt to deal with whether the tools would support analysis over the lifetime of the project—from design through construction into operation and maintenance.

We also found that there was a relatively new level of attention and interest in publishing validation results. Several program developers also indicated that they plan to make the simulation inputs available to users for download in the near future.

There is also the issue of trust—do the tools really perform the capabilities indicated, and which level of effort by the user is involved? How detailed is the model behind a tick in the table? For open source tools, everyone can check the model and adapt it. For the other tools, only very detailed BESTEST-like procedures can give the answer. We may need a way for users to provide feedback and ratings for these in the future.

Next generation of the report? Dynamic web-based community resource with direct links for each tool to example input files for each capability as well as the suite of validation inputs … and in some sense this is already beginning. The authors' organizations have begun making their input files for IEA BESTEST easily available.

We envision this report as a community resource which will be regularly updated and expanded as the tools (and the simulation field) mature and grow.

REFERENCE

Crawley, Drury B., Jon W. Hand, Michaël Kummert, and Brent T. Griffith. 2005. *Contrasting the Capabilities of Building Energy Performance Simulation Programs.*

ACKNOWLEDGEMENTS

This paper could not have happened without the cooperation and help of the many people who provided information on tools they use or developed: Kim Wittchen of SBI for BSim. The EnergyPlus development team (Linda K. Lawrie, Curtis O. Pedersen, Walter F. Buhl, Michael J. Witte, Richard K. Strand, Richard J. Liesen, Yu Joe Huang, Robert H. Henninger, Jason Glazer, Daniel E. Fisher, Don B. Shirey, III, Robert J. Hitchcock, Brent T. Griffith, Peter G. Ellis, Lixing Gu, and Rahul Chillar) for DOE-2.1E, BLAST, and EnergyPlus. Professor Jiang Yi, Zhang Xiaoliang, and Yan Da of Tsinghua Univesity for DeST. Professor Andrew Marsh and Caroline Raines of Cardiff University and Square One Research for ECOTECT. Larry Degelman of Texas A&M University for Ener-Win. Steve Moller and Angelo Delsante of CSIRO for Energy Express. Norm Weaver of Interweaver Consulting for Energy-10. Mark Hydeman, Steve Taylor, and Jeff Stein of Taylor Engineering for an early critical review and for information on eQUEST. Nick Kelly and Ian Macdonald at University of Strathclyde for thought-provoking review which significantly broadened the scope of the comparisons. Jim Pegues and Carrier Corporation for HAP. Professor Murray Milne of UCLA for HEED. Per Sahlin of Equa for IDA ICE. Don McLean, Craig Wheatley, Eric Roberts, and Martin Gough for IES <VE>. Professor Nathan Mendes of Pontifical Catholic University of Parana for PowerDomus. Michael Deru of NREL for SUNREL. Alan Jones and Ian Highton of EDSL for Tas. Justin Wieman of the Trane Company and Larry Scheir of SEI Associates for TRACE. The TRNSYS developers team at TRANSSOLAR, CSTB and TESS.

ABBREVIATIONS IN THE TABLES

X feature or capability available and in common use

P feature or capability partially implemented

O optional feature or capability

R optional feature or capability for research use

E feature or capability requires domain expertise

I feature or capability with difficult to obtain input

Table 1 ***Zone Loads*** (11 of the 21 rows from Table 2 of the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Interior surface convection																				
▪ Dependent on temperature	X	X					P		X		X	X	X		X	X	X	X		X
▪ Dependent on air flow	X						X		P		X		X		X			X		E
▪ Dependent on surface heat coefficient from CFD									E		E		X							
▪ User-defined coefficients (constants, equations or correlations)		X	X	X	X				X		E	R	X		X	X	X	X		X
Internal thermal mass	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Automatic design day calculations for sizing																				
▪ Dry bulb temperature	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
▪ Dew point temperature or relative humidity			X	X		X	X		X	X		X	X	X				X	X	
▪ User-specified minimum and maximum			X	X		X	X		X	X		X	X	X	X			X	X	
▪ User-specified steady-state, steady-periodic or fully dynamic design conditions			X									X	X	X				X	X	X

Table 2 ***Building Envelope, Daylighting and Solar*** (9 of the 52 rows from Table 3 in the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Outside surface convection algorithm																				
▪ BLAST/TARP	X								X										X	
▪ DOE-2				X					X	X									X	
▪ MoWiTT									X		X								X	
▪ ASHRAE simple	X					X		X	X				X		X			X	X	
▪ Ito, Kimura, and Oka correlation											X	X								
▪ User-selectable			X						X		X	X	X			X		X	X	X
Inside radiation view factors		X	X						X		X	X	X				P	X		
Radiation-to-air component separate from detailed convection (exterior)		X	X						X	X	X	X	X				X	X	P	X
Solar gain and daylighting calculations account for inter-reflections from external building components and other buildings		P			X				X		X		X			P				X

Table 4 ***Infiltration, Ventilation, Room Air and Multizone Airflow***	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Single zone infiltration	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Automatic calculation of wind pressure coefficients		X	P						P				X				X	X		
Natural ventilation (pressure, buoyancy driven)		X	P						X	P	X	X	X			X	X	X		O
Multizone airflow (via pressure network model)		X	P						X		X	X	X				X	X		O
Hybrid natural and mechanical ventilation		X	P			X					I	X	X			X		X		O
Control window opening based on zone or external conditions			X			X			X		X		X			P	X			O
Displacement ventilation									X		X	X	X					X		O
Mix of flow networks and CFD domains			X								E									
Contaminants, mycotoxins (mold growth)		P									R					P				

Table 5 ***HVAC Systems/Components & Renewable Energy Systems*** [summary from report Tables 5, 7 & 8 (9 pages)]	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Renewable Energy Systems (12 identified, X+O)	1	2	2	1	4	0	0	2	4	2	7	1	3	0	0	1	2	2	0	12
Idealized HVAC systems	X		X		X	X			X		X	X	X				X			X
User-configurable HVAC systems		X	X				P		X		X	X	X	X	X	X	R	X	X	X
Pre-configured systems (among 34 identified, X+O)	14	14	20	16	0	16	5	7	28	24	23	32	28	28	10	8	1	23	26	20
Discrete HVAC components (98 identified, X+O)	51	24	34	39	0	24	8	15	66	61	40	52	38	43	7	15	3	26	63	82

Table 6 ***Economic Evaluation*** (energy costs portion of Table 11 of the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Simple energy and demand charges		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Complex energy tariffs including fixed charges, block charges, demand charges, ratchets		X	X	X			X		X	X			X	X	X	P			X	E
Scheduled variation in all rate components		X	X	X					X	X		X	X	X	X	P		X	X	X
User selectable billing dates				X					X	X					X	P			X	E