

# CONTRASTING THE CAPABILITIES OF BUILDING ENERGY PERFORMANCE SIMULATION PROGRAMS

A Joint Report by

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## 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 report provides an up-to-date comparison of the features and capabilities 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. This comparison is based on information provided by the program developers in the following categories: general modeling features; zone loads; building envelope, 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 interfaces, 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 throughout the building energy community. The core tools in the building energy field are the whole-building energy simulation programs that 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, including:

- Building Design Tool Council (BDTC 1984, 1985 and Willman 1985): a procedure for evaluating simulation tools as well as a report on ASEAM, CALPAS3, CIRA, and SERIRES.
- U.S. Army Construction Engineering Research Laboratory (Lawrie et al. 1984): evaluation of available microcomputer energy programs.
- International Energy Agency Solar Heating and Cooling Programme (IEA SHC) Task 8, Jorgensen (1983): survey of analysis tools; Rittelmann and Ahmed (1985): survey of design tools specifically for passive and hybrid solar low-energy buildings including summary results on more than 230 tools.
- Matsuo (1985): a survey of available tools in Japan and Asia.
- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (Degelman

and Andrade 1986): bibliography on programs in the areas of heating, ventilating, air-conditioning and refrigeration.

- Building Environmental Performance Analysis Club (Wiltshire and Wright 1989) and UK Department of Energy (Wiltshire and Wright 1987): comparison of three tools.
- Bonneville Power Administration: comparison of energy software for the Energy Edge new commercial building program (Corson 1990).
- Ahmad and Szokolay (1993): comparative study of thermal tools used in Australia.
- Scientific Computing: a series of reviews from 1993 through 1995 in Engineered Systems Magazine (Amistadi 1993, 1995).
- Kenny and Lewis (1995): survey of available tools for the European Commission.
- Lighting Design and Application magazine (1996): survey of lighting design software.
- Lomas, Eppel, Martin and Bloomfield (1994): IEA SHC Task 12 empirical validation of thermal building simulation programs using test room data.
- U. S. Department of Energy (Crawley 1996): directory of 50 building energy tools developed by DOE<sup>1</sup>.
- Aizlewood and Littlefair (1996): survey of the use of daylight prediction models.

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<sup>1</sup> This report comprised the initial content of the Building Energy Tools Directory launched in August 1996. This web-based directory now contains information on more than 300 tools: [www.energytoolsdirectory.gov](http://www.energytoolsdirectory.gov)

- Natural Resources Canada (Khemani 1997): directory of more than 100 tools for energy auditing.
- Underwood (1997): comparison of the results from two programs.
- Natural Resources Canada (Zmeureanu 1998, Haltrecht et al 1999): evaluation of capabilities of a broad range of simulation engines.
- IEA SHC Task 21 (de Boer and Erhorn 1999): survey of simple design tools for daylight in buildings including simple formulas, tables, nomographs, diagrams, protractors, software tools, and scale models.
- Waltz (2000): summary of contact and other basic information about a variety of building energy, life-cycle costing, and utility rate tools.
- ARTI 21CR (Jacobs and Henderson 2002): survey of user requirements (architectural designers, engineering practitioners, and design/build contractors), review whole building, building envelope, and HVAC component and system simulation and design tools, evaluate existing tools relative to user requirements, and provide recommendations for further tool development.

This paper provides an up-to-date comparison of twenty major building energy simulation programs: BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Energy-10, Energy Express, Ener-Win, 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, extending an earlier paper by Crawley et al. (2004) comparing DOE-2.1E, BLAST, and EnergyPlus. Because the programs differ substantially from DOE-2, BLAST, or EnergyPlus in structure, solution method, and features, the tables were extensively revised and extended.

Readers are reminded that the tables are based on vendor-supplied information and only a limited peer review has been undertaken to verify the information supplied. Some of the descriptions within the table employ vendor specific jargon and thus is somewhat opaque to the broader simulation community. One of the findings of this project is that the simulation community is a long way from having a clear language to describe the facilities offered by tools and the entities that are used to define simulation models. As a result the tables are not yet uniform in their treatment of topics. Some vendors included components as separate entries and others preferred a general description of component types. Clearly there is considerable scope for improvement in both the layout of the table and in the clarity of the entries.

It is the authors' hope that this will become a living document that will evolve over time to reflect the evolution of tools and an evolution of the language the community uses to discuss the facilities within tools. This task is beyond the resources of three or four authors. It requires community input that not only holds vendors to account for the veracity of their entries, but injects additional methodologies into the task of tool comparison.

This report first provides a brief overview of each of the programs. This is followed by 14 tables which compare the capabilities for each of the twenty simulation programs in the following areas: 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 twenty software programs are listed alphabetically in the tables.

### OVERVIEW OF THE TWENTY SIMULATION PROGRAMS

#### **BLAST Version 3.0 Level 334, August 1998**

[www.bso.uiuc.edu/BLAST](http://www.bso.uiuc.edu/BLAST)

The Building Loads Analysis and System Thermodynamics (BLAST) tool (Building Systems Laboratory 1999) is a comprehensive set of programs for predicting energy consumption and energy system performance and cost in buildings. The BLAST program was developed by the U.S. Army Construction Engineering Research Laboratory (USA CERL) and the University of Illinois. BLAST contains three major subprograms: Space Loads Prediction, Air System Simulation, and Central Plant. The Space Loads Prediction subprogram computes hourly space loads in a building based on weather data and user inputs detailing the building construction and operation. The heart of space loads prediction is the room heat balance. For each hour simulated, BLAST performs a heat balance for each surface of each zone described and a heat balance on the room air.

The Air System Simulation subprogram uses the computed space loads, weather data, and user inputs describing the building air-handling system to calculate hot water, steam, gas, chilled water, and electric demands of the building and air-handling system. Once zone loads are calculated, they are translated into hot water, steam, chilled water, gas, and electrical demands on a central plant or utility system. This is done by using basic heat and mass balance principles in the system simulation subprogram of BLAST. Once the hot

water, steam, chilled water, gas, and electrical demands of the building fan systems are known, the central plant must be simulated to determine the building's final purchased electrical power and/or fuel consumption. The Central Plant Simulation subprogram uses weather data, results of the air distribution system simulation, and user inputs describing the central plant to simulate boilers, chillers, on-site power generating equipment and solar energy systems; it computes monthly and annual fuel and electrical power consumption.

BLAST can be used to investigate the energy performance of new or retrofit building design options of almost any type and size. In addition to performing peak load (design day) calculations necessary for mechanical equipment design, BLAST also estimates the annual energy performance of the facility, which is essential for the design of solar and total energy (cogeneration) systems and for determining compliance with design energy budgets. BLAST is no longer under development and no new versions have been released since 1998.

### **BSim Version 4.4.12.11**

[www.bsim.dk](http://www.bsim.dk)

BSim (Danish Building Research Institute 2004) is a user-friendly simulation package that provides means for detailed, combined hygrothermal simulations of buildings and constructions. The package comprise several modules: SimView (graphic model editor and input generator), tsbi5 (hygro-thermal building simulation core), SimLight (tool for analyses of daylight conditions in simple rooms), XSun (graphical tool for analyses of direct sunlight and shadowing), SimPV (a simple tool for calculation of the electrical yield from PV systems), NatVent (analyses of single zone natural ventilation) and SimDxf (a simple tool which makes it possible to import CAD drawings in DXF format). Only the most central modules will be described in the following. For further information see Rode and Grau (2003).

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.

The SimView module offers the user advanced opportunities for creating the building geometry and attributing properties to any object of the building model. SimView has an interface split into five frames, four showing different views of the geometry and one showing the model in a hierarchical tree structure. In this way it is easy for the user to identify any model object and make changes to it.

The core of the BSim program package is a combined transient thermal and transient indoor humidity and surface humidity simulation module tsbi5. The transient simulation of indoor humidity conditions takes into account the moisture buffer capacity of building components and furnishings and the supply of humidity from indoor activities.

XSun is a tool for detailed analyses and simulation of solar radiation through windows and openings in building constructions. Analyses of shadows from remote objects such as neighboring buildings can also be analyzed by using XSun. During thermal simulations with tsbi5, the routines of XSun are used to distribute solar energy to the exact location in the model. Simulations with XSun can be shown as animations of the movements of sunspots in the spaces of the building model. Animations can be saved as standard Windows video sequences and be shown on a PC where BSim has not been installed.

### **DeST Version 2.0, 2005**

[www.dest.com.cn](http://www.dest.com.cn) (Chinese version only)

DeST (Designer's Simulation Toolkits) is a tool for detailed analysis of building thermal processes and HVAC system performance (Chen and Jiang 1999, Zhu and Jiang 2003). It can provide hourly building thermal performance, energy consumption and ratio of loads satisfied by the HVAC systems, and economic cost results base on the user description. Based on these results, designers can choose the best option at different stages in the design process.

Prior to 1995, DeST was called BTP (Building Thermal Performance), mainly for building thermal performance analysis (Jiang and Hong 1993). BTP was validated as part of the IEA BESTEST work in early nineties (Eppel 1993).

DeST comprises a number of different modules for handling different functions: Medpha (Meteorological Data Producer for HVAC Analysis) (Hong and Jiang 1993), VentPlus (Module for calculation of natural ventilation), Bshadow (module for external shadowing calculation), Lighting (module for indoor lighting calculation), and CABD (Computer Aided Building Description, provides the user interface for DeST, developed based on AutoCAD).

BAS (Building Analysis & Simulation) is the core module for building thermal performance calculation. It performs hourly calculations for indoor air temperatures and cooling/heating loads for buildings. BAS adopted the state space solution method for building thermal heat balance equations (Jiang 1982). For each room, DeST takes into account the thermal process of adjacent rooms. DeST can handle complicated buildings of up to 1000 rooms (Hong and Jiang 1997).

Scheme is the module for analysis of HVAC scheme, such as zoning method, system type selection (VAV, CAV or etc.). A designer provides his scheme (zoning method, system type, etc.) to DeST, DeST can provide the satisfied ratio and energy consumption of this scheme, based on simulation results. By comparing those different design, Designers can obtain an optimized solution for the buildings.

DNA (Duct Network Analysis) is the module in DeST to carry out duct network calculations for both system design and validation. AHU (Air Handling Unit) module can provide sufficient hourly data for the designers to validate the selected air handling equipments. And also it provides data needed by CPS module. CPS (Combined Plant Simulation) is a module to carry out cooling/heating plant and water pipe network calculations for both system design and validation, and it provides the consumption of energy sources. EAM (Economic Analysis Model) is a module to carry out the calculations of initial and operating costs of the designed HVAC system.

There are five versions in the DeST family: DeST-h (residential buildings), DeST-c (commercial buildings), 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](http://simulationresearch.lbl.gov)

DOE-2.1E (Winkelmann et al. 1993) 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. Using DOE-2.1E, designers can determine the choice of building parameters that improve energy efficiency while maintaining thermal comfort and cost-effectiveness. 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. The Building Description Language (BDL) processor reads input data and calculates response factors for the transient heat flow in walls and weighting factors for the thermal response of building spaces.

The LOADS simulation subprogram calculates the sensible and latent components of the hourly heating or cooling load for each constant temperature space taking into account weather and

building use patterns. The SYSTEMS subprogram handles secondary systems; PLANT handles primary systems. SYSTEMS calculates the performance of air-side equipment (fans, coils, and ducts); it corrects the constant-temperature loads calculated by the LOADS subprogram by taking into account outside air requirements, hours of equipment operation, equipment control strategies, and thermostat set points. The output of SYSTEMS is air flow and coil loads. PLANT calculates the behavior of boilers, chillers, cooling towers, storage tanks, etc., in satisfying the secondary systems heating and cooling coil loads. It takes into account the part-load characteristics of the primary equipment in order to calculate the fuel and electrical demands of the building. The ECONOMICS subprogram calculates the cost of energy. It can also be used to compare the cost-benefits of different building designs or to calculate savings for retrofits to an existing building.

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. DOE-2.1E has been used in the design or retrofit of thousands of well-known buildings throughout 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](http://www.ecotect.com)

ECOTECT (Marsh 1996) is a highly visual and interactive complete building design and analysis tool that links a comprehensive 3D modeller with a wide range of performance analysis functions covering thermal, energy, lighting, shading, acoustics, resource use 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 conceptual building design stages. The intent is to allow designers to take a holistic approach to the building design process making it easier to create a truly low energy building, rather than simply size a HVAC system to cope with a less than optimal design.

ECOTECT aims to provide designers with useful performance feedback both interactively and visually. Thus, in addition to standard graph and table-based reports, analysis results can be mapped over building surfaces or displayed directly within the spaces that generated them, giving the designer the best chance of understanding exactly how their building is performing and from that basis make real design improvements.

As well as the broad range of internal calculations that ECOTECT can execute, it also imports/exports to a range of more technical and focussed analysis

engines, such as Radiance, EnergyPlus, ESP-r, NIST FDS and others -- and for general data import/export facilities, it includes an array of formats suitable for use alongside most leading CAD programs.

The recent addition of a comprehensive scripting engine that provides direct access to model geometry and calculation results has made performance based generative design and optimisation a very real option for the environmental engineer/designer who uses ECOTECT. Scripting allows models to be completely interactive and self-generative, automatically controlling and changing any number of parameters, materials, zone settings or even geometry during calculations or as the user specifies—and at a more day-to-day level the scripting functions are excellent for automating the more mundane tasks involved in calculation runs, results comparison and report creation.

ECOTECT is unique within the field of building analysis in that it is entirely designed and written by architects and intended mainly for use by architects—although the software is quickly gaining popularity through the wider environmental building design community.

### **Ener-Win Version EC, June 2005**

[members.cox.net/enerwin](http://members.cox.net/enerwin)

Ener-Win, originally developed at Texas A&M University, is an hourly energy simulation model for assessing annual energy consumption in buildings. The software produces 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.

Ener-Win requires only three basic inputs: (1) the building type, (2) the building's location, and (3) the building's geometrical data. Default data derived from the initial inputs include economics parameters, number of occupied days and holidays, occupancy, hot water usage, lighting power densities, HVAC system types and schedules for hourly temperature settings, lighting use, ventilation and occupancy.

Weather data generation is done hour-by-hour (Degelman 1990) based on statistical monthly means and standard deviations derived from the World Meteorological Organization and the

National Solar Radiation Data Base from a 30-year period of record. The database currently contains 1280 cities. As an alternative, the user may elect to enter typical weather data from files such as TMY2 or WYEC2.

The sketching interface allows the user to sketch the building's geometry and HVAC zones, floor-by-floor, and specify parameters such as number of repetitive floors, floor-to-floor heights, and building orientation. The user can specify up to 25 zones on each floor or a building total of 98 zones. Zones are simply represented in plan by different colors. After the sketching process is complete, a drawing processor will analyze the geometrical conditions, including zone floor, roof and wall areas and how the walls are shaded by adjoining and outside structures.

Peak values for occupancy, hot water use, ventilation, lighting, and equipment are also specified and linked to their respective schedule numbers. Adjustments of any of the zone properties can be done by editing the zone description forms. Usually, some adjustments are desirable for occupancy numbers, lighting levels, whether daylighting is to be used and whether natural ventilation is to be specified. The default HVAC efficiencies may also be edited.

Load calculations, system simulations, and energy summations are performed each hour of the year (Degelman 1990). The resulting zone air conditioning loads are based on a thermal balance model. Convective gains are translated into loads immediately, while the radiative gains are delayed by weighting factors for each source of heat.

Daylighting algorithms are based on a modified Daylight Factor method and support dimmer controls.

The program also has the capability of simulating the floating space temperature (passive designs) for comfort analyses in unheated or uncooled spaces.

Output from Ener-Win is produced in both tabular and graphic forms. The tabular results include: breakdown of monthly energy loads and utility bills, energy savings from utilizing daylight, peak loads, electric demand charges, 24-hour energy use, temperature, energy and comfort profiles.

The Life-Cycle Cost prediction is the final step in the program procedures. First costs for the building are based on the unit costs of walls, windows, and roofs from the assemblies catalog. Additional first costs include the lighting system and the mechanical system. A "Present Worth" analysis is then performed on the future recurring costs of fuel, electric, and maintenance. These calculations are based on fuel price escalation rates and opportunity interest rates.

### **Energy Express Version 1.0, February 2005**

[www.ee.hearne.com.au](http://www.ee.hearne.com.au)

Energy Express (Moller 1996) is a design tool, created by CSIRO in Australia, for evaluating energy efficiency of commercial buildings by estimating energy consumption and cost at the design stage. The user interface allows fast and accurate model creation and manipulation.

Energy Express can be used for the analysis of alternative designs of new buildings and their mechanical and electrical systems, or in the assessment of retrofit options being considered for existing buildings. The energy cost savings of different design and operation options can then be evaluated and compared to produce the most effective combination, before construction.

Energy Express includes a dynamic multi-zone heat transfer model coupled to an integrated HVAC model so that zone temperatures are immediately impacted by any HVAC shortcomings (Moller 1999).

V1.00 includes data libraries covering Australia, New Zealand and S.E.Asia. EE is designed for the PC platform, English language and SI units.

There are two versions of Energy Express:

- Energy Express for Architects
- Energy Express for Engineers (in development)

Both versions of Energy Express offer

- Built-in 2D CAD facility- for fast geometric data input and editing.
- View up to ten output reports covering performance and diagnostics
- Ability to compare a range of alternative designs and calculate savings.
- Uses a reduced weather data set, derived from several years of actual weather data, to reduce run time
- A simple a/c model to enable architects to evaluate building facade options without having to specify details about the air-conditioning.
- Status bar hints on every input field.
- Detailed On-line help.

Energy Express for Engineers will offer:

- Peak load estimate - for equipment sizing.
- A customizable detailed HVAC model more suited to design engineers.
- Graphic editing of air handling system and thermal plant layouts.
- Read 8760 hour weather files.
- Read data files from Energy Express for Architects.

### **Energy-10 Version 1.8, June 2005**

[www.nrel.gov/buildings/energy10](http://www.nrel.gov/buildings/energy10)

Energy-10 is a user-friendly early design stage building energy simulation program that integrates daylighting, passive solar heating, and low-energy cooling strategies with energy-efficient shell design and mechanical equipment. The program is geared toward small commercial and residential buildings of 10,000 ft<sup>2</sup> or less—that's where the "10" in Energy-10 comes from. Developed by the U.S. Department of Energy since 1992, Energy-10 runs an hourly thermal network simulation while allowing users to rapidly explore a wide range of energy efficiency strategies and plot the results in a number of ways.

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. Starting from building location, footprint, usage type and HVAC type Energy-10 can generate reference and low-energy target cases in seconds based on full annual hourly simulation. Ranking graphs for individual strategies can guide early design analysis. Built-in graphs including an embedded version of "DVIEW" allow flexible review of summary and hourly results.

Energy-10 can be used to evaluate and select strategies for much larger buildings. Insulation levels, daylighting, glazing, shading, and passive solar strategies can be calculated under the assumption that a large building is kept at a reasonably uniform temperature. However, overall energy use may be underestimated because HVAC interactions between multiple zones may not be accurately represented.

Energy-10 allows rapid exploration of broad design issues effecting energy performance early in design based on a BESTEST (ASHRAE Standard 140-2001) validated thermal simulation engine.

### **EnergyPlus Version 1.2.2, April 2005**

[www.energyplus.gov](http://www.energyplus.gov)

EnergyPlus (Crawley et al. 2004) is a modular, structured software tool based on the most popular features and capabilities of BLAST and DOE-2.1E. It is primarily a simulation engine; input and output are simple text files. EnergyPlus grew out of a perceived need to provide an integrated (simultaneous loads and systems) simulation for accurate temperature and comfort prediction. 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 (down to 1 minute as needed), 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.

EnergyPlus has two basic components—a heat and mass balance simulation module and a building systems simulation module. The building systems simulation manager handles communication between the heat balance engine and various HVAC modules and loops, such as coils, boilers, chillers, pumps, fans, and other equipment/components. User-configurable heating and cooling equipment components give users flexibility in matching their simulation to actual system configuration. HVAC air and water loops are the core of the building systems simulation manager—mimicking the network of pipes and ducts found in real buildings. The air loop simulates air transport, conditioning and mixing, and includes supply and return fans, central heating and cooling coils, heat recovery, and controls for supply air temperature and outside air economizer. The air loop connects to the zone through the zone equipment. Users can specify more than one equipment type for a zone.

The heat and mass balance calculations are based on IBLAST—a research version of BLAST with integrated HVAC systems and building loads simulation. The heat balance module manages the surface and air heat balance modules and acts as an interface between the heat balance and the building systems simulation manager. The surface heat balance module simulates inside and outside surface heat balances; interconnections between heat balances and boundary conditions; and conduction, convection, radiation, and mass transfer (water vapor) effects. The air mass balance module deals with various mass streams—ventilation and exhaust air, and infiltration—accounting for zone air thermal mass and direct convective heat gains.

EnergyPlus inherits three popular windows and daylighting models from DOE-2.1E—fenestration performance based on WINDOW 5 calculations, daylighting using the split-flux interreflection model, and anisotropic sky models. EnergyPlus' detailed daylighting module calculates interior daylight illuminance, glare from windows, glare control, and electric lighting controls (on/off,

stepped, continuous dimming), and calculates electric lighting reduction for the heat balance module. In addition, a new daylighting analysis module named DELight has been integrated with EnergyPlus. This module uses a radiosity interreflection method, and includes newly developed methods for analyzing complex fenestration systems characterized by bi-directional transmittance data.

### **eQUEST Version 3.55, February 2005**

[www.doe2.com/equest](http://www.doe2.com/equest)

eQUEST is an easy to use building energy use analysis tool which provides professional-level results with an affordable level of effort. This is accomplished 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.

eQUEST features a building creation wizard that walks you through the process of creating an effective building energy model. This involves following a series of steps that help you describe the features of your design that would impact energy use, such as architectural design, HVAC equipment, building type and size, floor plan layout, construction materials, area usage and occupancy, and lighting system.

After compiling a building description, eQUEST produces a detailed simulation of your building, as well as an estimate of how much energy it would use. Although these results are generated quickly, this software utilizes the full capabilities of DOE-2.2.

Within eQUEST, DOE-2.2 performs an hourly simulation of your building design for a one-year period. It calculates heating or cooling loads for each hour of the year, based on the factors such as: 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. During the simulation, DOE-2.2 also tabulates your building's projected energy use for various end uses.

eQUEST offers several graphical formats for viewing simulation results. For instance, graphing the simulated overall building energy on an annual or monthly basis or comparing the performance of alternative building designs. In addition, eQUEST allows you to perform 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 common energy efficiency measures (by selecting preferred measures from a list). In the latest versions, a three-dimensional

view of the building geometry is available as well as HVAC system diagrams.

### **ESP-r Version 10.1, February 2005**

[www.esru.strath.ac.uk/Programs/ESP-r.htm](http://www.esru.strath.ac.uk/Programs/ESP-r.htm)

ESP (ESRU 2005, Clarke 2001) 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 have options to increase the geometric, environmental control and operational complexity of models to match the requirements of particular projects. It supports an explicit energy balance in each zone and at each surface and uses message passing between the solvers to support inter-domain interactions (Clarke 2001). It works with third party tools such as Radiance to support higher resolution assessments as well as interacting with supply and demand matching tools.

ESP-r is distributed as a suite of tools. A *project manager* controls the development of models and requests computational services from other modules in the suite as well as 3<sup>rd</sup> party tools. Support modules include: climate display and analysis, an integrated (all domain) simulation engine, environmental impacts assessment, 2D-3D conduction grid definitions, shading/insolation calculations, viewfactor calculations, short-timestep data definitions, mycotoxin analysis, model conversion (e.g. between CAD and ESP-r) and an interface to the visual simulation suite Radiance.

ESP-r is distributed under a GPL license through a web site which also includes an extensive publications list, example models, cross-referenced source code, tutorials and resources for developers. It runs on almost all computing platforms and under most operating systems.

Although ESP-r has a strong research heritage (e.g. it supports simultaneous building fabric/network mass flow and CFD domains), it is being used as a consulting tool by architects, engineers, and multidiscipline practices and as the engine for other simulation environments.

### **HAP Version 4.20a, February 2004**

[www.commercial.carrier.com](http://www.commercial.carrier.com)

Carrier's Hourly Analysis Program (HAP) (Carrier Corporation 2003) provides two powerful tools in one software package. HAP sizes HVAC systems for commercial buildings. It also simulates 8760-hr building energy performance to derive annual energy use and energy costs.

HAP is designed for the practicing engineer, to facilitate the efficient day-to-day work of estimating loads, designing systems and evaluating energy performance. Careful attention has been given to design of the graphical user interface and to reporting features. Tabular and graphical output reports provide both summary and detailed information about building, system and equipment performance.

HAP uses six calculation engines to perform its work. The Loads engine uses the ASHRAE Transfer Function Method to analyze dynamic heat transfer in the building, producing space cooling and heating loads. The Systems engine simulates the thermomechanical operation of air side systems. The Sizing engine integrates with both the Loads and Systems engines to determine required sizes for diffusers, air terminals, fans, coils and humidifiers. The Plant engine simulates the operation of chilled water and hot water plants. The Building engine collects energy and fuel consumption data from the System and Plant calculations and combines it with utility rate specifications to produce energy meter consumption totals and energy costs. Finally, a Life-cycle engine in a separate, but integrated program combines energy costs from HAP with purchase, installation and maintenance costs to derive life-cycle costs.

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. Energy costs can be calculated with simple or complex utility rates, the latter including energy and demand charges, time of day and year pricing, and demand determination clauses such as ratchets.

HAP is in its 20<sup>th</sup> year providing design and simulation solutions to the HVAC engineering community. It complies with simulation tool requirements outlined in ASHRAE Standard 90.1-2001 section 11.2 and Federal Register 10 CFR 434 section 434.521. Data generated with HAP is accepted for LEED project submissions. HAP has been tested using ASHRAE Standard 140-2001 procedures and test results are published with the software.

### **HEED Version 1.2, January 2005**

[www.aud.ucla.edu/heed](http://www.aud.ucla.edu/heed)

The objective of HEED (Milne et al. 2004) is to combine a single-zone simulation engine with a 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 uses an expert system to transform limited user inputs into two base case buildings, scheme 1 meets California's Title 24 Energy Code, and scheme 2 is usually about 30% more energy efficient. This second scheme incorporates the most appropriate mix of passive heating and cooling design strategies for the local climate, including improvements to geometry, orientation, construction, window shading, glazing, internal mass, intelligent natural/fan ventilation, daylighting, etc. The user can then easily modify the initial schemes for their specific requirements. For more advanced users, all this design data can be entered numerically. HEED automatically manages up to 9 schemes for up to 25 different projects.

Performance output data is presented graphically, in a wide array of formats, in addition to the conventional tabular form. The Basic output is a set of bar charts comparing gas and electricity costs for up to nine different schemes, showing how heating, cooling, fans, lights, and plug loads break out. Advanced outputs includes hourly 3D surface plots showing performance for each hour of each month of the year, for sixteen components of the building's total loads, plus heat gain and loss, indoor air temperatures, air change rate, furnace and air conditioner energy consumption, power for lights and fans, and gas and electricity costs. Comparing these 3D plots side-by-side for different schemes reveals the most subtle differences in of building performance. There are also 3D bar charts comparing over 40 variables against up to 9 schemes, including in pounds of air pollution, cubic feet of greenhouse gasses, and dollar cost for gas and electricity.

HEED uses the Solar-5 engine, a whole-building hourly heat balance simulation program that has been in development for over 30 years. It calculates an hourly heat balance for 8760 hours in a year (or for any 12 day snapshot) using the standard ASHRAE equations, plus the Mackey and Wright time lag and decrement factor method to account for heat flow through opaque surfaces, as well as the admittance factor method to account for the thermal storage in internal mass. It includes features like an intelligent whole-house fan thermostat, operable shading controls, window-dependent daylighting, operable night window insulation, and it calculates the air pollution produced by each scheme. HEED has been validated using the BESTEST envelope procedure (ASHRAE Standard 140-2001).

It comes with climate data for all 16 California climate zones, plus detailed rates for California's major electric and gas utilities. Other utility rates can be user input, and Energy Plus world-wide climate data can be imported directly. The Frequently Asked Questions file explains how to use HEED for non-residential buildings.

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](http://www.aud.ucla.edu/heed).

### **IDA ICE Version 3.0, build 15, April 2005**

[www.equa.se/ice](http://www.equa.se/ice)

IDA Indoor Climate and Energy (IDA ICE) (Sahlin et al. 2004, Sahlin et al. 2003) is based on a general simulation platform for modular systems, IDA Simulation Environment (Sahlin and Grozman 2003). 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) ([www.equa.se](http://www.equa.se)) or Modelica ([www.modelica.org](http://www.modelica.org)). User defined tolerances control solution accuracy, allowing complete isolation of numerical errors from modeling approximations. Efficient DAE solvers are used to achieve a close to linear relationship between problem size and execution time for most problem types. The building simulation end-user benefits from this approach in several ways:

1. Model extensions may be added as needed, by purchase or own development.
2. The mathematical model is fully transparent to the user, i.e. all variables, equations and parameters can be inspected to investigate model behavior.
3. Models from research work are easily made useful in commercial design.
4. The cost of maintaining and improving the general platform is shared among several domains, enabling commercially driven building simulation development. Locally adapted offerings of commercial quality, manufacturer-neutral, software and services can then become a reality.

The IDA building simulation application Indoor Climate and Energy was specified and partly financed by an industrial consortium and has since its release in 1998 grown to become a leading international tool. Special strengths are associated with a northern European engineering culture, represented by for example displacement ventilation, active chilled beams, radiative devices, air and water based slab systems. All Termodeck

buildings are for example designed using IDA ICE. A special strength is realistic modeling of controls, enabling study of local loop behavior in a whole-building context.

IDA ICE offers separated but integrated user interfaces to different user categories:

- Wizard interfaces – leading the user through the steps of building a model for a specific type of study. The Internet browser based IDA Room wizard for cooling and heating load calculations is available free of charge over the Internet, serving some 5000 registered users in six (soon eight) languages.
- Standard level interface – where the user is expected to formulate a reasonable simulation model using domain specific concepts and objects, such as zones, radiators and windows. A great majority of the approximately 500 paying users rely on this interface, which is currently available in English, German, Swedish and Finnish.
- 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](http://www.iesve.com)

IES <Virtual Environment> (IES <VE>) provides design professionals with a range of design-oriented building analysis within a single software environment. At the core of the model is a 3-D geometric representation of the building to which application specific data is attached in views tailored to specific design tasks. The single model allows easy data exchange among applications.

IES <VE> incorporates ApacheSim, a dynamic thermal simulation tool based on first-principles mathematical modelling of building heat transfer processes. It has been tested using ASHRAE Standard 140 and qualifies as a Dynamic Model in the CIBSE system of model classification. 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.

ApacheSim can be linked dynamically to MacroFlo for natural ventilation and infiltration analysis, to ApacheHVAC for component based system simulation and to SunCast for detailed shading and solar penetration analysis. Results from ApacheSim may be automatically exported as boundary conditions for the MicroFlo CFD program

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. Among the issues that can be addressed with ApacheSim are thermal insulation (type and placement), building dynamics & thermal mass, building configuration and orientation, climate response, glazing, shading, solar gain, solar penetration, casual gains, airtightness, natural ventilation, mechanical ventilation, mixed-mode systems, and HVAC systems.

Within ApacheSim, conduction, convection and radiation heat transfer processes for each element of the building fabric are individually modeled and integrated with models of room heat gains, air exchanges and plant. The simulation is driven by real weather data and may cover any period from a day to a year. The time-evolution of the building's thermal conditions is traced at intervals as small as one minute.

ApacheSim results are viewed in Vista, a graphics driven tool for data presentation and analysis. Vista provides facilities for interrogating the results in detail or at various levels of aggregation, and includes functions for statistical analysis. Simulation results include:

- Over 40 measures of room performance including air and radiant temperature, humidity, CO<sub>2</sub>, sensible and latent loads, gains and ventilation rates
- Comfort statistics
- Natural ventilation rates through individual windows, doors and louvers
- Surface temperatures for comfort analysis and CFD boundary conditions
- Plant performance variables
- Loads and energy consumption
- Carbon emissions

### **PowerDomus Version 1.5, September 2005**

[www.pucpr.br/lst](http://www.pucpr.br/lst)

PowerDomus (Mendes et al. 2003) 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, by using the finite-volume approach and the mathematical method developed by Mendes et al. (2002). The use of this method avoids numerical oscillations, since it keeps the discrete equations strongly coupled between themselves, preventing the occurrence of physically unrealistic behavior when time step is increased and producing a numerically stable method, which is very suitable

to be used in building yearly energy simulation programs. Integrated simulation of HVAC systems can be performed for both direct and indirect expansion systems.

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.

On-off and PID control strategies can be applied to individual heaters or DX-systems and 1-minute time intervals for schedules can be considered allover.

For the floor, the Dirichlet conditions for temperature and moisture content at the lower soil surface or adiabatic and impermeable conditions for deeper surfaces can be considered. There is also the possibility to read temperature and moisture content data generated by the Solum 3-D Simulation model (Santos and Mendes, 2003), which provides spatial distribution of temperature and moisture content in soils for each user-defined time sample.

PowerDomus has been conceived to be a very user-friendly software in order to stimulate a larger number of users to use building simulation software. It has been developed in the C++ language under C++ Builder environment using a 3-D OpenGL graphical interface and it is available on the PC platform under Windows 2000 and XP operating systems.

### **SUNREL Version 1.14, November 2004**

[www.nrel.gov/buildings/sunrel](http://www.nrel.gov/buildings/sunrel)

SUNREL (Deru et al. 2002) is an hourly building energy simulation program developed by NREL's Center for Building and Thermal Systems 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. The program is based on fundamental models of physical behavior and includes algorithms specifically for passive technologies, such as Trombe walls, programmable window shading, advanced glazing, natural ventilation, and rock bins. Conduction is calculated with a 1-D finite difference formulation; therefore, there is no practical limit on the thickness of walls or thermal capacitance. Interzone heat transfer by convection and radiation is handled by user defined heat transfer coefficients. External surface convection coefficients are user defined (or default) constants. Interior surface convection and radiation

heat transfer is calculated using user defined (or default) constants.

SUNREL has a simplified multizone nodal airflow algorithm that can be used to calculate infiltration and natural ventilation. Inputs for infiltration include the effective leakage area per zone and the estimated distribution of the leakage area over each wall. The natural ventilation inputs include the opening size, height, location, and operating temperature schedule. Wind pressure coefficients can be user defined or calculated from a simple correlation using wind speed and direction.

Windows can be modeled with detailed optical properties and U-values or via data import from Window 4 or 5. Thermochromic windows can also be modeled if the optical data is available to create a Window model.

SUNREL only models idealized HVAC equipment. The equipment and loads calculations are solved simultaneously, and the equipment capacities can be fixed by the user or set to always meet the load. Fans can be used to move a schedulable fixed amount of air between zones or from outside. SUNREL can read TMY, TMY2, BLAST, and SUNREL weather files. A graphical interface can be used to create and revise the text input files. The interface allows a single run or parametric runs for a single variable at a time.

### **Tas Version 9.0.7, May 2005**

[www.edsl.net](http://www.edsl.net)

Tas (EDSL 1989) 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.

Simulation data (shading, surface information etc) is extracted from the Tas 3D model, including an automatically generated air flow network. 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. It has a reputation for robustness,

accuracy and a comprehensive range of capabilities. There is an extensive Theory Manual detailing simulation principles and assumptions. Developments are regularly tested against ASHRAE, CIBSE and ISO/CEN standards. Originally developed at Cranfield Institute in the UK, it has been commercially developed and supported since 1984.

### **TRACE 700 Version 4.1.10, November 2004**

[www.tranecds.com](http://www.tranecds.com)

The TRACE 700 program (Trane 1992), developed by the Trane Company, is divided into four distinct calculation phases: Design, System, Equipment and Economics.

The user can choose from several different load methodologies: TETD, CLTD/CLF, ASHRAE RTS, and others.

During the Design Phase the program first calculates building heat gains for each month based on the building geometry, schedules of use, infiltration and ventilation. The heat gain profile is then converted into a cooling load profile which accounts for the thermal time lag characteristics of the building and peak loads. The program next performs a psychrometric analysis to determine the desired cooling and heating supply air temperatures. Then the load and psychrometric calculations are repeated to more accurately account for the hourly plenum temperature's affect on the space and coil loads. Finally, the program sizes all coils and air handlers based on these maximum loads and the psychrometrically determined values of supply air dry bulb.

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 program will track the wet and dry bulb condition of air as it travels through the building either gaining or releasing heat along the way. In addition to energy recovery, both indirect and direct dehumidification strategies can be simulated to predict the humidity levels in every room of the building.

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. In addition, the cooling equipment also takes into account the effect of the ambient dry and wet bulb temperatures upon equipment performance.

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. From the economic parameters input, a detailed life cycle analysis is performed for each alternative and comparisons made between the alternatives.

### **TRNSYS Version 16.0.37, February 2005**

[sel.me.wisc.edu/trnsys](http://sel.me.wisc.edu/trnsys)

TRNSYS (Klein et al. 2004) 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 are 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. The program typically uses 1-hour or 15-min time steps but can achieve 0.1-sec time steps. User-selectable (e.g. hourly and monthly) summaries can be calculated and printed.

In addition to a detailed multizone building model, the TRNSYS library includes many of the components commonly found in thermal and electrical energy systems: solar thermal and photovoltaic systems, low energy buildings and HVAC systems, renewable energy systems, cogeneration, and hydrogen systems (e.g. fuel cells). It also provides component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results.

The modular nature of TRNSYS facilitates the addition of new mathematical models to the program. Components can be easily shared between users without recompiling the program thanks to the drop-in DLL technology. Simple components, control strategies or pre- and post-processing operations can also be implemented directly in the input file using simple equations supporting the usual mathematical and logical operators and can use the (optionally delayed) outputs of other components. 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).

Additionally, TRNSYS includes the ability to add HTML-like syntax to any input file. An interpreter program called TRNSED allows non-TRNSYS users to then view and modify a simplified, webpage like representation of the input file and perform 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.

The remainder of this report contains the 14 tables which compare the capabilities and features of the 20 programs, which are listed alphabetically.

#### **Table 1 General Modeling Features**

This table provides an overview of how the various tools approach the solution of the buildings and systems described in a user's model, the frequency of the solution, the geometric elements which zones can be composed and exchange supported with other CAD and simulation tools. The table indicates that the majority of tools support the simultaneous solution of building and environmental systems. Increasingly tools allow users to study performance at finer increments than one hour, especially for environmental systems. In the vendors' view there is support for a full geometric description. Certainly geometric detail differs between the tools and users will want to check the vendors' web sites for specifics. A few tools support exchange data with other simulation tools so that second numerical opinions can be acquired without having to re-enter all model details.

#### **Table 2 Zone Loads**

This table provides an overview of tool support for solving the thermophysical state of rooms: whether there is a heat balance underlying the calculations, how conduction and convection within rooms are solved, and the extent to which thermal comfort can be assessed. The majority of vendors claim a heat balance approach although few of these report energy balance (see Table 12). This table indicates considerable variation in facilities on offer. Eight tools claim no support for thermal comfort. Of those that do, Fanger is supported almost as often as mean radiant temperature. The table indicates that there is a sub-set of tools supporting additional inside surface convection options. Most tools claim support for internal thermal mass, but the specifics are not yet included in the table. Users would need to check the vendors' web sites for further detail.

#### **Table 3 Building Envelope and Daylighting**

This table provides an overview of tool treatment of solar radiation outside a building as well as its distribution within and between zones. The table also covers outside surface convection, how interactions with the sky and ground are treated. Not stated in the table are assumptions that tools deal with the sun and that sunlight entering a room is accounted for. Inclusion in the table is mostly for additional facilities. The table indicates that most vendors view lighting control as worthy of support but few tools yet accept the full complexity of blinds or translucent façade elements. As expected, most vendors support only 1-dimensional conduction. But users are often confronted by restrictions in solar and visible radiation treatment that can be traced to the age of the underlying computational methods.

#### **Table 4 Infiltration, Ventilation and Multizone Airflow**

This table provides an overview of how air movement, either from the outside or between rooms or in conjunction with environmental systems are treated. All tools claim to provide at least a single zone infiltration model, somewhat fewer claim to deal with natural ventilation and fewer still, support airflow via a pressure network model. As expected, tool vendors associated with the manufacture of system components tend not to support much in the way of non-mechanical design options. Interestingly, a number of vendors now offer support for displacement ventilation. None of the tables include items related to indoor air quality yet even though this has certainly been an issue that has been raised in various international conferences and research journals. Clearly this table will expand in future versions, but for now readers should look for further information from the vendor sites.

#### **Table 5 Renewable Energy Systems**

This brief table provides an overview of renewable energy systems. The table is based on entries suggested by vendors and is not yet complete in terms of its coverage of such designs, what is required of the user to define such designs or the performance indicators that are reported. With a few exceptions, vendors have few facilities for such assessments.

#### **Table 6 Electrical Systems and Equipment**

This table provides an overview of how electrical systems and equipment are treated in each tool. The majority of tools claim support for building power loads. Yet most of these loads are simply scheduled inputs. As with renewable energy systems, support for electrical engineers is sparse. There appears to be increasing support for basic cogeneration

facilities, but readers should check with vendors to see what the specifics are.

### **Table 7 HVAC Systems**

This table provides an overview of HVAC systems, with additional sections for demand-controlled ventilation, CO<sub>2</sub> control and sizing. Readers should also consult Table 8, which has sections for other environmental control systems and components. At the beginning of the table is an indicator as to whether HVAC systems are composed from discrete components (implying that the user has some freedom in the design of the system) or that there are system templates provided. It is notable that some tools now claim to support CO<sub>2</sub> sensor control of HVAC systems. Automatic sizing is offered by quite a few tools. Most tools offer a range of zonal and room air distribution devices. However, without further investigations it would be difficult for a reader to confirm whether a particular vendors offering is appropriate or what aspects of its performance are assessed.

### **Table 8 HVAC Equipment**

This table provides an overview of the HVAC components as well as components used in central plant as well as components associated with domestic hot water. This table is diverse because it reflects the diversity that vendors currently support. Such diversity requires the user scan the full table for items of interest. For example, almost all tools support various types of pumps, but few claim to have heat exchangers in the early sub-section, but most mention heat exchangers in a later section on air-to-air energy recovery. DX coils seem to be included in multiple sub-sections. It remains for a later version to begin the substantial task of confirming the equivalence of like-named entities and imposing an overall structure. Table 7 and 8 in their current form mask even more diversity because vendors offering component X because it has the same name as that offered by another vendor. Each has likely taken a different approach to implementation ranging from curve fits to entities that take into account the underlying physics. We urge readers not to count the boxes ticked, but to dig deeper to confirm whether what is on offer actually is appropriate for use in a particular simulation project and we would be most interested in updating the table to reflect additional information.

### **Table 9 Environmental Emissions**

This table gives an overview of the emissions associated with the energy use of buildings and environment control systems. Users of most tools are able to get reports on major greenhouse gases. There are other environmental impacts which are available to support national standards. This table does not address how difficult it is to gather and

support the underlying data requirements for environmental emissions.

### **Table 10 Economic Evaluation**

This brief table provides a few hints as to vendor support for energy cost analysis and life-cycle cost analysis. Support is, at best, mixed and would appear to be sensitive to region-specific standards and laws. Probably there is no such thing as a life-cycle cost definition that would be agreed upon by every tool vendor that offers the facility. Clearly there is scope for this table to expand so as to highlight the diversity of vendor support.

### **Table 11 Climate Data Availability**

This table gives a summary of climatic data related issues. There is still a cacophony of climate file types and many tools support a range of formats. One trend over the last few years is the growth in the number of locations supported by the EPW file format as well as the number of tools which use this format. It will be interesting to see if some tool-specific formats disappear in preference to this emerging standard.

### **Table 12 Results Reporting**

At the end of the day, simulation use is only useful if users can get access to indicators of performance. The table indicates a considerable diversity in the data that simulation tools generate as well as the format of the reports. In general, users can create reports based on performance indicators that they choose. A few tools provide in-built facilities to graph and carry out statistical operations. Most tools assume considerable proficiency with third party graphing and spreadsheet applications. It is interesting to note that simulation tools are among the most disk-filling of applications, yet no tool vendor makes any claims about writing to enterprise class database formats.

### **Table 13 Validation**

This table gives an indication of the steps that vendors have taken to test software. In some cases the validation is against an analytical standard, in others validation is comparison between tools. Some show conformance to a particular national or international standard. The footnotes and references for the validation exercises are, perhaps among the primary findings of this report. Although vendors would not accidentally tick a box in error, readers are advised to check the references given for the specifics of the validation work.

### **Table 14 User Interface, Links to Other Programs, and Availability**

This table takes a different format from the others and allows brief discussions of aspects of each tool that did not fit into the other tables and footnotes. The authors commend this table to the reader

because it highlights issues which could be critical in their understanding of simulation tools.

### 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.

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

The tables attempt to clarify 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.

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.

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.

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? What level of effort and knowledge is required by the user? 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.

Where do we see the next generation of this report? First, 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. Ultimately, we see a 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. In some sense this is already beginning—the authors’ organizations have begun making their input files for IEA BESTEST easily available.

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ABBREVIATIONS IN THE TABLES

- X** feature or capability that is available and in common use (e.g. a mature facility, well supported in documentation/interface/examples)
- P** feature or capability that is partially implemented (e.g., it addresses part of an issue, does not yet fully represent the underlying physics or is a work-in-progress)
- O** optional feature or capability that is not included in the standard distribution or requires additional payment and/or a download.
- R** optional feature or capability that is intended for research use (e.g., links to experimental data, validation tests, and options to invoke alternative correlations or modify the underlying solution technique)
- E** feature or capability that requires considerable domain expertise or knowledge of the underlying models (e.g., computational fluid dynamics, 2D/3D conduction, fire evacuation)
- I** feature or capability that requires input data that can be difficult to obtain (e.g., parameter estimates from optimization, difficult to obtain curve fits, no manufacturer data available, little or no research has been done to characterize model coefficients)

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 1 General Modeling Features</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	T <sub>as</sub>	TRACE	TRNSYS
Simulation solution																				
▪ Sequential loads, system, plant calculation without feedback	X			X															X	
▪ Simultaneous loads, system and plant solution	X <sup>2</sup>	X	X		<sup>3</sup>	X	X	X <sup>4</sup>	X	X <sup>5</sup>	X	X <sup>6</sup>	X	X	X	X	X <sup>7</sup>	X		X
▪ Iterative non-linear systems solution		X			<sup>3</sup>			X	X		X	X	X	X	X	X		X	X	X
▪ Coupled loads, systems, plant calculations		X					X	X <sup>4</sup>	X	X	X		X	X	X	X	X		X	X
▪ Space temperature based on loads-systems feedback	X	X	X		X <sup>8</sup>	X	X	X	X		X	X	X	X	X	X	X	X	X	X
▪ Floating room temperatures <sup>9</sup>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Time step approach															X					
▪ User-selected for zone/environment interaction	X <sup>2</sup>	X <sup>10</sup>	R					X <sup>11</sup>	X <sup>12</sup>		X <sup>13</sup>			X	X	X <sup>14</sup>	X			X <sup>15</sup>
▪ Variable time intervals for zone air/HVAC system interaction	X <sup>2</sup>	X <sup>10</sup>					X		X	X <sup>16</sup>	X					R				
▪ User-selected for both building and systems											X			X	X	X				X <sup>17</sup>
▪ Dynamically varying based on solution transients									X		X			X <sup>18</sup>						
Full Geometric Description																				
▪ Walls, roofs, floors	X	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X <sup>19</sup>
▪ Windows, skylights, doors, and external shading	X	X	X	X	X	P	X		X	X	X		X	X <sup>20</sup>	X	X	X	X	X	X

<sup>2</sup> Only in IBLAST, an unreleased, integrated simulation version of BLAST. BLAST simultaneously calculates all zones in the “building” heat balance.

<sup>3</sup> ECOTECT exports its models to the native file formats of EnergyPlus, ESP-r, HTB-2, and Radiance, invoking calculations and then importing results for display and analysis.

<sup>4</sup> CNE simulation engine used by Energy-10 uses iterative convergence to achieve energy balance (thermal network coupled with building systems) at each time step.

<sup>5</sup> HVAC air-side and water-side combined calculation

<sup>6</sup> Loads and HVAC airside systems integrated with feedback. Plant is sequential with system/loads.

<sup>7</sup> Idealized HVAC equipment only in release version. Research version with more realistic HVAC models.

<sup>8</sup> Based on CIBSE Admittance Method for early design decision-making and analysis

<sup>9</sup> No environmental controls

<sup>10</sup> Up to 256 timesteps per hour

<sup>11</sup> For Energy-10 the CNE engine runs in 15-minute time steps with results reported on an hourly basis.

<sup>12</sup> 15-minute default, 10 minute to 1 hour time steps. Use can modify so that 1 minute time steps can be done but not recommended due to stability issues.

<sup>13</sup> 1 minute to 1 hour time steps for zones and flow networks and a multiple of that for detailed systems.

<sup>14</sup> 1-hour default, 1-second to 24-hour time steps. 1-minute time interval schedules.

<sup>15</sup> Building and system use the same time step. 1-hour default, user can select down to 0.1 second

<sup>16</sup> 5 minute time step for electric heat/cool/fan equipment for demand vs. energy cost calculation

<sup>17</sup> Type 56 (building) uses an internal time step for airflow and envelope coupling. Other components (e.g. storage tanks) have internal time steps

<sup>18</sup> User-specified tolerance controls time step and integration order

<sup>19</sup> Taking into account geometry for view factors, detailed shading, direct radiation distribution requires additional input data.

<sup>20</sup> Skylights with multiple beam reflections

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<i>Table 1 General Modeling Features</i>	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
▪ Multi-sided polygons		X	X	X	X	P			X	X	X <sup>21</sup>		X	X	X			X		
Import building geometry from CAD programs		X <sup>22</sup>	P		X		X <sup>22</sup>		X	X	X	P <sup>23</sup>		X <sup>24</sup>	X	X <sup>25</sup>		X	X	X <sup>26</sup>
Export building geometry to CAD programs					X				X <sup>22</sup>		X <sup>27</sup>				X			X	X <sup>28</sup>	
Import/export model to other simulation programs					X				X <sup>29</sup>		X <sup>30</sup>									
Number of surfaces, zones, systems, and equipment unlimited		X <sup>31</sup>	X		X				X	X <sup>32</sup>	X <sup>33</sup>	X <sup>34</sup>	X <sup>35</sup>	X	X	X		X	X	X <sup>36</sup>
Simple building models for HVAC system simulation									X	X	X			X					X	X
▪ Import calculated or measured loads			E		<sup>3</sup>				X	X	X			X					X	X
▪ Simple models (single lumped capacitance per zone)						X					X									XO <sup>37</sup>

<sup>21</sup> Up to 24 edges per polygon. Polygons also used to describe internal mass within zones.

<sup>22</sup> DXF

<sup>23</sup> CAD import via gbXML under development

<sup>24</sup> IFC 1.51, 2.0 and 2.x2

<sup>25</sup> Has its own OpenGL-based CAD interface. Sun path animation and shading effects can be visualized for a building complex.

<sup>26</sup> Through an optional program, SIMCAD, a CAD program with an interface to TRNSYS

<sup>27</sup> DXF, MicroGDS, THINGS, VRML

<sup>28</sup> XML

<sup>29</sup> Convert DOE-2.1E, BLAST geometry, load information only.

<sup>30</sup> Export to EnergyPlus, TSBI3, Radiance. Import from ECOTECT.

<sup>31</sup> Only one physical system of each type per zone, except for heating systems and window connected systems.

<sup>32</sup> 4096 spaces; 8192 exterior/interior/ground walls, windows, and material/constructions; 2048 air-side HVAC

<sup>33</sup> Fixed number (typically 62 surfaces per zone and 1000 surfaces per model, 99 flow nodes and components, and 50 zones) but can be recompiled with more.

<sup>34</sup> Unlimited wall, roof, window, door assemblies, 2500 spaces, 20000 wall surfaces, 10000 roof surfaces, 25000 zones, 250 airside HVAC, 100 plants.

<sup>35</sup> Maximum of 25 windows/doors/orientation types, orthogonal walls/roof/floor

<sup>36</sup> Default is 999 zones, 1000 components. TRNSYS can be recompiled with more

<sup>37</sup> Some components are part of the optional TESS libraries

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 2 Zone Loads</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	T <sub>as</sub>	TRACE	TRNSYS
Heat balance calculation <sup>38</sup>	X	X	X	X <sup>39</sup>	<sup>3</sup>	X			X	X <sup>39</sup>	X		X	X	X	X	X	X	X	X
Building material moisture adsorption/desorption <sup>40</sup>	X <sup>41</sup>	X			<sup>3</sup>				X		X			O	X	X <sup>42</sup>		X	P	X <sup>43</sup>
Element conduction solution method																				
▪ Frequency domain (admittance method)					X <sup>3</sup>								X	X	X					
▪ Time response factor (transfer functions)	X		X	X	<sup>3</sup>	X			X	X		X						X	X	X
▪ Finite difference / volume method								X			X			X	X <sup>44</sup>	X	X			
Interior surface convection																				
▪ Dependent on temperature	X	X			<sup>3</sup>				X		X <sup>45</sup>		X	X	X	X	X	X		X
▪ Dependent on air flow	X						P		P		X		X		X			X		E
▪ Dependent on CFD-based surface heat coefficient									E		E				X					
▪ User-defined coefficients <sup>46</sup>		X	X	X <sup>47</sup>	X				X		E <sup>48</sup>		X	R	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
Human thermal comfort <sup>49</sup>																				
▪ Fanger	X		X		X				X		X			X	X	X		X		X
▪ Kansas State University	X								X						X					
▪ Pierce two-node	X								X											
▪ MRT (Mean Radiant Temperature)	X				X	X			X		X <sup>50</sup>			X	X	X		X		X
▪ Radiant discomfort <sup>51</sup>											X			X	X			X		
▪ Simultaneous CFD solution									E		E <sup>52</sup>					P				
▪ PAQ (Perceived Air Quality) <sup>53</sup>		X	P																	

<sup>38</sup> Simultaneous calculation of radiation and convection processes each time step

<sup>39</sup> Only for calculation of custom weighting factors that are then used in the hourly calculation

<sup>40</sup> Combined building envelope heat and mass transfer

<sup>41</sup> Only in IBLAST, an unreleased, integrated simulation version of BLAST.

<sup>42</sup> Takes into account combined vapor diffusion and capillary migration using variable transport coefficients

<sup>43</sup> Simple or 2-node models.

<sup>44</sup> As option for loads calculations.

<sup>45</sup> A range of convection regimes can be specified. Heat transfer at each outside and inside face is re-evaluated at each timestep (unless specifically disabled).

<sup>46</sup> Constants, equations or correlations

<sup>47</sup> Constant coefficients only

<sup>48</sup> Includes correlations from Khalifa and Marshall (1990), Awbi and Hatton (1999), Fisher (1995), Fisher and Pedersen (1997), Alamdari and Hamilton (1983), Beausoleil-Morrison (2000).

<sup>49</sup> Based on occupant activity, inside temperature, humidity and radiation

<sup>50</sup> Either as average MRT in zone or at an internal body using explicit radiation view factors to other zone surfaces

<sup>51</sup> Explicit radiation view factors

<sup>52</sup> Occupants and small power devices can be treated as blockages and heat/humidity/CO<sub>2</sub> sources within the CFD domain.

<sup>53</sup> Simsonson, Solonvaara and Ojanen (2001)

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 2 Zone Loads</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Automatic design day sizing calculations	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
▪ Dry bulb temperature			X	X	X	X	X		X	X		X	X	X	X			X	X	
▪ Dew point temperature or relative humidity			X	X <sup>54</sup>	X <sup>3</sup>	X	X		X	X		X	X	X	X			X	X	
▪ User-specified <sup>55</sup>			X	X <sup>56</sup>	X <sup>3</sup>	X	X		X	X		X	X	X	X			X	X	X

<sup>54</sup> DOE-2 design day sequence includes humidity conditions

<sup>55</sup> User specified minimum and maximum or user-specified steady-state, steady-periodic or fully dynamic design conditions

<sup>56</sup> DOE-2 allows user-specified design-day maximum and minimum.

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 3</b> <b>Building Envelope, Daylighting and Solar</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
<b>Solar analysis</b> <ul style="list-style-type: none"> <li>▪ Beam solar radiation reflection from outside and inside window reveals</li> <li>▪ Solar gain through blinds accounts for different transmittances for sky and ground diffuse solar</li> <li>▪ Solar gain and daylighting calculations account for inter-reflections from external building components and other buildings</li> <li>▪ Creation of optimized shading devices</li> <li>▪ Shading surface transmittance</li> <li>▪ Shading device scheduling</li> <li>▪ User-specified shading control</li> <li>▪ Bi-directional shading devices</li> <li>▪ Shading of sky IR by obstructions</li> </ul>		X	P		X <sup>3</sup>	X			X											X
			X						X						X			X		X
		P			X				X		X <sup>57</sup>				X	P		X		X <sup>58</sup>
	X			P	X		X		X	X					X			X <sup>95</sup>		
	X	X	X	P	X				X	X			X <sup>83</sup>	X	X	P	X	X	X	X
		X	X	P	X <sup>59</sup>				X				X <sup>83</sup>	X	X			X	X	X
			P		<sup>3</sup>				X		X <sup>60</sup>			X	X			X	X	X
			X	X	<sup>3</sup>	X			X	X	X <sup>61</sup>			X	X			X	X	X
<b>Insolation analysis</b> <ul style="list-style-type: none"> <li>▪ time-invariant and/or user stipulated<sup>62</sup></li> <li>▪ distribution computed at each hour<sup>64</sup></li> <li>▪ distribution computed at each timestep<sup>67</sup></li> <li>▪ Beam solar radiation passes through interior windows (double-envelope)</li> <li>▪ Track insolation losses (outside or other zones)</li> </ul>	X			P <sup>63</sup>					X	P	X		X				X			X
	X			X <sup>65</sup>						X	X									E I <sup>66</sup>
		X	P		X				X	X <sup>68</sup>				X <sup>69</sup>	X	P		X		E I <sup>66</sup>
											X				X					X

<sup>57</sup> Does not include specular reflection from obstructing bodies or diffuse shading. Insolation calculation for any shape of room and includes surfaces within the room.

<sup>58</sup> No specular reflection

<sup>59</sup> Using embedded scripting engine allows a function to be called each time-step to change shading parameters or shading masks.

<sup>60</sup> For two blind positions and daylighting accounted for in light switching for multiple sensors and circuits per thermal zone.

<sup>61</sup> Via surfaces

<sup>62</sup> User defines where direct sunlight (insolation) falls in a room, e.g., put 45% on the floor and 55% on the back wall or the application distributes insolation in the same pattern for all hours.

<sup>63</sup> Time-invariant except for sunspaces, where solar distribution is calculated hour-by-hour

<sup>64</sup> At each hour, application calculates the distribution of direct sunlight (insolation) entering via each window (at run-time or calculated and stored for retrieval at run time).

<sup>65</sup> Direct solar radiation impinging on surfaces is calculated every hour, but the obstructed fraction due to shading surfaces is calculated hour-by-hour every two weeks.

<sup>66</sup> Must be calculated outside the building model and requires additional data.

<sup>67</sup> At each timestep, application calculates the distribution of direct sunlight (insolation) entering via each window (at run-time or calculated and stored for retrieval at run time).

<sup>68</sup> For sunspaces (atriums) only, not used for double envelope buildings

<sup>69</sup> With separate add-in for double sheet facades

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 3 Building Envelope, Daylighting and Solar</b>	BLAST	B5im	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Advanced fenestration																				
▪ Controllable window blinds		X	X	X	X <sup>70</sup>		X		X	X	X		X	X	X		X	X		X
▪ Between-glass shades and blinds			X	X	X				X	X	X <sup>71</sup>			X	X			X		X
▪ Electrochromic glazing					X <sup>72</sup>				X	X	X			X	X			X		E <sup>73</sup>
▪ Thermo-chromic glazing					X				X	X	X			X	X		I			E <sup>73</sup>
▪ Datasets of window types <sup>74</sup>		P <sup>75</sup>	X	P	X <sub>3</sub>		P		X	X <sup>76</sup>	P <sup>77</sup>	X <sup>78</sup>	X <sup>79</sup>	X	X			X	P	X
▪ WINDOW 5 calculations					X <sub>3</sub>				X	X <sup>76</sup>										X
▪ WINDOW 4.1 data import	X			X <sup>76</sup>	X <sub>3</sub>				X	X <sup>76</sup>	X						X <sup>80</sup>		X	X
▪ Dirt correction factor for glass solar and visible transmittance			E	P	X				X	P				X						E <sup>73</sup>
▪ Movable storm windows			X		X <sub>3</sub>				X		X <sup>81</sup>			X	X			X		X
▪ Bi-directional shading devices			P		X <sub>3</sub>				X		X <sup>61</sup>			X	X			X	X	X
▪ Window blind model <sup>82</sup>			X		X				X	X	X <sup>60</sup>		X <sup>83</sup>	X	X			X	X	X
▪ User-specified daylighting control		X	X		X <sup>84</sup>				X		X <sup>60</sup>		X <sup>83</sup>	X	X			X	X	X
▪ Window gas fill as single gas or gas mixture			X		X				X		X			X	X			X	X	X
General Envelope Calculations																				
▪ Outside surface convection algorithm																				
o BLAST/TARP	X								X										X	
o DOE-2				X					X	X <sup>85</sup>									X	
o MoWiTT									X		X								X	
o ASHRAE simple	X					X		X	X				X		X			X	X	X

<sup>70</sup> Using embedded scripting engine allows a function to be called each time-step to change glass parameters based on analysis results.

<sup>71</sup> Multiple representations possible: as part of a construction's optical properties, as solar obstructions associated with the zone or as explicit surfaces with full treatment of convection and radiation exchange.

<sup>72</sup> With freely available electrochromic/thermo-chromic plug-in developed at Welsh School of Architecture.

<sup>73</sup> By applying a correction factor outside the building model (Type-56) or defining several windows in WINDOW 5 and switching from one to the other during simulation based on conditions or control signal.

<sup>74</sup> Conventional, reflective, low-E, gas-fill, electrochromic, and WINDOW-5 layer-by-layer custom glazing description

<sup>75</sup> Extensible window library with possibility of defining individual 3<sup>rd</sup> order polynomial transmission versus angle of incidence curves.

<sup>76</sup> Window 4 single band calculation for layer-by-layer descriptions or accepts Window 5 multiband output for composite window descriptions.

<sup>77</sup> Window 5 import only by manual editing of optical data. Frames and edge-of-glass properties modeled via explicit surfaces.

<sup>78</sup> Configuration of window glazing and window assembly defined; performance calculations based on Window 4.

<sup>79</sup> Checklist with 11 glazing types and two frame types, or advanced numerical data input for up to 25 windows.

<sup>80</sup> Window 4.1, 5.1 and 5.2 data import capabilities

<sup>81</sup> Via general facility for substituting construction's thermophysical and optical properties during simulation.

<sup>82</sup> Slat-type shading devices such as Venetian blinds coupled to daylighting, with movable slats and associated slat-angle controls

<sup>83</sup> Intelligent controller manages operable exterior or interior window shades for passive heating/cooling/daylighting

<sup>84</sup> Using embedded scripting engine allows a function to be called each time-step to change shading parameters or shading masks.

<sup>85</sup> Uses combined MoWiTT, TARP and ASHRAE formulations for various portions

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 3</b> <b>Building Envelope, Daylighting and Solar</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
<ul style="list-style-type: none"> <li>○ Ito, Kimura, and Oka (1972) correlation</li> <li>○ User-selectable</li> <li>▪ Inside radiation view factors</li> <li>▪ Radiation-to-air component separate from detailed convection (exterior)</li> <li>▪ Air emissivity/radiation coupling</li> </ul>		X	X		<sup>3</sup>				X <sup>86</sup>	X	X			X	X	X		P	X	X
<ul style="list-style-type: none"> <li>▪ Air emissivity/radiation coupling</li> </ul>		X	X		<sup>3</sup>				X	X	X			X	X		X	X	P	X
Sky model <ul style="list-style-type: none"> <li>▪ Isotropic<sup>87</sup></li> <li>▪ Anisotropic<sup>89</sup></li> <li>▪ User-selectable</li> </ul>	X	X	X	X	X	X	X	X	X	X	X	X <sup>88</sup> X <sup>90</sup>	X	X	X	X	X	X	X	X
Daylighting illumination and controls <ul style="list-style-type: none"> <li>▪ Interior illumination from windows and skylights</li> <li>▪ Stepped or dimming electric lighting controls<sup>93</sup></li> <li>▪ Glare simulation and control</li> <li>▪ Geometrically and optically complex fenestration systems using bidirectional transmittance</li> <li>▪ Radiosity interior light interreflection calculation</li> <li>▪ Daylight illuminance maps</li> <li>▪ Daylighting shelves</li> <li>▪ Tubular daylighting devices<sup>97</sup></li> </ul>		X	X	X	X <sup>3</sup>	X		X <sup>92</sup>	X	X	X		X	X	X			X	X	X
		X		X	P <sup>3</sup>			X	X	X	X <sup>94</sup>		X	X	X			X	X	X
		X		X	<sup>3</sup>				X	X	X <sup>94</sup>			X	X			X <sup>95</sup>	X	X
		X		X	X <sup>3</sup>	X			X	X	X <sup>96</sup>			X	X			X <sup>95</sup>	X	X
		X		X	X <sup>3</sup>	X			X	X	X <sup>96</sup>			X	X			X <sup>95</sup>	X	X
Movable/transparent insulation	X	X	P	X	<sup>3</sup>				X		X		X <sup>98</sup>	X	X		P			X
Zone surface temperatures <sup>99</sup>	X	X	E	P <sup>100</sup>	X	X			X	X <sup>101</sup>	X <sup>102</sup>			X	X	X	X	X	X	X

<sup>86</sup> Can specify different correlations by surface type (e.g. all exterior windows)

<sup>87</sup> Uniform solar radiation and illumination distribution

<sup>88</sup> For energy simulation calculations

<sup>89</sup> Sky radiance, diffuse solar radiation and illumination vary with sun position

<sup>90</sup> For design day calculations

<sup>91</sup> ASHRAE, Perez and Kondratjev

<sup>92</sup> LBNL split-flux daylighting model

<sup>93</sup> Including heating and cooling effects

<sup>94</sup> Through a link with Radiance

<sup>95</sup> Through a link with Lumen Designer

<sup>96</sup> Resolution can be increased via use of Radiance to define shelf properties and light sensor characteristics. Tubular devices require combined Radiance & surfaces description.

<sup>97</sup> Including illuminance, solar gain, thermal resistance

<sup>98</sup> Automatic operable night time window insulation

<sup>99</sup> Wall, window, door, floor, ceiling, roof

<sup>100</sup> Reverse calculation from heat flows (module added by EMPA)

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 3</b> <b>Building Envelope, Daylighting and Solar</b>	BLAST	B5im	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Airflow windows					X				X		X <sup>103</sup>			O	X	X	X	X		X
Surface conduction																				
▪ 1-dimension	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ 2- and 3-dimension			P						X		R I			O						
Ground heat transfer																				
▪ ASHRAE simple method <sup>104</sup>																				
▪ 1-dimension	P	X	X	P	X <sub>3</sub>	X	X	X	X	X	X	X	X	X	X	X	X	X	P	X
▪ 2- and 3-dimension slabs									X <sup>106</sup>		R			O		O <sup>107</sup>	R			O <sup>105</sup>
▪ 2- and 3-dimension basements			P						X		R			O		O <sup>107</sup>	R			O <sup>105</sup>
Variable thermophysical properties					X						I			X		X				
Phase change materials			O								I			O		R	X			E
Building integrated photovoltaic system accounts for heat removed from surfaces layers which have defined electrical characteristics		X							X	X	X					P				E

<sup>101</sup> User selectable in some versions

<sup>102</sup> Also temperatures within constructions as well as full energy balance at each surface.

<sup>103</sup> As an additional zone with flow network or CFD domain

<sup>104</sup> ASHRAE (2001a)

<sup>105</sup> Through additional component (optional TESS libraries)

<sup>106</sup> 2-D and 3-D ground calculations for basements and slabs using auxiliary programs.

<sup>107</sup> Through a link with the Solum software (Santos et al. 2003)

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 4 Infiltration, Ventilation, Room Air and Multizone Airflow</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	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	X
Automatic calculation of wind pressure coefficients		X	P		<sup>3</sup>				P <sup>108</sup>						X		X	X			
Natural ventilation <sup>109</sup>		X	P		<sup>3</sup>				X	P <sup>110</sup>	X			X	X	X	X	X		O <sup>111</sup>	
Hybrid natural and mechanical ventilation		X	P			X					I			X	X	X		X		O <sup>111</sup>	
Window opening for natural ventilation controllable <sup>112</sup>			X <sup>113</sup>			X			X		X				X <sup>114</sup>	P	X	X		O <sup>111</sup>	
Multizone airflow (via pressure network model)		X	P		<sup>3</sup>				X		X			X	X		X	X		O <sup>111</sup>	
Displacement ventilation					<sup>3</sup>				X <sup>115</sup>		X <sup>116</sup>			X	X			X		O <sup>117</sup>	
Mix of flow networks and CFD domains			X								E										
Contaminants, mycotoxins (mold growth)		P									R <sup>118</sup>					P					

<sup>108</sup> Look-up table for single pressure coefficients per façade as per ASHRAE HOF; more detailed calculation developed by Mario Grosso not yet implemented, will still work only on simple geometries, i.e., rectangular blocks.

<sup>109</sup> Pressure, buoyancy driven

<sup>110</sup> Simple schedulable operable windows model

<sup>111</sup> Available as 3 options: CONTAM or COMIS engines can be used in separate components. The COMIS engine is also integrated to the building model in an optional package (TRNFlow)

<sup>112</sup> Based on zone or external conditions

<sup>113</sup> Air flow rate range should be defined in advance

<sup>114</sup> Simulation variables that can be used to control include same zone, other building zone, CO<sub>2</sub> concentration, external conditions (temperature, wind speed, wind direction)

<sup>115</sup> Mundt and UCSD models, automatically subdivides zones

<sup>116</sup> Via CFD or by subdividing zones

<sup>117</sup> In TRNFlow, with zone subdivision

<sup>118</sup> Multiple contaminants and sources and sinks for models with air flow networks. Microtoxin requires high resolution model and construction attributes

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<i>Table 5 Renewable Energy Systems</i>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	T <sub>as</sub>	TRACE	TRNSYS
Trombe wall	X	X <sup>119</sup>	P	X	X				X	X	X <sup>120</sup>			X <sup>120</sup>	X		X	X		X
Rock bin thermal storage											X <sup>120</sup>						X			X
Solar thermal collectors																				
▪ Glazed flat plate			X		X			X <sup>121</sup>	X		X				X	P		X		X
▪ Unglazed flat plate (heating and cooling)					X						X									X
▪ Evacuated tube			P																	X
▪ Unglazed transpired solar collector					3				X											O <sup>122</sup>
▪ High temperature concentrating collectors <sup>123</sup>																				X
User-configured solar systems <sup>124</sup>																				X
Integral collector storage systems																				X
Photovoltaic power		X			X			X <sup>125</sup>	X	X	X				X					X
Hydrogen systems <sup>126</sup>											X									X
Wind power											X									X

<sup>119</sup> Modeled as a separate zone

<sup>120</sup> Via extra zones and flow network

<sup>121</sup> Uses generalized collector efficiency curve where parameters can be selected to estimate devices ranging from unglazed flat plate to evacuated tube.

<sup>122</sup> Additional component in TRNLIB, the free add-on library

<sup>123</sup> For power generation

<sup>124</sup> Can include complex arrangement of storage tanks

<sup>125</sup> Photovoltaic power modeled in Energy-10 version 1.8 using EnergyPlus

<sup>126</sup> Fuel cells, storage, electrolyzers

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 6 Electrical Systems and Equipment</b>	BLAST	B <sup>3</sup> Sim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	T <sub>as</sub>	TRACE	TRNSYS
Renewable power (see Table 5 for details)		P			<sup>3</sup>			X	X	X	X									X
Electric load distribution and management																				
▪ On-site generation and utility electricity management including demand	X			X	P <sup>3</sup>				X	X	X					X			X	X
▪ Renewable components <sup>127</sup>											P									X
Power generators																				
▪ Internal combustion engine generator	X			X					X	X	X <sup>128</sup>								X	X
▪ Combustion turbine	X			X					X	X									X	O <sup>129</sup>
▪ Microgeneration <sup>130</sup> integrated with thermal simulation					P			X	P		X <sup>132</sup>									X
Grid connection					P <sup>3</sup>				X		X <sup>132</sup>									X
Electric conductors <sup>131</sup>											X <sup>132</sup>				X					P <sup>133</sup>
Building power loads <sup>134</sup>	X		X	X	X		X	X	X	X	X <sup>132</sup>	X		X	X	X		X		X

<sup>127</sup> Batteries, charge controllers, power-point trackers

<sup>128</sup> Combined heat and power and grid

<sup>129</sup> Part of the optional TESS libraries

<sup>130</sup> Fuel cells, photovoltaic (crystalline amorphous), and internal combustion engine combined heat and power

<sup>131</sup> DC, AC, 1/2/3-phase and mixed AC/DC cables/ transformers, inverters, generators, renewable sources

<sup>132</sup> General electrical network approach with solution of multi-phase power. Works at a similar timestep to that of the detailed plant system. Control can be applied to the individual loads and power sources. Electrical components can be connected together to define an electrical distribution network which is fully integrated with the thermal model of building and HVAC. All types of power distribution system can be simulated: single and multi-phase AC, DC and mixed AC/DC systems. Where appropriate the power simulation is integrated with the thermal solution for example, PV modules embedded in a façade and feeding into the building power supply. The solution of the distribution model yields, for all components: real and reactive power flows, power losses, current magnitudes and phase, voltage magnitudes and phase, phase loadings. Additionally grid import/export power flows can be calculated for systems connected to the grid. The facility assumes a general knowledge of power systems engineering.

<sup>133</sup> Power converters and bus bar (no explicit 3-phase current or line model)

<sup>134</sup> Computer equipment, process equipment, process loads, lighting, fans, pumps

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 7 HVAC Systems</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	T <sub>as</sub>	TRACE	TRNSYS
Discrete HVAC components <sup>135</sup>			X				P		X		X			X	X	R	R	X		X
Idealized HVAC systems	X		X		X	X			X		X <sup>136</sup>			X	X		X			X <sup>137</sup>
User-configurable HVAC systems		X	X				P		X	X	X <sup>138</sup>	X <sup>139</sup>	X	X	X	X	R	X	X	X
Air loops <sup>140</sup>			X				P		X	P	X	X		X	X	X	R	X	X	X
Fluid loops <sup>141</sup>			X				P		X	X	X	X		X	X	P	R	X	X	X
Run-around, primary and secondary fluid loops with independent pumps and controls			X						P	X	X	X		X		P		X	X	X <sup>142</sup>
Fluid loop pumping power <sup>143</sup>										X	X <sup>144</sup>	X		X						X
Pipe flow-pressure networks <sup>145</sup>											X			X						
Air distribution system <sup>146</sup>						X	P		X	X	X <sup>147</sup>	X	X	X	X		R			X
Multiple supply air plenums			P						X	P	X <sup>147</sup>				X					X
Simplified demand-controlled ventilation																				
▪ Ventilation rate per occupant and floor area			X			X			X	X			X	X <sup>148</sup>	X	X		X	P	X
▪ Ventilation air flow schedule		X	X			X			X	X	X		X <sup>149</sup>	X	X	X	X	X	X	X
▪ User-defined ventilation control strategy <sup>150</sup>		X <sup>151</sup>	X							X	X			X	X			X		X
CO <sub>2</sub> modeling																				
▪ CO <sub>2</sub> zone concentrations, mechanical and natural											X	X		X	X					O <sup>111</sup>

<sup>135</sup> Including part-load performance

<sup>136</sup> ESP-r users tend to use ideal zone controls to represent environmental controls as loops of sensors and actuators with a range of controls laws. These can be combined with flow networks to represent air distribution systems if increased resolution is needed. For projects where detailed component performance is required a network of detailed systems components can be defined.

<sup>137</sup> The multizone building model (Type 56) can optionally calculate the load from the temperature and humidity setpoints. A maximum power can be set and if that maximum is reached the model calculates the actual zone temperature

<sup>138</sup> See Table 14 for a general discussion of how ESP-r approaches detailed system components and for a list of component types.

<sup>139</sup> User selects a basic airside or waterside system type and then configures components permitted for that type of air loop or water loop.

<sup>140</sup> Connect fans, coils, mixing boxes, zones

<sup>141</sup> Hot water, chilled water and condenser loops connect equipment

<sup>142</sup> By combining available components

<sup>143</sup> Based on flow and pressure with 2/3-way valves with static head

<sup>144</sup> Static head not supported.

<sup>145</sup> Arbitrary structure with valves, pumps and controls

<sup>146</sup> Including conduction losses and air leakage

<sup>147</sup> Via plant components and/or flow network

<sup>148</sup> Via CO<sub>2</sub> based control

<sup>149</sup> Intelligent controller manages night flushing and daytime economizer for passive cooling

<sup>150</sup> Any combination of feed-forward/feed-back controllers

<sup>151</sup> CO<sub>2</sub> controlled ventilation rates

**Contrasting the Capabilities of Building Energy Performance Simulation Programs**

<b>Table 7 HVAC Systems</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS	
air path transport																					
▪ CO <sub>2</sub> based demand-controlled ventilation		X <sup>152</sup>									X	X		X	X					P	EO <sub>111</sub>
Automatic sizing																					
▪ HVAC components		P	X	X		X	X	X	X	X		X	X	X <sup>153</sup>	X	P	R	X	X	X	P <sup>154</sup>
▪ Air loop flow, outside air, zone airflow		X	P			X			X			X		X	X			X	X	X	P
▪ Hot, cold, and condenser water loops			P						X	X		X <sup>155</sup>		X	X			X	X	X	P
Zonal air distribution unit											I <sup>156</sup>										OI <sub>157</sub>
▪ Constant volume reheat	X	X	X	X		X	X		X	X	X	X		X	X	X		X	X	X	
▪ Constant volume 4-pipe induction	X		X				P		X		X	X		X	X					X	
▪ Variable air volume reheat	X	X	X	X			X		X	X	X	X		X	X			X	X	X	
▪ Variable air volume no reheat	X	X	X	X		X	X		X	X	X	X		X	X			X	X	X	
▪ Variable air volume reheat/variable speed fan (UFAD)		X	X				P		X		R				X			X	X	X	
▪ Powered induction unit																					
o Series PIU reheat				X			P		X	X		X		X						X	
o Parallel PIU reheat				X					X	X		X		X						X	
▪ Dual duct constant volume	X	X		X		X	P		X	X	X	X		X	X					X	
▪ Dual duct variable air volume	X	X		X			P		X	X	X	X		X	X					X	
Zone forced air unit											I <sup>156</sup>										
▪ Fan coil (2 pipe)	X		X				P				X	X								P	O <sup>158</sup>
▪ Fan coil (4 pipe)	X	X	X	X		X	P		X	X	X	X		X	X			X	X	X	O <sup>158</sup>
▪ Unit heater <sup>159</sup>	X		X	X		X		X	X	X	X	X		X	X	X		X	X	X	O <sup>158</sup>
▪ Unit ventilator <sup>160</sup>	X		P	X		X		X	X	X	X	X		X	X	X		X	X	X	O <sup>158</sup>
▪ Window air-conditioner (cycling)			X	X		X	P	X	X	X		X	X	X	X	X		X	X	X	O <sup>158</sup>
▪ Energy recovery ventilator (stand-alone)								X	X	X		X		X	X			X	X	X	O <sup>158</sup>

<sup>152</sup> Detailed demand controlled ventilation with CO<sub>2</sub> mass balance and CO<sub>2</sub> sensor control

<sup>153</sup> Via unlimited capacity components

<sup>154</sup> The total power

<sup>155</sup> Hot and cold water loops

<sup>156</sup> Combinations of detailed system components and/or flow networks can be used to define a range of HVAC designs. Also see component descriptions in Table 14.

<sup>157</sup> Combinations of detailed system components, most of which are available in the optional TESS libraries

<sup>158</sup> Through additional components or combinations of components that are part of the additional TESS libraries

<sup>159</sup> Water, gas or electric heating coil

<sup>160</sup> Water, gas or electric heating coil, water cooling coil

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<i>Table 7 HVAC Systems</i>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Unitary equipment																				
▪ DX system																				
○ Heating/cooling coils	X	X	X	X		X	P	X	X	X	X	X	X		X	X	R	X	X	X
○ Coil latent capacity degradation <sup>161</sup>									X	X	X				X					X
▪ Furnace <sup>162</sup>	X		X	X		X	X	X	X	X	R	X	X		X		R	X	X	X
▪ Air-to-air packaged heat pump	X	X	X	X		X	P	X	X	X	R	X	X		X	X	R	X	X	X
▪ Water-to-air packaged heat pump	X		X	X		X	P		X	X	R	X			X		R	X	X	X

<sup>161</sup> At part load (cycling) conditions

<sup>162</sup> Gas or electric heating coil, DX cooling coil

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<i>Table 8 HVAC Equipment</i>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Coils											1 <sup>156</sup>									
▪ Water heating coil	X	X	X	X		X	X		X	X	X	X		X	X	P	R	X	X	X
▪ Electric heating coil	X	X	X	X		X	X	X	X	X	X	X		R	X	X	R	X	X	X
▪ Gas heating coil	X			X		X	X		X	X	X	X			X	P	R	X	X	X
▪ Water cooling coil	X	X	X	X		X	X		X	X	X	X		X	X	X	R	X	X	X
▪ Detailed fin/tube water cooling coil	X <sup>163</sup>								X		X			X		X				X
▪ DX coil																				O <sup>158</sup>
o Bypass factor cooling empirical	X								X			X			X <sup>164</sup>					
o Multispeed cooling empirical	X								X						164					
o Heating empirical	X								X						164					
o Coil frost control									X	X	X	X			164				X	
▪ Water-to-air heat pump <sup>165</sup>	X		X	X			P		I	X		X			X			X	X	X
Radiative/convective unit											X <sup>166</sup>									
▪ Baseboard (electric)	X	X		X		X		X	X	X	X	X	X	X	X	X	X		X	O <sup>158</sup>
▪ Baseboard (hydronic)	X	X				X			X	X	X	X	X	X	X		R		X	
▪ Low temperature radiant																				
o Hydronic <sup>167</sup>	X <sup>163</sup>	X							X		X <sup>168</sup>			X	X					X
o Electric <sup>169</sup>	X <sup>163</sup>	X							X		X <sup>168</sup>			X	X					X <sup>168</sup>
▪ High temperature radiant (gas, electric)	X			P					X		X <sup>168</sup>			X <sup>170</sup>	X					X
Desiccant dehumidifier (solid)				X			P		X	X									X	X
Humidifier							P													
▪ Steam (electric)	X	X	X						X		X	X		X	X	X		X	X	O <sup>158</sup>
▪ Humidifier water consumption		X	X						X		X			X	X	X			X	O <sup>158</sup>
Humidity control <sup>171</sup>																				
▪ Cooling coils in combination with air-to-air heat exchanger for improved dehumidification performance		X							X		X			X	X	X			X	X

<sup>163</sup> Only in IBLAST, an unreleased, integrated simulation version of BLAST.

<sup>164</sup> Generic coil

<sup>165</sup> Reciprocating, rotary or scroll compressor, heating or cooling

<sup>166</sup> Various representations: as an ideal zone controller or via detailed plant components.

<sup>167</sup> Heating or cooling, floor, slab, wall, ceiling

<sup>168</sup> Via system components or heat injected into surfaces

<sup>169</sup> Floor, slab, wall, ceiling

<sup>170</sup> Electric

<sup>171</sup> Chilled water or DX cooling coils

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<i>Table 8 HVAC Equipment</i>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
▪ High humidity control (DX or chilled water coils)	X	X		X		X			X	X	X	X		X	X	X			X	X
Fans																				
▪ Constant volume	X	X	X	X		X	X	X	X	X	X	X		X	X	X	P	X	X	X
▪ Variable volume	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	R	X	X	X
▪ Exhaust	X	X	X	X					X	X	X	X	X	X	X	X		X	X	X
Pumps																				
▪ Constant speed	X		X	X		X	P		X	X	X	X		X	X	X	R	X	X	X
▪ Variable speed	X		X	X			P		X	X	X	X		X	X	P	R	X	X	X
▪ Multi-stage										X	X			X					P	X <sup>172</sup>
▪ Direct-couple to power source											X									O <sup>158</sup>
Heat exchangers <sup>173</sup>																				
▪ Plate frame									P	X	X			X					X	X
▪ Immersed coil											X			X						X
▪ Shell and tube											X			X						X
▪ User-defined effectiveness										X	X			X						X
Plant cooling equipment																				
▪ Electric chiller											X <sup>174</sup>									
o Centrifugal	X		X	X		X	P		X	X		X		O	X <sup>175</sup>	X			X	O <sup>158</sup>
o Centrifugal with VSD				X <sup>176</sup>					X <sup>177</sup>	X		X			<sup>175</sup>				X	O <sup>158</sup>
o Reciprocating	X		X			X	P		X	X		X		O	<sup>175</sup>				X	O <sup>158</sup>
o Double-bundle condenser/heat recovery	X		X	X			P		X	X					<sup>175</sup>				X	O <sup>158</sup>
o Screw			X	X <sup>178</sup>			P		X <sup>179</sup>	X		X		O	<sup>175</sup>				X	O <sup>158</sup>
o Scroll			X							X		X			<sup>175</sup>				X	O <sup>158</sup>
o Constant COP	X	X	X			X	P	X	X	X				X	<sup>175</sup>			X	X	O <sup>158</sup>
▪ Engine-driven chiller <sup>180</sup>	X		X	X			P		X			X			<sup>175</sup>				X	O <sup>158</sup>
▪ Combustion turbine chiller <sup>181</sup>	X		X				P		X			P			<sup>175</sup>				X	O <sup>158</sup>

<sup>172</sup> Through appropriate controller

<sup>173</sup> Various flow configurations

<sup>174</sup> Generic chiller representation.

<sup>175</sup> User can specify curves of chiller performance

<sup>176</sup> User can simulate VSD by substituting curves for centrifugal chiller.

<sup>177</sup> User can enter curves for VSD centrifugal chiller.

<sup>178</sup> User can replace compression chiller curves with curves for screw chiller.

<sup>179</sup> User can enter curves for screw chiller and use Chiller:Electric:EIR.

<sup>180</sup> Gas, diesel, gasoline, fuel oil

<sup>181</sup> With/without heat recovery, gas, diesel, gasoline, fuel oil



## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 8 HVAC Equipment</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
<ul style="list-style-type: none"> <li>▪ Water heater<sup>186</sup></li> <li>▪ Ground source water-to-water heat pump</li> </ul>	X		P	P		X		X <sup>188</sup>	X	X	I			X	X <sup>187</sup>			X	X	X
Air-to-air energy recovery																				
<ul style="list-style-type: none"> <li>▪ Generic sensible heat exchanger</li> <li>▪ Flat plate sensible heat exchanger</li> <li>▪ Sensible and latent energy exchanger</li> </ul>	X	X	X	P		P			X	X	X	X		X	X			X	X	X
<ul style="list-style-type: none"> <li>▪ Domestic/service water heating</li> <li>▪ User-configurable water piping network</li> <li>▪ Domestic/service water heater<sup>189</sup></li> <li>▪ D/SHW water consumption</li> <li>▪ Stratified water heater tank</li> <li>▪ Combi-tanks for space and water heating<sup>191</sup></li> </ul>	X			X		X		X	X	X	R			X	X		R	X	X	X
<ul style="list-style-type: none"> <li>▪ Controls, thermostats and strategies</li> <li>▪ Humidistat</li> <li>▪ Zone thermostat<sup>193</sup></li> <li>▪ Zone supply air setpoint<sup>194</sup></li> <li>▪ Outside air control<sup>196</sup></li> <li>▪ System availability<sup>197</sup></li> <li>▪ Plant heating/cooling load control for staging and sequencing plant equipment</li> <li>▪ Condenser control<sup>199</sup></li> <li>▪ Nighttime flushing for passive cooling</li> <li>▪ Economizer</li> </ul>	X	X	X			P	P		X		R	X		X	X	P		X	X	O <sup>158</sup>
	X	X	X	X		X	P	X	X	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X			P	X	X	X	X	X <sup>195</sup>		X	X	X			X	X
	X	X	X	P		P	P	X	X	X	X	X		X	X	P		X	X	X
	X	X	X	X		P	P	X	X	X	X	X <sup>198</sup>		X	X		R	X	X	X
	X		X	X			P		X	X		X		X	X	P		X	X	X
				X					X	X				O					X	X
				X		X			X	X	X		X	X	X		X		X	X
	X			X		X	P	X	X	X	X	X	X	X	X		X		X	X

<sup>187</sup> User can specify curves of boiler/heater performance

<sup>188</sup> Simple fixed efficiency model for ground-source heat pump

<sup>189</sup> Gas and electric

<sup>190</sup> Options include stratified water heater tank with up to 10 internal heat exchangers and 25 inlet/outlet ports, as well as multiple geometries (horizontal and vertical cylinder, rectangular cross-section, spherical)

<sup>191</sup> Multiple heat exchanger and or inlets/outlets with stratification devices

<sup>192</sup> Standard components as well as add-ons from Transsolar and components from the TESS libraries

<sup>193</sup> Single heating setpoint, single cooling setpoint, single heating/cooling setpoint, dual setpoint with deadband

<sup>194</sup> Scheduled, coldest, warmest, mixed air, outside air, minimum/maximum humidity

<sup>195</sup> Scheduled, coldest, warmest, outside air, min/max humidity

<sup>196</sup> Scheduled, outdoor dry bulb and wet bulb temperature, outdoor air flow

<sup>197</sup> Scheduled, night cycle control, differential thermostat, high/low temperature on/off

<sup>198</sup> Scheduled, high/low temperature on/off

<sup>199</sup> Uncontrolled, heating/cooling load range-based, outdoor range based (dry bulb, wet bulb, humidity, dew point), outdoor temperature difference based (dry bulb, wet bulb, dew point)

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 8 HVAC Equipment</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS	
<ul style="list-style-type: none"> <li>▪ User-defined control strategy<sup>200</sup></li> </ul>		X								X				X	X						X
Refrigeration systems for warehouse and retail food storage <ul style="list-style-type: none"> <li>▪ Refrigerant loops<sup>201</sup></li> <li>▪ Multiple staged refrigerant compressors</li> <li>▪ Refrigerated casework<sup>202</sup></li> <li>▪ Refrigerant air/evaporative condensers with heat reclaim and control</li> <li>▪ User-selectable refrigerants</li> <li>▪ Ammonia chillers and low temperature brine</li> <li>▪ Brine and refrigerant loop fan coil for coolers/freezers</li> </ul>				X					X	X						P					
Ice rink in building space <ul style="list-style-type: none"> <li>▪ Brine loop and chiller refrigeration system</li> <li>▪ Ice-to-ceiling radiative and ice-to-space air exchange</li> <li>▪ Under floor heating (with ice load)</li> <li>▪ Ice resurfacing</li> </ul> Indoor/outdoor swimming pool										X				O							O <sup>203</sup>

<sup>200</sup> Any combination of feedback/feed-forward controllers

<sup>201</sup> Connects coils, casework, compressors, condensers

<sup>202</sup> Zone interaction, frost forming refrigerant coil and controls

<sup>203</sup> Additional component from Transsolar

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<i>Table 9 Environmental Emissions</i>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Power plant energy emissions	X		P	X	<sup>3</sup>	X		X	X	X	X	X	X		X			X	X	I
On-site energy emissions	X	X	P	X	X	X		X	X	X	X	X	X		X			X	X	I
Major greenhouse gases (CO <sub>2</sub> , CO, CH <sub>4</sub> , NO <sub>x</sub> )	X	P	P	X	<sup>3</sup>	X		X	X	X	X	X <sup>204</sup>	X		X			X		
Carbon equivalent of greenhouse gases	X			X	<sup>3</sup>				X						X			X		I
Criteria pollutants (CO, NO <sub>x</sub> , SO <sub>2</sub> , PM, Pb)					<sup>3</sup>				X			X <sup>205</sup>			X					
Ozone precursors (CH <sub>4</sub> , NMVOC, NH <sub>3</sub> )					<sup>3</sup>				X											
Hazardous pollutants (Pb, Hg)					<sup>3</sup>				X											
Water use in power generation					<sup>3</sup>				X											X
High- and low-level nuclear waste					<sup>3</sup>				X											
Pollutant emissions factors <sup>206</sup>					<sup>3</sup>				X				X							

<sup>204</sup> CO<sub>2</sub>, NO<sub>x</sub>

<sup>205</sup> NO<sub>x</sub>, SO<sub>2</sub>

<sup>206</sup> State/provincial/regional/national aggregation for major fuels: electricity, natural gas, residual fuel oil, distillates, residential oil, LPG, gasoline, diesel, and coal

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 10 Climate Data Availability</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Weather data provided	X	X	X		X	X	X	X	X <sup>208</sup>	X <sup>209</sup>	X	X		X	X	P		X	X	X <sup>210</sup>
▪ With the program <sup>207</sup>		X			X	X			X <sup>208</sup>	X <sup>209</sup>	X	X		X	X			X	X	X
▪ Separately downloadable		X			X	X			X <sup>208</sup>	X <sup>209</sup>	X	X		X	X			X	X	X
Generate hourly data from monthly averages			X <sup>211</sup>		X	X									X				X	X
Estimate diffuse radiation from global radiation			X	X	<sup>3</sup>	X			X						X			X		X
Weather data processing and editing	X		X	X	X	X		X	X	X	X					X		X		X
Weather data formats directly read by program																				
▪ Any user-specified format		X <sup>214</sup>			X	X	X		X <sup>212</sup>					X <sup>213</sup>	X <sup>214</sup>	X <sup>214</sup>	X			X
▪ EnergyPlus/ESP-r <sup>215</sup>		X			X				X		X		X					X		X
▪ European Test Reference Year <sup>216</sup>		X			X				X		X		X					X		X
▪ Typical Meteorological Year <sup>217</sup>	X		X <sup>218</sup>	X	X		P		X	X	X		X		X <sup>219</sup>	X <sup>219</sup>	X		X	X
▪ Typical Meteorological Year 2 <sup>220</sup>	X			X	X	X		X <sup>221</sup>	X	X	X		X		X <sup>219</sup>	X <sup>219</sup>	X	X	X	X
▪ Solar and Wind Energy Resource Assessment <sup>222</sup>				X	X	X	P		X	X				X					X	X
▪ Weather Year for Energy Calculations 2 <sup>223</sup>			X	X	X	X	P		X	X				X					X	X
▪ Solar and Meteorological Surface Observation Network <sup>224</sup>									X											X
▪ International Weather for Energy Calculations <sup>225</sup>					X		P		X					X						X

<sup>207</sup> CD, DVD, distribution download

<sup>208</sup> Five weather files provided with EnergyPlus. More than 900 locations worldwide available for download

<sup>209</sup> Automatically downloads weather files from web site.

<sup>210</sup> More than 1000 locations worldwide including TMY2 data and Meteorism-generated data

<sup>211</sup> From daily measured data (max, min, average)

<sup>212</sup> By specifying the data format

<sup>213</sup> C source code for weather data conversion utility supplied to enable easy implementation of various formats.

<sup>214</sup> Any weather data given as hourly values in text files can be converted to the internal file format as long as it includes dry bulb temperature, two solar data, humidity parameter, wind speed, and wind direction.

<sup>215</sup> Crawley, Hand, and Lawrie (1999)

<sup>216</sup> European Commission (1985)

<sup>217</sup> NCDC (1981)

<sup>218</sup> Based on measured data

<sup>219</sup> Through an additional program, Domus weather converter, which comes with PowerDomus

<sup>220</sup> NREL (1995)

<sup>221</sup> Use of TMY2 and other text formats possible using companion WeatherMaker utility.

<sup>222</sup> swera.unep.net/swera/

<sup>223</sup> ASHRAE (1997)

<sup>224</sup> NCDC (1993)

<sup>225</sup> ASHRAE (2001b)

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<i>Table 10 Climate Data Availability</i>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
<ul style="list-style-type: none"> <li>▪ Japan AMeDAS weather data<sup>226</sup></li> <li>▪ DOE-2 text format</li> <li>▪ BLAST text format</li> <li>▪ ESP-r text format</li> <li>▪ ECOTECH WEA format</li> </ul>	X			X	X X				X X X X	X	X						X		X	X

<sup>226</sup> Akasaka et al. (2003)

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 11 Economic Evaluation</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Energy Costs																				
▪ 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 <sup>227</sup>		X	X	X	<sup>3</sup>		X		X	X		X	X	X	X	P			X	E
▪ Scheduled variation in all rate components		X	X	X	<sup>3</sup>				X	X		X	X	X	X	P		X	X	X
▪ User selectable billing dates				X	<sup>3</sup>				X	X			X			P			X	E
Life-cycle costs																				
▪ Component and equipment cost estimating			X	X	<sup>3</sup>	X		X	X	X		X <sup>228</sup>			X				X	
▪ Standard life-cycle costing <sup>229</sup>					<sup>3</sup>	X		X	X	X	P <sup>230</sup>	X		X	X					X

<sup>227</sup> Fixed charges, block charges, demand charges, ratchets

<sup>228</sup> Via companion program that integrates with HAP data.

<sup>229</sup> Including government methodologies and private-sector rates and taxes

<sup>230</sup> In ESP-r life cycle analysis includes up to 10 environmental impacts at and/or during: initial fabrication, transport to site, assembly on site, breakage during transport, maintenance on site, recycling and/or incineration and/or dumping.

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 12 Results Reporting</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA IES	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Standard reports	X		X	X	X	X	X	X	X	X	X <sup>231</sup>	X		X	X		X	X	X	X
User-defined reports	X <sup>232</sup>	X	X		X			X	X	X	X	X		X	X	X	X		P	X
User-selectable report format																				
▪ Comma-separated value					X	X		X	X	X	X				X		X		X	X
▪ Text		X	X		X				X	X	X	X	X	X	X	X	X		X	X
▪ Word												X	X	X	X			X	X	X
▪ Tab-separated value		P	X		X		X		X	X	X				X		X	X	X	X
▪ HTML		X			X				X	X	P				X			X	P	X
▪ Graph					X		X	X		X	X	X	X	X	X	X		X	P	X
▪ Statistics			X								X				X					X
Load, system, and plant variables reportable at time step with daily, monthly, and annual aggregation	X <sup>232</sup>	X	X		<sup>3</sup>	X		X	X	X	X	X	X	X	X	X		X		X
Standardized binned variable report																				
▪ Time-binned variable				P	<sup>3</sup>			X	X	X	X			X	X	X		X	P	X
▪ Variable versus variable					<sup>3</sup>				X	X	X			X	X	X		X		O <sup>158</sup>
Meters																				
▪ Energy end-uses <sup>233</sup>	X	X	X	X	<sup>3</sup>	X	X	X	X	X	X	X		X	X	X		X	X	X
▪ Peak demand	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X
▪ Peak demand period user-selectable <sup>234</sup>			X		<sup>3</sup>				X	X				X	X			X		X <sup>235</sup>
▪ Consumption by energy source	X		X	X	X	X	X	X	X	X	P	X	X	X	X	X	X	X	X	X
▪ Components user-assignable to any meter		X	X						X	X	X <sup>236</sup>			X	X			X		X
▪ Multiple levels of sub-metering		X	X		<sup>3</sup>				X	X				X	X			X		X
Auto-sizing report			X	X	<sup>3</sup>			X	X	X		X		X	X			X	X	
Automatic generation of energy balance checks <sup>237</sup>								X	X		X				X <sup>238</sup>			X		X

<sup>231</sup> Performance data is written to a binary file at four levels of detail: a summary, with zone energy balance and surface temperature added, with surface energy balance added. Flow and detailed system results are held in separate files. A results analysis module allows for any of the performance data to be graphed or reported in tables of integrated values or at each timestep. Data can also be binned, statistics produced or exported for use in third party applications.

<sup>232</sup> User reports processed by Report Writer Program

<sup>233</sup> Individual metering for lighting, heating, cooling, fan, pumps, etc.

<sup>234</sup> 15/30/60 minute fixed/moving window

<sup>235</sup> Must be a multiple of the selected time step

<sup>236</sup> ESP-r includes the concept of Integrated Performance Views, where the user defines issues of interest (such as glare or thermal comfort), locations where that interest is to be noted as well as periods of interest. A range of standard reports is generated for each of the interests and these can be viewed in a separate tool which takes into account the HCI implications of each metric of performance acquired from the assessments carried out.

<sup>237</sup> User-selected zones and surfaces (radiative, convective, conductive) at each time step

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 12 Results Reporting</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA IES	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Visual surface output (walls, windows, floors, roofs)		X	X		X		X		X	X	X		X	X	X	X		X	E	
HVAC system/flow network diagramming			P				P		X	X	X			X	X	X				
Graphical definition of simulated system							P							X	X	X		X	E	X
Plot of variables during simulation					X						X			X						X

<sup>238</sup> Zone energy balance

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 13 Validation</b>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
IEA ECBCS Annex 1 <sup>239</sup>											X									X
IEA ECBCS Annex 4 <sup>240</sup>											X									X
IEA SHC Task 8 <sup>241</sup>											X						X			X
IEA ECBCS Annex 10 <sup>242</sup>											X									X
IEA SHC Task 12																				
▪ Envelope BESTEST <sup>243</sup>	X		X	X	P		P	X <sup>244</sup>	X <sup>245</sup>		X	X <sup>246</sup>	X	X	X	X <sup>247</sup>	X	X	X <sup>248</sup>	X
▪ Empirical <sup>249</sup>		X <sup>250</sup>	X		P		P				X						X	X		X
IEA SHC Task 22																				
▪ HVAC BESTEST Volume 1 <sup>251</sup>				X					X <sup>252</sup>	X	X <sup>253</sup>			X					X <sup>248</sup>	X
▪ HVAC BESTEST Volume 2 <sup>254</sup>				X					X		X			X					X	X
▪ Furnace BESTEST <sup>255</sup>									X		X									
▪ RADTEST <sup>256</sup>				X							X			X						X
IEA ECBCS Annex 41 Moisture																X <sup>257</sup>				
HERS BESTEST <sup>258</sup>	X			X	P								X				X			
ASHRAE 1052-RP <sup>259</sup>	X			X					X											

<sup>239</sup> Oscar Faber and Partners (1980), US Department of Energy (1981)

<sup>240</sup> Glasgow Commercial Building Monitoring Project, 1984, as reported by Strachan (2000)

<sup>241</sup> Bloomfield (1989)

<sup>242</sup> Lebrun and Liebecq (1988)

<sup>243</sup> Judkoff and Neymark (1995a), also ANSI/ASHRAE Standard 140 (2001c)

<sup>244</sup> Testing done for CNE, the calculation engine for Energy-10, with results reported by Deru (1997)

<sup>245</sup> Henninger and Witte (2004a)

<sup>246</sup> Per ASHRAE Standard 140-2001

<sup>247</sup> Thermal Systems Laboratory (2004)

<sup>248</sup> [www.trane.com/commercial/software/Trace/BestTest.asp?pid=TRACE](http://www.trane.com/commercial/software/Trace/BestTest.asp?pid=TRACE)

<sup>249</sup> Lomas et al. (1994)

<sup>250</sup> The core of the simulation engine (tsbi3) was validated

<sup>251</sup> Neymark and Judkoff (2002), also ANSI/ASHRAE Standard 140 (2004)

<sup>252</sup> Henninger and Witte (2004b)

<sup>253</sup> Testing done for HOT3000 for which ESP-r is the underlying calculation engine [(Purdy and Beausoleil-Morrison(2003)]

<sup>254</sup> Neymark and Judkoff (2004)

<sup>255</sup> Purdy and Beausoleil-Morrison (2003)

<sup>256</sup> Achermann and Zweifel (2003)

<sup>257</sup> Comparison of whole-building hygrothermal simulation models

<sup>258</sup> Judkoff and Neymark (1995b)

<sup>259</sup> Spittler, Rees, and Xiao (2001)

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<i>Table 13 Validation</i>	BLAST	BSim	DeST	DOE-2.1E	ECOTECH	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
BEPAC Conduction Tests <sup>260</sup>									X		X									
BRE/EDF validation project <sup>261</sup>											X									
PASSYS project <sup>262</sup>											X									
CIBSE TM33 <sup>263</sup>					P						X				X <sup>264</sup>			X		
ISO 13791 <sup>265</sup>					P						X							X		
Other						X <sup>266</sup>														

<sup>260</sup> Bland (1993)

<sup>261</sup> Bloomfield et al. (1995)

<sup>262</sup> Jensen (1993)

<sup>263</sup> Macdonald, Strachan and Hand (2004)

<sup>264</sup> Study complete subject to revisions being made by CIBSE

<sup>265</sup> ISO TC 163/SC 2 (2004)

<sup>266</sup> Soebarto (1997)

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

**Table 14**  
***User Interface, Links to Other Programs, and Availability***

BLAST	<p>HBLC (Heat Balance Loads Calculator) is a Windows-based graphical interface for producing BLAST input files. HBLC allows the user to visualize the building model as it is developed and modify previously created input files. Within HBLC, each story of the building is represented as a floor plan that may contain several separate zones. Online helps provide valuable on-the-spot assistance that will benefit both new and experienced users. HBLC is an excellent tool which makes the process of developing BLAST input files much more intuitive and efficient.</p> <p>The BLAST data library contains selected schedules and room temperature control strategies, all materials and wall, roof, and floor sections found in the 1977 ASHRAE Handbook of Fundamentals are in the BLAST library; entry names are keyed to the tables in the ASHRAE handbook.</p> <p>The Weather Information File Encoder (WIFE) program is utilized to process raw weather data into a format that can be read by the BLAST program. WIFE can automatically read several standard weather data tapes (TDF-14, TMY, TRY, SOLMET, SOLAR Z80, ETAC-DATSAV) and allows any other type of weather data tape to be processed by means of a user-written routine.</p> <p>The Weather File Reporting Program has been developed to read processed BLAST weather files. The standard report produced by the Weather File Reporting Program shows monthly and daily averages as well as design temperatures.</p> <p>The Chiller program takes typical manufacturer's catalog data, convert it into the chiller parameters used in the EQUIPMENT PERFORMANCE PARAMETERS section of BLAST, and then test these parameters over a range of cooling loads and condenser temperatures.</p> <p>The Report Writer program is designed to be used in conjunction with output from the BLAST program. Its main function is to process hourly BLAST output into a form which can be manipulated in a spreadsheet environment. Report Writer has the ability to produce files which can be read directly into LOTUS and EXCEL. The user can then use these programs to manipulate the output, create reports and graphs, etc. Report Writer is also able to perform simple data reduction functions on output sets such as cut, slice, average, maximum, minimum, and frequency tabulation.</p> <p>In an annual BLAST simulation, with the Annual Comfort Report and a thermal comfort model, can be run to produce an hour-by-hour thermal comfort output file. The COMFORT program sorts all of the hourly data into thermal comfort "bins." This report is very useful in quickly determining if comfort conditions are being maintained within each zone during occupied hours.</p> <p>Program available from the Building System Laboratory at the University of Illinois at <a href="http://www.bso.uiuc.edu">www.bso.uiuc.edu</a>. Source code available for user reference.</p>
BSim	<p>SimView is the graphic user interface of several applications included in the program package and the graphic model editor. SimView is used for creating and defining properties of the building such as geometry, constructions, materials and systems.</p> <p>The model is shown simultaneously as a 3D drawing, a floor plan and two sections. Moreover, a hierarchical tree structure is shown on the left of the display, allowing the user to access and edit individual parts of the building model.</p> <ul style="list-style-type: none"> <li>• Models made in BSim can be exported (geometry and surface properties) to Radiance for advanced light simulation and visualization.</li> <li>• Geometry and surface heat fluxes can be exported as text files as input and start conditions for CFD programs.</li> <li>• Geometry and surface properties can be exported for visualizations in DirectX compatible visualization tools.</li> <li>• Envelope properties can be exported to the Danish building code compliance checker Bv98.</li> <li>• CAD drawings saved in DXF format can be imported as basis for making a building geometry in BSim.</li> <li>• Weather data in EnergyPlus format can automatically be converted to the binary format used by BSim.</li> <li>• Graphical and tabular outputs from BSim can directly be imported in any MS-Windows compatible tool.</li> <li>• 3D solar can create input files for BSim and execute simulations as macro controlled tasks.</li> </ul> <p>Available through the Danish Building Research Institute and a distributor in Germany worldwide.</p>
DeST	<p>CABD (Computer Aided Building Description) module in DeST provides a visual Windows-based user interface. CABD is developed base on AutoCAD, R14, R2000 and R2002 can be supported. With this user interface, all information required in calculation can be input.</p>

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<p><b>Table 14</b>  <b>User Interface, Links to Other Programs, and Availability</b></p>	
	<p>Libraries of building components can be extended easily.                      All the data are contained in two databases; user can delete or modify them.</p>
DOE-2.1E	<p>Input can contain C-like logic not just fixed values                      Parameter substitution for parametric analysis                      User can build libraries with building components                      Software available in Windows executable and DLL format                      Source available for user reference                      Source and/or executables licensing for derivative works distribution with no per copy royalty                      Licensing for re-distribution of source</p>
ECOTECT	<p>User-friendly and highly graphical 3D user interface for model and data visualization, editing and creation – (with OpenGL).                      Visual real-time display of shadows and sun penetration                      Auto creates optimised shading devices                      Auto creates sun-path diagrams, (shading and reflection data): stereographic, equidistant, BRE, Waldram, and orthographic                      Reusable or cached Shading Data                      Model generation based on solar geometries; solar projections, profiles                      Incident Solar Radiation (insolation) analysis                      Solar envelope calculation                      Interactive solar rays                      Fully scriptable with both embedded script interpreter and an external editor, useful for batch processing of any functions and report generation.                      Exports models to native file formats of Radiance, EnergyPlus, ESP-r, HTB2 and NIST FDS.                      Includes graphical input and output data viewers for Radiance, EnergyPlus, ESP-r and HTB2.                      Imports, visualize, check and edit CAD geometry prior to analysis.                      Fully customizable libraries of materials, schedules and zone settings.                      Wizards for all thermal, lighting, solar access and shading design calculations.                      Built-in compliance checking for UK Part L energy and right-to-light regulations, US, Australian and other building regulations in development.                      Excellent on-line and interactive help.                      Demos and downloads available from <a href="http://www.ecotect.com/">http://www.ecotect.com/</a></p>
Ener-Win	<p>When user chooses hourly output reports, program generates three separate files that automatically invoke Microsoft Excel (if available on user's computer). The files can then be viewed in various formats. The files are:</p> <ol style="list-style-type: none"> <li>1. Hourly dry-bulb, dew-point, relative humidity, sun altitude and azimuth angles, direct normal insolation, diffuse horizontal, horizontal global, wind speed, site pressure, and cloud cover fraction, accompanied by whole-building energy loads for heating, cooling, lighting, receptacles, fans and water heating.</li> <li>2. Hourly temperatures and RH for outside and each HVAC zone in the building (mainly for comfort analysis.)</li> <li>3. Hourly weather data for 12 variables, including temperature and RH, sun angles, insolation, cloud cover, wind speed, and station pressure.</li> </ol>
Energy Express	<p>Built-in 2D CAD facility- for fast geometric data input and editing.                      Import DXF files for tracing building geometry                      Libraries of location data, climatic data, material properties, constructions, shading devices, operating schedules, energy tariffs and part-load performance data                      Group editing of selected zone or element properties                      Status bar hints on every input field.</p>

Contrasting the Capabilities of Building Energy Performance Simulation Programs

<p><b>Table 14</b>  <b>User Interface, Links to Other Programs, and Availability</b></p>	
	<p>Detailed On-line help.                      Comparison tool: compare a range of alternative designs and calculate savings.                      Further information: <a href="http://www.ee.hearne.com.au">www.ee.hearne.com.au</a></p>
Energy-10	<p>Energy Design Measures (EDMs), Apply and Rank – automatic adjustment of building model for predefined EDMs and control logic to run EDMs in sequence to rank effectiveness of each.                      User can build libraries of building components.                      Wizards for creating building models.                      Available at <a href="http://www.sbicouncil.org/store/e10.php">www.sbicouncil.org/store/e10.php</a></p>
EnergyPlus	<p>Has a macro language                      Parameter substitution for parametric analysis                      User can build libraries with building components                      3-D building display                      2-D floor plan display                      SPARK link for complex and innovative HVAC equipment and systems                      Software available in Windows executables and DLL formats as well as Linux                      Source available for user reference under license                      Source and/or executables licensing for derivative works distribution                      Source licensing for re-distribution of source                      Executables available at <a href="http://www.energyplus.gov">www.energyplus.gov</a></p>
eQUEST	<p>Input can contain C-like logic not just fixed values                      Parameter substitution for parametric analysis                      User can build libraries with building components                      Capabilities for energy code compliance analysis built-in                      Wizards for creating building models                      3-D building display                      2-D floor plan display                      Import CAD drawing for floor/space layouts                      2-/3-D displays linked to component property displays                      HVAC air-side system diagramming                      HVAC water-side system diagramming                      Complete input available in interface                      Wizards to assist in model creation                      Wizards to assist in running parametric analyses                      Graphical results reporting with multi-run comparisons                      Freeware executables in windows exe format                      Freeware executables in windows DLL format                      Freeware source for user reference                      Source and/or executables licensing for derivative works distribution with no per copy royalty</p>

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 14</b> <b>User Interface, Links to Other Programs, and Availability</b>	
	Source licensing for re-distribution of source
ESP-r	<p>Graphic interface for definition of zones, controls, schedules, networks, etc. Files are a mix of free and fixed format with extensive documentation.</p> <p>Databases for materials, constructions, wind pressure profiles, events, climate data, mycotoxins, templates for detailed system components and electrical components with graphic interface.</p> <p>Import and export of models with several CAD and simulation tools.</p> <p>Multi-domain assessments – building fabric, mass flows, CFD domains, electrical power, detailed systems components.</p> <p>Distributed under GPL license and can be run on most Linux distributions, Unix variants, Mac OSX, and Windows via Cygwin. Has been compiled as a DLL for use as an embedded simulation engine (e.g. HOT3000 from Natural Resources Canada).</p> <p>ESP-r supports the description and solution of power flow via a general network approach with solution of multi-phase power. It is intended to work at a similar frequency to that of the detailed plant system rather than at high frequency. Components are available in the following categories:</p> <ul style="list-style-type: none"> <li>• electrical conductors: dc and one/two/three phase ac cables/lines; transformers</li> <li>• grid connection;</li> <li>• power only components such as wind turbines;</li> <li>• building power loads: computer equipment, lighting, fans, pumps (also integrated into building model and coupled to thermal simulation);</li> <li>• building integrated micro generation: fuel cells, photovoltaic (crystalline/amorphous), ICE CHP (integrated into building/HVAC model and thermal simulation), and micro wind turbines.</li> </ul> <p>Control can be applied to the individual loads and power sources. This mix of components can be connected together to define an electrical distribution network which is fully integrate with the thermal model of building and HVAC. All types of power distribution system can be simulated: single and multi-phase AC, DC and mixed AC/DC systems. Where appropriate the power simulation is integrated with the thermal solution for example, PV modules embedded in a façade and feeding into the building power supply. The solution of the distribution model yields, for all components: real and reactive power flows, power losses, current magnitudes and phase, voltage magnitudes and phase, phase loadings. Additionally grid import/export power flows can be calculated for systems connected to the grid. The facility assumes a general knowledge of power systems engineering.</p> <p>In addition to idealized controls which can be applied to the zone and flow domains, users can define networks of detailed environmental systems components via a finite volume approach. It is designed to solve at short frequency (sub-second to several minutes). Components are available in the following categories:</p> <ul style="list-style-type: none"> <li>• Air based: mixing box, converging junction, diverging junction, centrifugal fan, cooling coil (flux or mass controlled), heating coil (flux or mass controlled), ducts, dampers, plate heat exchangers.</li> <li>• Latent spray/steam humidifier</li> <li>• Water based: radiator, pipe, junctions, cooling coil, heating coil, thermostatic valve, heat exchangers (air to air, air to water, water to water, some as plate exchanges and some as shell and tube.</li> <li>• Boilers: non-condensing wet central heating boiler with and without aquastat control, condensing boiler with on-off control, gas fired water heater with storage, WCH calorifier.</li> <li>• There are also a set of 27 so-called primitive parts from which components and environmental control systems can be built.</li> </ul> <p>This mix of entities can be used to define a network representing plant systems in fine detail and where the internal state of components or the psychrometric state of the system is of interest. The definition of system components and linking is supported by the GUI. Results analysis provides a full range of graphs and statistics and frequency information for nodes within components as well as output from components.</p>
HAP	<p>Complete input available in graphical user interface</p> <p>Extensive, context-sensitive on-line help.</p>

Contrasting the Capabilities of Building Energy Performance Simulation Programs

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<b>Table 14</b> <b>User Interface, Links to Other Programs, and Availability</b>	
	<p>User can build libraries of building components                      Global search and replace for building data.                      Global rotate for building envelope surfaces.                      Offers project sharing for collaboration                      Offers project archival features.                      Offers data sharing between projects.                      Extensive graphical and tabular reports.                      Comparative reports for multiple alternatives.                      Free telephone support available.                      Software training available.</p>
<b>HEED</b>	<p>Parameter substitution for parametric analysis                      Capabilities for energy code compliance analysis built-in                      Wizards for creating building models                      3-D building display                      2-D floor plan display                      Complete input available in interface                      Graphical results reporting with multi-run comparisons                      Freeware executables in windows exe format                      Source and/or executables licensing for derivative works distribution                      Cost of current version                      Number of months since initial release: 43                      Number of copies of current version in circulation: 6105</p>
<b>IDA ICE</b>	<p>Is commercially supported in English, German, Swedish and Finnish.                      Regular training classes offered.                      Fully customizable directly by user or under contract.                      Resolves real controller timescales for multi-zone buildings.                      Wizards to assist in model creation.                      All GUI operations may be performed by an external process.                      Has a macro language.                      Parameter substitution for parametric analysis.                      User can build libraries with building components.                      Data sharing between projects.                      Any variable in a simulation can be plotted.                      Detailed diagnostics of solution process available.                      2-D floor plan display. 2D displays linked to component property displays.                      HVAC air-side system diagramming                      HVAC water-side system diagramming                      Complete input available in interface.</p>

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 14</b> <b>User Interface, Links to Other Programs, and Availability</b>	
	<p>Provided with source code of models. Source and/or executables licensing for derivative works distribution. Available for hardware-in-the loop simulations.</p>
IES <VE>	<p>IES &lt;Virtual Environment&gt;, a commercial product aimed at design professionals, offers a comprehensive range of design-oriented building analysis within a single software environment. At the core of the model is a 3-D geometric representation of the building to which application specific data is attached in <i>views</i> tailored to specific design tasks. Use of a single model eliminates the duplication of input data, ensures a consistent mode of working and encourages integration and optimization of all aspects of the design. The &lt;Virtual Environment&gt; offers the following capabilities: dynamic thermal simulation, day-lighting simulation, artificial lighting design and simulation, design load calculation, component based HVAC plant simulation, natural ventilation and mixed mode modeling, solar shading and penetration analysis, code and regulation compliance, computational fluid dynamics, lifecycle cost analysis, capital cost/net present value analysis, optimization/scenario analysis, energy/cost/tariff assessments, vertical transportation, fire evacuation modeling, mechanical and electrical design software (duct sizing, pipe sizing, domestic hot and cold water pipe sizing, radiator selection, electrical wiring design). A powerful feature of the single model is the ease with which data can be exchanged and shared between applications. Lighting and solar shading analysis feed into the thermal model, which may optionally include HVAC and natural ventilation analysis, and this in turn can be used to drive CFD. &lt;VE&gt; has an integrated, graphics-driven results viewer with export facilities to all common analysis packages Excel/Word etc and report generation options. IES &lt;Virtual Environment&gt; can import and export geometrical information about the single data model. This information can then be used by other CAD based products. The import features include 2-D dxf and gbxml, export features include gbxml, 2-D and 3-D dxf. Animated inspection ‘fly-rounds’ of the building and 3-D results views for solar shading and CFD analysis can be exported as animation files.</p> <p>&lt;Virtual Environment&gt; modules include:</p> <ul style="list-style-type: none"> <li>• ModelIT – geometry creation and editing</li> <li>• ApacheCalc – loads analysis</li> <li>• ApacheSim – thermal simulation</li> <li>• MacroFlo – natural ventilation</li> <li>• Apache HVAC – component based HVAC</li> <li>• SunCast – shading visualisation and analysis</li> <li>• MicroFlo – 3D computational fluid dynamics</li> <li>• FlucsPro &amp; Radiance – lighting design</li> <li>• DEFT – model optimisation</li> <li>• LifeCycle – life-cycle energy and cost analysis</li> <li>• Simulex – building evacuation simulation</li> </ul> <p>IES &lt;Virtual Environment&gt; is sold worldwide. It has a large and growing user base covering North America, Europe, Asia and Australasia and is available in both SI and IP units. Academic licenses and reduced rates for students are also available. &lt;Virtual Environment&gt; is a fully modular product; users only need purchase the products they need. For example a lighting designer might only require the day-lighting, artificial lighting and solar shading packages. &lt;VE&gt; is also a development environment: a development licence provides the user with the means to extend its capabilities and customise them to particular tasks.</p>
PowerDomus	<p>Parameter substitution for parametric analysis Vapor diffusion and capillary migration are considered using highly moisture-content-dependent transport coefficients.</p> <p>3-D building display 2-D surface plan display HVAC air-side system diagramming</p>

## Contrasting the Capabilities of Building Energy Performance Simulation Programs

<b>Table 14</b> <b>User Interface, Links to Other Programs, and Availability</b>	
	HVAC water-side system diagramming Complete input available in interface Reports with graphical results such as zone temperature and relative humidity, PMV and PPD, thermal loads statistics, temperature and moisture content (or relative humidity) within user-selectable walls/roofs, surface vapor fluxes and daily-integrated moisture sorption/desorption Building power loads integrated into building model and coupled to thermal simulation On-off and PID control strategies can be applied to individual heaters or DX-systems Animated visualization of Sun path 1-minute time intervals for schedules Software available in Windows Operating Systems (XP, 2000)
SUNREL	User interface for creating text input files Single or parametric runs through the user interface Executable available for a fee from <a href="http://www.nrel.gov/buildings/sunrel">www.nrel.gov/buildings/sunrel</a> Source and executable available for other applications with a license agreement with NREL Integrated into TREAT home energy auditing software – <a href="http://www.treatsoftware.com">www.treatsoftware.com</a>
TAS	Has a macro language Input can contain C-like logic not just fixed values User can build libraries with building components Capabilities for energy code compliance analysis built-in Wizards for creating building models 3-D building display 2-D floor plan display 2-/3-D displays linked to component property displays Complete input available in interface Graphical results reporting with multi-run comparisons Source available for user reference under license or for a fee
TRACE	Parameter substitution for parametric analysis User can build libraries of building components Wizards for creating building models Complete input available in interface Wizards to assist in running parametric studies Graphical results reporting with multi-run comparisons
TRNSYS	Fully integrated interface for defining the system setup (the TRNSYS Simulation Studio) with optional plug-ins to enter component parameters. Building input data is entered in a dedicated visual interface (TRNBuild) that presents an object-oriented (non-geometrical) representation of the building. Optional link to SimCad (Object-oriented CAD interface) Any component output can be plotted during a simulation and printed to a file. The program can also output useful debugging information (e.g., inputs-outputs of any component at each iteration). Components can be programmed in any language able to create a Windows DLL and are easily shared between users by dropping DLL's in a folder. Components can also be implemented in different programs in order to re-use existing work or to take advantage of features that would require a considerable effort if they had to be programmed in Fortran, C++, etc. This includes links to:

Contrasting the Capabilities of Building Energy Performance Simulation Programs

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**Table 14**  
***User Interface, Links to Other Programs, and Availability***

	<ul style="list-style-type: none"> <li>- Matlab/Simulink. Components or subsystems can be implemented using m-files or in a Simulink project.</li> <li>- MS Excel. Components can use simple spreadsheet functions or advanced VBA macros.</li> <li>- EES (Engineering Equation Solver). The program allows users to enter equations "as they are written" instead of programming their solution. It also includes very detailed material properties for a very broad range of fluids</li> <li>- COMIS and CONTAM. Both engines are available as TRNSYS components (in addition to the fully integrated COMIS option, TRNFLOW)</li> </ul> <p>Performs parametric studies through the "parametric runs" feature in TRNEdit. An optional visual interface (TRNOpt, part of the TESS libraries) is available to perform optimization studies with GenOpt in a user-friendly environment.</p> <p>Sold by 10 distributors worldwide. It is provided with full source code for components and simulation engine. MS Windows</p> <p>Users can create stand-alone executables (TRNSED applications) that can run a predefined set of input files. TRNSED users can make simple modifications to the application (changing parameters, selecting configurations). Those applications can be distributed freely to non-TRNSYS users.</p>
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