ABSTRACT

> Note: This document is intended to supplement the attached table comparing BEST's function to other internationally approved simulation programs. The table was modified from the original form referenced below to add BEST. Reference: Drury B. Crawley, Jon W. Hand, Michaël Kummert, Brent T. Griffith：Contrasting the capabilities of building energy performance simulation programs, Version1.0, July 2005

The present integrated building energy simulation tool, BEST, was developed in 2005 as a new and more effective simulation tool through a collaboration between industry, government, and academia, consisting of general contractors, designers, manufacturers, universities, and government agencies such as the Ministry of Land, Infrastructure, Transport and Tourism. The initial version of BEST was released in March of 2008 and has been updated continually since its release. The latest version was released in October of 2018. BEST attempts to satisfy the needs of the building industry who use it as a design and operation tool, government agencies as a calculation tool for the application of building permits, and academia as a research and education tool for studying building energy consumption and indoor environments.

BEST is being continuously developed by providing a number of distinctive features.

1. Whole-building energy consumption can be obtained through simulations in which the building thermal behavior is integrated with the control of HVAC systems and electrical and plumbing systems.
2. BEST can be used for various types of evaluation, including energy simulations and conventional thermal load simulations such as simulation of design peak load and annual load. The changes in thermal comfort can also be evaluated.
3. Four types of user interfaces are currently provided with the tool, whereby a user can select the appropriate interface for his/her specific application. The expert interface can be used for research or detailed examinations. The designer interface can be used to design energy-saving buildings and systems as well as to confirm energy savings. This designer interface can also be used for application of permits based on the Act in the Rational Use of Energy. A third type is the simple interface which can be used in the basic design phase that includes numerous unspecified conditions for simulations. It requires only about fifty input conditions, because the default assumptions are ready for all other conditions. It can be applied to computational design. A fourth type is the graphical interface which is provided for residential use and is easy to use for beginners. Each of

the four interfaces provides simulation conditions suitable for its use and operable by the same simulation engine.

4. BEST is being continuously refined and functionally extended. The program codes are written in Java, which is flexible and expandable and allows object-oriented programming. Support services are also provided for users.

The simulation engine of BEST consists of components for building simulation and for system simulation. Thermal load simulations require only the building simulation component, whereas integrated energy simulations require both the building and system simulation components.

The building simulation component of the engine has the following features:

1. Two techniques for solving heat balance equations can be used depending on the types of simulation. For integrated energy simulations, an explicit technique can be used to solve the heat balance between zones and systems, and an implicit technique can be used to solve the heat balance between zones while suspending system operation. The implicit technique is always used for thermal load simulation in order to obtain the required cooling/heating rate or unconditioned space conditions.
2. A simulation time interval can be changed according to the cooling/heating schedule. Short time intervals are suitable for solutions obtained using an explicit technique as well as rapidly changing conditions in the space of interest. A time interval of 60 minutes, for example, is sufficient to be used in an implicit technique for slowly changing conditions.
3. Thermal interactions between zones can be simulated, and there is no upper limit on the number of zones.
4. The radiant heat transfer can be solved approximately. In sensible heat balance equations for zones, the unknown variables are taken for zone air temperatures or sensible supply heat rates, and not for surface temperatures. The delay of heat transfer due to radiation absorbed by surfaces is considered using transfer functions of the response of convective heat to the convective and radiant heat gain. This method does not require 3D information and has no limitation in terms of space shape.
5. In the case of design peak load calculation, daily-cycle unsteady- state thermal load simulations can be performed under various weather conditions on design weather days. For intermittent heating and cooling, special conditions such as early starts for operation can be assumed in order to avoid overdesign.
6. Space thermal comfort sensation indices, such as operative temperature and PMV, can be obtained.
7. The effects of window systems, such as airflow windows (AFWs) and naturally ventilated

double-skin facades (DSFs), can be evaluated. The theoretical formulae for thermal performance, including the U-value and solar heat gain coefficient, have been derived to enable performance prediction based on the vertical distribution of air temperature in the ventilated cavity.

8. Indoor natural ventilation is simply simulated. Airflow balance is not solved and the height of the neutral zone is assumed. Various conditions for control of natural ventilation can be set for simulations.
9. The energy saving effects of lighting control with automatically adjusting blinds can be obtained using a simplified estimation of the horizontal illuminance distribution in the cross-section of the space.

The system simulation component of the engine has the following features:

1. Heat balance equations are solved using an explicit technique, preferably at five minute intervals.
2. The behavior of each piece of equipment is expressed as a Java class according to the rules associated with data transmission. The class is called a module. Modules are interconnected to one another in order to configure the entire system. Such a modular structure enables the use of a wide variety of modeling techniques and also has the advantages of facilitating both maintenance and extension of the program.
3. By developing various modules, users can simulate entire complex systems that include not only HVAC equipment but also electrical and plumbing equipment.
4. Templates are provided for easy configuration of entire HVAC systems. Templates are the sets of pre-configured modules, such as AHUs and chillers in combination with a cooling tower.
5. Control elements are prepared as modules that are independent from other parts of the engine. Therefore, several types of control can be selected, and modules for new control algorithms can be easily added.
6. Modules are prepared for various HVAC systems including both decentralized and central systems and the systems for effective use of energy such as thermal storage tank systems, co-generation systems, and photovoltaic panels. The tool can be used for the planning of zero-energy buildings (ZEBs).

BEST can be applied to a wide variety of weather databases.

The 2006 weather dataset for Tokyo with intervals of one minute, which was developed for the tool, and the Expanded AMeDAS Design Weather Datasets for 840 locations in Japan are incorporated into the tool. Typical year weather datasets, such as EPW and Expanded

AMeDAS, as well as design weather datasets, such as WEADAC (which contains data for 3,700 cities throughout the world), can also be used by users after acquisition of such datasets . Fenestration databases containing the thermal and optical properties of windows were developed specifically for the tool. These databases include one for 4,200 typical windows and another for 1,700 window systems. A database of the thermal properties of wall materials for 150 Japanese materials and 160 foreign materials is also incorporated into the tool. HVAC equipment performance databases have been prepared for central systems and decentralized systems, and will further be extended in future.

BEST was tested using a test method for evaluating building energy analysis computer programs.

Its test procedures are now standardized as specified in the ANSI/ASHRAE Standard 140-2011. The validity of the tool was confirmed by comparing the values of peak load, annual load, and electricity consumption obtained from the tool with the simulation results of several tools that are commonly used in various countries. Furthermore, the measured and simulated values obtained using other domestic programs were compared, and the results of a sensitivity analysis of the simulation were made public.

Contrasting the capabilities of building energy performance simulation programs

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)

Table 1 General Modeling Features	BEST	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
Simulation solution																					
・Sequential loads, system, plant calculation without feedback		X			X															X	
・Simultaneous loads, system and plant solution	X	X *2	X	X		*3	X	X	X *4	X	X *5	X	X *6	X	X	X	X	X *7	X		X
・Iterative non-linear systems solution	P		X			*3			X	X		X	X	X	X	X	X		X	X	X
・Coupled loads, systems, plant calculations	X		X					X	X *4	X	X	X		X	X	X	X	X			X
・Space temperature based on loads-systems feedback	X	X	X	X		X *8	X	X	X	X		X	X	X	X	X	X	X	X	X	X
・Floating room temperatures *9	X	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	X *2	X *10	R					X *11	X *12		X *13			X	X	X *14	X			X *15
・Variable time intervals for zone air/HVAC system interaction	P	X *2	X *10					X		X	X *16	X					R				
・User-selected for both building and systems	X											X			X	X	X				X *17
・Dynamically varying based on solution transients	P									X		X			X *18						
Full Geometric Description																					
・Walls, roofs, floors	X	X	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X *19
・Windows, skylights, doors, and external shading	X	X	X	X	X	X	P	X		X	X	X		X	X *20	X	X	X	X	X	X
・Multi-sided polygons			X	X	X	X	P			X	X	X *21		X	X	X			X		

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

*3 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.

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

*5 HVAC air-side and water-side combined calculation

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

*7 Idealized HVAC equipment only in release version. Research version with more realistic HVAC models.

*8 Based on CIBSE Admittance Method for early design decision-making and analysis

*9 No environmental controls

*10 Up to 256 timesteps per hour

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

*12 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.

*13 1 minute to 1 hour time steps for zones and flow networks and a multiple of that for detailed systems.

*14 1-hour default, 1-second to 24-hour time steps. 1-minute time interval schedules.

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

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

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

*18 User-specified tolerance controls time step and integration order

*19 Taking into account geometry for view factors, detailed shading, direct radiation distribution requires additional input data.

*20 Skylights with multiple beam reflections

*21 Up to 24 edges per polygon. Polygons also used to describe internal mass within zones.

Table 1 General Modeling Features	BEST	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
Import building geometry from CAD programs			X *22	P		X		X *22		X	X	X	P *23		X *24	X	X *25		X	X	X *26
Export building geometry to CAD programs						X				X *22		X *27				X			X	X *28	
Import/export model to other simulation programs						X				X *29		X *30									
Number of surfaces, zones, systems, and equipment unlimited	X		X *31	X		X				X	X *32	X *33	X *34	X *35	X	X	X		X	X	X *36
Simple building models for HVAC system simulation																					
･Import calculated or measured loads	P			E		*3				X	X	X			X					X	X
･Simple models (single lumped capacitance per zone)							X					X									XO *37

*22 DXF

*23 CAD import via gbXML under development

*24 IFC 1.51, 2.0 and 2.x2

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

*26 Through an optional program, SIMCAD, a CAD program with an interface to TRNSYS

*27 DXF, MicroGDS, THINGS, VRML

*28 XML

*29 Convert DOE-2.1E, BLAST geometry, load information only.

*30 Export to EnergyPlus, TSBI3, Radiance. Import from ECOTECT.

*31 Only one physical system of each type per zone, except for heating systems and window connected systems.

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

*33 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.

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

*35 Maximum of 25 windows/doors/orientation types, orthogonal walls/roof/floor

*36 Default is 999 zones, 1000 components. TRNSYS can be recompiled with more

*37 Some components are part of the optional TESS libraries

Table 2 Zone Loads	BEST	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
Heat balance calculation *38	X	X	X	X	X *39	*3	X			X	X *39	X		X	X	X	X	X	X	X	X
Building material moisture adsorption/desorption *40	P	X *41	X			*3				X		X			O	X	X *42		X	P	X *43
Element conduction solution method																					
・Frequency domain (admittance method)						X								X	X	X					
・Time response factor (transfer functions)	X	X		X	X	*3	X			X	X		X						X	X	X
・Finite difference / volume method									X			X			X	X *44	X	X			
Interior surface convection																					
・Dependent on temperature		X	X			*3		P		X		X *45		X	X	X	X	X	X		X
・Dependent on air flow		X						X		P		X		X		X			X		E
・Dependent on CFD-based surface heat coefficient										E		E				X					
・User-defined coefficients *46			X	X	X *47	X				X		E *48		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	X
Human thermal comfort *49																					
・Fanger	X	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)	P	X				X	X			X		X *50			X	X	X		X		X
・Radiant discomfort *51												X			X	X	P		X		
・Simultaneous CFD solution										E		E *52									
・PAQ (Perceived Air Quality) *53			X	P																	
Automatic design day sizing calculations																					
・Dry bulb temperature	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
・Dew point temperature or relative humidity	X			X	X *54	*3	X	X		X	X		X		X	X			X	X	
・User-specified *55	X			X	X *56	*3	X	X		X	X		X	X	X	X			X	X	X

*38 Simultaneous calculation of radiation and convection processes each time step

*39 Only for calculation of custom weighting factors that are then used in the hourly calculation

*40 Combined building envelope heat and mass transfer

*41 Only in IBLAST, an unreleased, integrated simulation version of BLAST.

*42 Takes into account combined vapor diffusion and capillary migration using variable transport coefficients

*43 Simple or 2-node models.

*44 As option for loads calculations.

*45 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).

*46 Constants, equations or correlations

*47 Constant coefficients only

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

*49 Based on occupant activity, inside temperature, humidity and radiation

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

*51 Explicit radiation view factors

*52 Occupants and small power devices can be treated as blockages and heat/humidity/CO_2sources within the CFD domain.

*53 Simsonson, Solonvaara and Ojanen (2001)

*54 DOE-2 design day sequence includes humidity conditions

*55 User specified minimum and maximum or user-specified steady-state, steady-periodic or fully dynamic design conditions

*56 DOE-2 allows user-specified design-day maximum and minimum.

Table 3 Building Envelope, Daylighting and Solar	BEST	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
Solar analysis																					
・Beam solar radiation reflection from outside and inside window reveals	X		X	P		X				X											X
・Solar gain through blinds accounts for different transmittances for sky and ground diffuse solar	X			X		*3	X			X						X			X		X
・Solar gain and daylighting calculations account for inter-reflections from external building components and other buildings	P		P			X				X		X *57				X	P		X		X *58
・Creation of optimized shading devices						X															
・Shading surface transmittance		X			P	X		X		X	X					X			X *95		
・Shading device scheduling	X	X	X	X	P	X				X	X			X *83	X	X	P	X	X	X	X
・User-specified shading control			X	X	P	X *59				X		X *60		X *83	X	X			X	X	X
・Bi-directional shading device	X			P		*3				X		X *61			X	X			X	X	X
・Shading of sky IR by obstructions				X	X	*3	X			X	X					X			X		X
Insolation analysis																					
・time-invariant and/or user stipulated *62		X			X *63					X	P	X		X				X			X
・computed at each hour *64		X			X *65						X	X				X					EI *66
・distribution computed at each timestep *67	X									X						X					EI *66
・Beam solar radiation passes through interior windows (double-envelope)	X		X	P		X				X	X *68				X *69	X	P		X		X
・Track insolation losses (outside or other zones)												X				X					

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

*58 No specular reflection

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

*60 For two blind positions and daylighting accounted for in light switching for multiple sensors and circuits per thermal zone.

*61 Via surfaces

*62 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.

*63 Time-invariant except for sunspaces, where solar distribution is calculated hour-by-hour

*64 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).

*65 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.

*66 Must be calculated outside the building model and requires additional data.

*67 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).

*68 For sunspaces (atriums) only, not used for double envelope buildings

*69 With separate add-in for double sheet facades

Table 3 Building Envelope, Daylighting and Solar	BEST	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
Advanced fenestration																					
・Controllable window blinds	X		X	X	X	X *70		X		X	X	X		X	X	X		X	X		X
・Between-glass shades and blinds	X			X	X	X				X	X	X *71			X	X			X		X
・Electrochromic glazing						X *72				X	X	X			X						E *73
・Thermochromic glazing						X						X			X			I			E *73
・Datasets of window types *74	X		P *75	X	P	X		P		X	X *76	X *77	X *78	X *79	X	X			X	P	X
・WINDOW 5 calculations						*3				X	X *76										X
・WINDOW 4.1 data import		X			X *76	*3					X *76	X						X *80		X	X
・Dirt correction factor for glass solar and visible transmittance				E	P	X				X	P				X						E *73
・Movable storm windows				X		X				X		X *81			X	X			X		X
・Bi-directional shading devices	X			P		*3				X		X *61			X	X			X	X	X
・Window blind model *82	X			X		X				X	X	X *60		X *83		X					X
・User-specified daylighting control	X		X	X		X *84				X		X *60		X *83	X	X			X	X	X
・Window gas fill as single gas or gas mixture	X			X		X				X		X				X			X		X
General Envelope Calculations																					
・Outside surface convection algorithm																					
○BLAST/TARP		X				*3				X										X	
○DOE-2					X	*3				X	X *85									X	
○MoWiTT						*3				X		X								X	
○ASHRAE simple		X				*3	X		X	X				X		X			X	X	
○Ito, Kimura, and Oka (1972) correlation												X			X						
○User-selectable				X		*3				X *86		X			X	X	X		X	X	X

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

*71 Multiple representations possible: as part of a constructions optical properties, as solar obstructions associated with the zone or as explicit surfaces with full treatment of convection and radiation exchange.

*72 With freely available electrochromic/thermochromic plug-in developed at Welsh School of Architecture.

*73 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.

*74 Conventional, reflective, low-E, gas-fill, electrochromic, and WINDOW-5 layer-by-layer custom glazing description

*75 Extensible window library with possibility of defining individual 3rd order polynomial transmission versus angle of incidence curves.

*76 Window 4 single band calculation for layer-by-layer descriptions or accepts Window 5 multiband output for composite window descriptions.

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

*78 Configuration of window glazing and window assembly defined; performance calculations based on Window 4.

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

*80 Window 4.1, 5.1 and 5.2 data import capabilities

*81 Via general facility for substituting constructions thermophysical and optical properties during simulation.

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

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

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

*85 Uses combined MoWiTT, TARP and ASHRAE formulations for various portions

*86 Can specify different correlations by surface type (e.g. all exterior windows)

Table 3 Building Envelope, Daylighting and Solar	BEST	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
•Inside radiation view factors			X	X		*3				X	X	X			X	X		P	X		
•Radiation-to-air component separate from detailed convection (exterior)			X	X		*3				X	X	X			X	X		X	X	P	X
•Air emissivity/radiation coupling																X					
Sky model																					
•Isotropic *87		X				X		X	X			X	X *88	X		X	X	X	X		X
•Anisotropic *89	X		X	X	X	X	X			X	X	X	X *90		X	X				X	X
•User-selectable			X			X						X			X *91	X					X
Daylighting illumination and controls																					
•Interior illumination from windows and skylights	X		X	X	X	X	X		X *92	X	X	X		X	X	X			X	X	
•Stepped or dimming electric lighting controls *93	X		X		X	*3	X		X	X	X	X		X	X	X			X	X	X
•Glare simulation and control					X	P *3				X	X	X *94				X			X		
•Geometrically and optically complex fenestration systems using bidirectional transmittance										I		X *94			X	X			X *95		
•Radiosity interior light interreflection calculation						*3				X		X *94			X	X			X *95		
•Daylight illuminance maps			X			X				X		X				X			X *95		
•Daylighting shelves						X	X			X		X *96				X			X *95		
•Tubular daylighting devices *97						*3				X		X *96				X					
Movable/transparent insulation		X	X	P	X	*3				X		X		X *98	X	X		P			X
Zone surface temperatures *99		X	X	E	P *100	X	X			X	X *101	X *102			X	X	X	X	X	X	X

*87 Uniform solar radiation and illumination distribution
*88 For energy simulation calculations
*89 Sky radiance, diffuse solar radiation and illumination vary with sun position
*90 For design day calculations
*91 ASHRAE, Perez and Kondratjev
*92 LBNL split-flux daylighting model
*93 Including heating and cooling effects
*94 Through a link with Radiance
*95 Through a link with Lumen Designer
*96 Resolution can be increased via use of Radiance to define shelf properties and light sensor characteristics. Tubular devices require combined Radiance & surfaces description.
*97 Including illuminance, solar gain, thermal resistance
*98 Automatic operable night time window insulation
*99 Wall, window, door, floor, ceiling, roof
*100 Reverse calculation from heat flows (module added by EMPA)

Table 3 Building Envelope, Daylighting and Solar	BEST	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
Airflow windows	X					X				X		X *103			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	X
・2- and 3-dimension				P						X		RI			O						
Ground heat transfer																					
・ASHRAE simple method *104																					X
・1-dimension	X	P	X	X	P	X	X	X	X	X	X	X	X	X	X	X	X	X	X	P	O *105
・2- and 3-dimension slabs						*3				X *106		R			O		O *107	R			O *105
・2- and 3-dimension basements				P		*3				X		R			O		O *107	R			O *105
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			*3				X	X	X					P				E

*101 User selectable in some versions

*102 Also temperatures within constructions as well as full energy balance at each surface.

*103 As an additional zone with flow network or CFD domain

*104 ASHRAE (2001a)

*105 Through additional component (optional TESS libraries)

*106 2-D and 3-D ground calculations for basements and slabs using auxiliary programs.

*107 Through a link with the Solum software (Santos et al. 2003)

Table 4 Infiltration, Ventilation, Room Air and Multizone Airflow	BEST	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
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		X	P		*3				P *108						X		X	X		
Natural ventilation *109	X		X	P		*3				X	P *110	X			X	X	X	X	X		O *111
Hybrid natural and mechanical ventilation	X		X	P			X					I			X	X	X		X		O *111
Window opening for natural ventilation controllable *112	X			X *113			X			X		X				X *114	P	X	X		O *111
Multizone airflow (via pressure network model)	X		X	P		*3				X		X			X	X		X	X		O *111
Displacement ventilation						*3				X *115		X *116			X	X			X		O *117
Mix of flow networks and CFD domains				X								E									
Contaminants, mycotoxins (mold growth)			P									R *118					P				

*108 Look-up table for single pressure coefficients per facade 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.

*109 Pressure, buoyancy driven

*110 Simple schedulable operable windows model

*111 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)

*112 Based on zone or external conditions

*113 Air flow rate range should be defined in advance

*114 Simulation variables that can be used to control include same zone, other building zone, CO_2 concentration, external conditions (temperature, wind speed, wind direction)

*115 Mundt and UCSD models, automatically subdivides zones

*116 Via CFD or by subdividing zones

*117 In TRNFLOW, with zone subdivision

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

Table 5 Renewable Energy Systems	BEST	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
Trombe wall		X	X *119	P	X	X				X	X	X *120			X *120	X		X	X		X
Rock bin thermal storage												X *120						X			X
Solar thermal collectors																					
･Glazed flat plate	X			X		X			X *121	X		X				X	P		X		X
･Unglazed flat plate (heating and cooling)						X						X									X
･Evacuated tube	X			P																	X
･Unglazde transpired solar collector						*3				X											O *122
･High temperature concentrating collectors *123																					X
User-configured solar systems *124																					X
Integral collector storage systems																					X
Photovoltaic power	X		X			X			X *125	X	X	X				X					X
Hydrogen systems *126												X									X
Wind power	X											X									X

---

*119 Modeled as a separate zone

*120 Via extra zones and flow network

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

*122 Additional component in TRNLIB, the free add-on library

*123 For power generation

*124 Can include complex arrangement of storage tanks

*125 Photovoltaic power modeled in Energy-10 version 1.8 using EnergyPlus

*126 Fuel cells, storage, electrolyzers

Table 6 Electrical Systems and Equipment	BEST	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
Renewable power (see Table 5 for details)	X		P			*3			X	X	X	X									X
Electric load distribution and management																					
・On-site generation and utility electricity management including demand	X	X			X	P *3				X	X	X					X			X	X
・Renewable components *127	X											P									X
Power generators																					
・Internal combustion engine generator	X	X			X					X	X	X *128								X	X
・Combustion turbine		X			X					X	X									X	O *129
・Microgeneration *130 integrated with thermal simulation	X					P			X	P		X *132									X
Grid connection						P *3				X		X *132									X
Electric conductors *131	P											X *132				X					P *133
Building power loads *134	X	X		X	X	X		X	X	X	X	X *132	X		X	X	X		X		X

*127 Batteries, charge controllers, power-point trackers

*128 Combined heat and power and grid

*129 Part of the optional TESS libraries

*130 Fuel cells, photovoltaic (crystalline amorphous), and internal combustion engine combined heat and power

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

*132 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 facade 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.

*133 Power converters and bus bar (no explicit 3-phase current or line model)

*134 Computer equipment, process equipment, process loads, lighting, fans, pumps

Table 7 HVAC Systems	BEST	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
Discrete HVAC components *135	X			X				P		X		X			X	X	R	R	X		X
Idealized HVAC systems		X		X		X	X			X		X *136			X	X		X			X *137
User-configurable HVAC systems	X		X	X				P		X	X	X *138	X *139	X	X	X	X	R	X	X	X
Air loops *140	X			X				P		X	P	X	X		X	X	X	R	X	X	X
Fluid loops *141	X			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			X						P	X	X	X		X		P		X	X	X *142
Fluid loop pumping power *143	P										X	X *144	X		X					X	
Pipe flow-pressure networks *145												X			X						
Air distribution system *146	P						X	P		X	X	X *147	X	X	X	X		R			X
Multiple supply air plenums	X			P						X	P	X *147				X					X
Simplified demand-controlled ventilation																					
・Ventilation rate per occupant and floor area	X			X			X			X	X			X	X *148	X	X		X	P	X
・Ventilation air flow schedule	X		X	X			X			X	X	X		X *149	X	X	X	X	X	X	X
・User-defined ventilation control strategy *150	X		X *151	X								X			X	X			X		X
CO_2 modeling																					
・CO_2 zone concentrations, mechanical and natural air path transport	X											X	X		X	X					O *111
・CO_2 based demand-controlled ventilation	X		X *152									X	X		X	X				P	EO *111

*135 Including part-load performance

*136 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.

*137 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

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

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

*140 Connect fans, coils, mixing boxes, zones

*141 Hot water, chilled water and condenser loops connect equipment

*142 By combining available components

*143 Based on flow and pressure with 2/3-way valves with static head

*144 Static head not supported.

*145 Arbitrary structure with valves, pumps and controls

*146 Including conduction losses and air leakage

*147 Via plant components and/or flow network

*148 Via CO_2 based control

*149 Intelligent controller manages night flushing and daytime economizer for passive cooling

*150 Any combination of feed-forward/feedback controllers

*151 CO_2 controlled ventilation rates

*152 Detailed demand controlled ventilation with CO_2 mass balance and CO_2 sensor control

Table 7 HVAC Systems	BEST	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
Automatic sizing																					
・HVAC components	X		P	X	X		X	X	X	X	X		X	X	X *153	X	P	R	X	X	P *154
・Air loop flow, outside air, zone airflow	X		X	P			X			X			X		X	X			X	X	P
・Hot, cold, and condenser water loops	X			P						X	X		X *155		X	X			X	X	P
Zonal air distribution unit												I *156									OI *157
・Constant volume reheat		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	
・Variable air volume reheat		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	
・Powered induction unit																			X		
〇Series PIU reheat					X			P		X	X		X		X					X	
〇Parallel PIU reheat					X					X	X		X		X					X	
・Dual duct constant volume	X	X	X		X		X	P		X	X	X	X		X	X				X	
・Dual duct variable air volume	X	X	X		X			P		X	X	X	X		X	X				X	
Zone forced air unit												I *156									
・Fan coil (2 pipe)	X	X		X				P				X	X							P	O *158
・Fan coil (4 pipe)	X	X	X	X	X		X	P		X	X		X		X	X			X	X	O *158
・Unit heater *159	P	X		X	X		X		X	X	X	X	X	X	X	X	X	R	X	X	O *158
・Unit ventilator *160		X		P	X		X		X	X	X	X	X	X	X	X			X	X	O *158
・Window air-conditioner (cycling)	X			X	X		X	P	X	X	X		X	X	X	X	X	R	X	X	O *158
・Energy recovery ventilator (stand-alone)	X									X			X		X	X			X	X	O *158
Unitary equipment												I *156									
・DX system																					
〇Heating/cooling coils	X	X	X	X	X		X	P	X	X	X	X	X	X		X	X	R	X	X	X
〇Coil latent capacity degradation *161	X									X	X	X				X					X
・Furnace *162		X		X	X		X	X	X	X	X	R	X	X		X		R	X	X	X
・Air-to-air packaged heat pump	X*267	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		X	P		X	X	R	X			X		R	X	X	X

*152 Detailed demand controlled ventilation with CO_2 mass balance and CO_2 sensor control

*153 Via unlimited capacity components

*154 The total power

*155 Hot and cold water loops

*156 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.

*157 Combinations of detailed system components, most of which are available in the optional TESS libraries

*158 Through additional components or combinations of components that are part of the additional TESS libraries

*159 Water, gas or electric heating coil

*160 Water, gas or electric heating coil, water cooling coil

*161 At part load (cycling) conditions

*162 Gas or electric heating coil, DX cooling coil

*267 Including the function of a generator

Table 8 HVAC Equipment	BEST	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
Coils												I *156									
・Water heating coil	X	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	P	R	X	X	X
・Water cooling coil	X	X	X	X	X		X	X		X	X	X	X		X	X	X	R	X	X	X
・Detailed fin/tube water cooling coil	X	X *163								X		X			X		X				X
・DX coil																					O *158
○Bypass factor cooling empirical		X								X			X			X *164					
○Multispeed cooling empirical		X								X						*164					
○Heating empirical		X								X						*164					
○Coil frost control										X	X	X	X			*164				X	
・Water-to-air heat pump *165		X		X	X			P		I	X		X			X			X	X	X
Radiative/convective unit												X *166									
・Baseboard (electric)		X	X		X		X		X	X	X	X	X	X	X	X	X	X		X	
・Baseboard (hydronic)		X	X				X			X	X	X	X		X	X		R		X	O *158
・Low temperature radiant																					
○Hydronic *167	X	X *163	X							X		X *168			X	X					X
○Electric *169		X *163	X							X		X *168				X					X *168
・High temperature radiant (gas, electric)		X			P					X		X *168			X *170	X					X
Desiccant dehumidifier (solid)	X				X			P		X	X									X	X
Humidifier								P													
・Steam (electric)	X	X	X	X						X		X	X		X	X	X		X	X	O *158
・Humidifier water consumption	X		X	X						X		X			X	X	X			X	O *158
Humidity control *171																					
・Cooling coils in combination with air-to-air heat exchanger for improved dehumidification performance	X		X							X		X			X	X	X			X	X
・High humidity control (DX or chilled water coils)		X	X		X		X			X	X	X	X		X	X	X			X	X

*163 Only in IBLAST, an unreleased, integrated simulation version of BLAST.

*164 Generic coil

*165 Reciprocating, rotary or scroll compressor, heating or cooling

*166 Various representations: as an ideal zone controller or via detailed plant components.

*167 Heating or cooling, floor, slab, wall, ceiling

*168 Via system components or heat injected into surfaces

*169 Floor, slab, wall, ceiling

*170 Electric

*171 Chilled water or DX cooling coils

Table 8 HVAC Equipment	BEST	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
Fans																					
・Constant volume	X	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	X
Pumps																					
・Constant speed	X	X		X	X		X	P		X	X	X	X		X	X	X	R	X	X	X
・Variable speed	X	X		X	X			P		X	X	X	X		X	X	P	R	X	X	X
・Multi-stage	X										X	X			X					P	X *172
・Direct-couple to power source												X									O *158
Heat exchangers *173																					
・Plate frame	P									P	X	X			X					X	X
・Immersed coil															X						X
・Shell and tube												X			X						X
・User-defined effectiveness											X	X			X						X
Plant cooling equipment																					
・Electric chiller												X *174									
○Centrifugal	X	X		X	X		X	P		X	X		X		O	X *175	X			X	O *158
○Centrifugal with VSD	X				X *176					X *177	X		X			*175				X	O *158
○Reciprocating		X		X			X	P		X	X		X		O	*175				X	O *158
○Double-bundle condenser/heat recovery		X		X	X			P		X	X					*175				X	O *158
○Screw	X*268			X	X *178			P		X *179	X		X		O	*175				X	O *158
○Scroll	X*268			X							X		X			*175				X	O *158
○Constant COP	X	X	X	X			X	P	X	X	X				X	*175			X	X	O *158
・Engine-driven chiller *180	X	X		X	X			P		X			X			*175				X	O *158
・Combustion turbine chiller *181		X		X				P		X			P			*175				X	O *158

*172 Through appropriate controller

*173 Various flow configurations

*174 Generic chiller representation.

*175 User can specify curves of chiller performance

*176 User can simulate VSD by substituting curves for centrifugal chiller.

*177 User can enter curves for VSD centrifugal chiller.

*178 User can replace compression chiller curves with curves for screw chiller.

*179 User can enter curves for screw chiller and use Chiller:Electric:EIR.

*180 Gas, diesel, gasoline, fuel oil

*181 With/without heat recovery, gas, diesel, gasoline, fuel oil

*268 Constant speed / With VSD

Table 8 HVAC Equipment	BEST	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
・Absorption Chiller																					
〇Steam absorption chiller	X*269	X		X	X			P		X	X		X *182			*175				X	O *158
〇Gas-fired absorption chiller	X							P					X			*175				X	
〇Gas-fired hot water absorption chiller heater	X*182	X			X					X	X									X	X *182
・Free cooling chiller	X	X			X					X	X				X				X	X	X
・Air-to-water heat pump chiller	X			X			X				X				O	*175			X	X	X
・Water-to-water heat pump chiller		X		X			X			X	X				X	*175			X	X	X
Plant condenser/evaporator equipment																					
・Cooling tower																					
〇Single speed	X	X		X	X		X	P	X	X	X	X	X				X			X	X
〇Two speed	X									X		X	X							X	X
〇Variable speed	X				X					X	X	X	X				P			X	X
・Air-cooled condenser		X		P	X		X	P	X	X	X	X	X				X			X	X
・Simple evaporative condenser		X		P	X					X	X									X	X
・Direct evaporative cooler		X		P			X			X										X	O *158
・Indirect evaporative cooler		X								X										X	O *158
・Free cooling, hydronic heat exchanger *183				X	X					X	X		X		X					X	X
・Pond heat exchanger										X	X		X								X
・Ground surface heat exchanger										X	X										X
・Ground loop vertical borehole heat exchanger	X									I	X	R	X		X *184					X	X
・DX cooling coil evaporative condenser																					
〇Simple effectiveness model					X					X	X									X	X
〇Water usage and water pump power										X											X
Seasonal heat and cold storage											X										
・Hot-/chilled-water/ice thermal energy storage	X	X		P				P		P										X	XO
・Ground heat exchangers	X										X										O *158
・Stratified thermal storage tank	X	X									X										X
・Ground-coupled (uninsulated) stratified tank																					O *158
・With phase change																					O *185
Plant heating equipment																					
・Boiler *186	P	X		X	X		X	P	X	X	X	I	X	X	X	X			X	X	XO
・Water heater *186	X	X					X			X	X	I			X	X *187				X	X
・Ground source water-to-water heat pump				P	P		P		X *188	I	X	R			O	X *187			X	X	X

*182 Single- and double-effect chillers

*183 Water-side economizer

*184 As add-in. Vertical or slanted holes in user-specified configuration. 3D model.

*185 Additional component from Transsolar

*186 Gas, electric, diesel, gasoline, propane, fuel oil, coal, steam

*187 User can specify curves of boiler/heater performance

*188 Simple fixed efficiency model for ground-source heat pump

*269 Hotwater single-effect chiller / steam double-effect chiller

Table 8 HVAC Equipment	BEST	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
Air-to-air energy recovery																					
・Generic sensible heat exchanger		X	X	X	P			P		X	X	X	X		X	X			X	X	X
・Flat plate sensible heat exchanger			X	X						X	X	X	X		X	X				X	X
・Sensible and latent energy exchanger	X	X	X	X				P		X	X	X	X		X	X				X	X
Domestic/service water heating																					
・User-configurable water piping network	X											X									X
・Domestic/service water heater *189	X				X		X		X	X	X	R			X	X		R	X	X	X
・D/SHW water consumption									X	X		R			X					X	X
・Stratified water heater tank		X										R									X *190
・Combi-tanks for space and water heating *191																					XO *192
Controls, thermostats and strategies																					
・Humidistat	X	X	X	X			P	P		X		R	X		X	X	P		X	X	O *158
・Zone thermostat *193	X	X	X	X	X		X	P	X	X	X	X	X	X	X	X	X	X	X	X	X
・Zone supply air setpoint *194	X	X	X	X	X			P	X	X	X	X	X *195		X	X			X	X	X
・Outside air control *196	X	X	X		P			P		X	X	X	X		X	X	P		X	X	X
・System availability *197	X	X	X	X	X			P	X	X	X	X	X *198		X	X		R	X	X	X
・Plant heating/cooling load control for staging and sequencing plant equipment		X		X	X			P		X	X		X		X	X	P		X	X	X
・Condenser control *199					X					X	X				O					X	X
・Nighttime flushing for passive cooling	X				X		X			X	X	X		X	X	X		X		X	X
・Economizer		X			X		X	P	X	X	X	X	X	X	X	X				X	X
・User-defined control strategy *200			X								X				X	X					X

*189 Gas and electric

*190 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)

*191 Multiple heat exchanger and or inlets/outlets with stratification devices

*192 Standard components as well as add-ons from Transsolar and components from the TESS libraries

*193 Single heating setpoint, single cooling setpoint, single heating/cooling setpoint, dual setpoint with deadband

*194 Scheduled, coldest, warmest, mixed air, outside air, minimum/maximum humidity

*195 Scheduled, coldest, warmest, outside air, min/max humidity

*196 Scheduled, outdoor dry bulb and wet bulb temperature, outdoor air flow

*197 Scheduled, night cycle control, differential thermostat, high/low temperature on/off

*198 Scheduled, high/low temperature on/off

*199 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)

*200 Any combination of feedback/feed-forward controllers

Table 8 HVAC Equipment	BEST	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
Refrigeration systems for warehouse and retail food storage																					
・Refrigerant loops *201											X										
・Multiple staged refrigerant compressors											X										
・Refrigerated casework *202					X					X	X						P				
・Refrigerant air/evaporative condensers with heat reclaim and control					X					X	X										
・User-selectable refrigerants											X										
・Ammonia chillers and low temperature brine											X										
・Brine and refrigerant loop fan coil for coolers/freezers											X										
Ice rink in building space																					
・Brine loop and chiller refrigeration system											X				O						
・Ice-to-ceiling radiative and ice-to-space air exchange											X				O						
・Under floor heating (with ice load)											X				O						
・Ice resurfacing											X				O						
Indoor/outdoor swimming pool												R			O						O *203

*201 Connects coils, casework, compressors, condensers

*202 Zone interaction, frost forming refrigerant coil and controls

*203 Additional component from Transsolar

Table 9 Environmental Emissions	BEST	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
Power plant energy emissions		X		P	X	*3	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_2, CO, CH_4, NOx)		X	P	P	X	*3	X		X	X	X	X	X *204	X		X			X		
Carbon equivalent of greenhouse gases		X			X	*3				X						X			X		I
Criteria pollutants (CO, NOx, SO_2, PM, Pb)						*3				X			X *205			X					
Ozone precursors (CH_4, NMVOC, NH_3)						*3				X											
Hazardous pollutants (Pb, Hg)						*3				X											
Water use in power generation						*3				X											X
High- and low-level nuclear waste						*3				X											
Pollutant emissions factors *206						*3				X				X							

*204 CO_2, NOx

*205 NOx, SO

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

Table 10 Climate Data Availability	BEST	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
Weather data provided																					
・With the program *207	X	X	X	X		X	X	X	X	X *208	X *209	X	X		X	X	P		X	X	X *210
・Separately downloadable			X			X	X			X *208	X *209	X	X		X	X			X	X	X
Generate hourly data from monthly averages				X *211		X	X									X				X	X
Estimate diffuse radiation from global radiation				X	X	*3	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 *214			X	X	X		X *212					X *213	X *214	X *214	X			X
・EnergyPlus/ESP-r *215	X		X			X				X		X		X					X		X
・European Test Reference Year *216			X			X						X			X						X
・Typical Meteorological Year *217	X	X		X *218	X	X		P		X	X	X			X		X *219	X		X	X
・Typical Meteorological Year 2 *220	X	X			X	X	X		X *221	X	X	X			X		X *219	X	X	X	X
・Solar and Wind Energy Resource Assessment *222										X											
・Weather Year for Energy Calculations 2 *223				X	X	X	X	P		X	X				X						
・Solar and Meteorological Surface Observation Network *224										X											
・International Weather for Energy Calculations *225						X		P		X					X					X	X
・Japan AMeDAS weather data *226	X																				X
・DOE-2 text format					X	X				X	X									X	
・BLAST text format		X				X				X								X			
・ESP-r text format										X		X									
・ECOTECT WEA format						X				X											

*207 CD, DVD, distribution download

*208 Five weather files provided with EnergyPlus. More than 900 locations worldwide available for download

*209 Automatically downloads weather files from web site.

*210 More than 1000 locations worldwide including TMY2 data and Meteonorm-generated data

*211 From daily measured data (max, min, average)

*212 By specifying the data format

*213 C source code for weather data conversion utility supplied to enable easy implementation of various formats.

*214 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.

*215 Crawley, Hand, and Lawrie (1999)

*216 European Commission (1985)

*217 NCDC (1981)

*218 Based on measured data

*219 Through an additional program, Domus weather converter, which comes with PowerDomus

*220 NREL (1995)

*221 Use of TMY2 and other text formats possible using companion WeatherMaker utility.

*222 swera.unep.net/swera/

*223 ASHRAE (1997)

*224 NCDC (1993)

*225 ASHRAE (2001b)

*226 Akasaka et al. (2003)

Table 11 Economic Evaluation	BEST	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
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 *227			X	X	X	*3		X		X	X		X	X		X	P			X	E
・Scheduled variation in all rate components			X	X	X	*3				X	X		X	X	X	X	P		X	X	X
・User selectable billing dates					X	*3				X	X			X			P			X	E
Life-cycle costs																					
・Component and equipment cost estimating				X	X	*3	X		X	X	X		X *228			X				X	
・Standard life-cycle costing *229						*3	X		X		X	P *230	X			X					X

*227 Fixed charges, block charges, demand charges, ratchets

*228 Via companion program that integrates with HAP data.

*229 Including government methodologies and private-sector rates and taxes

*230 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.

Table 12 Results Reporting	BEST	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
Standard reports	X	X		X	X	X	X	X	X	X	X	X *231	X		X	X		X	X	X	X
User-defined reports		X *232	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	
・Tab-separated value			P	X		X		X		X	X	X				X		X	X	X	X
・HTML			X			X				X	X	P				X				P	
・Graph	X					X		X	X		X	X	X	X	X	X	X		X	P	X
・Statistics	X			X								X				X					X
	X	X *232	X	X		*3	X		X	X	X	X	X	X	X	X	X		X		X
Standardized binned variable report																					
・Time-binned variable					P	*3			X	X	X	X			X	X	X		X	P	X
・Variable versus variable						*3				X		X			X	X	X		X		O *158
Meters																					
・Energy end-uses *233	X	X	X	X	X	*3	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	X
・Peak demand period user-selectable *234	X			X		*3				X	X					X			X		X *235
・Consumption by energy source	X	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 *236			X	X			X		X
・Multiple levels of sub-metering	X		X	X		*3				X	X				X						X
Auto-sizing report	X			X	X	*3			X	X	X		X		X	X			X	X	
Automatic generation of energy balance checks *237									X	X		X				X *238			X		X
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						X

*231 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.

*232 User reports processed by Report Writer Program

*233 Individual metering for lighting, heating, cooling, fan, pumps, etc.

*234 15/30/60 minute fixed/moving window

*235 Must be a multiple of the selected time step

*236 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.

*237 User-selected zones and surfaces (radiative, convective, conductive) at each time step

*238 Zone energy balance

Table 13 Validation	BEST	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
IEA ECBCS Annex 1 *239												X									X
IEA ECBCS Annex 4 *240												X									X
IEA SHC Task 8 *241												X						X			X
IEA ECBCS Annex 10 *242												X									X
IEA SHC Task 12																					
・Envelope BESTEST *243	X	X		X	X	P		P	X *244	X *245		X	X *246	X	X	X	X *247	X	X	X *248	X
・Empirical *249			X *250	X		P		P				X						X	X		X
IEA SHC Task 22																					
・HVAC BESTEST Volume 1 *251					X					X *252	X	X *253			X					X *248	X
・HVAC BESTEST Volume 2 *254					X					X		X			X					X	X
・Furnace BESTEST *255										X		X									
・RADTEST *256					X							X			X						X
IEA ECBCS Annex 41 Moisture																	X *257				
HERS BESTEST *258		X			X	P								X				X			
ASHRAE 1052-RP *259		X			X					X											

*239 Oscar Faber and Partners (1980), US Department of Energy (1981)

*240 Glasgow Commercial Building Monitoring Project, 1984, as reported by Strachan (2000)

*241 Bloomfield (1989)

*242 Lebrun and Liebecq (1988)

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

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

*245 Henninger and Witte (2004a)

*246 Per ASHRAE Standard 140-2001

*247 Thermal Systems Laboratory (2004)

*248 www.trane.com/commercial/software/Trace/BestTest.asp?pid=TRACE

*249 Lomas et al. (1994)

*250 The core of the simulation engine (tsbi3) was validated

*251 Neymark and Judkoff (2002), also ANSI/ASHRAE Standard 140 (2004)

*252 Henninger and Witte (2004b)

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

*254 Neymark and Judkoff (2004)

*255 Purdy and Beausoleil-Morrison (2003)

*256 Achermann and Zweifel (2003)

*257 Comparison of whole-building hygrothermal simulation models

*258 Judkoff and Neymark (1995b)

*259 Spitler, Rees, and Xiao (2001)

Table 13 Validation	BEST	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
BEPAC Conduction Tests *260										X		X									
BRE/EDF validation project *261												X									
PASSYS project *262												X									
CIBSE TM33 *263						P						X				X *264			X		
ISO 13791 *265						P						X							X		
Other							X *266														

*260 Bland (1993)
*261 Bloomfield et al. (1995)
*262 Jensen (1993)
*263 Macdonald, Strachan and Hand (2004)
*264 Study complete subject to revisions being made by CIBSE
*265 ISO TC 163/SC 2 (2004)
*266 Soebarto (1997)