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BUILDING ENERGY
EFFICIENCY PROJECT

Different Simulation Programs

Ministry of POWER
GOVERNMENT OF INDIA

ENERGY IS LIFE
BEE
CONSERVE IT

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Embassy of Switzerland in India

Simulation during the design process: Too often used later in the design

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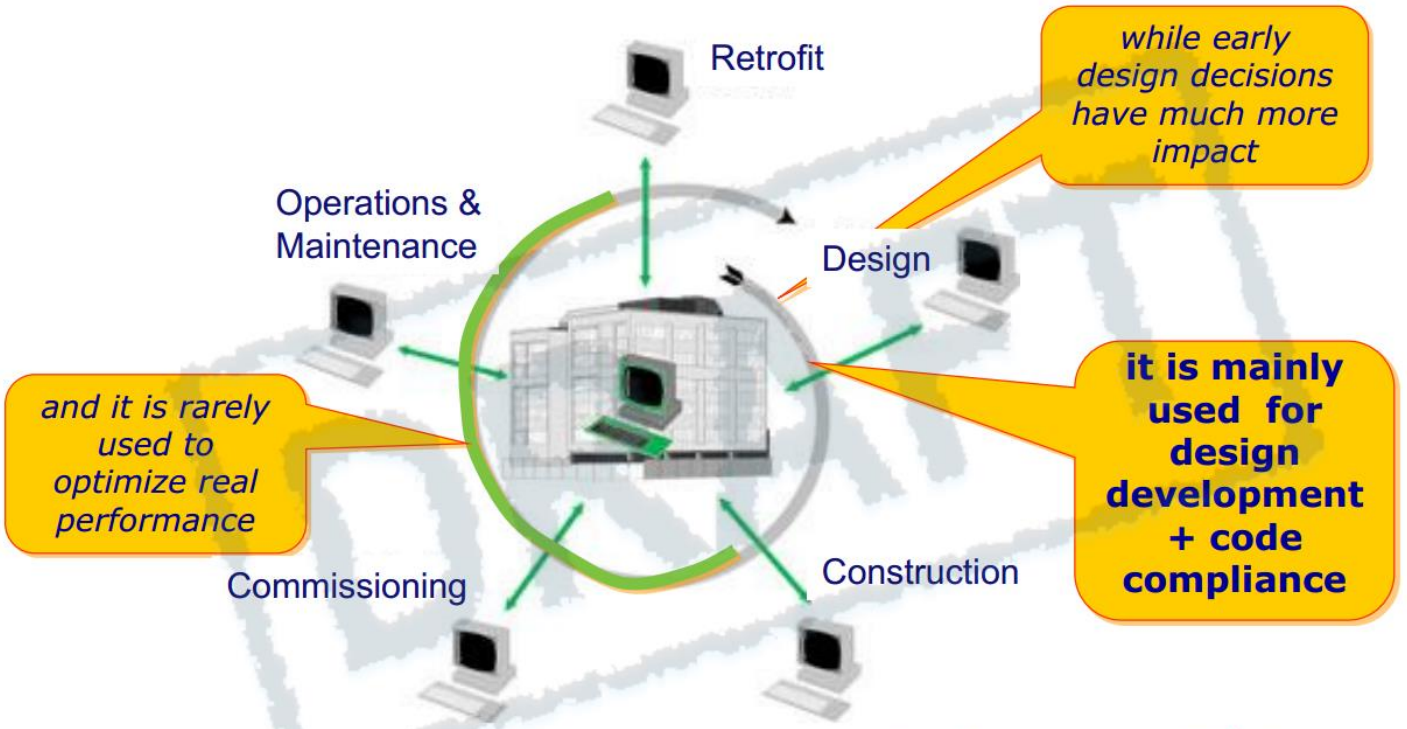
Simulation in the building life-cycle



/ Jan Hensen

Objectives of the presentation

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- Compare softwares under different criteria
- Incomplete analysis by nature
- Look at capabilities for Integrated Design Process, early stage design concepts of advanced systems

Building simulation programs Typology

- Monthly balance
  - LESOSAI, ….
- Some of the dynamic building simulation programmes
  - Simplified
    - Ecotect
  - Complete detailed
    - Energyplus
    - TRNSYS
    - IDA-ICE
    - IES-VE
  - Manufacturer based programs
    - HAP
    - Trace

Building centered programs with systems

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- Public domain source code
  - Energyplus
    - Well documented, tested
    - Design Builder (Interface)
      - Graphical building interface
      - CFD (validation …)
      - HVAC interface still limited (need knowledge of input files to go further, cannot be taken back to Design Builder)
- Private source code
  - IES-VE
  - TAS

System centered programs with building

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- TRNSYS
  - System based, building integrated as a component
  - Modular
    - User written modules can be added
    - Many additional modules available
    - Many PhD, Master with a Trnsys routine as side product
    - Good user forum
    - Physically intuitive
    - Danger of the freedom for the user
  - Co-simulation possible (EES, Matlab, …)
  - Well documented, validated

Algorithmic

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- Energyplus
- TRNSYS

Equation based models

- Spark
- Dymola
- Simulink
- Modelica
- IDA-ICE

Algorithmic versus equation based

- Equation more flexible
- Not sure to get a working model
- Normally much longer simulation time

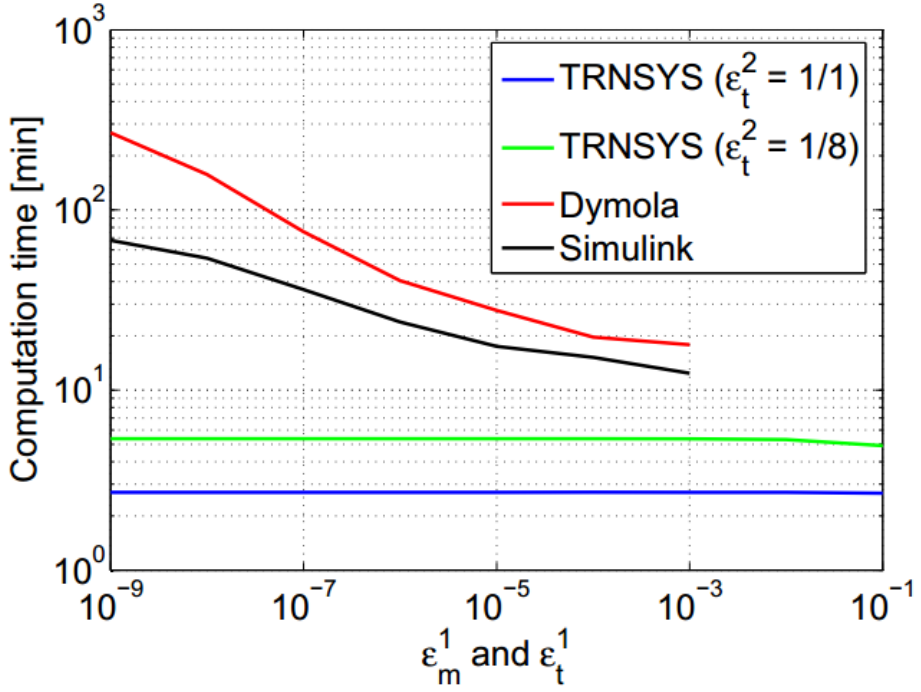

Figure 5: Computation time as a function of the solver tolerance and the number of time step per hour.

Summary of features (2005 status)

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Table 1 ***General Modeling Features***	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[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		X			[3]			X	X		X	X	X	X	X	X		X	X	X
▪ Coupled loads, systems, plant calculations		X					X	X[4]	X	X	X		X	X	X	X	X			X
▪ Space temperature based on loads-systems feedback	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
Time step approach															X					
▪ User-selected for zone/environment interaction	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	X[2]	X[10]					X		X	X[16]	X					R				
▪ User-selected for both building and systems											X			X	X	X				X[17]
▪ Dynamically varying based on solution transients									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[19]
▪ Windows, skylights, doors, and external shading	X	X	X	X	X	P	X		X	X	X		X	X[20]	X	X	X	X	X	X

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Table 1 ***General Modeling Features***	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[21]		X	X	X			X		
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[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 ▪ Simple models (single lumped capacitance per zone)			E		[3]	X			X	X	X X			X					X	X XO[37]

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Table 2 ***Zone Loads***	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[39]	[3]	X			X	X[39]	X		X	X	X	X	X	X	X	X
Building material moisture adsorption/desorption[40]	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	[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
Human thermal comfort[49]																				
▪ 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[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																	

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Table 2 Zone Loads	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 design day sizing calculations																				
▪ Dry bulb temperature	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
▪ Dew point temperature or relative humidity			X	X[54]	[3]	X	X		X	X		X		X	X			X	X	
▪ User-specified[55]			X	X[56]	[3]	X	X		X	X		X	X	X	X			X	X	X

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Table 3 ***Building Envelope, Daylighting and Solar***	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	P		X				X											X
▪ Solar gain through blinds accounts for different transmittances for sky and ground diffuse solar			X		[3]	X			X						X			X		X
▪ Solar gain and daylighting calculations account for inter-reflections from external building components and other buildings		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	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 devices			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			P[63]					X	P	X		X				X			X
▪ distribution computed at each hour[64]	X			X[65]						X	X				X					E I[66]
▪ distribution computed at each timestep[67]									X						X					E I[66]
▪ Beam solar radiation passes through interior windows (double-envelope)		X	P		X				X	X[68]				X[69]	X	P		X		X
▪ Track insolation losses (outside or other zones)											X				X					

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Advanced fenestration																				
▪ Controllable window blinds		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[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]		P[75]	X	P	X		P		X	X[76]	P[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			P		[3]				X		X[61]			X	X			X	X	X
▪ Window blind model[82]			X		X				X	X	X[60]		X[83]		X					X
▪ User-specified daylighting control		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
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	

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○ Ito, Kimura, and Oka (1972) correlation											X			X						
○ User-selectable			X		[3]				X[86]		X			X	X	X		X	X	X
▪ 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[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[92]	X	X	X		X	X	X			X	X	
▪ Stepped or dimming electric lighting controls[93]		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

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Table 3 ***Building Envelope, Daylighting and Solar***	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[103]			O	X	X	X	X		X
Surface conduction ▪ 1-dimension ▪ 2- and 3-dimension	X	X	X P	X	X	X	X	X	X X	X	X R I	X	X	X O	X	X	X	X	X	X
Ground heat transfer ▪ ASHRAE simple method[104] ▪ 1-dimension ▪ 2- and 3-dimension slabs ▪ 2- and 3-dimension basements	P	X	X P	P	X [3] [3]	X	X	X	X X[106] X	X	X R R	X	X	X O O	X	X O[107] O[107]	X R R	X	P	X O[105] O[105] 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

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Table 4 Infiltration, Ventilation, Room Air and Multizone Airflow	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	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
Automatic calculation of wind pressure coefficients		X	P		[3]				P[108]						X		X	X		
Natural ventilation[109]		X	P		[3]				X	P[110]	X			X	X	X	X	X		O[111]
Hybrid natural and mechanical ventilation		X	P			X					I			X	X	X		X		O[111]
Window opening for natural ventilation controllable[112]			X[113]			X			X		X				X[114]	P	X	X		O[111]
Multizone airflow (via pressure network model)		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				

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Table 5 ***Renewable Energy Systems***	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[121]	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[122]
▪ High temperature concentrating collectors[123]																				X
User-configured solar systems[124]																				X
Integral collector storage systems																				X
Photovoltaic power		X			X			X[125]	X	X	X				X					X
Hydrogen systems[126]											X									X
Wind power											X									X

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

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Table 7 ***HVAC Systems***	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				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				P		X	X	X[138]	X[139]	X	X	X	X	R	X	X	X
Air loops[140]			X				P		X	P	X	X		X	X	X	R	X	X	X
Fluid loops[141]			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[142]
Fluid loop pumping power[143]										X	X[144]	X		X					X	
Pipe flow-pressure networks[145]											X			X						
Air distribution system[146]						X	P		X	X	X[147]	X	X	X	X		R			X
Multiple supply air plenums			P						X	P	X[147]				X					X
Simplified demand-controlled ventilation																				
▪ Ventilation rate per occupant and floor area			X			X			X	X			X	X[148]	X	X		X	P	X
▪ Ventilation air flow schedule		X	X			X			X	X	X		X[149]	X	X	X	X	X	X	X
▪ User-defined ventilation control strategy[150]		X[151]	X								X			X	X			X		X
CO_2 modeling																				
▪ CO_2 zone concentrations, mechanical and natural											X	X		X	X					O[111]

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Table 7 HVAC Systems	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 path transport																				
▪ CO_2 based demand-controlled ventilation		X[152]									X	X		X	X				P	EO[111]
Automatic sizing																				
▪ HVAC components		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	P			X			X			X		X	X			X	X	P
▪ Hot, cold, and condenser water loops			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	
▪ Variable air volume reheat/variable speed fan (UFAD)		X	X				P		X		R				X			X	X	
▪ Powered induction unit																		X		
○ Series PIU reheat				X			P		X	X		X		X					X	
○ 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[156]									
▪ Fan coil (2 pipe)	X		X				P				X	X							P	O[158]
▪ Fan coil (4 pipe)	X	X	X	X		X	P		X	X		X		X	X			X	X	O[158]
▪ Unit heater[159]	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	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	O[158]

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Table 7 HVAC Systems	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
Unitary equipment											I[156]									
▪ DX system																				
o Heating/cooling coils	X	X	X	X		X	P	X	X	X	X	X	X		X	X	R	X	X	X
o Coil latent capacity degradation[161]									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	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

Table 8 ***HVAC Equipment***	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	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	R	X	X	X
▪ Detailed fin/tube water cooling coil	X[163]								X		X			X		X				X
▪ DX coil																				O[158]
o Bypass factor cooling empirical	X								X			X			X[164]					
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[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																				
o Hydronic[167]	X[163]	X							X		X[168]			X	X					X
o 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			P		X	X									X	X
Humidifier							P													
▪ Steam (electric)	X	X	X						X		X	X		X	X	X		X	X	O[158]
▪ Humidifier water consumption		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

Table 8 ***HVAC Equipment***	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
▪ 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		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[172]
▪ Direct-couple to power source											X									O[158]
Heat exchangers[173]																				
▪ Plate frame									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]									
o Centrifugal	X		X	X		X	P		X	X		X		O	X[175]	X			X	O[158]
o Centrifugal with VSD				X[176]					X[177]	X		X			[175]				X	O[158]
o Reciprocating	X		X			X	P		X	X		X		O	[175]				X	O[158]
o Double-bundle condenser/heat recovery	X		X	X			P		X	X					[175]				X	O[158]
o Screw			X	X[178]			P		X[179]	X		X		O	[175]				X	O[158]
o Scroll			X							X		X			[175]				X	O[158]
o Constant COP	X	X	X			X	P	X	X	X				X	[175]			X	X	O[158]
▪ Engine-driven chiller[180]	X		X	X			P		X			X			[175]				X	O[158]
▪ Combustion turbine chiller[181]	X		X				P		X			P			[175]				X	O[158]

Table 8 ***HVAC Equipment***	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																				
o Steam absorption chiller	X		X	X			P		X	X		X[182]			175				X	O[158]
o Gas-fired absorption chiller							P					X			175				X	
o Gas-fired hot water absorption chiller heater	X			X					X	X									X	X[182]
▪ Free cooling chiller	X			X					X	X				X				X	X	X
▪ Air-to-water heat pump chiller			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																				
o Single speed	X		X	X		X	P	X	X	X	X	X				X			X	X
o Two speed									X		X	X							X	X
o Variable speed				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									I	X	R	X		X[184]					X	X
▪ DX cooling coil evaporative condenser																				
o Simple effectiveness model				X					X	X									X	X
o Water usage and water pump power									X											X
Seasonal heat and cold storage										X										
▪ Hot-/chilled-water/ice thermal energy storage	X		P				P		P										X	XO
▪ Ground heat exchangers										X										O[158]
▪ Stratified thermal storage tank	X									X										X
▪ Ground-coupled (uninsulated) stratified tank																				O[158]
▪ With phase change																				O[185]
Plant heating equipment																				
▪ Boiler[186]	X		X	X		X	P	X	X	X	I	X	X	X	X			X	X	XO

Table 8 ***HVAC Equipment***	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
▪ Water heater[186]	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
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				P		X	X	X	X		X	X				X	X
Domestic/service water heating																				
▪ User-configurable water piping network											X									X
▪ Domestic/service water heater[189]				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			P	P		X		R	X		X	X	P		X	X	O[158]
▪ Zone thermostat[193]	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			P	X	X	X	X	X[195]		X	X			X	X	X
▪ Outside air control[196]	X	X		P			P		X	X	X	X		X	X	P		X	X	X
▪ System availability[197]	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
▪ Economizer	X			X		X	P	X	X	X	X	X	X	X	X				X	X

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Table 8 ***HVAC Equipment***	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
▪ User-defined control strategy[200]		X								X				X	X					X
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]

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Table 9 ***Environmental Emissions***	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, NO_x)	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, NO_x, 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							

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Table 10 ***Climate Data Availability***	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[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
▪ European Test Reference Year[216]		X			X						X			X						X
▪ Typical Meteorological Year[217]	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[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

Table 10 ***Climate Data Availability***	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
▪ Japan AMeDAS weather data[226]																				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											

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Table 11 ***Economic Evaluation***	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

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Table 12 ***Results Reporting***	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	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[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	
▪ 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	P	X
▪ Statistics			X								X				X					X
Load, system, and plant variables reportable at time step with daily, monthly, and annual aggregation	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	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
▪ Peak demand period user-selectable[234]			X		3				X	X					X			X		X[235]
▪ 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[236]			X	X			X		X
▪ Multiple levels of sub-metering		X	X		3				X	X				X						X
Auto-sizing report			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

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Table 13 Validation	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	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											
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]														

Some other aspects of simulation programs capabilities

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	BLAST	Bsim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EneryPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	Power Domus	SUNREL	Tas	TRACE	TRNSYS	Design Builder
Co-simulation																				X EES, Matlab, …	
Source code				X					X	X	X						?			X	
Modularity																				XX	
Compile own version				X					X		X									X	
Developing own modules																				XX	
Debugging																				XX	
Visualising the simulation and results				X					X						X					XX, flexible, with EES if necessary	
External movable blinds									X detailed		?			?	?			?		X basic, detailed	
Slab cooling									X		?			X	?			?		X	
Radiant panels									X		?			X	?			?		X	
Natural ventilation									X		?			?	X			?		X	
Interoperability									X					X	X						X
Whole building energy compliance				X					X	X		X	X		X			X	X	(X)	X
Detailed modeling at concept level																				X	
Flexibility																				X	

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THANK YOU