EnergyPlus Articles from the *Building Energy Simulation User News*

Through 12/31/2002

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January 2003

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technologies, Building Systems and Materials Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

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Ask an EnergyPlus Expert: Surface Vertices

Question: Surface Vertices
Following the convention in the object SurfaceGeometry, from which side do the surfaces need to be faced: inside or outside? And what about floor and ceiling?

Answer:
The surface geometry rules are applied when viewing a surface from its exterior side, as if you are standing outside the zone looking at a surface.

For ceilings, view from above, for floors, view from below. The choice of which vertex is the starting point is arbitrary. Any corner may be selected, but you must follow the correct clockwise or counterclockwise order for the remaining vertices. An implied azimuth is computed based on your selection of starting vertex.

To verify your geometry, request the surface details report: REPORT, Surfaces, Details;

This produces a summary of all surfaces with length, width, tilt, and azimuth in the eio output file. For ease of reading, paste the report into a spreadsheet program and separate on commas.

The IOReference states:
Field: VertexEntry
Surfaces are always specified as being viewed from the outside of the zone to which they belong. (Shading surfaces are specified slightly differently and are discussed under the particular types). EnergyPlus needs to know whether the surfaces are being specified in counterclockwise or clockwise order (from the SurfaceStartingPosition). EnergyPlus uses this to determine the outward facing normal for the surface (which is the facing angle of the surface very important in shading and shadowing calculations.

Surfaces are always specified from the "outside" of the surface.

ASK AN ENERGYPLUS EXPERT: SYSTEM TYPES, BLINDS AND SLATS, HEAT TRANSFER SURFACES, CONTROL TYPES SCHEDULES

Question:
Does EnergyPlus support heating or cooling systems other than air conditioning systems? I am thinking of water systems like underfloor heating, active wall/ceiling systems and radiator systems.
Answer:
Yes, it can do all of these. In addition to forced air systems using DX and chilled water cooling, EnergyPlus can model hot water radiators (BASEBOARD HEATER:Water:Convective), heated and cooled surfaces (LOW TEMP RADIANT SYSTEM:HYDRONIC, LOW TEMP RADIANT SYSTEM:ELECTRIC) and gas or electric radiant heaters (HIGH TEMP RADIANT SYSTEM).

Question:
I noticed in the EnergyPlus Input/Output Reference Manual that Fig. 5 (p. 60) does not show blinds consisting of slats. Further the verbal description of slat details in the Manual is unclear.
My question, then, is this: What is the slat width and the slat separation?
Answer:
In the field descriptions for Material:WindowBlind, the references to Fig. 5 are incorrect; they should all be references to Fig. 6, found on p. 66. Our apologies for the confusion. Also, check out the "blinds" section of the Engineering Doc Reference under "Optical Properties of Windows". There is also an example file: PurchAirWindowBlind.idf which may illustrate the use for you.

Question:
In the Control Types Schedules, say for the thermostat of a VAV with reheat, you are using discrete numbers 0 through 4. When the Day Schedules are created, I assume each whole number in the Day Schedule corresponds to a type of control such as SINGLE COOLING SETPOINT or DUAL SETPOINT WITH DEADBAND and is used to switch between the different types of control based on occupancy. How is the correlation made between the whole numbers used in the Day Schedule and the type of control?
Answer: **(see pp. 324ff in the Input Output Reference for more details)**
0 – Uncontrolled (No specification or default)
1 – Single Heating Setpoint
2 – Single Cooling SetPoint
3 – Single Heating/Cooling Setpoint
4 – Dual Setpoint (Heating and Cooling) with deadband

Question:
I'm confused about what is supposed to be inserted in the Surface:HeatTransferSub-OutsideFaceEnvironmentObject ?
Is (it) the surface of the other zone or the name in the UserSuppliedSurfaceName ?
Answer:
Excerpt from the InputOutputReference for HeatTransfer surfaces:

<u>Field: Outside Face Environment</u>
This value can be one of several things depending on the actual kind of surface.

1) OtherZoneSurface
If this surface is an internal surface, then this is the choice. The value will either be a surface in the base zone or a surface in another zone. The heat balance between two zones can be accurately simulated by specifying a surface in an adjacent zone. EnergyPlus will simulate a group of zones simultaneously and will include the heat transfer between zones. However, as this increases the complexity of the calculations, it is not necessary to specify the other zone unless the two zones will have a significant temperature difference. If the two zones will not be very different, temperature-wise, then the surface should use itself as the outside environment. In either case, the surface name on the "outside" of this surface is placed in the next field.

2) ExteriorEnvironment
If this surface is exposed to outside temperature conditions, then this is the choice. See Sun Exposure and Wind Exposure below for further specifications on this kind of surface.

3) Ground
If this surface is exposed to the ground, then this is the choice.
The temperature on the outside of this surface will be the Ground Temperature.

4) OtherSideCoeff
If this surface has a custom, user-specified temperature or other parameters (see OtherSideCoefficient specification), then this is the choice. The outside face environment will be the name of the OtherSideCoefficient specification.

<u>Field: Outside Face Environment Object</u>

If neither OtherZoneSurface or OtherSideCoeff are specified for the Outside Face Environment (previous field), then this field should be left blank. As stated above, if the Outside Face Environment is "OtherZoneSurface" then the value of this field must be the surface name whose inside face temperature will be forced on the outside face of the base surface. This permits heat exchange between adjacent zones (interzone heat transfer) when multiple zones are simulated, but can also be used to simulate middle zone behavior without modeling the adjacent zones. This is done by specifying a surface within the zone.
Continued on the next page

Answer: (continued)

For example, a middle floor zone can be modeled by making the floor the Outside Face Environment for the ceiling, and the ceiling the Outside Face Environment for the floor. Note that zones with interzone heat transfer are not adiabatic and the internal surfaces contribute to gains or losses. Adiabatic surfaces are modeled by specifying the base surface itself in this field. Equally, if the Outside Face Environment is "OtherSideCoeff" then this field's value must be the OtherSideCoefficient name.

<u>Field: Outside Face Environment Object</u>

If the base surface has Outside Face Environment = OtherZone or OtherSideCoeff, then this field must also be specified for the subsurface. Otherwise, it can be left blank.

If OutsideFaceEnvironment for the base surface is OtherZone, this field should specify the subsurface in the opposing zone that is the counterpart to this subsurface. The constructions of the subsurface and opposing subsurface must match, except that, for multi-layer constructions, the layer order of the opposing subsurface's construction must be the reverse of that of the subsurface.

If OutsideFaceEnvironment for the base surface is OtherSideCoeff, this field could specify the set of Other Side Coefficients for this subsurface. If this is left blank, then the Other Side Coefficients of the base surface will be used for this subsurface. Windows and GlassDoors are not allowed to have Other Side Coefficients.

So, to answer your question specifically …

If the base surface is an interzone surface (i.e., OtherZone case), then this field should be the name of the surface (HeatTransfer:Sub) in the opposing Zone.

INTERNATIONAL WEATHER DATA FOR ENERGYPLUS

One of the most common questions asked of the EnergyPlus Development Team is *'where can I get weather data for my location?'* In the US and Canada, there are good quality, free, public domain data (TMY2 and CWEC). For other locations, it's a bit tougher. ASHRAE (TC 4.2 Weather Information) sponsored development of IWEC (International Weather for Energy Calculations) data for 227 locations in more than 70 countries outside the US and Canada. In your country, the local meteorological office often has better and more complete data than is available through the World Meteorological Organization (and in the US, the National Climatic Data Center, where ASHRAE obtained the source hourly data for the IWEC). If there wasn't enough good quality data available, there is no location in the IWEC.

Below is the list of international locations (IWEC) that will be available (again) soon from ASHRAE. We have licensed the data for EnergyPlus users at no cost. We will place the new IWEC data on our web site (www.energyplus.gov) as soon as it becomes available. If you have data for locations that are not listed below and would be willing to share the data with other EnergyPlus users, please contact Dru Crawley (Drury.Crawley@ee.doe.gov).

INTERNATIONAL WEATHER FOR ENERGY CALCULATIONS (IWEC WEATHER FILES)
Station_name,Country,Time Zone,Latitude (deg min),Longitude (deg min),Elevation (m)

Algeria	ALGIERS,DZA,+ 01 00,N 36 43,E 003 15,25
Australia	
BUENOS AIRES,ARG,- 03 00,S 34 49,W 058 32,20	LEARMONTH,AUS,+ 08 00,S 22 14,E 114 05,6
ADELAIDE,AUS,+ 09 30,S 34 56,E 138 31,4	MELBOURNE,AUS,+ 10 00,S 37 40,E 144 50,141
BRISBANE,AUS,+ 10 00,S 27 23,E 153 06,5	PERTH,AUS,+ 08 00,S 31 56,E 115 57,29
CANBERRA,AUS,+ 10 00,S 35 18,E 149 11,577	PORT HEDLAND,AUS,+ 08 00,S 20 14,E 119 06,8
DARWIN,AUS,+ 09 30,S 12 24,E 130 52,30	SYDNEY,AUS,+ 10 00,S 33 57,E 151 11,3
Austria	
GRAZ,AUT,+ 01 00,N 47 00,E 015 26,347	SALZBURG,AUT,+ 01 00,N 47 48,E 013 00,450
INNSBRUCK,AUT,+ 01 00,N 47 16,E 011 21,593	VIENNA SCHWECHAT,AUT,+ 01 00,N 48 07,E 016 34,190
LINZ,AUT,+ 01 00,N 48 14,E 014 12,313	
Belarus	MINSK,BLR,+ 02 00,N 53 52,E 027 32,234
Belgium	
BRUSSELS,BEL,+ 01 00,N 50 54,E 004 32,58	SAINT HUBERT,BEL,+ 01 00,N 50 02,E 005 24,557
OOSTENDE,BEL,+ 01 00,N 51 12,E 002 52,5	
Bolivia	LA PAZ,BOL,- 04 00,S 16 31,W 068 11,4042
Bosnia and Herzegovina	BANJA LUKA,BIH,+ 01 00,N 44 47,E 017 13,156
Brazil	
BELEM,BRA,- 03 00,S 01 23,W 048 29,16	SAO PAULO,BRA,- 03 00,S 23 37,W 046 39,803
BRASILIA,BRA,- 03 00,S 15 52,W 047 56,1061	BANDAR SERI BEGAWAN,BRN,+ 08 00,N 04 56,E 114 56,15
RECIFE,BRA,- 03 00,S 08 06,W 034 53,19	
Bulgaria	
PLOVDIV,BGR,+ 02 00,N 42 08,E 024 45,185	VARNA,BGR,+ 02 00,N 43 12,E 027 55,43
SOFIA,BGR,+ 02 00,N 42 44,E 023 23,595	
Chile	
ANTOFAGASTA,CHL,- 04 00,S 23 26,W 070 26,120	PUNTA ARENAS,CHL,- 04 00,S 53 00,W 070 51,37
CONCEPCION,CHL,- 04 00,S 36 46,W 073 03,16	SANTIAGO,CHL,- 04 00,S 33 23,W 070 47,476
EASTER ISLAND,CHL,- 06 00,S 27 09,W 109 25,47	

Continued …

INTERNATIONAL WEATHER FOR ENERGY CALCULATIONS (IWEC WEATHER FILES)
Station_name,Country,Time Zone,Latitude (deg min),Longitude (deg min),Elevation (m)

China	
BEIJING,CHN,+ 08 00,N 39 48,E 116 28,32	LANZHOU,CHN,+ 08 00,N 36 03,E 103 53,1518
GUANGZHOU,CHN,+ 08 00,N 23 08,E 113 19,8	SHANGHAI,CHN,+ 08 00,N 31 10,E 121 26,7
HARBIN,CHN,+ 08 00,N 45 43,E 126 41,143	SHENYANG,CHN,+ 08 00,N 41 47,E 123 29,43
KUNMING,CHN,+ 08 00,N 25 01,E 102 41,1892	URUMQI,CHN,+ 08 00,N 43 50,E 087 32,786
Colombia	BOGOTA,COL,- 05 00,N 04 42,W 074 08,2548
Cuba	HAVANA,CUB,- 05 00,N 22 59,W 082 24,59
Cyprus	LARNACA,CYP,+ 02 00,N 34 53,E 033 38,2
Czech Republic	
OSTRAVA,CZE,+ 01 00,N 49 43,E 018 11,256	PRAGUE,CZE,+ 01 00,N 50 06,E 014 17,366
Denmark	COPENHAGEN,DNK,+ 01 00,N 55 38,E 012 40,5
Ecuador	QUITO,ECU,- 05 00,S 00 09,W 078 29,2812
Egypt	
ASWAN,EGY,+ 02 00,N 23 58,E 032 47,194	CAIRO,EGY,+ 02 00,N 30 08,E 031 24,74
Fiji	NADI,FJI,+ 12 00,S 17 45,E 177 27,18
Finland	
HELSINKI,FIN,+ 02 00,N 60 19,E 024 58,56	TAMPERE,FIN,+ 02 00,N 61 25,E 023 35,112
France	
BORDEAUX,FRA,+ 01 00,N 44 50,W 000 42,61	MONTPELLIER,FRA,+ 01 00,N 43 35,E 003 58,6
BREST,FRA,+ 01 00,N 48 27,W 004 25,103	NANCY,FRA,+ 01 00,N 48 41,E 006 13,217
CLERMONT-FERRAND,FRA,+ 01 00,N 45 47,E 003 10,330	NANTES,FRA,+ 01 00,N 47 10,W 001 36,27
DIJON,FRA,+ 01 00,N 47 16,E 005 05,227	NICE,FRA,+ 01 00,N 43 39,E 007 12,10
LYON,FRA,+ 01 00,N 45 44,E 005 05,240	PARIS ORLY,FRA,+ 01 00,N 48 44,E 002 24,96
MARSEILLE,FRA,+ 01 00,N 43 27,E 005 14,36	STRASBOURG,FRA,+ 01 00,N 48 33,E 007 38,154
Germany	
BERLIN,DEU,+ 01 00,N 52 28,E 013 24,49	KOLN,DEU,+ 01 00,N 50 52,E 007 10,99
BREMEN,DEU,+ 01 00,N 53 03,E 008 48,5	MANNHEIM,DEU,+ 01 00,N 49 31,E 008 33,100
DUSSELDORF,DEU,+ 01 00,N 51 17,E 006 47,44	MUNICH,DEU,+ 01 00,N 48 08,E 011 42,529
FRANKFURT AM MAIN,DEU,+ 01 00,N 50 03,E 008 36,113	STUTTGART,DEU,+ 01 00,N 48 41,E 009 13,419
HAMBURG,DEU,+ 01 00,N 53 38,E 010 00,16	
Great Britain	
ABERDEEN/DYCE,GBR,+ 00 00,N 57 12,W 002 13,65	HEMSBY,GBR,+ 00 00,N 52 41,E 001 41,14
AUGHTON,GBR,+ 00 00,N 53 33,W 002 55,56	JERSEY/CHANNEL ISLANDS,GBR,+ 00 00,N 49 13,W 002 12,84
BELFAST,GBR,+ 00 00,N 54 39,W 006 13,81	LEUCHARS,GBR,+ 00 00,N 56 23,W 002 52,12
BIRMINGHAM,GBR,+ 00 00,N 52 27,W 001 44,99	LONDON/GATWICK,GBR,+ 00 00,N 51 09,W 000 11,62
FINNINGLEY,GBR,+ 00 00,N 53 29,W 001 00,17	OBAN,GBR,+ 00 00,N 56 25,W 005 28,4
Greece	
ANDRAVIDA,GRC,+ 02 00,N 37 55,E 021 17,12	THESSALONIKI,GRC,+ 02 00,N 40 31,E 022 58,4
ATHENS,GRC,+ 02 00,N 37 54,E 023 44,15	
Hungary	
DEBRECEN,HUN,+ 01 00,N 47 29,E 021 38,112	SZOMBATHELY,HUN,+ 01 00,N 47 16,E 016 38,221
Iceland	REYKJAVIK,ISL,+ 00 00,N 64 08,W 021 54,61
India	
AHMADABAD,IND,+ 05 30,N 23 04,E 072 38,55	MADRAS,IND,+ 05 30,N 13 00,E 080 11,16
BOMBAY,IND,+ 05 30,N 19 07,E 072 51,14	NAGPUR,IND,+ 05 30,N 21 06,E 079 03,310
CALCUTTA,IND,+ 05 30,N 22 39,E 088 27,6	NEW DELHI,IND,+ 05 30,N 28 35,E 077 12,216
GOA/PANAJI,IND,+ 05 30,N 15 29,E 073 49,60	TRIVANDRUM,IND,+ 05 30,N 08 29,E 076 57,64
Ireland	
BELMULLET,IRL,+ 00 00,N 54 14,W 010 00,10	KILKENNY,IRL,+ 00 00,N 52 40,W 007 16,64
BIRR,IRL,+ 00 00,N 53 05,W 007 53,72	MALIN,IRL,+ 00 00,N 55 22,W 007 20,25
CLONES,IRL,+ 00 00,N 54 11,W 007 14,89	VALENTIA OBSERVATORY,IRL,+ 00 00,N 51 56,W 010 15,14
DUBLIN,IRL,+ 00 00,N 53 26,W 006 15,85	
Israel	JERUSALEM,ISR,+ 02 00,N 31 47,E 035 13,782

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INTERNATIONAL WEATHER FOR ENERGY CALCULATIONS (IWEC WEATHER FILES)
Station_name,Country,Time Zone,Latitude (deg min),Longitude (deg min),Elevation (m)

Italy
BRINDISI,ITA,+ 01 00,N 40 39,E 017 57,10
GENOVA,ITA,+ 01 00,N 44 25,E 008 51,3
MESSINA,ITA,+ 01 00,N 38 12,E 015 33,51
MILAN,ITA,+ 01 00,N 45 37,E 008 44,211
NAPLES,ITA,+ 01 00,N 40 51,E 014 18,72
PALERMO,ITA,+ 01 00,N 38 11,E 013 06,34
PISA,ITA,+ 01 00,N 43 41,E 010 23,1
ROME,ITA,+ 01 00,N 41 48,E 012 14,3
TORINO,ITA,+ 01 00,N 45 13,E 007 39,287
VENICE,ITA,+ 01 00,N 45 30,E 012 20,6

Japan
KAGOSHIMA,JPN,+ 09 00,N 31 34,E 130 33,5
MATSUMOTO,JPN,+ 09 00,N 36 15,E 137 58,611
MIHO (CIV/JASDF),JPN,+ 09 00,N 35 29,E 133 15,9
NAGOYA,JPN,+ 09 00,N 35 15,E 136 56,17
OSAKA,JPN,+ 09 00,N 34 47,E 135 27,15
SAPPORO,JPN,+ 09 00,N 43 03,E 141 20,19
SHIMONOSEKI,JPN,+ 09 00,N 33 57,E 130 56,19
TOKYO HYAKURI,JPN,+ 09 00,N 36 11,E 140 25,35
TOSASHIMIZU,JPN,+ 09 00,N 32 43,E 133 01,33

Kazakhstan
SEMIPALATINSK,KAZ,+ 06 00,N 50 21,E 080 15,196

Kenya
NAIROBI,KEN,+ 03 00,S 01 19,E 036 55,1624

Korea (North)
CH'ONGJIN,PRK,+ 09 00,N 41 47,E 129 49,43
HAEJU,PRK,+ 09 00,N 38 02,E 125 42,81
P'YONGYANG,PRK,+ 09 00,N 39 02,E 125 47,38

Korea (South)
INCH'ON,KOR,+ 09 00,N 37 29,E 126 33,70
KANGNUNG,KOR,+ 09 00,N 37 45,E 128 54,27
KWANGJU,KOR,+ 09 00,N 35 08,E 126 55,72
ULSAN,KOR,+ 09 00,N 35 33,E 129 19,33

Libya
TRIPOLI,LBY,+ 02 00,N 32 40,E 013 09,81

Lithuania
KAUNAS,LTU,+ 02 00,N 54 53,E 023 53,75

Macau
MACAU,MAC,+ 08 00,N 22 12,E 113 32,86

Madagascar
ANTANANARIVO,MDG,+ 03 00,S 18 48,E 047 29,1276

Malaysia
GEORGE TOWN,MYS,+ 08 00,N 05 18,E 100 16,4
KOTA BAHARU,MYS,+ 08 00,N 06 10,E 102 17,5
KUALA LUMPUR,MYS,+ 08 00,N 03 07,E 101 33,22
KUCHING,MYS,+ 08 00,N 01 29,E 110 20,27

Martinique
FORT-DE-FRANCE,MTQ,- 04 00,N 14 36,W 061 00,4

Mexico
ACAPULCO,MEX,- 06 00,N 16 46,W 099 45,5
MEXICO CITY,MEX,- 06 00,N 19 26,W 099 05,2234
VERACRUZ,MEX,- 06 00,N 19 12,W 096 08,14

Mongolia
ULAANBATAAR,MNG,+ 08 00,N 47 56,E 106 59,1316
ULAANGOM,MNG,+ 08 00,N 49 53,E 092 05,936

Morocco
CASABLANCA/NOUASSER,MAR,+ 00 00,N 33 22,W 007 35,206

Netherlands
AMSTERDAM,NLD,+ 01 00,N 52 18,E 004 46,-2
BEEK,NLD,+ 01 00,N 50 55,E 005 47,116
GRONINGEN,NLD,+ 01 00,N 53 08,E 006 35,4

New Zealand
AUCKLAND,NZL,+ 12 00,S 37 01,E 174 48,6
CHRISTCHURCH,NZL,+ 12 00,S 43 29,E 172 33,34
WELLINGTON,NZL,+ 12 00,S 41 18,E 174 47,67

Norway
BERGEN,NOR,+ 01 00,N 60 18,E 005 13,50
OSLO/FORNEBU,NOR,+ 01 00,N 59 54,E 010 37,17

Pakistan
KARACHI,PAK,+ 05 00,N 24 54,E 067 08,22

Paraguay
ASUNCION,PRY,- 04 00,S 25 15,W 057 34,101

Peru
AREQUIPA,PER,- 05 00,S 16 19,W 071 33,2520
CUZCO,PER,- 05 00,S 13 33,W 071 59,3249
LIMA,PER,- 05 00,S 12 00,W 077 07,13

Philippines
MANILA,PHL,+ 08 00,N 14 31,E 121 00,21

Poland
KOLOBRZEG,POL,+ 01 00,N 54 11,E 015 35,5
KRAKOW,POL,+ 01 00,N 50 05,E 019 48,237
POZNAN,POL,+ 01 00,N 52 25,E 016 50,92
WARSAW,POL,+ 01 00,N 52 10,E 020 58,107

Portugal
BRAGANCA,PRT,+ 00 00,N 41 48,W 006 44,692
COIMBRA,PRT,+ 00 00,N 40 12,W 008 25,140
EVORA,PRT,+ 00 00,N 38 34,W 007 54,321
FARO,PRT,+ 00 00,N 37 01,W 007 58,4
LAJES,PRT,- 01 00,N 38 46,W 027 06,55
PORTO,PRT,+ 00 00,N 41 14,W 008 41,73

Continued …

INTERNATIONAL WEATHER FOR ENERGY CALCULATIONS (IWEC WEATHER FILES)
Station_name,Country,Time Zone,Latitude (deg min),Longitude (deg min),Elevation (m)

Romania	
BUCHAREST,ROM,+ 02 00,N 44 30,E 026 08,91	CRAIOVA,ROM,+ 02 00,N 44 14,E 023 52,195
CLUJ-NAPOCA,ROM,+ 02 00,N 46 47,E 023 34,413	GALATI,ROM,+ 02 00,N 45 30,E 028 01,72
CONSTANTA,ROM,+ 02 00,N 44 13,E 028 38,14	TIMISOARA,ROM,+ 02 00,N 45 46,E 021 15,88
Russia	
ARKHANGEL'SK,RUS,+ 04 00,N 64 32,E 040 28,13	OMSK,RUS,+ 06 00,N 54 56,E 073 24,123
CHITA,RUS,+ 09 00,N 52 01,E 113 20,685	SAINT-PETERSBURG,RUS,+ 03 00,N 59 58,E 030 18,4
EKATERINBURG,RUS,+ 05 00,N 56 48,E 060 38,237	SAMARA,RUS,+ 04 00,N 53 15,E 050 27,44
IRKUTSK,RUS,+ 08 00,N 52 16,E 104 21,513	YAKUTSK,RUS,+ 09 00,N 62 05,E 129 45,103
MOSCOW,RUS,+ 03 00,N 55 45,E 037 38,156	
Saudi Arabia	RIYADH,SAU,+ 03 00,N 24 42,E 046 48,612
Senegal	DAKAR,SEN,+ 00 00,N 14 44,W 017 30,24
Singapore	SINGAPORE,SGP,+ 08 00,N 01 22,E 103 59,16
Slovakia	
BRATISLAVA,SVK,+ 01 00,N 48 12,E 017 12,130	KOSICE,SVK,+ 01 00,N 48 42,E 021 16,232
Slovenia	LJUBLJANA,SVN,+ 01 00,N 46 13,E 014 29,385
South Africa	
CAPE TOWN,ZAF,+ 02 00,S 33 59,E 018 36,42	
JOHANNESBURG,ZAF,+ 02 00,S 26 08,E 028 14,1700	
Spain	
BARCELONA,ESP,+ 01 00,N 41 17,E 002 04,6	SANTANDER,ESP,+ 01 00,N 43 28,W 003 49,40
MADRID,ESP,+ 01 00,N 40 27,W 003 33,582	SEVILLA,ESP,+ 01 00,N 37 25,W 005 54,31
PALMA,ESP,+ 01 00,N 39 33,E 002 44,8	VALENCIA,ESP,+ 01 00,N 39 30,W 000 28,62
Sweden	
GOTEBORG LANDVETTER,SWE,+ 01 00,N 57 40,E 012 18,169	OSTERSUND/FROSON,SWE,+ 01 00,N 63 11,E 014 30,370
KARLSTAD,SWE,+ 01 00,N 59 22,E 013 28,55	STOCKHOLM ARLANDA,SWE,+ 01 00,N 59 39,E 017 57,61
KIRUNA,SWE,+ 01 00,N 67 49,E 020 20,452	
Switzerland	GENEVA,CHE,+ 01 00,N 46 15,E 006 08,416
Syria	DAMASCUS,SYR,+ 02 00,N 33 25,E 036 31,605
Taiwan	TAIPEI,TWN,+ 08 00,N 25 04,E 121 33,6
Thailand	BANGKOK,THA,+ 07 00,N 13 55,E 100 36,12
Tunisia	TUNIS,TUN,+ 01 00,N 36 50,E 010 14,4
Turkey	
ANKARA,TUR,+ 02 00,N 40 07,E 032 59,949	IZMIR,TUR,+ 02 00,N 38 30,E 027 01,5
ISTANBUL,TUR,+ 02 00,N 40 58,E 028 49,37	
Ukraine	
KIEV,UKR,+ 02 00,N 50 24,E 030 27,168	ODESSA,UKR,+ 02 00,N 46 27,E 030 42,35
United Arab Emirates	ABU DHABI,ARE,+ 04 00,N 24 26,E 054 39,27
Uruguay	MONTEVIDEO,URY,- 03 00,S 34 50,W 056 00,32
Uzbekistan	TASHKENT,UZB,+ 05 00,N 41 16,E 069 16,458
Venezuela	CARACAS,VEN,- 04 00,N 10 36,W 066 59,48
Vietnam	HANOI,VNM,+ 07 00,N 21 01,E 105 48,6
Yugoslavia	
BELGRADE,YUG,+ 01 00,N 44 49,E 020 17,99	PODGORICA,YUG,+ 01 00,N 42 22,E 019 15,33
Zimbabwe	HARARE,ZWE,+ 02 00,S 17 55,E 031 08,1503

If you want to know more about weather data in EnergyPlus and how to use the WeatherConverter, go to the DocMainMenu (under Start, Programs, EnergyPlus Programs) and click on Auxiliary Programs and Developer Guides. Then click on Auxiliary Program Information. The Weather Converter is discussed beginning on page 16.

Thanks, **EnergyPlus Development Team**

ASK AN ENERGYPLUS EXPERT: SYSTEM TYPES, BLINDS AND SLATS, COOLING COIL CONTROLS,

Question:
Does EnergyPlus support heating or cooling systems other than air conditioning systems? I am thinking of water systems like underfloor heating, active wall/ceiling systems and radiator systems.
Answer:
Yes, it can do all of these. In addition to forced air systems using DX and chilled water cooling, EnergyPlus can model hot water radiators (BASEBOARD HEATER:Water:Convective), heated and cooled surfaces (LOW TEMP RADIANT SYSTEM:HYDRONIC, LOW TEMP RADIANT SYSTEM:ELECTRIC) and gas or electric radiant heaters (HIGH TEMP RADIANT SYSTEM).

Question:
I noticed in the EnergyPlus Input/Output Reference Manual that Fig. 5 (p. 60) does not show blinds consisting of slats. Further the verbal description of slat details in the Manual is unclear.
My question, then, is this: What is the slat width and the slat separation?
Answer:
In the field descriptions for Material:WindowBlind, the references to Fig. 5 are incorrect; they should all be references to Fig. 6, found on p. 66. Our apologies for the confusion. Also, check out the "blinds" section of the Engineering Doc Reference under "Optical Properties of Windows". There is also an example file: PurchAirWindowBlind.idf which may illustrate the use for you.

Question:
I am having trouble getting my controls to work for a single duct VAV with reheat.
My cooling coil is producing 28F discharge air and my reheat terminals are running full reheat.
Answer:
See the VAVSingleDuctReheat.idf example in EnergyPlus\Examples\Misc to see how the cooling coil controls should be set up.

Question:
If the building's electric consumption only depends on the lighting and the electric equipment, then where do I input the chiller and chilled water pump electric consumption to effect the building total electric consumption? If i change the nominal capacity in CHILLER:ELECTRIC, the result on total building electric consumption doesn't change at all. What is the effect of CHILLER:ELECTRIC in this building simulation?
Answer**:**
To report the master meter for the entire building, including HVAC equipment, add the following to your input file: report meter, electricity:facility, hourly; (or monthly, or environment)
To see just the electric consumption of the chiller, add this:
report variable, *, Chiller Electric Consumption, hourly;
See the Input Output Reference, pp. 530-537 for more information.

ASK AN ENERGYPLUS EXPERT: IDF, PEOPLE LATENT HEAT GAIN, WETNESS FACTOR

Question**:**
In the Input-Output Reference Manual, under regular material IDF example on p. 39, the IDF input has “thermal absorptance,” but on p. 43 the IDF example names the same input as “thermal emittance.” Would you please clarify?
Answer:
The two properties are equal to each other since materials absorb and emit longwave radiation the same way, and this field is used both ways. Our intent has been to standardize on the term "absorptance.” Thank you for calling the inconsistency to our attention.

Question**:**
How can I incorporate an IDF file from the data set folder into the "main" IDF?
Answer:
The only way to do this is to open your project IDF file and the dataset IDF file in a text editor and copy/paste the desired objects into your project file. If you are using the IDF Editor, be sure to save changes and close the file in IDF Editor before editing it in the text editor.

Question**:**
Since EnergyPlus does not have an input field for people latent heat gain, I was wondering what assumptions the program makes about people latent heat gain. The only discussion of latent gains I could find was a note for the Fraction Radiant field (p. 132 of the Input-Output Reference) which states, "Note that latent gains from people are not included in either the radiant or convective heat gains."
Answer:
Actually there is also a note under the PEOPLE LATENT GAIN output variable (unknown page number but just after the input fields for People). However, it's not much more helpful and states "an internal procedure is used..." The short answer (from looking at the code) is that the TotalPeopleGain = Number of Occupants * Activity Level (activity level is input as an hourly schedule value). Sensible People Gain then is a combination of internal coefficients applied to the activity level and the current mean air temperature in the zone.
Finally, the Latent is Total - Sensible.

And looking at the code tells us:

```
!       The function is based on a curve fit to data presented in Table 48 Heat Gain from
!       People of Chapter 1 of the Carrier Handbook of Air Conditioning System Design,
!       1965. Values of Sensible gain were obtained from the table at average adjusted
!       metabolic rates 350, 400, 450, 500, 750, 850, 1000 and 1450 Btu/hr each at
!       temperatures 82, 80, 78, 75 and 70f. Sensible gains of 0.0 at 96f and equal to the
!       metabolic rate at 30f were assumed in order to give reasonable values beyond the
!       the reported temperature range.
```

Question**:**
Does EnergyPlus consider wetness factor in calculating heat transfer (e.g., consider water absorption/evaporation from exterior building surfaces).
Answer:
We handle the boundary conditions for the exterior surface that is exposed to rain by increasing the exterior heat transfer coefficient to a high value and then exposing the surface to the wet bulb temperature instead of the dry bulb. This is done for either the CTF or the MTF solution for heat transfer. For moisture transfer the moisture boundary conditions will also have a high exterior mass transfer coefficient and the vapor density is calculated using the wet bulb and a Relative Humidity = 1.0. Bulk fluid flow is not handled with the MTF calculations so the only boundary conditions that will affect the model is the increased vapor density and high exterior mass transfer coefficient during the time that it is raining.

Building Energy Simulation User News, Vol. 23, No. 4 (May/June 2002)

THERMAL BRIDGE MODELING IN ENERGYPLUS

by

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Introduction

We describe here work that has been done on integrating thermal bridge models into the EnergyPlus building energy simulation program. The models used and the assumptions made are presented. Then we focus on how the existing code was modified to incorporate the new models. Finally, we describe how the newly integrated modules were tested.

Thermal Bridges: Description and Modeling

What is a Thermal Bridge?

Thermal bridges are weak points in building insulation. They are located where the thermal resistance is significantly lower than in the surrounding region. Thermal bridges are usually caused by a geometric or material inhomogeneity. The consequences of a thermal bridge in winter are an increase in heat loss, and a reduction of inside surface temperature in the neighborhood of the thermal bridge, possibly resulting in condensation.

There has been tremendous improvement in the thermal insulation of buildings in the last twenty years. This has increased the relative importance of thermal bridges in the overall heat loss. For example, in France the heat losses from thermal bridges in a house that complies with the energy code can be 10% to 15% of the heat loss.

Mathematical Modeling

A thermal bridge can typically be represented as a linear time invariant (LTI) system in the following state-space form:

$$\begin{cases} \dot{T} = AT + BU \\ Y = CT + DU \end{cases} \qquad (1)$$

where

- A, B, C and D are arrays that characterize the thermal bridge. The values in these arrays depend neither on time nor on system inputs. In a finite-difference calculation the elements of these arrays are determined by applying the conduction equation and Fourier's law to each node.
- The matrix U contains the values of the system inputs. For a thermal bridge, the system inputs are the air temperatures in different places around the bridge (outside air temperature, inside air temperature, etc.). You can choose whether or not to specify an air film convection resistance in the system inputs. If not, the temperatures actually correspond to surface temperatures.
- The T array contains intermediate calculation variables. For example, for a finite-difference solution to Eq. (1), T contains values of the temperature at the mesh nodes. $\dot{T}$ is the derivative array of T.

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- Y is the system output, usually the average heat flux through the configuration.

If the system is solved using finite differences, the size of the arrays can be very large. For a simple configuration, A is about 300 x 300. For more complex configurations, arrays can be 1000 x 1000 or larger.

Reducing Array Size

Large arrays require a lot of computer memory and can lead to very time-consuming calculations, especially in energy software, like EnergyPlus, where the calculations have to be done every time step for up to a year. Therefore, we need to reduce the size of the system. A reduced system that is an approximation to Eq. (1) can be represented as follows:

$$\begin{cases} \dot{X} = A_r X + B_r U \\ Y = C_r X + D_r U \end{cases} \tag{2}$$

where the arrays A_r, B_r, C_r and D_r are in the 1 x 1 to 4 x 4 range. Unlike T and $\dot{T}$, and the other arrays in system (1), the variables in Eq. (2) have no direct physical meaning; therefore, we call system (2) a "black box."

From "Black Box" to "Gray Box"

Although the variables in system (2) have no direct physical meaning, it is possible to find relationships between these variables and physical quantities such as material properties (conductivity, heat capacity, density and thickness), time constants and steady-state conductance. To find these relationships we have simulated a large number of thermal bridge configurations and have expressed the results, using regression analysis, in terms of a few physical parameters. These parameterized models are then suitable for use in EnergyPlus and other building energy simulation programs.

The Modeling Process

Sisley Modeling

The first step was to model each thermal bridge configuration using a finite difference method. This was done with an Electricité de France (EdF) program called Sisley, whose environment is shown in Fig. 1. In this step, it is important to model a large enough number of different configurations so that the gray box models resulting from the regression analysis are reasonably accurate.

Modeling a thermal bridge configuration with Sisley software yields the state-space arrays (Eq. (1)) for that configuration.

Model Reduction

Model reduction transforms the Sisley-generated state-arrays, which are large, to equivalent smaller arrays that approximate the full solution. The reduction method that was used is derived from the Marshall method [11], also called the "modal reduction method." A reduction order of one was found to be accurate enough for the current application. The reduction calculation was done with MatLab [12], into which the reduction algorithm was programmed.

Modal reduction uses numerical methods, such as base changing and eigenvalue selection, that cause the state-space arrays to lose some of their physical meaning, but enough physical meaning is retained so that analysis can be performed to determine what physical parameters the array values are sensitive to.

Sensitivity Study

Using Microsoft Excel, a statistical analysis was performed to characterize the reduced state-space arrays in terms of physical parameters. This analysis has two steps: determining the main parameters and designing the "gray box" relationships.

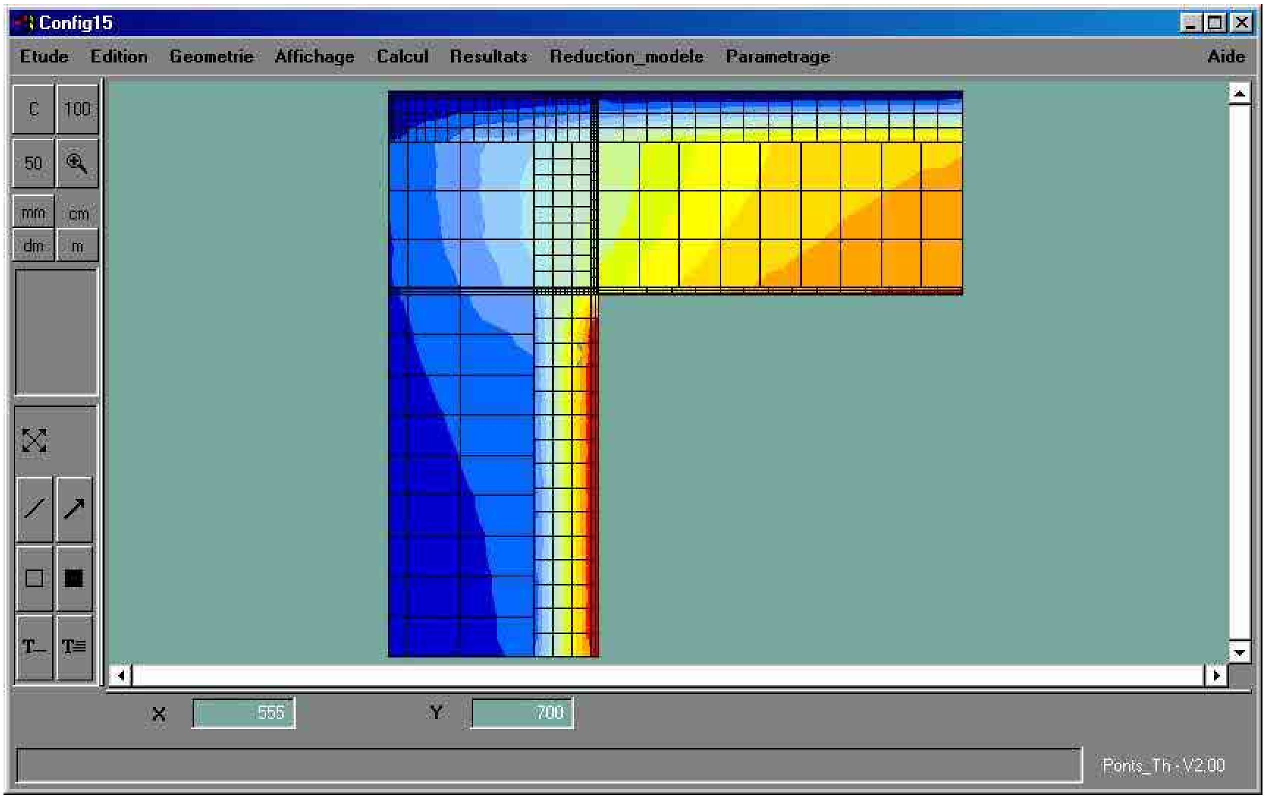

Figure 1: Main Screen of the Sisley Finite Difference Program

Determining the Main Parameters

First we need to study the relative importance of the physical parameters and of the values contained in the reduced state-space arrays. Some array elements have little influence on the overall behavior of the modeled systems. Therefore, there is no need to accurately determine these elements. In some cases, it is sufficient to use an average value for these elements calculated from all the modeled configurations of the thermal bridge database. Also, there are *degrees of freedom* in a state-space model. That means that some arrays may be chosen at random if some others have been chosen accordingly.

Simplification of the gray box relationships is accomplished through graphical analysis and the requirement that the results make physical sense. For instance, static heat flux is independent of material density and heat capacity, but these parameters do influence the dynamic behavior of the system.

Designing the "Gray Box" Relationships

The final gray box relationships were determined from least-squares regression. We first assume a general form for the relationships needed to compute the state space models. This work is done in conjunction with the first task of the sensitivity study described above.

Once we have these general relationships, we have to characterize them completely by determining the unknown coefficients. This is done with the least-squares method.

For example, for the Matisse Apartment (page 23), an L-shaped thermal bridge is described for a large number of physical parameter sets. Once we have these sets of configurations, we can plot various graphs showing the features of the state space models, such as time constants or heat gains, as a function of these parameters. For instance, if we decide to plot the time constant of the L-shaped bridge as a function of the concrete wall thickness, we get the following graph :

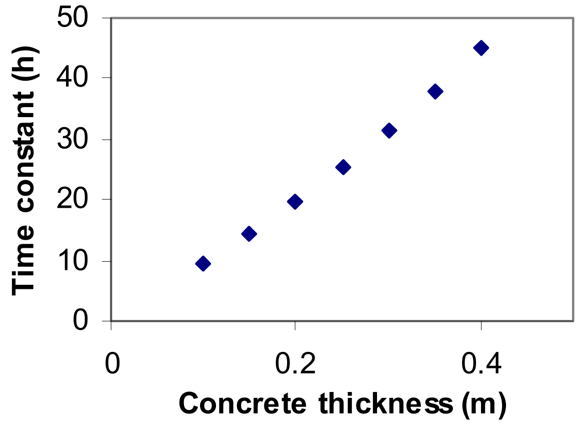

Figure 2: Example of the Behavior of a State Space Model Time Constant as a Physical Parameter Varies

This tells us that we have an almost linear relationship between the time constant and the concrete wall thickness. Repeating this technique with the other physical parameters allows us to find the general form of the calculated time constant. In this example, we get:

$$\tilde{\tau}_1 = a e_{concrete} + b Cp_{concrete} + c \qquad (1)$$

where

- $e_{concrete}$ is the concrete thickness (m)
- $Cp_{concrete}$ is the concrete specific heat (J/kg.K)
- *a*, *b* and *c* are coefficients to be determined
- $\tilde{\tau}_1$ stands for the calculated time constant (h)

We now have to find the values of the unknown coefficients. To do so, we compute the sum of the squares of differences between the calculated time constant and the exact time constant as found in the reduced state space models, for all the studied configurations:

$$\Sigma = \sum_{configurations} \left(\tau_1 - \tilde{\tau}_1\right)^2 \qquad (2)$$

where $\tilde{\tau}_1$ is the time constant of the models built with Sisley (h).

The values to choose for the unknown coefficients are then the ones which make this sum as small as possible. In our numerical example, we eventually find:

$$\tilde{\tau}_1 = 1.187x10^2 e_{concrete} + 2.074x10^{-2} Cp_{concrete} - 2.261x10^1 \qquad (3)$$

The same work can be done with the other interesting values of the reduced state space models. For the L-shaped thermal bridge example, we finally get:

$$\tilde{\tau}_1 = 1.187x10^2 e_{concrete} + 2.074x10^{-2} Cp_{concrete} - 2.261x10^1$$

$$g_1 = -7.685x10^1 e_{concrete} - \frac{1.597x10^{-2}}{e_{wallinsulation}} - 3.098\,\lambda_{wallinsulation} - 2.452\,\lambda_{roofinsulation} - 3820.10^1$$

$$g_2 = -g_1$$

$$A_r = \left[\frac{1}{3600\,\tilde{\tau}_1}\right] \qquad (4)$$

$$B_r = \left[A_{r1,1}\frac{D_{r1,1}-g_1}{C_{r1,1}} \quad A_{1,1}\frac{D_{r1,2}-g_2}{C_{r1,1}} \right]$$

$$C_r = [0.22]$$

$$D_r = [0.4\ 2.75]$$

where

- $e_{wallinsulation}$ is the wall insulation thickness (m)
- $\lambda_{wallinsulation}$ is the wall conductivity (W/m.K)
- $\lambda_{roofinsulation}$ is the roof insulation conductivity (W/m.k)
- g_1 and g_2 are the heat gains of the thermal bridge (W/K)

This allows the computation of the whole set of state space arrays, starting from a few physical parameters.

Integration of Thermal Bridge Models into EnergyPlus

The current EnergyPlus program (July 2002) does not simulate thermal bridges. Except for the foundation, the building envelope assumes 1-D heat transfer whereas 2-D or 3-D heat transfer is required to properly characterize thermal bridges. The existing walls in EnergyPlus are described with "Constructions" made up of one or more material layers through which 1-D heat transfer takes place.

A thermal bridge is a configuration through which heat flows in 2 or 3 dimensions. The bridge is modeled as a system with inputs and outputs, where the inputs are the outside conditions (outside air temperature or zone air temperature) and the outputs are the heat flux transmitted through the bridge from a zone to the outside or from one zone to another zone. It is important to properly integrate the thermal model with the existing heat balance calculation methodology in EnergyPlus.

Existing Code Structure and Calculation Methods

Zone Heat Balance

In EnergyPlus the heat flow calculations for the building envelope are based on heat balances, from which the zone air temperature is calculated. The basic heat balance expression is:

Zone Air Energy Variation = Σ (Thermal Loads and Heat Transfers with the Zone)

Integrating thermal bridges into EnergyPlus is equivalent to adding a new term to the right-hand side of this equation.

Calculation Sequence

We discuss here how the EnergyPlus loads calculations are carried out. The goal is to determine at what point the thermal bridge calculations should be done in the code. Figure 3 shows the organization of calculation modules in EnergyPlus. Arrows show the subroutine calls that are relevant to integrating the thermal bridge calculations. The Simulation Manager manages the subroutine calls. At every heat balance time step, it launches the HeatBalanceManager, which controls the heat balance and surface temperature calculations. It also launches the HVACManager every system time step. The HVACManager does the HVAC system calculations and determines zone air temperatures.

The other important modules as far as thermal bridges are concerned are ConductionTransferFunctionCalc and ZoneTempPredictorCorrector, both of which were modified to include thermal bridges.

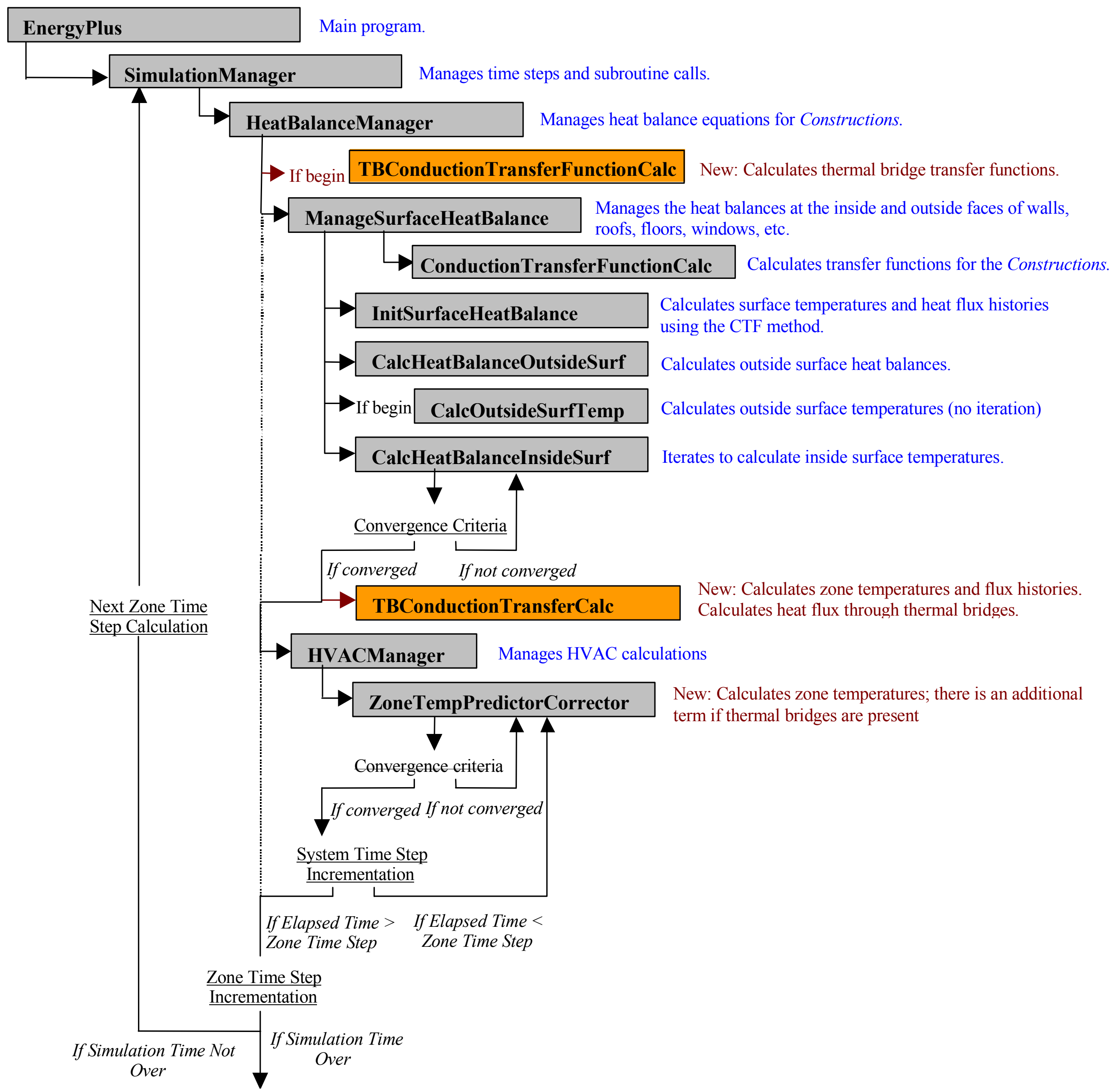

Figure 3: Integration of Thermal Bridges into the EnergyPlus Calculation Sequence

Parallelism between Modeling Walls and Modeling Thermal Bridges

The gray box models presented earlier are linear differential systems in which the main mathematical features, such as the heat gains and the time constants, are linked to the main physical parameters, such as dimensions and material properties. EnergyPlus currently simulates walls (by “walls” we mean walls as usually understood, as well as floors, ceilings and roofs) using conduction transfer functions derived from state-space models. Figure 4 shows the parallelism between the way walls and thermal bridges are handled.

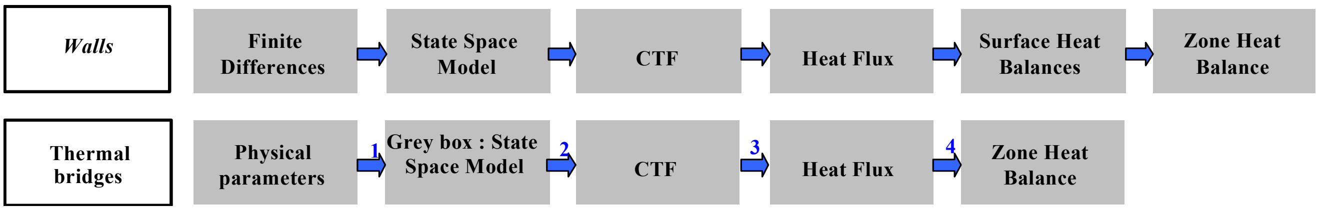

Figure 4: Comparison Between the Modeling of Constructions and Thermal Bridges in EnergyPlus

Wall Modeling

The top row in Fig. 4 shows how walls are modeled in EnergyPlus. The walls are composed of 1 to 15 layers whose thickness and material properties are user inputs. From these inputs, EnergyPlus derives a set of linear differential heat flow equations using a 1-D finite-difference method. This set of equations can be written in state-space form as:

$$\begin{cases} \dot{T} = AT + BU \\ \varphi = CT + DU \end{cases} \tag{5}$$

where, analagously to Eq. (1), T and $\dot{T}$ are the temperatures at the nodes of the finite-difference mesh; A, B, C and D are arrays that depend neither on time nor on system inputs, U is the array of system inputs and φ is the array of system outputs (heat fluxes).

The finite-difference method uses nodes in each layer of the wall. The number of nodes is chosen in order to satisfy a numerical convergence criterion. A heat balance equation applies at each node.

From Eq. (5) EnergyPlus builds a new model of the wall that consists of transfer functions (called Conduction Transfer Functions, or CTFs) that relate the outputs of the system (heat flux) at the current time step to the outputs at the previous time step and the inputs (inside and outside surface temperatures) at the current and previous time steps [8]. This relationship can be written as follows:

$$\varphi_t = \sum_{k=0}^{M} S_{i,k} T_{i,t-k\delta} + \sum_{k=0}^{M} S_{o,k} To_{i,t-k\delta} - \sum_{k=1}^{M} e\varphi_{t-k\delta} \tag{4}$$

where s and e are the CTFs, T_i and T_o are the inside and outside surface temperature, respectively, t is the current time, and δ is the time step.

The resultant heat fluxes are then used in inside- and outside-surface heat balance equations to get the values of the inside and outside surface temperatures at the next time step. Finally, the convective inside air film conductance, the surface air temperature difference and the surface areas are used to calculate the convective heat gain to the zone air.

Thermal Bridge Modeling

The bottom row in Fig. 4 shows how thermal bridges are modeled. The basic differences between the two rows are the following:

(1) The thermal bridge finite differences calculation is done outside of EnergyPlus. A regression process, also done outside of EnergyPlus, leads to thermal bridge state-space models that are parameterized in terms of physical parameters as gray boxes.

(2) The heat flux in the wall construction case participates in a surface heat balance calculation, from which inside surface temperatures are obtained that yield heat gain to the zone air via a convective inside air film conductance. For thermal bridges, the surface heat balance step is skipped and heat flux from the thermal bridge goes directly into the zone air via a combined radiative/convective inside film conductance.

(3) The wall calculation considers absorption of solar radiation on the outside face and absorption of solar, short-wave radiation from lights and long-wave radiation from lights, equipment and people on the inside face. These are ignored for thermal bridges. A near-term improvement to the thermal bridge calculation would be to take this absorbed radiation into account, perhaps in terms of a surface "sol-air" temperature.

As the modeling process is simplified for the thermal bridges, the heat flux through the studied configurations does not contribute to intermediate heat balances, but is used directly in the overall heat balances that determine the zone temperatures.

To summarize, the steps in thermal bridge modeling, numbered from 1 to 4 in Fig. 4, are the following:

Step (1) From thermal bridge parameters to gray box state-space models:
This is done outside of EnergyPlus and results in an internal EnergyPlus library of parameterized models of different thermal bridge configurations.

Step (2) Calculate CTFs from state-space model:
We use an adaptation of the algorithm used for walls.

Step (3) Calculate heat flux from the thermal bridge:
We apply CTF-based equation relating the current outputs to the past outputs and current and past inputs. Code has been added to EnergyPlus to store the past inputs and outputs for thermal bridges.

Step (4) Add thermal bridge heat flux to zone heat balance.

Adding a New Thermal Bridge Configuration into EnergyPlus

To integrate a new thermal bridge into the EnergyPlus code, the programmer needs only to enter the gray box coefficients, from the previous step, into the source code and then add a new data structure fitted for this new configuration, which would require the user to input only the few physical parameters (the ones obtained in the beginning of the sensitivity study) needed to completely describe the numerical system. EnergyPlus will then make the link between these physical parameters and the coefficients entered in the source code, and will rebuild the corresponding gray box model, taking the calculations into account.

EnergyPlus Test Simulations of Thermal Bridges

The Matisse Apartment

"Matisse" is an apartment with one wall exposed to outside temperatures. It has a total area of 65.8m^2 including three main rooms (living room and two bedrooms) plus kitchen and bath. It is located on the top floor, under a terraced roof. It is a hypothetical structure often used for simulations carried out by EdF to compare the results from different energy simulation programs. Heating is provided by a simple zone- thermostat-controlled electric coil.

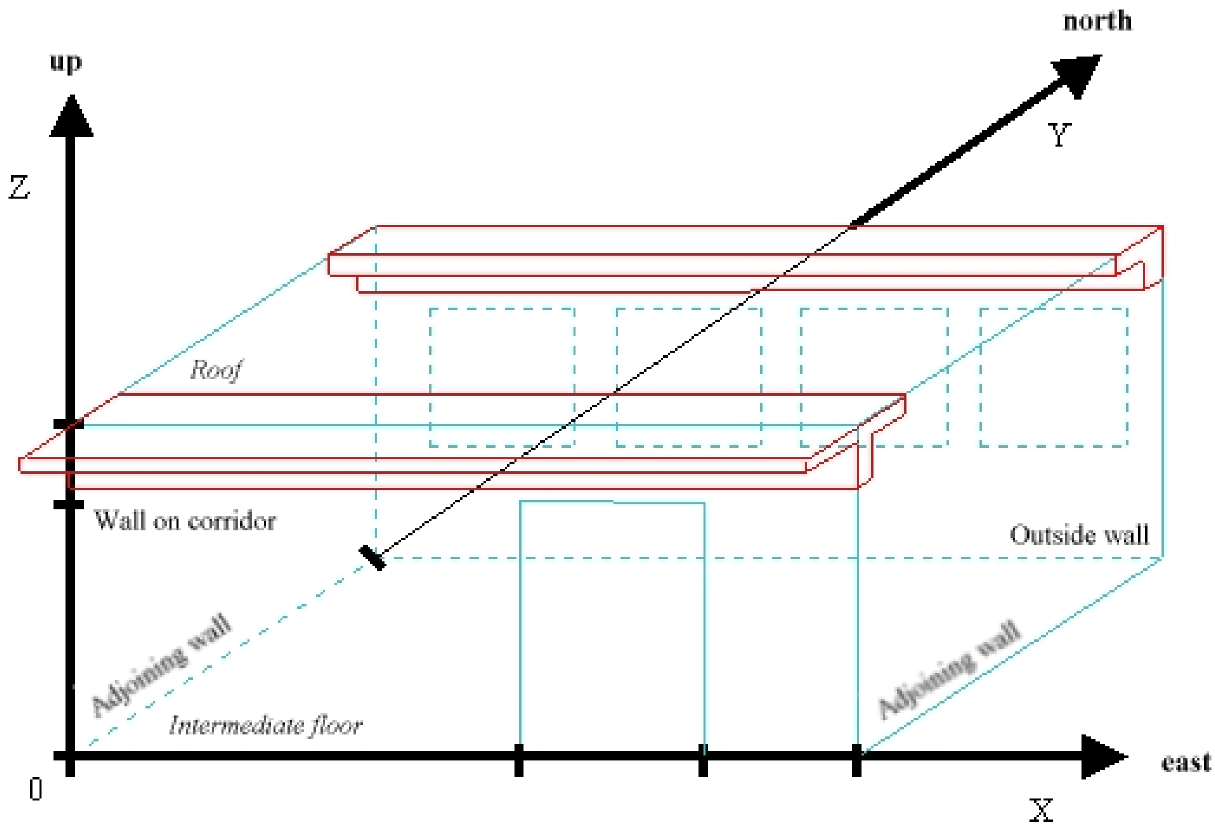

Figure 5: The Matisse Building

The following choices for the envelope components have been made so that the building is in agreement with the French thermal regulation :

Name	Surface (m²)	material	Description of the wall (outside → inside) thickness (m)	λ (W/m.K)	ρ (kg/m³)	Cp (J/kg.K)
Outside wall	17.88	Concrete Polystyrene Plaster	0.2 0.08 0.01	1.75 0.03 0.35	2450 35 900	920 1210 837
Wall on corridor	25.67	Concrete Polystyrene Plaster	0.2 0.04 0.01	1.75 0.03 0.35	2450 35 900	920 1210 837
Intermediate floor	65.77	Concrete	0.18	1.75	2450	920
Adjoining wall	14.95 15.13	Plaster Concrete Plaster	0.01 0.2 0.01	0.35 1.75 0.35	900 2450 900	837 920 837
Roof	65.77	Roof waterproofing Polyurethane Concrete Plaster	0.01 0.06 0.18 0.01	0.23 0.025 1.75 0.35	1050 55 2450 900	920 1400 920 837

Matisse is modeled with two different thermal bridges whose area represents 10% of the total building wall area (Figs. 5 and 6). There is a T-shaped thermal bridge where the corridor wall meets the roof. The top of this bridge is exposed to outside air. The other surfaces are exposed to the corridor air and the apartment air.

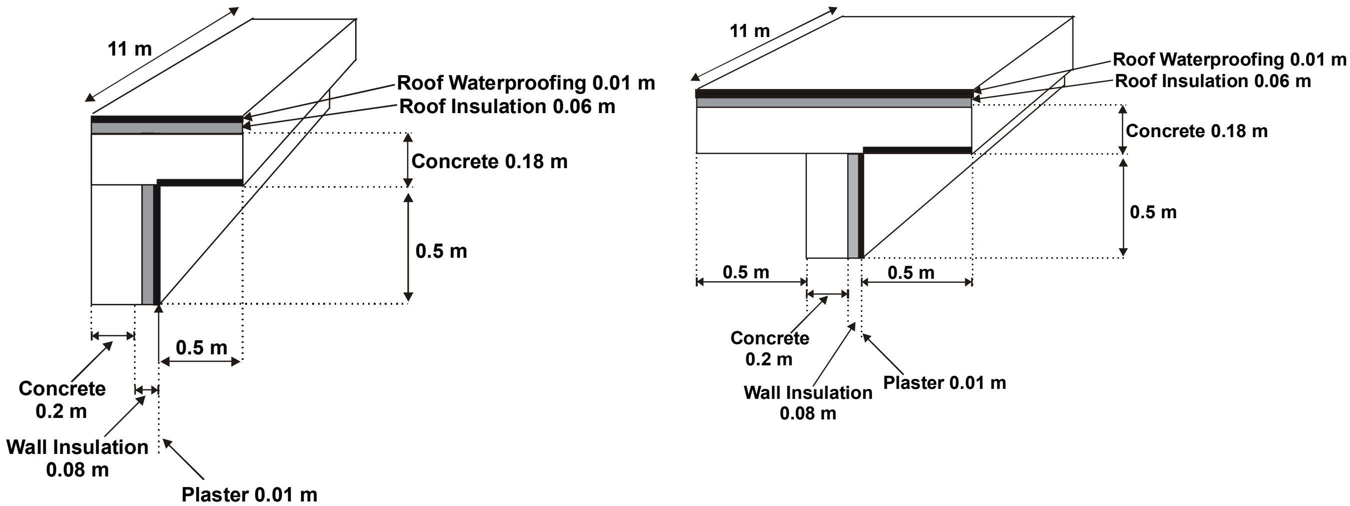

Figure 6: L- and T-Shaped Thermal Bridges

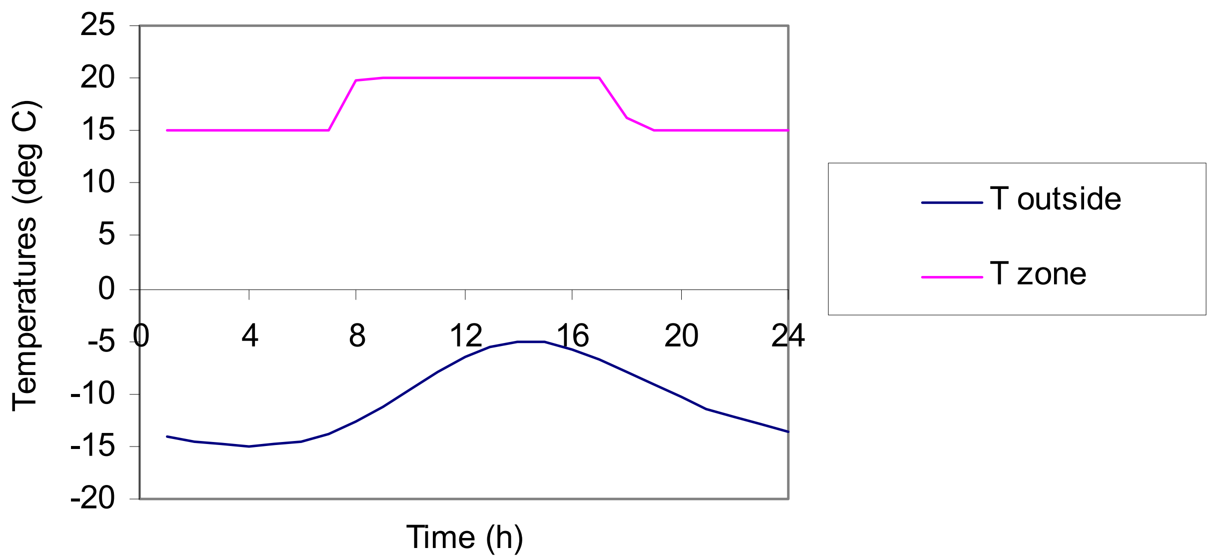

Figure 7: Temperatures During the Simulation

There is an L-shaped thermal bridge where the outside wall meets the roof. Two surfaces of this bridge are exposed to the outside air and two are exposed to the inside air. The simulation takes place over a single design day. The heating set point is 20°C between 8 AM and 5 PM and 15°C at other times. The outside temperature varies between –5°C and –15°C (Fig. 7).

Results

Figure 8 compares the heating rate with and without thermal bridges**.** For the case with thermal bridges, the wall and roof areas were decreased to take into account the thermal bridge areas. As expected, the heating rate is higher when the thermal bridges are modeled.

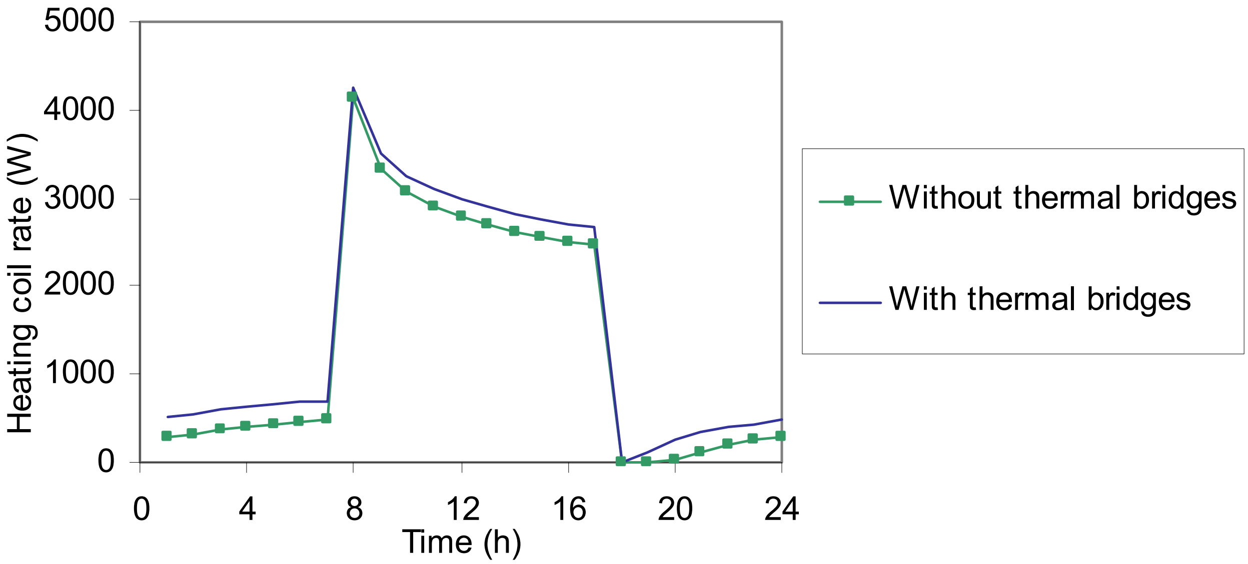

Figure 8: Heating Rate With and Without Thermal Bridges

For the design day shown, the heating required is 14% higher when the thermal bridges are modeled.

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ASK AN ENERGYPLUS EXPERT: DIFFERENCES BETWEEN PROGRAM VERSIONS, HOURLY WEATHER DATA

Question:
I have a question regarding the difference between EnergyPlus 1.0 and 1.0.1. I had built a model in EnergyPlus 1.0 and it was running fine. When I tried to run it in EnergyPlus 1.0.1, I got several severe errors and couldn't produce any output. Is there any way of updating files without a lot of modification to the original file?

Answer:
There is a transition utility included with version 1.0.1 which will help you move your 1.0 files into 1.0.1
Depending on the objects in your files, some may require further editing to add new information.
To learn how to use the transition program, go to the "OtherInformation.pdf" file and read the section entitled "Transition_Vold_Vnew". To reach this document from the EnergyPlus main menu, select "Auxiliary Programs / Developer Guides" then select "Auxiliary Program Information."

Question:
In an EnergyPlus weather file, what does "hour1" represent?
Is it the reading at 12:00 AM or 1:00 AM? Is it instantaneous or average for the past 1 hour?

Answer:
We take it to be the temperature for the time period 00:01 to 1:00 AM. If the simulation is using more than 1 time step in an hour, then the temperature used at the time step is a weighted interpolation of the temperature of the current hour with the temperature at the next hour.

To explain, for time=00:15, you will have a 3/4 weight to the temperature for (00:01 to 1:00AM) and a 1/4 weight for the temperature (1:01 to 2:00 AM). Assuming time steps in hour=4.

Most national weather services record observed temperature on the hour (or generally within a few minutes), so it's a snapshot not an average of the temperature for the hour. Again, we take the data as being for the entire hour, 00:01 AM to 01:00 AM. This is true for all the weather files that are available on the EnergyPlus web site.

INNOVATIVE USE OF ENERGYPLUS IN A NEW FEDERAL BUILDING

EnergyPlus was instrumental in the design of an innovative 18-floor federal office building to be constructed in San Francisco. In addition, the program contributed significantly to nearly $9 million in energy costs savings. EnergyPlus was also directly responsible for simplifying the design of the façade, saving almost another $1.5 million in construction costs.

Architects with the building's design firm wanted to use only natural ventilation for the top 13 floors; security concerns mandated that the lower floors be completely sealed. However, they were hesitant to move forward with the idea without simulation results to assure them that the building could meet comfort standards without air conditioning.

FEDERAL BUILDING
SAN FRANCISCO, CA

Using EnergyPlus and its link to the COMIS multizone air flow program, Philip Haves (phaves@lbl.gov) of LBNL convinced both the client and the design team that natural ventilation would keep the building comfortable during San Francisco's brief but significant episodes of hot weather.

The new San Francisco building uses natural ventilation to provide cooling without the use of fans or refrigeration. For most of the year, the building is cooled by air flow through windows controlled by the occupants. When the outside air is too hot to provide cooling during the daytime, heat from the interior is absorbed by exposed heavy-weight ceiling slabs and then removed by ventilating the building at night when the air is cooler. Cooling and ventilation were maximized by orienting the building and its windows to take advantage of natural wind conditions.

This is the first application of EnergyPlus to model natural ventilation flows for a new, major building. Implementation of natural ventilation required redesign of the interior office space. "Instead of having cellular offices around the outside of the building and open plan office space in the interior, free air flow required open plan office space on the exterior and cellular offices and other enclosed spaces along the spine. These enclosed spaces have lowered false ceilings with space above to allow air driven by wind pressure to flow from one side of the building to the other," explains Haves.

Although LBNL's contribution to the design of the building envelope has been completed, Haves is still working on the project, helping the designers to develop control strategies that optimize indoor comfort by opening and closing different windows at different times of the day. One problem they will address is how to combine these automated strategies that ensure comfort for everyone in the building with the desire to allow individuals to have control of windows near them. LBNL will also be helping with the innovative aspects of the design of a federal courthouse to be built in Los Angeles.

Excerpt from an article by Robin Johnston, Science Writer, LBNL Technology Transfer Department

ENERGYPLUS INTEROPERABILITY: ACQUISITION OF BUILDING GEOMETRY FROM IFC-COMPLIANT CAD TOOLS

The use of energy simulation tools has historically been hampered by the difficulty involved in gathering and accurately entering the myriad building description data required for simulation. The International Alliance for Interoperability (www.iai-na.com) is developing a common data model for the exchange of data between software applications for the Architectural/Engineering/Construction and Facilities Maintenance Industry (AEC/FM). This data model is called Industry Foundation Classes (IFC). Software implementations based on the IFC data model can easily share input and output data.

EnergyPlus Interoperability with CAD

Several popular CAD tools now have implementations of IFC-compliant import/export capabilities that allow the geometry created in these tools to be written to, and read from, IFC data files. Commercially available versions of these tools will likely be based on different released versions of the IFC data model, including the R1.5.1, R2.0, and the 2x platforms. Olof Granlund Oy (www.granlund.fi) offers BSPro COM-Server, a software development middleware tool (www.bspro.net) that provides access to IFC data files and is based on all release versions. BSPro COM-Server, tailored to the building services sector of the AEC/FM Industry, includes a client software module that automatically acquires the geometry of spaces, walls, windows, doors, floors, and roofs from an IFC data file, and generates an EnergyPlus input data file (IDF) containing this building geometry. The EnergyPlus client to the BSPro COM-Server,
referred to as the IFCtoIDF utility [see *User News,* Vol. 21, No. 5, p. 4 "*The BSPro COM-Server: Interoperability Among Software Tools using Industry Foundation Classes*"], has been developed as a Windows DLL using Microsoft Visual C++. The current version of the IFCtoIDF utility is compatible with the EnergyPlus Version 1.0 Input Data Dictionary. An executable version of the utility has been distributed as part of EnegyPlus, Version 1.0. Olof Granlund Oy is making a runtime version of their server available to registered EnergyPlus users free of charge.

Limitations of the IFCtoIDF Utility

Please note that the IFCtoIDF utility is still in Beta testing. This utility, along with the BSPro COM-Server and several other software tools, has been officially certified by the IAI as being compliant with IFC Release 2.0. However, this does not mean that the utility is capable of seamlessly importing all data required for an EnergyPlus simulation from an IFC data file. The utility focuses on geometry only at this point. For example, construction material characteristics are currently defaulted in the resulting IDF. These data are not imported from an IFC data file simply because there is not yet an IFC-compliant tool that provides a user interface for inputting material characteristics. Furthermore, interoperability based on the object-oriented IFC standard is still a relatively new technology. Even the seemingly simple exchange of geometry representing objects such as a space and the parts of walls, floors and ceilings that bound this space can result in misunderstandings between different tools.

More experience in exchanging data between a wide variety of software tools is required before this technology matures to a stage of full and foolproof functionality.

FOR MORE INFORMATION, PLEASE REFER TO THE NEW REPORT ON PAGE 3 TITLED:
"*BSPRO COM-SERVER -- INTEROPERABILITY AMONG SOFTWARE TOOLS USING INDUSTRY FOUNDATION CLASSES* "

ENERGYPLUS MEETS BESTEST

EnergyPlus meets BESTEST[1]

The Benchmark for Building Energy Simulation Programs

BESTEST (Building Energy Simulation TEST) is a comparative testing procedure for thermal building simulations primarily related to the building envelope. These tests build upon each other and evaluate a range of model effects including thermal mass, direct solar gain windows, window-shading devices, internally generated heat, infiltration, sunspaces, earth coupling, and deadband and setback thermostat control. In addition, a large number of diagonostic tests can be run if the program fails any of the primary tests. The tests start with the basic structure (a “shoebox” shape) which is then manipulated by moving the windows, adding exterior shading, changing the wall constructions, modifying the coupling with the ground, adding sunspaces, etc.

Background

Numerous software programs are available to simulate energy performance in buildings. But these programs often produce widely divergent results — even on the same building. Consequently, architects and engineers have not trusted the programs and have continued to design buildings without focusing on energy use.

BESTEST was created to systematically compare whole-building energy software programs and diagnose the sources of prediction differences. Originally designed to help software developers produce reliable energy software, BESTEST is also used to assure potential software users (architects and engineers) that a particular simulation program gives reasonable results or that a program is appropriate for their particular application.

The BESTEST technique applies a series of carefully specified test case buildings that progress systematically from the extremely simple to the relatively realistic. Output values for the cases—such as annual loads, temperature ranges, and peak loads—are compared and diagnostic logic used to pinpoint the algorithms responsible for prediction differences.

The more realistic cases, although geometrically simple, test the ability of the programs to model effects such as thermal mass, direct solar gain windows, window-shading devices, internally generated heat, infiltration, sunspaces, earth coupling, and deadband and setback thermostat control. The more simplified cases facilitate diagnosis by allowing excitation of certain heat transfer mechanisms.

Field trials of the method were conducted with a number of "reference" programs selected by the IEA researchers to represent the best of the state-of-the-art detailed simulation capability in the US and Europe. These included BLAST, DOE-2, ESP, SERIRES, S3PAS, TASE, TRNSYS, CLIM2000, and DEROB.

Three versions of BESTEST are currently available:

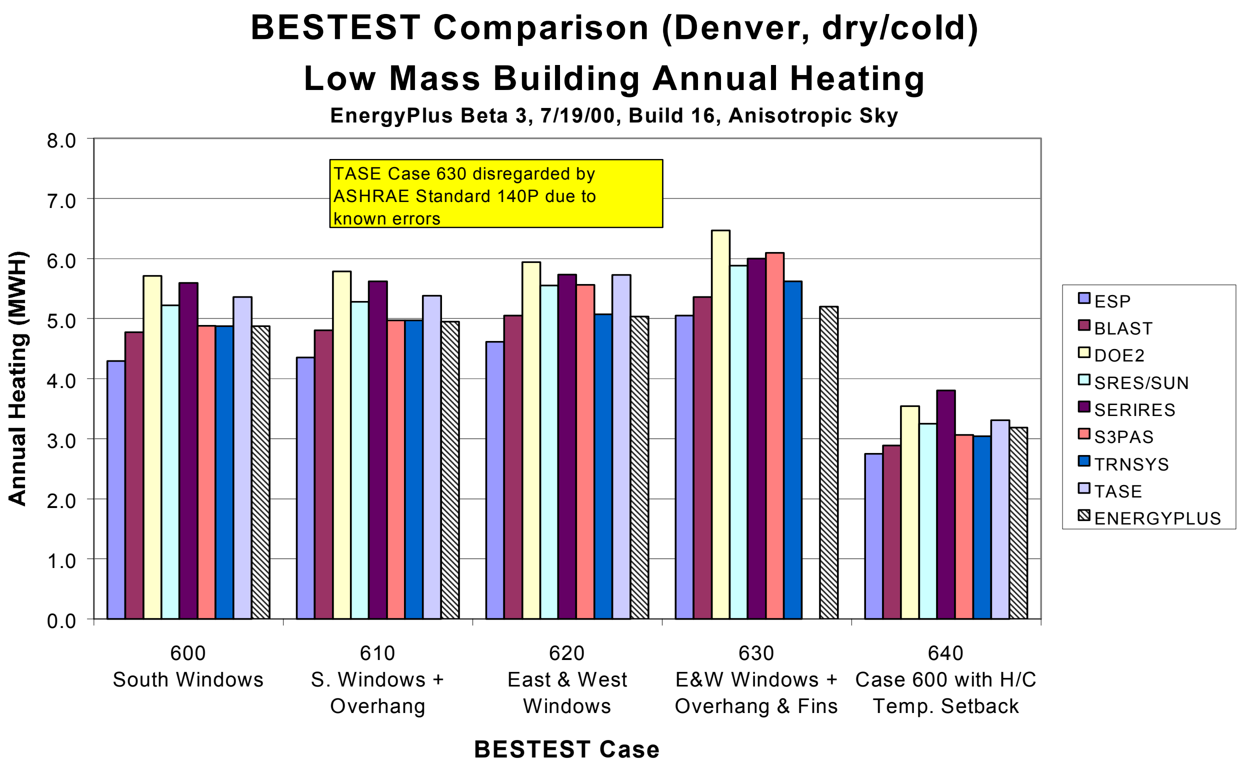
- IEA BESTEST (detailed hourly (or shorter) time-step simulation programs),

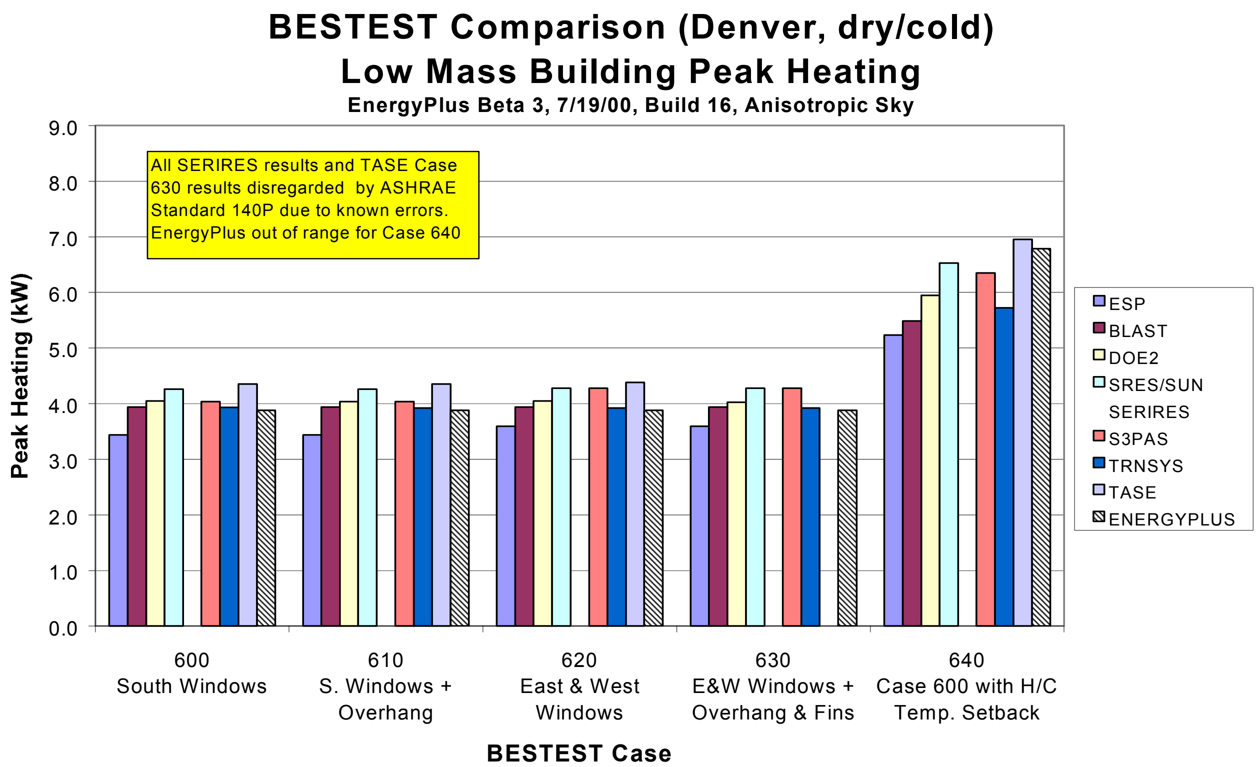
[1] BESTEST is the result of a collaboration between the International Energy Agency (IEA) and the U. S. National Renewal Energy Laboratory (NREL). Please direct technical questions to Ron Judkoff of NREL (R_Judkoff@nrel.gov).

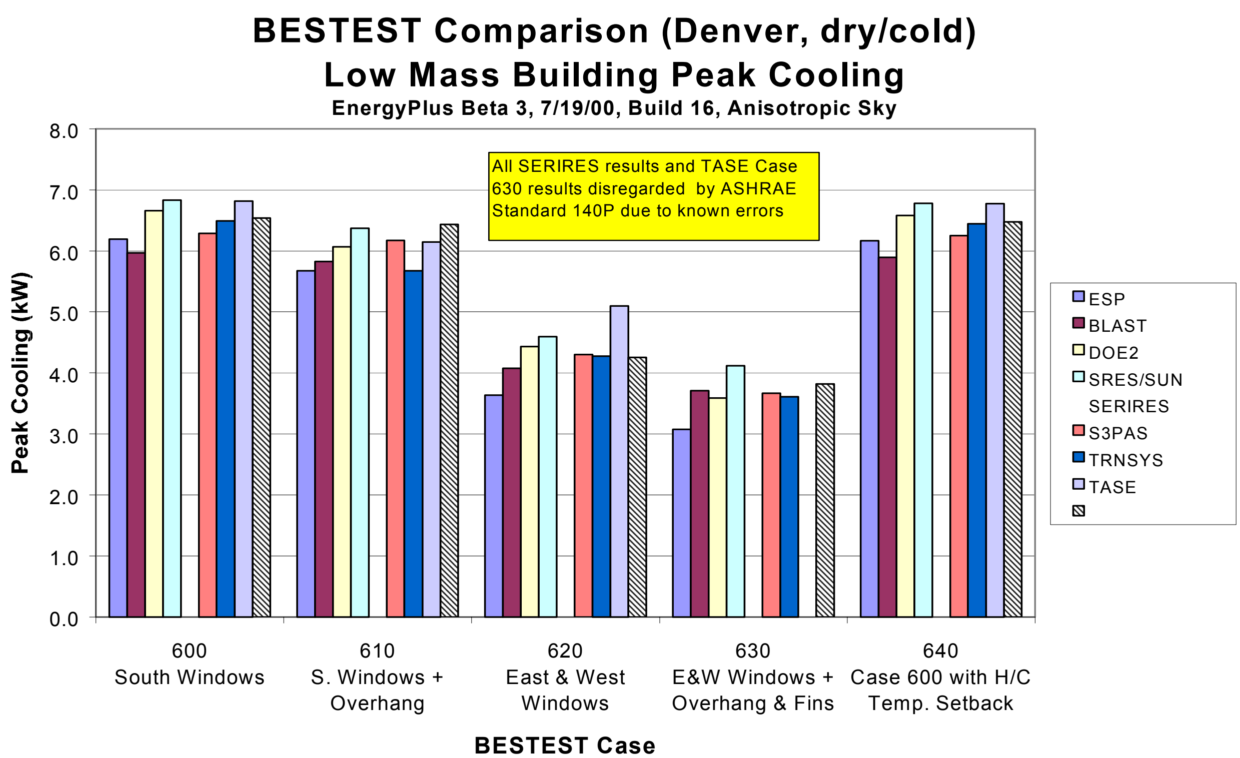
- HERS BESTEST (detailed and simplified programs with an emphasis on modeling houses), and
- Florida BESTEST (hot-humid climates).

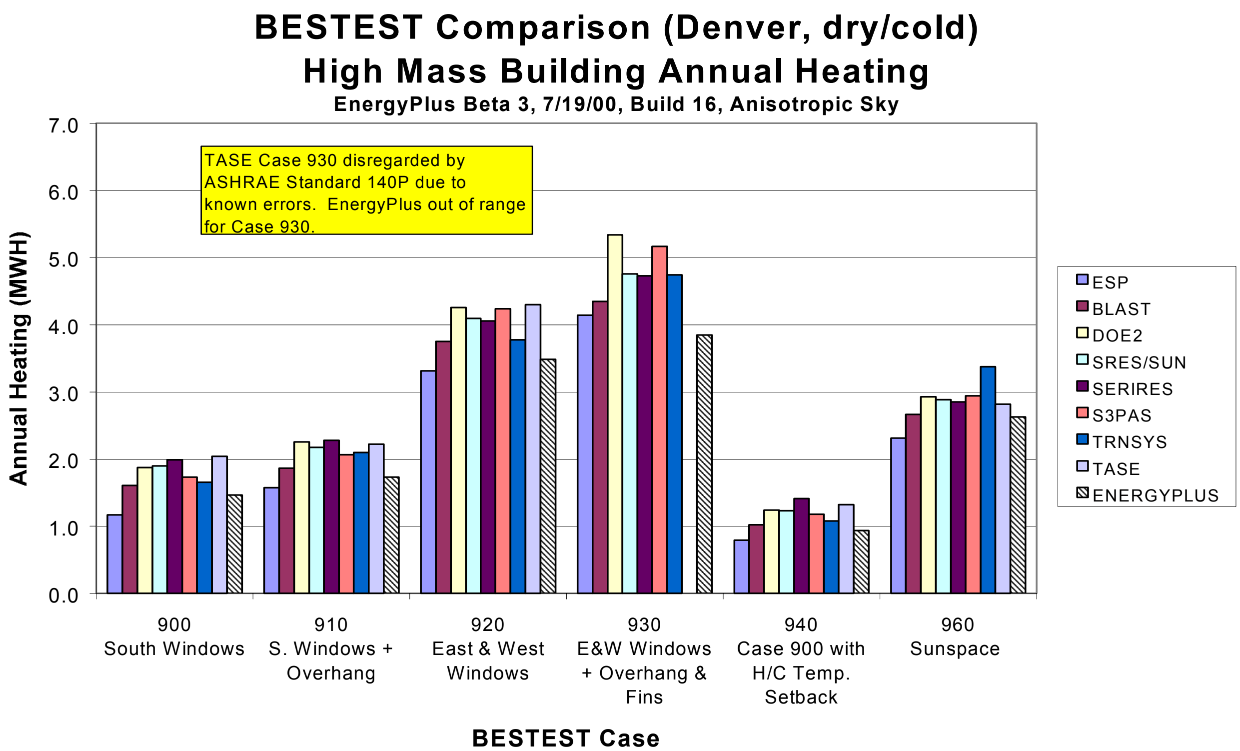
EnergyPlus BESTEST Results

In July the EnergyPlus program (Beta 3) was run by GARD Analytics on the BESTEST cases. The results are shown in the next 11 figures. (The DOE-2 values shown in these figures were obtained by GARD Analytics using the Windows version of DOE-2.1E available from ESTSC, p. 19.)

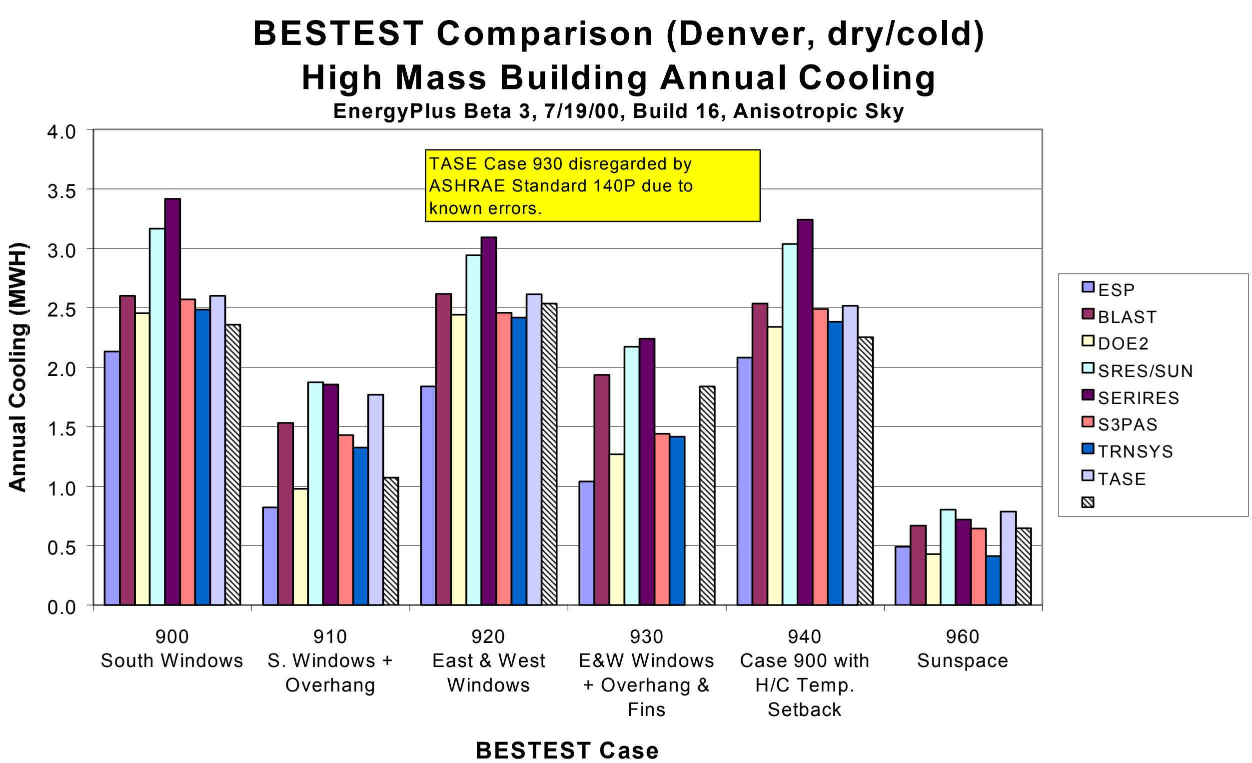



BESTEST Comparison (Denver, dry/cold)
Low Mass Building Peak Heating
EnergyPlus Beta 3, 7/19/00, Build 16, Anisotropic Sky
All SERIRES results and TASE Case 630 results disregarded by ASHRAE Standard 140P due to known errors. EnergyPlus out of range for Case 640
Peak Heating (kW)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
600 South Windows
610 S. Windows + Overhang
620 East & West Windows
630 E&W Windows + Overhang & Fins
640 Case 600 with H/C Temp. Setback
BESTEST Case
ESP
BLAST
DOE2
SRES/SUN SERIRES
S3PAS
TRNSYS
TASE
ENERGYPLUS

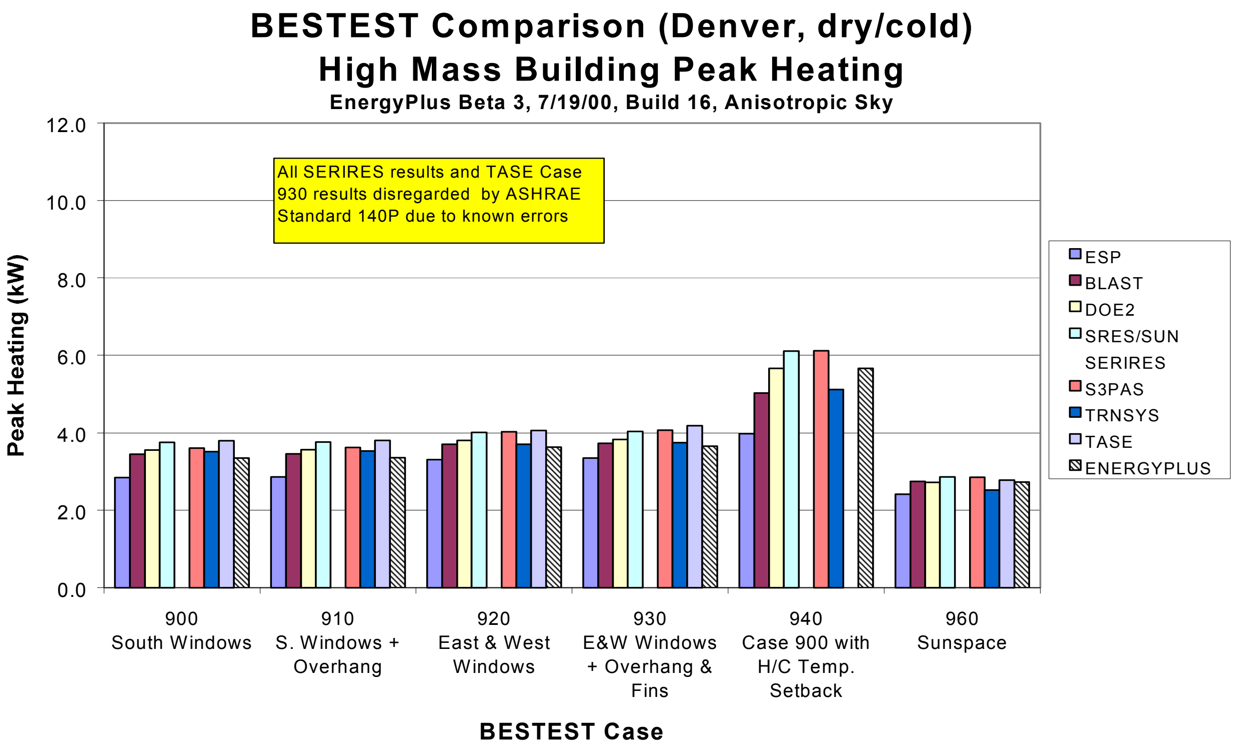

BESTEST Comparison (Denver, dry/cold)
Low Mass Building Peak Cooling
EnergyPlus Beta 3, 7/19/00, Build 16, Anisotropic Sky
All SERIRES results and TASE Case 630 results disregarded by ASHRAE Standard 140P due to known errors
Peak Cooling (kW)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
600 South Windows
610 S. Windows + Overhang
620 East & West Windows
630 E&W Windows + Overhang & Fins
640 Case 600 with H/C Temp. Setback
BESTEST Case
ESP
BLAST
DOE2
SRES/SUN SERIRES
S3PAS
TRNSYS
TASE

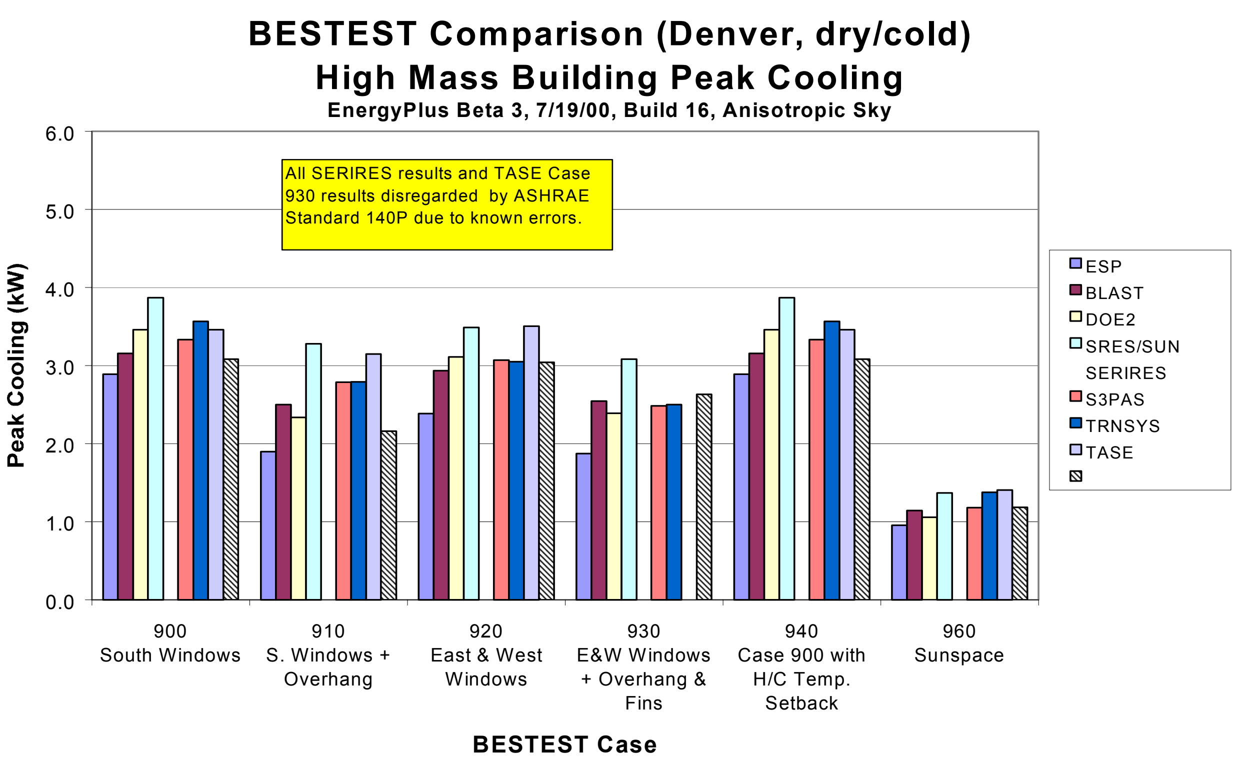


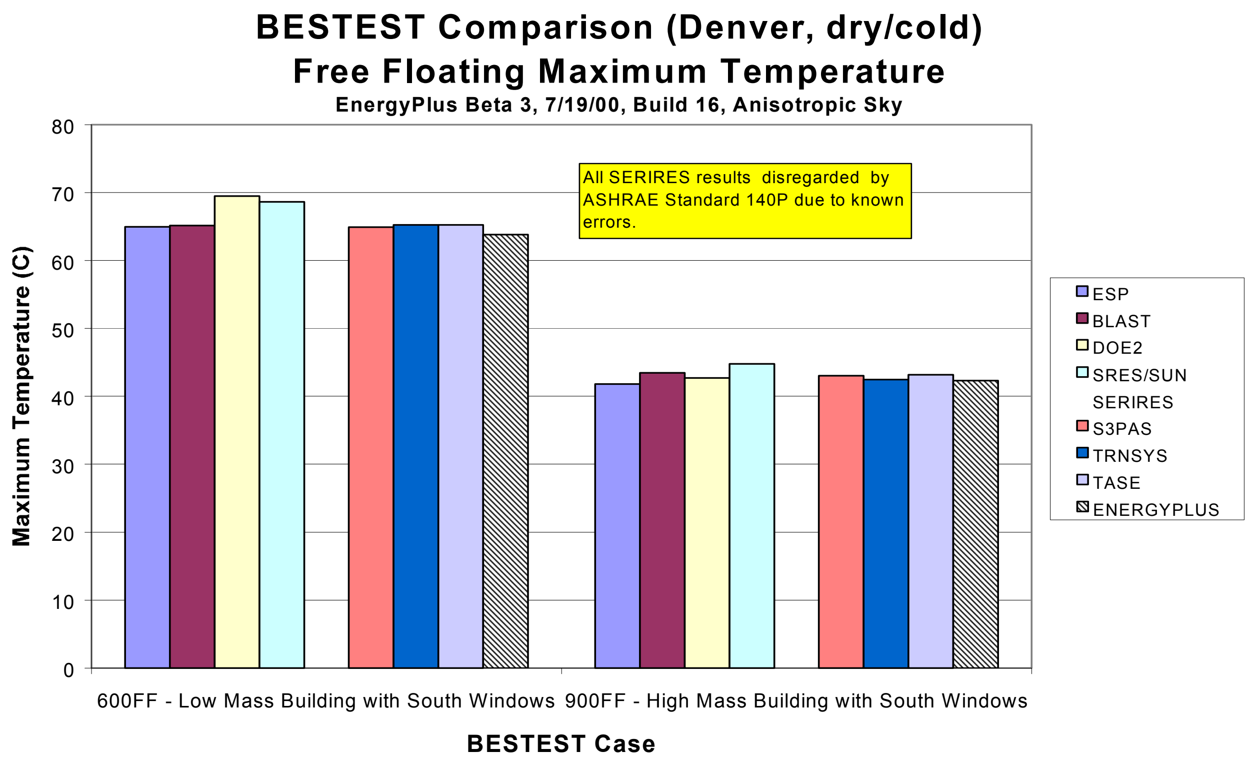
BESTEST Comparison (Denver, dry/cold)
High Mass Building Annual Heating
EnergyPlus Beta 3, 7/19/00, Build 16, Anisotropic Sky
TASE Case 930 disregarded by ASHRAE Standard 140P due to known errors. EnergyPlus out of range for Case 930.
Annual Heating (MWH)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
900 South Windows
910 S. Windows + Overhang
920 East & West Windows
930 E&W Windows + Overhang & Fins
940 Case 900 with H/C Temp. Setback
960 Sunspace
BESTEST Case
ESP
BLAST
DOE2
SRES/SUN
SERIRES
S3PAS
TRNSYS
TASE
ENERGYPLUS



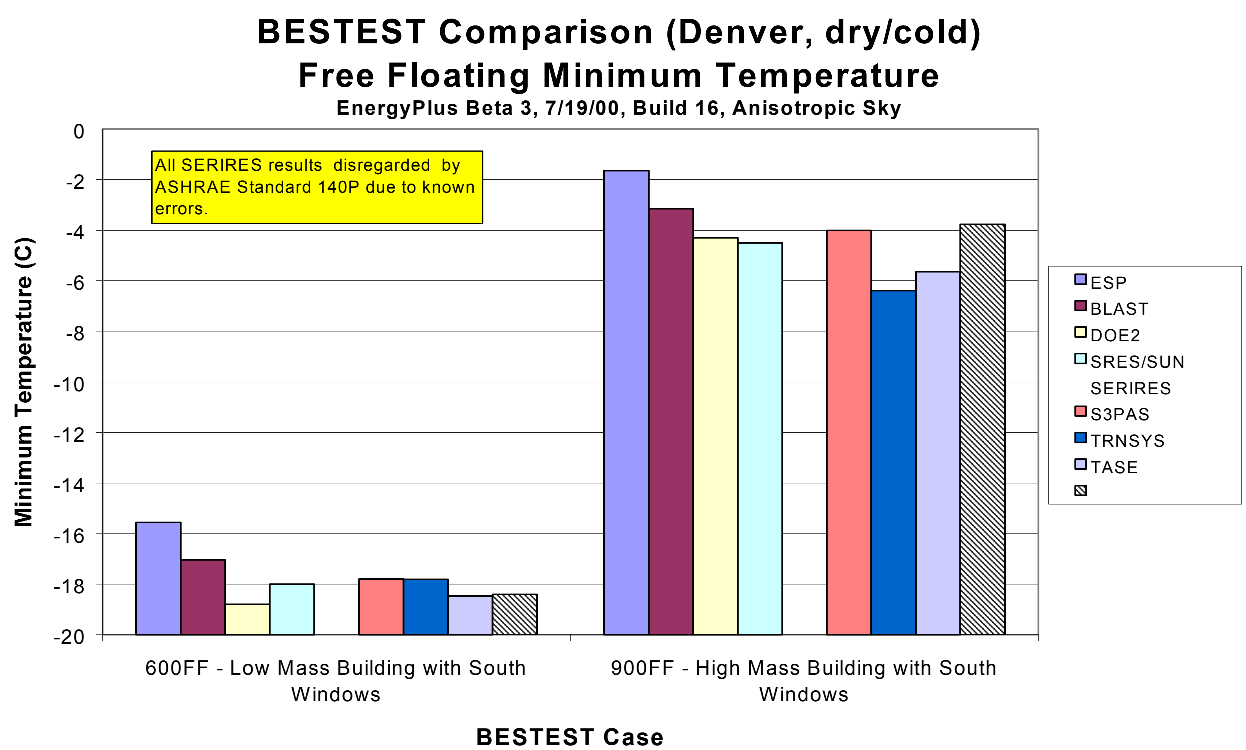
BESTEST Comparison (Denver, dry/cold)
High Mass Building Annual Cooling
EnergyPlus Beta 3, 7/19/00, Build 16, Anisotropic Sky
TASE Case 930 disregarded by ASHRAE Standard 140P due to known errors.
Annual Cooling (MWH)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
900 South Windows
910 S. Windows + Overhang
920 East & West Windows
930 E&W Windows + Overhang & Fins
940 Case 900 with H/C Temp. Setback
960 Sunspace
BESTEST Case
ESP
BLAST
DOE2
SRES/SUN
SERIRES
S3PAS
TRNSYS
TASE


BESTEST Comparison (Denver, dry/cold)
High Mass Building Peak Heating
EnergyPlus Beta 3, 7/19/00, Build 16, Anisotropic Sky
All SERIRES results and TASE Case 930 results disregarded by ASHRAE Standard 140P due to known errors
Peak Heating (kW)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
900 South Windows
910 S. Windows + Overhang
920 East & West Windows
930 E&W Windows + Overhang & Fins
940 Case 900 with H/C Temp. Setback
960 Sunspace
BESTEST Case
ESP
BLAST
DOE2
SRES/SUN
SERIRES
S3PAS
TRNSYS
TASE
ENERGYPLUS

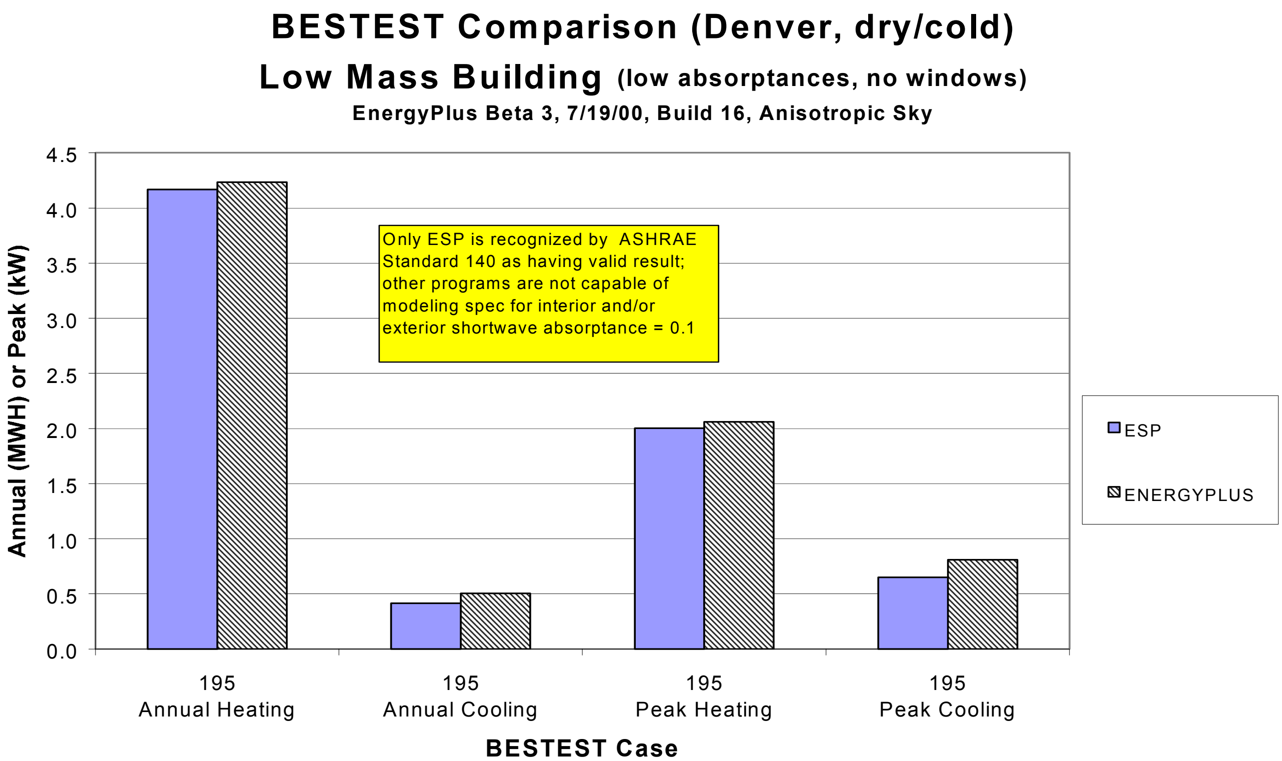

BESTEST Comparison (Denver, dry/cold)
High Mass Building Peak Cooling
EnergyPlus Beta 3, 7/19/00, Build 16, Anisotropic Sky
All SERIRES results and TASE Case 930 results disregarded by ASHRAE Standard 140P due to known errors.
Peak Cooling (kW)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
900 South Windows
910 S. Windows + Overhang
920 East & West Windows
930 E&W Windows + Overhang & Fins
940 Case 900 with H/C Temp. Setback
960 Sunspace
BESTEST Case
ESP
BLAST
DOE2
SRES/SUN
SERIRES
S3PAS
TRNSYS
TASE



BESTEST Comparison (Denver, dry/cold)
Free Floating Maximum Temperature
EnergyPlus Beta 3, 7/19/00, Build 16, Anisotropic Sky
All SERIRES results disregarded by ASHRAE Standard 140P due to known errors.
Maximum Temperature (C)
80
70
60
50
40
30
20
10
0
600FF - Low Mass Building with South Windows
900FF - High Mass Building with South Windows
BESTEST Case
ESP
BLAST
DOE2
SRES/SUN
SERIRES
S3PAS
TRNSYS
TASE
ENERGYPLUS



BESTEST Comparison (Denver, dry/cold)
Free Floating Minimum Temperature
EnergyPlus Beta 3, 7/19/00, Build 16, Anisotropic Sky
All SERIRES results disregarded by ASHRAE Standard 140P due to known errors.
Minimum Temperature (C)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
600FF - Low Mass Building with South Windows
900FF - High Mass Building with South Windows
BESTEST Case
ESP
BLAST
DOE2
SRES/SUN
SERIRES
S3PAS
TRNSYS
TASE


BESTEST Comparison (Denver, dry/cold)
Low Mass Building (low absorptances, no windows)
EnergyPlus Beta 3, 7/19/00, Build 16, Anisotropic Sky
Annual (MWH) or Peak (kW)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Only ESP is recognized by ASHRAE Standard 140 as having valid result; other programs are not capable of modeling spec for interior and/or exterior shortwave absorptance = 0.1
ESP
ENERGYPLUS
195 Annual Heating
195 Annual Cooling
195 Peak Heating
195 Peak Cooling
BESTEST Case

ENERGYPLUS: A NEW-GENERATION BUILDING ENERGY SIMULATION PROGRAM

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ABSTRACT
Many of the popular building energy simulation programs around the world are reaching maturity –some use simulation methods (and even code) that originated in the 1960s. For more than two decades, the U.S. government supported development of two hourly building energy simulation programs, BLAST and DOE–2. Designed in the days of mainframe computers, expanding their capabilities further has become difficult, time-consuming, and expensive. At the same time, the 30 years have seen significant advances in analysis and computational methods and power—providing an opportunity for significant improvement in these tools.

In early 1996, a Federal agency began developing a new building energy simulation tool, EnergyPlus, building on develop-ment experience with DOE–2 and BLAST. EnergyPlus includes a number of innovative simulation features—such as variable time steps, built-in template and external modular systems that are integrated with a heat balance-based zone simulation—and input and output data structures tailored to facilitate third party module and interface development. Other planned simulation capabilities include multi-zone airflow, and electric power and solar thermal and photovoltaic simulation. Beta testing of EnergyPlus begins in mid 1999.

INTRODUCTION

For the past 20 years, the U.S. government supported development of DOE−2 and BLAST. BLAST [BLA 92], sponsored by the U.S. Department of Defense (DOD), has its origins in the NBSLD program developed at the U.S. National Bureau of Standards (now NIST) in the early 1970s. DOE–2 [WIN 93], sponsored by the U.S. Department of Energy (DOE), has its origins in the Post Office program written in the late 1960s for the U.S. Post Office. The main difference between the programs is the load calculation method—DOE–2 uses a room weighting factor approach while BLAST uses a heat balance approach. Both programs are widely used throughout the world.

Each program comprises hundreds of subroutines working together to simulate heat and mass energy flows throughout a building. In some cases, subroutines in DOE–2 were more accurate. In other cases, subroutines in BLAST were more accurate. In both programs, however, simulation methodologies (or loops) are often difficult to trace due to decades of development (and multiple authors). Often, this results in "spaghetti code" with data and subroutines for a particular simulation capability spread throughout the program. To modify either program, a developer must have many years of experience working within the code, knowledge of code unrelated to their task (because of the spaghetti), and (for sponsors) an extraordinary investment of time and money.

Why the U. S. government supported two separate (and comparable capability) programs has been questioned for many years. Discussions on merging the two programs began in earnest in 1994 with a DOD-sponsored workshop in Illinois. Nothing concrete resulted from that workshop, but eventually, DOE took the initiative and began developing a new program, named EnergyPlus, in 1996. The EnergyPlus team includes U. S. Army Construction Engineering Research Laboratories (CERL), University of Illinois (UI), Lawrence Berkeley National Laboratory (LBNL), and DOE. In this paper, we present an overview of the organization and capabilities of EnergyPlus and explain the rationale and structure behind the overall program.

Why a New Program?

As mentioned earlier, DOE–2 and BLAST have become expensive to maintain, modify and enhance, because of 20+ year-old code and old Fortran structures (or general lack of structure). When DOD ended support for BLAST in 1995 due to budget constraints, we took the opportunity to combine the resources, teams, and best capabilities and features of BLAST and DOE–2. The last version of BLAST was released in spring 1998 and the last version of DOE–2 with contributions under DOE-sponsorship was completed in 1998. Initially, we thought that we could create a "best of" program—combining modules from the two programs—without starting from scratch. After initial development work, we determined that EnergyPlus would cost less to develop, be released faster, and be easier to modify and extend if we wrote all new, modular, structured code. Thus, EnergyPlus is all-new Fortran 90 code.

What is EnergyPlus?
EnergyPlus is a new building performance simulation program that combines the best capabilities and features from BLAST and DOE–2 along with new capabilities. EnergyPlus comprises completely new code written in Fortran 90. It is primarily a simulation engine—there is no interface. Input and output are simple comma-separated, ASCII text files, a much simpler input structure than either DOE–2 or BLAST. Both BLAST and DOE–2 have been successful in attracting third-party developers for user interfaces and new modules. We have invited these same developers to participate in EnergyPlus beginning during beta testing—to work on new simulation modules or user interfaces.

Modular Code
One of the main goals for the EnergyPlus development effort has been to create a well-organized, modular structure that facilitates adding features and links to other programs. In evaluating programming languages, we found we had two choices—move to C/C++ or stay with Fortran. Despite the advantages of the structure and object-orientation of C/C++, we decided to select Fortran 90 as the programming language for EnergyPlus because Fortran 90:
is a modern, modular language with good compilers on many platforms
allows C-like data structures and mixed language modules
provides structure that begins to be object-based
allows long variable names (up to 32 characters)
provides backward compatibility during the development process

We began working on EnergyPlus by modularizing (restructuring) code from the heat balance engine in IBLAST, a research version of BLAST with integrated loads and HVAC calculation [TAY 90, 91]. Normally such restructuring would result in major rewrites involving a long development period, and very extensive testing to ensure the new code performs as intended. However, because the EnergyPlus team selected Fortran 90 (and Fortran 77 is a subset of Fortran 90), development is proceeding through a process which we call Evolutionary Reengineering (ER). This process incrementally moves the program from old unstructured legacy code to new modular code by incorporating new code with old. The existing code still works with user input data, and is extended to generate parameters needed by the new code modules. In this way the new modules can be verified without having to completely replace the entire functional capability of the old program with new code before it can be tested. As the process proceeds, the parameters supplied by old routines are replaced by new routines and data structures. This makes the transition evolutionary and permits a smooth transition with a greater capability for verification testing.

ENERGYPLUS STRUCTURE
In two recent workshops on next generation energy tools sponsored by DOE and DOD [CRA 97] there was strong consensus that a more flexible and robust tool with additional capabilities was needed. Recurrent themes for simulation needs throughout the workshops were design, environment, economics, and occupant comfort and safety. Designers need tools that provide answers to very specific questions during design. They want tools that provide the highest level of simulation accuracy and detail reasonably possible but that don't get in the user's way. One of the highest priorities was an integrated (simultaneous) simulation for accurate temperature and comfort prediction.

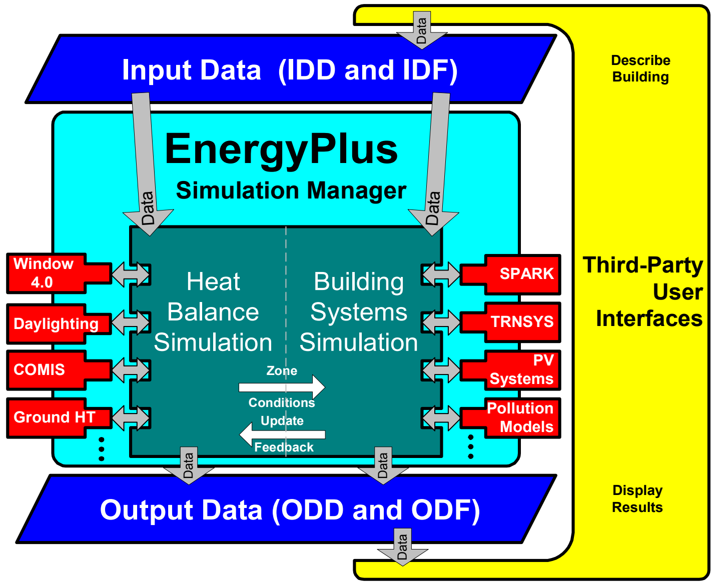
In response to these findings, we decided that integrated simulation should be the underlying concept for EnergyPlus—loads calculated (by a heat balance engine) at a user-specified time step (15-minute default) are passed to the building systems simulation module at the same time step. The building systems simulation module, with a variable time step (down to seconds), calculates heating and cooling system and plant and electrical system response. Feedback from the building systems simulation module on loads not met is reflected in the next time step of the load calculations in adjusted space temperatures if necessary.

By using an integrated solution technique in EnergyPlus, the most serious deficiency of the BLAST and DOE–2 sequential simulations can be solved—inaccurate space temperature predication due to no feedback from the HVAC module to the loads calculations. Accurate prediction of space temperatures is crucial to energy efficient system engineering—system size, plant size, occupant comfort and occupant health are dependent on space temperatures.

Integrated simulation also allows users to evaluate a number of processes that neither BLAST nor DOE–2 can simulate well. Some of the more important include:
Realistic system controls
Moisture adsorption and desorption in building elements
Radiant heating and cooling systems
Interzone air flow

Figure 1 shows the overall program structure. EnergyPlus has three basic components—a simu-lation manager, a heat balance simulation module, and a building systems simulation module. The simulation manager controls the entire simulation process. The heat balance calculations are based on IBLAST—a research version of BLAST with integrated HVAC systems and building loads simulation.

A new building systems simulation manager handles communication between the heat balance engine and various HVAC modules and loops, such as coils, boilers, chillers, pumps, fans, and other equipment/components. (In the first release, the building systems simulation manager only has HVAC systems and equipment / components. Future releases of EnergyPlus will include elec-trical systems simulation.).



1.1.1 Figure 1 Overall EnergyPlus Structure

The building systems simulation manager also controls inter-action and data exchange between EnergyPlus and SPARK [BUH 93] and HVACSIM+ [MET 95] simulations. Gone are the hardwired "template" systems (VAV, Constant Volume Reheat, etc.) of DOE–2 and BLAST—they are replaced by user-configured heating and cooling equipment components formerly within the template. This gives users much more flexibility in matching their simulation to the actual system configurations. The building systems simulation module also manages data communication between the HVAC modules, input data, and output data structures.

A comparison of major features and capabilities of EnergyPlus, BLAST, IBLAST, and DOE–2 are shown in Tables 1, 2, and 3. Table 1 shows general features, Table 2 shows load calculation features, and Table 3 shows HVAC features.

Table 1 Comparison of General Features and Capabilities

General Feature	DOE-2	BLAST	IBLAST	EnergyPlus
Integrated, Simultaneous Solution • Integrated loads/systems/plant • Iterative solution • Tight coupling	No	No	**Yes**	**Yes**
Multiple Time Step Approach • User-defined time step for interaction between zones and environment (15-minute default) • Variable time-step for interactions between zone air mass and HVAC system (≥ 1 minute)	No	No	**Yes**	**Yes**
Input Functions • Users can modify code without recompiling	**Yes**	No	No	**Yes**
New Reporting Mechanism • User-definable reports	No	No	No	**Yes**

Table 2 Comparison of Loads Features and Capabilities

Loads Feature	DOE-2	BLAST	IBLAST	EnergyPlus
Heat Balance Calculation • Simultaneous calculation of radiation and convection processes each time step	No	**Yes**	**Yes**	**Yes**
Interior Surface Convection				
• Dependent on temperature and air flow	No	**Yes**	**Yes**	**Yes**
• Internal thermal mass	**Yes**	**Yes**	**Yes**	**Yes**
Moisture Absorption/Desorption • Combined heat and mass transfer in building envelopes	No	No	**Yes**	**Yes**
Thermal Comfort • Human comfort model based on activity, inside drybulb, humidity, and radiation	No	**Yes**	**Yes**	**Yes**
Anisotropic Sky Model • Sky radiance depends on sun position for better calculation of diffuse solar on tilted surfaces	**Yes**	No	No	**Yes**
Advanced Fenestration Calculations				
• Controllable window blinds	**Yes**	No	No	**Yes**
• Layer-by-layer glazing input	**Yes**	**Yes**	**Yes**	**Yes**
• Electrochromic glazing	**Yes**	**No**	**No**	**Yes**
WINDOW 4 Library • More than 200 window types—conventional, reflective, low-E, gas-fill, electrochromic • User defined using WINDOW 4	**Yes**	**Yes**	**Yes**	**Yes**
Daylighting Illumination and Controls • Interior illuminance from windows and skylights • Stepped, dimming, on/off luminaire controls • Glare simulation and control • Effects of dimming on heating and cooling	**Yes**	No	No	**Yes**

Table 3 Comparison of HVAC Features and Capabilities

HVAC Systems and Equipment Feature	DOE-2	BLAST	IBLAST	EnergyPlus
Fluid Loops • Connect primary equipment and coils • Hot water loops, chilled water and condenser loops, refrigerant loops	**Yes**	No	No	**Yes**
Air Loops • Connect fans, coils, mixing boxes, zones	No	No	No	**Yes**
User-configurable HVAC systems	No	No	No	**Yes**
Hardwired Template HVAC systems	**Yes**	**Yes**	**Yes**	No
High-Temperature Radiant Heating • Gas/electric heaters, wall radiators	No	**Yes**	No	**Yes**
Low-Temperature Radiant Heating/Cooling • Heated floor/ceiling • Cooled ceiling	No	No	**Yes**	**Yes**
Atmospheric Pollution Calculation • CO_2, SO_x, NO_x, CO, particulate matter and hydrocarbon production • On-site and at power plant • Calculate reductions in greenhouse gases	**Yes**	**Yes**	No	**Yes**
SPARK Connection	No	No	No	**Yes**
TRNSYS Connection	No	No	No	**Yes**

Simulation Management

At the outermost program level, the Simulation Manager (shown schematically in Figure 2) controls the interactions between all simulation loops from a sub-hour level up through the user selected time step and simulation period—whether day, month, season, year or several years. Actions of individual simulation modules are directed by the simulation manager, instructing simulation modules to take actions such as initialize, simulate, record keep, or report.

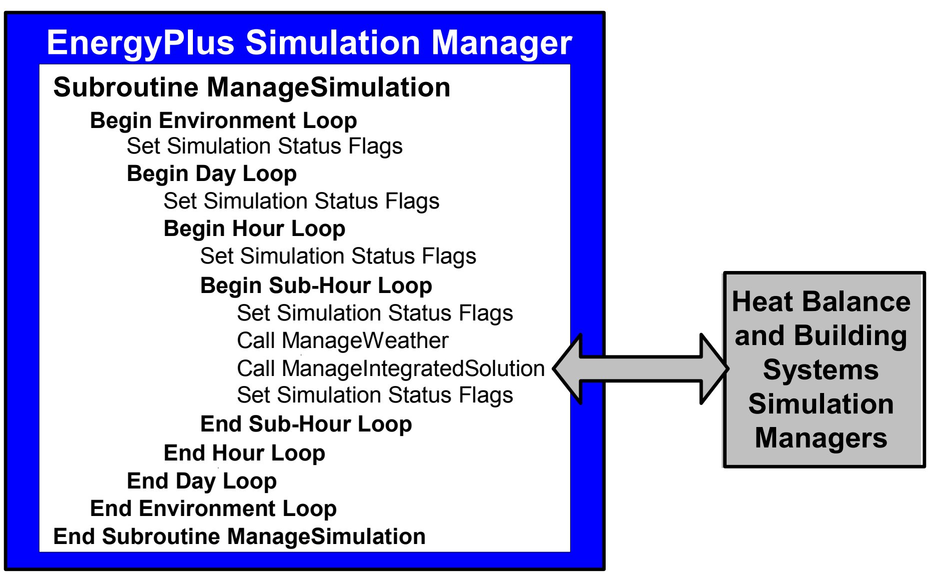


Figure 2 EnergyPlus Simulation Manager

Figure 3 shows the structure of the EnergyPlus integrated solution manager that manages the surface and air heat balance modules and acts as an interface between the heat balance and the building systems simulation manager. The surface heat balance module simulates inside and outside surface heat balance, interconnections between heat balances and boundary conditions, conduction, convection, radiation, and mass transfer (water vapor) effects. The air mass balance module deals with various mass streams such as ventilation air, exhaust air, and infiltration. It accounts for thermal mass of zone air and evaluates direct convective heat gains. Through this module that we are connecting to COMIS [FEU 90] for improved multi-zone airflow, infiltration, indoor contaminant, and ventilation calculations.

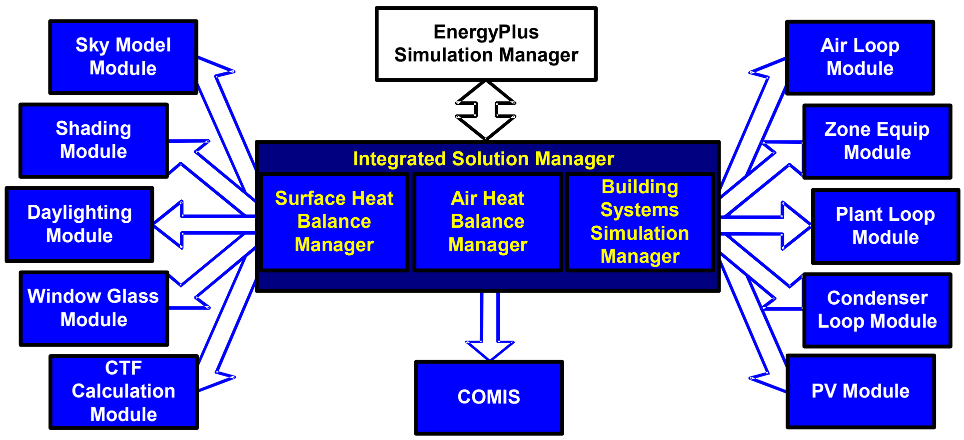


Figure 3 Integrated Simulation Manager

We created the simulation manager to specifically address the legacy issues of spaghetti code and lack of structure in DOE–2 and BLAST. The simulation manager provides several critical benefits:
major simulation loops are contained in a single module
modules are self-contained and more object-based
data access is controlled
new modules are easily added

Heat and Mass Balance
As noted earlier, the underlying building thermal zone calculation method in EnergyPlus is a heat balance model. The fundamental assumption of heat balance models is that air in each thermal zone can be modeled as well stirred with uniform temperature throughout. Although this does not reflect physical reality well, the only current alternative is Computational Fluid Dynamics (CFD)—a complex and computationally intensive simulation of fluid (in this case, air) movement. Currently, CFD is most useful in research applications. Several groups are developing models somewhere between the well-stirred model and a full CFD calculation. The modular structure of EnergyPlus allows these new models to be included in future releases once they are available. The other major assumption in heat balance models is that room surfaces (walls, windows, ceilings, and floors) have:
uniform surface temperatures,
uniform long and short wave irradiation,
diffuse radiating surfaces, and
internal heat conduction.

In addition to the basic heat balance engine from IBLAST, we are creating three new modules based on capabilities within DOE–2: daylighting illumination [WIN 85], WINDOW 4-based fenestration [ARA 94], and anisotropic sky. The daylighting module calculates hourly interior daylight illuminance, glare from windows, glare control, electric lighting controls (on/off, stepped and continuous dimming), and electric lighting reduction for the heat balance module. In the future, the daylighting module will include an improved interior inter-reflection calculation, light shelves, roof monitors, and reflection from neighboring buildings. The fenestration module includes capabilities from WINDOW 4—accurate angular dependence of transmission and absorption for both solar and visible radiation, and temperature-dependent U-value. Users can enter a layer-by-layer window description or choose windows from the library (conventional, reflective, low-e, gas fill electrochromic). Also simulated are movable window shades for sun and/or glare control. In the near future, the algorithms will be upgraded to the WINDOW 5 algorithms for coatings and framing elements. The sky model includes non-isotropic radiance and luminance distribution throughout the sky based on the empirical model by Perez as a function of sun position and cloud cover. This non-uniform radiance distribution improves calculation of diffuse solar on tilted surfaces (walls and sloped roofs).

Several other modules have been re-engineered for inclusion in EnergyPlus: solar shading from BLAST and conduction transfer function calculations from IBLAST. The major enhancements of the IBLAST (and EnergyPlus) heat balance engine over BLAST include mass transfer and radiant heating and cooling. The mass transfer capability within EnergyPlus allows fundamental, layer-by-layer solution for mass transfer through surfaces and a mass balance on zone air similar to the air heat balance. The radiant heating and cooling models are an expansion of the conduction transfer function and incorporate thermal comfort calculations. This provides a means for improved modeling and control capabilities for the new building systems simulation manager.

One last important feature of the EnergyPlus heat balance engine is that it is essentially identical in functionality to the Loads Toolkit being developed by UI under ASHRAE RP-987. UI is developing both the Loads Toolkit and the EnergyPlus heat and mass balance engine and is using the programming standard developed in the EnergyPlus project to produce the Loads Toolkit. Both projects benefit—modularization efforts started by EnergyPlus will be useful in the Loads Toolkit and new component models developed for the Loads Toolkit will enhance EnergyPlus.

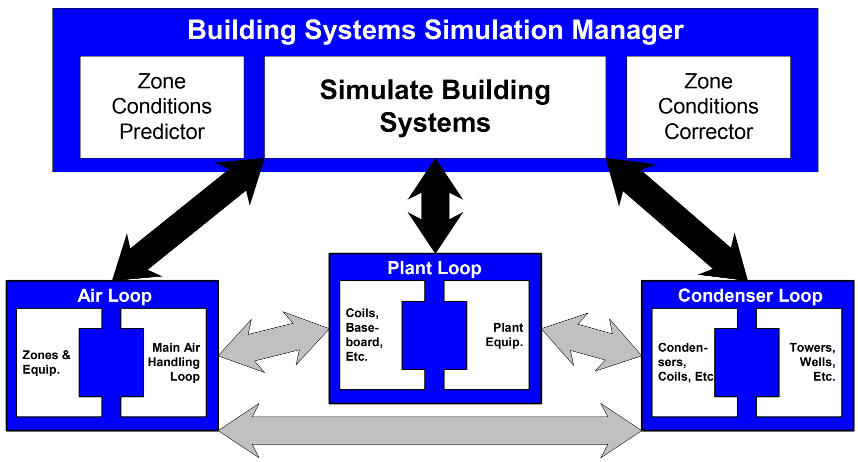


Figure 4 Building Systems Simulation Manager

Building Systems Simulation Manager

After the heat balance manager completes simulation for a time step, it calls the Building Systems Simulation Manager (see Figure 4) which controls the simulation of HVAC and electrical systems, equipment and components and updates the zone-air conditions. EnergyPlus does not use a sequential simulation method (first building loads, then air distribution system, and then central plant) as found in DOE–2 and BLAST since this imposes rigid boundaries on program structures and limits input flexibility. Instead, we designed the building systems simulation manager with several objectives in mind:

- fully integrated simulation of loads, systems, and plant
- modular
- extensible

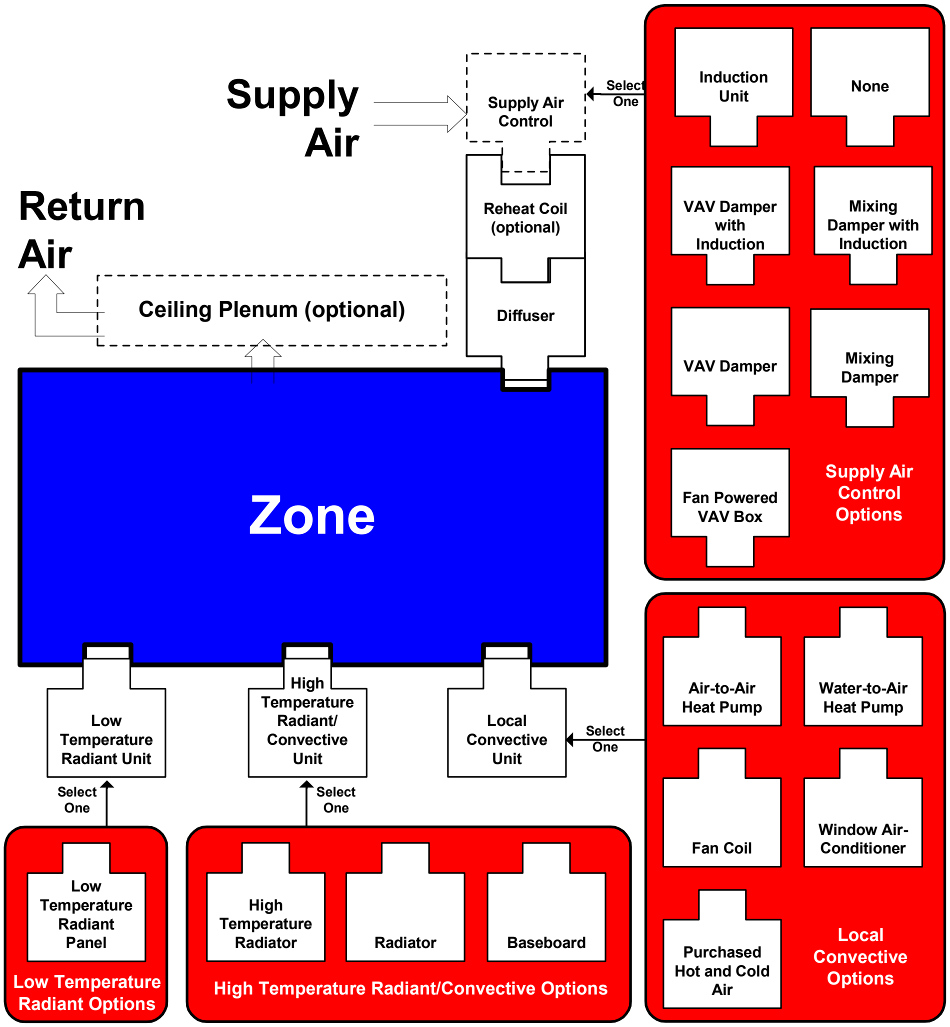


Figure 5 Zone Equipment Module

Integrated simulation models capacity limits more realistically and tightly couples the air and water side of the system and plant. Modularity is maintained at both the component and system level. This eases adding new components and flexibly modeling system configurations and, at the system level, equipment and systems are clearly connected to zone models in the heat balance manager. To implement these concepts, we use loops throughout the building systems simulation manager—primarily HVAC air and water loops. Loops mimic the network of pipes and ducts found in real buildings and eventually will simulate head and thermal losses that occur as fluid moves in each loop. As mentioned earlier, EnergyPlus has no hardwired "template" systems. Instead, we developed input file templates for the each of the major system types in BLAST and DOE–2. These templates provide an easy starting point for users with system configurations that differ from "default" configurations. The air loop simulates air transport, conditioning, and mixing and includes supply and return fans, central heating and cooling coils, heat recovery, and controls for supply air temperature and outside air economizer. The air loop connects to the zone through the zone equipment. Zone equipment includes diffusers, reheat/recool coils, supply air control (mixing dampers, fan-powered VAV box, induction unit, VAV dampers), local convection units (window air-conditioning, fan coil, water-to-air heat pump, air-to-air heat pump), high temperature radiant/convective units (baseboard, radiators) and low temperature radiant panels. Figure 5 shows equipment connections to zones—note that more than one equipment type can be specified for a zone. However, users must specify equipment in the order it will be used to meet zone heating and cooling demand.

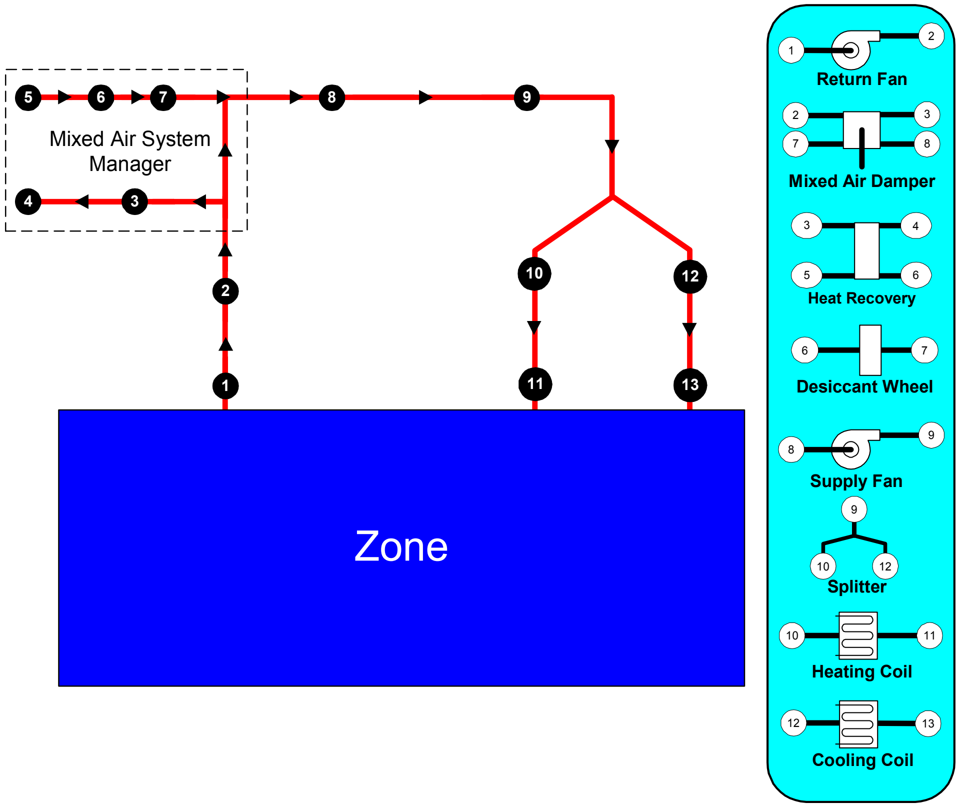


Figure 6 Simple Air Loop Node Diagram

For the air loop, the solution method is iterative, not single-pass as in DOE–2 and BLAST. In order to specify equipment connections to a loop, nodes are defined at key locations around the loop with each node assigned a unique numeric identifier as shown in Figure 6. Node identifiers store loop state variables and set-point information for that location in the loop. We use an iterative solution technique to solve for unknown state variables along with control equation representations. These representations connect the set points at one node with the control function of a component, such as fan damper position and cooling coil water flow rate. In this schema, all the loop components are simulated first, then the control equations are updated using explicit finite difference. This procedure continues until the simulation converges. Typical control schemes are included in the input file templates described earlier.

There are two loops for HVAC plant equipment—a primary loop (for supply equipment such as boilers, chillers, thermal storage, and heat pumps) and a secondary loop (for heat rejection equipment such as cooling towers and condensers). Figure 7 presents a schematic view of equipment connections on the primary plant loop. Equipment is specified by type (gas-fired boiler, open drive centrifugal chiller) and its operating characteristics. In the first release of EnergyPlus, we are supporting performance-based equipment models (such as in BLAST and DOE–2). But because of the modular code, it will be easy for developers to add other types of models. As in the air loop, the primary and secondary plant loops use explicit nodes to connect equipment to each loop. Connections between the air loop and zone equipment and the primary and secondary loops are made through the node data structure and must be explicitly defined in the input file.

A similar loop approach is proposed for a new electrical loop for simulating electrical systems—supply (utility, photovoltaic modules, and fuel cells), demand (plug loads, lighting, and other electrical loads), and measurement (meters).

In the longer term, EnergyPlus users will have more systems and equipment options through a link to SPARK [BUH 93], a new equation-based simulation tool. SPARK is a better solver for complex iterative problems and is currently in beta testing. SPARK already has a library of HVAC components based on the ASHRAE primary and secondary toolkits. EnergyPlus will continue to have system types (in input file templates) but developers and advanced users will be able to easily build complex new HVAC models with SPARK.

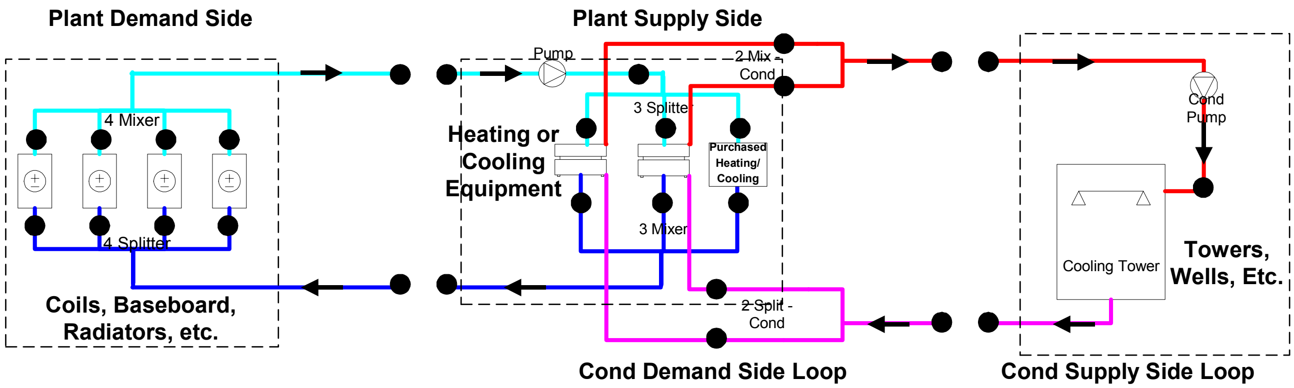


Figure 7 Example Plant Loop

INPUT, OUTPUT, AND WEATHER DATA

Both DOE–2 and BLAST have highly-structured but user readable input file definitions that have evolved over many years. Instead of user readability, we designed the EnergyPlus input data files for easy maintenance and expansion. We chose to keep the input file simple in order to accept simulation input data from other sources such as CADD systems, programs that also do other functions, and pre-processors similar to those written for BLAST and DOE–2. An EnergyPlus input file, while readable, is cryptic and definitely not user-friendly—it is not intended to be the main interface for typical end-users. We expect most users will use EnergyPlus through an interface from a third-party developer. To make it easy for current DOE–2 and BLAST users to move to EnergyPlus, the team has written utilities that convert BLAST and DOE–2 input to the new EnergyPlus input structure.

Depending on how quickly the International Alliance for Interoperability (IAI) progresses in defining a de facto standard for building information exchange, a common object-oriented data store such as the IAI's proposed Industry Foundation Classes [BAZ 97] may eventually become the main interface to the program.

EnergyPlus uses a free format input file that contains a complete object-based description of the building and its systems. The basic syntax is:
object, name, value, value, . . ., value;
"Object" is a pre-defined word denoting a building component, such as WALL, MATERIAL, LIGHTING, SYSTEM, HEATING COIL, and BOILER. This word is followed by a list of data values and terminates with a semicolon. These data describe performance characteristics and intended use for that object in the simulation. Unlike BLAST and DOE–2, the input file must explicitly provide all information—there are no default assumptions. Users may include comments throughout their input data file. A comparison of input file syntax for BLAST, DOE–2, and EnergyPlus is shown in Table 4.

During a simulation, EnergyPlus saves results for each time step in an output data structure. HVAC results are aggregated and reported at the time step. This structure uses a similar philosophy to the input—simple text files with a syntax of object, time stamp, data, data, data, . . ., data; . The output data is simple yet contains all the simulation results so that users and interface developers cam easily access specific results without modifying the calculation engine. Four types of reports are planned—standard output (aggregate hourly time step), one time output (such as input echo), detailed output (user-defined time step), and standard reports such as those in BLAST and DOE–2. Because the data structure is simple and comma-separated, output post-processors can easily read the data and create more elaborate reports. One drawback of our simple file format is that the output files can become very large.
The other major data input is weather. Rather than a binary file created by a separate weather processor, again we use a simple text-based format, similar to the input data and output data files. The weather data format includes basic location information in the first eight lines: location (name, state/province/region, country), data source, latitude, longitude, time zone, elevation, peak heating and cooling design conditions, holidays, daylight savings period, typical and extreme periods, two lines for comments, and period covered by the data. The data are also comma-separated and contain much of the same data in the TMY2 weather data set [NRE 95].

EnergyPlus does not require a full year or 8760 (or 8784) hours in its weather files. In fact, EnergyPlus allows and reads subsets of years and even sub-hourly (5 minute, 15 minute) data—the weather format includes a "minutes" field. EnergyPlus comes with a utility that reads standard weather service file types such as TD1440 and DATSAV2 and newer "typical year" weather files such as TMY2 and WYEC2.

In summary, all the data files associated with EnergyPlus—input, output, and weather—have simple self-contained formats but they can become quite large. The data files can be easily read and interpreted by other programs—spreadsheets, databases, or custom programs. By working with third party interface developers early, we will keep these files simple and easy to use by other programs that building designers use.

Table 4 Comparison of BLAST, DOE-2 (BDL) and EnergyPlus Input

		BLAST	BDL (DOE-2)	EnergyPlus
Location **(Simple Input)**	Description	Location defined in library. Library includes name, latitude, longitude, elevation, and time zone.	Location information defined by input, defaults to information on weather file	Location information defined by input.
	Input Syntax	LOCATION = Name;	BUILDING-LOCATION Latitude = W, Longitude = X, Altitude = Y, Time-Zone = Z ..	LOCATION, Name, Latitude, Longitude, Elevation, TimeZone;
	Example Input	**LOCATION = CHICAGO;**	**BUILDING-LOCATION LATITUDE = 41.98 LONGITUDE = 87.90 ALTITUDE = 673 TIME-ZONE = 6 ..**	**LOCATION, Chicago Illinois USA, 41.98, 87.90, 205, -6;**
Material **(More Complex)**	Description	Material defined in library. Library includes material name, conductivity, density, specific heat, resistance, roughness, and moisture properties.	Material from library or defined in input, includes thickness, conductivity, density, specific heat, or resistance. Thickness restated during Layer input (optional).	All material information defined by input.
	Input Syntax	TEMPORARY MATERIAL: Usname = (L=usn1, K=usn2, CP=usn3, D=usn4, ABS=usn5, TABS=usn6, R=usn7, TRANS=usn8, IR=usn9, FILMTRANS=usn10, REF=usn11, SC=usn12, roughness,asg); END;	A = Material, Thickness = W, Conductivity = X, Density = Y, Specific Heat = Z ..	MATERIAL, Name, Thickness, Conductivity, Density, Specific Heat, Roughness, Moisture Permeance, Moisture Resistance;
	Example Input	**Brick = (L=0.3333, K=5.6, CP=0.19, D=120, ROUGH);**	**BRICK = MATERIAL THICKNESS = 0.3333 CONDUCTIVITY = 5.6 DENSITY = 120 SPECIFIC-HEAT = 0.19 ..**	**MATERIAL, Brick, 0.1016, 0.721, 1922, 837, 46, 0.022;**

ADDING A NEW MODULE

One of the main goals for EnergyPlus is to make it easy for developers to add new features and modules. The process is relatively simple. First, a developer defines a new module with model parameters and equations, specialized coefficients, and data needed. A developer then finds the "plug-in" point—where the module would be called within EnergyPlus. Next the developer writes the module (using the EnergyPlus programming standard), breaking the simulation tasks into modules. Finally, the developer writes new input file syntax based on the input needed for the module and uses EnergyPlus "get" routines to read the needed input data into the new simulation module. The input file syntax is not hardwired within EnergyPlus; instead EnergyPlus reads an input data dictionary at runtime to determine the syntax of the input data file. The general syntax is:

```
Object, A1 [what this is], N1 [a number],...;
```

For example, for the EnergyPlus Location command, the data dictionary line is:

```
Location, A1 [Location Name], N1 [Latitude], N2 [Longitude], N3 [Elevation], N4
[Time Zone];
```

This tells the input processor that, for the Location command, to expect one text field (A1) with the location name, and four numeric inputs (N1, N2, N3, and N4)–latitude, longitude, elevation, and time zone respectively. Words in brackets [ ] describe the variable and its units (meters, liters/second, etc.).

RELEASE 1.0 AND BEYOND

"More people have ascended bodily into heaven than have shipped great software on time." [McC 95]

The first working version of EnergyPlus, or alpha version, was completed in December 1998 for internal testing by the team. The alpha version did not contain all the modules intended for the first release of EnergyPlus—those will be included in the first beta version, an internal version for testing that will be completed in Spring 1999. By Summer 1999, a beta version will be available to outside developers for testing. Shortly thereafter, a beta test version will be available for general testing. We plan to release version 1.0 of EnergyPlus in early 2000.

In late 1999 we will begin planning for the second release of EnergyPlus based on new features suggested by users, developers, and the team. Working with a coordinating group of users and developers, we will select the features and capabilities for that release. We plan to release updates to EnergyPlus on an 18-month release cycle. Some new features already under development are a connection to the COMIS airflow program, improved ground heat transfer, electrical system simulation, solar thermal and photovoltaic modules, and link to SPARK. The link to COMIS will allow better calculation of infiltration, natural ventilation, multi-zone airflow, and air pollutant transport. The ground heat transfer model will either be a 2-dimensional or 3-dimensional heat transfer calculation for various foundation calculations.

SUMMARY

EnergyPlus is a new building energy simulation program that builds on the strengths of BLAST and DOE–2. It is being written in Fortran 90 with structured, modular code that is easy to maintain, update, and extend. Benefits of EnergyPlus include:

For simulation program users:

- limits built into BLAST and DOE–2 (such as number of zones, schedules, or systems) are eliminated by the new structures in EnergyPlus—now limited only by a user's computer resources rather than hardwired in code
- EnergyPlus source code is open for inspection—and understandable
- developers around the world will be able to develop new modules—algorithmic or interfaces

new module development can keep pace with new building technologies, maximizing public impact of latest buildings research

For simulation developers:

- standardized structure significantly decreases the learning curve for developers
- new, structured, modular code is easier to understand and work with
- modular structure allows developers to work in parallel on new modules

General benefits include:

- simulation capabilities include integrated simulation, combined heat and mass transfer balance, multi-zone airflow, HVAC loops (flexible system and plant simulation), links to SPARK system/plant simulation, and algorithms from the new ASHRAE Loads Toolkit

- input, output, and simulation capabilities are much more flexible
- EnergyPlus will be released quicker than a next-generation program, but offer similar benefits

Although the two workshops sponsored by DOE and DOD [CRA 97] pointed up the critical need for good user interfaces in the success of any simulation tool, the EnergyPlus team is focusing first on developing the heart of a new simulation tool—the calculation engine. We consciously incorporated the priorities of the workshop participants in our development effort (many can be seen in Figure 1). The EnergyPlus team has begun working with third party interface developers to ensure user-friendly interfaces and new modules are ready when the program is released.

EnergyPlus not only combines the best features of the BLAST and DOE–2 programs, but also represents a significant step towards next-generation building simulation programs both in terms of computational techniques and program structures. Connectivity and extensibility are overriding objectives in the design and development process. This will ensure broad participation in program enhancement and facilitate third party interface and module development. EnergyPlus beta testing begins in early 1999. Up to date information on EnergyPlus is provided on the EnergyPlus web site.

WEB RESOURCES

1. Information on EnergyPlus including schedule, documentation, programming standards, and availability of beta releases: **www.eren.doe.gov/buildings/energy_tools/energyplus.htm**

2. Workshops on Next Generation Energy Simulation Tools:
www.eren.doe.gov/buildings/energy_tools/workshops.htm

3. Web-based directory of more than 130 building-related software tools from around the world:
www.eren.doe.gov/buildings/tools_directory/

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ENERGYPLUS INPUT – AN EVOLUTIONARY APPROACH

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Remember?
It was the early 1970s. Mainframe computers abounded, but were difficult to access and expensive to use. Engineers had figured out that automation could make their difficult analysis jobs easier and less prone to computational errors. Fortran IV or Fortran 66 was the language of choice for most scientific applications. Computer Science was a recent addition to engineering disciplines.

Control Data Corporation (CDC) mainframe computers were being used in the scientific and engineering communities. The CDC machines and most others insisted that all entries be in UPPERCASE – computers weren't used for text processing!

"User friendly" wasn't in anyone's vocabulary. Most people using computers would or could write their own programs. And interfaces to most programs were cryptic, to say the least. Oriented around the 80-column punch card, numbers in specific columns were probably the closest thing to a "user interface".

DOE-2 and BLAST Input Structures
DOE-2 and BLAST each tried to break the mold of the cryptic interface to their simulation programs.

To quote from the *DOE-2 Users Guide*, Section 3, The Building Description Language: "Many programs require the input data to be punched onto data cards according to a strict and rigid format such as 'the night-time temperature set-point must be in columns 59-60 of the 15th card.' Such requirements are not only stringent, allowing little or no flexibility to the user, but also result in a deck of cards that is almost unintelligible to the user unless exact locations are memorized for each datum. The Building Description Language (BDL) has been developed to allow the designer to translate design concepts into a form the computer can recognize and to allow the designer to see easily what has been done. With very few exceptions the designer does not need to be concerned with what column of the card is being used and in every case the input data are labeled with recognizable words for easy identification."[2]

The *BLAST Users Manual* similarly states: "The BLAST program uses an unformatted, English-like input language which permits rapid inspection and easy interpretation of user-supplied input. Error detection and some automatic corrections assist in debugging the input file. While the input is unformatted, it does require proper syntax. In many cases the BLAST input language provides defaults which reduce the input required."[3]

Did any of us think that 20 years later we would still have the same basic inputs for each of these programs? While the number of engineers and users of computers has increased drastically over those 20 years, the number of people that can create new simulation models has certainly not grown at the same rate. And, I dare say, the number of people that can add new syntax to either DOE-2 or BLAST has probably remained the same (even perhaps the same people!).

Skip forward to 1998
The computing environment today is much different than 20 years ago. With the advent of the Personal Computer (circa 1981), computing became more open to all kinds of people. Today's computer users are no longer expected to be able to write programs for their computers (though many still can and new tools have made those tasks available to others). And, today's computer users expect much more from the software that they use. "User-friendly" is almost the minimum for people to be attracted to a new product. Fast, responsive, and online assistance is a must for new software. Written manuals are rarely (in my experience) read – the online assistance being easier to scan through.

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[2] DOE-2 Users Guide, Version 2.1, 1980

[3] BLAST Users Manual, Version 2.0, 1979

Many of the same people who have worked with BLAST and DOE-2 over the years are now working to bring the simulation community a new simulation product, EnergyPlus. Representing over 100 years of experience in the energy analysis/simulation community, the collaborative efforts of the EnergyPlus team are creating the software that has been talked about previously in the Building Energy Simulation *User News*[4], on the EnergyPlus web site

http://www.eren. doe.gov/buildings/energy_tools/energyplus.htm

and in several international conferences. Highlights of the effort include modularization of the code, using standard Fortran 90 language features, and an emphasis on development that can be readily adapted or enhanced by others outside the EnergyPlus development team.

Learning from experience, we decided to concentrate on developing the "engine" of the simulation code and involve outside parties for the "user friendly" interfaces to the simulation.

But, EnergyPlus is software and where would software be without inputs and outputs? So, we devised a very simple structure for the inputs for EnergyPlus. Recognizing that many other programs may use the EnergyPlus engine, we have devised a simple, plain text format that can be produced by virtually any other piece of software.

There are two key elements to EnergyPlus input: the input data dictionary (often just called the IDD) and the input data file (IDF) which will drive the simulation.

EnergyPlus Input Data Dictionary

The input data dictionary (IDD), an example of which is shown in Fig. 1, is used to help the input processor properly interpret the incoming file. Basically, it defines the types of input data.

There are two types of items in the data dictionary: SECTIONS and OBJECTS. SECTIONS are used to partition the input data file into more readable sections. OBJECTS define the data for actual building components.
For each object, the Input Data Dictionary defines the "rules" for that object's data. Namely, the positions of each data item in the input and whether the data item is numeric or alpha.

As currently implemented, the only significant parts of the IDD are the SECTION and OBJECT names (ZONES, MATERIAL, etc.) and the nature of the data items ("A" for alpha or "N" for numeric). All other information is ignored by the input processor though it might be used in post-processing or general information to the users.

```
!SECTIONS  (sections have no "parameters")
Simulation Data;
ZONES;
SYSTEMS;
!OBJECTS
Location,A1 [Location Name],N1 [Latitude: validity: +N -S -90 to +90],
   N2 [Longitude: validity: +W -E -360 to +360],
   N3 [Time Zone: validity: 0 to 24: 0 correspond to -7.5 long to +7.5 long: GMT];
MATERIAL,A1 [Name],A2 [Type],A3 [Roughness],N1 [Thickness{M}],
   N2 [Conductivity{W/(M*K)}],N3 [Density{KG/M^3}],N4 [Specific Heat{KJ/(KG*K)}],
   N5 [Thermal Resistance{M^2*K/W}],N6 [Absorptance Thermal],
   N7 [Absorptance Solar],N8 [Transmittance],N9 [Transmittance Film],
   N10 [Shade Reflectance],N11 [IndexRefraction],N12 [ShadingCoeff],
   N13 [VaporDiffusivity{m^2/hr}],N14 [Porosity{m^2/m^2}],
   N15 [Thermal-Gradient Coeff for Moisture Capacity {kg/(kg*K)}],
   N16 [Isothermal moisture capacity {m^3/kg}];
```

Figure 1. Input Data Dictionary Example

Note that the ! character is used to represent comments. SECTIONS then shows what words will be included as "sections" in the input file (i.e. "Simulation Data" -- "End Simulation Data" pairs). Finally the OBJECTS will describe all the possible object lines (either all possible or all included in the particular input file).

[4] "EnergyBase, the "Best of" DOE-2 and BLAST," User News, Vol. 17, No. 3, Fall 1996; "EnergyPlus, The Merger of BLAST and DOE-2," User News, Vol. 18, No. 4, Winter 1997.

The description fields shown (in the MATERIAL and LOCATION definitions) may be useful for new developers or people trying to read the source code. Note that semi-colons terminate the data dictionary objects because object definitions can span more than one “line”.

A major advantage of the IDD is that it is extensible. New SECTIONS or OBJECTS can be added without any changes to the input processor code.

EnergyPlus Input Data File

This is the file (Fig. 2) that all the routines will naturally use to get the data. It can be hierarchically structured (1 level) but the maintenance of the hierarchy will be the responsibility of the EnergyPlus code developers. The input processor needs to know nothing about the actual content of the data in each object, only whether it is alpha or numeric. So far, the team has gone the route of no hierarchical input and uses reference items (e.g. Zone Names, Surface Names, etc.) to preserve the inherent hierarchical nature of buildings (i.e. walls have windows, zones have walls, internal heat gains are in zones). This allows the input to be order independent but adds a burden to the developer if the data should be in some specific order for efficient processing.

Note in the example that numbers are very flexibly input. (All processed into single precision variables).

```
Lead Input;
  MATERIAL,  R13LAYER,  RegularMaterial,  Rough,   0,
  0,   0,   0,   2.29096500E+00, .9,   .75,   0,   0, 0,   0,   0,   0, 0,   0,   0;
  MATERIAL,  GLASS - CLEAR SHEET 1 / 8 IN,  RegularGlass,  VerySmooth,
 0,   0,   0,   0, 4.15898200E-03,   .9,   .75,   .87, 0,   0,   1.52,   0, 0,   0,   0,   0;
  MATERIAL,  B1 - AIRSPACE RESISTANCE,  Air,  Rough,   0,
 0,   0,   0,   1.60367500E-01, .9,   .75,   1.0,   0, 0,   1.0,   0,   0, 0,   0,   0;
End Lead Input;
```

Figure 2. Input Data File Example

Summary

We have tried to place fewer burdens on maintaining the input language for EnergyPlus than was implicit in both BLAST and DOE-2. So far, we have had good success with developers being able to create their own “syntax” for the input processor and successfully get the appropriate data into the right spots in the EnergyPlus program. This highlights one of the most important features of the input structure. Developers can add their syntax to the IDD, use the standard routines already written (and debugged) to retrieve their data after the input processor “parses” it, and use the resultant data in their models. Developers can do this without having to customize any part of the “parser”, generate keyword tables, run separate programs or “mess” in parser code.