

# BUILDING ENERGY SIMULATION

*For Users of EnergyPlus, SPARK, DOE-2, BLAST, Genopt, Building Design Advisor, ENERGY-10 and their Derivatives*

# U S e r N e w s

## What's New ?

### .....Release of EnergyPlus 1.0.1

EnergyPlus 1.0.1 may be downloaded free of charge from [www.energyplus.gov](http://www.energyplus.gov). Turn to p. 2 for the new features.

### .....EnergyPlus Support Tools

The Deringer Group of Berkeley, CA, is offering free EnergyPlus support tools. See page 4.

### .....Release of ENERGY-10 1.5

Turn to p. 9 or visit [www.sbicouncil.org](http://www.sbicouncil.org) to learn what's new in ENERGY-10, Version 1.5.

### .....Release of VisualSPARK 1.0.2

Version 1.0.2 of VisualSPARK is a free download from [SimulationResearch.lbl.gov](http://SimulationResearch.lbl.gov). User manuals are available as PDF files.

### .....DOE-2 Bug/Change List

The entire, up-to-date bug fix/additions list for DOE-2.1E is available as a text file on our web site. Go to [SimulationResearch.lbl.gov](http://SimulationResearch.lbl.gov) and look under "DOE-2" in the left menu

### ..... US DOE Drops CADDET Support

As of April 1, 2002, the U.S. stopped its participation in CADDET, the Center for the Analysis and Dissemination of Demonstrated Energy Technologies. A CADDET member for over 10 years, the Department of Energy dropped CADDET activities due to budget cutbacks.

However, you can still keep current by subscribing to E-announcements, a free electronic newsletter. Go to [www.caddet.org](http://www.caddet.org).

### .....IBPSA-USA Free Membership

IBPSA-USA has waived its annual membership fee for 2002; see p. 13.

## What's Inside ?

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# EnergyPlus Version 1.0.1

To download a free copy of the program go to

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



## New Features

1. Linux version
2. End-use meters
3. Auto sizing of system components and equipment.
4. Trombe wall
5. Photovoltaic calculations (through TRNSYS link)
6. New input file example for each new feature.
7. Air-to-air heat pump
8. Water-to-water heat pump (Ground loop heat exchanger and Ground Source Heat Pump)
9. Air Cooled Condenser
10. Evaporatively cooled condenser (simplified)
11. IDFEditor (support for ',' as decimal point)
12. Dehumidification Control (Cooling Coil) added for unitary systems. DX coil meets the dehumidification load; uses heating coil to offset excess sensible cooling that is provided.
13. DOE-2 Translator Improvements: (INTERIOR-WALL, FIXED-SHADE, LIKE, SET DEFAULT, purchased air solution, bug fixes)
14. Major updates to gas heating coil--electric parasitics, part-load performance curve, and fan and coil cycling controls.
15. Node connection validation.
16. Branch and Node Details report (.bnd file)
17. Surface Details report
18. Movable transparent insulating material for walls
19. Introduction of translation programs for converting previous version input files to latest release
20. WinEPDraw utility program
21. Versioning on all input data files
22. New Window-Related Features
  - Window blind model (slat-type shading devices such as Venetian blinds).
  - Coupling of window blinds to daylighting calculation.
  - More control types for shading devices, including heating season controls.
  - Capability to import a window data file from WINDOW 5; allows EnergyPlus to do annual energy run on a window designed with WINDOW 5.
  - Ability to assign a shading device to a window imported from WINDOW 5.
  - Calculation of beam solar radiation passing through interior windows (needed for modeling double-envelope buildings).
  - Window blinds with movable slats and associated slat-angle control options.
  - Window gap fill as a mixture of gases rather than a single gas.
  - Triangular windows.
23. Weather utility updates—now automatically includes ASHRAE 2001 HOF design conditions, typical/extreme periods within weather file, new summary report, and processes new formats such as ASHRAE IWEK and ESP-r text. Weather data now available on EnergyPlus web site for more than 570 locations (80 countries).

24. New HVAC system templates:

- Zone Thermostat
- Purchased Air
- Four Pipe Fan Coil
- Single Boiler Supply Loop
- VAV Single Duct with Reheat
- Packaged Furnace with DX Air Conditioner
- Purchased Hot Water and Chilled Water Supply Loop
- Single Chiller Supply Loop

25. Version 1.0.1 has been tested against:

- HVAC BESTEST (IEA SHC Task 22 Building Energy Analysis Tools)
- ASHRAE RP-1052, Development of an Analytical Verification Test Suite for Whole Building Energy Simulation Programs - Building Fabric
- ANSI/ASHRAE Standard 140-2001 [BESTEST] (updated results)

26. Many HVAC/plant changes, details on request. New or changed items include:

- Gas Turbine Chiller
- Heat Recovery in Gas Turbine Chiller
- Electric Baseboard option
- Boilers, Plant Supply and Condenser Supply
- DX Coil
- System night cycle control



## Ask An EnergyPlus Expert



**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.

*EnergyPlus is being developed by University of Illinois, CERL, and Lawrence Berkeley National Laboratory, with the assistance of the Florida Solar Energy Center, GARD Analytics, the University of Wisconsin, Oklahoma State University and others. Development of EnergyPlus is supported by the U. S. Department of Energy, Dru Crawley, Program Manager.*

## Support Tools for EnergyPlus and DOE-2 from The Deringer Group

### EzPlus-Parm

This is a standalone Windows tool intended for EnergyPlus parametric analysis. It was designed to simplify the running of multiple parametric EnergyPlus simulations by helping a user organize and edit all needed files.

### Draw EzPlus

A tool that displays the 3-D geometry embedded in an EnergyPlus file. The user can toggle between line and surface (fill) presentation modes, and can select to draw any mix of key building objects – floor, walls, roof, windows, and attached and detached shading.

### EnergyPlus Online Simulations

One set of tools is online and embedded in the [EcoAdvisor](#), a set of online training modules for sustainable buildings. These tools can be used by anyone and require no special knowledge of EnergyPlus.

### EnergyPlus Interface Support Tools

This is a set of stand-alone Windows-based tools intended to make the text-based use of EnergyPlus faster, easier, and more accurate.

### DOE-2 Parametric Study Tool -- DOE2Parm

DOE-2 parametric analysis can be complicated because you need to link, run and edit multiple files that can be located anywhere on your computer. DOE2Parm allows you to run the parametric analysis in the same window. DOE2Parm is an MS Windows-based tool.



*Founded in 1980, **The Deringer Group (TDG)***

*specializes in sustainable and energy efficient*

*building design projects and studies*

*throughout the world. TDG is developing*

*several support tools for EnergyPlus all of*

*which may be freely downloaded.*

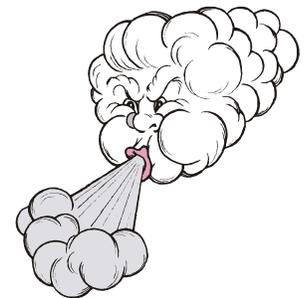
• [www.deringergroup.com](http://www.deringergroup.com) • [www.deringergroup.com](http://www.deringergroup.com) • [www.deringergroup.com](http://www.deringergroup.com) • [www.deringergroup.com](http://www.deringergroup.com) •

## **New!! EnergyPlus Weather Data**

The EnergyPlus development team is pleased to announce that our web site now offers more than 570 weather locations available for download and ready to use with EnergyPlus. There are 275 locations in the United States, 16 California thermal zones, 55 Canadian locations, and 233 international locations in more than 80 countries.

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

On the right side, under Weather Data, click on one of the following links:  
USA, California, Canada or International.



We recommend that you also download the weather utility RPT file for each location. The RPT file includes design data where available, statistics for the weather file, including typical and extreme periods (hottest summer week, coldest winter week, typical spring week, etc), Koppen climate classification, heating and cooling degree days, monthly average minimum and maximum dry bulb and dew point temperatures, undisturbed ground temperatures, direct and diffuse solar radiation, relative humidity, and wind speed and direction.



## 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.



Using EnergyPlus and its link to the COMIS multizone air flow program, Philip Haves ([phaves@lbl.gov](mailto: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

This newsletter was prepared as an account of work sponsored by the United States Government (USG). While this document is believed to contain correct information, neither the USG, nor any agency thereof, nor the Regents of the University of California (RUC), nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process or service by its trade name, trademark, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the USG or any agency thereof, or the RUC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or of the Regents of the University of California



Join the  
EnergyPlus  
User Group

The developers of EnergyPlus have formed a support group in order to foster discussion and maintain an archive of information for program Users. We invite questions about program usage and suggestions for improvement to the code. To join, go to [groups.yahoo.com/group/EnergyPlus\\_Support/](http://groups.yahoo.com/group/EnergyPlus_Support/)



You are invited to test **DoeRayMe**, a new DOE-2.1E screening tool application currently being developed by Jason Glazer, P. E., of GARD Analytics, Inc. **DoeRayMe** is a simple and flexible interface that uses a specially developed DOE-2 input file (template) that contains special codes describing the parameters available to be changed in the user interface. This allows new screening tools to be developed by any DOE-2 user. Please visit the **DoeRayMe** web site at <http://www.gard.com/DoeRayMe>.



**Question:**

We drive DOE-2.1E through our user interface. On several occasions, I have gotten the error "Material/Layer too thin or light" or "Material/Layer too thick or heavy". Is there some calculation or data range to figure out *a priori* if a construct/layer/material combination will pass DOE-2's muster?

**Answer:**

I don't think there is any 100% accurate way of determining if a DOE-2 construction will successfully pass through the response factor calculation. The "too light" case means that DOE-2 was unable to calculate a response factor series for the wall with a 1-hour time step. The "too heavy" case means that after obtaining 100 response factors the program couldn't find a response factor common ratio yet. So very roughly speaking the wall time constant must be somewhere between 1 hour and 100 hours.

For a single layer we can calculate a time constant:  $RC = 9^{**2} * dens * sh / k$

where

|                         |                |                    |
|-------------------------|----------------|--------------------|
| R = thermal resistance  | 9 = thickness  | sh = specific heat |
| C = thermal capacitance | dens = density | k = conductivity   |

Some examples:

- 8 inch concrete block, perlite filled, has a time constant of 43.6 hours. No problem calculating response factors.
- Heavy weight concrete, dried, 12 inch, has a time constant of 37 hours. Again no problem.
- More interesting, wd01 - 3/4 inch soft wood, has a time constant of 0.62 and response factors are calculated.
- But pw03 - 1/2 inch plywood, has a time constant of 0.26, and does not produce response factors.
- Somewhere around RC = 0.5 hours is likely the rather mushy boundary for "too light or too thin". For multilayer walls the case is more complicated. However, if one of the layers has RC > 0.5 it should be OK.
- I haven't explored the "too heavy" end; 2 feet of dirt with a time constant of around 120 hours is OK. I think 3 feet will fail.

Please email your "DOE-2 Puzzler" questions to [klellington@lbl.gov](mailto:klellington@lbl.gov)



# DOE-2



**DOE-2.1E (version 119) 1,000-Zone version for Windows from ESTSC; other vendors of DOE-2 based programs are listed on our web site: <http://SimulationResearch.lbl.gov> > DOE-2**

Cost is as follows:

- \$ 300 U.S. Government, non-profit Educational
- \$ 575 U.S., Mexico, Canada
- \$ 1268 Japan only
- \$ 1075 All Other Non-U.S.

**DOE-2 Documentation on a CD from ESTSC - Cost US\$100**

***What is included on the CD?***

- DOE-2 Reference Manual (Part 1)
- DOE-2 Reference Manual (Part 2)
- DOE-2 Supplement to the Reference Manual (2.1E)
- DOE-2 BDL Summary (2.1E)
- DOE-2 Engineers Manual (2.1A)

**Order Software and ESTSC Documentation**

Ed Kidd

NCI Information Systems, Inc.

Energy Science and Technology Software Center (ESTSC)

P.O. Box 1020

Oak Ridge, TN 37831

Phone: 865/576-1037

Fax: 865/576-6436

Email: [estsc@adonis.osti.gov](mailto:estsc@adonis.osti.gov)

**Free DOE-2 Documentation (<http://SimulationResearch.lbl.gov> > DOE-2 > Documentation)**

- DOE-2 Basics (2.1E)
- Update Package #1: DOE-2.1E Basics, the Supplement and BDL Summary
- Update Package #2: (Version 107, DOE-2.1E) BDL Summary and Supplement.
- Update Package #3: Appendix A of the Supplement.
- Update Package #4: (1000-zone DOE-2.1E) BDL Summary.
- DOE-2 Modeling Tips (pdf)

DOE-2 Basics Manual and Update Packages 1, 2, 3 and 4, not included on the ESTSC CD, consist of scanned pdf files and may be downloaded from our web site. You may also request the same information on a CD by sending email to [klelligenton@lbl.gov](mailto:klelligenton@lbl.gov).

The files need to be printed and the update pages inserted into the existing DOE-2 manuals.

Note that Update Packages are **not** cumulative and each one contains different information. You have to download all four packages to update the DOE-2 documentation completely.

DOE-2 Modeling Tips a compilation of all the "how to" articles from the *Building Energy Simulation User News* (through 2001).

*DOE-2 listings are continued on the next page*

### Purchase DOE-2 Documentation

DOE-2 Sample Run Book (2.1E) -- The Sample Run book is the only remaining DOE-2 manual not available electronically. It must be purchased separately from NTIS; information is at <http://SimulationResearch.lbl.gov> > DOE-2 > Documentation

### DOE-2 Training

Private or group DOE-2 courses for beginning and advanced users:  
Contact Marlin Addison at (602) 968-2040, or send email to [marlin.addison@doe2.com](mailto:marlin.addison@doe2.com)

### DOE-2 Help Desk

Email, phone or fax the Simulation Research Group with your questions ([klleington@lbl.gov](mailto:klleington@lbl.gov)).  
Phone: (510) 486-5711, Fax: (510) 486-4089

Don't forget to take our User Survey.  
Go to <http://SimulationResearch.lbl.gov>  
and click on "Survey" in the left menu. Thanks!

## Building Design Advisor 2.0

*Decision making through the  
integrated use of multiple  
simulation tools and  
databases*

The **Building Design Advisor (BDA)** is a Windows<sup>®</sup> program that addresses the needs of building decision-makers from the initial, schematic phases of building design through the detailed specification of building components and systems. The BDA is built around an object-oriented representation of the building and its context, which is mapped onto the corresponding representations of multiple tools and databases. It then acts as a **data manager** and **process controller**, automatically preparing input to simulation tools and integrating their output in ways that support multi-criterion decision-making. BDA 3.0, Beta version 2, is available for Beta and includes links to these simulation tools: **SGE** (a graphical editor for schematic design), **DELIGHT** (a daylighting simulation tool), **ECM** (a simplified electric lighting simulation tool) and the **DOE-2.1E** building energy simulation program.

**ECM**, the **new electric lighting simulation tool** in BDA 3.0 beta, is integrated through BDA with DOE-2. BDA's Schematic Graphic Editor (**SGE**) allows placement of electric lighting luminaires and specification of reference points for daylight-based electric lighting controls. Moreover, BDA now has the capability of **running DOE-2 parametrically** to generate a plot that shows the relationship between effective aperture and energy requirements. BDA 3.0 beta provides the added functionality of working with either **English units or Metric units**.

Current research and development efforts are focused on the development of links to **Desktop Radiance**, a Windows 95/98/NT version of the **Radiance** lighting/daylighting simulation and rendering software.

The BDA source code is available for licensing; if interested, please contact Dr. Papamichael at [K\\_Papamichael@lbl.gov](mailto:K_Papamichael@lbl.gov). To learn more about the BDA software and to download a copy of the latest public version (BDA 2.0), go to <http://gaia.lbl.gov/BDA>

**For Beta Testing of BDA 3.0, contact Vineeta Pal at [VPal@lbl.gov](mailto:VPal@lbl.gov).**

## RELEASE OF ENERGY-10, VERSION 1.5

**ENERGY-10** is a design tool for smaller residential or commercial buildings that are less than 10,000 ft<sup>2</sup> or buildings that can be treated as 1- or 2-zone increments. It performs whole-building energy analysis for 8760 hours/year, including dynamic thermal and daylighting calculations. ENERGY-10 was specifically designed to facilitate the evaluation of energy-efficient building features in the very early stages of the design process.

### Version 1.5 Upgrades

#### Life Cycle Costs

A whole new capability is included to evaluate life-cycle costs. The year-by-year cash flow of the building is determined and discounted to the present value. The difference between Bldg-1 and Bldg-2 is determined in terms of net present value, NPV (the difference in life-cycle costs), internal rate of return, benefit-to cost ratio, or simple payback.

#### Up-to-date compiler

The entire program has been ported to 32-bit and (with the exception of the CNE thermal simulation engine) programmed in Visual C++ 6.0, the current Microsoft compiler. One benefit that users will appreciate is that it is no longer necessary to close ENERGY-10 before starting a new project.

#### More Wall Layers

In previous versions, you were restricted to 6 layers in a wall construction. This has now been expanded by 3, giving you the opportunity to define a 7-layer wall plus two air films.

#### New Graphs

Graphs are programmed in a new and powerful graphing package (Olectra).

#### New Reports

A Cost Summary report tabulates the results of the life cycle cost evaluation. An HVAC and EES Cost report details the components of HVAC cost and each of the EES costs. A Peak Loads report identifies the peak loads and corresponding HVAC rated capacities for the AutoSize calculations and also the peak loads and consumptions during the annual simulation showing when the peaks occurred.

**Douglas K. Schroeder**  
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Washington, DC 20004



**Tel: 202.628.7400 ext 210**  
**Fax: 202.383.5043**  
**[www.sbicouncil.org](http://www.sbicouncil.org)**

### ***Sustainable Buildings Industry Council (SBIC)***

**ENERGY-10 User Group at <http://www.sbicouncil.org/forum>**

**SBIC Bookstore at <http://www.sbicouncil.org/store/resources.php#pubs>**

The *Green Building Guidelines* is SBIC's second generation of sustainable residential design guidelines created in cooperation with the National Association of Home Builders. Written in plain language with complementary illustrations, case studies, and check lists, the *Guidelines* is a valuable resource for builders and even buyers interested in producing or purchasing energy- and resource-efficient homes. Cost is \$50; to order, go to [www.sbicouncil.org](http://www.sbicouncil.org).





[www.gard.com/weather/](http://www.gard.com/weather/) \*

**Building Simulation Weather Data Resource Page**

Jason Glazer, the BLDG-SIM moderator, has compiled some good sources for weather data. Links include those for TMY2, WYEC2, CWEC, CWEEDS, IWEC, EnergyPlus Weather, WeatherBank, CIBSE Guide J, etc. If you have additional resources, please send Jason email at [jglazer@gard.com](mailto:jglazer@gard.com).

[www.energytools.gov](http://www.energytools.gov) \*

**U. S. Department of Energy, Building Energy Tools Directory**

If you want to find a software tool concerning energy use in buildings, the U.S. Department of Energy has been keeping a list for many years.

[www.eren.doe.gov/buildings/  
highperformance/case\\_studies/](http://www.eren.doe.gov/buildings/highperformance/case_studies/) \*

**U. S. DOE, High Performance Buildings Database**

Case studies of DOE's high performance buildings.

[timezoneconverter.com](http://timezoneconverter.com)\*\*

**Time Zone Converter**

Where am I, how did I get here and what time is it? This web site will help answer two out of three questions ☺

[www.fabsoft.com](http://www.fabsoft.com) \*\*

**CoolRuler v.1.5 (free!)**

CoolRuler is a stand-alone applet which may be freely moved around your screen to take measurements (horizontally or vertically). Use centimeters, pixels, inches, or your own system for measurement. Create as many rulers on your screen as you need.

\* from the BLDG-SIM forum, for users of building simulation tools. To join, send email to [bdg-sim-subscribe@gard.com](mailto:bdg-sim-subscribe@gard.com)

\*\* from the LockerGnome e-newsletter. To subscribe (free!), go to [www.lockergnome.com](http://www.lockergnome.com)



**PG&E Spring 2022 Programs**

**To register call the Pacific Energy Center (at least one week in advance) 415.973.7268 or go to [www.pge.com/pec](http://www.pge.com/pec)**

|                |   |
|----------------|---|
| <b>July 9</b>  | <b>Lighting Design for Architects</b> – Lighting concepts for architects, including terminology, visual perception, surface properties, light and color theory, equipment, design criteria, and applied design. |
| <b>July 10</b> | <b>Task and Ambient Lighting Solutions</b> – Using the 2001 Advanced Lighting Guidelines, we will explore the techniques for optimizing occupant lighting comfort and energy efficiency.                        |
| <b>July 11</b> | <b>Data Collection for Packaged Units</b> – Energy-saving opportunities available for maintaining or retrofitting packaged HVAC units.  |

## Join the BLDG-SIM Mail ing List

BLDG-SIM is a mailing list for users of building energy simulation programs like EnergyPlus, DOE-2, Trace-600, HAP, BLAST, ESP, SERIRES, TRNSYS, TASE, ENERGY-10 and others.

Because building simulation professionals are located worldwide, the BLDG-SIM list is an attempt to foster the development of a community of those users. Users of all levels of expertise are welcome and are encouraged to share their questions and insights about these programs.

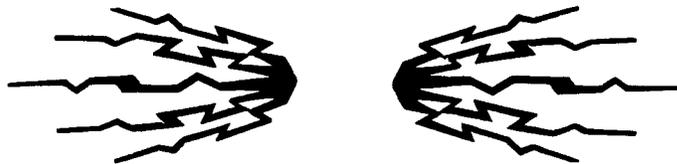
The web page for BLDG-SIM is <http://www.gard.com/bldg-sim.htm>

Jason Glazer, P.E., Of GARD Analytics, Inc. Is the list administrator ([jglazer@gard.com](mailto:jglazer@gard.com)).



The Building Energy Simulation User News is published bi-monthly and distributed electronically by the Simulation Research Group at Lawrence Berkeley National Laboratory. Direct comments or submissions to Kathy Ellington ([KLEllington@lbl.gov](mailto:KLEllington@lbl.gov)). Direct BLAST-related inquiries to the Building Systems Laboratory ([support@blast.bso.uiuc.edu](mailto:support@blast.bso.uiuc.edu)).

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# GenOpt 1.1.2

## Generic Optimization Program

**GenOpt** is a multi-parameter optimization program; it automatically finds the values of user-selected design parameters that minimize a cost function, such as annual energy use, calculated by an external simulation program like EnergyPlus, SPARK, DOE-2, BLAST, TRACE, TRNSYS, etc.

**GenOpt** can be used with any simulation program that has text-based input and output. It also offers an interface for adding custom optimization algorithms to its library.

### Release of GenOpt 1.1.2

**GenOpt 1.1.2** fixes problems in reading simulation output files where the objective function value is followed by a comma. Such output strings can be found, for example, in some EnergyPlus outputs.

Also, a method called 'postProcessObjectiveFunction(int, double[] f)' has been added to the file named 'Optimizer.java'. You can modify this function to easily implement post-processing of the objective function value, such as adding two outputs to seek the minimum of the sum of the two outputs.

Example files have been added to the **GenOpt** web page (<http://SimulationResearch.lbl.gov> > GenOpt) to help users set up the program to optimize EnergyPlus simulations. **GenOpt** input files still have the same syntax as in version 1.1.1. Therefore, your **GenOpt** input files are compatible with the new version.

**GenOpt 1.1.2 (with user manual) may be downloaded free of charge from**

**<http://SimulationResearch.lbl.gov> > GenOpt**

## The Lowdown on Downloads from Lawrence Berkeley National Laboratory

| <b>Free Downloads</b>   |   |
|---|---|
| <b>BDA 2.0 (Building Design Advisor)</b><br>A beta version of 3.0 is available from <a href="mailto:vpal@lbl.gov">vpal@lbl.gov</a>  | <a href="http://gaia.lbl.gov/BDA">gaia.lbl.gov/BDA</a>  |
| <b>COMIS</b><br>(multi-zone air flow and contaminant transport model)   | <a href="http://www-epb.lbl.gov/comis">www-epb.lbl.gov/comis</a>  |
| <b>EnergyPlus 1.0.1</b><br>(new-generation whole-building energy analysis program, based on BLAST and DOE-2)  | <a href="http://www.energyplus.gov">www.energyplus.gov</a><br>--or--<br><a href="http://SimulationResearch.lbl.gov">SimulationResearch.lbl.gov</a> > EnergyPlus |
| <b>GenOpt<sup>®</sup> 1.1.2</b> (generic optimization program)  | <a href="http://SimulationResearch.lbl.gov">SimulationResearch.lbl.gov</a> > GenOpt   |
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| <b>RESEM (Retrofit Energy Savings Estimation Model)</b><br>(calculates long-term energy savings directly from actual utility data)  | <a href="http://eetd.lbl.gov/btp/resem.htm">eetd.lbl.gov/btp/resem.htm</a>  |
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| <b>THERM 2.1a</b><br>(models two-dimensional heat-transfer effects in building components where thermal bridges are of concern)   | <a href="http://windows.lbl.gov/software/therm/therm.html">windows.lbl.gov/software/therm/therm.html</a>  |
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| <b>WINDOW 5</b><br>(thermal analysis of window products)  | <a href="http://windows.lbl.gov/software/window/window.html">windows.lbl.gov/software/window/window.html</a>  |
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# BLASTnews

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# 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:

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

---

\* Visiting Researcher from Electricité de France

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  $T$ .
- $Y$  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:

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

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.

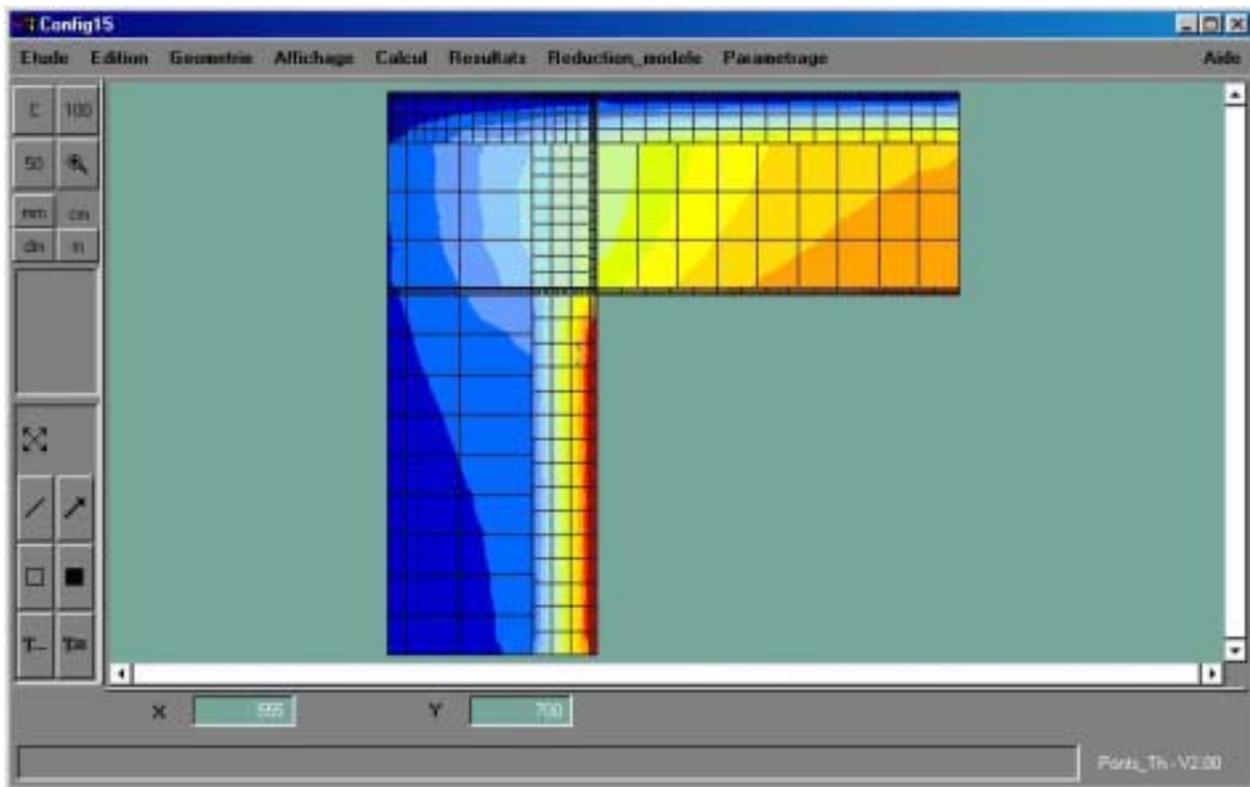


Figure 1: Main Screen of the Sisley Finite Difference Program

### 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.

### 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.

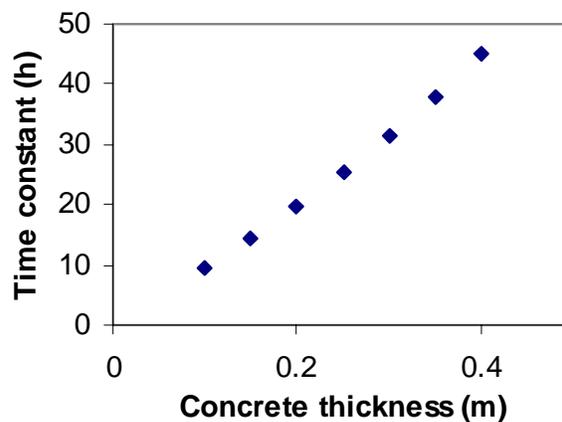
Simplification of the gray box relationships is accomplished through graphical analysis and the requirement that the results make physical sense. For instance, static heat flux is independent of material density and heat capacity, but these parameters do influence the dynamic behavior of the system.

### 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:

$$\tilde{\tau}_1 = ae_{concrete} + bCp_{concrete} + c \quad (1)$$

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:

$$\Sigma = \sum_{\text{configurations}} (\tau_l - \tilde{\tau}_l)^2 \quad (2)$$

where  $\tilde{\tau}_l$  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:

$$\tilde{\tau}_l = 1.187 \times 10^2 e_{\text{concrete}} + 2.074 \times 10^{-2} C_{p_{\text{concrete}}} - 2.261 \times 10^1 \quad (3)$$

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:

$$\tilde{\tau}_l = 1.187 \times 10^2 e_{\text{concrete}} + 2.074 \times 10^{-2} C_{p_{\text{concrete}}} - 2.261 \times 10^1$$

$$g_1 = -7.685 \times 10^1 e_{\text{concrete}} - \frac{1.597 \times 10^{-2}}{e_{\text{wallinsulation}}} - 3.098 \lambda_{\text{wallinsulation}} - 2.452 \lambda_{\text{roofinsulation}} - 3820.10^1$$

$$g_2 = -g_1 \quad (4)$$

$$A_r = \left[ \frac{I}{3600 \tilde{\tau}_l} \right]$$

$$B_r = \left[ A_{r1,l} \frac{D_{r1,l} - g_1}{C_{r1,l}} \quad A_{l1,l} \frac{D_{r1,2} - g_2}{C_{r1,l}} \right]$$

$$C_r = [0.22]$$

$$D_r = [0.4 \ 2.75]$$

where

- $e_{\text{wallinsulation}}$  is the wall insulation thickness (m)
- $\lambda_{\text{wallinsulation}}$  is the wall conductivity (W/m.K)
- $\lambda_{\text{roofinsulation}}$  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:

$$\text{Zone Air Energy Variation} = \Sigma (\text{Thermal Loads and Heat Transfers with the Zone})$$

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.

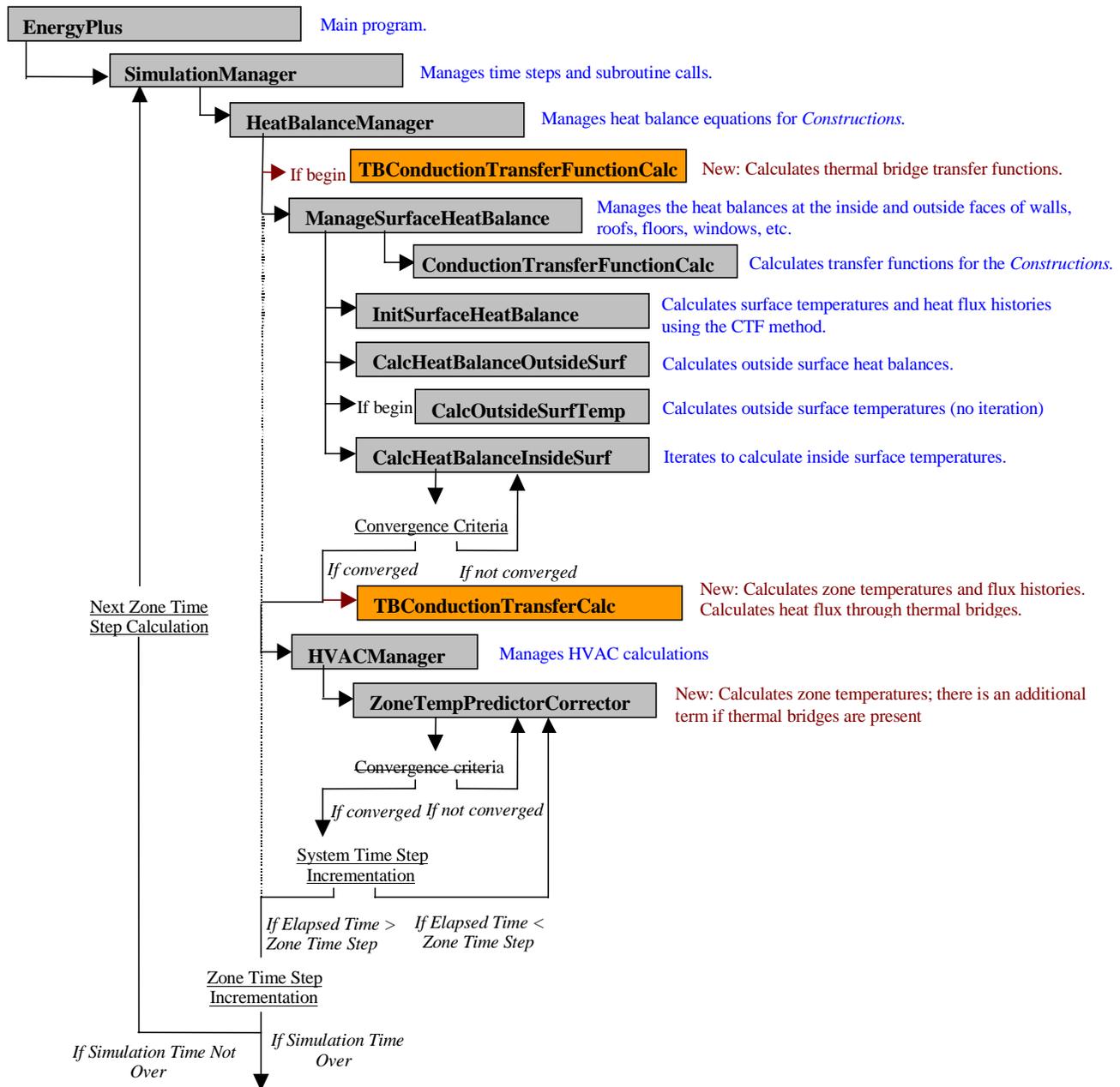
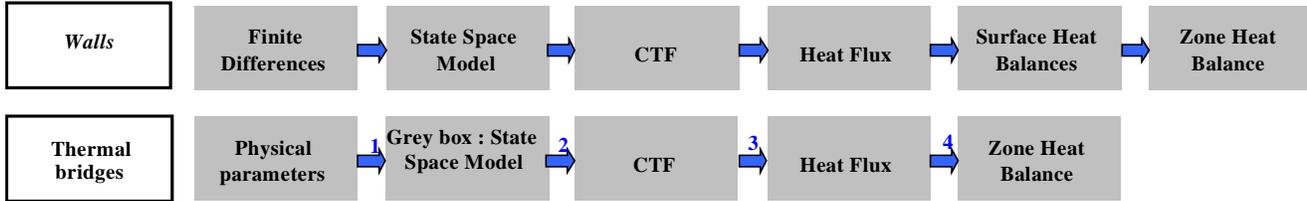


Figure 3: Integration of Thermal Bridges into the EnergyPlus Calculation Sequence

### 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:

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

where, analogously 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  $\varphi$  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:

$$\varphi_t = \sum_{k=0}^M s_{i,k} T_{i,t-k\delta} + \sum_{k=0}^M s_{o,k} T_{o,t-k\delta} - \sum_{k=1}^M e \varphi_{t-k\delta} \quad (4)$$

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  $\delta$  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<sup>2</sup> 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.

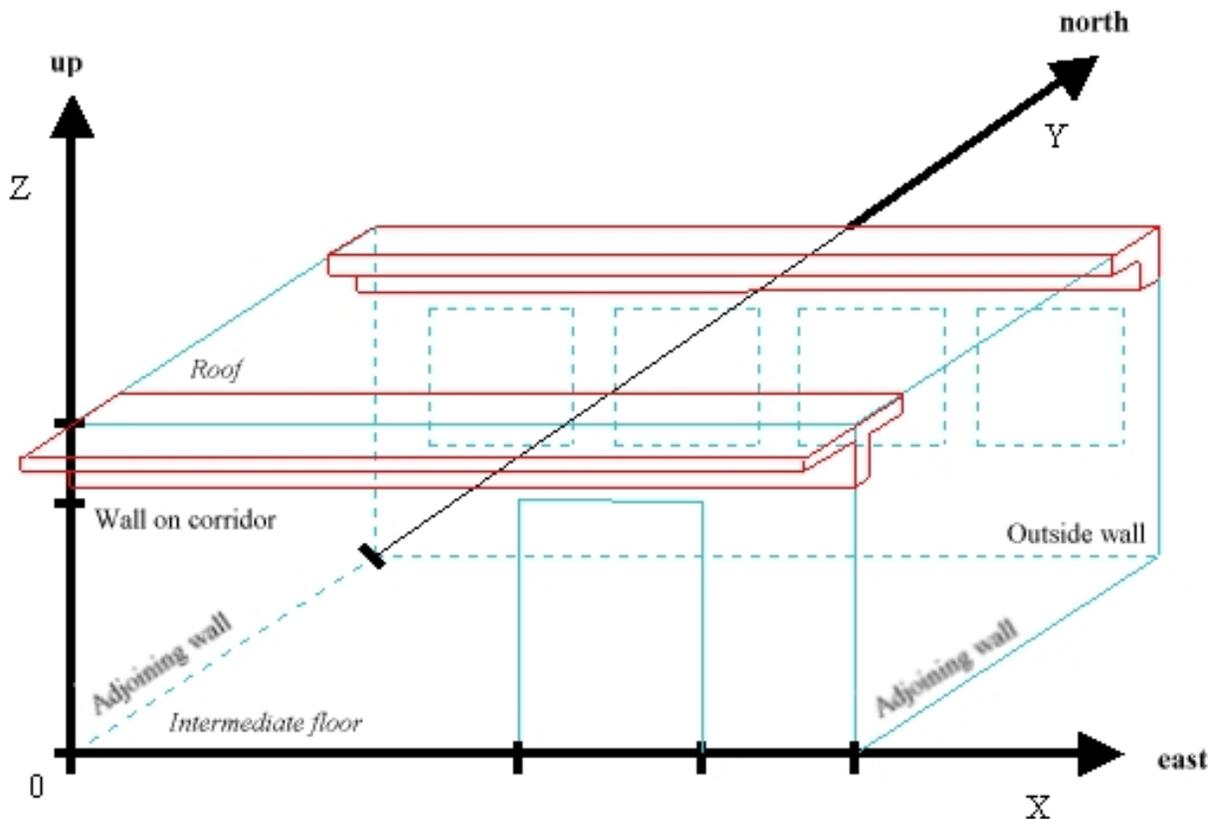


Figure 5: The Matisse Building

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

| Name               | Surface (m <sup>2</sup> ) | Description of the wall (outside → inside) |               |                   |                             |             |
|--------------------|---------------------------|--|---------------|-------------------|-----------------------------|-------------|
|                    |                           | material                                   | thickness (m) | $\lambda$ (W/m.K) | $\rho$ (kg/m <sup>3</sup> ) | Cp (J/kg.K) |
| Outside wall       | 17.88                     | Concrete                                   | 0.2           | 1.75              | 2450                        | 920         |
|                    |                           | Polystyrene                                | 0.08          | 0.03              | 35                          | 1210        |
|                    |                           | Plaster                                    | 0.01          | 0.35              | 900                         | 837         |
| Wall on corridor   | 25.67                     | Concrete                                   | 0.2           | 1.75              | 2450                        | 920         |
|                    |                           | Polystyrene                                | 0.04          | 0.03              | 35                          | 1210        |
|                    |                           | Plaster                                    | 0.01          | 0.35              | 900                         | 837         |
| Intermediate floor | 65.77                     | Concrete                                   | 0.18          | 1.75              | 2450                        | 920         |
| Adjoining wall     | 14.95<br>15.13            | Plaster                                    | 0.01          | 0.35              | 900                         | 837         |
|                    |                           | Concrete                                   | 0.2           | 1.75              | 2450                        | 920         |
|                    |                           | Plaster                                    | 0.01          | 0.35              | 900                         | 837         |
| Roof               | 65.77                     | Roof waterproofing                         | 0.01          | 0.23              | 1050                        | 920         |
|                    |                           | Polyurethane                               | 0.06          | 0.025             | 55                          | 1400        |
|                    |                           | Concrete                                   | 0.18          | 1.75              | 2450                        | 920         |
|                    |                           | Plaster                                    | 0.01          | 0.35              | 900                         | 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.

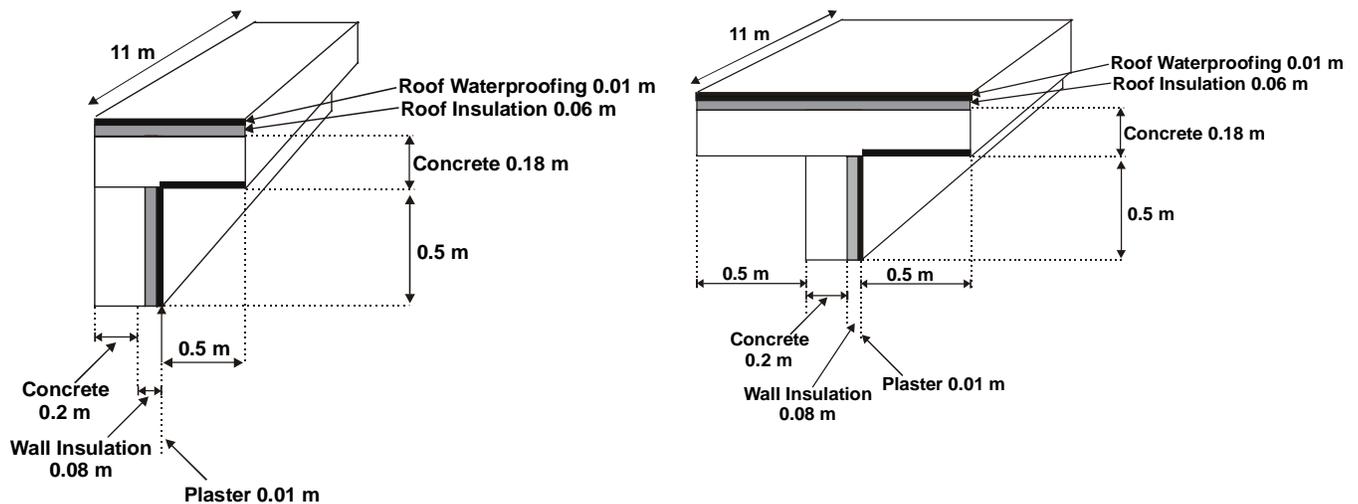
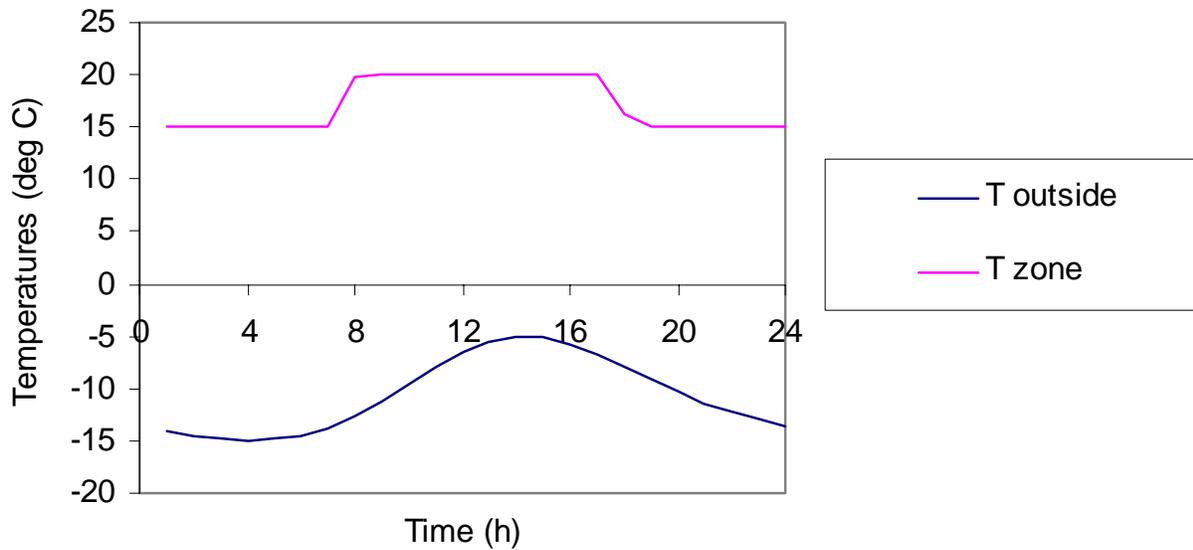


Figure 6: L- and T-Shaped Thermal Bridges

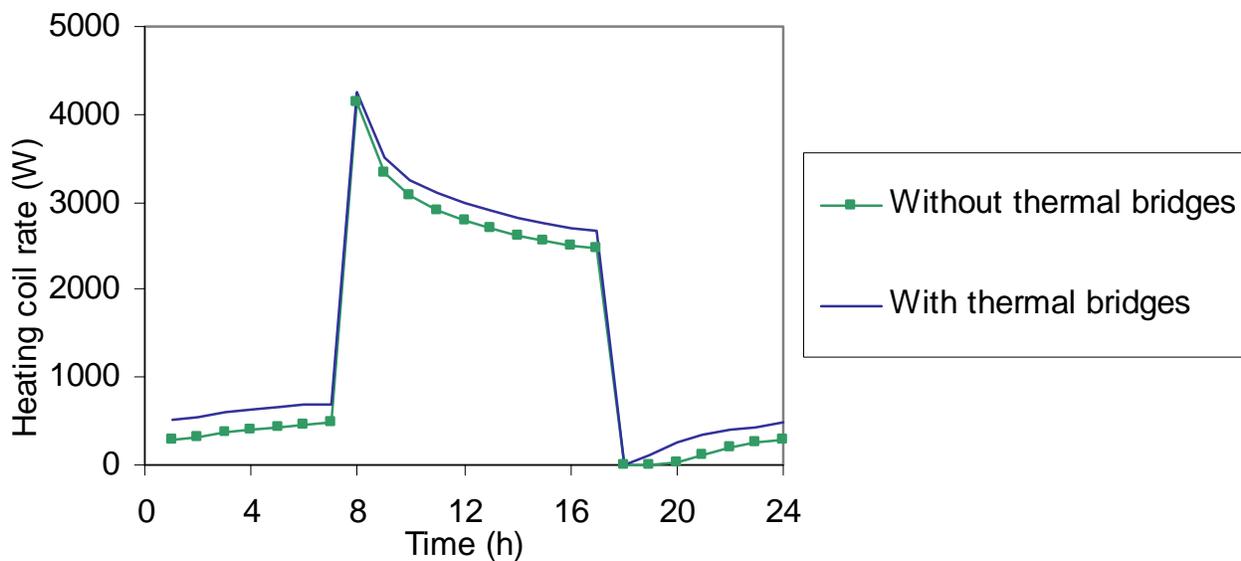


**Figure 7: Temperatures During the Simulation**

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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**SPARK is an equation-based simulation environment that allows you to build customized models of complex physical processes by connecting calculation objects that represent system components like walls, fans, heat exchangers, chillers, ducts, mixing boxes, controls, etc. It is aimed at the simulation of innovative and/or complex building systems that are beyond the scope of whole-building programs like DOE-2 and EnergyPlus. VisualSPARK adds a graphical user interface to SPARK to simplify use of the program.**

## New features

### Default preferences in `setupcpp`

- Added support for default values for the component preferences specified in a file called `default.prf` and residing in the working directory. The default values are used to populate the template preference file associated with the solution sequence generated by `setupcpp` for the problem.
- If the file exists upon calling `setupcpp`, the values in the file are used in place of the hard-coded default preference settings. If no such file exists, then `setupcpp` will generate a template file with the hard-coded default preferences for possible future modification by the user.

### Absolute tolerance property for each problem variable

- A new variable property, `ATOL`, was added to the *SPARK* language on the `PROBE`, `PORT` and `LINK` statements in order to specify the absolute tolerance for each problem variable. The `ATOL` property should be set to the absolute value at which the variable in question is essentially insignificant.
- In *solver*, added support to load the `ATOL` property for each problem variable, thus replacing the `Abstolerance` keyword previously specified in the `problem.prf` file at the component level.
- Improved the input handler to allow it to read in properties of problem variables along with the variable values at the specified time stamps. The syntax to specify the property `ATOL` of the variable `X` is the qualified name `X:ATOL`. The input handler can read in values for any variable properties, namely `MIN`, `MAX`, `ATOL` and `INIT`.

### Sparse linear solution technique

- Added sparse linear solution method based on the C library *umfpack* (<http://www.cise.ufl.edu/research/sparse/umfpack>) v3.2 by Tim Davis. This new solution method is selected by specifying the value 4 for the key `MatrixSolvingMethod` in the `problem.prf` file. It does not rely on vendor-specific BLAS routines but instead on vanilla C code, thus ensuring portability of the *SPARK* program.
- Drastic gains in calculation speed by many orders of magnitude have been observed on large problems for which the Jacobian matrix is typically more than 90% sparse.

### Full affine invariant scaling scheme

- Replaced previous scaling schemes with a single scaling scheme that achieves fully affine invariant scaling in both the variable space and residual space. This makes *solver* less sensitive to changes in the variable units and to formulations where the variables show very different orders of magnitude.
- If convergence difficulties are encountered with a particular problem, the full scaling scheme should be selected in the `problem.prf` file to improve the numerical behavior of *solver*.

### Automatic Jacobian refresh strategy

- Added value 0 as a possible choice for the `TrueJacobianEvalStep` key in the `problem.prf` file. The value 0 indicates that the Jacobian matrix will be refreshed automatically by the solver code whenever it is needed to ensure robust and fast convergence. The refresh strategy is based on the convergence behavior of weighted residual and increment norms between successive iterations.
- For values larger than zero, the key `TrueJacobianEvalStep` still specifies the iteration frequency at which the Jacobian should be reevaluated.

## Statistics log file

At the end of the simulation, *solver* generates a log file with performance statistics about the solver operation. In particular, you can find information on :

- the preference settings used for the simulation for each strong component;
- the average sparsity of the Jacobian matrix and the number of times it has been refreshed; and
- the operation of both the linear solver and the nonlinear solver with average calculation times.

This information can be used to compare the computational efficiency of solving models with different formulations or different preference settings.

## Problem driver API

The problem driver application programming interface (API) added to *VisualSPARK* 1.0.2 allows an advanced user to:

- customize the sequence of operations to re-solve the same problem,
- manage and solve multiple problems,
- retrieve solution values and specify new inputs for a new simulation of the same problem, and
- change runtime parameters (e.g., to perform sensitivity analysis).

We have also modified the `main.cpp` file that implements the main *SPARK* driver function to use the new set of API. Comprehensive documentation on how to write such a problem driver function is available at <http://simulationresearch.lbl.gov>.

## Changes

### Documentation

- Merged glossary of terms between the *SPARK Reference Manual* and the *VisualSPARK Users Guide*.
- Enforced text conventions throughout the documentation to better distinguish the different elements of the *SPARK* language.

### Parser

Discontinued usage of the keyword `UPDATE_FROM_LINK` in `LINK`, `PORT` and `PROBE` statements and replaced it with the keyword `INPUT_FROM_LINK` that better reflects its behavior

### Solver

#### *Improved convergence strategy*

In order to ensure that badly-scaled systems are solved with satisfactorily precision, we now force the convergence check in the non-linear solver to occur in the variable space, i.e. solely based on the increments value, after the first iteration. This represents a change from *VisualSPARK* 1.0.1 where a successful residual check carried out even after the first iteration was a sufficient condition to stop the iteration. The convergence test is stricter and more robust, especially for problems with variables with very different order of magnitudes.

#### *Variable scales based on individual absolute tolerances*

The introduction of the `ATOL` property in the *SPARK* language allows to consider an individual absolute tolerance for each problem variable, as opposed to for each strong component as in *VisualSPARK* 1.0.1. The convergence check in the nonlinear solver and the computation of the cost function used with the backtracking Newton schemes have been updated to support the new absolute tolerance mechanism.

### Graphical User Interface

- Changed default wall clock settings to year 2002
- Changed title of button from "MODIFY" to "MODIFY CLASS PATH"
- Added support for new solver features in the component preferences editor
- The absolute tolerance entry has been removed from the component preferences editor because it is now specified on a variable-by-variable basis.
- Added the sparse LU matrix solving method.
- Reduced scaling types to "None" and "Full" in place of the former scaling options in *VisualSPARK* 1.0.1.

## Bug Fixes

### Documentation

Corrected typo in description of the macro links where the single quote ' used to prefix an object name in a hierarchy of objects was replaced with the single quote ` as prescribed by the *SPARK* syntax.

```
obj1'obj2'obj3~linkname
```

has been replaced with

```
obj1`obj2`obj3~linkname
```

### Parser

- Keyword `PARAMETER` did not work when there were more than one `PARAMETER` statement in one class.
- Fixed infinite loop bug caused by aliased variables. Aliased variables are created in `LINK` statements that do NOT contain `obj.port` connections.

### Setupcpp

Write out error message showing the calling syntax if *setupcpp* is executed with no argument at the command-line instead of crashing.

### Solver

Fixed bug in *sparksym* for the *mathomatic* symbolic solver that limited to 14 the number of variables allowed in the equation to be processed.