RESOURCES FOR TEACHING BUILDING ENERGY SIMULATION

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ABSTRACT

This paper describes a variety of training courses that have been created for the EnergyPlus program. EnergyPlus is a whole-building energy analysis simulation program developed under the auspices of the United States Department of Energy. The four different training courses outlined in this paper include a beginner course for engineers with little or no experience in simulation, an "experienced user" course for simulators familiar with other programs, an advanced course for users who want to investigate some of the more sophisticated features of the program, and an university course for students that provides both an introduction to buildings and to simulation. For each course, an overview of the lecture material and problems/workshops that are part of the course as well as the philosophy and availability of the course will be provided. Experiences in using these materials will also be presented.

INTRODUCTION

Numerous studies have shown the positive impact of simulation on society, particularly in the area of building energy. Simulation allows architects and engineers to test ideas and designs before a building is built to see what the impact of their decisions will be on energy consumption and the environment. Once one agrees with the premise that simulation is good for society as a whole, the simulation community faces two challenges. First, how does one increase simulation use in architectural/engineering firms? Second, how does one keep up with new programs that improve one's ability to model buildings and their related primary and secondary systems? "Through education" is one answer that provides a valid response to both questions. Curricula at both the university and professional level increase the ability of current and future architects and engineers to use simulation in their work. In addition, properly

designed courses can also be used to help experts in one program adapt to the language and assumptions of a new program. The remainder of this paper describes a variety of training courses that have been created for the EnergyPlus program.

Four different training courses are outlined in this paper, three professional short courses and one university course:

- *Beginner Course* - for engineers with little or no experience in simulation,

- *Experienced User Course* - for simulators familiar with other programs,

- *Advanced Course* - for users who want to investigate some of the more sophisticated features of the program, and

- *University Course* - for students that provides both an introduction to buildings and to simulation.

For each course, an overview of the lecture material and problems/workshops that are part of the course as well as the philosophy and availability of the course will be provided. For the beginner, experienced user, and advanced course, experiences in using these materials during actual training sessions will also be presented.

COURSE OBJECTIVES AND OUTLINES

These courses were designed around the basic interface tools which are provided standard with the software and did not attempt to utilize any third-party user interface software. The course lengths were chosen based on general impressions of the amount of time various types of participants would be willing to invest in learning about the software. Then the material was tailored to cover as many topics as possible within the allocated time. The three professional courses were designed to alternate between

lecture and hands-on workshops with approximately equal time for each. The course objectives and outlines for each of the four courses are listed below.

Beginner Course

The objective of this course is to introduce EnergyPlus to beginning modelers and to teach the basic concepts of building energy simulation such as thermal zoning, building geometry, specifying materials and construction, internal loads, and schedules. It discusses the basic techniques involved in properly applying simulation tools during the building design process, for example, comparing two or more alternative systems. At the conclusion of the course the student should understand the basic concepts of:

- Thermally zoning a building.
- Creating a simple building envelope in EnergyPlus, including internal loads.
- Creating a basic HVAC system and plant in EnergyPlus, including simple air and water loops.
- Producing and interpreting EnergyPlus reports.

This course is structured as a 4-day course:

Lecture 1	Overview, Environment and Reporting
Lecture 2	Running EnergyPlus and Output
Workshop 1	Run a Single-Zone Building Input, Run EnergyPlus, modify design day, add report variables and review outputs.
Lecture 3	Building Envelope, Schedules, Weather Data, and Internal Gains
Workshop 2	Modify a Single-Zone Building Input File Add materials and constructions, describe subsurfaces, schedule, and people.
Lecture 4	HVAC Overview, Thermostats, Zone Equipment and Meters
Workshop 3	Add Thermostat and Purchased Air to Single Zone.
Lecture 5a	HVAC Air-Side Equipment and Templates
Lecture 5b	HVAC Air-Side Equipment and Templates
Workshop 4	Describe a 1-Zone Furnace with DX Cooling using Templates
Lecture 6	HVAC Water-Side Loops and Output

Workshop 5	Describe 5-Zone VAV System w/Purchased Supply using Templates – Options and Cold Deck Setpoints.
Lecture 7	HVAC Water-Side Equipment and Auto-Sizing
Workshop 6	Add an Air-Cooled Chiller and Load Management
Lecture 8	HVAC OA Systems and Modeling Guidelines
Workshop 7	Boiler, Chiller, Condenser Loop Template, Outside Air Mixing Box and Controls, Set Points, and System Availability
Lecture 9	Miscellaneous and EnergyPlus Resources

The presentation materials and workshop files are available for download from the EnergyPlus web site (www.energyplus.gov) as pdf files and text files for workshop input files. While the materials have not been designed for self study, they have been made available as a supplement to the software documentation.

Experienced User Course

The objective of this course is to introduce EnergyPlus to experienced modelers. The emphasis of the material is on aspects of EnergyPlus that differ substantially from other common modeling tools (e.g., DOE-2 and BLAST), such as the use of a multiple time-step approach, the integrated simulation of loads, systems and plant, and defining fluid and air loops. At the conclusion of the course the student should understand the basic concepts of:

- The advantages of EnergyPlus over other common modeling tools.
- Creating a simple building envelope in EnergyPlus, including internal loads.
- Creating a basic HVAC system and plant in EnergyPlus, including simple air and water loops.
- Producing and interpreting EnergyPlus reports.

This course is structured as a 2-day course:

Lecture 1	EnergyPlus Features and Benefits
Lecture 2	Overview, Global Inputs, Outputs, and Auxiliary Tools
Lecture 3	Building Envelope
Workshop 1	Modify a Single Zone Building Input File
Lecture 4	HVAC Overview, Zone Controls and Zonal Equipment

Lecture 5	HVAC Central Air-Handling Equipment, Autosizing & Templates
Workshop 2	Describe a 1-Zone Furnace with DX Cooling using Templates
Lecture 6	HVAC Outside Air Systems & Water-Side Loops
Workshop 3	Describe a 5-Zone VAV System with Purchased Supply using Templates – Options and Cold Deck Setpoints
Lecture 7	HVAC Water-Side Equipment
Workshop 4	Boiler, Chiller, Condenser loop Template, Outside Air Mixing Box and controls, set Points, and System Availability
Lecture 8	Folders, Weather Data, Importing Building Geometry, COMIS & Miscellaneous, Support, and Summary

The presentation materials and workshop files are available for download from the EnergyPlus web site (www.energyplus.gov) as pdf files and text files for workshop input files. Again, while the materials have not been designed for self study, they have been made available as a supplement to the software documentation.

Advanced Course

The objective of this course is to introduce more complex features of EnergyPlus that provide greater power and flexibility to advanced modelers. The course builds on concepts introduced in the "EnergyPlus Introductory Workshop for Beginning Modelers" and "EnergyPlus Introductory Workshop for Experienced Modelers" and introduces some of the more advanced simulation concepts such as daylighting, secondary pumping, set point controllers, outside air treatment, air-side heat recovery and water-side economizers. Time is set aside to allow students to model building envelopes and systems using the latest version of EnergyPlus on their own laptop computers. Time for questions and answers is provided for each topic.

This course is structured as a 2-day course:

Lecture 1	Ground Heat Transfer & HVAC Templates
Workshop 1	Using the Ground Heat Transfer Program & HVAC Templates
Lecture 2	Daylighting
Workshop 2	Daylighting
Lecture 3	HVAC Water-side Loops

Workshop 3	HVAC Primary-Secondary Loops & Free Cooling
Lecture 4	HVAC Outside Air Systems
Workshop 4	HVAC Outside Air Systems
Lecture 5	COMIS Airflow Modeling
Workshop 5	Using the EnergyPlus/COMIS Link for Air Flow Analysis COMIS Airflow Modeling
Lecture 6	EnergyPlus Resources and General Discussion

The presentation materials and workshop files are available for download from the EnergyPlus web site (www.energyplus.gov) as pdf files and text files for workshop input files. As with the Beginner and Experienced User course, though the materials have not been designed for self study, they have been made available as a supplement to the software documentation.

University Course

The intent of the university course is to provide a curriculum outline for an undergraduate course that teaches the student about the usage of EnergyPlus. While not all of the curriculum is specific to the EnergyPlus program and teaches more basic concepts about buildings and their HVAC systems, the vast majority is intended to instruct the student on how EnergyPlus works and what information it needs as input and provides as output.

Every university is slightly different in how it approaches courses, and every instructor will approach a course differently as well. However, it was necessary in creating the curriculum to make several assumptions:

- This course is intended to be taught primarily to upper-level undergraduate students at the (USA) university level but could also be taught at the graduate level.

- The primary audience is a student in mechanical or architectural engineering who has had background courses in heat transfer and thermodynamics. Instructors in affiliated fields such as civil engineering, architecture, etc. may need to supplant some of the lecture material with more basic information on heat transfer, thermodynamics, engineering analysis, etc.

- This course was designed for a university on the semester system where a semester lasts approximately 15 weeks.

- The lectures were designed for a traditional 50 minute lecture period with three class sessions per week.

- It is imperative that students spend supervised time in computer laboratories to gain more experience using the program and the input language. Thus, some of the class periods are assumed to meet in a computer laboratory rather than a lecture hall.
- The lectures were developed without referring to any interface. The IDF Editor and EP-Launch can be used in computer laboratories as desired. Existing templates may also be utilized. The use of an interface is strongly recommended.
- Complete expertise in EnergyPlus cannot be gained in a single semester. Thus, this course strives to give the student a working knowledge of most features of the program rather than expertise in a specific area.
- Lectures provide enough background about what is being simulated so that the students understand "what" is being simulated not just "how" to simulate it.

Based on the assumptions listed above, the following breakdown of the 45 class sessions was made. Since the main focus of this project was to develop the lectures and example assignments ideas, course syllabi, exams, homework assignments, reviews, course evaluations, etc. were left to the discretion of the individual instructors.

- Course Syllabus and Class Overview—1 Session
- Formal Lectures (PowerPoint Slide Shows Provided)—26 Sessions
- Computer Laboratories (Example Exercises to be developed by Instructor)—14 to 15 Sessions, some of which may be used as semester project work sessions
- Exams and/or Presentation of Semester Projects—2 to 3 Sessions
- Final Review, Course Evaluations, Wrap-up—1 Session

The PowerPoint files for the 26 formal lectures as well as other notes about the university course can be downloaded at no charge from the EnergyPlus web site (www.energyplus.gov). One of the hopes of the authors is that instructors who use the course will share their experiences, computer exercises, etc. to maximize the benefits of having this course available.

PROFESSIONAL SHORT COURSE WORKSHOP EXERCISES

The Beginner Course, Experienced User Course, and Advanced Course were each offered once in 2004 for the first time. These three professional short courses were structured to be approximately half lecture and half hands-on workshop. For each of these courses a laptop computer was required by each of the class participants for use during scheduled workshops. Participants were expected to have the latest version of EnergyPlus installed on their laptop prior to arriving at the workshop. Other software requirements include: Adobe Acrobat Reader to view the PDF files, a text editor such as WordPad or Notepad to view example input files, a spreadsheet program to view CSV formatted output files, and Autodesk VoloView Express for viewing DXF files. Input files required for the workshops were e-mailed to the students prior to each course.

Workshop problems were designed to give users practice in taking a practical description of a problem and generating the corresponding simulation inputs. In designing each problem, there was a tension between keeping things simple enough to complete within a 2-hour workshop time yet complex enough to be interesting. This was accomplished by providing the students with a base input file for each workshop problem which the students then completed by adding new objects or editing existing ones. The goal was to focus the students' efforts on thinking through a problem and determining the proper input, yet minimizing the amount of data entry required. Each workshop also included extra exercises for those who were able to complete the base tasks in less than the allotted time.

EXPERIENCE TEACHING COURSES

Each of the three professional short courses has been taught at least once. At the conclusion of each course, a student evaluation was distributed. The evaluation questions were grouped into four main topics: content, format, background (about the student), and overall. A sample evaluation summary table is shown in Figure 1. Student and instructor feedback is discussed below.

Participant Evaluation of the EnergyPlus Introductory Workshop for Beginning Modelers	Highly Effective	Effective	Neutral	Ineffective	Highly Ineffective	Satisfied	Somewhat Satisfied	Neutral	Somewhat Dissatisfied	Dissatisfied	Yes	Somewhat/Neutral	No	Too Short	About Right	Too Long	High	Somewhat High	Average	Somewhat Low	Low	1 Day	2 Days	3 Days	4 Days	Check Sum
1 Content: How would you rate the course content, organization, balance of topics?																										0
2 Content: How would you rate the presentation materials?																										0
3 Content: Were you satisfied with the level of detail for each topic area?																										0
4 Content: What topic areas would you compress or expand?	*(See attached sheet)*																									
5 Content: How would you rate the speaker's presentation of the material?																										0
6 Content: How would you rate the workshop materials?																										0
7 Content: Was the complexity of the workshop materials appropriate for the course?																										0
8 Content: How would you rate the amount of time allocated to workshops?																										0
9 Content: Was the content adequate to get you started using EnergyPlus?																										0
10 Content: General comments regarding content (presentation material and workshops).	*(See attached sheet)*																									
11 Format: How would you rate the overall structure of the workshop utilizing laptop computers and previously downloaded software and data files?																										0
12 Format: Was the time allocated for each day of the course appropriate?																										0
13 Format: Was the overall length of the course appropriate?																										0
14 Format: General comments regarding format	*(See attached sheet)*																									
15 Background: What is your level of building simulation experience?																										0
16 Background: How many days did you attend the course?																										0
17 Overall: Were you satisfied with the course overall (was it worth your time and money, did it meet your objectives)?																										0
18 Overall: How could this course be improved?	*(See attached sheet)*																									
Score Distribution	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 1. Student Evaluation Summary

Beginner Course (4 days)

Student Responses

In general, the students felt the course length and format were appropriate and the the course was effective. Most comments focused on changing the emphasis of the course content. Selected student comments are listed below.

Content: What topic areas would you compress or expand?

- Building geometry less important, more on equipment schedules, outside air, reporting and report generation to diagnose problems or conflicts in components/setpoints/schedules.
- I would compress HVAC and expand materials; color, radiation…etc.
- Focus on logic of modeling and not so much on the system components. Discuss what the ID names mean to the developer so we can understand.
- Present the process from start to finish, do a complete structure's analysis. Without an interface, users need to be able to work through a project. Identify when to use the text editor and when to use the IDF Editor.
- More evaluation of modeling results, i.e., trouble shooting such as competing cooling and heating coils in Workshop 6.

Content: General comments regarding content (presentation material and workshops).

- Some additional information in regarding how to create quick study models and how to start integrating templates would be welcome.
- Need more calculations.
- Workshop material was informative.
- It gives an overall idea although more in depth analysis of each topic is needed.
- Need more workshops, but not more time per workshop – that was a bit long.
- Less presentation - more hands on, particularly at the start of the workshop. It all sticks better after you play around in the software.

Format: General comments regarding format.

- Format was appropriate for an entry-level course.
- It is a short course but it gives an overall view. An advance course is needed.
- Perhaps start at the modeling concepts and then expand from there.

Overall: How could this course be improved?

- I think that it would be very useful to setup this course according to professional area of interest, and then let users bridge gap for themselves.
- Possibly by working examples in the class on the overhead as the students work simultaneously on their laptops.
- If earlier material could be condensed to leave the last day mostly free, it would be nice to try to build a model (maybe have envelope entered) from a sketch and description to get a better feel of how to

work on a file without explicit direction. That way, there are experts around to help solve the inevitable problems.

Instructor Comments

In this course the students' response was varied from expand the building section to compress the building input section and expand on HVAC. An issue with a beginner's course is the varied background that each person brings to the course, from no simulation, building design, or computer experience to maybe some experience in 1 or all 3 of these areas. This was a four day course. For the instructors, this was a day too long, but the students generally thought it was about the right length.

Experienced User Course (2 days)

Student Responses

In general, the students felt the course length and format were appropriate and the course was effective, although 20% would have liked a longer course. This course was the very first one taught, and most comments focused on changing the emphasis of the lecture materials. Many of these comments have been incorporated into this course and were used in the Beginner Course which was developed later, especially the addition of more diagrams and sample inputs. Selected student comments are listed below.

Content: What topic areas would you compress or expand?

- Information on daylighting (probably too much for this seminar).
- Suggest more diagrams showing structures.
- Basic nodal configuration.
- Compress envelope; expand systems and plants.
- Controls [discussion should be] 20 to 30 minutes.
- Examples of complex HVAC system should be covered/expanded; node/branches/ connectors should be clarified/expanded with example on how to assemble them together.
- More on branches and nodes.
- Need examples.
- More HVAC system examples - sketch of the system and IDF.
- For this particular course, I would show an example from DOE-2 and BLAST and show how you would set up [model] in

EnergyPlus. This would help those familiar with these modeling programs.

- Drop Lecture 1. Add IFC-IDF and ground temperature calculations.
- Nodes, loops and branches.
- I would like to see more about configuration of systems and plants.

Content: General comments regarding content (presentation material and workshops).

- Could improve presentations of nodes in mechanicals – diagram for clarity.
- Should walk you through full examples.
- Use schematics drawn up to explain the zone, systems and plant showing branch, splitter, and node names.
- Reorganize to show conversion of system schematics to topology rather than jumping into object details.
- Need more visual schematics/topology; consistent node names and overlay on schematics.
- Could use node diagrams for Workshop 3.
- Could start with syntax, hierarchy of objects/classes.
- Copies of the presentation are not necessarily good reference for later use. It would be nice to have handouts that follow the presentations but have more detail.
- More documented example files, i.e., sketch of the system and IDF.
- Some issues with workshop handouts for continuity – liked having working time during lunch and end of day session (not too rushed).
- Need a checker.
- Would like diagrams of the systems with the IDF information in the presentation materials.
- Should have more talks about HVAC system set up and connections.

Format: General comments regarding format.

- [Overall length appropriate] for more experienced modelers.
- The course and workshop should walk you through an example.
- Control programming module might be included.
- Need examples for the lectures.

- Extend course to allow more workshops.
- The syntax of loops, nodes and branches is a new concept and seemed to be covered too rapidly.
- Workshops made all the difference; possibly [present] work example and then workshop would help more. The same example throughout the course would help with familiarity and give a sense of continuity from beginning to end for a whole simulation.

Overall: How could this course be improved?

- Discuss zone multipliers.
- Discuss IFC conversions – "user friendliness".
- The air-side lectures lost me in detail – maybe work through the topology with an example of the objects needed rather than details of objects. Water-side lectures were easier to follow, discussion of water-side objects… was good organization.
- No notes on output files.
- Longer course, more workshops.
- Add steam component (e.g., purchased, loops, boilers, HX).
- Would like to see more diagrams of the systems used in the templates and example files.
- More time for workshops.

Instructor Comments

The Experienced User Course is the easiest course to teach. In this course you assume that each user has had experience with another simulation program and you are teaching them how to translate that experience into EnergyPlus inputs and philosophy.

Advanced Course (2 days)

Student Responses

In general, the students felt the course length and format were appropriate and the course was effective, although 40% would have liked a longer course. Most comments focused on changing the emphasis of the course content. Selected student comments are listed below.

Selected student comments are listed below.

Content: What topic areas would you compress or expand?

- Tips and tricks were a good last minute addition

- Less review and more time on what the different inputs really mean.
- Compress daylighting.
- Expand daylighting.
- Expand analysis methods for working with data (outputs).
- [Add a] water loop simulation workshop.
- I would expand the HVAC waterside loop topic.
- How about a seminar focusing on retrofit models (DD to VAV, economizer additions, etc.).
- More on output and utility rates - for consultants it will come down to dollars in the end.
- Expand controls and HVAC.

Content: General comments regarding content (presentation material and workshops).

- Solution IDF files were very helpful.
- Some of the material was a bit over my head, but the HVAC waterside loop and outside air lectures were quite beneficial.
- I would like accurate diagrams for each workshop discussed.
- Printouts of the IDF [file] would be nice as it's hard at times to track branch lists, branches, etc.
- People didn't always finish [workshops], but that's okay to cover more material [since] the ideas are conveyed.

Format: General comments regarding format.

- I would approve of a detailed course outline being sent to participants before course.
- One extra day.
- Can we get electronic copies of presentation materials?
- Emphasize speed a little more for those that have previously only used the software on their desktop PC's.

Overall: How could this course be improved?

- More reading material before hand to get up to speed and, therefore, come prepared with solutions/problems.
- More time is needed for the workshops.

Instructor Comments

This is actually the hardest course to teach and not because this course contains advanced topics. The problem is that each student has their

personal definition of what advanced means to them and their personal areas that they would like to see covered. Some students brought their own projects or list of questions to work on instead of the planned workshops. Others were overwhelmed with all of the advanced topics, once again attesting to the broad diversity of backgrounds of the students. Both of these situations kept the instructors very busy with questions during the workshop and break times.

CONCLUDING REMARKS

It is interesting to watch how the students interact to the basic input files necessary to simulate a building in EnergyPlus. The vertices input for buildings has been around for many years, but since users are somewhat familiar with what is being presented, no matter how complex, they seem to have a better understanding with the concepts. The HVAC loop simulation input was newly developed for EnergyPlus and because of the lack of familiarity from other programs such as BLAST and DOE2 it was much harder for the users to tackle these concepts. The biggest problem seems to be keeping track of the process in their minds or developing a visual roadmap of the process. The level of complexity for both is similar but the students complained about not having program generated HVAC Loop diagrams. This feedback from the course has led the EnergyPlus Team to develop and implement a way to view the user's input for the HVAC Loops.

Another concern for instructors is to teach and present a complex simulation program without the associated, and nowadays expected, graphical interface. There are some interface pieces that help the user with some input and output tasks, but not an integrated, complete, graphical interface. It has been the experience of the instructors that the interface makes or breaks the usability and acceptance of major building simulation programs. On the other hand, some of the integrated interfaces have led to users that do not understand the underlying assumptions, physics, and expectations from results from the simulation programs. Some refer to these types of users as black-box users. Working with the basic inputs allows the users more understanding of the models and an ability to fine tune models that might not be possible through an integrated interface.

One of the biggest issues with teaching all 3 short courses was dealing with the diversity of background of the students. Since some users wanted to learn about and get experience in EnergyPlus, they would sometimes enroll in a course that was not well suited for their background just to fit their busy schedule. Another issue is how to balance lecture time with workshop time. One has to present enough background material before a hands-on workshop is attempted, but a lot of the material is not learned until the users try it for themselves. In the University course, this is not as big of an issue since this can be accomplished with homework assignments, but time is much more critical in 2 or 4-day short courses.

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