

Application of Computer Simulation in Engineering Education

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Abstract: *Today it has become a widespread practice to use computer-based tools to enhance learning. Use of computer simulation in higher education is growing rapidly and has become a major trend in technical education because teaching of technical subjects is a very complicate and complex process and it is demand on logical thinking and imagination. This paper presents the application of interactive computer simulation tools Energy2D and Energy3D in the technical education process. Energy2D covers many topics in the science of heat transfer and its engineering applications. Energy-efficient building design challenges are used as the engineering examples to illustrate the learning and teaching opportunities created by the modeling, simulation, and data mining capabilities of the Energy3D software. The proposed application help students to analyze and solve problems with relevant knowledge and enhance their practical abilities.*

Keywords: *computer simulation, technical education, 2D/3D simulations of heat energy, flow and solar radiation*

1. INTRODUCTION

Learning involves acquiring and retaining new information, concepts, or skills. Students learn in various ways. Simulation is a very general and flexible teaching approach that can be used in most disciplines. The computer simulation has a high potential to influence learning in technical science [1]. The use of simulations in science education can make significant contributions by providing appropriate learning opportunities to diverse learners and motivating students to learn science, both inside and outside of the school environment. Due to an increase in computational power and improvement of software designs, computer systems can imitate situations of great complexity and provide a high level of interactivity.

There are many prerequisites strongly influence learning achievements. The main are that the choice of the simulation software has to closely match the interests and abilities of the students, and that the simulation tools have to be user-friendly. On the one hand, the "fun" factor is not to be underestimated: if students like to play around with the tool, they also learn more. On the other hand, user-friendliness is required in order that students are efficient in their assignment work.

Teaching courses using simulation software have to be supported by suitable didactic concepts, which need to cover classroom activities as well as computer homework [2]. Simulations allow group cooperation, which is effective in generating new ideas, solving problems, and helping students learn

from each other. In contrast to using video material in teaching, the application of simulation tools is very close to real "hands-on" activities.

Simulations can motivate students of different learning abilities by enabling them to interact with a given task and work with problems that bring meaningful results. Simulations can reduce teachers' teaching times, provide opportunities for student discussion and interaction, and thus, increase communication and reduce both social and learning differences. During simulation sessions, the teacher acts in the role of a coach and students are actively pursuing their design projects [3]. Other advantages when using simulation software and modern ICT technology for teaching are:

- Is applicable to students of all levels and ages
- Students are activated. They have to take responsibility, make decisions and organize their work.
- Trainees can pick the topic that is relevant for them.
- Progress in the exercise is visible to the teacher during class and easily measurable after class.
- Helps students see complex relationships that would otherwise involve expensive equipment or dangerous experiments
- Exceptionally high motivation, in particular for in-service and screen sharing training.

Every discipline treats the conceptual structure of the simulation differently. Teaching of technical subjects is a very complicate and complex process. It demands a logical thinking and imagination. Using of illustrative examples of the real process is one of the ways how to make learning process simplify.

2. COMPUTER SIMULATION IN EDUCATION PROCESS

The complexity and diversity of problems and concepts make engineering education a challenge for many students. Today, with the advent of computers and various easily accessible software packages, computer aided teaching tools have become an essential part of both classroom lectures and laboratory experiments in any kind of engineering education curriculum. This interactive learning environment, consisting of simulations, demonstrations and exercises, can fulfill the role of a bridge from passive learning to active engagement and thus stimulate deeper thinking, grounding a problem based-learning environment. The applications are also very important for relating theory to practice, so that the students can develop engineering judgment and understand how process behavior can be captured using real time simulations. Students need to get a feel for sizes and sensitivities of system parameters, to examine the relationship between and responses of such parameters and to understand the value and limitations of numerical methods used in system solutions.

A number of authors have suggested that simulations can have positive effects on student learning. Xueyi Li et.al [4] improved teaching effectiveness and proposed a novel teaching mode by applying simulation technology to a particular mechanical design course. Tajvidi & Fang [5] analyzed literature review focusing on computer simulation application and pedagogical innovations in engineering education. They concluded that interactive features, animation, and problem solving are the main characteristics of effective computer simulation application and in combination with typical face-to-face or online classes presented the most effectively educational tool. Camaj et al. [6] argued that the computer simulation of technical systems enables testing of alternative solutions, proposals and decision-making strategies with essentially lower costs in comparison with experiments on the real system, which are often even not feasible.

A "computer simulation" is supposed to accept inputs, incorporate those inputs into calculations or modeling, and present functional outputs. Compared to "computer animation", "computer simulation" is usually more calculation-oriented to characterize the real phenomenon of interest.

Instructors in most engineering lectures try to represent 2D and 3D motion through static diagrams and explanations. To date, numerous educational tools and methods have been developed by various researchers to improve student performance in education.

Engineering design course covers various contents, and most of them are complex theoretical knowledge. Many engineering disciplines are becoming increasingly digital, which means relying on an increasing number of digital tools. It is essential that students learn to use the same simulation programs during their time at university as they will be expected to use in the professional world, so that they can then bring those skills into their internships.

Computer-aided design (CAD) is one of the most fundamental changes brought by computer technology to engineering. CAD tools empower users to conceptualize products before making prototypes. In this paper application of an educational CAD tool called Energy2D and Energy3D in technical education is analyzed.

3. USE OF ENERGY2D AND ENERGY3D IN TECHNICAL EDUCATION

Dr Charles Xie, a physicist working at the Concord Consortium based in Concord, Massachusetts, USA created Energy2D in 2010 and is being actively developed by him and his team. The development of Energy 2D has recently slowed down as dr Xie is currently focused on developing Energy3D. Energy2D software is based on a unique semi-Lagrangian McCormack method, which is invented by dr Xie, that approximately solve the Navier-Stokes equation. Although this solver is not unconditionally stable, it is capable of simulating turbulent flows.

The models generate dynamic visualizations, so by running them the student can see the flow of energy in real time and generate time-series graphs of the temperature detected by any sensor they choose. They also execute quickly, which is key to maintaining student interest and making it possible to undertake many experiments and design modifications in a short time.

These software packages support open-ended, constructivist learning because they are all highly interactive and graphic. For instance, in Energy2D students can easily change the location, thickness, and thermal properties of the walls, add and remove heat sources, move the sun, and place temperature sensors anywhere [7].

Both Energy2D and Energy3D software are free to download and use.

3.1. Energy2D visual simulation program

Energy2D is a two-dimensional interactive heat transfer simulation program based on

computational fluid dynamics. Students can use Energy2D as an inquiry tool to investigate heat flow and energy usage in 2D model systems [7].

Students can simplify and approximate 3D problems, that they encounter through technical teaching courses, by a 2D model that can be easily and quickly simulated in Energy2D.

Some of the models that comes with the software are presented further in this paper, but it should be noted that all models are changeable (initial temperatures and other parameters, resize or move objects) and students can also easily create new models from scratch on their own or interfere anytime while a simulation is already running. There are also graph options which can print temperature and anemometer sensor values. All sensor data can be exported in a table which is convenient for further use if needed.

Overall, Energy2D is a great software which could supplement classroom instructions with visual learning experiences for students through visualizations of heat and temperature.

In this section, it is shown a set of examples for teaching courses of conduction and convection. There are also a radiation examples which will not be covered with this paper.

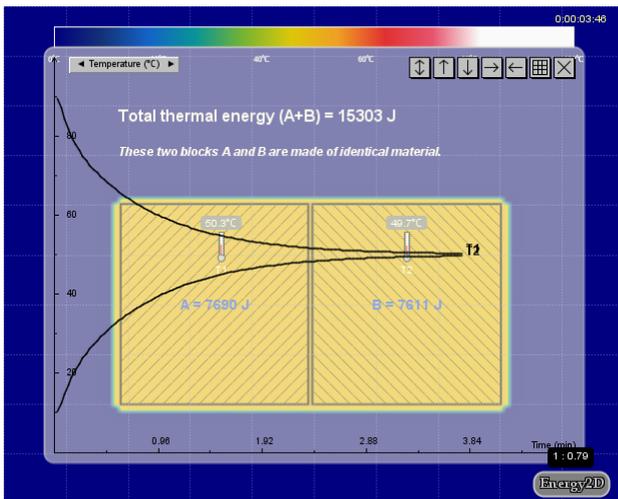


Figure 1. Simulation of the first and second law of thermodynamics

The Figure 1 represent the model of first and second law of thermodynamics, i.e. two blocks of same dimensions and material, joined together in an insulated system, causing heat transfer between each other. At the beginning of the test, block on the left had the higher temperature and energy than the block on the right. The sum of the total thermal energy of the blocks remains the same through entire test, and after certain time the temperature of the both blocks will approach the same value as shown on the graph of Figure 1.

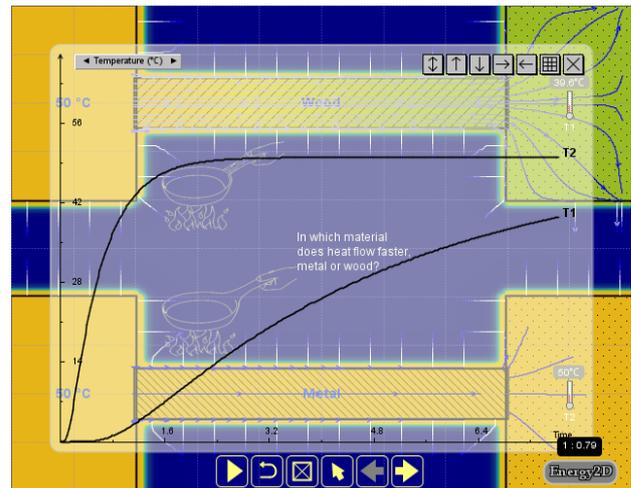


Figure 2. Simulation of the heat conduction through different materials

Since different materials have different heat conduction coefficients, heat transfer will take place at different speeds. At Figure 2, it can be seen that the heat travels faster through material with a higher conduction coefficient (e.g. metal) than through a material with a lower coefficient (e.g. wood) as can be seen in a graph.

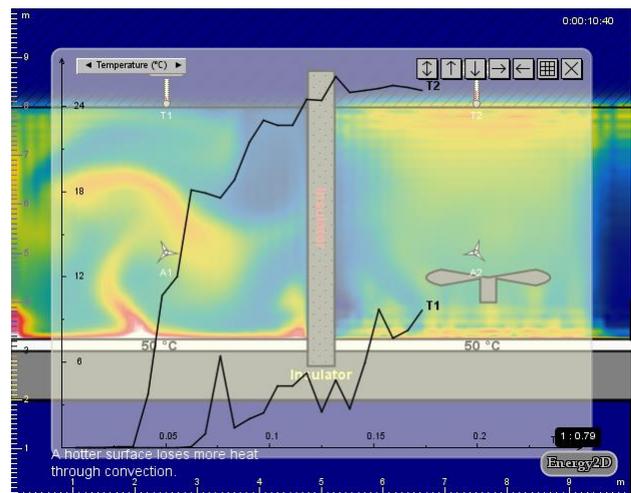


Figure 3. Simulation of the natural and forced convection

The Figure 3 shows the differences in natural and forced convection heat transfer at the same temperature source conditions. The left side shows natural and the right side shows the forced convection. It can be seen that the thermometers which are placed on the opposite material of the heat source shows different values of temperature.

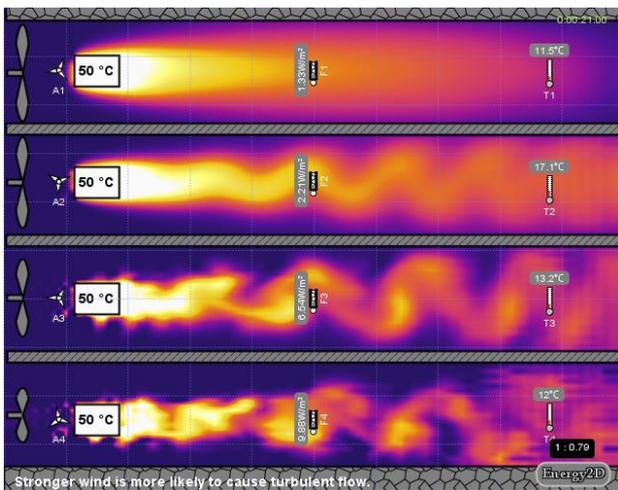


Figure 4. Simulation of forced convection with different wind speeds (higher speeds causing turbulent flows)

In Energy 2D, laminar and turbulent flows can be simulated. Figure 4 shows flows through the same chambers with increasing wind speeds in each chamber (from top to bottom), where it can be seen differences between each flow.

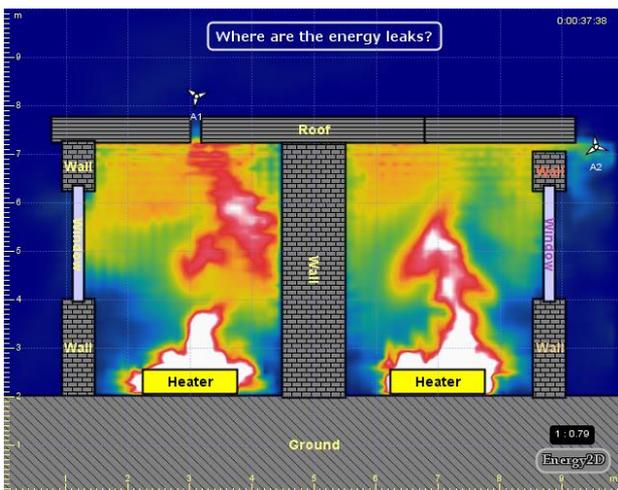


Figure 5. Simulation of air infiltration in a building with two leaks

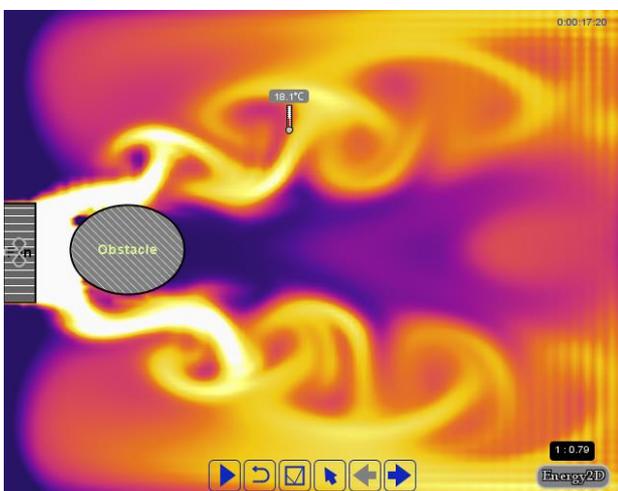


Figure 6. Simulation of forced air flow around an obstacle

Energy losses through leaks are common problem in some applications. Two identical chambers in are shown in Figure 5 with the same heat source and different places of air leak.

3.2. Energy3D simulation program

Energy3D is a simulation-based engineering tool for designing green buildings and power stations that harness renewable energy to achieve sustainable development.

The program was written in the Java programming language with the goal to support the teaching and learning of engineering design. Two important features make Energy3D an appropriate tool for learning and teaching design. The first one is its intuitive interface for 3D modeling and its graphical representations of simulation results.

Students can sketch a structure or import existing form CAD file, place it in any day and location on a map like "Google Maps". Energy3D can add, combine, and modify standard elements to make a wide variety of designs.

To bridge the gap between the virtual and real worlds, Energy3D can deconstruct a 3D structure into 2D pieces and generate a layout of them for printing. Every piece is numbered and annotated to guide students to scale up to constructional materials such as cardstock or foam board. The entire deconstruction process is animated so that the user has an intuitive understanding of the relationship between the 3D representation of a house and its 2D pieces [8].

Based on computational physics and weather data, solar irradiance heat map can be evaluated. Solar irradiance heat map visualizes the distribution of solar radiation on surfaces on a daily basis which can be used for the solar energy potential analysis.

Both photovoltaic and concentrated solar power station can be designed, simulated, analyzed and optimized in Energy3D [7].

Energy3D offers integrated tutorials for students with models for understanding solar energy and other energy applications which is will not be show in this paper due to simplicity, and only some of the models integrated in Energy3D will be further presented in this paper.

Solarize Your World is based on Energy3D software, a CAD tool anyone can use to design any type of solar power system in cyberspace and calculate its hourly, daily, or yearly outputs based on numerical simulation from first principles. With weather data of over 600 regions in 190 countries, Energy3D can produce satisfactory results for most parts of the inhabited world, enabling millions to work on local projects.

A simulation of solar irradiance map of two same houses with different roof colors for a location in Belgrade is shown in Figure 7. Simulation can be run for any day of year. Then, students can compare energy needed for cooling in the summer

and energy needed for heating in the winter (e.g. 1st July and 1st January) for both houses.

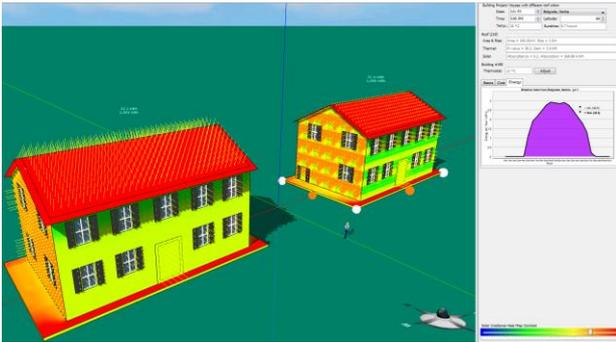


Figure 7. Solar irradiance map of two houses with different roof colors

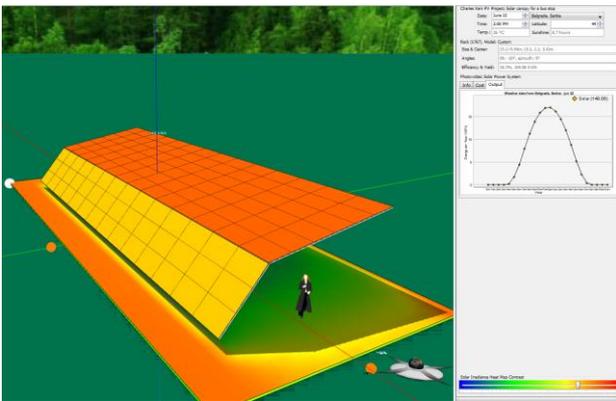


Figure 8. Simulation of a solar canopy for a bus stop

Some of the software already designed examples of solar stations are shown in Figure 8 and Figure 9. Figure 8 shows a photovoltaic solar power station on a bus stop for a Belgrade location and sun conditions for the 1st July. Software allows students to design photovoltaic systems from scratch and to change dimensions, angles and orientation of panels, conditions, locations, etc.

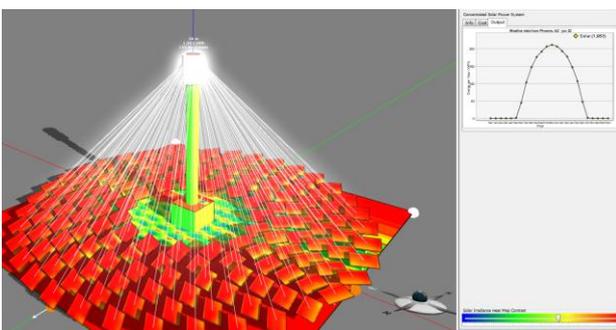


Figure 9. Concentrated solar power tower

A concentrated solar power tower for a Phoenix Arizona location is shown in a Figure 9. Software can show absorbed solar potential energy in a graph or it can be exported as raw data. Additionally, software can project build and maintenance costs through 50 years of use.

4. CONCLUSIONS

In the past decades the context of engineering education has changed dramatically. Because of the complexity of concepts, engineering education courses are suitable courses for using computer simulation techniques as pedagogical tools. Comparing the traditional teaching mode with teaching mode based on simulation technology can compensate for the limitations of the traditional mode and consequently improve teaching quality.

In this paper application of an educational tools Energy2D and Energy3D in technical education is analyzed. The most important advantages of these computer simulation in education are interactive feature, fostering students' visualization, and enhancing their problem-solving process. It is suggested that computer simulation in education cannot be considered as a stand-alone pedagogical resource since they cannot replace conventional classroom instructions, but it can make learning and understanding for students a whole lot easier and quicker.

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