

Simulation by Design: A Parametric Design Tool for Zero Energy Buildings

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Abstract

To address the shortcomings of integrating building simulation in architectural design and to make it more appealing to students, a simple interface to Energyplus was created. This interface models a simple rectangular building that is passively heated by direct gain and cooled by ventilation. A simple photovoltaic interface has also been added to supply fan energy. This tool has an OpenGL modeler for visualization and uses Energyplus for calculations. The interface will run a full year simulation and graph the results. The results are reported in a yearly graph that shows the outdoor and indoor temperature. The indoor temperature range is based on adaptive comfort level. The interface was tested and used in an introductory design studio in order to comply with the 2010 imperative. The students simulated a simple box and changed the buildings parameters until the building fell within the adaptive comfort zone for most of the year. The climate simulated was Chicago, IL. Using these parameters the students then designed the building. The resulting designs show that even though the students were restricted in parameters, such as window percentage, they were still able to creatively design unique buildings that use zero to negative net energy for heating and cooling in a climate such as Chicago.

Introduction

The 2010 Imperative states: "To successfully impact global warming and world resource depletion, it is imperative that ecological literacy become a central tenet of design education. Yet today, the interdependent relationship between ecology and design is virtually absent in many professional curricula. To meet the immediate and future challenges facing our professions, a major transformation of the academic design community must begin today. To accomplish this, The 2010 Imperative calls upon this community to adopt the following: Beginning in 2007, add to all design studio problems that: "the design engage the environment in a way that dramatically reduces or eliminates the need for fossil fuel.'" How does the "2010 Imperative" fit into an introductory design studio where the students have limited knowledge of building materials and have not yet taken an environmental control systems class? A new simulation tool was developed to allow students in the second of a five year accredited Architecture college to explore energy use in buildings at the very beginning of the design process. This type of building simulation software will have an impact on the built environment.

The Problem

Architecture students who want to design sustainable, green and energy efficient buildings frequently find it difficult or too time consuming to use and learn building simulation software. Therefore, building simulation software should be designed in a way that makes it easy to use in the early stages of a building design. This early design phase is the time when the greatest impact can be made on the energy use of the building. (Grau and Wittchen, 1999) A tool that helps make crucial decisions at the very beginning of the process would then have the greatest impact.

An energy simulation tool, SolarShoeBox, was developed to help students discover parameters that would achieve a zero energy building that is comfortable before they started their design. The interface for SolarShoeBox was built on the following guidelines.

1. Very little information about the building will be needed in order to use the program and get results. This will allow the designer to explore different ideas and configurations of building elements that helps to actually use the software to design.
2. All information (both input and output) is presented in a single view. Nothing is hidden from the user so they can see all of the variables.
3. The manipulation of the data can be explained in a few sentences. The user can master the program in minutes without using a manual or needing any special training just to use the program.
3. The input of data can be done with a mouse. This helps to put parameters on the input data. The program can put reasonable limits on the properties of materials, freeing the user from having to know what values to enter.
4. The calculations and output should happen automatically and almost instantaneously. This gives the user feedback so they feel free to explore and get a sense of what design changes have the greatest impact.
5. The program should already contain data when the program is opened so the user knows what to expect in terms of input and output. This gives the user an example of how the program works when they first open the program.

SolarShoebox

SolarShoeBox models a simple direct gain passive solar building. A direct gain passive solar building uses only the energy supplied from the sun to achieve thermal comfort for the occupants of the building. The architect of the building will need to use their knowledge of the climate where the building will sit and their knowledge of the yearly movement of the sun to manipulate the fabric of the building in order to maintain a comfortable interior environment for the occupants. One can think of the building fabric as a filter between the outside climate and the inside thermal environment. The architect using SolarShoeBox can manipulate the filter by changing the quantity and characteristics of these architectural components and strategies; Building Orientation, Building Form, Building Thermal Conduction, Solar radiation Collection, Solar Radiation Control, Heat Storage/Distribution and Controlled Porosity, in order to

make the interior thermal environment as comfortable as possible for a given climate without using any fossil fuels.

This tool has an OpenGL modeler and uses Energyplus for calculations. Energyplus is a new generation energy simulation program developed by the U. S. Department of Energy and has been validated. Optimization in SolarShoeBox is based on indoor comfort levels and not on fuel usage, since no energy will be used to heat the interior. On the graph below, January 1 is on the left and December 31 is on the right. The top is 1 AM and the bottom is Midnight. The Top graph shows the outside temperature and the bottom graph shows in inside temperature. The color blue represents temperatures less than the set comfort zone temperature and the color red represents temperatures higher than the comfort zone. The color green represents temperatures in the comfort zone. The goal is to make the inside temperature graph turn completely green.

Using SolarShoeBox

Seven main parameters can be changed when using SolarShoeBox. Figure 1. These parameters can be changed in steps with intermediate simulation runs by Energyplus. It takes approximately 6 seconds for Energyplus to calculate the results and to refresh the graph, allowing many iterations to be done very quickly. All of these steps can be performed before the design process begins and should be the basis for the building design.

Basic Steps to design a comfortable solar building with SolarShoeBox

Choose a weather file and Run Energyplus . The weather file is selected by a pull down menu. The menu list all EPW files available in the Energyplus weather file on the users hard drive. This step is needed for Energyplus to run and it sets the latitude for sun shading design. To download more weather files available from the Internet click on the Weather button. The web site that opens in your browser has weather files for 1042 locations in the USA, 71 locations in Canada, and more than 1000

locations in 100 other countries throughout the world. Download the EPW file by left clicking.

Adjust the season start sliders based on outside temperature patterns. Most climates will have a cold, cool to hot transition, hot and hot to cool transition season.

Energyplus can be run at anytime during the following steps. The steps can be done in any order but this sequence first.

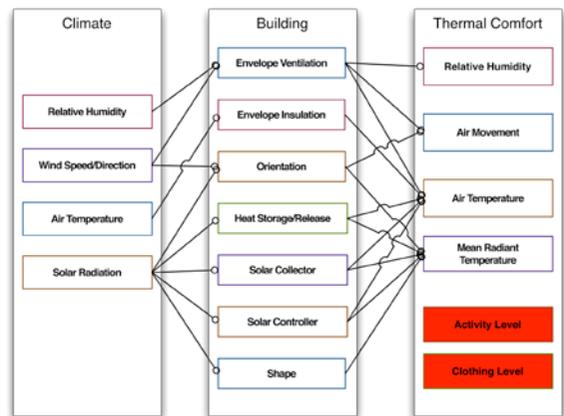


Figure 1. Seven parameters that can be changed to create a comfortable indoor environment.

Adjust Building Orientation. The building can be rotated 45° East and West from North by using the rotation slider. General Rule: 0° from South is best for optimum solar gain through south facing window and easy shading control.

Adjust Building Geometry (Height, Length and Width). The building height, length and depth are changed using sliders. As the sliders move the OpenGL modeler is updated in real time. The model can be zoomed in and out using the mouse wheel and rotated by click dragging. General Rule: Buildings elongated towards east/west will allow more southern exposure, allowing more solar gain and higher indoor temperatures.

Turn off all shading.

Adjust hot season ventilation until hot season comfort chart is mostly green.

Adjust Insulation levels and South facing window (Percentage, Type) until average cold season temperature is about 20 °C or 68 °F. The insulation value is chosen for the envelope. This differs from most energy simulation programs because it reverses the decision order. Instead of choosing a wall type and figuring out the insulation level, the designer discovers what the required R-value should be and then designs a wall to that specification. General Rule: Higher insulation values will raise indoor temperature levels. Window orientation, type and area as percent of wall area can be changed using sliders and pull down menus. General Rule: Larger south facing windows will increase indoor temperature levels.

Adjust the amount of mass (Thickness and Surface Area) to decrease the indoor diurnal temperature swings during the cold season. Mass type, area and thickness are manipulated to decrease the indoor temperature swings. The internal mass modeled has both sides exposed so a thickness of 12 inches or 30 cm will act like a mass of half that thickness or 6 inches and 15 cm. General Rule: Mass area of 11 times the south window area and mass thickness of less than 6 inches or 15 cm are good starting points.

Turn on south shading and adjust length until one of the transition seasons is mostly green without decreasing cold season comfort levels. Horizontal shading devices can be added to any wall. A slider changes the length of the shading device. Shadows are cast based on the

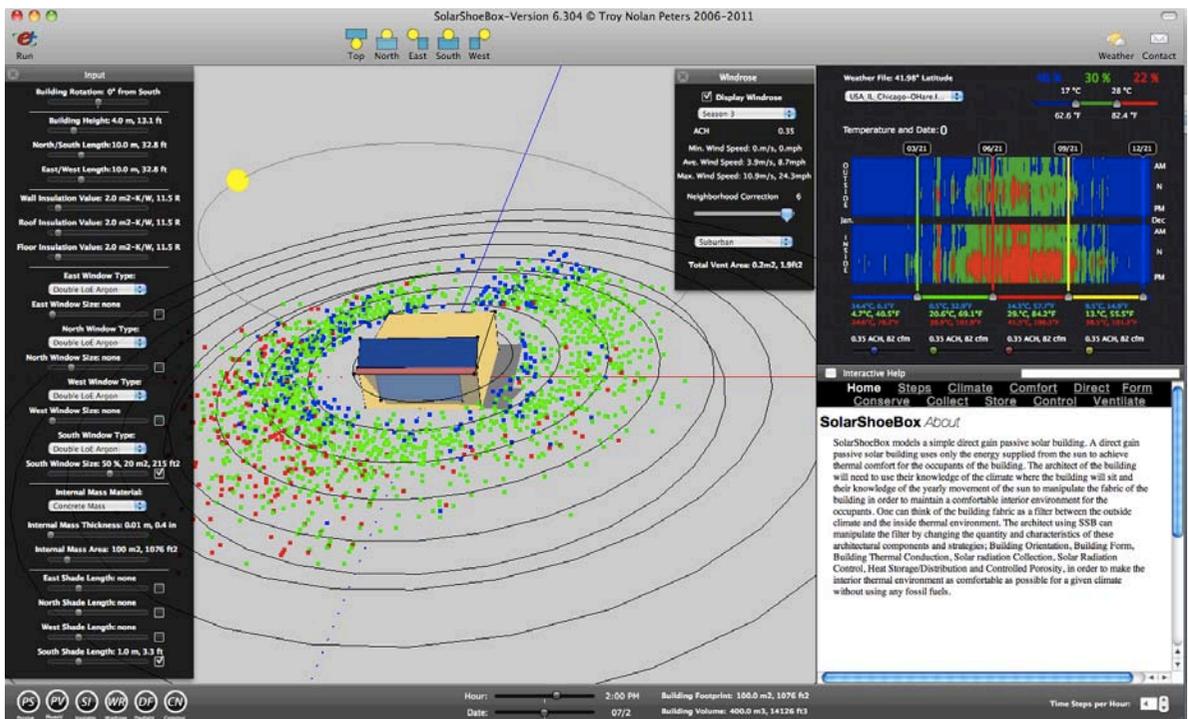
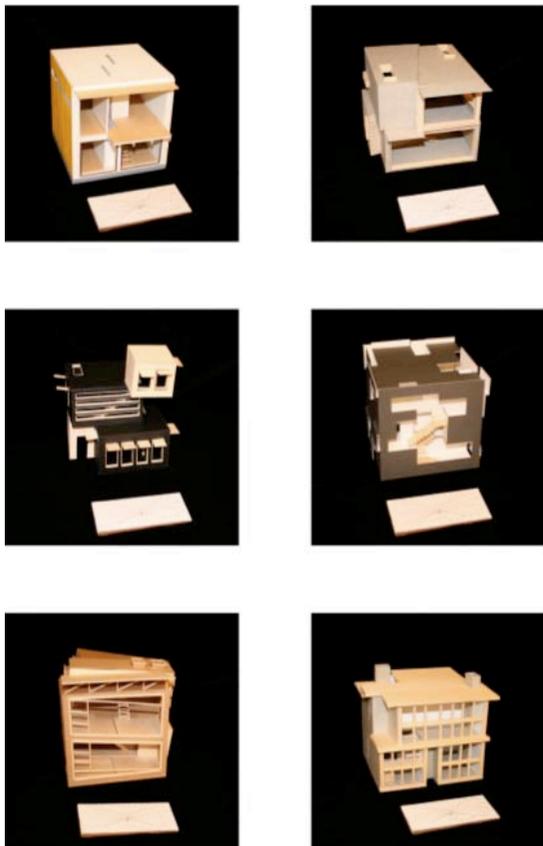


Figure 2. SolarShoeBox interface.

latitude, date and time. The date and time can be changed to visually decide how long to make the shading device. General Rule: Adjust shading to create comfort during the transition seasons.

Adjust ventilation levels for transition seasons until indoor temperatures are in the comfort zone. Each season can have a different ventilation rate. A minimum ventilation rate of .35 air changes per hour should be kept to meet indoor air quality standards. Thermal comfort in the summer is usually achieved by raising the ventilation rate. The ventilation rate is controlled by an electric fan, which is powered by photovoltaic panels on the roof.

Figure 3. Examples of Student Work



Go back and fine-tune settings until the indoor comfort chart is mostly green. The building parameters can now be used to begin designing a non-shoebox direct gain passive solar building.

When the comfort level is achieved for entire year the student can then export the model to another design program and really start the design process. They will be able to refine the building shape, design the wall components, window patterns and shading devices. They still need to figure out internal mass placement and roof design for integrating the photovoltaic panels. They will be able to concentrate on design instead of how to make the building more efficient, since they know it is already a

comfortable building that uses zero net energy. The model can be carried through the whole design process. The SolarShoeBox model can be opened in Sketchup and used with the plugin OpenStudio + Energyplus, the Sketchup model can be used in Revit + Ecotect + Green Building Studio so nothing is lost. This helps the student refine the building while always having access to an Energy Simulation tool.

Example Building

The students in the first studio of their second year at a five- year school of Architecture were asked to design a cube shaped building. The dimensions of the building were 24 feet on each side and would be a place for two people. The building had to have views in each direction. The location was Chicago and it had to be comfortable for the entire year without using any fossil fuels for heating and cooling. They started by modeling the building in SolarShoeBox and extracting the particular specifications for the amount of glazing, the insulation values, shading devices and internal mass. The wall R-value called for a R-70 wall which when designed was approximately 24" thick. The internal mass was placed as a floor slab with the remainder used as internal walls. The Southern glazing was 70%, West 3%, East 5% and North 10%. The

students then started to design their buildings using the given solar specifications much as one uses the site to constrain views and shape of the building.

Lessons Learned

SolarShoeBox makes energy analysis part of the process, not an after thought or additional step. Since the initial energy analysis was performed before the building was designed, the students had a better understanding of the building components that must go into a zero energy building. A simple design tool used early in the design process can have a greater impact on the final energy use of a building than a complex tool used at the middle of the design process. . The student should use this information similarly to using the information of how big a column must be to hold up a building; the combination of components given by SolarShoeBox are necessary for their building to be comfortable while using no fossil fuels. It is also important for the student to imagine, for example, that a window that takes up 50% of the area of a wall does not have to be a single window, but can be many windows arranged in an infinite number of ways. Using the column analogy, a thin steel pipe or a heavy timber post might perform in a similar way but are aesthetically and sensorially very different. As building simulation becomes more sophisticated, it can also become more user friendly. When this merger of sophistication and ease of use takes place, more designers will be willing to use building simulation tools at the beginning of the design process.

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