RECENT PROGRESS IN NON RESIDENTIAL BUILDING ENERGY SIMULATION SOFTWARE

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Abstract – In the last period, much educational, free or commercial building energy simulation software was released. This paper makes a general analysis of recent progress made in the building energy simulation software field. The analysis has a practical approach by taking into consideration all the information and methods used by the analysed programs to simulate the energetic processes which take place in a building. This analysis is oriented on programs which are specialized on simulating energetic processes in non-residential buildings, like office buildings, public administration buildings, industrial buildings etc. The energetic processes in these buildings are extremely complex and that is the reason why the creation of the correct model is a great challenge. In order to detect eventual errors in the result we need to understand very well the energetic processes which we need to simulate and also the physical and mathematical model of our simulation.

Keywords: building, energy, simulation, software, analysis

1. INTRODUCTION

Nowadays, newly built constructions have to satisfy more demands than ever before, pushing engineers and architects to achieve building excellence. These demands are further passed to the materials used in the building process. Starting with increased resistance demands, because we want to build bigger volumes with less material, continuing with, aesthetic demands because we want our new constructions to look spectacular, with low costs demands because in the current international financial context financial resources are limited and finally getting to environmental demands, because we aim to build constructions which during their life-cycle, use low energy to be operated and generate low carbon quantities, which generate low quantities of waste materials. Beside this, during the construction process, the waste materials generated must be as low as possible.

So, we see that the society is demanding from engineers, architects and researchers excellent efficiency, putting a high responsibility on their shoulders. In the current climatic changing environment, the responsibility becomes greater.

Can this efficiency be achieved? Which are the tools at hand, for the three mentioned professional categories, responsible for innovation in the building industry?

As we have seen, in the past decades the building industry showed a dynamic growth of quality and efficiency due to introduction on the market of new materials. These materials are the result of many years of research and testing done by universities and private laboratories. So we see that investing in research has brought the construction materials industry, big steps forward, helping new and old constructions respond to the increasing demands of our society.

Along with the fast progress of the information technology, the building industry also knew a fast growth. Information Technology provides architects, engineers and researchers with useful tools (computer programs, computing power, sensors, measurement devices etc.) which are constantly being improved to be faster, more accurate, more "visual" and easier to understand. These attributes help the user get to a touchable result much faster than ever before. Of course that the results got from a computer verified model must be compared, before applying it in practice, with the results got from an experimental model, but let's think about how many experimental models researchers would have to build before obtaining reliable results if those model couldn't be computer simulated, previously. This possibility saves a lot resources and time, and helps researchers know which model is closer to verify their theory.

Our article aims to make a comprehensive description of the latest software tools available on the market (academic and commercial use), by comparing their approach towards the building energy systems modelling and simulation.

2. BASIC APPROACH OF ACTUAL COMPUTER PROGRAMS TOWARDS THE BUILDING ENERGY SYSTEMS MODELLING AND SIMULATION

In the last years, hundreds of computer programs were developed to help simulate energetic (controlled and uncontrolled) processes which occur inside a building or during the interaction of o building with the external environment. Some of the programs are focused on one component of the energetic system (doors, windows, HVAC Systems etc.) while others are focused on the whole energetic system. Behind any program are a series of algorithms which require input data in order to solve a problem and give results. The same principle is used in our case also. The inputs are used by the program to calculate the loads on the building and the total energy consumption, which after being processed give results.

Usually, two values are calculated for a building: annual energy use and peak design energy. Annual energy calculations determine the energy consumed over a one year period, often by calculating energy at time steps such as one hour intervals. Peak energy calculations determine the maximum energy that will be used by the building at any time, usually at the coldest winter heating day and warmest or most humid summer cooling day. Peak calculations are used for sizing mechanical equipment, while annual energy calculations are more often used for determining appropriate energy efficiency measures in the design of a low energy building.

2.1 Peak Energy Demand Estimation

Peak demand is important because electricity networks require spare capacity to accommodate extremely high power usage, which typically occurs only for a few hours, a few times a year, typically on hot summer days. The research shows there is potential to reduce some of this large spending through energy efficiency and demand management.

In order to accurately estimate the peak energy demand, a particular case study must be made for every analysed building because of a very important factor, which is occupant behaviour.

The energy used in a building can vary greatly depending on the behaviour of its occupants. The acceptance of what is considered comfortable varies widely. Studies of identical homes in the United States have shown dramatic differences in energy use, with some homes using more than twice the energy of others. Occupant behaviour can vary from differences in setting and programming thermostats, varying levels of illumination and hot water, and the amount of miscellaneous electric devices or plug loads used. (1)

2.2 Annual Energy Performance Estimation

There are a number of different ways of estimating annual energy performance. Most simulation programs employ a time step of one hour (smaller time steps give better accuracy but increase computation time). The heat transfer load acting on the space is calculated at each time step, and the total system energy required to meet the load is calculated at each time step. The load calculation is complicated by thermal storage effects; heat may be stored in building components, known as

"Thermal mass", and released at later times. For example a concrete wall exposed to solar radiation during the day will store heat and release heat to the space at night when the sun sets.

The following graph will present the important factors which have to be considered, when calculating Annual Energy Consumption.

Below, we will describe the items found in the graph above.

A thermal area is a segment of a building with similar thermal requirements serviced by the same mechanical equipment and controls. The number of thermal zones will vary depending on many factors including the building use, size, and shape. For example,
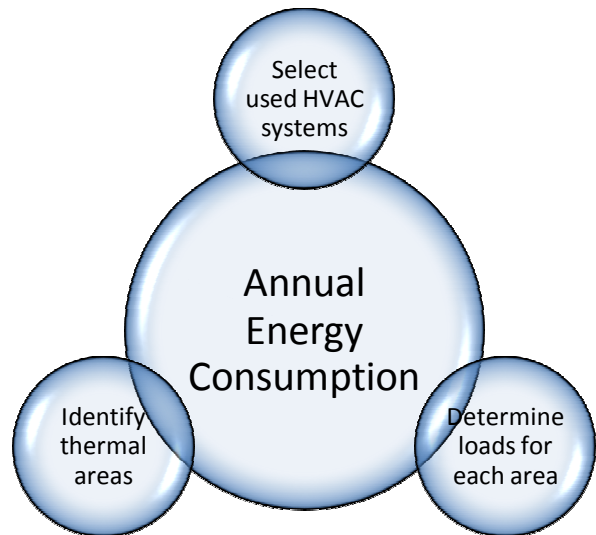

Figure 1 - Annual Energy Consumption factors scheme

a single family house or free-standing branch bank may have only one or two zones while a large office building may have over one hundred.

The thermal load is the required, hourly rate of heat removal in summer (or heat supply in winter) necessary to keep a building comfortable. In step two, the annual, peak hourly heating and cooling loads for each zone must be calculated.

Based on the peak loads calculated in step two, size and select building mechanical equipment. For comprehensive simulations of multi-zone structures, thermal interactions between zones must be taken into account (such as the mixing that occurs in water-loop heat pump systems).

3. USED METHODS IN ENERGY ESTIMATION AND SIMULATION

The first step in calculating building energy consumption is to determine the loads on the building. Loads are instantaneous heat gains or losses that occur by conduction, convection, and radiation. Heat transfer acting on a building at any instant in time is simple to calculate based on heat transfer physics. However, load calculations are complicated by thermal storage effects. Though a building experiences a certain heating or cooling load at any given time, energy is stored and released by thermal mass in the building, creating a time delay on the load experienced by the heating, ventilating and air conditioning (HVAC) system. Most energy modeling programs employ similar methods of calculating instantaneous loads but differ in how they account for thermal mass time delay effects.

Energy simulation tools predict the energy performance of a given building and the thermal comfort for its occupants. Such tools support the understanding of how a given building should perform under certain criteria and provide a means to compare different building design alternatives. All competing energy simulation tools have limitations, thus it is necessary to understand the

basic principles of energy simulation. Simulating a building's energy usage is a difficult task, requiring not only a model of the building's geometry, its components (such as insulation, windows, foundation, walls and HVAC systems), but also detailed and accurate environmental data. Environmental data includes weather conditions within the proximity of the relevant building, humidity, wind speed and external temperatures over various time periods. In addition, data supporting the building's internal electricity load (lighting devices, electronic equipment, and occupant electricity demands), heating and cooling loads are also required.

Building loads can be described as being part of the following categories:
- Conduction Through the Enclosure
- Infiltration
- Solar Heat Gain
- Internal Heat Gains
- Ventilation (natural or mechanical)

Around the world different professional associations adopted different methods when taking into account the thermal mass of the building

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, 2007) has identified two primary methods of accounting for thermal mass in a building, the Heat Balance method (HB) and the Radiant Time Series method (RTS).

Figure 2 - Schematic of the heat balance method (ASHRAE 2007)

There are also a number of older, less accurate methods that are no longer recommended, but still used by some modelling programs, including the bin method and the transfer function method. The HB method is the most direct and accurate method of calculating heating and cooling loads, though it is complex and computationally intensive. In this method, a set of energy balance equations are created and solved for each surface in a building. Figure 2-1 shows a schematic of the components for the heat balance of each surface. The HB method is described in detail in ASHRAE Fundamentals 2007. The programs EnergyPlus and ESP-r use the HB method.

The thermal network method (Deru 2002; McQuiston 2005) is a variation of the heat balance method where the building is divided into thermal zones, modeled as a series of nodes. Each zone represents a space in the building that operates on the same indoor temperature control. Zones experience heat transfer between the outdoors (and ground), the sun, and each other. At each time step, the thermal network method collects all energy flows from each zone air node to zone elements and calculates the new zone air temperatures. Thermal network models can be more complicated and computationally intensive than HB models. The program SUNREL uses a thermal network model.

The RTS method is simpler and less computationally intensive than the HB method, though not as accurate. Figure 3 shows an overview of the RTS method. This method assumes that convection heat transfer affects the load instantaneously, while conduction and radiation heat transfer has a time delay. Each heat transfer mechanism acting on the space is separated into conduction, convection and radiation components. Weighting factors are then applied to the conduction and radiation components to account for time delays. Weighting factors are derived from the HB method and represent portions of past heat gains that impact the load for the current hour. The values of the weighting factors depend on the amount of thermal mass in the building construction.

(2). This method is used by the program TRNSYS.

The Transfer Function (TF) method (ASHRAE 2007) is an earlier version of the RTS method that is still used in common energy modeling software programs. This method applies weighting factors directly to all conduction and radiation loads without splitting loads into radiation and convection components. This method is very simple to apply and still accurate for annual energy calculations, though it is not accurate for peak or hourly load calculations. The program DOE-2 uses the TF method.

The bin method (McQuiston 2005) is a very simple method of estimating annual building energy consumption. Weather data for a location is given in -15° (5°F or 258.15 kelvin) intervals or "bins", with the number of hours of occurrence of each bin. It is assumed that the building uses the same amount of energy for 12 each outdoor temperature bin. A load profile is developed to determine the building energy consumption for each bin. The bin method does not include hourly thermal mass effects. The program HOT2000 uses the bin method.

BES: Building Energy Simulation

Because BES and FEM have quite different approaches the methodology of this research is very important: Step 1, start with a simple reference case
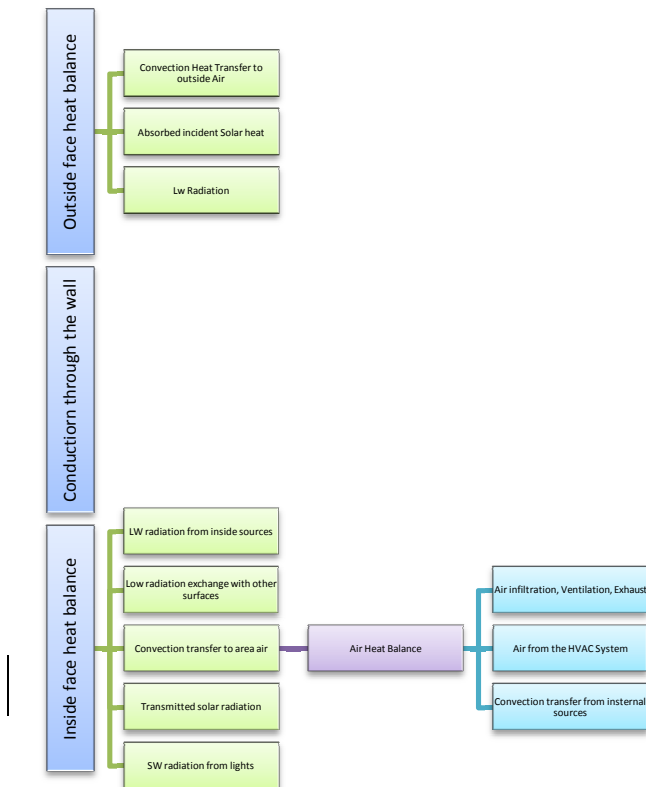
where both BES and FEM tools provide identical results. Step 2, add complexity and simulate the effects with both tools. Step 3, compare and evaluate the results. The paper is organized as follows: Section 2 provides an introduction to BES modeling. Section 3 presents the methodology and preliminary results on BES using Comsol.
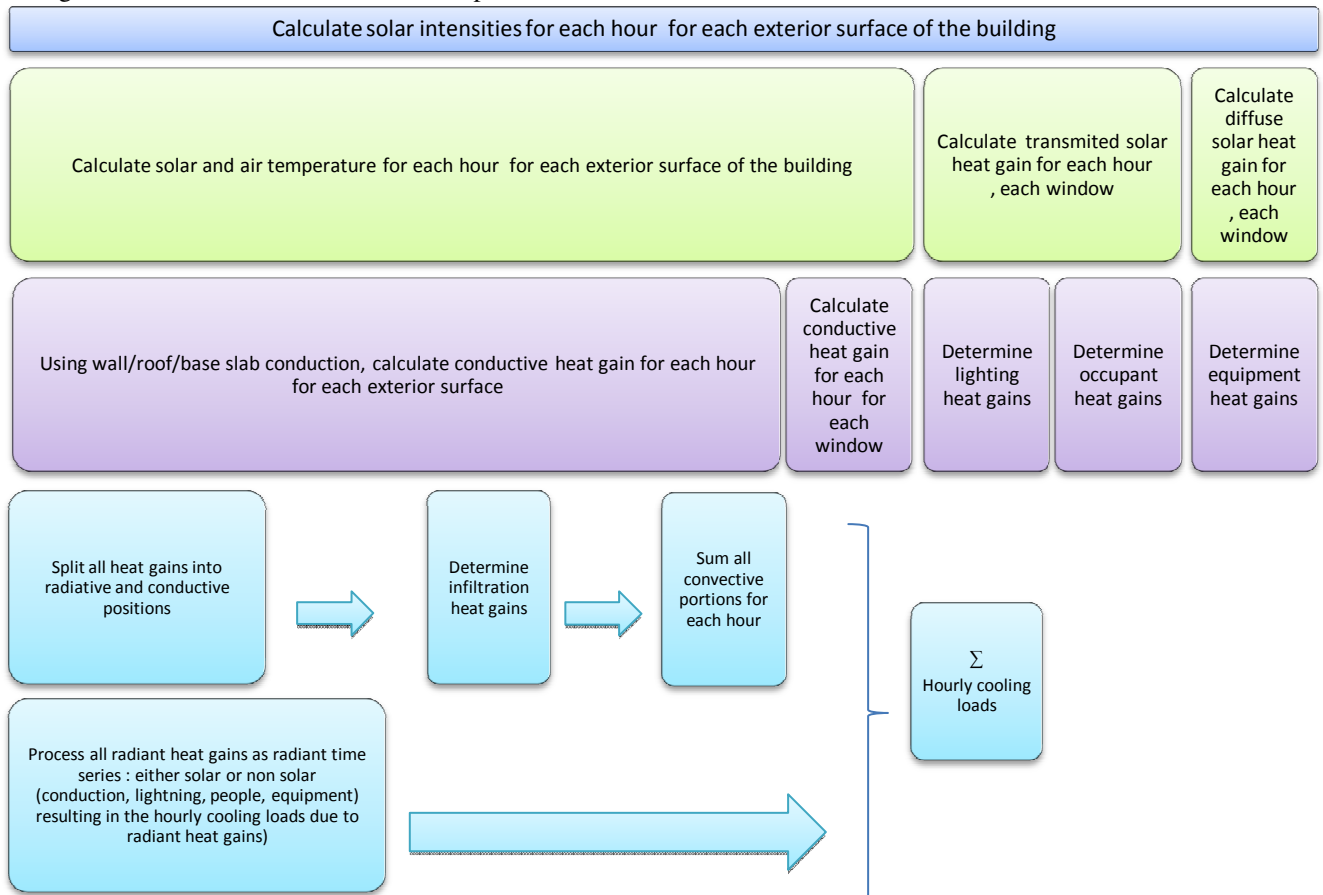
Calculate solar intensities for each hour for each exterior surface of the building

Calculate solar and air temperature for each hour for each exterior surface of the building

Calculate transmited solar heat gain for each hour , each window

Calculate diffuse solar heat gain for each hour , each window

Using wall/roof/base slab conduction, calculate conductive heat gain for each hour for each exterior surface

Calculate conductive heat gain for each hour for each window

Determine lighting heat gains

Determine occupant heat gains

Determine equipment heat gains

Split all heat gains into radiative and conductive positions

Determine infiltration heat gains

Sum all convective portions for each hour

Σ Hourly cooling loads

Process all radiant heat gains as radiant time series : either solar or non solar (conduction, lightning, people, equipment) resulting in the hourly cooling loads due to radiant heat gains)

Figure 3 Outline of the Radiant Time Series method (ASHRAE 2007)

The website the of U.S. Department of energy (Energy.gov 2012) provides information on about 300 building software tools from over 40 countries for evaluating energy efficiency, renewable energy, and sustainability in buildings. Commonly used within these tools are: Zonal approaches of the volumes, assuming uniform temperatures in each zone and 1D modeling of the walls.

The earliest developments of HAMBase originate from 1988, by prof. Martin H. de Wit. Since 1995, this thermal-hygric model, has become available in MatLab. A short summary of the HAMBase model is presented below, further details can be found in (HAMLab 2012).

The HAMBase model uses an integrated sphere approach. It reduces the radiant temperatures to only one node. This has the advantage that also complicated geometries can easily be modeled
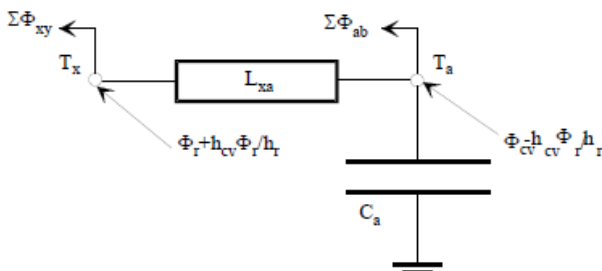

Figure 4 - The room model as a thermal network

Ta is the air temperature and Tx is a combination of air and radiant temperature. Tx is needed to calculate transmission heat losses with a combined surface coefficient. hr and hcv are the surface weighted mean surface heat transfer coefficients for convection and radiation. Φr and Φcv are respectively the radiant and convective part of the total heat input consisting of heating Excerpt from the Proceedings of the 2012 COMSOL Conference in Milan or cooling, casual gains and solar gains.[*] For each heat source a convection factor can be given. For air heating the factor is 1 and for radiators 0.5. The factor for solar radiation depends on the window system and the amount of radiation falling on furniture. Ca is the heat capacity of the air.

4. BUILDING ENERGETIC PROCESSES SIMULATION SOFTWARE

The development of Energy Simulation Models through the implementation of the BIM (Building Information Model) will allow facility managers and maintenance crews to monitor and evaluate energy systems operating in buildings, in order to optimize energy consumption and provide building performance data. Current energy simulation models are static and do not account for dynamic changes in building

characteristics including occupancy and the building's external environmental conditions.

Building geometry comprises of the basic building input for energy simulation which is created by CAD tools. There are differences between building models created by architects and the building models required for energy simulation. One of the main differences is the use of the entity space by architects and the use of the entity boundary in energy simulation models. Architectural spaces, for example, rooms, are divided by walls. In energy simulation models, such spaces are referred to as thermal spaces and are defined by space boundaries. The combination or division of architectural spaces is based on the thermal perspective and the design and layout of the HVAC systems.

Energy simulation modeling of HVAC systems is accommodated significantly by all energy simulation tools. However, HVAC systems can be modeled to reflect the actual system if the energy simulation tool provides enough flexibility. To define a realistic representation of a real HVAC system within a building structure can be challenging. The HVAC operating schedule is a key input for energy simulations of this nature. Operating schedules define the behavior of HVAC components, such as peak or off-peak time periods, for all of the HVAC systems.

Weather conditions are extremely important for energy simulation models. The weather data format includes basic location information; name, state/province/region/country, latitude, longitude, time zone, elevation, peak hot and cold temperatures. In addition, daylight savings, average and extreme temperature periods are also included as input data. The collected weather data are not used to reflect weather conditions for a specific year, but rather to provide statistical references for typical weather parameters for a specific location.

Internal loads, such as energy consumed by occupants, lighting devices and electronic devices depend on the actual usage of a relevant space within a building and the behavior of its occupants. Assumptions have to be made about the quantity of internal loads in a given space within a building for energy simulations.

All of the above mentioned parameters provide basic input data for energy simulation. Energy simulation is enhanced by including additional input parameters that become more relevant to specific phases of a building's lifecycle. In addition, different types of simulation engines will also influence a building's energy simulation results.

4.1 IES

The Integrated Environmental Solution Virtual Environment (IES<VE>) performance analysis software suite allows architects and engineers to facilitate a sustainable design process by offering quantitative feedback on the environmental performance of different design options. On average, green buildings use 30% less energy than conventional buildings, although through the use of IES software the potential is much higher. It is a robust energy analysis tool that offers a high degree of accuracy and interoperability (3) with the BIM model. The drawbacks are its current complexity for the user and the relatively expensive cost of the tool suite. Below are few of the latest version features:

- Numerous customizable pre-defined systems and equipment options in HVAC library
- Components based modeling affords exceptional flexibility and controls modeling
- Pre-define conventional and advanced systems can be modified to match design
- Supports interaction with thermal models for natural ventilation, DSF, labyrinths, UFAD, etc.
- Multiple systems, models, and VE modules can interact within a single thermal zone.
- Increasingly user-friendly system setup, sizing, and customization
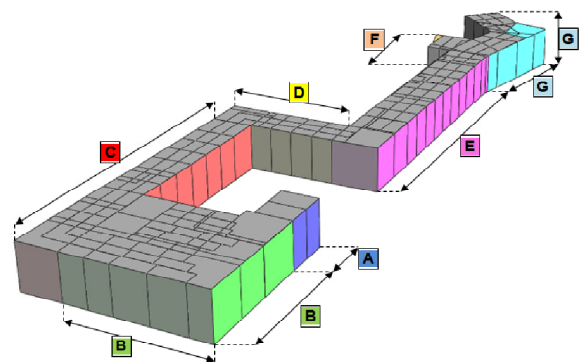- System loads/sizing reports and detailed results analysis options

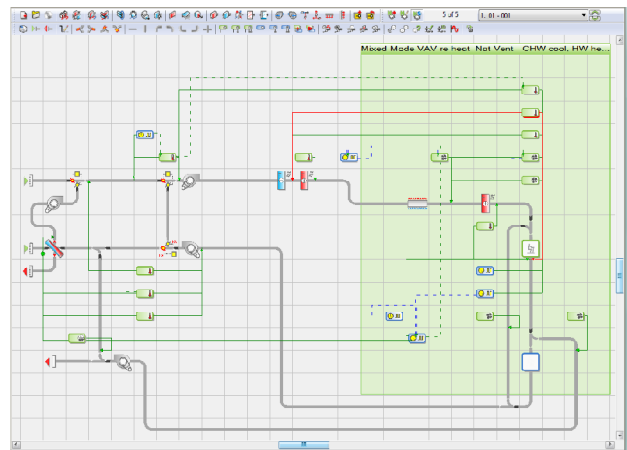**Figure 5 - IES VE - Simulation software**

Figure 6 IES VE - Simulation software interface (3)

4.2 EnergyPlus

EnergyPlus is a modularly structured software tool based on the previous capabilities of BLAST and DOS-2.1E. It is a simulation engine, which uses text files for input and output. It was developed to provide an integrated simulation for accurate temperature and comfort prediction. It calculates heating, cooling, plant and electrical system response, with a variable time step. It allows users to evaluate realistic system controls, moisture absorption and desorption in building elements, radiant heating and cooling systems, and inter-zone air flow. A day lighting module calculates daylight

luminance and glare, and calculates electric lighting reduction for the heat simulation tool. EnergyPlus is open source software, and since its launch in 2001 it has become the most used simulation tool. However it has a poor user interface which is difficult to use and demands specialist knowledge to interpret results. DesignBuilder and IDF Generator are a comprehensive user interface for the EnergyPlus dynamic thermal simulation engine.

Tab. 1 shows the major functionalities between IES and EnergyPlus. IES is older than EnergyPlus and it is a commercial product supporting standard graphical user interfaces and standalone weather file formats. IES and EnergyPlus both support 3-D geometry input and can interconnect with other tools. Although EnergyPlus includes a variety of links to other simulation engines (COMIS, SPARK), several limitations apply to the usage of these links.
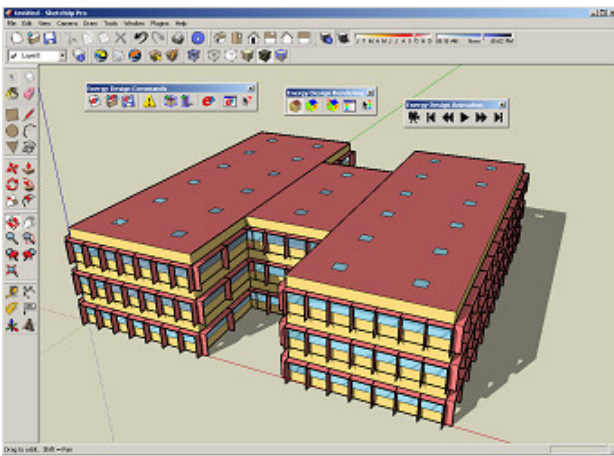

Figure 7 - EnergyPlus Sketchup plugin

4.3 TRNSYS

TRNSYS (pronounced 'tran–sis') is an extremely flexible software tool used to simulate the performance of transient systems. Although most often the systems that we investigate are focused on energy, TRNSYS can equally well be used to model other dynamic systems such as traffic flow, or biological processes.
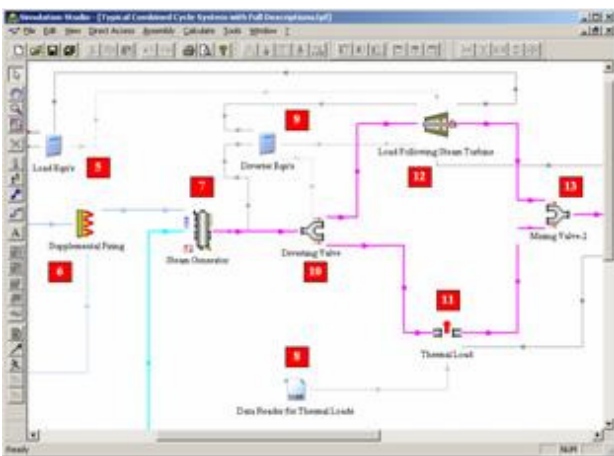

Figure 8 - TRNSYS Graphical Input Interface

Engine and Interface:

At its heart, TRNSYS is a robust algebraic and differential equation solver that is able to read and process a text based input file. On top of this solution engine is stacked an impressive library of components that model everything from simple pumps to detailed multi-zone building; in short a component is anything whose outputs can be represented as a mathematical function of inputs (time-dependent values) and parameters (time independent values). TRNSYS is also endowed with a powerful graphical front end that makes the user's job of assembling a detailed system simulation from component parts a simple endeavor – similar in nature to hooking up the pipes and wires in a real system.

Online Results:

In addition to its flexibility, TRNSYS is also a very transparent tool. Users can watch the value of ANY system variable on an online plot as the simulation progresses (any temperature, flow rate, heat transfer etc.). Output devices also allow the user great flexibility in integrating, printing, and reporting all component variables as well.

Components:

Because the structure of all components is the same, and because TRNSYS is distributed with its source code, users can and often do develop their own models, expanding the capabilities of the program to suit their needs. We have made heavy use of this feature in our consulting efforts and have written well over 500 components, many of which are cleaned up, fully documented, and are distributed in a series of 13 component libraries for TRNSYS.

TRNSYS, while a very complex and vast simulation tool, is equipped with a feature that allows users to develop customized graphical interfaces for specific applications. Using this TRNSED feature, the TRNSYS user can create a web-page like interface that allows non-TRNSYS users to change system parameters, run simulations, and process output without having to learn the intricacies of the TRNSYS program. (4)

4.4 Comsol MultiPhisics

In order to predict, improve and meet a certain set of performance requirements related to the indoor climate of buildings and the associated energy demand, building energy simulation (BES) tools are indispensable. Due to the rapid development of FEM software and the Multiphysics approaches, it should possible to build and simulate full 3D models of buildings regarding the energy demand. The paper presents a methodology for performing building energy simulation with COMSOL. The method was applied to an international test box experiment. The results showed an almost perfect agreement between the used BES model and COMSOL. These preliminary results confirm the great opportunities to use FEM related software for building energy performance simulation.

Methodology: The methodology was as follows:

Step 1, start with a simple reference case where both BES and FEM tools provide identical results. Step 2, add complexity and simulate the effects with both tools. Step 3, compare and evaluate the results.
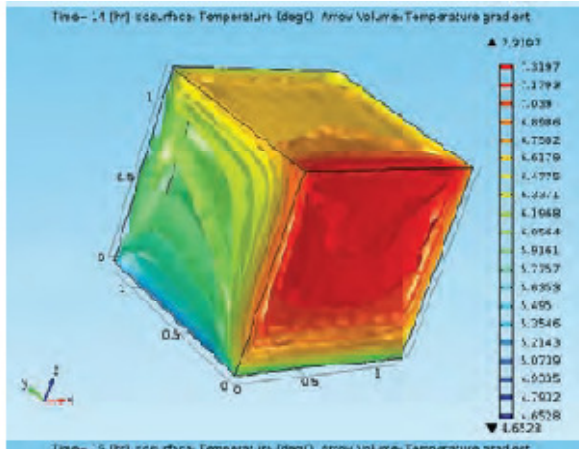
Figure 9 - Comsol Multiphisics

5. CONCLUSION

Non-residential buildings are, in general, big volume constructions, which require special attention from the conventional energetic point of view. This means that correct decisions have to be made by the design team starting from the early stages of the project (predesign phase). Unfortunately, at this point, little information is available. This is the reason why many assumptions are made. The computer software industry provides architects, engineers and researchers better tools which help get detailed answers to questions from the future. The breakthrough in the computer modelled building energy simulation field is the ability to create and use more accurate mathematical and physical models, get more accurate results faster than ever, thanks to the FEM (Finite Element Method) which is implemented in many of the latest building energy simulation software. The FEM can be used to simulate large scale models, as small scale models, respecting the accuracy of the input data. The FEM implemented computer software requires good computing power, which nowadays is available. It remains to be seen what new features the future generation of building energy simulation software will bring.

For the future

It is now widely accepted by the leading building performance simulation groups in Europe and North America that the best way to proceed is to develop a flexible model construction system, which can then be used to build and test future modelling systems. Only in this way can we escape from the inflexibility of monolithic, single structure programs, and move instead towards an object oriented approach to model construction which encourages task sharing. To this end an international research project has been formulated. The intention is to develop a Kernel system comprised of three distinct elements as follows. (5)

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