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Software tools for HVAC research

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ABSTRACT

Energy saving methods can be employed to reduce energy consumption in buildings, or improve indoor thermal conditions. An example of those methods is the use of permeable coverings, but there are other important parameters like thermal inertia. To understand and predict these energy saving procedures, one may employ different software resources. In the present paper a review of existing software resources is carried out, and, as a consequence of this review, HAM tools were selected to simulate the indoor environment of school buildings. Results show that parameters like thermal inertia can interfere in the solar heat gains, changing the building time constant. Other parameters, like air changes per hour or the use of permeable coverings, present a clear enhancement of indoor environment conditions.

1. Introduction

In Spanish public buildings there is a high energy consumption due to air conditioning during the winter season, but during the spring the heating system is employed only if indoor conditions are under certain temperature and relative humidity values. In this sense, some energy saving methods could be employed to reduce energy consumption or, in some cases, even substitute the heating systems. An example of those methods is the use of permeable coverings, but there are other important parameters like thermal inertia.

An easy way to solve the energy equations related to a given building environment is to use a building energy simulation tool. These are computer programs that can simulate a building and its HVAC system. They can predict results such as the heating and cooling loads of a building, as well as the indoor thermal climate of a space [1]. Before the software package can accurately simulate a building, there are some key parameters that need to be entered into the program. These include the geometry of the building, the number of zones that make up the building, as well as its internal heat loads.

Another way in which building energy tools differ, is in the type of simulations that they can perform. Most programs can calculate peak heating and cooling loads, the total energy consumption, system performance and costs. Many programs also estimate the indoor temperature. However, the capability to predict indoor humidity is also required by the scientific community, like IEA in its Annex 41. Using the Building Energy Software Tools Directory [2] (a website listing 265 different energy related software tools), a list was made of all software packages that might have the desired capabilities. These software resources will be analysed due to their interest for future research works.

1.1. BLAST

Building Loads Analysis and System Thermodynamics (BLAST), [3], provides a simulation of energy consumption, system performance and cost. It also calculates hourly heating and cooling loads based on a fundamental heat balance method. Information on the building structure can be put in from a library, which has data from ASHRAE Fundamentals. The disadvantage that this software presents is that it requires a high expertise level and it may not take into account humidity transfer through the building coverings.

1.2. BSim

The BSim family of computer simulation tools was created by Danish Building and Urban Research [4] and a database with moisture properties of different materials can be added to the program. This simulates the moisture within the building construction. This building simulation tool has the ability to analyse complex buildings, as well as those with special requirements for indoor climatic conditions.

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1.3. CHVAC

CHVAC is a product of Elite Software [5]. It is a simulation tool for calculating peak heating and cooling loads for commercial buildings. The building loads are calculated using the somewhat outdated CLTD procedures, as described in the 1997 ASHRAE Handbook of Fundamentals. This allows the program to perform calculations for buildings of any orientation and the building to be analysed can be broken down into different zones. Its disadvantages are that it can only calculate design loads and not perform an energy analysis on the building, and cannot simulate moisture storage.

1.4. DOE-2

The DOE-2 [6] building simulation package was developed by the USA Department of Energy. The program simulates the energy performance of the building, including the life cycle cost of operating the HVAC system. It has been extensively validated by comparison with actual measurements and calculations and, in consequence, is highly recommended by ASHRAE as a complete energy simulation tool. The equations used to perform all calculations within the program are based on ASHRAE published algorithms. Its main disadvantage is that the program inputs require a high knowledge from the user, and it does not have the ability to simulate IAQ and moisture storage.

1.5. EnergyPlus

The Building Systems Laboratory together with Lawrence Berkeley National Laboratory and the Department of Energy has combined two programs: BLAST and DOE-2 [7]. With this program, the heating, cooling, lighting, ventilation and other energy related flows in a building can be simulated. It uses a heat balance-based zone simulation method to perform calculations. When analysing buildings, EnergyPlus can account for moisture adsorption and desorption within the building elements. A major disadvantage of the program is that it was not designed to have a main graphical interface, making the program more difficult to use.

1.6. HAP

Hourly Analysis Program (HAP) from Carrier [8] is a load estimation simulation tool. It provides results of both building loads and equipment operation for commercial buildings. All load calculations are performed using the Transfer Function load method. Its main disadvantage is that there is no access to the source code, making it somewhat inadequate for researchers, and cannot analyse moisture flow through constructions.

1.7. TRNSYS

The TRaNsient SYstems Simulation (TRNSYS) [9] program was developed by the Solar Energy Laboratory at the University of Wisconsin since 1975. It is a flexible simulation tool that can simulate the transient performance of thermal energy systems. The simulation program does not make any assumptions about the building or system being used, and so the user must have all the necessary details required for program input. It has the ability to calculate indoor temperature and relative humidity and permits the user to develop and run models of other building components and systems.

1.8. UMIDUS

UMIDUS [10] was developed at the Thermal Systems Laboratory of Pontifical Catholic University of Parana in Brazil. This program has the capability to analyse the hygrothermal performance of building elements taking into account one-dimensional heat and moisture transfer. Furthermore, it has the ability to predict moisture and temperature profiles within different layers of the construction, but is not able to predict indoor relative humidity. This program is free to download from the Internet.

1.9. HAM-tools

The need to develop an open and freely available building physics toolbox among authors has given rise to the HAM-tools software. The beginning of the International Building Physics Toolbox (IBPT) was laid down by two groups of researchers working independently of each other developing building physics models in Simulink. For both groups, the reason for starting to use Simulink as the development environment was the need to model, in great detail, the processes of Heat, Air and Moisture transfer. In both groups the reason for choosing Simulink, which is part of the Matlab package, was a larger degree of flexibility, modular structure, transparency of the models and ease of use in the modelling process. Simulink had already been previously used by other research communities (SIMBAD and CARNOT), but the models had either not been an open source, free of cost or had not been directly applicable to building physics modelling.

The modular structure in Simulink makes it easier to maintain an overview of the models, and new models can just as easily be added to the pool of existing models. Another advantage of using Simulink is the graphical programming language based on blocks, with different properties such as arithmetic functions, input/output, data handling, transfer functions, state space models and more. Furthermore, Simulink has built-in state of the art ordinary differential equation (ODE) solvers, which are automatically configured at model run-time. Therefore, only the physical model needs to be implemented, and not the solver. Furthermore, models can be created using a number of different approaches. These include assembling models directly in Simulink using the standard blocks, Matlab m-files, S-functions, and Femlab9 models using one, two, or three-dimensional finite element calculations. This wide variety of modelling techniques, with different advantages and disadvantages, means that the optimal choice can always be made with respect to the task.

The graphical approach also makes it easy to show the very complex interaction between the different parts of the model. In addition, people who are not used to programming can easily start building their own models or altering existing ones. Therefore, the toolbox also represents a good way to teach building physics.

As shown, a host of commercially available computer tool models already exist for modelling single components or whole buildings. For modelling whole buildings, there are models for hourly energy balances like Bsim1, ESP-r2, EnergyPlus3, and more. While these tools are fully appropriate for designing standard buildings, they are not suitable for modelling innovative building elements such as building integrated heating and cooling systems, ventilated glass façades and solar walls, as these have not been defined in the program [11].

As a consequence, another option for modelling whole buildings is the use of modular simulation tools, represented e.g. by TRNSYS4 and SPARK5. In Strand et al. [12], the differences in the two types of tools are discussed. Here it was found that the major shortcomings of building energy simulation programs have so far been the inability to accurately model HVAC systems that are not "standard". This