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The Building Dynamic Simulation Software ODESSE (Optimal DESign for Smart Energy): Analysis and Suggested Improvement

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Abstract. Dynamic simulation software packages allow us to describe a building-plant system over time and are very useful for estimating energy consumption in architectural projects. However, its use by professionals in the construction industry is currently rather limited because it is difficult to use. In fact many dynamic simulation software programs are not widely used because of their complicated Graphical User Interface (GUI). The software ODESSE (Optimal Design for Smart Energy), developed by ENEA (National Agency for New Technologies, Energy and Sustainable Economic Development) in Italian and English, has the great advantage of a simple and intuitive GUI. On the other hand, compared to other programs it is not yet entirely satisfactory from the technical and mathematical points of view. This article presents an analysis of ODESSE and some proposals for its improvement, in particular with regard to heat exchange algorithms between thermal zones of a building and to the program language. In order to achieve these objectives, a new simulation engine written in C++ has been created that is able to evaluate heat exchanges between zones, even when they are connected temporarily or permanently by doors or openings of some type. The tests performed demonstrate the stability of the multi-zone model developed, but the numerical method of resolution initially used needs to be changed.

Keywords: dynamic simulation, energy, buildings, sustainability, software, odesse.

1. Introduction

The energy consumption of buildings in developed countries comprises 20–40% of total energy use and is higher than the figures for industry and transport in the EU and the USA [1]. The policy instrument adopted by the European Commission for the definition of strategies for the development of energy technologies with low carbon impact, with targets for 2020 and 2050, is the Strategic Energy Techology Plan (SET-Plan), and the specific directive related to buildings is the European Energy Performance of Buildings Directive (EPBD). Scientific research is trying to provide appropriate operating instruments in order to comply with European law. One of these instruments is the project of the ENEA Research Center Casaccia (Rome, Italy), called ODESSE, based on a Framework Agreement with the Ministry of Economic Development on "Study and demonstration of innovative forms of finance and planning and programming tools for the promotion of efficient technologies for the rationalization of electricity consumption on urban and regional scale". This project led to the development of a dynamic simulation program, also called ODESSE, available on the ENEA website in Italian and English, which is characterized by an open source license and with the aim of providing a suitable tool for engineers and architects for predicting the energy consumption of buildings. The final goal is to extend the use of the software to the energy districts, so that energy distribution in a system consisting of buildings with different usage profiles and different power sources could be possible, also in the context of the emergence of distributed energy management through smart grids. As Zahedi specified in his article [2], “Future grids will be combination of centralized and distributed power generations with more flexibility which allows multi-directional power flow”.

Dynamic simulation software for buildings began to spread from about the 1980s, and unlike static software, it enables us to describe a building-plant system over time [3]. A description and comparison of these programs is illustrated in the report Contrasting the capabilities of building energy performance simulation programs [4]. Compared with other programs, ODESSE has the advantage of a simple and intuitive GUI which encourages its use by all professional people in the construction industry and not only by specialists and researchers. In fact, one of the major limitations of many programs (such as TRNSYS, Energy Plus, EPS-r, just to mention a few) is their low application because they are difficult for non-specialists to use. Many research projects are moving in this direction and a very interesting and significant example is that of the Architecture and Town Planning Faculty of the Israel Institute of Technology [5].

Criticisms of ODESSE concern the absence of algorithm development related to the heat exchange between different thermal zones of a building and the use of a translation program from SIMULINK algorithms to C language which results in great limits on performance. This article presents an analysis of the software and some proposals for its improvement in order to achieve completely its basic objectives: the widespread availability of the program through the simplification of the data input entering method without sacrificing the reliability of the physical-mathematical model.

2. Materials and methods: analysis and proposal for improvement

The structure of the ODESSE program consists of the following parts: a) a calculation engine, which solves the system of differential equations that describe the building-plant system according to the methods of MATLAB ODE3; b) a Data Base that contains a large number of templates that describe the thermodynamic properties of the main construction materials; c) a climatic data generator called Neural Weather Generator (NWG); d) an essential and "user friendly" graphical interface written in Java that allows users to set in data in a very intuitive way [6]. The main limitation of ODESSE is that it does not consider the thermal exchanges within the building, so the walls between the thermal zones are considered adiabatic (the definition of thermal zone can be found in the UNI EN ISO 13790:2008). From an informatics point of view. the software was initially realized using MATLAB/SIMULINK ® and then it was connected to a program for translation to C language, which means that the code is difficult to interpret and is therefore difficult for third parties to use and edit. Another technical disadvantage is that memory dynamic allocation of data structures was not carried out, thus bearing down on the RAM and creating difficulties for the software scalability. In order to make the software more competitive it is necessary to overcome these problems. So the code has been rewritten and modified using the object oriented paradigm in the C + + language. In the block diagram of figure 1 the classes and objects constituting the core architecture of the model are outlined; the large arrows indicate the heredity, while the thin arrows indicate that an entity is contained in the other (which is called container). Each class has attributes and functions.

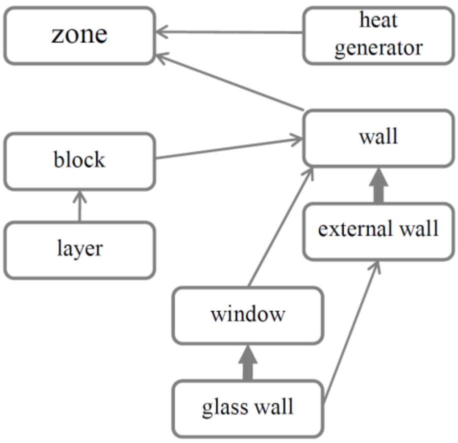

Fig. 1: block diagram of the model architecture.

The most complex class is "zone" because it is the container of all other classes. The storage has been made through carriers connected together by an adjacency matrix (A), where the element Ai, j represents the connection status between the i-th zone and the j-th zone. Both the adjacency matrix and the vectors of the zones are dynamically allocated. Once the changes are applied definitively, the code and its documentation can be downloaded from the ENEA website.

2.1. Development of the multi-zone model: conduction between thermal zones

With regard to the development of the multi-zone model, the first step was to define the heat exchange between two adjacent thermal zones separated by a wall. This is a simple case of conduction[1] and can be solved by calculating the thermal resistance of the wall, assuming for purposes of simplification that the temperature gradient in a wall is constant and therefore the temperature drop is linear. In these conditions heat is defined as:

$$Q = \frac{\Delta T}{R} \tag{1.1}$$

Where R is the thermal resistance of a wall and in the case of n layers in series is equal to (1.2) and for n layers in parallel to (1.3), where Ri is defined by the (1.4):

$$R = \sum_{i=1}^{n} Ri \tag{1.2}$$

$$R = \frac{1}{\sum_{i=1}^{n} \frac{1}{R1}} \tag{1.3}$$

$$Ri = \frac{l}{KiSi} \tag{1.4}$$

In order to verify the heat transfer model, a dynamic simulation was started for two thermal zones connected by a wall having low thermal resistance and isolated from external variable weather conditions. An underpowered architecture was chosen to run the program in order to assess the execution speed of the program (IBM T40, Pentium M single-core 1.5 GHz with 32-bit parallelism, 1 GB of RAM and operating system GNU / Linux Ubuntu 10.04 32 - bit). The following diagram shows the temperature trend.

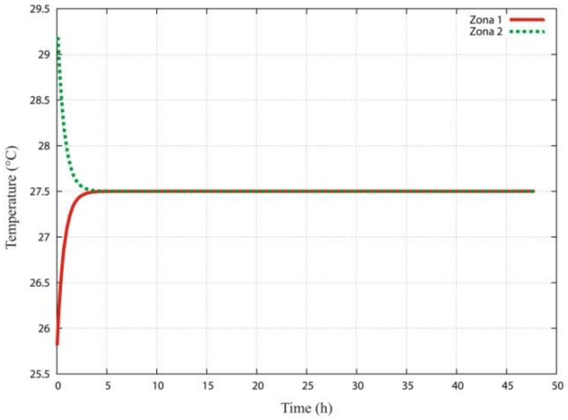

Figure 2: temperature trend in two adjacent zones. Simulation time: 48h. Time step:15 min. Execution time << 1 s

As expected, the temperatures converge to the midpoint after a few hours, and from that point on, the temperature reaches the steady state. The algorithm is stable despite the long time-step. The second test evaluates the temperature trends of three thermal zones, all communicating through walls with different thermal resistances. Following the graph that points out the effect of the differences in thermal resistance.

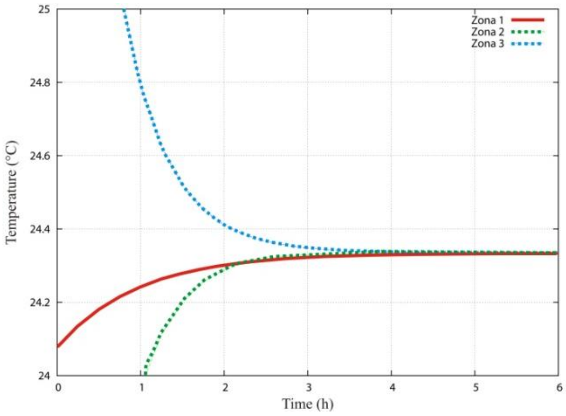

Figure 3: temperature trend in three adjacent zones. Simulation time: 48h. Time step:15 min. Execution time << 1 s

[1] According to the Fourier equation: $\frac{dQ}{dt} = KdS(\frac{dT(x)}{dx})$; where Q is the heat exchanged, T (x) represents the temperature in function of the position, k is a coefficient called thermal conductivity and it depends on the material and S is the area of the contact surface.

The temperature of zone 2 exceeds that of zone 1. This is due to the fact that zone 2 exchanges heat very quickly with zone 3 (which has a higher initial temperature), through a wall with lower resistance.In the third test two thermal zones were simulated in one of which is a heat generator is introduced. As the graph shows, the heat generator fails to bring the temperature to the comfort range (which is defined as between 23 and 25 ℃), when it would decrease as a result of conduction to the other zone.

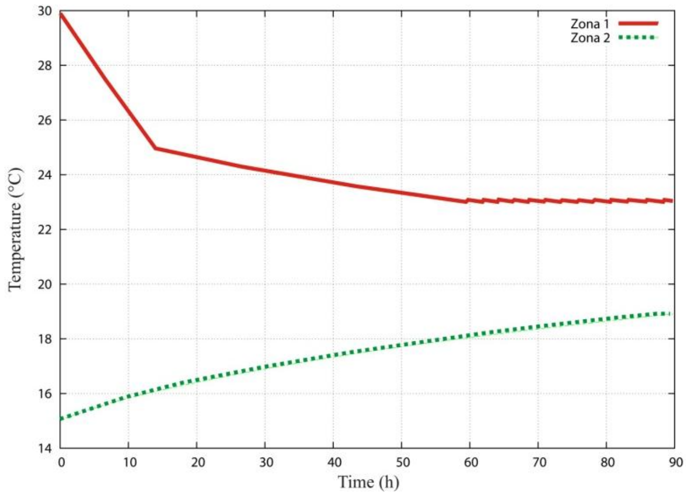

Figure 4: temperature trend in two adjacent zones with a heat generator. Simulation time: 90h. Time step:15 min. Execution time << 1 s

2.2. The case of openings between thermal zones

The determination of thermal exchanges between zones connected temporarily or permanently through opened doors or openings of any type is more complex. This phenomenon can be described by the gas law. A certain mass of gas contained within a zone passes to the adjacent zone, which is in different conditions of temperature and pressure, carrying with it the possessed energy. This problem of fluid dynamics can be solved by the Navier-Stokes equations, simplified in order to reduce the computational burden for the software. So the air mass flow passing through an opening in a wall has been defined with the following equation:

$$\frac{dm}{dt} = \sqrt{\rho} C d A \sqrt{|p1 - p2|} \tag{1.5}$$

where ρ is the density of the gas contained in the zone, A is the area of the opening between the two zones, Cd is an empirical coefficient which takes into account the temperature difference between the zones and p1 - p2 is the pressure difference between them [7]. When the air mass exchanged is determined, the energy per unit mass possessed by the gas that passes from a zone to another one in the form of heat can be calculated:

$$u = cvT \tag{1.6}$$

where cv is the gas specific heat at constant volume and T is the temperature. Actually u depends on several parameters, some of which are determined experimentally but the air behavior in the rooms has been considered ideal. In the following versions the software will implement a more comprehensive approach for this issue. At this point the heat flow exchanged can be defined as:

$$\frac{dQ}{dt} = \frac{dm}{dt} u \tag{1.7}$$

the mass (and thus heat) always moves from the zone with higher pressure toward the zone with lower pressure, but the airflow direction cannot be deduced with the (1.5), as the pressure difference is under square root. So the sign function must be used2. At this point another equation must be introduced because there are three variables in the system (mass, pressure and temperature) and only two equations. Therefore the equation of state for an ideal gas is added, where M is the molar mass:

$$p = \rho \frac{R}{M} T \tag{1.8}$$

2 $\frac{dQ}{dt} = \frac{dm}{dt} u \, sgn(p1 - p2)$

3. Discussion

In the case of simple conduction between thermal zones the algorithm works efficiently and is stable for a certain period of discretization, as shown in the the graphics. The program stability begins to fade introducing the transfer of mass and energy through doors and windows. This problem can be solved by changing the numerical method of resolution. The Euler method of resolution was chosen in an initial phase for reasons of simplicity. However, it has very low tolerance of ill-conditioned problems, which makes it particularly unstable. If this was not influential in the simple case of conduction in thermal zones connected by walls, it is much more evident in the case of openings in the walls between thermal zones because for small variations in time there are great corresponding variations in the dependent variables (temperature, pressure and mass); this means that the algorithm does not converge. So the next step will be the use of a higher order Runge-Kutta solution method, which is known for its stability and its tolerance of ill-conditioning problems. A further development will be the elimination of the simplification that considers temperature drop to be linear. The temperature variation in the wall, in fact, is not linear and constant in each homogeneous layer, but it continuously varies for each infinitesimal layer.

4. Conclusion

The proposed study aims to improve the detailed description of the physical behavior of a building-plant system in the ODESSE software, finding the best informatics tools to ensure a fast execution time of the complex mathematical calculations. The main result has been the development of the multi-zone case in a more comprehensive way compared with the previous version in which walls were considered adiabatic leading to oversimplification, especially in buildings with many zones in different temperature conditions. Now the thermal exchanges between zones through walls and openings can be calculated by a system of equations defined in order to describe the mass and energy movement between zones in case of openings and this is an important step forward for the definition of the mathematical model of the building system. As heat is exchanged with great speed through internal openings, the user has to define precisely their condition of opening or closing, in the case in which their schedules of use are fixed and repetitive (for example in a building of the tertiary sector). As an alternative the software allows, through a probability function, the prediction of when and how long the doors are open. Of course the program, rewritten in C ++ and improved from the mathematical point of view, still needs further developments and extensions. Moreover, in addition to the improvement of the algorithms which describe the mathematical model, the development of the graphical interface is essential in order to achieve the primary objective of the software, that is its wider use in virtue of its simplicity and reliability.

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