VALIDATION OF MESTRE BUILDING SIMULATION SYSTEM ACCORDING TO BEST-TEST MULTI-ZONE, NON-AIRFLOW, IN-DEPTH DIAGNOSTIC CASES

Schmid, Aloísio Leoni1 and Graf, Helena Fernanda2
1Mechanical Engineer, Dr.-Ing. Professor, UFPR, iso@ufpr.br
2Architect, MSc. in Civil Construction, UFPR, helenafernanda@terra.com.br
Laboratório de Ambiente Construído – Departamento de Arquitetura e Urbanismo
Federal University of Paraná – UFPR - Phones (+55 41) 3361-3069

ABSTRACT
The MESTRE building simulation system is a highly portable tool written in Java for describing the thermal, acoustic and luminic performance of buildings. The present paper introduces the validation results of the thermal behavior module according to IEA Building Energy Simulation Test and Diagnostic Method (Bestest), for multi-zone, non-air flow, in-depth diagnostic cases. Results were compared with theoretical results as well as results provided by already validated simulation packages. Results by MESTRE is in reasonable approximation. Comments on the improvement process in order to achieve the correct range and difficulties found are presented too.

INTRODUCTION
The MESTRE building simulation system was started in 2001 as a tool for describing the thermal behaviour of buildings. The author intended to address the main mechanisms of heat transfer in buildings without oversimplifying the geometry. Besides, he intended to create a portable tool, based on a light code. Further, it should be operational with climate and material data available in Brazil. His belief was that, rather than adopting one of the then available commercial systems, the development of a new tool could deepen the comprehension of such systems. A close knowledge of the methods and algorithms beyond them could provide a support to the classroom needs.

MESTRE was written in the Java language. This allowed an extremely lightweight code, totaling only 201 kB in the current, 2011 version. Several numeric algorithms were implemented. For data input, a simple (not necessarily user-friendly) language was created.

In 2003, a daylighting module was added, with the generation of realistic images. An example of an image generated by MESTRE (daylight on an office desk) is shown in Figure 2.

Figure 2
Daylighting image by MESTRE

In 2006, an acoustics module was added, including auralization (i.e. the generation of audible simulation from anechoic recordings and computation of the impulse response of rooms). Figure 3 shows some views of the computation of the impulse response of a room by means of
raytracing. In order to build impulse responses, a vectorial acoustical field is combined to a diffuse acoustical field. The number of reflections has to be much higher than in daylighting simulations, as the human ear registers sound intensities in a range from 1 to 1 trillion. This generates a huge number of reflections. Therefore, view factors generated by raytracing provide a bound to the possible arrangements of surfaces hit in the way from the sound source to the receiver.

In a next processing, the impulse response is Fourier-transformed, generating data in frequency (instead of time) domain. An anechoic recording in .WAV format is opened and its main (wave) part also Fourier-transformed. Both arrays are convoluted and the result becomes audible (reverberation was added to the anechoic recording). The Fourier transform is necessary to significantly reduce computation time.

In 2010, a review was conducted in the thermal simulation module. Instead of only providing the zone temperatures as a result, an automatic computation of the energy requirements for acclimatization in each zone was included (heating and cooling, based on predefined temperature setpoints).

The present paper presents the new version of thermal analysis module, including the latest improvements. Analysis is based on a lumped mass approach (that resembling resistive-capacitive electric circuits). Thermal zones are associated to temperature nodes and are defined in correspondence with the building compartments, but not exclusively: building walls and other solid elements contain each a temperature node, too. Solid elements (as walls and slabs) have a thermal resistance and a thermal capacity. Air zones have a film coefficient and a thermal capacity. Direct and diffuse solar irradiation are approximated by means of a Ray-tracing technique.

The system understands data, which includes following groups:

- General simulation parameters like location, duration and convergence criteria;
- Model geometry (of solid elements like walls, slabs and windows), including dimensions, placement relative to the local coordinate system and the zone numbering scheme, and material code;
- Thermal zones including zone thermal capacity, film coefficients, schedules for zone heat generation, ventilation, and temperature setpoints;
- Materials (thermal properties, besides visual and acoustic properties, here not used);
- Climate data: daily, monthly or annual records of air temperature, direct and diffuse solar radiation.


VALIDATION

In December, 2010 an attempt was initiated to validate the MESTRE system according to the IEA’s Building Energy Simulation Tool Test and Diagnostic Method (Bestest) for multiple zones, non-airflow building models. At the same time, the new version of the software was created. Both were concluded in 2011.

The TR2 climate file for Miami, USA was downloaded and converted into a compatible format. Data files were generated considered five test cases:

- MZ320 (three-zone, steady-state, with internal heat generation in two of the zones and a temperature setpoint in the third zone),
- MZ340 (six-zone, west-facing building, as a calorimeter to measure transmitted beam and diffuse solar energy in hourly timesteps over one representative year),
- MZ350 (same with partial shading by a fin),
- MZ355 (fin replaced by a shading zone)
- MZ360 (a triple window with intermediate zones between the panes).

The main information source on the Bestest procedure was a NREL report by Neymark and Judkoff (2008).

Next, a description of each test is provided. At the end of the paper, some reflections on the improvements in the code are added. Further, a discussion is presented on the difficulties found during the validation process, as well as on the meaning of developing a new simulation tool.
MZ320
This test is related to the behavior or a single-floor building, consisting of three adjacent zones. Every zone has a different heat production rate. Only a steady-state analysis is performed. No solar radiation is considered. The geometry is depicted in Figure 4.

Simulation results by MESTRE are shown in Table 1, besides the Bestest result range (obtained by several participating packages such as ESP and Energy Plus). The analytic solution according to Neymark e Judkoff (2008) is also presented.

| MZ320 simulation results by MESTRE |
|-------------------------------|----------|----------------|----------------|
|                               | Heat load (W) | Temperature, Zone 1 | Temperature, Zone 2 | Temperature, Zone 3 |
| Mestre                        | 1541       | 31.06             | 24.8             | 15               |
| Best Test, minimum            | 1517       | 30.99             | 24.65            | 15               |
| Best Test, maximum            | 1546       | 31.93             | 24.8             | 15               |
| Analytic solution             | 1541       | 31.06             | 24.8             | 15               |
| Deviation, 1-4 (%)            | 0          | 0                 | 0                | 0                |

MZ340
This test refers to the behavior of a two-floor, six-zone building. All zones have a wide aperture facing west. Hour-by-hour solar gains (both direct, on a perpendicular plane, and diffuse, on a horizontal plane) were read from the TR2 weather data file, which is valid for Miami, USA. All walls are adiabatic. Figures 5 and 6 present the building geometry.

Solar angles considered were as for Miami, USA. Outside air temperature was kept at 20°C. As solar radiation is the only heat source, its elimination by means of artificial refrigeration had to be achieved. Results are presented in Table 2.

| MZ340 simulation results by MESTRE |
|-------------------------------|----------|----------------|----------------|
|                               | Refrigeration load: average of six zones (W) |
| Mestre                        | 13682 |
| Best Test, minimum            | 12290  |
| Best Test, maximum            | 12849  |
| Deviation, 1-3 (%)            | 6.30%  |

MZ350
This test is derived from MZ340 with the addition of a vertical plan throwing shadows mainly to A, B, D and E zones. Results are presented in Table 3. They resemble those of MZ340, as other than the shadow, there are no differences.
MZ355

The MZ355 test is a variation of MZ350, which uses, to throw shadow, an additional zone, instead of a fin. Thus, insolation on zones C and F is completely blocked. Figure 7 presents the building geometry.

Results are presented in Table 4.

MZ360

This test consists in an approximately cubic shape with a complex window, consisting in three layers. The windows face southwest (Figure 8).

Results are presented in Table 5.

DISCUSSION

The MESTRE system showed a tendency to agree with the Bestest standards, but showed some deviation in tests MZ340 and MZ350. Next, a closer analysis of accuracy issues will be presented.

MESTRE has proven accurate in the following simulation tasks:

- Zone interaction
- Natural convection phenomenon
- Heat conduction
- Modelling of direct solar energy and shadow projection
Some difficulties in convergence were initially reported, due to the less common characteristics of the tests, as the assumption of adiabatic walls in MZ340 thru MZ360 and the lack of thermal capacity. However, after some corrections, the performance was considered adequate.

Some deviations in the non-shadowed zones facing West are probably due to the lack of critical considerations in the implementation of the diffuse Sky model according to Pérez et al. (apud Duffie & Beckmann, 1991), which divides diffuse solar radiation in three components:

- Uniform
- Circumsolar
- Close to horizon

This discrepancy becomes noticeable at the end of the days in Windows facing sunset.

In cases MZ340 e MZ350, where there is a stronger exposition to West, the circumsolar component seems excessive, deviating from the IEA range the yearly totals of diffuse radiation. It is worth mentioning that the IEA BESTEST report (Neymark & Judkoff, 2008) mentions the fact that the Pérez et al. model superestimates diffuse radiation.

Other discrepancies are due to the adoption, by MESTRE, of solar positions at half time steps: for example, the 12h00 computation uses the 11h30 values and so on. To achieve a higher accuracy, rather, a better numerical integration procedure should be implemented, with use of shorter timesteps than one hour.

The validation attempt according to IEA Bestest was useful as it motivated the introduction of two major changes in the 2011 version of MESTRE:

- Hour-by-hour simulation along the year, based on 8760 hourly records;
- Automatic computation of climatization energy, based on setpoints;

In addition, following improvements were done:

- Differentiation of the radiation absorbances of two opposing surfaces of the same wall element;
- Modelling of diffuse radiation

However, data on diffuse radiation are not available for Brazilian cities.

Comments on modelling

In MESTRE both direct and diffuse radiation were first mathematically described and then numerically approximated. The decision for a model is based on the developer’s knowledge of the physical phenomena, and also his or her ability of translating it into algorithms, and there may be a limitation in both aspects. However, only a validation procedure provides the developer an opportunity to really quantify the merit or demerit of his developing work.

To calculate the contribution of direct radiation, first the position of the sun is calculated in terms of local coordinates Psun (X,Y,Z). Subtraction of this point from the building domain’s central point Pcentral (X,Y,Z) originates a vector representing the instantaneous direction of the incident solar rays vray. On a plane perpendicular to that vector, a grid is generated to expand the point representing the sun to a surface. Each of these grid points will generate a new ray projected to the building domain. A test is made to verify whether the ray intersects a building surface.

Modelling of direct radiation was first based on the admission of every radiant flux through a window to the corresponding zone. First Best Test validation attempts demonstrated noticeable deviations. Consequently, there is a not fair distribution of heat flux between the zone where the solar ray first hits an opaque surface and the other zone limited by that wall. But physically it represents a worse mistake: this first model considered every surface a 100% reflective and the air 100% absorbing. This was not realistic at all.

Therefore, the following improvement was made. If a surface is hit, a radiant flux contribution is added to that surface. If it is an outside surface, this flux is considered when calculating the sun-air temperature. If it is a window surface, it is admitted into the zone and the absorbed component generates a sol-air temperature at the corresponding inners surface it hits on; the reflected component is added to the zone air. To adequately represent the effect of the windows, a grid density has to be chosen which as at least the half height and width of the smallest window in the model.

Diffuse radiation was not modeled before the Best Test. It was introduced as calculations widely deviated from the expected values. Introduction of diffuse modeling has two tradeoffs:

- As in daylighting simulation, an accurate modeling of radiation exchange between surfaces has to be achieved without causing the computation time to be excessive;
- A sky model has to be chosen, which represents the main influences on the building model, but does not excessively idealize the real sky (it has to be noted that data on diffuse radiation are not available in Brazil).

Only the rays from the sky and neighboring surfaces (albedo) to the building surfaces were modeled. No further reflections were included. Every surface was first represented by its central point. On it, a hemisphere was generated and discretized in a number of height angles and azimuth angles. A raytracing procedure was then adopted (diffuse radiation was traced back to its origin – the sky). Only a ray hitting the sky either directly or through
one or more transparent elements has a contribution to be accounted for.

This first attempt to model diffuse radiation proved insufficient. A new attempt was then made, adopting not only the central point of every surface, but four points in rectangular surface elements (by dividing every rectangular surface element in four regions), and three points in triangular elements (by dividing every triangular surface element in three regions). This procedure certainly demanded programming effort, and also added an extra delay to the computation time. However, the MZ360 results became closer to the expected range.

Comments on the general orientation in system development

MESTRE attempts to be object-oriented, but it is not really. It attempts, first because of the Java logics, which lets almost no choice to the developer. Second, because an object-oriented software is much easier to update; the interface with building design software would also become much easier. It is not really due to the developer inability to think object-oriented. In object-oriented programming, by definition, a class encompasses variables and methods (functions) involving these variables; however, this is true, mainly, for the variables; several methods were implemented outside the classes, due to an initial lack of comprehension that they belong within the class. In addition, sometimes the developer’s hurry to see simulation results may have encouraged several precarious solutions which are not compatible to a fully object-oriented approach. There is a set of global variables which were included along the development history. Such global variables are not necessarily considered when, for instance, a wall class is modified. Thus, the programming effort to refine or even verify the performance of a given class may be almost prohibitive.

The development of MESTRE by a single author made not necessary any collaborative effort, thus allowing the use of a rather hermetic code. As the software was initiated in 2001, it is prohibitive to repair this deficiency. The best decision would be to write a new code within a team, raising the concern for information design and information management.

Why to write a new simulation code?

There have been multiple didactic and scientific benefits, allowing a customized use in undergraduate classrooms and graduate seminars. MESTRE has proved useful particularly in the education of Architects, where sustainable design choices require a comprehension of combined building physics problems (rather than stressing on a single physical context). A detailed description was presented by Schmid (2008).

The treatment of three different problems such as heat transfer, acoustics and daylighting profited from a library of vectorial algebra methods.

Student complaints about the complexity of the data files to be entered motivated a discussion on a possible interface with Building Integrated Modelling packages like Autodesk Revit or Archicad. A review on the topic of access to the integrated building model is provided by Ayres (2007). Accordingly, the best found choice was defined as the implementation of translating methods from IFC classes. MESTRE would then give up the task of refining the graphical input. However, no progress was done so far.

FINAL REMARKS

A new thermal module of the MESTRE building simulation code was presented.

There was a very good agreement, with perfect similarity to the theoretical solution at MZ320. Results were 6.3 % above the Bestest range in yearly cooling loads at MZ340. A similar deviation was found in the yearly cooling loads at two of the zones at MZ350. Results were almost within Bestest range in yearly cooling loads at MZ355, and there was only a 0.1% deviation in zone A at MZ360.

The ratio of costs and benefits of developing MESTRE have been favorable. However, there are still several improvements to be done. Probably, a team will be formed and a new code will be started.

REFERENCES


