DOMUS 1.0: A BRAZILIAN PC PROGRAM FOR BUILDING SIMULATION

Nathan Mendes, Ricardo C.L.F. de Oliveira and Gerson H. dos Santos
Pontifical Catholic University of Paraná – PUCPR/CCET
Thermal Systems Laboratory
Rua Imaculada Conceição, 1155
Curitiba – PR, 80.215-901 – Brazil
nmendes@ccet.pucpr.br

ABSTRACT

The software DOMUS has been developed to model coupled heat and moisture transfer in multi-zone buildings. DOMUS has been conceived to be a very user-friendly software so that to stimulating a larger number of users in Brazil to use building simulation software and meet national energy conservation program goals. Besides this aspect, as the weather in Brazil permits the analysis of building architecture, thermal comfort passive strategies can be easily analyzed. DOMUS models predict temperature profiles within multi-layer walls for any time step and the temperature and relative humidity for each zone. In the article, we will show the DOMUS 1.0 models and interface and some capabilities.

INTRODUÇÃO

We describe the DOMUS software for simulation of multi-zone buildings and analysis of both thermal comfort and energy use. The software DOMUS has been developed to model coupled heat and moisture transfer in buildings, in order to analyze the performance of typical Brazilian rooms when subjected to any kind of climate conditions.

DOMUS has been built in C++Builder which is an OOP language to be a fast and precise easy-to-use software. The program runs in the Windows 95, 98 and NT operating systems. The user interface consists of a series of windows in which the user can enter the relevant input data and review the results. The user can move between other applications when the DOMUS simulations are running and several DOMUS projects can be open and running at the same time. DOMUS projects with all their input information and results may be saved and reopened.

DOMUS development consisted of a CACSD environment creation for the analysis of thermal building performance. The program has a simplified CAD interface so that the user can easily edit the building geometry.

The calculation of conduction heat transfer through multi-layer walls is done by using the finite difference approach and, for each zone, it was employed a capacitive lumped model to calculate the temperature and relative humidity.

DOMUS models predict temperature profiles within multi-layer walls for any time step and the temperature and relative humidity for each zone. Input files containing hourly data provide information on the conditions at the interior and exterior of the building, a library of material properties is also available. The convection coefficients at the exterior of the wall are calculated hourly from wind velocity and direction data.

DOMUS has been conceived to be a very user-friendly software so that to stimulating a larger number of users in Brazil to use building simulation software and meet Brazilian energy conservation program goals. Besides this aspect, as the weather in Brazil permits the usage of passive architecture, DOMUS will have a module, which will allow the user to simulate, in an easy way, passive or low-energy strategies to reach thermal comfort conditions.

In the article, we will show the DOMUS 1.0 models and interface and some capabilities.

MATHEMATICAL MODEL

The present work uses a dynamic model for analysis of the hygrothermal behavior of a room without HVAC system. Therefore, a lumped formulation for temperature as well as for water vapor is adopted. Eq. 1 describes the energy balance, where the room is submitted to loads of conduction, convection, short-wave solar radiation, inter-surface long-wave radiation and infiltration.

$$\dot{E}_t + \dot{E}_g = \rho_{air} c_{air} V_{air} \frac{dT_{\text{int}}}{dt} \qquad (1)$$

$\dot{E}_t$ energy flow that crosses the room (W)

$\dot{E}_g$ internal energy generation rate (W)

ρ_{air} air density (kg/m^3)

c_{air} specific heat of air (J/kg-K)

V_{air} room volume (m^3)

T_{int} room air temperature (^{o}C)

The term $\dot{E}_t$, on the energy conservation equation, includes loads for building envelope (conduction), fenestration (conduction and solar radiation) and openings (ventilation and infiltration). The conduction heat flux - $Q(t)$ - that crosses the room control surface is calculated by the Newton's law for cooling,

$$\dot{Q}(t) = hA\left[T_n(t) - T_{int}(t)\right] \quad (2)$$

where h represents the convection heat transfer coefficient, A, the heat transfer area, and $T_n(t)$ the envelope internal surface temperature. This temperature is calculated by an energy balance, in an elemental volume, using the Fourier's law as it is presented below:

$$\rho c \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial x^2} \quad (3)$$

Thus, the temperature T shown in Eq. 3, is the temperature for a control volume within the building envelope, calculated as a function of the following thermophysical constants: density (?), specific heat (c) and thermal conductivy (?).

On the external side of the room, the walls, ceiling, doors and windows are exposed to solar radiation and to convection heat transfer. This way, the external boundary condition (x=0) of Eq. 3 can be mathematically expressed as:

$$-\left(\lambda \frac{\partial T}{\partial x}\right)_{x=0} = h_{ext}\left(T_{ext} - T_{x=0}\right) + \alpha q_r \quad (4)$$

where:

$h_{ext}\left(T_{ext} - T_{x=0}\right)$ convection heat transfer (W/m2)

$\alpha\, q_r$ absorbed solar radiation (W/m2)

λ thermal conductivity (W/m-K)

On the internal side (x=L), we have included the inter-surface long-wave radiation as:

$$\left(\lambda \frac{\partial T}{\partial x}\right)_{x=L} = h_{int}\left(T_{int} - T_{x=L}\right) + \sum \sigma f_f \varepsilon \theta (T^4{}_{sur} - T^4{}_{x=L}) \quad (5)$$

where:

f_f shape factor.

ε emissivity.

σ Stefan-Boltzmann constant (5.67.10-8 W/m^2-K^4)

T_{sur} temperature of internal surfaces of surrounding walls (K).

The temperature $T_{x=L}$ of Eq. 5 is equivalent to a temperature of the n-th node of the wall the temperature needed to calculate $\dot{Q}(t)$.

For the floor, we have adopted the imposed-temperature boundary condition, equaling $T_{x=0}$ to the ground temperature at a depth of 2m. On the other hand, for the ceiling, long-wave radiation losses were considered (R_{lw}) so that Eq. 4 has assumed the following form:

$$-\left(\lambda \frac{\partial T}{\partial x}\right)_{x=0} = h_{ext}\left(T_{ext} - T_{x=0}\right) + \alpha q_r - (\varepsilon)_{ceil} R_{lw}$$

where the term $(\varepsilon)_{ceil}$ represents the ceiling emissivity.

The infiltration loads formulation was taken from ASHRAE (1993). The solar radiation (direct and reflected) came from models presented by Szokolay (1993) and ASHRAE (1993).

In terms of water-vapor balance, it was considered ventilation, infiltration and internal generation from equipment and people breath so that the lumped formulation becomes:

$$(\dot{m}_{inf} + \dot{m}_{vent})(W_{ext} - W_{int}) + \dot{m}_b + \dot{m}_{ger} = \rho_{air} V_{air} \frac{dW_{int}}{dt}$$

where:

$\dot{m}_{inf}$ mass flow by infiltration (kg/s)

$\dot{m}_{vent}$ mass flow by ventilation (kg/s)

W_{ext} external humidity ratio (kg water/kg dry air)

W_{int} internal humidity ratio (kg water/kg dry air)

m_b water vapor flow from the breath of occupants (kg/s)

$\dot{m}_{ger}$ internal water-vapor generation rate (kg/s)

ρ_{air} air density (kg dry air/s)

V_{air} room volume (m3)

The water-vapor mass flow from the people breath is calculated as it is shown in ASHRAE (1993), which takes into account the room air temperature and humidity ratio and physical activity as well.

The electric oil-heating system that is optional can be described as:

$$\rho_c c_c V_c \frac{dT_c}{dt} = P(t) - hA[T_c(t) - T_A(t)]$$

where $P(t)$ is the thermal power generated by the heater, ρ_c, the density, c_c, the specific heat, V_c, the heater oil volume, $T_A(t)$, the room air temperature, $T_c(t)$, the heater temperature, t, time, h_c, convection heat transfer coefficient and A_c the heat exchange area.

DOMUS INTERFACE

The software interface is modularly divided in the parts that are described below.

Building Description Module

This module is responsible by the definition of the building geometry and dimensions. A building can have several zones and each zone can have several walls and each wall can have several layers and each layer shall be defined by its physical characteristics.

The user can interact with building envelope and openings and after defining the geometry, a text file will be automatically created so that the user can verify all the inputs.

Inter-Zone Relationship

As a building can have several zones, an important aspect is how to geometrically conceive the inter-zone relationship in order to have a generic code. This implementation stage is one of the most complex and that takes longer to get ready.

As the software allows the user to freely decide what he wants to, all the geometric consistency has to be transferred into the code. The theoretic basis for the solution of these complexities is the computational geometry directly turned to arithmetic and logics operations between 2-D flat surfaces.

We show below some examples that require a special treatment.

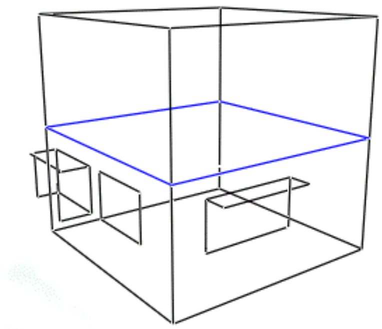

Figure 1 - Adjacent walls with total symmetry

In the case shown in Fig. 1, the geometric treatment is simple as the 1st floor ceiling just plays either a role as a ceiling or as a floor.

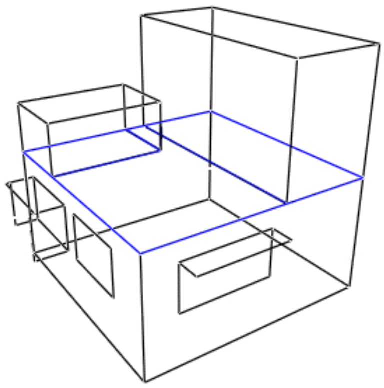

Figure 2 - Adjacent walls with no symmetry.

In Fig. 2, we show the case in which the first floor ceiling may be either connected to other 2 zones or exposed to outdoor conditions. In this case of adjacency with no symmetry, DOMUS distinguishes which surface area is external or internal so that it gives a special mathematical treatment for the boundary conditions.

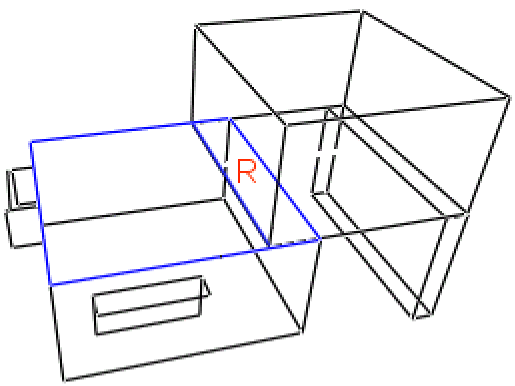

Figure 3 - Partially adjacent walls.

In Fig. 3 is shown the case where the walls are partially adjacent. Actually, this is the most complex case.

Only a part of each wall has an adjacency (region R) to another zone. The program executes an intersection operation (operation "AND") between both walls. The results will be a region defined for a rectangle. If openings are added within the adjacency area, they should be considered in the intersection operation as well, which increases the algorithm complexity.

Interface

The edition interface (Fig. 4) is simple, allowing the user to build a construction without much of specific knowledge. There are two visualization panels, one showing the whole building and a second one showing just the current wall in the edition module where the user can change its dimensions and physical properties. By clicking on that wall, the user can open the building element description window (Figure 6).

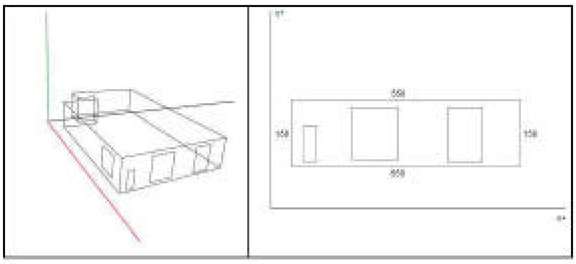

Figure 4 – Building edition general scheme.

For the 3-D visualization panel, it is provided tools to rotate, translate and change building scale and colors. A building can be loaded from text files saved in a special DOMUS format. In Fig. 5, it is shown the main screen layout.

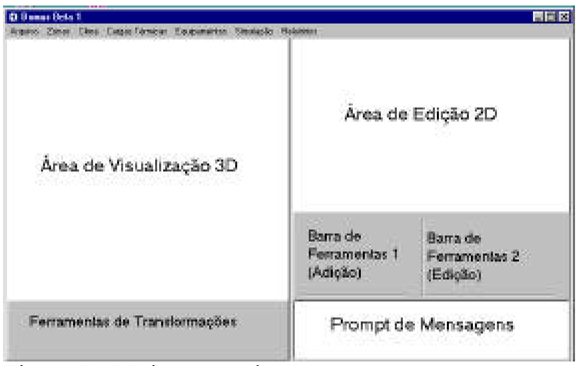

Figure 5 - Main screen layout

Configuration Module

In this module, it is allowed to the user configure all the parameters directly related to the simulation, which are cited below:

Building Envelope Editor

The wall layers are edited in a particular window (Fig. 6), where it is shown all the available materials, geographical orientation (wall azimuth and inclination), soil properties, painting, etc.

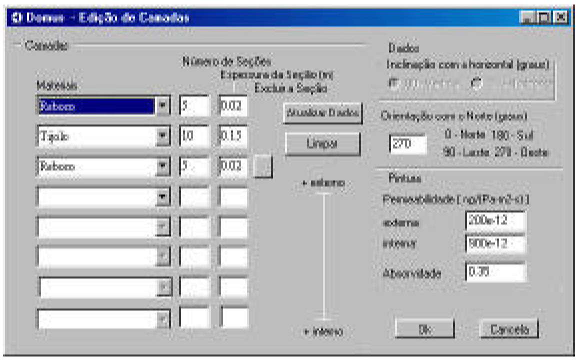

Figure 6 – Building envelope description window.

Weather

The external building climate is chosen in the weather configuration window (Fig. 7). To make easier, the program load all the existing weather files in a specified directory and list all of them to the user.

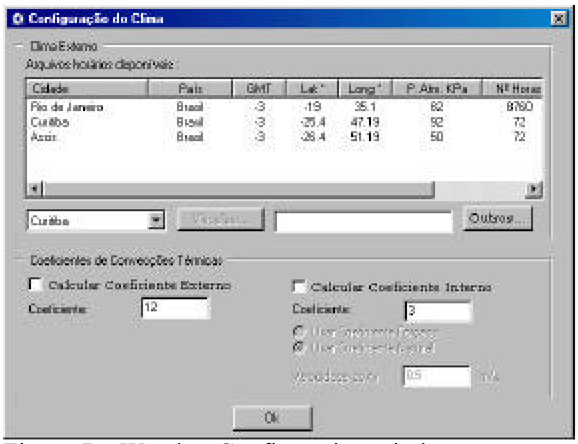

Figure 7 – Weather Configuration window

The DOMUS hourly weather files provide dry bulb temperature, relative humidity, direct and diffuse solar radiation and wind speed and direction.

Presently, the program reads just weather files in the DOMUS format (.dom). Afterwards, it will be added options for several weather file formats such as TRY (Test Reference Year), TMY (Typical

Meteorological Year) and WYEC (Weather Year for Energy Calculations).

The internal and external convection heat transfer coefficients are also configured on the weather window. In the case, the user wants the coefficients to be calculated in time of execution, he just has to click in the option. DOMUS has correlations for those coefficients obtained by Allandari and Hammond (Clarke, 1985).

Internal Gains

Figure 8 shows the window where the user can configure the internal energy gains of each zone. The number of gains is limitless and can be from different sort such as people, equipment, lights, vapor generation etc.

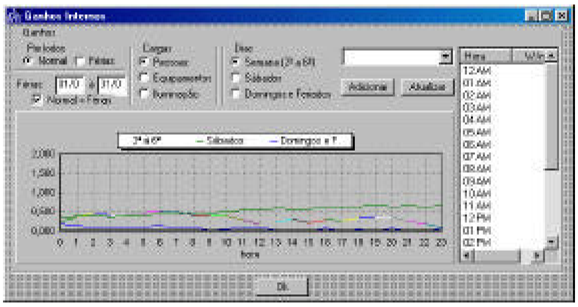

Figure 8 – Internal gains

As the user enters the gains, a figure is displayed to show the internal power for each hour. Beyond that, in this window, ventilation and infiltration can be configured for each particular zone.

HVAC Systems

In this window, the user will be able to specify HVAC equipment for each zone. The user will also be able to define a controller for each equipment in each zone.

Figure 9 – HVAC systems window.

Simulation General parameters

Figure 10 shows the general parameters configuration window.

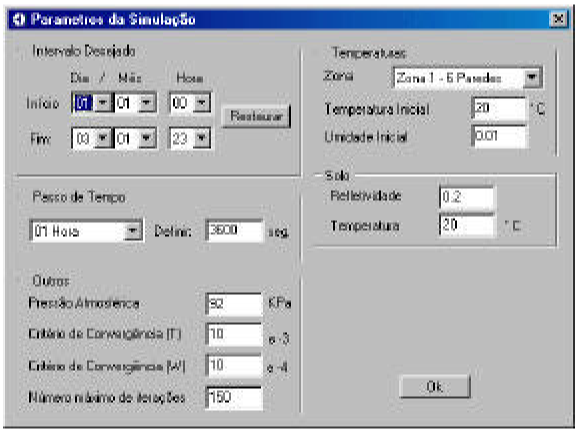

Figure 10 - general parameters configuration window

Output Reports

Before executing the simulation, the user has to choose all the types of reports that the program will have to generate. However, the higher the number of options chosen slower will be the simulation.

The program provides a great variety of report options such as hourly reports for temperature, relative humidity, thermal comfort level (PMV and PPD), energy consumption, thermal loads, energy costs, and monthly general statistics. The report options can be seen in Fig. 11.

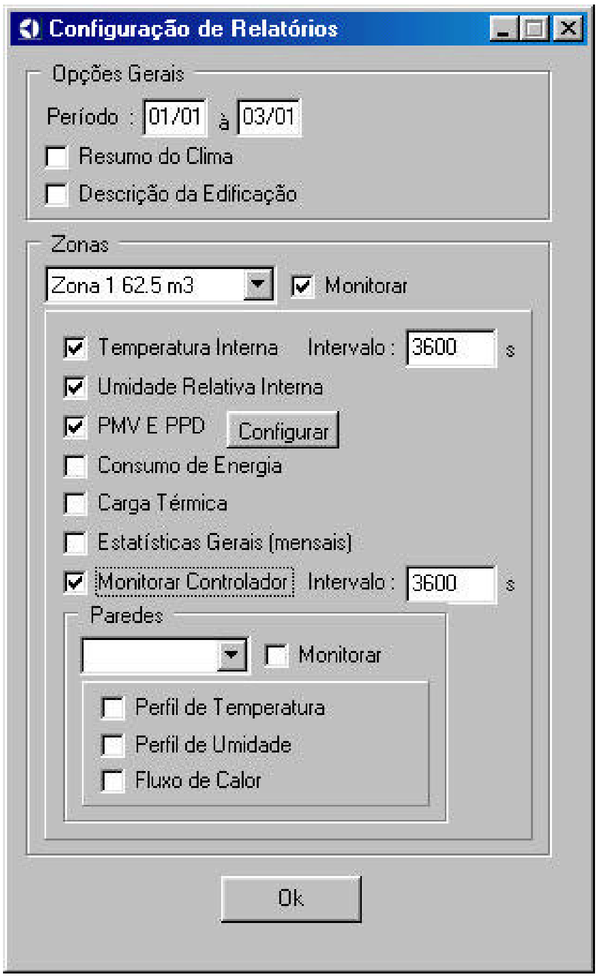

Figure 6 - Report configuration window

It is possible to the user to monitor the temperature and/or the controller output with different simulation time steps. It is important to remember that for very small time steps, the program will generate very large files.

RESULTS

We have chosen one-month period from July 1st to July 31st to simulate the building shown in Figure 11. We have selected the Rio de Janeiro weather file with a time step of 5 minutes.

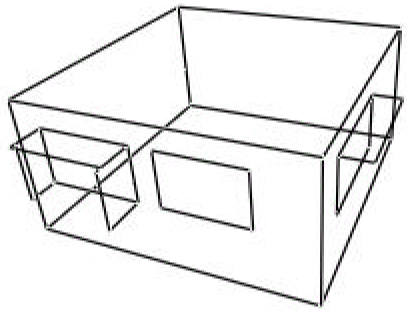

Figure 12 – Building sample

Fig. 13 shows the internal and external air temperature and relative humidity.

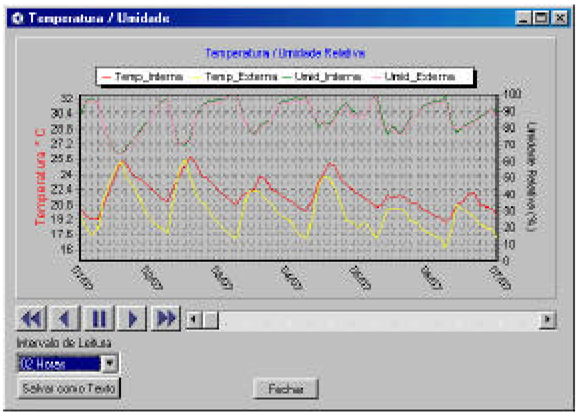

Figure 13 - Internal and external temperature and relative humidity.

Fig. 14 presents the Fanger`s comfort indexes (PMV and PPD) along the month of July in the city of Rio de Janeiro, which shows a good predict mean vote with a low percentage of dissatisfied people.

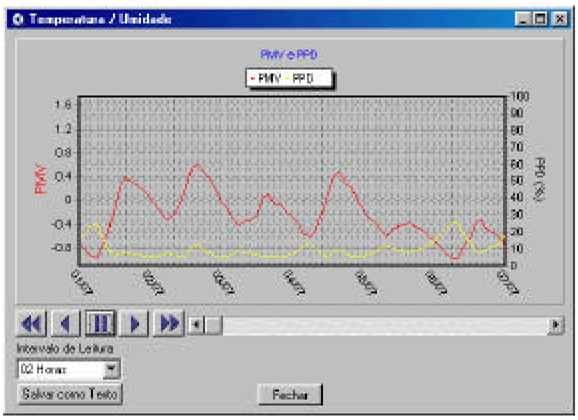

Figure 14 - Report of PMV and PPD.

The graphs presented in Figures 13 and 14 can be saved as a text file. We can also zoom them in/out and select a different plotting time step.

CONCLUSIONS

We have described the DOMUS building simulation program, which has a CAD interface The software was developed for building thermal analysis, by using the finite difference method.

DOMUS has been built in C++Builder which is an OOP language to be a fast and an easy-to-use software. The program runs in the Windows 95, 98 and NT operating systems. The user interface consists of a series of windows in which the user can easily enter the relevant input data and review the results. The user can move between other applications when the DOMUS simulations are running and several DOMUS projects can be open and running at the same time. DOMUS projects with all their input information and results may be saved and reopened.

The program provides a great variety of report options such as hourly reports for temperature, relative humidity, thermal comfort level (PMV and PPD), energy consumption, thermal loads, energy costs, and monthly general statistics.

For further work, we will incorporate within DOMUS models the UMIDUS program features, increasing its potential for hygrothermal simulation.

REFERENCES

ASHRAE Handbook-Fundamentals, Atlanta: ASHRAE, 1993.

CLARKE, J.A., Energy Simulation in Building Design, Adam Hilger Ltd., USA, 1985.

CRAWLEY, D. B.; LAWRIE, L. K. e PEDERSEN, C. O.. Energyplus: a new generation building energy simulation program. Proceedings of renewable and advanced energy systems for the 21st century, Lahaina, Maui, Havaí (EUA), 1999.

ESRU. ESP-R: a building and plant energy simulation environment, user guide version 9. ESRU publication – University of Strathclyde. Glascow (Reino Unido),1997.

FAUCONNIER, R.; GUILLEMARD, P. e GRELAT, A. Algorithmes des simulateurs du comportement thermique des bâtiments BILGA et BILGO. Annales de I'ITBPT. N°458, p. 77 - 115,1987.

MENDES N., RIDLEY I., LAMBERTS R., PHILPPI P.C. and BUDAG K.," UMIDUS: A PC Program for the Prediction of Heat and Moisture Transfer in Porous Building Elements"; Building Simulation Conference - IBPSA 99, p.277-283, Japan 1999.

MENDES N., MENDONÇA K.C, SANCHEZ H.M. e FONSECA C.E.L., Simulação Computacional do Edifício Sede da TELEPAR: Analise Energética e Proposta de Retrofit, V Encontro Nacional de Conforto Térmico no Ambiente Construído/ENTAC e II Encontro Latino Americano de Conforto no Ambiente Construído, Fortaleza-CE, novembro de 1999.

MENDES N., ARAÚJO H.X. e OLIVEIRA G.H.C., O Problema do Controle de Temperatura em Aquecimento de Edificações, VIII Encontro Nacional de Tecnologia do Ambiente Construido (ENTAC 2000), Salvador, 2000a.

MENDES N., OLIVEIRA G.H.C e ARAÚJO H.X. , O Uso do Matlab/Simulink para Análise de Comportamento Térmico de Ambientes, VIII Encontro Nacional de Ciências Térmicas - ENCIT 2000, Porto Alegre, 2000b.

MENDES N., Sun, Rain and Moisture Influences on Conduction Cooling Loads, International Conference on Comfort and Thermal Performance of Buildings (COTEDI-2000), Venezuela, Junho, 2000c.

MENDES N., The Potential of Passive Latent Cooling in Brazil, XVII PLEA - Passive and Low Energy Conference, England, 2000d.

MENDES N., RIDLEY I. and LAMBERTS R., Conduction Heat Transfer through Porous Walls in Brazil, 34th National Heat Transfer Conference, ASME – American Society of Mechanical Engineers, Pittsburgh, Pennsylvania, August 20–22, 2000e.

PRESSMAN, R.S. "Engenharia de Software'; Makron Books do Brasil, 1995;

ROUX, J. J. Proposition de modèles simplifiés pour l'étude du comportement thermique des bâtiments, thèse de Docteur-Ingénieur, INSA de Lyon, Lyon – France, 1984.

WALTON, G. N.. Airflow network model for element-based building airflow modelling. ASHRAE Transactions. Vol. 95, part 2, p. 611-620, 1989.

WINKELMANN, F. C.; BIRDSALL, B. E. e BUHL, W. F.. DOE-2 Supplement Version 2.1, LBL - 34947. Lawrence Berkeley National Laboratory, EUA, 1993.