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A NEW CODE FOR THE HOUR-BY-HOUR THERMAL BEHAVIOR SIMULATION OF BUILDINGS

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ABSTRACT

This work presents the program SIMEDIF, a code conceived for the design and simulation of the thermal transient behavior of buildings, entirely developed at INENCO. Unlike other common programs, SIMEDIF does not calculate the needed auxiliary energy for indoor air conditioning from fixed indoor range of temperatures. In fact, the aim of the calculation is to obtain these indoor temperatures. SIMEDIF simulates the thermal behavior of *multiroom* buildings with natural and passive air conditioning systems and with indoor heat gains. It also evaluates the variations in the buildings behavior due to climatic and meteorological factors. Besides it facilitates the detection of problems in thermal comfort (overheating or low temperatures) inside the zones of the studied building.

INTRODUCTION

The study of building thermal performance by means of software simulation packages is increasingly being used to face real world problems in the design of energy efficient buildings. A great effort has been done on this aspect, and a wide variety of simulation programs is available. Some of these programs study only the steady-state situation, which is useful only at the earlier building design stage. Others offer simplified models and fail in accuracy, some are more sophisticated and detailed, thus their use on larger structures becomes difficult. As the number of users become wider, there is an increasing probability that a program will be used improperly or outside its range of applicability. SIMEDIF has been designed as a detailed input-data program, useful for pre-design stage, simulation, and adjusment of measured data. SIMEDIF has been conceived for Windows environment, user-friendly, flexible to allow users to add, remove, or modify the construction elements, materials, constructive systems, and meteorological data. SIMEDIF has an hour-by-hour temperature output for each room in the building, clear output graphic results, and it is quick to run.

SIMEDIF simulates the transient thermal behavior of *multiroom* buildings with natural and passive air conditioning systems and indoor heat gains. It also evaluates the variations in the building behavior due to climatic and meteorological factors, and facilitates the detection of problems on thermal comfort (overheating o low temperatures) inside the rooms of the studied building. It is a useful design tool in the evaluation of different geometrical alternatives in the construction of buildings, orientation, passive solar systems, or thermal properties of building materials. In fact, the use of SIMEDIF for pre-design enables the influence of building characteristics on thermal behavior to be studied parametrically, an analysis which would be too tedious and onerous to develop by experimental means. Moreover, by this code, conditions that are not experimentally reproducible can be studied, for example, by imposing arbitrary external climatic conditions. Thus, the building thermal performance in the more disadvantageous meteorological situations can be studied to determine the possible solutions if problems arise, and to facilitate the design decisions that have to be taken.

The DOS version of SIMEDIF (Casermeiro and Saravia, 1984) was developed at INENCO (Non Conventional Energy Research Institute). It has been largely validated throughout years of experimental work in Argentina by numerous groups that have used it for research, design, and simulation of the thermal behavior of buildings (Caso et al., 1986; Binda and Lesino, 1987; Hernández and Lesino, 1993; Reyes and Evans, 1993; Esteves et al., 1994; Beascochea and Filippín, 1998; Hernández et al., 1999; Hernández and Lesino, 2000). In all cases, comparison between the simulated transients of temperature and the experimental data confirmed the reliability of the numerical code.

The DOS version has been substituted by a new modern version for Windows with a user-friendly environment. Useful simplifications on the data input and final analysis have been made. Visual Basic language has been used for the code development. In the near future, two modules for evaporative cooling system and earth-to-air heat exchanger simulations will be added to this software.

INNOVATIVE ASPECTS OF SIMEDIF

At preliminary building design stage, steady-state models are often applied. These simplified models benefit the reliability and the calculation time, but they are poor in accuracy (Hong and Jiang, 1997). They are generally applied to preliminary building design and to estimate the annual energy requirements of a building. At this design stage SIMEDIF can be applied to simulate *transient* behavior of buildings. At this early stage the use of a dynamic model permits to obtain a more realistic and accurate response of the building.

Due to the coupling of air movement among the thermal zones of a building, the related zones have to be simultaneously simulated. One of the common characteristic of conventional simulation programs is that they can be applied in buildings with one or at most two thermal zones (Seminar, 1998; Nannei and Schenone, 1999) . For a large residential building this is a disadvantage, because of 10 or more zones are needed to describe the entire building. SIMEDIF can easily simulate up to 50 zones, with the subsequent compromise between accuracy and computational time.

The building simulation programs are often applied in the analysis of annual energy requirements and in the performance of building HVAC systems. Thus, the indoor temperatures can fluctuate inside a fixed comfort temperature range, as in the case of room air conditioning with thermostats. The situation in developing countries is quite different: the relatively low incomes of most of the population and the possibility of spending only small amounts of money on thermal comfort makes unrealistic the use of such air conditioning systems, and fixed indoor temperature-based programs are not useful. Thus, the necessity of a code that allows the freely fluctuation of the inner temperature becomes relevant. SIMEDIF have been designed to obtain these floating indoor temperatures and to provide a better description of this usual situation in our developing countries.

Detailed dynamic models benefit accuracy. These kind of programs require users to face a generally complicated and time-consuming data input. This is particularly true during the early phases when many crucial design decisions must be made. SIMEDIF simplifies this tedious work by an interactive data input, with helpful notes, data base on construction materials and empirical heat transfer coefficients, an assistant for navigation guide, a thematic help for a quickly information access, calculator, text editor, plot tools, maps, etc. The final result is expected to be sufficiently ductile to allow an inexperienced user to get profit the software capabilities without any additional complications, to save hours of bibliographic data searching, and to improve the tedious data input work.

For the simulation, the use of convective heat transfer coefficients of 6 W/m^2°C for inner non insolated surfaces and 8 W/m^2°C for inner insolated surfaces are recommended. Our experimental experience on building thermal simulation shows that these values give a more accurate adjust. This results in a more approximated simulation of real building thermal behavior than the usual value of 5.7 W/m^2°C. As usual, for outdoor surfaces the convective heat transfer coefficient is calculated from wind velocity. Another recommendation is to be very careful in the selection of certain storage masses that can be neglected to simplify the data input. Thermal mass is important for any building, but even more in the case of a building with passive solar heating and/or cooling. An inappropriate selection of these masses can give inaccurate results in indoor temperatures.

A general recommendation before simulating a building is to take time for a detailed and conscious study of the building geometrical and thermal characteristics to understand the building "physics". A previous comprehension of the possible thermal behavior of a building allows better simplification assumptions, a quicker data input, a more accurate simulation, a more satisfactory analysis of the results, and a more realistic identification of problems and their possible solutions.

ELEMENTS OF THE BUILDING DESCRIPTION

Each one of the elements which describes a building has special thermal characteristics that must be specified in detail during the data input, and with an intelligent combination of them it is possible to describe almost any usual building configurations.

The constructive elements that can be used for building description are:

- *Massive walls:* massive parallel faced constructive elements (as brick walls, roofs, etc.). Their structures may have various successive layers of different materials (each layer may be massive or not, except the two layers at the beginning and at the ending of the wall, which must have mass). The thermal contact between the wall surfaces and room air is described by means of complexive convective-radiative heat transfer coefficients. The wall surface may or may not receive solar radiation. An absorption coefficient α and the radiation area A_R describes this phenomenon.

- *Lightweight* w*alls:* opaque parallel faced constructive elements with negligible mass. They are characterized by thermal transmission and solar absorption coefficients (as in the case of metallic covers, wood doors, gypsum plates, etc.). A door predominantly closed must be considered a lightweight wall.

- *Water walls:* rectangular parallelepiped tank of width "*d*", filled with water and placed in front of a solar aperture. Water is mixed by natural convection and therefore a uniform temperature is assumed. There is some question about how isothermal the water is in tanks, but vertical stratification is considered to have little influence on performance (Balcomb, 1992).

- *Windows:* parallel faced constructive elements connecting two zones by means of thermal transmission coefficients that can vary from day to night. This allows to simulate night insulation due to the use of wickets, curtains, roll-down blinds, etc. The *windows* elements are neither associated to solar gain (which in fact must be considered in the wall radiation areas) nor to ventilation (which is considered in the air renewals).

- *Doors:* connection openings between zones that allow a convective air exchange. Their dimentions are those of the wall openings for doors and windows. A closed door is not a *door* but a *lightweight wall*. The heat transfer coefficient is a function of the temperature difference between the zones connected by the door under consideration. The door sheet position is described by means of a discharge coefficient C_D.

- *Vents:* openings on the top and bottom of a wall that allow the air circulation from a hotter zone to a colder one due to natural convection. Their characteristics are the opening area and the distance between the top and bottom vent centers. Vents work as thermal diodes and are important in Trombe wall description. The air movement is unidirectional (from hotter to colder zone), unlike a *door*, in which the convective exchange is bidirectional.

The radiation data input is global daily energy flux on a horizontal surface. Hourly data on surfaces of other slopes and/or orientations are calculated with Liu-Jordan model and Collares Pereyra-Rabl correlations. The *radiation index* and the *radiation area* refer to the orientation, slope, and area of the surface. The absorption coefficient takes into account the energy effectively absorbed by the wall surface.

Hourly radiation data input on a horizontal surface is also possible. In that case, hourly data on other surfaces are calculated by the code.

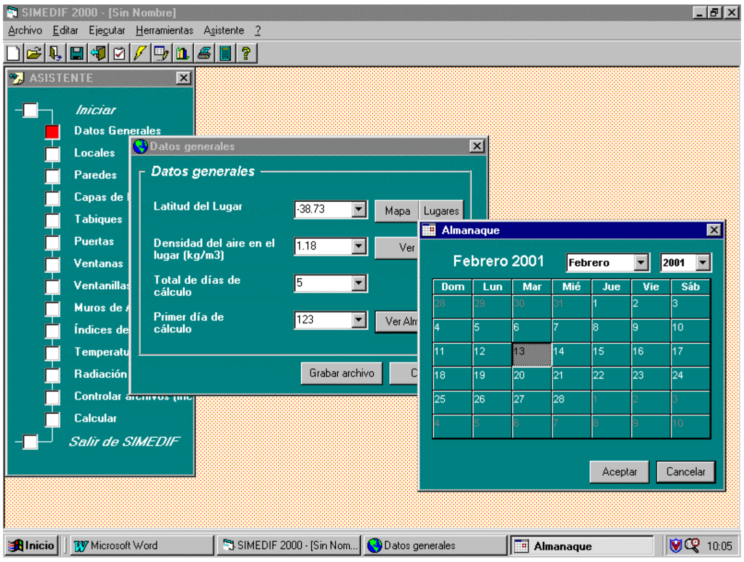
The geometrical data and thermal properties that must be entered for each element are presented in Table 1.

Table 1: simulation data input.

Elements	***Characteristical inputs***
Zone	Name, volume and air renewals of the zone.
Massive wall	Area and number of layers of the massive wall. Absorption coefficient, convective-radiative coefficient, radiation area, and radiation index for both sides of the wall.
Lightweight wall	Area and conduction coefficient of the lightweight wall. Absorption coefficient, convective-radiative coefficient, radiation area, and radiation index for both sides of the lightweight wall.
Water wall	Area and thickness of the water wall. Absorption coefficient, convective-radiative coefficient, radiation area, and radiation index for both sides of the water wall.
Window	Area, day and night coefficients.
Vent	Area and discharge coefficient of the vents, placing of the top vent damper, and distance between the centers of the top vent and the bottom vent.
Door	Length, width, and discharge coefficient of the door, opening and closing hours.

Radiation Index	Slope, azimuth, albedo, number of covers, cover refraction index, cover extinction coefficient, cover thickness.
Wall Layers	Conductivity, density, specific heat, thickness, and number of nodes of each layer.
Radiation Data	1) Mean Daily Radiation (Liu Jordan method), or 2) File data input.
Temperature Data	1) Daily maximum and minimum temperatures; 2) Mean daily maximum and minimum temperatures and Fourier coefficients, or 3) File data input.
General Data	Latitude, air density, number of simulated days and first simulation day.

In Fig. 1 and Fig. 2 both a data-input screen and a graphic output are shown.



Datos generales

Latitud del Lugar: -38.73

Densidad del aire en el lugar (kg/m3): 1.18

Total de días de cálculo: 5

Primer día de cálculo: 123

Almanaque: Febrero 2001 — Febrero, 2001

Dom	Lun	Mar	Mié	Jue	Vie	Sáb
28	29	30	31	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	1	2	3
4	5	6	7	8	9	10

Fig. 1: a view of a SIMEDIF data-input screen.

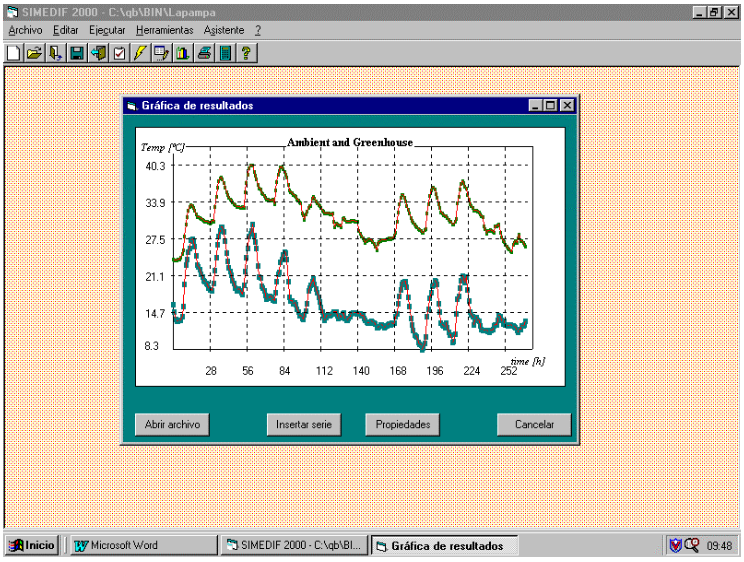


Fig. 2: a graphic output of SIMEDIF results.

It is possible to introduce auxiliary gains as electric o gas heaters, intervals of opened and close doors, etc. For the building materials there exists a data base with the usual thermal properties. Because of the lack of hour-by-hour ambient temperature and solar radiation data in many locations, the user can evaluate these variables by means of the maximum, minimum, and mean daily ambient temperatures and the mean daily solar radiation.

MATHEMATICAL MODEL

The numerical program has been developed under the following assumptions:

1. The heat fluxes through the walls are considered unidirectional.

2. The heat transfer between the indoor air and the inner surfaces of massive, water, and lightweight walls is of convective nature.

3. The convective-radiative heat transfer coefficients of the surfaces account for convection and radiation. Radiation is therefore linearized.

4. No view factors are taken into account in the computation of radiant energy exchange between surfaces.

5. The temperature distribution at the starting time is known.

6. Solar incident radiation on any wall is uniformly spread over all the wall surface.

7. Heat transfer due to air humidity is negligible, thus a mass balance is not necessary.

The simulated building is divided into “zones”. A “zone” is a building space that can be considered isothermal (thus a zone can be a group of various rooms in the building or a part of a room). Thus, each zone has a unique temperature whose temporal evolution is determined by the code, using the building data, materials, siting, orientation, ambient temperature, and solar radiation in the simulation period. Those zones are connected to each other and with the environment by elements that have any of the following thermal characteristics:

- Storage and heat transfer by conduction, such as brick walls, adobe walls, concrete walls, etc. These elements are called *massive walls*.

- Storage into a uniform temperature mass such as water walls where the water is supposed to convect and has a uniform temperature.

- Heat transfer by conduction without storage, such as wood, expanded polystyrene, etc. In SIMEDIF, these elements are called *lightweight walls*.

- Heat transfer by conduction with two heat transfer coefficients (day and night), such as windows with night insulation. These elements are called *windows*, and they do not describe to solar gain or ventilation.

- Heat transfer by convection, such as openings in the walls that allow a convective air exchange. These elements are *doors* and *vents* in SIMEDIF.

An energy balance is expressed at each node for which the temperature is to be determined. These nodes are of two different types: massive nodes (i.e., the nodes on massive walls and water walls) and nonmassive nodes (i.e., the nodes on air and lightweight walls).

a) Energy balance for massive nodes

Typically, a mass element is represented as one-dimensional and is sliced into a number of layers of thickness *Δx* (inner nodes) and *Δx/2* (edge nodes).

The inner and surface massive nodes of a wall are separately analyzed (see Fig. 3).

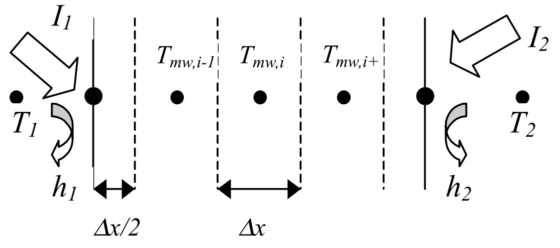


Fig.3: massive wall discretization.

An energy balance on the inner nodes gives:

$$\rho_{wall} c_{pwall} \frac{\partial T_{mw,i}}{\partial t} = k_{wall} \frac{\partial^2 T_{mw,i}}{\partial x^2} \qquad (1)$$

while an energy balance on the surface left node gives:

$$\begin{aligned} &\rho_{wall} c_{pwall} A_{wall} \frac{\Delta x}{2} \frac{\partial T_{mw,i}}{\partial t} = \\ &\alpha_1 I_1 A_1 - h_1 A_{wall} (T_{mw,i} - T_1) + \qquad (2) \\ &-\left(- k_{wall} A_{wall} \frac{\partial T_{mw,i}}{\partial x} \right) \end{aligned}$$

The finite-difference explicit method is used to replace the time and spatial derivatives by finite differences.

The result is a set of equations for *m* massive nodes. The temperature at time $t + \Delta t$ can be evaluated from temperatures at the previous time *t*. This set of equations constitutes an initial value problem. Initial conditions, consisting of the starting storage mass temperatures and air temperatures, must be specified.

<u>a) Energy balance for nonmassive nodes</u>

There are two kinds of nonmassive nodes: the nodes on lightweight walls and the nodes on air. The temperatures at the nodes of lightweight walls can be eliminated (dissolved) by combining the conductances between the node and the air into a single conductance. Thus, the energy balance for an air node, referred to the control volume of the zone, considers energy contributions due to indoor heat sources, and losses and gains due to the elements which connects a zone to another:

$$\begin{aligned}
&\frac{\rho c_p V_i N_i}{3600}\left(T_i^t - T_{amb}^t\right) = Qaux_i^t + \\
&+\sum_{k=1}^{Nloc}\sum_{lw=1}^{Nlw} I_{lw,i,k}^t \alpha_{lw,i,k}\, frac_{lw,i,k} + \\
&+\sum_{k=1}^{Nloc}\sum_{lw=1}^{Nlw} I_{lw,k,i}^t \alpha_{lw,k,i}\, frac_{lw,k,i} + \\
&-\sum_{j=1}^{Nmw} h_{mw,j,i} A_{mw,j}\left(T_i^t - T_{mw,i}^t\right) + \\
&-\sum_{k=1}^{Nloc}\sum_{j=1}^{Nlw} U_{lw,j,i} A_{lw,j}\left(T_i^t - T_k^t\right) + \\
&-\sum_{j=1}^{Nww} h_{ww,j,i} A_{ww,j}\left(T_i^t - T_{ww,i}^t\right) + \\
&-\sum_{k=1}^{Nloc}\sum_{j=1}^{Nwin} C_{win,j}^t A_{win,j}\left(T_i^t - T_k^t\right) + \\
&+\sum_{k=1}^{Nloc}\sum_{j=1}^{Nvent} C_{vent,j}\left(T_i^t - T_k^t\right)^{3/2} + \\
&+\sum_{k=1}^{Nloc}\sum_{j=1}^{Ndoor} C_{door,j}\left(T_i^t - T_k^t\right)^{3/2}
\end{aligned} \tag{3}$$

In this equation the summatory in k indicates a sum over all zones *k* in contact with zone *i*., and the supraindex *t* indicates the hourly value for the referred quantity. $U_{lw,j,i}$, $C_{vent,j}$, $C_{door,j}$, $frac_{lw,i,k}$ and $C_{lw,j}$ are given by the following expressions:

$$U_{lw,j} = \frac{h_{lw,j,i} h_{lw,j,k} C_{lw,j}}{h_{lw,j,i} C_{lw,j} + h_{lw,j,k} C_{lw,j} + h_{lw,j,i} h_{lw,j,k}} \tag{4}$$

$$C_{vent,j} = A_{vent,j} c_p \rho C_{Dvent,j} \sqrt{\frac{g H_{vent,j}}{\theta_{vent,j}}} \tag{5}$$

$$C_{door,j} = 62{,}66 W_{door,j} \frac{C_{Ddoor,j}}{\sqrt{\theta_{door,j}}}\left(H_{door,j}\right)^{3/2} \tag{6}$$

$$C_{lw,j} = \frac{k_{lw,j}}{W_{lw,j}} \tag{7}$$

$$frac_{a,b,c} = \frac{h_a^b C_a + h_a^b h_a^c}{h_a^b C_a + h_a^c C_a + h_a^b h_a^c} \tag{8}$$

Equation (3) can be repeated for each building zone. The result is a set of equations for *n* nonmassive nodes. Thus, a system with as many equations as unknown variables is obtained and solved with the usual numerical techniques. Because of the non-linearity of the coefficients, iterations are performed until the convergence is achieved.

The calculation method consists of an explicit finite difference scheme advancing in Δt steps, with Δt a submultiple of one hour (its value is chosen during the data input). The results are saved hour by hour in a file. By using the temperature values at time *t* and the finite-defference explicit method, the temperatures at $t + \Delta t$ in the massive nodes are calculated. These temperatures are introduced in the system of nonmassive nodes to obtain the temperatures at $t + \Delta t$. Once all the nodal temperatures are estimated, a balance of the heat gain provided by the solar radiation, the heat loss of the building, and the heat accumulated in the different masses is performed. These calculations allow the detection of possible problems with the input data.

The use of the explicit finite difference scheme restricts the possible values of Δt to avoid oscillations in the numerical solutions. This instability cause the calculated node temperatures to oscillate with increasing error in each step, which is a common error when using finite-difference algorithms. Until now, in all the studied cases adequate choices of Δt have been possible.

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CONCLUSIONS

Numerical programs greatly facilitates the study of thermal transients in buildings, which is very important both for evaluating heating and/or cooling energy requirements and for achieving environmental comfort conditions.

The program SIMEDIF presented in this work enables the transient thermal behavior of *multiroom* buildings to be analyzed as a function of the building structure thermophysical characteristics, of the inner heat gains supplied to the building, of the air renewals, of the building siting, and of the external climatic conditions.

SIMEDIF is a useful tool for the designer, who has to face many considerations, usually conflicting, in the preliminar design stages, as the evaluation of different geometrical alternatives in the building construction, orientation, passive solar systems to be applied, or materials to be used. In addition, SIMEDIF is useful to simulate and adjust measured data, and to detect problems in thermal comfort inside the rooms of the studied building.

Unlike other common programs, SIMEDIF does not calculate the needed auxiliary energy for indoor air conditioning from fixed indoor range of temperatures, but allows the freely fluctuation of the inner temperatures. This is a better description of the usual situation in our developing countries, in which there are no possibilities of spending large amounts of money on air conditioning systems or improving the thermal comfort.

REFERENCES

Beascochea A. and C. Filippín, "Un edificio solar pasivo para la Universidad Nacional de La Pampa", Avances en Energías Renovables y Medio Ambiente, Vol.2 Nº1, Argentina, 1998.

Balcomb J., "Passive Solar Buildings", MIT Press, London, 1992.

Binda A. and G. Lesino, "Simulación computacional del comportamiento térmico de edificios para verano", Proc. 12 ASADES, Buenos Aires, Argentina,1987.

Casermeiro M. and L. Saravia, "Cálculo Térmico Horario de Edificios Solares Pasivos", Proc. 9º ASADES, San Juan, Argentina, 1984.

Caso R., Lesino G. and L. Saravia, "Mediciones de edificios solares en Cachi y Abdón Castro Tolay", Proc. 11 ASADES, San Luis, Argentina, 1986

Esteves A., Fernández J., Basso M., Mitchel J. and C. de Rosa, "Simulación térmica de edificios: aplicación de los modelos Quick y SIMEDIF", Proc. 17º ASADES, Rosario, Argentina, 1994.

Hernández A. and G. Lesino, "Análisis de la performance térmica de un prototipo de vivienda liviana: monitoreo y simulación macrodinámica. Parte I", Proc. 16 ASADES, La Plata, Argentina, 1993.

Hernández A., Flores S., Salvo N. and G. Lesino, "Simulación no estacionaria mediante SIMEDIF del ala oeste del edificio de Agronomía de la Universidad Nacional de La Pampa", Avances en Energías Renovables y Medio Ambiente,Vol.3 Nº2, Argentina, 1999.

Hernández, A. and G. Lesino, "Simulación mediante SIMEDIF del comportamiento térmico de un prototipo de vivienda liviana construido en la Universidad Nacional de Salta", Avances en Energías Renovables y Medio Ambiente, Vol.4 Nº2, Chaco, Argentina, 2000.

Reyes J. and J.M. Evans, "Normas de aislación e inercia térmica. Desarrollo y aplicación. Reporte Final", Proc. 16 ASADES, La Plata, Argentina, 1993.

Nannei, E. and C. Schenone, "Thermal transient in buildings:development and validation of a numerical model", Energy and Buildings, Vol. 29(3), 1999.

Hong, T. and Y. Jiang, "A new multizone model for the simulation of building thermal performance", Building and Environment, Vol. 32(2), 1997.

"Designing Low-Energy Buildings with Energy-10 Seminar", Passive Solar Industries Council, University of New Mexico, 1998.

NOMENCLATURE

$A_{vent,i}$	Vents *i* area in m^2
$A_{win,i}$	Window *i* area in m^2
$A_{ww,i}$	Waterwall *i* area in m^2
$C_{Ddoor,i}$	Door *i* discharge coefficient
$C_{door,i}$	Door *i* coefficient, given by Eq.(4)

$C_{Dvent,i}$	Vent *i* discharge coefficient
$C_{lw,i}$	Lightweight wall *i* coefficient, Eq. (7).
c_p	Air specific heat to constant pressure
$C_{vent,i}$	Vent *i* coefficient, given by Eq.(3)
$C^t_{win,i}$	Window *i* coefficient for time *h*.
g	gravity acceleration (9,81 m/s^2)
$H_{door,i}$	Door *i* height, m
$H_{vent,i}$	Vent *i* height, m
$h_{lw,j,i}$	Convective-radiative coefficient for *i* side of lightweight wall *j*, W/m^2°C
$h_{mw,j,i}$	Convective-radiative coefficient for *i* side of massive wall *j*, W/m^2°C
$h_{ww,j,i}$	Convective-radiative coefficient for *i* side of waterwall *j*, W/m^2°C
$I^t_{lw,j,i}$	Solar radiation on *i* side of lightweight wall *j* for time *t*, W/m^2°C
$k_{lw,j}$	Conductivity of lightweight wall *j*, W/m °C
N_{door}	Number of doors in the building
N_i	Air renewals for zone *i*, 1/h
N_{loc}	Number of zones in the building
N_{lw}	Number of lightweight walls in the building
N_{mw}	Number of massive walls in the building
N_{vent}	Number of vent pairs in the building
N_{win}	Number of windows in the building
N_{ww}	Number of water walls in the building
$Qaux^t_i$	Inner heat gain for zone *i* in time *t* (W)
t, Δt	time and time step.
T^t_{amb}	Ambient temperature for time *t*
T^t_i	Temperature of zone *i* for time *t*
$T^t_{ww,i}$	Temperature of waterwall *i* for time *t*
$U_{lw,i}$	Conductance of lightweight wall *i*, Eq. (4)
V_i	Volume of zone *i* in m^3
$W_{door,j}$	width of door *j* in m
$\alpha_{lw,i,j}$	Absorption coefficient of ligtweight wall *j*, side *i*.
$\theta_{vent,j}$	Mean absolute air temperature of the zones connected by vent *j*, ºK
$\theta_{door,j}$	Mean absolute air temperature of the zones connected by door *j*, ºK
ρ	Air density, kg/m^3.

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