# MEASUREMENT AND SIMULATION OF THE THERMAL BEHAVIOR OF A MASSIVE BUILDING WITH PASSIVE SOLAR CONDITIONING

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## ABSTRACT

The measured thermal behavior of a massive building that uses passive techniques for indoor air conditioning is presented. The building thermal transient behavior was simulated with SIMEDIF code. The measured mean indoor temperatures fall between 20 and 23.5ºC, while the outdoor temperature is around 15ºC. Because of the symmetry of the building with respect to the north-south plane, the assumption that there is no heat flux between east and west wings has been made. Measured data set and simulated data set are both in good agreement. Thus, the assumed symmetry hypothesis was appropriated and the great potentiality of SIMEDIF code for transient simulation behavior was proved.

## INTRODUCTION

Passive solar techniques include solar heating, natural ventilation, daylighting, storage in thermal mass, ground cooling, etc. The use of passive solar design integrated with other conventional strategies benefits buildings like banks, offices, schools, stores, residences, and others. They are more comfortable and environmentally-friendly, they increase occupant health and productivity, and use less energy than their conventional counterparts (Cook, 1989).

The energy needs of a particular building vary with its size, complexity, siting, and climate of the region (Seminar, 1998). The building studied in this work uses passive techniques to provide a comfortable working place with reduced conventional energy requirements.

The thermal building simulation has been made with SIMEDIF code (Casermeiro and Saravia, 1984). SIMEDIF allows to simulate the thermal behavior of *multiroom* buildings with natural and passive air conditioning systems and indoor heat gain. The code also evaluates the variations in the building behavior due to climatic and meteorological factors (Flores Larsen and Lesino, 2000). SIMEDIF was designed as a detailed input-data program, useful for pre-design stage, simulation and for measured data adjustment. The program runs on a user-friendly Windows environment, it is flexible to allow users to add, remove, or modify the construction elements, materials, constructive systems, and meteorological data. 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.

Numerous groups in Argentina have used SIMEDIF for research, design, and simulation of thermal behavior of buildings (Caso et al., 1986; Binda and Lesino, 1987; Reyes and Evans, 1993; Esteves et al., 1994; Hernández and Lesino, 1993). The user is able to choose among materials or constructive systems during the first stages of the design process. SIMEDIF calculates the hour-by-hour temperature of each zone in the building in a relatively short computational time.

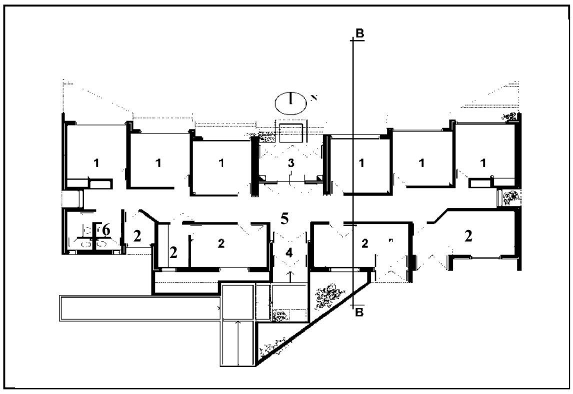
## BUILDING DESCRIPTION

The studied building is a section of the Agronomy Department at the National University of La Pampa, Argentina, and there are research offices in it. Its total covered area is 315 $m^2$ and its volume is 631.5 $m^3$. Figs. 1 and 2 show the plant and a cross view of the measured building. There are six offices, five laboratories, a bathroom, a greenhouse, and a central corridor in the building. Offices are marked with number 1, laboratories with number 2, the greenhouse with 3, the access with 4, the corridor with 5, and bathrooms with 6.

The building has north windows for receiving direct solar gain in winter months, a clerestory with a window for solar gain and daylighting in the lab 2 (see Fig. 2), buried pipes for ventilation and air cooling in summer period, and peripherical insulation in the building envelope.

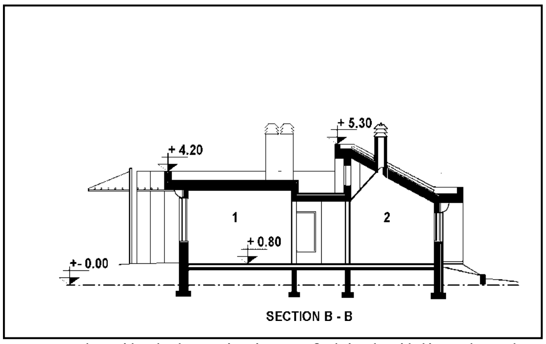
The buried pipes system is made of three brick drainage pipes (0.2 m height and 0.4 m width), with lengths between 4 m and 12 m, buried in the soil at 0.8m depth. The outlet of the pipes that emerge from the soil are connected with the offices and lab 2.

Fig 1: plant view of the studied building (La Pampa,




Argentina).

Fig. 2: north-south cross plane view.




A more detailed description of this building has been made in an earlier work (Filippín and Beascochea, 1998).

## MEASUREMENT

The measurements were performed on the north-west side of the building. In Fig. 1, from left to right: office 1, office 2, office 3, and the greenhouse (north side); bathroom, lab 3, lab 1, lab 2 (south side), and the central corridor were simulated. Lab 1 has not been monitored. Over a whole winter week from March 25$^{th}$ to April 1$^{st}$ and every fifteen minutes solar radiation, ambient temperature, wind velocity and direction, indoor zone temperatures, indoor and outdoor duct temperatures, and indoor duct humidity were measured. These variables were measured with a data-acquisition system, consisting of 4 NUDAM modules connected to a laptop PC (16 channels with T-thermocouples for temperature measurements and 16 channels with voltage inputs), with pyranometers, anemometers, and humidity sensors.

During the measuring period the offices and labs were occupied by the professors and researchers. Thus, the building thermal behavior in real working conditions was analyzed. This occupation modified the environment by the addition of metabolic heat, electrical origin (computers), and lights for illumination. It also increased the air mixing due to openings and closings doors. Besides, the professors included an aleatory factor on solar gains: they used roll-down blinds to decrease the illumination levels in their offices. During the measurement period biological experiments on growing plants at the greenhouse were made. These experiments required seven lamps of 250W to be turned on (an additional thermal load of 1750W). It was necessary to take into account the on/off situation of the lamps through an hour-by-hour data input.

## SIMULATION

The building was considered symmetric respect to the north-south plane. This is equivalent to assume that there is no heat flux between east and west wings. Therefore an imaginary adiabatic thin wall was included in the simulation. Thus, the number of thermal zones to simulate is reduced to nine: office 1, office 2, office 3, lab 1, lab 2, lab 3, the greenhouse, the central corridor, and the bathroom.

The simulation was made hour-by-hour with SIMEDIF (Flores Larsen and Lesino, 2001), a program developed at INENCO (Non Conventional Energy Research Institute), Argentina, for passive building design and simulation of transient thermal behavior of buildings.

To simulate a building with SIMEDIF, it is divided into "zones", building spaces that can be considered isothermal (thus a zone can be a group of various rooms in the building or a part of a room). 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" like *massive walls* (as a brick wall, an adobe wall, etc.), *windows*, *lightweight walls* (as wood, expanded polystyrene, etc.), *doors* (connection openings between zones that allow a bidirectional convective air mixing), *vents* (wall openings that allow unidirectional air exchange, like those in Trombe walls), and *water walls* (tanks filled with water and placed in front of a solar aperture). The characteristics of these elements are specified in a very detailed manner during the data input. With certain combination of these elements it is possible to describe almost any usual building configuration. Also it is possible to introduce auxiliary gains as electric or gas heaters, intervals of opened and closed doors, night protection for windows, etc. There is a data base of building materials and their 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. The hourly radiation is estimated from mean daily data by the Liu-Jordan method (Duffie and Beckman, 1991). There are two ways to estimate the hourly temperatures from mean daily data with SIMEDIF: by using a sine-exponential approach for arid climates, or by using a four-term Fourier model (Flores Larsen and Lesino, 1999).

Convective-radiative heat transfer coefficients of 8 W/m$^2$ºC and 6 W/m$^2$ºC (with and without solar gain respectively) were imposed on the floor and the walls inside the building. The usual value of 5.7 W/m$^2$ºC obtained from the dimensional equation for flat plates exposed to winds (Duffie and Beckman, 1991).

$$h = 5.7 + 3.8v \qquad (1)$$

where $v$ is the wind speed in m/s and $h$ is in W/m$^2$ºC, was not used. Our experimental experience on building thermal simulation shows that heat transfer coefficients of 6 and 8 W/m$^2$ºC give a more accurate adjustment (Caso et al., 1986; Esteves et al., 1994; Beascochea and Filippín, 1998; Hernández and Lesino, 2000), and a better approximation to real building thermal behavior. The measured mean wind velocity was 1.6 m/s, thus a heat transfer coefficient of 12 W/m$^2$ºC was imposed at the outside wall surfaces. The geometrical data and thermal properties of materials were obtained from the construction planes of the building and common material properties tables. The adjustment variables were the air renewals $N_R$ and the radiation areas $A_R$ (mean area on which solar radiation incides), whose optimum values are presented in Table 1 together with the volume $V$ of each zone.

In the simulated building, the insolated rooms were offices, 1, 2, and 3, the greenhouse, and the labs 1 and 2. Because the occupation of the building, to evaluate the real wall areas exposed to solar radiation it was necessary to take into account the rolling level of the window blinds. The central corridor has not ventilation ducts and it is connected to the environment by a window and a leakproof door, thus the air renewals for this corridor was set to zero. The adjustment of the air renewals in the three offices allowed to approach the buried pipes effect. The thermal behavior of the buried pipes was analyzed and simulated in a previous work (Flores Larsen and Lesino, 2001) but the ground-to-air heat exchangers module has not been integrated yet to SIMEDIF. This work will be done in a near future.

The use of buried pipes involves the ground as heat source or heat sink. The ground has a large thermal inertia, which must be considered when the ground is used in large periods of time, as in seasonal storage. In the studied case, the assumption that the buried pipes don't affect the temperature distribution of the soil was made. The constructive and experimental data show that the buried pipes have ventilation functions more than air heating/cooling functions.

Table 1: volume V, air renewals $N_R$ and radiation areas $A_R$ for each zone.

| | $V$ [m$^3$] | $N_R$[1/h] | $A_R$ [m$^2$] |
|---|---|---|---|
| Office 1 | 42.14 | 2 | 3 |
| Office 2 | 42.14 | 2 | 4.5 |
| Office 3 | 42.14 | 1 | 1 |
| Bathroom | 18,36 | 1.5 | 0 |
| Lab 1 | 21.66 | 1.5 | 2.5 |
| Lab 2 | 47.65 | 1.5 | 6 |
| Lab 3 | 10.42 | 1 | 0 |
| Corridor | 72.14 | 0 | 0 |
| Greenhouse | 17.26 | 3 | 5.75 |

When simulating a building in transient regime, initial conditions must be specified (i.e. room temperatures, wall temperatures, and so on). In addition, due to the thermal inertia of all massive buildings, a previous simulation period is necessary to reach the periodic regime.

A gross estimation of the building thermal inertia indicates that a five day period of repeated climatic conditions gives a good approximation of the node temperatures in a periodic regime.

To simulate the results obtained in the monitored week, a previous set of five days was calculated. The meteorological data for this period (not monitored) were provided by a meteorological station next to the University campus.

Once the indoor calculated temperatures in the previous period adjusted with the measured indoor temperatures in the first day of measurements, the simulation for the monitored period was performed.

## RESULTS

The measured ambient temperature, solar radiation and wind velocity for the monitored period are presented in Fig. 3. There are four sunny days and four cloudy days. The week previous to starting the measurements was sunny, and the temperature and radiation data for this period were obtained from a meteorological station next to the university campus.

A measured data set and SIMEDIF simulation for the building zones were taken from March $25^{th}$ to April $1^{st}$. They are presented in Figures 4-7.

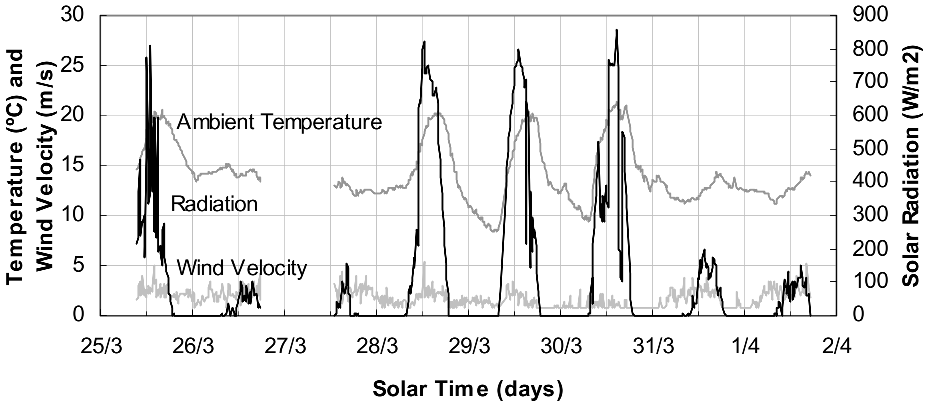



Fig. 3: measured ambient temperature, global solar radiation on a horizontal surface and wind velocity for La Pampa, Argentina.

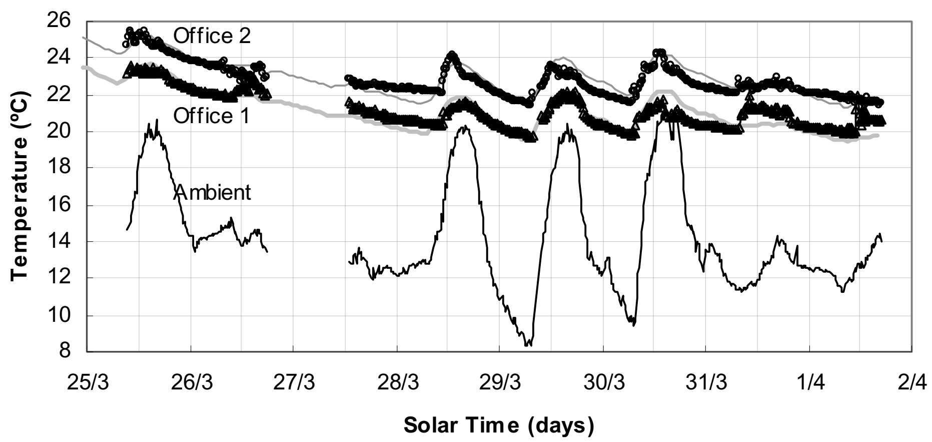



Fig. 4: measured and simulated data for Offices 1 and 2.

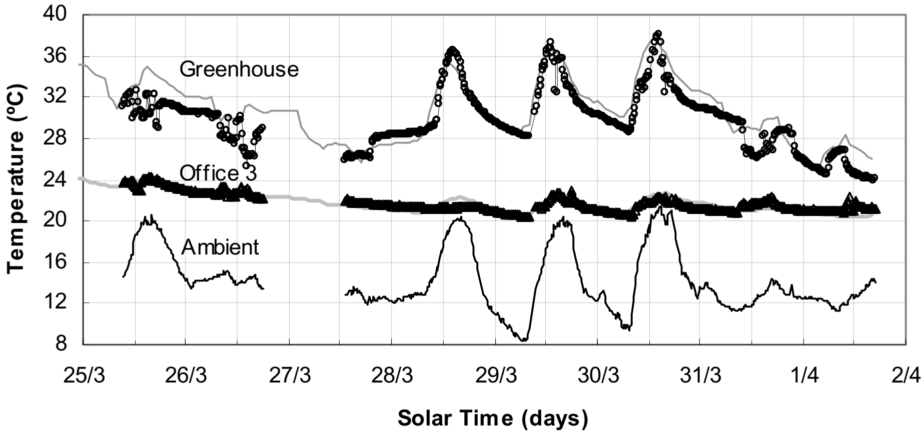



Fig. 5: measured and simulated data for Greenhouse and Office 3.

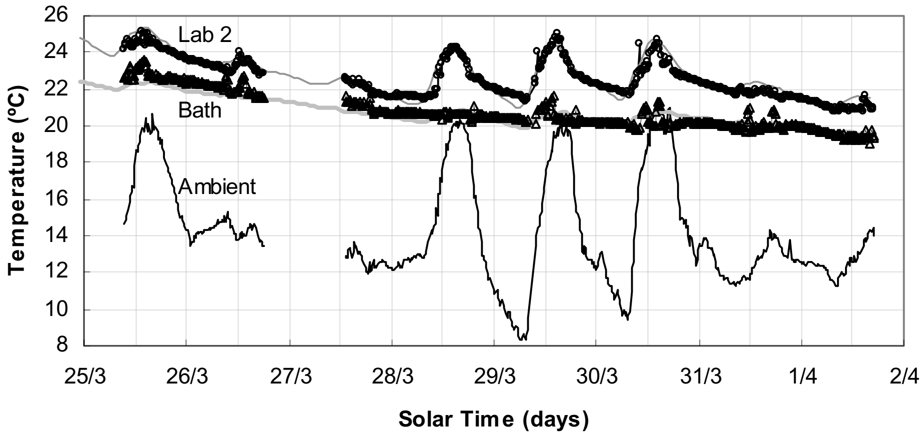



Fig. 6: measured and simulated data for Lab 2 and Bathroom.

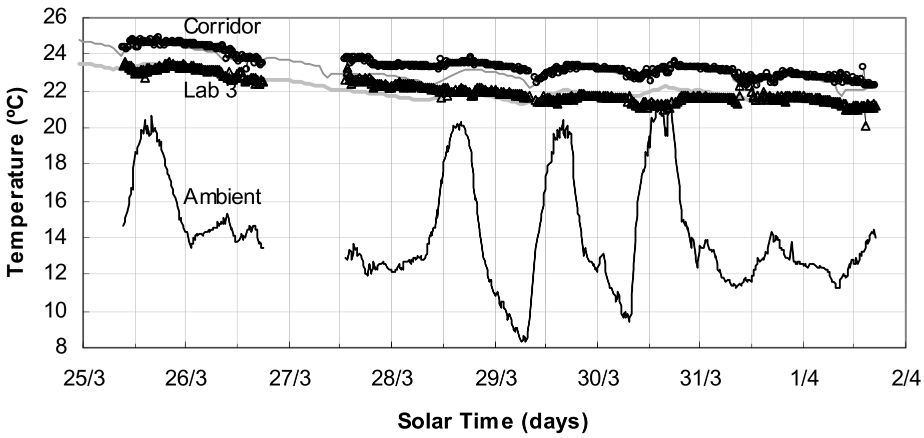



Fig. 7: measured and simulated data for lab 3 and corridor.

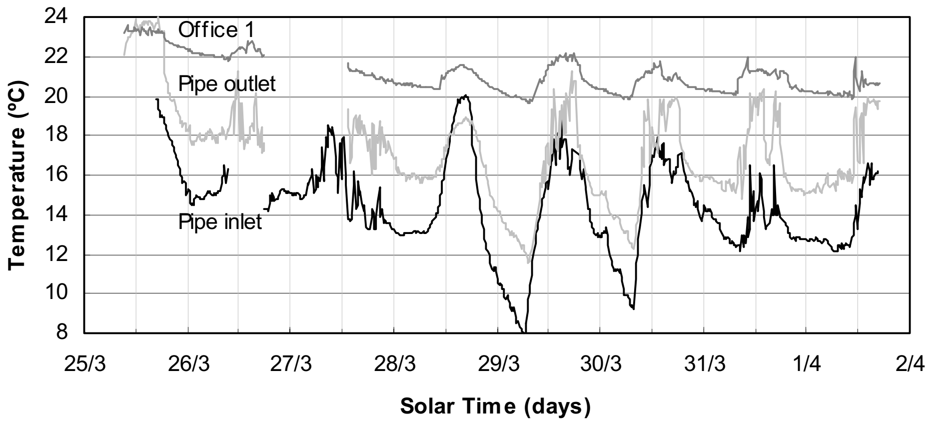



Fig. 8: pipe inlet and outlet temperatures for Office 1.

## ANALYSIS

In all the plots the interrupted sectors correspond to out of service equipment periods. The mean temperatures during the measuring period are shown in Table 2.

Table 2: solar gain and mean temperature of the zones.

| Zone | Mean temperature | Solar gain |
|---|---|---|
| Office 1 | 21.1 | Yes |
| Office 2 | 22.7 | Yes |
| Office 3 | 21.7 | Yes |
| Bathroom | 20.7 | No |
| Lab 2 | 22.5 | Yes |
| Lab 3 | 21.9 | No |
| Corridor | 23.3 | No |
| Greenhouse | 29.6 | Yes |

Office 1 is the coldest one because two of its walls are in contact with air at ambient temperature. Office 2 (between office 1 and office 3) is the hottest of them. A verification of no auxiliary energy gains was made, except the lighting and a computer with no-permanent use.

The bathroom with a mean temperature around 21ºC and negligible thermal amplitude is the coldest zone in the building. This is because the bathroom is south-oriented and its two walls are in thermal contact with outdoor air. The hottest room is the greenhouse with a mean temperature around 30ºC and 8ºC of thermal amplitude. The greenhouse is orientated to north and it riceives direct solar gain. The effect of the seven lamps of 250W each one increases 2ºC the mean temperature of the zone. The simulation shows a greater coupling than the observed between the greenhouse and the central corridor (separated only by a glass panel).

The effect of the solar gain throughout the clerestory is visualized in lab 2, with a mean temperature of 23ºC during the three sunny days and an amplitude of 3ºC. Lab 3 has no solar gain, a mean temperature of 21ºC and negligible thermal amplitude during the same sunny period.

In Fig. 8, the effect of buried pipes for office 1 is shown (the output of the pipe is the input into this office). Almost all the time the buried pipe outlet air temperature is greater than the inlet pipe air temperature. The mean temperature difference between pipe inlet and outlet is around 2ºC. By means of smoke lines, it has been seen an aleatory air movement, incoming and outgoing from the office. The air temperature incoming into the office oscillates considerably during windly daylight periods.

The agreement between simulated and measured data is around 1ºC in the three offices (except in the first hours due to the greater radiation contribution), the bathroom, and lab 2 (see Figs. 4, 5, and 6) with a good prediction of the mean temperatures, the amplitudes, and the hours of maxima and minima temperatures. The mean, maxima and minima simulated temperatures of the greenhouse agree with the experimental data set. Fig. 7 shows a good agreement for the central corridor and lab 3. This demonstrates the adequacy of the adiabaticity hypothesis in the mean plane of the building.

## ACKNOWLEDGEMENTS

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## CONCLUSIONS

The west side of the Ecology Sector of the Agronomy Department at the National University of La Pampa was measured and simulated.

The building uses passive techniques for indoor air conditioning: north windows for direct solar gain in winter months, a clerestory with a window for solar gain in the lab 2, buried pipes for ventilation and air cooling in summer periods, and peripherical insulation.

The building was monitored under real working conditions when people were using the offices and labs.

Because of the solar gain and the peripherical building insulation, the mean indoor temperatures of all the building offices and labs obtained from measured data fall between 20 and 23.5ºC, with an ambient mean temperature around 15ºC. People's opinions are that the building is thermally comfortable, that the effect of buried pipes is greatly refreshing during summer period, and that there is not neccessary the use of additional heaters in winter.

The assumed symmetry hypothesis is appropriated in the simulation with SIMEDIF. The measured data set is in very good agreement with the simulated data set, with a maximum difference of the order of 1ºC. Using five previous days the initial measured conditions was achieved. With these initial values an analysis of the transient behavior in the next seven days was performed. The success in the achievement of these initial conditions and the simulation of the non-steady building behavior, with sunny and cloudy days, have proved the great potentiality of SIMEDIF code, whose usage is usually limited to steady meteorological conditions in the building-design stage.

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## NOMENCLATURE

$A_R$ Radiation area ($m^2$). The mean wall area on which incides solar radiation.

$h$ Convective-radiative coefficient, $W/m^2$.

$N_R$ Air renewals, 1/h.

$v$ wind velocity, m/s.

$V$ Volume of a room, $m^3$.

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