MEASUREMENT AND NUMERICAL SIMULATION BY MEANS OF SIMEDIF OF A LIGHT CONSTRUCTION BUILDING LOCATED IN THE ARGENTINEAN NORTHWEST

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ABSTRACT

In this work, the results obtained during the monitoring of a building together with the adjustment curves achieved with the numeric simulation program SIMEDIF are presented. SIMEDIF has been developed in the INENCO (Non Conventional Energy Research Institute), Salta, Argentina,. In the measured data (from 1 to Aug. 4, 1997) the light weight character of the construction is evidenced by the lack of an appreciable phase out between the interior and the external temperature. The expected dissimilar behavior between the rooms facing South and North was observed. During the day, the warmest room is the one that faces the South and West, as expected. The agreement between measured and simulated data is considered acceptable by the authors, within a 1 °C error.

INTRODUCTION

In order to evaluate the thermal behavior of a house donated to the National University of Salta by the organizers of Camel Trophy, located in the town of Payogasta (25° 05´of South latitude and 2.180 meters over the sea level), in the Northwest of the Argentine Republic, a short winter monitoring campaign (4 days) was programmed, given the light construction characteristics of the building.

The building basically consists of a dining room of 30 m^2 facing the North and two rooms of 9 m^2 each one, one facing to the South and East and the other one to the South and West. Between the bedrooms, there is a corridor with an exit to the South that will operate as pantry and that, at present, houses the batteries of the photovoltaic system that provides electric power to the building. The external and internal walls are built with pine wood 1.5 cm thick with thermal insulation of expanded polistyrene 6 cm thick and 20 Kg/m^3 of density, covered with Corlok panels.

The roof of the building is made of interior pine wood, has a thermal insulation of expanded polistyrene 6 cm thick and has galvanized iron sheets on the outer side.

The floor consists of a 10 cm concrete slab over a 10 cm light concrete slab insulated from the ground by an under layer of 5 cm of expanded polistyrene. A polistyrene layer there is also around the perimeter.

The thermal insulation has been arranged so that there are no thermal bridges between the interior and the exterior of the building.

MEASSUREMENT

The monitoring equipment election was conditioned by the absence of AC power in the site. Therefore, autonomous instruments, battery powered, were selected.

For the dry bulb temperature measurement, a programmable datalogger with 8 analog channels for termocuples type T was used . The temperature data were stored every 30 minutes.

By means of an anemometer that generates a linear signal in volts with the wind speed, this speed was measured using another datalogger equipped with 8 channels for voltage inputs, storing the data every 5 minutes.

The solar radiation was manually sensed every 30 minutes by means of a solarimeter with photovoltaic sensor of analog signal.

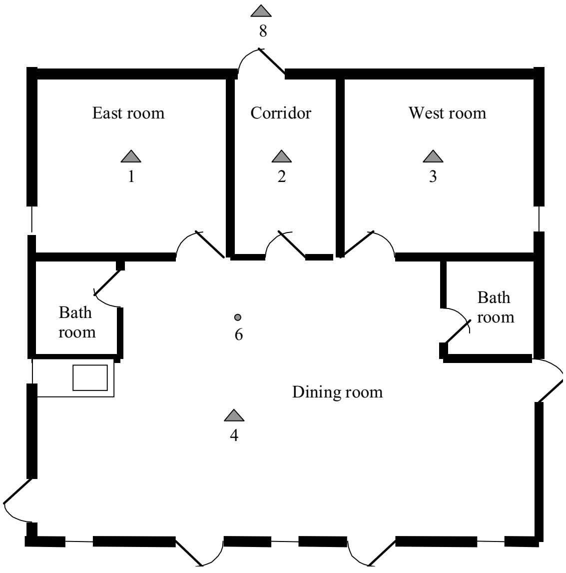
The relative humidity was manually sensed three times a day (morning, afternoon and night) by means of a psicrometer with dry and wet bulb thermometers.

METHODOLOGY

The monitoring methodology was conditioned by the availability of measuring instrument. Thus, it was not conceived as a testing strategy for specific aspects of SIMEDIF. A set of T-thermocouples for inner room dry bulb temperatures measurement was used. An aluminium cover to minimize the radiative interchange between the sensor and the sourroundings was added to each temperature sensor Perforations were made on each cover to allow a good sensor ventilation. The location of indoor T-thermocouples was 1.55m from the floor level, while the outdoor thermocouple for ambient temperature measurement was located 2m from the south wall and 2.5m from the ground (see Fig. 1). In order to detect a possible air stratification and to analyze the effect of night infrared radiation, additional thermocouples in dinning room floor surface and ceiling, and in the outdoor galvanized roof cover were used.

Radiation data on horizontal surface was measured in the top of the building roof, and an anemometer for wind velocity measurement was located 5m from the ground level and 3m from the east wall.

In order to simplify the simulation, dinning room and bathrooms have been considered to have the same air temperature. Thus the bathrooms were maintained with their doors opened during the measurement period and their inner temperatures were not measured.



▲ Thermocouples at 1.55 m over the ground level.

O Thermocouple at ground level (N° 6).

Figure 1: Top view of the building and location of the sensors

The Termocouple N° 5 was in contact with the surface of ceiling, on the vertical of N° 6, whereas N° 7 is in contact with the galvanized sheet cover on the Pantry. The Termocouple N° 8 is at 2,5 m of height.

SIMULATION

Dinning room, bedrooms East and West, and corridor (Pantry) thermal behavior simulation was performed by means of SIMEDIF, a transient building simulation program for Windows developed at INENCO (Non Conventional Energy Research Institute) of the National University of Salta, Argentina. In another work presented at this conference, its description was detailed (Flores et al, 2001). The calculation method consists of an explicit finite difference scheme advancing in Δt steps, with Δt a submultiple of one hour (its value can be fixed during de data input). The results are saved hour by hour in a file. The unknown variables are the temperatures of each room and the temperatures in the nodes, which are defined by the finite difference scheme in each massive element. Knowing the nodal temperature values at a time t, the scheme determines the new values in $t + \Delta t$. Thus, a set of initial temperature conditions must be entered. In the massive nodes, the temperature values in $t + \Delta t$ are obtained by the energy balance equation in the node, using the temperature values in the previous step t. 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 in the nodes without mass, iterations are performed until the convergence is achieved. Once the temperatures are estimated, a calculus of the heat gain provided by the solar radiation, the heat loss of the buildings, and the heat accumulated in the different masses is performed. These calculations allow the detection of possible problems with the input data.

Thermophysical properties of the building construction materials were obtained from common heat transfer bibliography (Incropera and DeWitt, 1990). The outdoor convective heat transfer value h_e (W/m^2°C) was obtained from the equation:

$$h_e = 2.8 + 3.v \qquad (1)$$

where v is the wind velocity in m/s.

The most frequent value for the measured wind velocity was 2 m/s, thus a 9 W/m^2°C value obtained from Eq. (1) have been used in the program data input.

For inner convective heat transfer coefficient, h_i, a 8 W/m^2 °C value for sunny rooms and 6 W/m^2 °C for the others was used.

The solar absorption value used were: 0.7 for pine wood and old galvanized sheet cover, and 0.6 for concrete floor. Air renewals and solar radiation absorber areas are the adjusting simulation variables.

Air renewals values of 1, 0.5, and 2 for dinning room, bedrooms and corridor respectively were used.

A 14 day simulation was performed, from July 22 to August 4. The 10 previous days were simulated with statistical meteorological data that allow the building to achieve a periodic regime, and subsequent 4 days with measured radiation and ambient temperature data.

The values resulting from the simulation correspond to those of thermocouples located in the center of each room. Thus comparative results for thermocouples fixed to the ground and the ceiling do not appear.

ANALYSIS

Considering the 9 criteria for classifying the quality of data sets to be used in the validation of any dynamic thermal buildings simulation programs, Lomas (1991), 6 of them were fulfilled by the collected data. Given that the first three criteria are totally satisfied, the quality of the collected data classify like " Acceptable Data Set". Nevertheless, these criteria are not applicable in this case since they have been conceived for validations by means of test rooms whereas the objective of the present work was not to validate the SIMEDIF program but to simulate the data collected in a monitoring campaign of a real building with more than a room.

The hour showed in the time axes is the official (hour clock).

In Figure 2 the evolution of climatic variables during a period that includes four nights and three days is observed. Days were sunny, and with good radiation levels. Due to the presence of a storm installed on the Cachi mountain, located to the West of house, the sun was screened during the dusks and the sky was covered by clouds during the nights, diminishing therefore the atmospheric cooling by nocturnal IR radiation. In the last night, storm clouds due to a cold and humid air mass coming from East were formed around the 2 a.m. The three days were windy, with 2.83 m/s average value throughout the measurement period, but with bursts that surpassed the 10 m/s. Its preponderant direction was SW - > NW at dawn and, W - > E from the noon at night,.

In Figure 3 the temperatures of the Dining room, Pantry and the external temperature are compared. The temperatures of these rooms differ 1 to 2 °C during the day periods. In addition, the daily thermal oscillation of these rooms, excluding the last night, has an average value of 20 °C, with an amplitude of only 4 °C (due to thermal insulation and the accumulating effect of the cement floor), whereas the outside average value of temperature is 15 °C (with an oscillation amplitude of 8 °C). This difference shows a heat gain in the inner air due to the increase of external temperature during sunny hours and the solar radiation that enters the building through the windows.

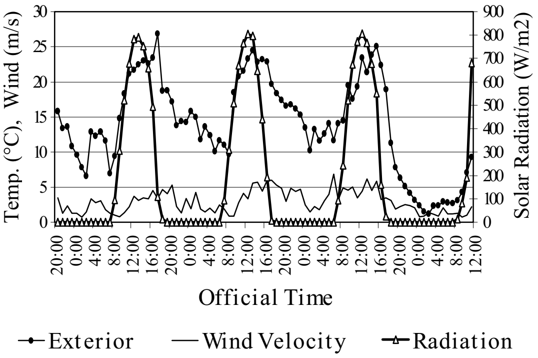


Figure 2: Evolution of the measured data of Exterior Temperature, Wind Velocity and Solar Radiation

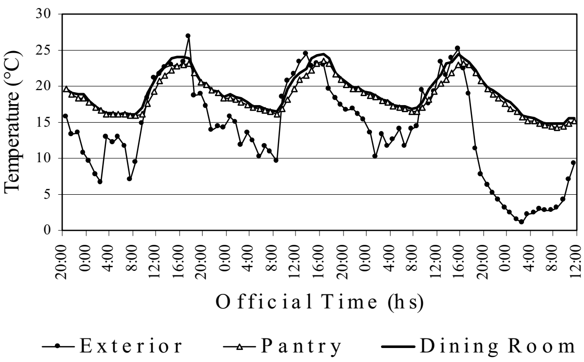


Figure 3: Evolution of the measured data of Exterior Temperature, Pantry and Dining Room

Figure 4 shows the thermal behavior of both bed-rooms, East room and West room, and of the Dining room. It can be observed that the East room was warmed more than the West room during the morning, happening the opposite during the afternoon. A reason for this behavior is the out of phase entrance of solar radiation through the windows. In addition, the West room is the hottest towards the afternoon due to the combined effect of radiation and the maximum exterior temperature. The average temperature of East room is 19.5 °C with an oscillation amplitude of 3.5 °C whereas the average temperature in West room is 20.5 °C with an amplitude of 4.5 °C, excepting again the last night.

On the other hand the Dining room temperature had the most symmetrical behavior respect to solar noon, as expected given its north orientation.

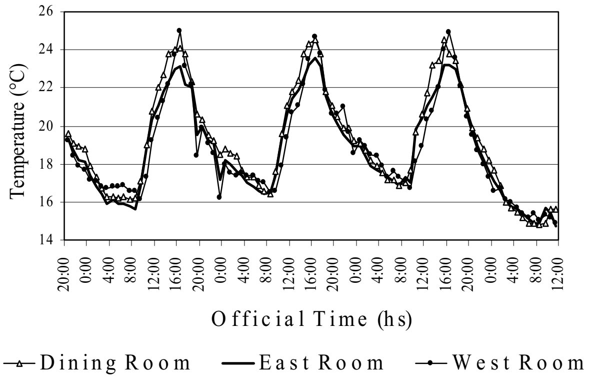


Figure 4: Evolution of the measured data of Dining Room, Est Room and West Room

In Figure 5, the meassured values of air temperature at heights of 1.55 m, 3.50 m (ceiling surface) and to the Dining room floor level, in order to detect possible thermal stratifications in the air, are shown. The curves corresponding to 1.55 m and 3.50 m demonstrate a greater stratification during the sunny hours than during the night.

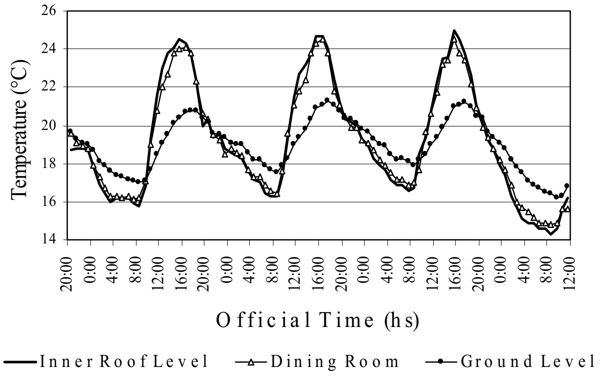


Figure 5: Evolution of the measured data of temperature to Inner Roof Level, Dining Room and Ground Level.

During the sunny hours, the roof was externally warmed many degrees over the atmosphere due to solar radiation. Being the ceiling warmer than the floor, the convection is not promoted. Instead, the roof cools off (outwards) below the floor temperature during night, favoring convection and a uniform Dining room temperature. When the temperature was increased in the house, energy was transfer to the floor, being accumulated, which is demonstrated by the oscillation of its temperature being slightly out of phase with respect to the air temperature and its amplitude smaller.

This accumulating effect serves as well to limit the temperature oscillation inside the house, yielding the heat during the night.

In Figure 6, the thermal jump through the roof is analyzed. The temperatures of the inner and outer side of roof are compared to the external temperature. During the sunny hours the outer galvanized sheet cover warms up over 40 °C, whereas at night it cools off to two degrees below the atmospheric temperature, showing a radiative cooling effect towards the cold Andean sky, due to the low humidity content of air.

In figure 7, the measured and the simulated temperatures for the dining room are compared. An excellent agreement between both behaviors is observed, excepting in the last night where the difference is of the order of 1 °C. This error was considered acceptable due to the sensors´ error, the simplifications made in the physical description of the building and the hypotheses made on nonmeasured magnitudes (such as termophysicals properties of materials and convective heat transference coefficients). The auxiliary heat gains produced by food cooking, fluorescent illumination and the metabolism of the inhabitants (researchers) were not included.

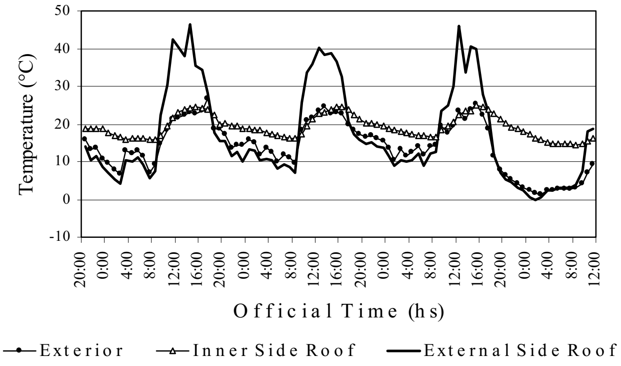


Figure 6: Evolution of the measured data of temperature of Inner Side Roof and External Side Roof.

The daily average value of these auxiliary heat gains is 277 W. Regarding that it´s smaller than the power dissipated by 4 incandescent lamps of 75 W each one, distributed in whole the house, its influence is not significant Therefore its effect is masqueraded within de simulation variables, the air renewals and the solar radiation absorber areas in this case. Nevertheless, it would be included in order to obtain a better agreement of the air renewals in a detailed simulation.

In figures 8 and 9 the comparisons between measured and simulated values for both bed-rooms is shown. Again, the adjustment was sufficiently good within the acceptable error rank. The room located to the West displays the greater disagreement in the simulation during the mornings, showing a greater heating with respect to the measured data. The last night, in which the atmosphere was considerably cooled off by the presence of a cold front, the simulated temperatures are below the measured ones in the order of 1 °C.

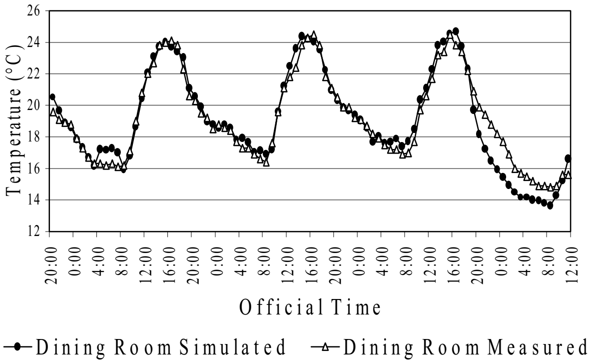


Figure 7: Evolution of the measured and simulated temperatures of the Dining room.

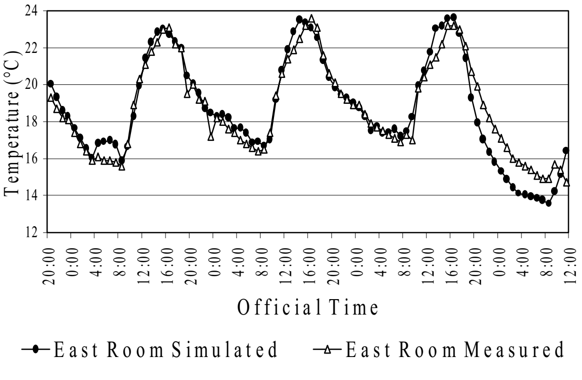


Figure 8: Evolution of the measured and simulated temperatures of the East room.

Finally, in figure 10 the results measured and simulated for the pantry are compared. The agreement between both behaviors is acceptable considering that, due to its low habitability, this room is one of less interest from the point of view of thermal comfort.

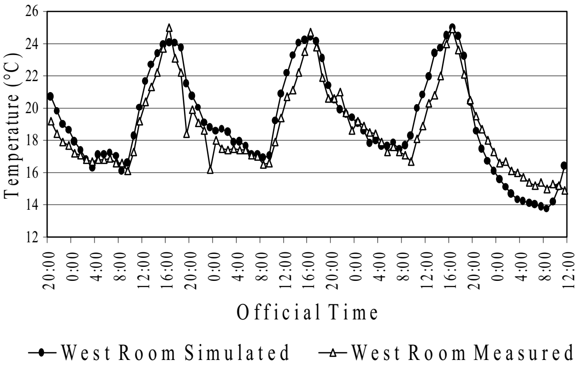


Figure 9: Temporary evolution of the measured and simulated temperatures of the West room.

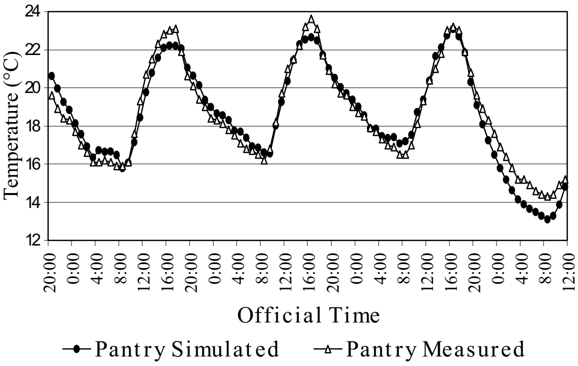


Figure 10: Temporary evolution of the measured and simulated temperatures of the Pantry.

CONCLUSIONS

During four days from August 1 to 4, a lightweight building at Payogasta town was monitored. The non-massive nature of the building is evidenced by the absence of dephasage between indoor and outdoor temperatures.

South facing bedrooms and north facing dining room have different thermal behavior: the south-west bedroom is the hottest one during the sunny hours because of the solar gain due to a glazed west window.

The mean temperatures of all rooms in the building falls inside the comfort range, in spite of the low solar gain through the building glazed windows. The daily thermal amplitudes around 7ºC are explained by the small thermal masses concentrated mainly in the building floor. As expected, a variable day/night air thermal stratification between floor and ceiling was detected.

Finally, the selective nature of the galvanized sheet cover was appreciated. This cover warmed up to

40ºC during day and cooled down to -2ºC during night, because of the infrared night sky radiation.

The authors lived at the building during the monitoring and they have the opinion that the building provides a comfortable thermal sensation for the winter climatic outdoor conditions, and a low humidity (4 gr of water/kg of dry air) due to the extremely dry climate in the building site.

The simulation results show a good agreement between measured and simulated data sets, with an approximation of 1ºC. The West room has the poorest adjustment during mornings, but the mean temperature and amplitude values agrees with the measured ones.

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