CALIBRATION OF A COMPUTER MODEL OF A NATURALLY-VENTILATED HOUSE LOCATED IN SOUTHERN BRAZIL

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ABSTRACT

The main objective of this article is to present the calibration process of a computer model of a naturally-ventilated house built in southern Brazil. The house was monitored over two seven-day periods by using Hobo data loggers. The EnergyPlus computer program was used to create a computer model for the house; parameters related to air infiltration and natural ventilation were modeled by using the AirflowNetwork. The internal air temperatures obtained from the simulations were compared with those measured in the house. During the calibration process, parameters such as thermal resistance and absorptance of the materials, radiant heat gain generated by equipment, and coefficients related to air infiltration and natural ventilation were changed. In general, results obtained from the simulations were adequate. However, air temperature obtained from the simulations were higher than the actual figures when natural ventilation was considered. This may indicate a deficiency of the EnergyPlus computer program to predict air temperature of rooms under natural ventilation.

INTRODUCTION

Various simulation computer tools have become important instruments for the analysis of buildings with regard to their energy and thermal performance. According to Mendes et al. (2005), one of the benefits in employing simulation programs consists in evaluating the thermal and energy performance of buildings with different project alternatives. The latter consist of several options featuring architectonic designs, building components, illumination systems or air conditioning systems.

Few Brazilian engineers and architects use these programs as professional tools, perhaps due to their complexity, subsequent difficulties and time consuming procedures in learning. Westphal and Lamberts (2005) state that the complexity of these phenomena involving the buildings' thermal performance implies a great deal of input data in simulations and, therefore, require multidisciplinary knowledge.

Users' lack of experience, the difficulty to define certain input data and the resulting simplification of computer models may trigger simulation mistakes and, consequently, some simulation-obtained results do not fit in a real environment. A calibrated model is needed so that a computer program produces reliable results. In other words, a virtual model of the building under analysis should represent with great fidelity the building's thermal and energy performance.

Current research undertakes the calibration of a computer model so that the thermal performance of a naturally ventilated residential building in the city of Florianópolis, south Brazil, may be analyzed.

METHODOLOGY

Calibration dealt with in this paper has been undertaken by comparing simulation-obtained data and measured data. Measurements of a building in the city of Florianópolis SC, southern Brazil, indicated in Figure 1, were taken. Florianópolis lies at latitude 27.7° S, at sea level (although altitudes of approximately 500m may be reached on hill tops). Its climate is classified as humid mesothermal, with high temperatures in the summer and low ones in the winter.

Figure 2 shows a one-family residence with a floor plan area of 124m^2, currently under analysis, built according to research on technologies and strategies to obtain energy efficiency and environmental comfort in residential buildings and funded by the two government departments Eletrosul and Eletrobras.

The house has double walls made of solid clay bricks with a layer of rock wool covering on the internal part which produces thermal insulation. Only some internal walls of the house are single with a layer of solid clay bricks.

The house's external door frames and window frames are made of PVC with double glass panes so that thermal insulation is warranted. They have white external PVC blinds for light screening, when required.

The floor is made up of solid concrete with baked clay sheathing. Three different solutions have been used in the house ceiling (Figure 3):

1. Light-colored clay shingle, internal layer of rock wool covering and reflection insulation, timber ceiling (on kitchen, double bedroom and hall);

2. Metal shingle, internal layer of rock wool covering, timber ceiling (on dining room and living room);

3. Horizontal flagging, totally or partially covered by garden, or ceiling garden (on single bedroom, bathroom and laundry).

Figure 1 – Map of Brazil showing the city of Florianópolis

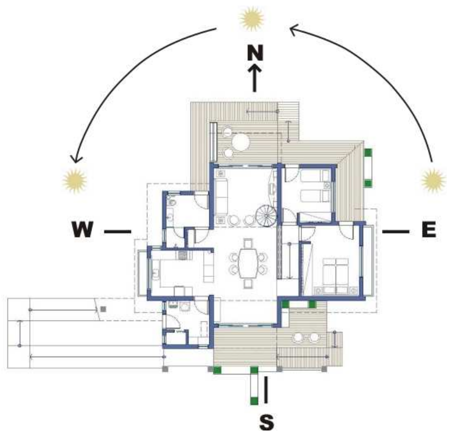

Figure 2 – Residence's ground floor plan

Figure 3 – Photo of house (North and West sides)

Measurements

The room temperatures for the house under analysis allowed the calibration of a model to be used in thermal performance computer simulations. Hobos data loggers, Hobo U12 model, manufactured by Onset Computer Corporation, were used to measure and store room temperature data for a time period. The resolution of the data loggers is 0.03°C and the accuracy is ±0.35°C.

Although Hobos were installed in all rooms, this paper shows data of only three, namely, double bedroom, living room and bathroom. They were placed in the middle of the rooms, some 1.80 m above the floor.

Two seven-day monitoring periods were selected: between 15 and 21 August 2007 and between 7 and 13 January 2008. Limited number of monitored days occurred owing to the fact that the house functions not only as a study and research laboratory but also as a showroom for visits and technology propaganda. In fact, manipulation of apertures and house occupation for control of measurements are restricted. The house had its windows and external doors closed, without any ventilation, during the August period; during the January period the house remained open, with natural ventilation.

External environment variables were provided by the meteorological station of the Laboratory of Engineering of Conversion Processes and Energy Technology (LEPTEN) of the Mechanic Engineering Laboratory of the Federal University of Santa Catarina (UFSC). Above-mentioned station lies some 550 m distance from the house under analysis and provides data on temperature, relative air humidity, wind velocity and direction, atmospheric pressure and direct and diffused global solar radiation.

Computer simulation

Calibration was obtained by modeling the monitored house and by comparing data obtained through measurements and simulation. Such procedure verified the quality of data through simulation by means of proximity to true data.

A file with the climate data for the city of Florianópolis, provided by the LEPTEN meteorological station, was employed during the monitoring months (August 2007 and January 2008). Calibration was thus simulated for only two weeks, a week for each month.

EnergyPlus program estimated the house's thermal exchange with the environment as from the house modeling, its geometry and construction materials, ventilation systems, illumination, internal loads, occupation and other items. An initial calibration model, featuring the characteristics given below, has been thus defined.

Description of initial model

The definition of the model's thermal zones is required for house simulation by EnergyPlus computer program. The house has been modeled on nine thermal zones, each representing the following environments: laundry, kitchen, bathroom, sitting and dining room, hall, double bedroom, single bedroom, water reservoir area (above kitchen) and boiler area (above hall). Figure 4 shows an outline of the model; Figure 5 shows plans with their dimensions.

Openings for doors and windows were modeled on those in the house, or rather, with blinds. Solar protections on several sides of the house were also included in the model. The model's main difference from the house lies in the geometry of coverings which were modeled in a simple manner, or rather, without inclinations. Heights of covering planes have been calculated to provide an internal volume similar to that of the real rooms.

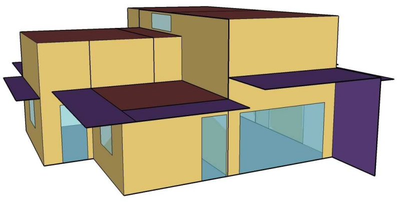

Figure 4 – Outline of simulation calibration model

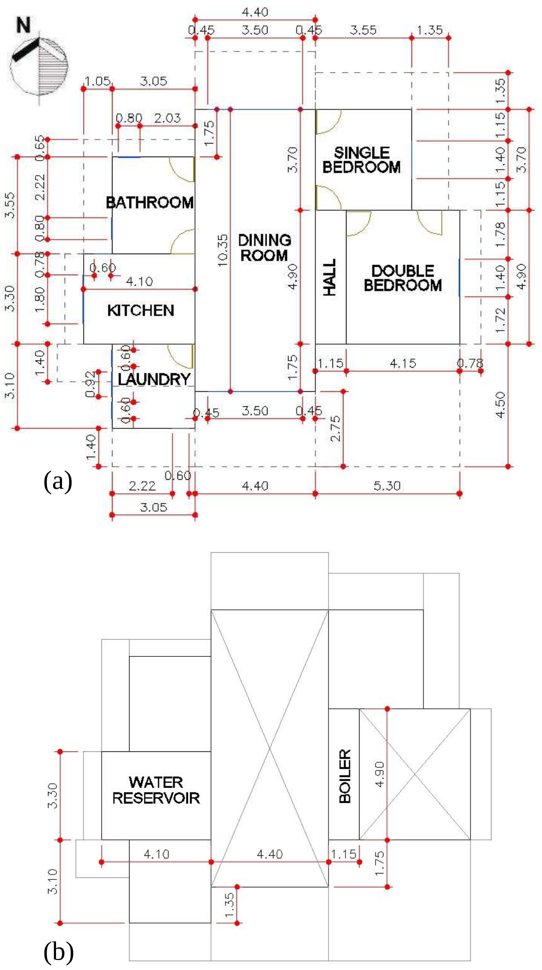

Figure 5 – Floor plans of simulated calibration model: ground (a) and first (b) floor

Information on ground temperature is highly important for the simulation of ground houses. Ground temperatures provided by the Test Reference Year (TRY) of Florianópolis, namely 17.48°C in August and 22.75°C in January, were used.

Construction materials have also been adapted according to those used in the house. Thermal features of most of the material used, such as thermal conductivity, density, specific heat, solar radiation solar absorption and thermal resistance, were obtained from the Brazilian NBR 15220 (ABNT, 2005). Table 1 shows such data.

EnergyPlus provides internal heat gains caused by electric appliances, illumination and users' activities. In the case of calibration, internal gains were included according to activities in the house during the monitoring days within the two determined periods.

A fridge and a computer were the two extant electric appliances. Rate of heat gain radiation fraction for the two appliances was 0.5, usually accounted for by researchers. This is due to the fact that the division between the radiation and convective (heat gain) parts for most appliances is normally uniform (ASHRAE, 2005).

AirflowNetwork system inserted in EnergyPlus program simulates natural ventilation in a building. This includes air exchange between the outside and thermal zones and between the zones. Ventilation in the above calibration has been modeled according to performance during the house's monitoring periods. During August all windows and external doors remained closed with air infiltration coming from cracks and inadequate sealing of openings. During January the windows and external doors remained open at certain periods of the day and thus ventilation occurred naturally.

Through AirflowNetwork, air infiltration is defined by parameter Air Mass Flow Coefficient When Opening is Closed, in kg/s.m (for 1 Pa per meter of crack). Rate employed by parameter amounted to 0.001 kg/s.m, similar to that in simulation models (example files) of EnergyPlus.

In the case of air exchange when windows and doors are open, one of the main AirflowNetwork definitions is performed by Discharge coefficient. Rate in this parameter was 0.6 for windows and doors. According to Flourentzou et al. (1998), 0.6 (± 0.1 precision) is the discharge coefficient for rectangular openings (windows and doors).

Another important factor for natural ventilation simulation is the Wind Pressure Coefficient. It is defined for each aperture in the building and for different wind directions. These data are difficult to define since they depend on the building's volume, surroundings and any obstacle to wind passage. The coefficient of wind pressure in such simulations was obtained by Cp Generator, developed by TNO Building Research.

Further, the Wind Velocity Profile Exponent is defined according to rugosity of surroundings which may vary between 0 and 0.5. Rate 0.32, which corresponds to a heterogeneous surrounding for buildings with more than one storey, has been adopted for this exponent.

Adjustments of model

Model adjustments were undertaken for calibration with the modification of certain parameters, coupled to the comparing of results of simulations with measurements previously undertaken in the house.

Table 1
Characteristics of material employed in computer simulation

MATERIAL	THERMAL CONDUCTIVITY [W/m.K]	DENSITY [kg/m^2]	SPECIFIC HEAT [J/kg.K]	SOLAR ABSORPTION
Solid clay bricks 10 cm, with building mortar	0.900	1764	920	0.3
Plasterwork 2.5 cm	1.150	2000	1000	0.2
Solid concrete 10 cm	1.750	2200	1000	0.3
Clay shingle 1 cm	1.050	2000	920	0.4
Metal shingle 1 mm	112.00	7100	380	0.2
Ceiling timber 1.5 cm	0.140	600	2300	0.7
Door woodwork 3 cm	0.150	600	1340	0.2
PVC for frames 1 cm	0.200	1350	960	0.2
Aluminum polyethylene 5 mm	0.400	1200	2299	0.2
Rock wall covering 2.5 cm	0.045	100	750	-
Extruded polystyrene 2 cm	0.035	30	1420	-

These parameters were chosen due to the fact that they were the main input data used for simulation by EnergyPlus. Although a new parameter was changed at every new simulation, alterations remained unchanged, when adequate, in the following simulations.

At the initial stage, first modified parameters were compared with measurements undertaken in August 2007 when the house, without any ventilation (windows and doors closed), was monitored. Parameters comprised:

- Ground temperature: ground temperature data were changed and rates measured on the ground of premise under analysis (monthly mean) were employed: 18.7°C for August and 26.3°C for January.

- Building's geometry: since initial model was built with horizontal coverings, change was undertaken by coverings with current inclinations in the building under analysis. Figure 6 shows the model.

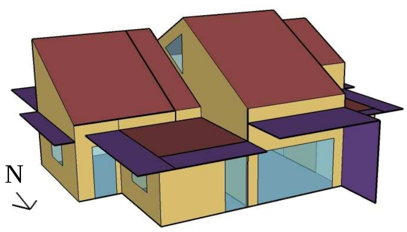

Figure 6 – Outline of calibration model with changes in covering volumetry

- Thermal resistance of envelope materials: thermal features of materials employed in the initial model, obtained from norms, are merely indicative since they vary according to prime matter and type of manufacture. Simulations with 10% and 20% increase in the thermal resistance of all components were undertaken to verify the influence of rate differences in the components' thermal resistance.

- Solar absorption of envelope materials: Materials' solar absorption in the initial model has been defined by complying with the colors of the building under analysis and by adopting norm rates. Compliance, however, failed to define these rates with any precision since dirt may cause changes in this specific feature. Therefore, on the spot measurements with Alta II equipment were undertaken to confirm the true rate of solar absorption of the materials used in the envelope of the house under analysis. True solar absorption could be calculated by electronic gadgets when rates were taken and measurements on a blank sheet of paper were employed as reference. Table 2 shows rates obtained and employed in the simulation.

Table 2
Corrected solar absorption rates of materials.

MATERIAL	SOLAR ABSORPTION
Solid clay bricks	0.36
Clay shingle	0.48
Metal shingle	0.36
PVC for frames	0.26

- Internal heat gain by appliances: rate 0.5 was adopted at initial simulation as a radiant heat gain fraction by appliances, with 0.5 for convective fraction. According to ASHRAE (2005), the division between the radiant and convective (heat gain) parts is usually uniform for most equipments. An important difference exists in equipments featuring cooling fans, as in computers. A simulation was undertaken, in the case of the radiant heat gain fraction, employing 0.20 for the computer and 0.35 for the fridge, according to data by ASHRAE (2005b).

- Air Infiltration: rate initially used in parameter Air Mass Flow Coefficient When Opening is Closed was 0.001 kg/s.m. In the above modification, rate 0.0001 kg/s.m was employed for horizontal sliding sash windows and doors, and 0.0005 kg/s.m for awning windows, following Liddament (1986).

New modifications were simulated at a second stage when the model was corrected and the best options of first stage simulations were adopted. Alterations were compared with the January 2008 measurements data. Parameters related to natural ventilation were altered in the model, as follows.

- **Discharge coefficient**: rate of discharge coefficient in initial simulations was 0.6 for windows and doors. Since Flourentzou et al. (1998) suggest 0.6 with a ±0.1 precision, simulations were undertaken by changing discharge coefficient from 0.7 to 0.5. Another simulation reduced this rate to 0.3 to analyze the influence of greater changes in the parameter.

- **Wind velocity exponent**: Rate 0.32, which has been initially adopted for this exponent, was altered to 0.5, maximum range accepted by the program. The new rate would mean high rugosity surroundings, or rather, a great number of hindrances. This fact may better fit the studied building owing to the hills surrounding the site.

Pressure coefficients were not changed owing to the difficulty in obtaining them.

Criteria for calibration

The comparison of the results of these simulations with rates measured on the true building required, as the model's output data, mean hourly temperature of air in the interior of the dining room, bathroom and double-bedroom. Three most significant days within each of the two defined periods were chosen for analysis. Criterion consisted of the sequence of days with similar temperature variation which provided stability in the house's thermal performance.

Data obtained by measurements and simulation were compared and differences between rates, quadratic error and temperature range in the period were calculated. Differences between simulated and measured rates were verified for each hourly datum. Minimum, maximum and mean differences were then calculated for each period within the days under analysis. Whereas Equation 1 calculates mean difference, Equation 2 indicates the calculation of the quadratic error.

$$Dm = \frac{\sum_{i=l}^{N}(y_i - x_i)}{N} \qquad \textit{Equation 1}$$

$$QE = \left[\frac{\sum_{i=l}^{N}(y_i - x_i)^2}{N}\right]^{\frac{1}{2}} \qquad \textit{Equation 2}$$

Where:

- Dm is the mean difference;

- QE is the quadratic error;

- yi is the hourly temperature obtained from simulations;

- xi is the hourly temperature measured in the house;

- N is the number of evaluated items.

RESULTS AND DISCUSSION

Results indicate comparison of mean air temperature rates obtained by simulation and by measurements in the building under analysis. Table 3 gives a summary of simulations undertaken for model calibration.

All graphs refer to three days within the total period of the building's monitoring for each month and indicate mean air temperature rates, measured and simulated. Figure 7 shows the exterior air temperature for the three days in January and August. First simulations were compared with measurements undertaken in August 2007 when the house was kept with windows and doors closed, in other words, without any ventilation.

Table 3
Summary of Calibration

SIMULATION		MONTH
1	Initial Model	Aug/07
2	Initial Model + modified ground temperature	Aug/07
3	Simulation 2 + modified cover volumetry	Aug/07
4	Simulation 3 + thermal resistance + 10%	Aug/07
5	Simulation 3 + thermal resistance + 20%	Aug/07
6	Simulation 3 + modified solar absorption	Aug/07
7	Simulation 6 + modification of heat gain by appliances	Aug/07
8	Simulation 7 + modification of air mass flow coefficient when opening is closed	Aug/07 Jan/08
9	Simulation 8 + discharge coefficient = 0.7	Jan/08
10	Simulation 8 + discharge coefficient = 0.5	Jan/08
11	Simulation 8 + discharge coefficient = 0.3	Jan/08
12	Simulation 8 + exponent of wind velocity profile = 0.5	Jan/08

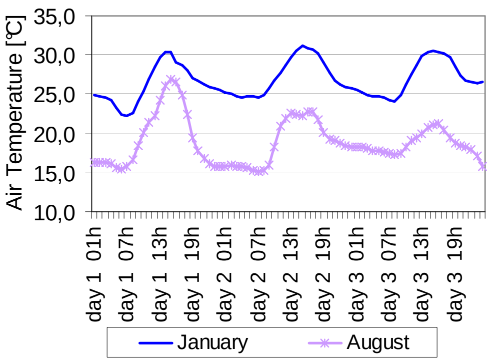

Figure 7 – Exterior air temperature for the three days in January and August

In the first simulation case with initial model described above, results for the three chosen days, within the three rooms analyzed, are shown in Figure 8. It may be seen that, although behavior of temperature curve is similar, simulations are always lower than the measured rates. Mean differences between simulated and measured temperatures comprise 1.1°C for the dining room; 1.0°C for the double bedroom and 1.1°C for the bathroom, as may be seen in Table 4.

Figure 9 shows results of the second simulation with modifications in ground temperature rates. Great improvement may be perceived when compared to the first simulation. Simulation's temperature curves are close to those obtained by measurements, with a mean difference of 0.4°C in the dining room; 0.3°C in the double bedroom and 0.4°C in the bathroom (Table 4). Quadratic error shows values which are almost equal to mean difference: 0.5°C in the dining room; 0.4°C in the double bedroom and 0.5°C in the bathroom. Modification has been kept in all following cases.

In the third simulation featuring modifications in the model's covering volumetry, results similar to the former have been obtained. Although lacking significant changes in results, modification was kept in the other cases since volumetry represents better the real house under analysis.

The thermal resistance of the house's building material was modified by an increase of 10% and 20% in the following two simulations. As Table 4 shows, differences with regard to the former model were very small. Results show that changes in the resistance of materials had only a slight effect on air temperature rates of the rooms and failed to contribute significantly in equating the model to the measurements. This fact may have occurred because resistance rates initially used were already high and provided high thermal insulation of the rooms. The other simulations kept the original resistance rates of the initial model.

The sixth simulation showed modifications in the solar absorption rates of the house's envelope materials. Table 4 indicates that mean differences were lower than the value of the data loggers' accuracy. Quadratic error remained unaltered as in the former case, or rather, 0.5°C in the dining room; 0.3°C in the double bedroom and 0.5°C in the bathroom. Solar absorption data remained similar in subsequent simulations.

The seventh simulation was undertaken by modifying the heat gain radiant fraction through appliances. Results in Table 4 show that quadratic error was 0.5°C in the dining room; 0.2°C in the double bedroom and 0.4°C in the bathroom. This means that a slight decrease in difference occurred with regard to previous simulation. Temperature ranges were kept at 2.5°C in the dining room; 1.9°C in the double bedroom and 2.4°C in the bathroom. Such alteration is scantily significant in the model due to the small number (two) of appliances. Nevertheless, alterations were kept for the following simulations due to the fact that they cause a slight decrease in the differences.

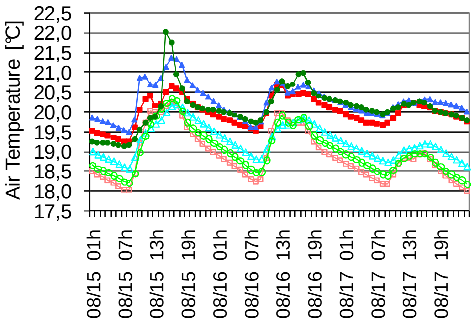

Figure 8 – Comparing results of simulation 1 with measurements in August 2007

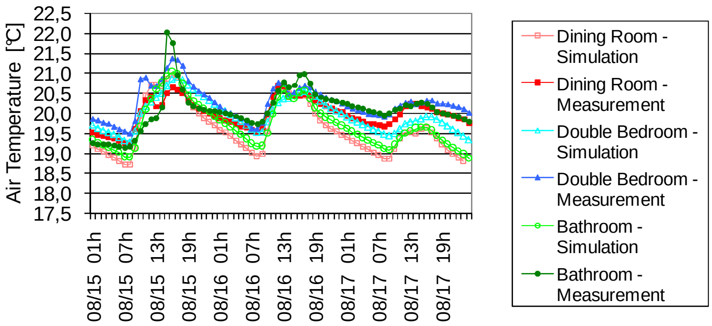

Figure 9 – Comparing results of simulation 2 with measurements in August 2007

Table 4

Results of simulation when compared with measurements in August 2007

	SIMULATION	DIFFERENCE [°C]									QUADRATIC ERROR [°C]			AMPLITUDE [ºC]			ADOPTED ADJUSTMENTS
		MINIMUN			MAXIMUM			MEAN									
		R	D	B	R	D	B	R	D	B	R	D	B	R	D	B	
-	Measurements	-	-	-	-	-	-	-	-	-	-	-	-	1.4	1.9	2.9	-
1	Initial Model	-1.8	-1.6	-1.8	-0.2	-0.7	0.0	-1.1	-1.0	-1.1	1.2	1.0	1.1	2.2	1.6	2.2	-
2	Initial Model + modified ground temperature	-1.1	-0.8	-1.1	0.5	0.0	0.7	-0.4	-0.3	-0.4	0.5	0.4	0.5	2.2	1.6	2.2	Yes
3	Simulation 2 + modified cover volumetry	-1.1	-0.9	-1.0	0.7	0.0	0.8	-0.4	-0.3	-0.3	0.6	0.4	0.5	2.5	1.8	2.3	Yes
4	Simulation 3 + thermal resistance + 10%	-1.1	-0.8	-1.0	0.7	0.0	0.8	-0.4	-0.3	-0.3	0.5	0.3	0.5	2.4	1.7	2.2	No
5	Simulation 3 + thermal resistance + 20%	-1.0	-0.8	-1.0	0.7	0.0	0.9	-0.3	-0.2	-0.3	0.5	0.3	0.5	2.4	1.6	2.2	No
6	Simulation 3 + modified solar absorption	-1.0	-0.8	-0.8	0.9	0.2	1.0	-0.2	-0.1	-0.2	0.5	0.3	0.5	2.6	1.9	2.4	Yes
7	Simulation 6 + modification of heat gain by appliances	-0.9	-0.6	-0.8	0.9	0.4	1.0	-0.2	0.0	-0.2	0.5	0.2	0.4	2.5	1.9	2.4	Yes
8	Simulation 7 + modification of air mass flow coefficient when opening is closed	-0.9	-0.6	-0.9	0.9	0.4	1.0	-0.2	0.1	-0.2	0.4	0.2	0.4	2.4	1.7	2.2	Yes
R = DINING ROOM; D = DOUBLE BEDROOM; B = BATHROOM																	

The eighth simulation case (the last one which was compared with the August 2007 period) showed that model underwent alterations in the air infiltration parameter. Results in Figure 10 show that no significant changes occurred in mean differences with regard to the previous simulation. However, slight modifications occurred in temperature range of the rooms, featuring 2.4°C in the dining room; 1.7°C in the double bedroom and 2.2°C in the bathroom. Infiltration rates were maintained in following simulations. As shown in Table 4, quadratic errors are close to the data loggers' accuracy (±0.35°C), while the mean differences are lower.

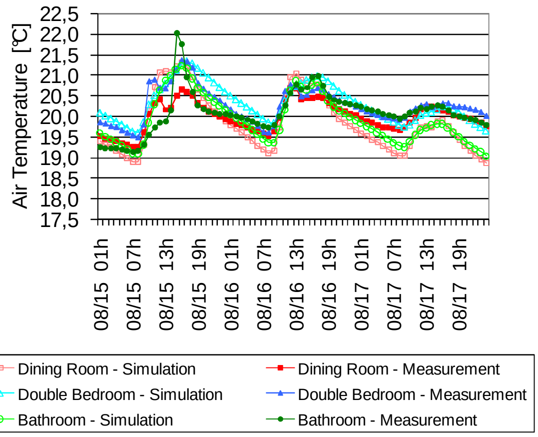

Figure 10 – Comparing results of simulation 8 with measurements in August 2007

The last calibration simulations were compared with measurements undertaken in January 2008 when the house was monitored with open windows and doors, or rather, with natural ventilation. Figure 11 shows results for the simulation of the eighth case (with modifications in air infiltration) compared to measurements on the three days of January. It has been verified that ventilation affected significantly the rooms' internal temperature in the simulation than that which occurred during monitoring, especially in the dining room and in the bathroom.

When the windows were closed at night, simulation results are more similar than the measurement ones. However, during the day period, when the windows remained open, simulation results reached rates higher than the measurement results. Table 5 shows that difference reaches a maximum of 2.0°C in the dining room, 1.9°C in the double bedroom and 2.2°C in the bathroom.

Nevertheless, mean differences were small: 0.2°C in the dining room; 0.4°C in the double bedroom and 0.6°C in the bathroom. It may be verified that, when temperature ranges during the period are analyzed, measurements increased by 3.0°C in the dining room; 2.8°C in the double bedroom and 2.5°C in the bathroom. Increases in simulations were higher: 4.8°C in the dining room; 3.3°C in the double bedroom and 4.3°C in the bathroom.

Simulations' changing the discharge coefficient rate to 0.7 and 0.5 were undertaken. Results in Table 5 for simulation 9, which employed discharge coefficient 0.7, show that such alteration caused a slight increase in temperature rates and ranges obtained in simulation. Results were more different from measured rates. Results of simulation 10, with discharge coefficient 0.5, a slight decrease in temperature ranges were verified even though no modifications in mean differences occurred. The simulation's temperature ranges were 4.7°C in the dining room; 3.0°C in the double bedroom and 4.2°C in the bathroom. Results were very close to measurements, even though with maximum differences of 2.0°C in the dining room; 1.9°C in the double bedroom and 2.1°C in the bathroom. This fact always occurred during the hottest hours of the day, with ventilation.

Since the above two alterations had only a slight effect on results, a new simulation was undertaken employing a lower discharge coefficient, equivalent to 0.3 (simulation 11). Although temperature rates are closer to measurements, they still show maximum differences of 1.8°C in the dining room; 1.7°C in the double bedroom and 1.9°C in the bathroom. Temperature ranges in the simulation were 4.4°C in the dining room; 2.5°C in the double bedroom and 3.7°C in the bathroom. Above alteration were not maintained.

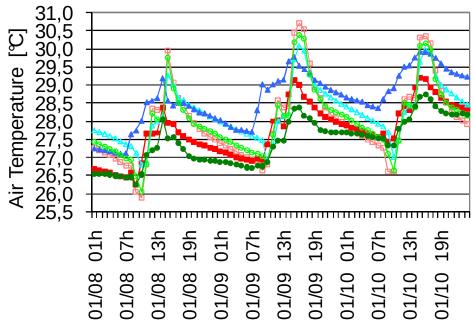

Figure 11 – Comparing results of simulation 8 with measurements in January 2008

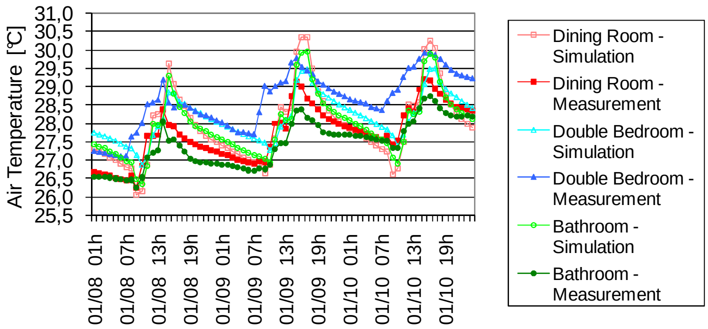

Figure 12 – Comparing results of simulation 12 with measurements in January 2008

Table 5
Results of simulation when compared with measurements in January 2008

SIMULATION		DIFFERENCE [°C]									QUADRATIC ERROR [°C]			AMPLITUDE [ºC]			ADOPTED ADJUSTMENTS
		MINIMUN			MAXIMUM			MEAN									
		R	D	B	R	D	B	R	D	B	R	D	B	R	D	B	
-	Measurements	-	-	-	-	-	-	-	-	-	-	-	-	3.0	2.8	2.5	-
8	Simulation 7 + modification of air mass flow coefficient when opening is closed	-1.0	-1.9	-0.7	2.0	0.7	2.2	0.2	-0.4	0.6	0.7	0.7	0.8	4.8	3.3	4.3	Yes
9	Simulation 8 + discharge coefficient = 0.7	-1.0	-2.0	-0.8	2.1	0.8	2.3	0.3	-0.4	0.6	0.7	0.8	0.8	4.9	3.4	4.5	No
10	Simulation 8 + discharge coefficient = 0.5	-0.9	-1.9	-0.6	2.0	0.6	2.1	0.2	-0.4	0.6	0.6	0.7	0.8	4.7	3.0	4.2	No
11	Simulation 8 + discharge coefficient = 0.3	-0.8	-1.7	-0.5	1.8	0.6	1.9	0.2	-0.4	0.5	0.6	0.7	0.7	4.4	2.5	3.7	No
12	Simulation 8 + exponent of wind velocity profile = 0.5	-0.8	-1.6	-0.4	1.7	0.5	1.8	0.2	-0.4	0.5	0.6	0.7	0.7	4.3	2.6	3.6	Yes
R = DINING ROOM; D = DOUBLE BEDROOM; B = BATHROOM																	

Remaining differences may have been caused by imprecision of pressure coefficients. Since the latter is a complex parameter, with the inclusion of a set of rates for each aperture and different wind angles, it will be difficult to define its variation. A last modification in the exponent rate of wind velocity related to rugosity of surroundings has been adopted to minimize differences in results. Figure 12 shows results for this last simulation (simulation 12). They are, in fact, closer to measurements, with maximum differences of 1.7°C in the dining room; 1.6°C in the double bedroom and 1.8°C in the bathroom. Mean differences were 0.2°C in the dining room; 0.4°C in the double bedroom and 0.5°C in the bathroom.

Simulation's temperature ranges were 4.3°C in the dining room; 2.6°C in the double bedroom and 3.6°C in the bathroom. Since the last alteration has been maintained, the final model was defined.

In spite of some differences kept on purpose, the final model showed mean differences and quadratic errors less than 1^{o}C. It was thus considered adequate to be employed in simulations to evaluate the thermal performance of the house.

CONCLUSION

Results above show that computer programs, such as EnergyPlus, provide adequate results and are important tools to analyze thermal performance of houses.

Calibration showed that simulations without natural ventilation are simpler and give more precise results. In this case, results obtained were very similar to measurements taken in the house under analysis and underlined the importance of a correct definition of ground temperature rates for the simulation of ground premises.

Simulations with natural ventilation did not reveal precise rates as those without any ventilation. Temperatures obtained with the final model had an approximately 0.7 quadratic error. Temperature curves obtained by simulation showed temperature peaks which were higher than those obtained by measurements. Therefore, a greater influence of ventilation occurred in the simulated model than that reported in the monitored house.

These differences may have been triggered by imprecision in the wind pressure coefficient rates, but mainly due to the fact that the computer program assumes a perfect mixing of the air within the environment. It should be emphasized that calibration was undertaken within short measuring periods which may actually cause imprecision.

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