THE INFLUENCE OF THE SELECTIVE VENTILATION IN THE THERMAL PERFORMANCE OF MODERN NATURALLY-VENTILATED HOUSES IN GOIÂNIA – BRAZIL

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ABSTRACT

The aim of this paper is to investigate the influence of the selective ventilation in the thermal performance of modern naturally-ventilated houses built in the 1950's and 1960's in Goiânia, located in middle-west of Brazil. The selective ventilation is one of the passive thermal conditioning strategies recommended for buildings located in this city, in the summer. This study allows the analysis how much important is the selective ventilation as a bioclimatic strategy in the studied cases, considering the application of this strategy before the establishment of contemporary concepts as "zero energy building", helping us to reflect on the future from a historical perspective. Seven rooms in two houses were selected for in situ measurements and simulations. Indoor and outdoor air temperatures and relative air humidity were measured with data loggers HT-500, during 91 days in three different months in 2011: June (low air temperatures and low relative humidity); September (high air temperatures and low relative humidity); and December (medium air temperatures and medium relative humidity). The measured dates are used to calibrate the virtual model of the dynamic simulations. Based on this calibrated model, a reference model for computer simulations was defined in the EnergyPlus building energy simulation program, used also to solve the energy balances and to evaluate the thermal performance of the cases. Variations in the ventilation were carried out and hourly air temperature and relative air humidity were the output data for the same thermal zones studied in each measured case. By imputing such data in the Analysis Bio Computer Programme, the percentage of discomfort hours in the models was obtained. Correlations among the results were investigated considering different variables in the time and the space, allowing the comparison among different buildings and comfort zones, periods of the day and seasons. The main conclusion is that it is possible to verify the sensibility of the technical solutions applied in the cases in relation to the selective ventilation, demonstrating its importance in the building thermal performance and identifying important variables to improve the thermal performance of modern naturally-ventilated houses.

KEYWORDS
Selective ventilation, thermal performance, naturally-ventilated houses, modern houses.

INTRODUCTION

In Brazil, building codes about ventilation of dwellings require a very small area for natural ventilation and most of the dwellings around the country would benefit from larger areas. The minimum window areas that can be opened to be 1/6 (long occupancy spaces) or 1/8 (short occupancy spaces) of the floor area and openings are normally only half of this area. [1]

This paper presents the importance and the influence of the selective ventilation in the thermal performance of the buildings. Specifically, this paper focus the modern naturally-ventilated houses built in the late 1950's and early 1960's in the city of Goiânia, capital of Goiás state, located in the Midwest of Brazil. (Lat. 16.41S, Long. 49.25W, Alt. 741m/29,173.23in). Standard NBR15220 recommends for Goiânia (Bioclimatic Zone 6) medium ventilation openings (15%< A < 25%) but as it is only a recommendation, only a few buildings follow them. [1, 2] The selective ventilation is one of the passive thermal conditioning strategies recommended for buildings located in this city, in the summer. This study allows the analysis how much important is the selective ventilation as a bioclimatic strategy in the studied cases, considering the application of this strategy before the establishment of contemporary concepts as "zero energy building", helping us to reflect on the future from a historical perspective.

Due to be naturally-ventilated buildings, the study focuses on calculating variations of internal hygrothermal conditions and estimating the periods of lack of comfort, comparing the results with the external city conditions and also the immediate surroundings, and determining the thermal loads in reference to individual contribution of individual architectural elements of the two houses. Were considered the actual Brazilian normalization and the singularities indicated on the ResHB method about the internal thermal improvements, use of spaces and thermal zones differentiation [3].

The thermal performance of the modern houses located in Goiânia is a theme that transcends the technical study as it is related to a very important historical moment for Brazil in the 20th century. It is necessary to consider a historical, socio political and economic contextualization of a moment and place, so the theme can be addressed in its real complexity. This paper intends to study the object without losing this contextualized view.

ANALYSIS METHOD

Below are presented the basis for the study object definition, the methods and research procedures, the tools and instruments, also the general considerations regarding the analyses of the results.

The ABNT NBR 15575-1 (2008) [4] defines two levels of approach in assessing the thermal performance of houses: simplified normative and global informative, recommended on more detailed evaluations. In this paper we adopted the global informative evaluation that defines two procedures of requirements and criteria verification: by measurements on constructed buildings and through computer simulations.

Two houses were selected (1 and 2), starting from studies and surveys of the modern architectural heritage from the city of Goiânia [5]. To select the rooms to be measured we considered the requirements of the mentioned regulation that: relates the thermal conditions inside the houses with external conditions at shade; and focuses the study on prolonged stay rooms, living rooms and bedrooms, preferably those with the biggest surface exposed to direct sunlight and less favorable solar orientation. To define the measurement period we considered the typical conditions of the reference year in accordance to the meteorological data from 1961-1990 [6] as the summer and winter recommendations of the used regulations. This way, for each house were selected: 01 external environment shaded, 01 living room and 01 bedroom with easy access during the experiment. At the house 1, the central covered patio was also selected, for its peculiarity and strategic location. All in all, 07 environments were chosen in both houses for the measurements to be taken. Indoor and outdoor air temperatures and relative humidity were measured with thermal hygrometric Data Loggers HT-500, during 91 days in three different months in 2011: June (low air temperatures and low relative humidity); September (high air temperatures and low relative humidity); and December (medium air temperatures and medium relative humidity). The measured dates are used to calibrate the virtual model of the dynamic simulations. The environmental dates about the city of Goiânia were obtained by the measured dates of INMET (2011) [7].

All rooms of the residential units were simulated, considering the thermal exchanges between them, and the social and intimate functional sectors were also evaluated, with emphasis on the measured rooms. EnergyPlus building energy simulation program 4.0.0.024 was used to solve the energy balances and to evaluate the different contributions of each significant envelope component in the thermal performance of the houses, further allowing the comparison with the data obtained through measurements. These simulations were performed for the same period of the in situ measurements. The reference model for thermal performance simulations was based on the calibrated model, maintaining its volume and solar orientation. It was defined within the same thermal zones. The thermal properties of the materials and components used in the evaluation were determined as prescribed in the ABNT NBR 15220-3 (2005) [2], as shown in **Table 1.**

Variations in the ventilation were carried out and hourly air temperature and relative air humidity were the output data for the same thermal zones studied in each measured case. By imputing such data in the Analysis Bio computer programme, used to determine the periods of comfort, to obtain the percentage of discomfort hours and to compare the different variables allowing the analysis based on Givoni (1998) [8].

Data from the measurements and simulations have been treated to allow comparison such as: year period, territorial scales (urban/ immediate surroundings), type of spaces (internal or external), different houses (1 and 2), functional sectors (social/intimate) and internal rooms (living room/ bedroom). In this paper the data was analyzed from the thermo-hygrometric amplitude in accordance with the evaluation parameters of thermal performance existing on ABNT NBR 15575 (2008) [4], in a way to enable the analysis for surroundings correction and the thermal performance of the buildings in this scale. At the analysis of the results the particularities of residential typology in relation to other ones listed on ResHB Method were considered. The ResHB Method is an implementation of RHB Method, developed by the research project ASHRAE RP-1199, in order to adapt the HB Method to the particularities of residential typology, characterized by: less internal heat gain, mainly from the surrounding components, although it is generally more exposed to the other typologies [3]. The internal spaces were understood from the diversity and flexibility of related uses in these rooms, therefore higher tolerance of users to internal thermal fluctuations.

Correlations among the results were investigated considering different variables in the time and the space, allowing the comparison among different buildings and comfort zones, periods of the day and seasons.

Envelope components	U	φ
External Walls (thickness: 270mm) of solid brick (100x60x220mm)	2,25 W/m2K (0,39 Btu/ft2 h ºF)	6,8h
Roof of fibro-cement roofing tile (thickness: 7mm) with slab of concrete of 200mm	1,99 W/m2K (0,35 Btu/ft2 h ºF)	7,9h

Table 1. Description of the walls and roofs of the references models and its thermal properties: thermal transmittance (U) and thermal delay (φ)

CASE STUDIES

From a brief historic contextualization of the studied cases, below are presented the climatic characteristics from the city of Goiânia, followed by the case studies presentation.

Goiânia was founded in 1937 to be the new State Capital of Goiás, located in the Brazilian Midwest. In a context of national order characterized by political and economical changes, Goiânia eventually stood out as an expression of progress in a quest for modernization of the countryside. The early 50s were characterized by the countryside development, with the construction of a new capital for the country, Brasília, and the expansion of national infrastructure. It is in that decade that the first examples of modern architecture begin to appear in Goiânia [9].

The arrival of this new architecture transformed the architectural procedures that guaranteed the continuity of local tradition, changing the way these buildings adapted to climate, the factor which most interfere in the Brazilian architecture. Among the different typologies built, the residential ones were highlighted for their relevant role in the expression of the new architectural language. Among the strategies for climate adaptation used the highlights are: expansion of the openings in the building surroundings; constant use of cross ventilation in internal rooms; replacement of external porches and corridors for stilts, terraces and balconies; use of "*brise soleil*" as main solar protection element, extensively studied by architects and engineers of the time. The architectural changes mentioned affected the transparency, porosity and solar protection of the residential surroundings and directly influenced their thermal performance, mainly for being naturally ventilated.

The region where Goiânia is located is characterized by the continental and regular cyclic process of air masses displacements, implying a clear rainfall, causing the city climate to be formed by the composition of two main seasons: wet and dry (Aw according to Köppen). An important factor in relation to the dichotomy between the dry and wet seasons arise from the combined effects of nebulosity and insolation. Because of the nebulosity of 80% in December and 43% in June, although the difference between the number of daily hours of the summer and winter solstice is approximately 2h, the insolation in December is lower than in June, 161h/month and 275h/month respectively. Even thought the solar irradiation in December is higher than in June, 3361 W/m2 per day (1,066.13 Btu/ft2 h) and 2708 W/m2 per day (859 Btu/ft2 h) respectively, causes the south facade, struck by summer insolation, can be more transparent and free of solar protections. In opposite to the North facade, exposed to winter insolation, which should be well protected and more opaque [10].

According to ABNT NBR 15220-3 (2005) [2], the buildings located in the city of Goiânia (Bioclimatic Zone 6) must have: shaded openings with ventilation surface between 15% and 25% of the pave surface; heavy external walls, light and isolated roof. The passive thermal conditioning strategies recommended are: in the summer, evaporating cooling, thermal mass for selective cooling and ventilation; in the winter, internal thermal inertia. This way the characteristics of the surroundings have a greater influence in the environmental conditions during summer time, while the internal conditions of the buildings have bigger influence during wintertime.

Among the 78 modern houses currently identified in Goiânia, 2 houses in good state of conservation were selected, as shown in **Fig. 1**: House Abdala Abrão, projected by David Libeskind and built in 1961 (House 1), and House Eurípedes Ferreira, projected by Eurico Godoy and built in the late 50s (House 2), both located at Setor Sul, central area of the city, far from each other 280m (306 yards) approximately. Both houses have 2 floors and a functional shed on the back, focusing the residential areas (social, intimate and service) at the upper floor and leisure activities at the ground floor. Due to the topography, House 1 has the upper floor partially resting on the ground, allowing the main building access through this pave. Its intimate sector is located at the North side, oriented Northwest (Azimuth 343º), while the social areas are located at the South side. On House 2 is the opposite, the social areas are located at Northeast (Azimuth 44º) and the intimate at Southeast. As to shape, the design of House 1 is a square, with central covered patio while House 2 has an “L” shape. Externally both have a swimming pool, partially paved areas and permeable gardens with trees and grass.

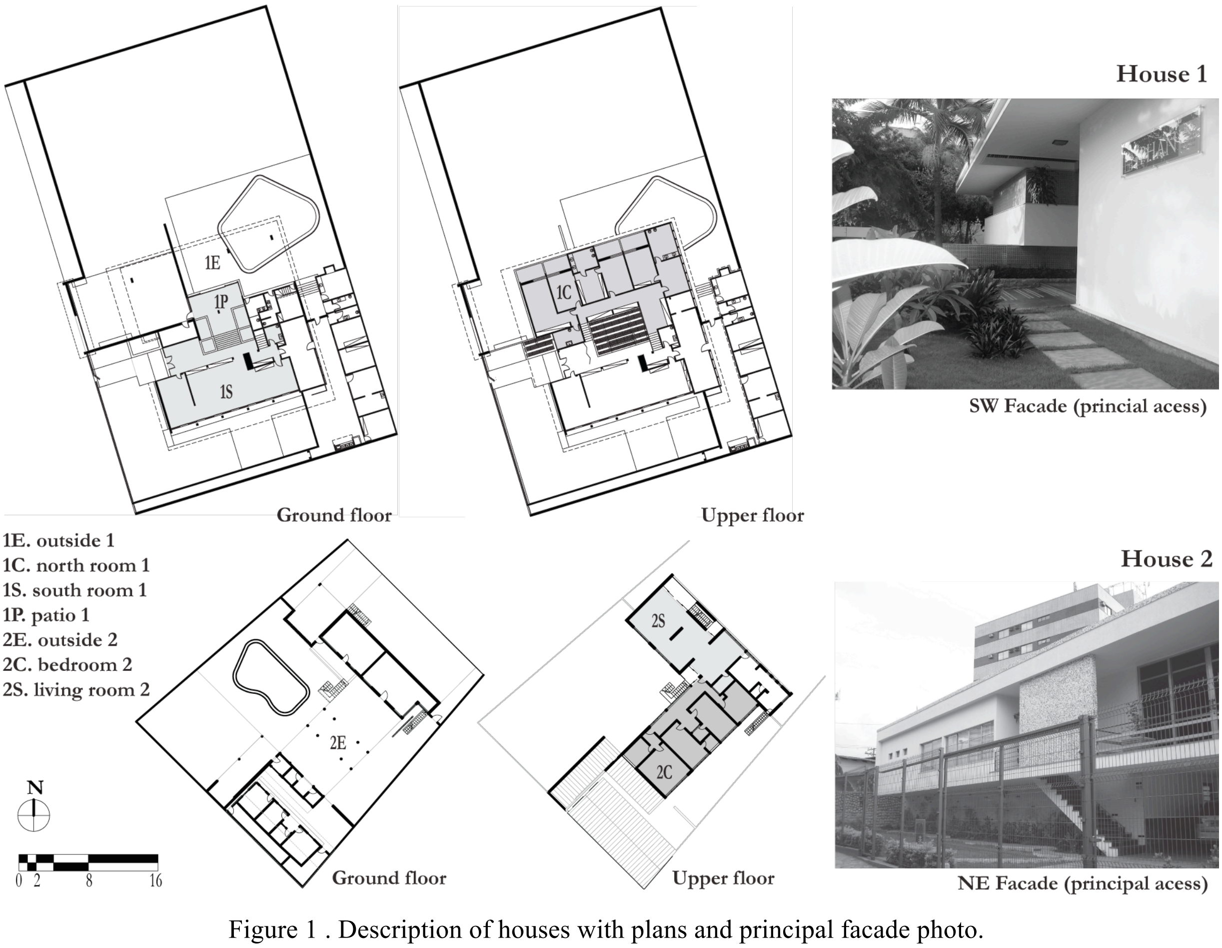


Figure 1 . Description of houses with plans and principal facade photo.

RESULTS AND DISCUSSION

The main results of the study are presented below comparing different results with Energyplus and AnalysisBio simulations.

The simulations done with AnalisisBio Programme pointed that passive solutions result in a zero energy demand in June. December presents more uncomfortable hours because the surround corrections are thought for dry seasons. Because this, the problem in December is the air humidity and it is not the air temperature. **Fig. 2** shows the Givoni graphic for the three sites and the three studied months. In September, the conditioning air was used in the bedroom of the House 1 (1C in Fig.1). It was the unique month and room that used this active system.

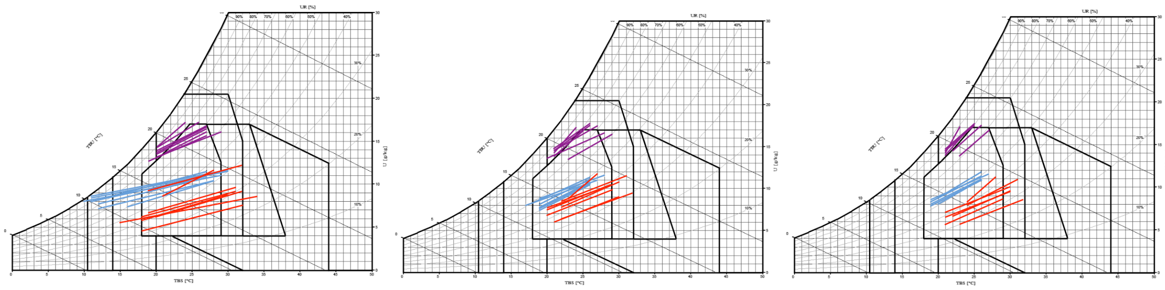


Figure 2 . Comfort graphics about the surround corrections in the different houses: on the left) Goiânia site measure dates; on the middle) House 1 outside; on the right) House 2 outside. Blue is June, red is September and lilac is December.

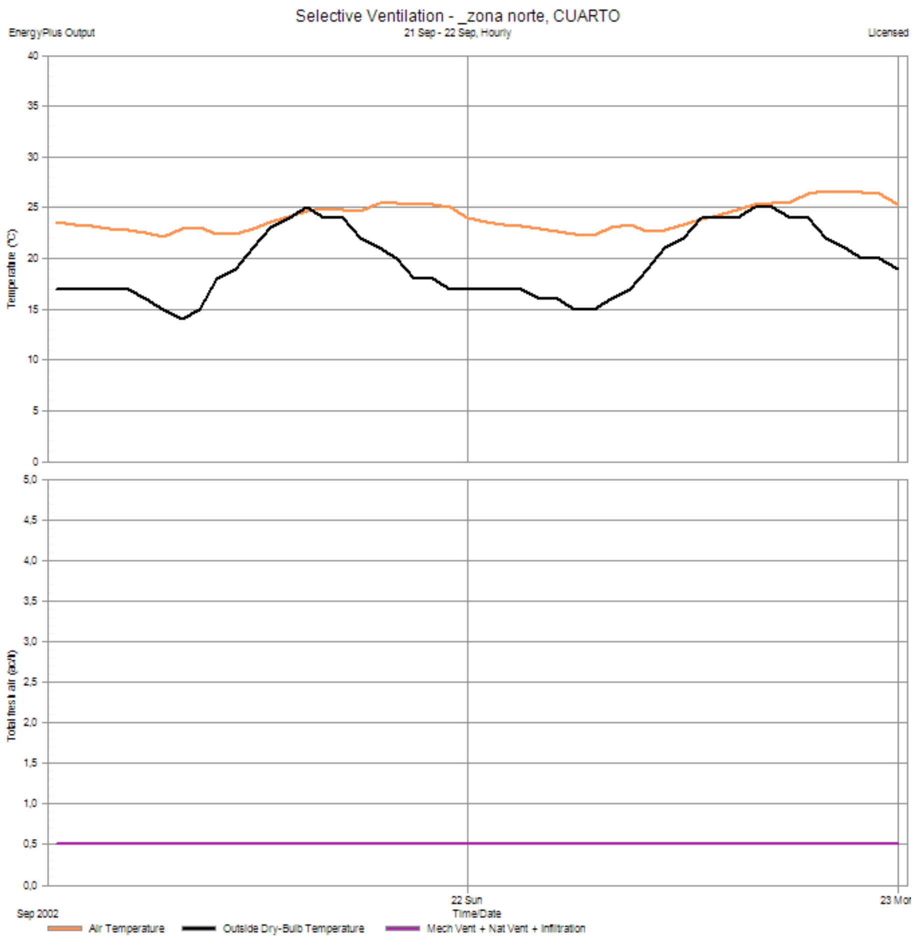
The simulations done with EnergyPlus Programme pointed the elements of thermal inertia as the factor of higher intervention rate on the thermal performance of the studied cases. The principal architectural components about its influence in the thermal performance of the building were: the ceiling and the walls. The internal ceiling was pointed as the main responsible for heat accumulation during sun exposure and for the thermal delay on the buildings, resulting it to be the main re-emitter of heat during the last hours of insolation, increasing the temperatures in this period of the day. The walls were the responsible for heat emission during the first daily hours, reducing the peaks of minimum air temperature during this time of the day. This combination between horizontal and vertical elements in the building confirms the importance of the integration of shaded and solar exposure architectural components, as the internal walls and the internal ceilings.

Variations in the ventilation were carried out and hourly air temperature and air relative humidity waere the output data for the same thermal zones studied in each measured case. Table 2 presents different ventilation schedules.

The schedule D represents a closed house and the schedule E represents an oppened house. Comparing the schedules D and E, variation in the ventilation can to oscilate the interior air temperature in almost 3ºC (37.4 ºF). The graphics presents that the oscilation is more evident in the last hours of the day. This evidence the needs of the night ventilation in this climate to help to reduce the effect of the thermal mass in the interior environment. Fig 3 shows the comparison between schedules D and E presenting the differences of the variation of the air temperature on September 21 and 22.

Schedule A	Schedule B	Schedule C	Schedule D	Schedule E
Schedule:Compact,	Schedule:Compact,	Schedule:Compact,	Schedule:Compact,	Schedule:Compact,
Dwell_DomBed_Cool,	Dwell_DomBed_Cool,	Office_OpenOff_Occ,	Office_all_closed,	Office_all_oppened,
Temperature,	Temperature,	Fraction,	Fraction,	Fraction,
Through: 31 Dec,	Through: 31 Dec,	Through: 31 Dec,	Through: 31 Dec,	Through: 31 Dec,
For: Weekdays	For: Weekdays	For: Weekdays	For: Weekdays	For: Weekdays
SummerDesignDay,	SummerDesignDay,	SummerDesignDay,	SummerDesignDay,	SummerDesignDay,
Until: 05:00, 0,	Until: 09:00, 1,	Until: 07:00, 0,	Until: 24:00, 0,	Until: 24:00, 1,
Until: 09:00, 1,	Until: 17:00, 0,	Until: 08:00, 0.25,	For: Weekends,	For: Weekends,
Until: 17:00, 0,	Until: 18:00, 1,	Until: 09:00, 0.5,	Until: 24:00, 0,	Until: 24:00, 1,
Until: 24:00, 1,	Until: 24:00, 1,	Until: 12:00, 1,	For: Holidays,	For: Holidays,
For: Weekends,	For: Weekends,	Until: 14:00, 0.75,	Until: 24:00, 0,	Until: 24:00, 1,
Until: 05:00, 0,	Until: 09:00, 1,	Until: 17:00, 1,	For:	For:
Until: 24:00, 1,	Until: 17:00, 0,	Until: 18:00, 0.5,	WinterDesignDay	WinterDesignDay
For: Holidays,	Until: 18:00, 1,	Until: 19:00, 0.25,	AllOtherDays,	AllOtherDays,
Until: 05:00, 0,	Until: 24:00, 1,	Until: 24:00, 0,	Until: 24:00, 0;	Until: 24:00, 1;
Until: 09:00, 1,	For: Holidays,	For: Weekends,		
Until: 17:00, 0,	Until: 09:00, 1,	Until: 24:00, 0,		
Until: 24:00, 1,	Until: 17:00, 0,	For: Holidays,		
For: WinterDesignDay	Until: 18:00, 1,			
AllOtherDays,	Until: 24:00, 1,			
Until: 24:00, 0;	For: WinterDesignDay			
	AllOtherDays,			
	Until: 24:00, 0;			

Table 2 . Different ventilation schedules simulated



a)

b)

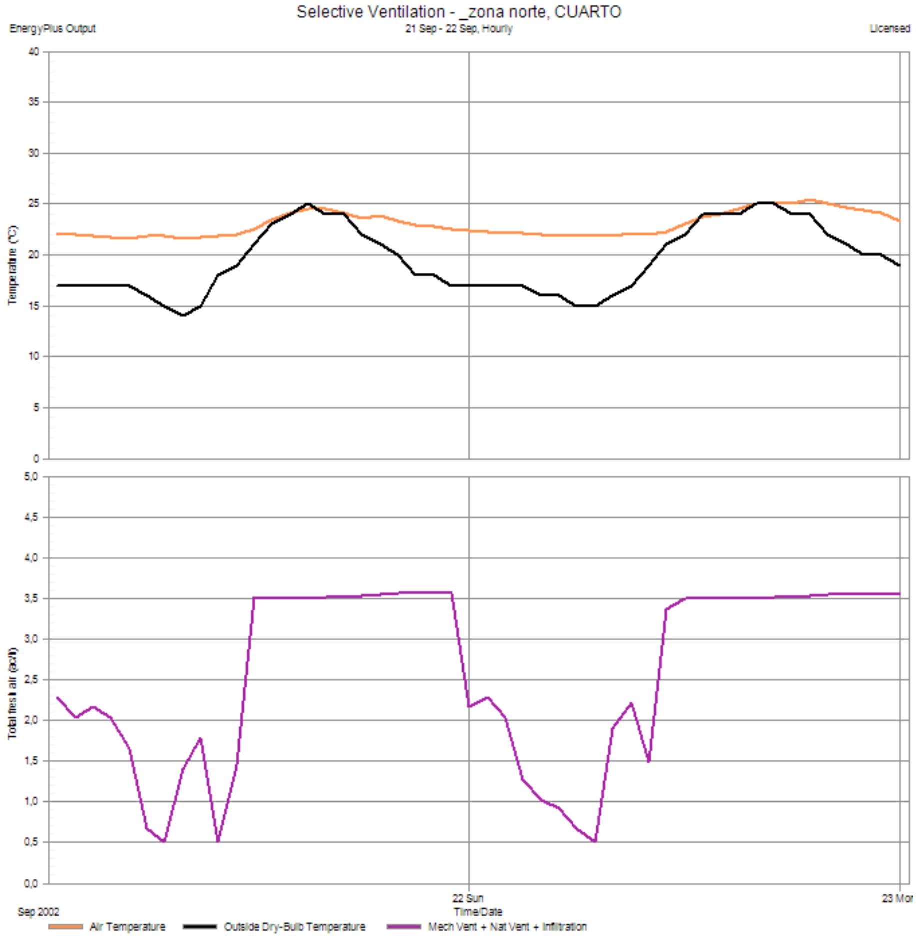


Figure 3 . Variations interior air temperature ºC (orange), outside dry-bulb temperature ºC (black), total air fresh ac/h (mechanic ventilation, natural ventilation and infiltration - lilac) of House 1: a) schedule D; b) schedule E.

CONCLUSIONS

The use of two methods of analysis, merging various computational tools and measuring instruments proven particularly adequate for the type of study, allowing: analysis of the cases from different scales, from global to specific, besides allowing the isolation, differentiation and comparison of various elements and intervening variables to the thermal performance of the studied cases. The results obtained with the different methods are complementary, indicating in both houses, that while some building components help to improve the thermal performance of the modern naturally-ventilated houses, others worsen this, resulting in a thermal performance below his potential.

June is a month with the best index with a good surround correction and good inside conditions. The most critic period of the year is September with higher air temperatures and low air relative humidity. The comparison between measure and simulated dates evidences the use of air conditioning in the bedroom of house 1 (1C in the **Fig. 1**) in some days of this month. Although, the air temperature peak does not represent an uncomfortable situation in the others studied rooms for people that live in this climate, as Givoni (1998) [8] indicates. Still thus, the air temperature peak occurs with 3 hours of delay, sufficient time: to reduce the inconvenient effects with a mix of external and internal air, and to supply the critical moment applying cooling systems with low energy demand. Despite September presents the worst situation, a simple strategy demostrates to be efficient in this month too. The control of the dwellings in the house is very important to guarantee the interior comfort during all the day.

It is possible to verify the sensibility of the technical solutions applied in the cases in relation to the selective ventilation, demonstrating its importance in the building thermal performance and identifying important variables to improve the thermal performance of modern naturally-ventilated houses. The reduction of the interior air temperature oppening the house in the correct hours is a easy strategy that can be used without complex active systems in the house but with the simple conscious of the inhabitant. Many times easy strategies are the best solution.

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