# PERFORMANCE CONFRONTATION BETWEEN PARAMETRIC ANALYSIS AND EVOLUTIONARY ALGORITHM TO ACHIEVE PASSIVE HOUSES IN WARM CLIMATES

António Figueiredo[1]; Jérôme Kämpf[2], Romeu Vicente[1]

*1: RISCO - Department of Civil Engineering, University of Aveiro, Campus Universitário de Santiago, Aveiro, 3810-193 Aveiro, Portugal*

*2: Solar Energy and Buildings Physics Laboratory, École Polytechnique Fédérale de Lausanne, Switzerland*

## ABSTRACT

Passive House (PH) is a concept that serves as a starting point for future zero balance energy houses. With its particular technical and constructive features adapted to specific climate zones and their corresponding climatic boundary conditions, the application of the concept is a necessary strategic condition to support and promote high-energy efficient dwellings. The latter is important to fulfil the main objectives established by the recast of the Energy Performance of Buildings Directive (2010/31/EU, EPBD) for 2018. Acknowledging that the PH concept was established and adopted mostly in cold climate context, the present study investigates how this approach can be extended to warmer climates, in particular to Portugal Mainland climate. In such south-western European climates, in addition to meeting the heating requirements, it is necessary and crucial to provide comfortable conditions in summer, due to a high risk of overheating in the case of fairly glazed dwellings. In this study, a comparison between two approaches: i) a parametric analysis, and an ii) optimisation with a hybrid evolutionary algorithm is proposed to achieve the PH requirements in terms of energy demand imposed by the PH concept (15 kWh/m$^2$.a). The base case, a representative contemporary architecture dwelling of concrete frame and masonry infills was modelled resourcing to dynamic thermal simulation with Energy Plus software as the energy-modelling tool. The paper presents the optimal solutions obtained by resorting to the parametric study and the evolutionary algorithm (EA), together with an analysis of their performance. The paper compares, taking into account the advantages and disadvantages of the use of an evolutionary algorithm to standard trial and error practice approach.

*Keywords: Energy Efficiency, Optimization, Evolutionary algorithms, Passive House*

## INTRODUCTION

In the recent decades the primary energy demand has increased exponentially, mainly due to the impact of the building sector. It is estimated that this sector is responsible for consuming 40% of the total energy use of the European Union (EU) [1]. In Portugal, the General Division for Energy and Geology (in Portuguese: Direção Geral de Energia e Geologia (DGEG)) collected data that revealed a significant impact on the global energy demand. Approximately 17% of the energy in 2009 is used in residential buildings [2]. On one hand in recent years (2000-2009 period), the energy consumption in EU buildings has not changed significantly, but on the other hand, in the South western European countries it increased, due to the cooling energy demand [3]. Therefore, it is important to highlight the need to thoroughly understand and assess the external envelope constructive solutions adopted in those countries by optimizing insulation thickness, windows solutions, shading protections, etc. for mitigation of the cooling demand without undertaking high overheating risk in summer. To fight against these numbers, the PH concept is foreseen as the way to reduce the annual energy demand in buildings and to provide high comfort level. Acknowledging that this concept was born in Germany and is well been established mostly in central Europe, other studies in South European zones should be developed. In these zones the summer interior temperature is ever more reliant on window size and orientation, shading devices, interior heat sources and ventilation rate, since there are concerns in respect to overheating risk. As a consequence, the construction technology and detailing has to be adapted to the specific climate zone location and specific climatic boundary conditions. The goal of this work consists in the definition of envelope solutions to apply in buildings located in Mediterranean zones that comply with the PH requirements, comparing parametric and evolutionary optimisation methods.

## METHODOLOGY

Dynamic thermal simulation of a detached building was accomplished using EnergyPlus® 8.2.0 (EP) software. EP was used as calculation engine to support the parametric and evolutionary optimization analyses. The first step starts by a hygrothermal monitoring campaign of the building, used to validate the numerical model. The second step was accomplished resourcing to a parametric analyse. Many features were assessed and evaluated, such as glazing type and orientation, bypass air flow rate, and insulation thickness in order to assess the building thermal response. A comparison between parametric analyses and evolutionary approaches was performed. An EA for minimization of a multi objective function, heating and cooling demand was used and the results were presented and compared. Once, the improvements achieved, as third step was defined, a set of new simulations were carried out in order to define the best Passive House solution for other regions of Portugal mainland. The parameters from the best solutions found in the parametric analysis were used as restrictions (upper limit) in the optimized parameter approach. In this way a comparative survey was developed, to find new optimized solutions and to compare parametric versus evolutionary optimization results.

## CASE STUDY OF A DETACHED BUILDING

### Building characterization

The building is located in Aveiro at about 5 km from the centre city and 12 km from the Atlantic coast, in North central Portugal. This building is situated at latitude of 40.613427ºN, a longitude of -8.652487ºE and 17 m of altitude. Two floors define the proposed architectural solution. The ground floor entails the common part of the building and the first floor comprises the bedrooms and bathrooms (Figure 1). The building has 163 m$^2$ of treated floor area with a 405 m$^2$ of exterior surface area and the global percentage of glazing is about 21% of the opaque facade area. The glazing oriented to the North represents a relative percentage of the total glazed area of 26%, 47% to South, 25% to East and finally 2% to West.

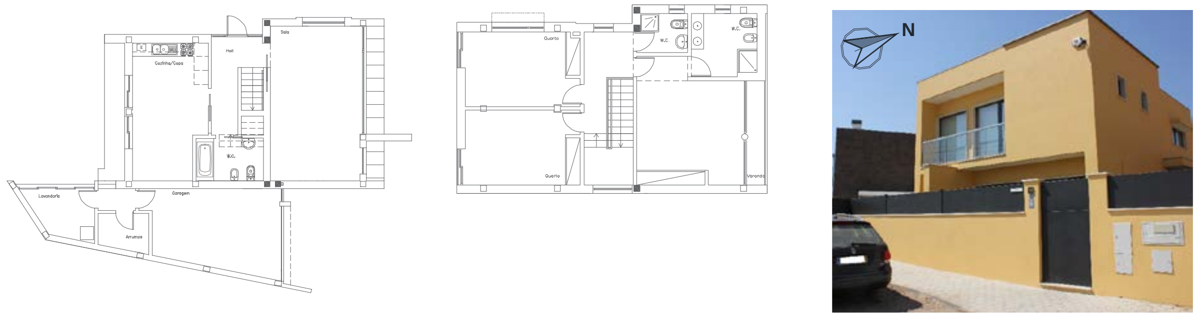


*Figure 1: Architectural blueprints (no scale): ground floor level on the left, elevated floor level on the centre and a real 3D view on the left*

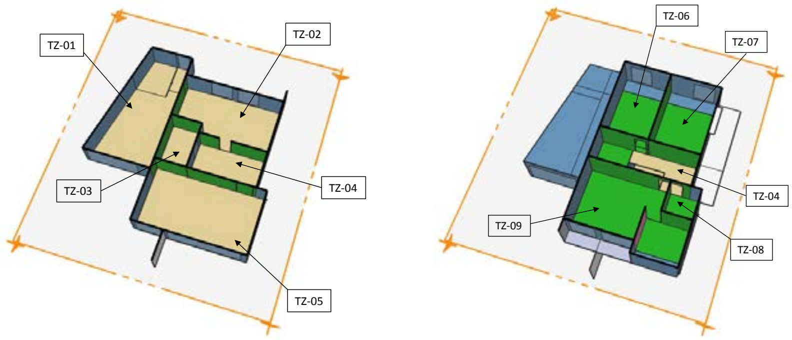
The building's envelope walls are composed of a double leaf horizontally hollow clay brick with an air gap, partially filled with 4 cm of XPS insulation. The thermal properties of the adopted constructive solutions were (in $W/m^2$ °C): ground floor slab $U_{value}$ = 0.693; façade walls $U_{value}$ = 0.454; flat roof $U_{value}$ = 0.332. The value of thermal transmission coefficient used for windows ($U_{w,\ installed}$ = 1.77 and solar heat gain coefficient = 0.56) and external glazed doors ($U_{w,installed}$ = 1.40), taking into account the thermal bridges (linear thermal transmittance, $\Psi$) from the frame, spacer and the window installation. In order to optimize the parametric analysis, an average value, $U_{w,installed}$, was calculated, according to the Passive House Planning Package data Sheet (PHPP).

## Numerical modelling: monitoring and validation

The numerical model was validated with data provided from a hygrothermal monitoring campaign developed during some periods in 2013. To record temperature and relative humidity it was used sensors with a temperature probe with 0.5ºC error and a resolution 0.1ºC and with a humidity probe with 3% error and 0.1% resolution. The deployment of *in-situ* sensors, inside of the compartments was done in accordance with ISO 7726 [4]. The numerical model was validated with weather data collected from a local weather station (7km from the local site). The comparison between measured and simulated results was done for the indoor air temperatures during the last week of August without occupation and during December with occupation to validate the numerical model with a real occupancy profile and internal gains. The overlapped results shows a fairly good agreement between the numerical model and *in-situ* measurements with differences between both curves of 1°C maximum.

## Thermal building simulation

SkectchUp® tool with OpenSudio plugin, with a graphical interface, were used to reproduce the geometry of the model and define features related to thermal zoning and constructive solutions. The annual thermal behaviour of the building was simulated and calculated resourcing to EnergyPlus® software. A detached multi-zone model was assembled using nine thermal zones (TZ), corresponding to internal compartments of the building. The ground floor has five TZ including the garage (unheated space), and the first floor has another five TZ. One of these five zones is common to both floors levels, including the corridors and the staircase.



Nomenclature:
TZ-01 – Garage
TZ-02 – Kitchen
TZ-03 – Bat_GF
TZ-04 – Hall (2 floors)
TZ-05 – LivRoom
TZ-06 – BedR_1N
TZ-07 – BedR_2N
TZ-08 – Bat_1ºF
TZ-09 – BedR_1S

*Figure 2: Indoor space thermal zone layout*

## RESULTS AND DISCUSSION

## Building characterization

The original building which constitutes our reference case was modelled with an HVAC system to determine the annual energy consumption for heating and cooling as a first approach. In a second approach, the dwelling was modelled without the mechanical ventilation system for heating or cooling. However 0.6 $h^{-1}$ was ensured as a natural ventilation mode. The second approach without a mechanical system allowed a passive comfort assessment in accordance with standard EN 15251 category II [5]. The overall energy demand for heating the dwelling was 34.39 kWh/m$^2$a and for cooling was 6.96 kWh/m$^2$a considered that the temperature setpoint range was 20-26ºC for all thermal zones. In the passive approach four thermal zones were selected as representative of the overall dwelling behaviour.

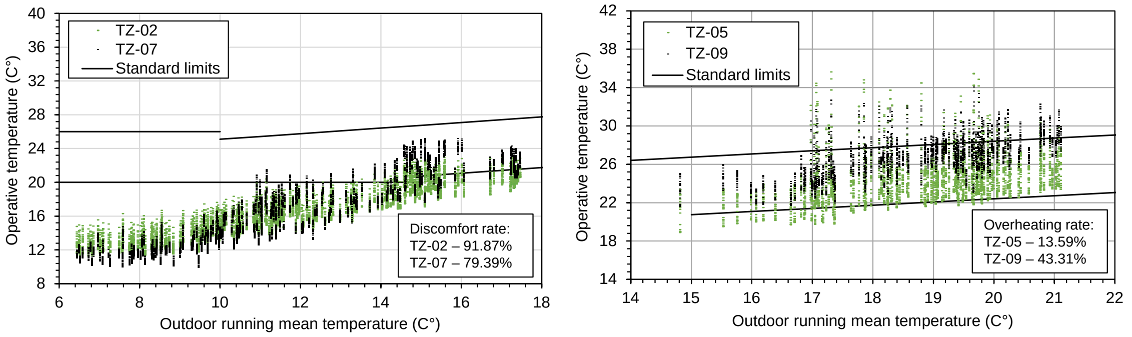


*Figure 3: Indoor air temperature for heating (left plot) and for cooling (right plot) seasons*

Analysing Figure 3, it is possible to verify an exceedance of the adaptive comfort limits below the lower limit curve for indoor air temperature in heating season and above the upper limit for the summer, indicating long periods of discomfort in winter and overheating in summer.

## Parametric simulations - improvements

A series of numerical simulations were carried out in order to analyse the effect and improvement of passive techniques. Different scenarios were defined to evaluate the thermal behaviour. The simulations, were performed combining the following parameters: a) rotation of the building with 0° (original position) 90°, 180°, and 270°; b) additional air flow rate from 0 to 2.4 (bypass capacity is expressed in h$^{-1}$); c) insulation thickness (walls, roof and floor) between 4 and 12 centimetres; d) original windows solution with double glazing (characterized in section “Building characterization”) and another solution with triple glazing with thermal transmission coefficient of $U_{w,installed}$ = 1.18 and a solar heat gain coefficient value SHGC = 0.5. Summing up, a total of 72 models ran and analysed.

## Selected scenarios and results

### Parametric analyses

From the simulations performed, the best scenarios were discussed in terms of energy demand for heating and cooling for the comfort range defined (20º - 26°C). Figure 4 lists the best simulations that lead to the best performance. This is the lowest combined heating and cooling energy demand for an annual simulation. The best scenario corresponds to a solution resourcing to a triple glazing, 12cm of insulation for walls, roof and floor, ACH equal to 0.6 with additional bypass rate (ACH = 2.4h$^{-1}$), and, with the dwelling rotated from the North to 180°C. Comparing with the original solution (34.39 kWh/m$^2$a), a reduction of 42% of the heating energy demand is obtained and the reduction in the cooling demand was 64%.

### Multi-objective evolutionary optimization definition

Optimization is an ongoing process of searching and comparison of feasible solutions to a given problem, until no better solutions can be found [6]. In this study four types of decision parameters were used concerning the alternative combinations. The parameters used in the optimization process were the same used in the manual trial and error process. The alternative input parameters considered, and correspondent input method are shown in the Table 1.

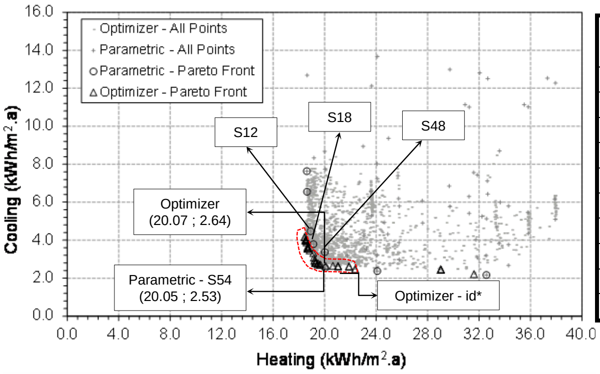
| Parameter id. | Designation | Box Constrains | Step |
|---|---|---|---|
| x0 | Insulation Thickness | 0.04 – 0.12 (mm) | 0.01 |
| x1 – x8 (by TZ) | Bypass Air flow | 0.00 – 2.40 ($h^{-1}$) | 0.01 |
| x9 | Dwelling Orientation | 0 – 360 (º) | 1 |
| **Strings** | | | |
| x10 | Window Solution | $U_{value}$ = 1.77 ($W/m^2$ °C) and SHGC = 0.56 | |
| x11 | | $U_{value}$ = 1.18 ($W/m^2$ °C) and SHGC = 0.50 | |

*Table 1: List of parameters and constraints*

As objective functions a multi-objective optimization was used to minimize the opposite functions: heating and cooling demand.

<u>Multi-objective evolutionary optimization results versus parametric results</u>

The results in this sub-section contain the points of the Pareto front that represents a set of optimal solutions and the points which represent the best solutions from parametric analysis.



| Simulation id. | Insulation Thickness (cm) | Building Orientation | Windows type | By pass air rate $h^{-1}$ |
|---|---|---|---|---|
| Parametric solutions | | | | |
| S12 | 12 | 0º | TG | 1.2 |
| S18 | 12 | 0º | TG | 2.4 |
| S48 | 12 | 180º | TG | 1.2 |
| S54 | 12 | 180º | TG | 2.4 |
| Evolutionary optimization | | | | |
| Id5811 | 12 | 270º | TG | 1.98 |
| Id3808 | 12 | 241º | TG | 2.02 |
| Id8682 | 12 | 101º | TG | 2.18 |
| Id6773 | 10.5 | 271º | TG | 2.09 |

[a] TG – Triple glazing | DG – Double glazing

*Figure 4: Comparison between multi-objective optimizer and parametric analysis*

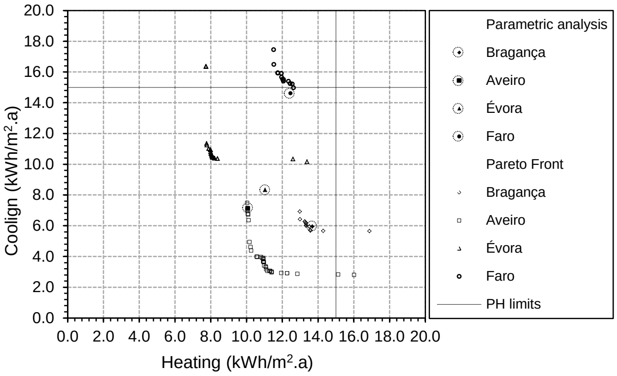
Comparing the results from the parametric analysis with the results from the optimizer (Figure 4) differences between 2% to 3% were observed for heating demand and differences between 3.5% and 17% were observed for cooling demand. The results were always better in the optimizer with the exception of the scenario S54 that represents a solution with all the parameters in the upper limit of the defined constraint range. The difference observed between this scenario and the closest non-dominated scenario from the optimizer, was 0.1% for the heating demand and 4.1% for the cooling demand.

## PASSIVE HOUSE ASSESSMENT FOR DIFFERENT REGIONS

In this section the PH adaptability measures are assessed for different regions in Portugal mainland. To broadly characterize the different climatic regions of the country, two regions, representative of the interior North and South (Bragança and Évora) and two other near to the coast (Aveiro and Faro) were chosen. As the original building model definition does not comply with the PH requirements as well the improved solutions, a mechanical ventilation system with heat recovery (80% efficiency) was used in turn of the conventional HVAC system used in the first approach.

### Results and discussion

The same parameters ranges were used in the attained parametric solutions for each region and were also adopted as the upper limit restriction in the optimizer parameters. The following plot (Figure 5) shows the best solutions provided from the parametric analyses versus Pareto front from the optimizer approach.



| Simulation id. | Insulation Thickness (cm) | Building Orientation | Windows type* | By pass air rate $h^{-1}$ |
|---|---|---|---|---|
| Parametric solutions | | | | |
| Bragança | 12 | 180º | TG | 2.40 |
| Aveiro | 8 | 270º | DG | 2.40 |
| Évora | 8 | 180º | DG | 2.40 |
| Faro | 4 | 180º | DG | 2.40 |
| Evolutionary optimization | | | | |
| Bragança | 12 | 85º | TG | 1.77 |
| Aveiro | 8 | 262º | DG | 1.79 |
| Évora | 8 | 87º | DG | 2.16 |
| Faro | 4 | 90º | DG | 1.91 |

[a] TG – Triple glazing | DG – Double glazing

*Figure 5: Attained solutions for different zones (Pareto Front with 10.000 evaluations)*

Analysing the results the major advantage in use the evolutionary optimization is a wide range of possible solutions assembly. In this particular study and because the attained solutions were always in the upper frontier of the range proposed for the four parameters, the parametric analysis solutions are always near to the best configured solution form the EA approach. The best obtained solution from the parametric analysis for Évora and Faro present less cooling demand, however from the optimisation approach, some solutions attained in the Pareto front show optimised results for these regions by the sum of cooling and heating demand. The optimizer works to finding the best commitment between the both objective function defined.

## CONCLUSION

A comparison between two different approaches (optimization and parametric analysis) was applied to a detached dwelling case study. Regarding the results, the parametric analysis is always dependent on the previously defined parameters increment chosen. A parametric analysis can be useful to test an individual set of parameters to understanding the impact of an improvement measure package defined. Multi-objective evolutionary algorithms produce a wide range of non-dominated solutions. The final decision can therefore be based on a real understanding and can be taken by the owner or the designer. In sum the proposed approaches shows a great potential for the evolutionary algorithm approach to solve problems related to retrofit or improvement package solutions. EA can be used as an aid to decision-making in the context of a design project definition.

## REFERENCES

1 Buildings Performance Institure Europe.: Europe's buildings under the microscope. 2011.
2 Directorate General for Energy and Geology.: Residential Energy Consumption Survey 2010, in *Statistics Portugal, Lisbon, Portugal, 2011*
3 Balaras, C. Grossman, G. Henning, H. Infante Ferreira, A. Podesser, E. Wang, *L.:* Solar air conditioning in Europe, an overview, *Renewable and Sustainable Energy Reviews,* vol. 11, pp. 299-314, 2// 2007.
4 Ergonomics of the Thermal Environment, Instruments for measuring physical quantities, I. 7726, 1998.
5 EN 15251:2007-08.: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. CEN, Brussels, Belgium, ed, August 2007.
6 Kalyanmoy, D.: Multi-Objective Optimization using Evolutionary Algorithms, ed. Chichester, England: John Wiley & Sons, Ltd, 2001.