Designing low energy buildings: application of a parametric tool and case studies

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ABSTRACT: Still the traditional design approach, and even more the Integrated Design Process, need an effective and efficient design methodology and smart, useful and fast design support tools, in order to fulfil the requirements of low energy buildings besides all other issues included in the “building design”: aesthetic, functionality, budget limit, customer requirements. How can the design team being well supported in the choice of the final set of solutions? Which operative and useful approach can become a common design method in order to efficiently achieve the compulsory low energy standards? Based on PHPP (Passive House Planning Package) an excel macro has been developed in order to perform parametric analyses on many design input variables. This parametric approach is the core of a wider design methodology including also the use of guidelines for the definition of the design concept, the definition of a base case in PHPP relying on the already fixed, the post-processing and the repetition of the parametric analysis at different design steps, each time with less free variables. Two office buildings under design process have been chosen as case studies for testing and assessing the whole methodology. The parametric tool – through fast, numeric, quantitative and parametric results – has proven to be an effective design support tool.

Keywords: energy, designing process, tools, designing variables parameterization

1. INTRODUCTION

Still the traditional design approaches, and even more the Integrated Design Process, need an effective and efficient design methodology and smart, useful and fast design support tools, in order to fulfil the requirements of low energy and net zero energy buildings together with all other issues concerning “building design”: aesthetic, functionality, budget limit, investor/owner request, etc. How can the design team being well supported in the choice of the final set of solutions? Is there an operative and useful approach that can become a design method in order to efficiently achieve the now compulsory tight energy standards?

The presented work describes an effective integrated design methodology, made of a design planning process and tools for supporting design team with the aim to easier achieve low energy targets.

The pursued goals are high indoor environmental quality and the performance requirement of NZEB: Net Zero Energy Building, as defined in EU directive 2010/31 (even if it replaces “Net” with “Nearly”).

The above goals lead to implement a control and assessment procedure for energy and indoor comfort, to be carried out in the design phase when it is still possible to modify the technological, operative and architectural choices, without or keeping down the extra-costs. Such a procedure is easy to apply, useful for several scopes in various climatic contexts and able to determine the most meaningful building parameters affecting its performance level.

In the following the methodology will be described and then two different applications for office buildings, often afflicted by overheating and high energy need for summer cooling, are presented.

2. OBJECTIVE

The objective of the work is to develop a parametric approach as a practical methodology for the designing of low energy building. The use of new designing methods and processes should be more and more stressed as fundamental for the achievement of the strict energy standards as written in recent Europeans directives and step by step accepted by national norms and standards. The traditional designing approach fails (from an energy point of view) mainly in the lack of interdisciplinary (to handle a holistic approach) and in the needs of a fast, cheap and “easy to understand” designing tools.

3. METHODOLOGY

3.1. Work context

The elaborated approach is based on the parameterization concept applied to the building energy simulation. The energy simulations were carried out using the software tool PHPP (Passive House Planning Package), implemented in an MS Excel file, whilst for the parameterization an MS Excel macro has been developed by EURAC. The MS Excel macro contains some procedures that allow to automatically modify particular PHPP inputs, to launch simulations and to post-process the obtained results. With this methodology is possible to obtain a certain number of energy simulations (and relative building configurations in terms of constructive and technological solutions), starting from a basis numerical model. The number of solutions depends on the number of variables and on the values assumed from such variables. The MS Excel macro is thought as an intuitive, easy to use tool, collecting the physical and geometric features of the building as inputs data for the relative numerical model.
The possibility to produce a wide range of different solutions in short time and in few and easy steps, obtained combining input in different way, allows to define a set of solutions in compliance with several requirements. Depending on the needs and on the performance targets of the project it is possible to select the most convenient solution or solutions.

One application of the parameterization is to define the most important inputs values (statistical analyses) and to define the optimal configuration (research of the optimum) for each particular building project in order to achieve the fixed target: e.g. for every building configurations fulfilling the NZEB requirements, a statistical analysis is made, calculating the frequency of appearance of the input variables values as explained in the following. For example a low U-value means thick thermal insulation that, on the other hand, means a costs increasing for delivering raw materials. Using the methods described it is possible to define a range of solutions, varying others inputs (e.g opening size, shading systems and internal loads) while keeping fix the insulation material thickness and then the relative costs for delivering, in order to reach the fixed goals.

3.2. The proposed methodology

Design approach. The starting point is an analysis of the location, climates and the morphology of the area where the building will be realized (or retrofitted), and then the development of the design concept. Just before this step, variables (free choice of the designers) and fixed parameters/constraints are normally highlighted. These constants are the already fixed parameters connected with the climate, morphological, urban, the normative context where the building will be (or is) placed, the requirements asked by the investors or the owner, etc.

The set of physical variables of the building envelope are:
- Architectural, connected to the building typology and operative composition, and expressed in terms of orientation, exposure, shape and volume.
- Constructive, that is the set of features depending on the materials, components and systems choices, such as U-value, thermal capacity, finishing emissivity.
- Operative, connected on the activities in the built environment; depending on the final use, the comfort requirements are modified and, as a consequence, the requested operative performances and the control and regulation of the incoming and outgoing energy flows, to pursue and reach the desired indoor environmental quality level (ventilation, lighting, internal loads, etc.).

In this phase there is the shifting from architectural concept to the parameterization of the building in a numerical model, made of several physical / mathematical parameters. Possible values of the input variables are inserted in the MS Excel macro interface in order to be ready to launch the multiple energy simulations.

Of course the numerical values assigned to the physical parameters must have an actual physical meaning (realizable both technologically and economically).

Definition of the building performance indicators. They are the measures of the energy demand of the building. They are used in order to evaluate the building energy efficiency and in the present work summer and winter thermal net energy needs, primary energy demand, summer overheating were taken into consideration on an annual values.

Parameterization and energy simulations. The input variables (or building parameters) are entered through the MS Excel macro, that successively launches several times the calculation tool PHPP, modifying automatically such inputs and sorting the output sets calculated for each input sets. The number of output sets depends on the numbers of values for each variable raised to the power of the number of variable parameters. In the case studies presented in the following different number of variables were used, but considering only two values for each of them (low or high). The meaning of the analyses in this case is to evaluate the building behavior for some particularly meaningful conditions (as the standard set by the norms and the Passive House high performance conditions).

Results selection and determination of leading variables. The solutions choice is carried out considering minimum energy requirements for the building in compliance with law in force and certification schemes. Once the feasible solutions have been highlighted and the statistical population created, the next step is the results analysis, through the use of diagrams that show the percentage frequency of high and low variables values of this selected set of solutions. On the x-axis there are the input variables (Uwall, Uroof, Ubasement, etc.), on the y-axis the frequency of appearance of the two possible values, as a percentage of the total selected solutions (Figure 1).

![Figure 1: Example of frequency diagram. In grey the percentage of appearance of the low value of the x-axis variable. In black the high value. The frequency values help in finding which variables have an higher influence on the investigated output (i.e. cooling demand).](image)

Farer from the 50% is the value, higher is the importance of the variable, since that value is presented more time in the selected set of solutions. 50% means that low and high value of the variable are equally presented in the statistical population. In
other words, a designer for the considered building in the defined conditions, can choose equally a low or a high value of the design variable and the final building performance will have the same possibility to remain in the feasible group as it will depends by other variables. In the following lines, two applications on to case studies are reported:

- Typical office building, designed in compliance with the standard and regulations and hypothesized as placed under three different climatic conditions.
- Actual preliminary project of a new office building located in Bolzano (north east Italy).

4. FIRST APPLICATION: PRE DESIGN PHASE AND CONCEPT DEFINITION

4.1. Case study description

A lifelike office building project has been sketched in order to have a general but realistic case study. The common architectural design rules have been taken into account as far as indoor space usage and shape geometric variables (length, depth, height) are concerned. Building shape and internal space, worker density, hygienic air changes, internal loads, lighting level requested and relative system have been fixed as set by the current Italian standards and laws (UNI10339, UNI/TS11300, UNI7995). The reference building has been also considered in three different typical Italian climate conditions (Bolzano, Pescara, Palermo) in order to test the method also in relation to climate. The three locations are characterized by significantly different values concerning the Winter Severity Index WSI (respectively 7.55, 4.47 and 2.25 kWh/m²y) and the Summer Severity Index SSI (respectively 2.1, 2.33 and 2.78 kWh/m²y) and are therefore representative of three typical Italian climate conditions.

4.2. Support of the parametric approach

In the study case many variables have been no fixed on purpose in order to identify a situation of building concept definition. The orientation (1), the presence of balcony (2), the percentage of transparent surface North (3), South (4) and East and West (5), the thermal transmittance U of the opaque envelope (6) and of the windows (U North – 7, U South – 8, U East and West - 9), the glazing solar factor (g North - 10, g South – 11, g East and South – 12), the summer movable shading effect (13), the building specific thermal capacity (14), the level additional summer ventilation (15) and the internal loads (16). The total number of considered cases increases exponentially being the number of values each variable can assume the base and the total number of considered variables the exponent \(2^{16}=65536\).

In Figure 2 the solutions satisfying a cooling demand under 15 kWh/m²a are reported. The variables with a frequency closed to 50% (central dotted area) have to be considered less influencing in order to achieve the desired performance target (low cooling demand in this case). On the contrary the parameters more influencing are highlighted with black circles: under the dotted area there are thermal mass (low frequency of “low value” of thermal mass corresponding to a high importance of an “high value” of thermal mass in order to reduce cooling demand) and night natural ventilation (it means high night ventilation to reduce cooling demand); above the dotted area there are transparent surface and summer movable shading effect (both low to reduce cooling demand).

Figure 3 shows the best 100 solutions considering the cooling demand. These design possibilities have been grouped depending on the architectural input variables. The variables are: orientation (North-South), balcony (with or without), and windows dimensions (high or Low). On the horizontal axis it’s possible to see the eight categories representing the different combination of variables (e.g. presence of balcony, orientation NS and high transparent area is one architectural category). The graph shows as the cooling demand is really influenced by the dimension of the glazed areas: case n.1 has lower dimension of the transparent area than case n.2. In Palermo the high value of this variable increases cooling demand from 5 kWh/m²y (with low value of windows) to 23 kWh/m²y (with high value of windows), and of the overheating frequency values from 13% to 26%. Furthermore, from all the presented graphs, the influence of the different climate locations on the design choices is clearly represented. For example, the E-W transparent area variable has a 10% higher influence in Palermo respect to Bolzano in order to satisfy the requirement of 15 kWh/m²y (Figure 2) with an averaged saving potential of circa 20 kWh/m²y for Palermo and of circa 3 kWh/m²y for Bolzano (Figure 3).

The parametric approach can be used also to find the best configurations of variable’s values to be used as best case examples for the design process.
The output here presented shows their usability as design tool to be applied to each specific design process and building case more than as numeric values for the office building used as case study.

Figure 3: Average of the cooling demand of the best 100 cases divided in 8 architectural categories. Influence of the transparent area ratio on the architectural group without balcony and with the main axes oriented North-South.

5. SECOND APPLICATION: TECHNOLOGY DEFINITION

5.1. Case study description

The analysed system is a preliminary building project by John Norman Leslie Oldridge & Claudio Lucchin & architetti associate, winners of the design competition for the refurbishment of the industrial area “ex-Alumix” in Bolzano. The planning foresen the design of a Scientific and Technological Park made of refurbished existing historical building and new ones, used for tertiary activities: offices, laboratories, multi-functional room, etc. In this case the performance targets are the realization of a building characterized by a very good indoor comfort and a zero balance between consumed and produced primary energy (NZEB).

Analysis of the state of the art and context. The first analysis was the review of existing technological solutions for the envelope, suitable for the case study. Such a review brought to the proposal of two different constructive typologies: double skin, with the external one as semi-opaque shading system, and compact brick skin.

Sizing and operative analysis of the preliminary design. Stated an existing preliminary design the already fixed featured were defined: shape, volume, orientation, exposure, envelope gross surface, shadows and net surface (in compliance with German standard DIN 277-2).

Analysis of the variables. Values to assign at the variable were chosen. Such value must have two specific characteristics:

- the numeric value must reflect a technology available on the market;
- such a technology must be cost-effective.

Starting from the features of the two facade typologies, double and compact skin, two values for each variable were assigned: a standard one in compliance with the Italian regulation and a best practice in compliance with passive house rules.

In the solution “compact skin” the standard value (1,16W/m2K) is a mean value of the steel and glass parts of the curtain wall.

Table 1: Variables considered in the second case study

<table>
<thead>
<tr>
<th>Variables</th>
<th>Solution 1</th>
<th>Solution 2</th>
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<tbody>
<tr>
<td>Shading</td>
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<tr>
<td>Passive House Standard</td>
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<td>Uwall (W/m2K)</td>
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<td>Ubasement on air</td>
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<td>UNeighbour</td>
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<td>Heat Capacity (W/unità)</td>
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<tr>
<td>CPC (W/ºK)</td>
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<td>80</td>
</tr>
<tr>
<td>Heating Loading Monitor (W/unità)</td>
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<td>28</td>
</tr>
<tr>
<td>Summer Night ventilation</td>
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<td>2</td>
</tr>
</tbody>
</table>

Renewable Energy Sources. The energy production from renewable sources, through PV placed on the roof, considering an average over 20 years, is 369'119 kWh/year, becoming 996'623 kWh/year, when multiplied per energy electricity conversion index (2.7).

5.2. Support of the parametric approach

Parameterization. Fixed and variables values have been decided and inserted in PHPP thanks to the Excel macro. In the presented case 8 variables have been considered and each variables could assume 2 values (one maximum and minimum). The number of the design evaluated is $2^8=256$ for each facade configuration (256 solutions for the double skin facade and 256 solutions for the compact brick facade).

Results selection. Starting from the energy target of NZEB and the need of a high comfort, the results respecting the fixed goals have been selected. The energy performance indexes evaluated are the
heating and cooling demand less than 15 kWh/m²a, a null or positive energy balance between the estimated energy consumption and production (from a PV plants roof integrated and partially in the south upper façade) and overheating time percentage less than 10%.

Reading the results. For the same building, the two possible façade structures lead to a substantially different number of “feasible” solutions and therefore to a different importance of some parameters compared to the other façade set. Nevertheless, for both case, the imposed energy standards show to be difficult to be achieved as the number of feasible solutions is still quite low (between 6 - for the double skin structure - and 10 for the single skin).

First solution (double skin). Only 6 solutions have been found feasible on 256 results.

In Figure 7 the frequency of appearance for the considered variables of the low (and therefore high) values is shown.

- Values of 100% are shown for the low value (grey) of the variables Uglass (windows thermal transmittance), Pc, Monitor and Phone power, e glazing solar factor g for south, east and west windows; high values (black) for the variables building overall heat capacity and the summer night ventilation air rate.
- A low value of the thermal transmittance U for the opaque parts happened for a still high value of frequency (67%). This let more freedom in the choice of the opaque wall construction, even if the importance is clear represented by the 33% of solutions that have a higher U in the respect of the performance goals.
- The solar factor g variable for the glazing facing north has a 50% frequency value, meaning that for the considered maximum and minimum variable values there is not any influence on the energy output. Therefore, the design choice for the north glazing typology (concerning the g values!) will be made depending on other factors – economic for example.

For the case study (double skin), the design choice for the variables with 100% as value of frequency of appearance should follow the parameterization results in order to reach the performance targets, because in the simulation conditions there are not any design cases with another variable value. On the contrary for lower values, depending on the percentage value, an indication of the importance of the variables can be read. For values near to 50% other criteria can be used for the design choice. E.g. in the shown case study, the choice of the insulation grade of the opaque part (between “low transmittance” 0.1 W/m²K and “high transmittance” 0.3 W/m²K) is not so influent and the design choice could be made based on the economic point of view.

In the second solution (brick compact façade in Figure 6) 10 on 256 have resulted as feasible. In Figure 8 can be noticed that the opaque transmittance value has to be “low” in order to meet the energy goals as all the feasible solutions have a low Uwall value (100% of appearance frequency in the statistical population of feasible solutions).

Moreover:
- With 100% of frequency, also the variables electric devices powers and summer night ventilation appear respectively with low values (of electric power) and high values (of air change rate);
- The building thermal mass (overall building heat capacity) should be set high as the variable appearance frequency is circa 80%; furthermore the glazings facing south, east and west should possibly have a low value of solar factor, as the variable has a relative high importance.
- Similarly, low values of the windows transmittance and the low g factor for the north facing glazings have a frequency of 70%, meaning a not neglectable importance.
- Low influence (60% of frequency) characterize the U for the opaque surfaces (external wall, basement and roof).

Comparing the two façade solutions, the single skin case results in being more flexible. More solutions fulfill the performance goals and more variables have not extreme importance in terms of frequency of appearance. A higher number of variables can be defined also basing on other parameters (e.g. the economic point of view).

The use of the parametric tool on two different façade system for the same building, shows which are the main factors influencing the final simulated building performance for reaching the set targets (in this case Net Zero Energy Building).
Figure 8: Considering the 10 solutions fulfilling the target requirements for the case of a single skin façade, the design variables frequencies of appearance are shown.

Results show that both facade structures (double and single skin) can be used, even if the grade of design freedom is different for different design variables. The main differences regards:

- A different number of feasible solutions and different influences of the design variables following the frequency of appearance values (Fig. 7 and Fig. 9);
- The first solution (double skin) shows less freedom of choice in the design variables choice and therefore less general design flexibility in reaching the design objectives. A lower design flexibility in the variables choices needs generally higher costs as some factors have to be fixed at a more performance value and this goes straight in higher cost level. For example, the need of a “low value” of transmittance for the opaque facades gives a required investment in insulations materials, reducing the possibility of investing in other technologies.

6. CONCLUSIONS

The use of a parametric methodology applied at the low energy building design process results to be useful, easy and repeatable. It can effectively support the architect and engineer (design team) work in order to find the more important design variable and the optimal solutions in order to reach the design goals, once requirements and constraints have been fixed. The methodology – in these cases developed thanks to the use of an excel macro applied at the Passive House Planning Package - is pretty fast in the input data management and in the simulation process itself (few minutes for 256 PHPP simulations).

The main advantages are summarized in the following points:

- The ease of use for a technical final user – i.e. a building designer (architect or engineer) familiar with the classical energy design variables and with the concept of energy simulation.
- The possibility to analyze and to compare many building design solutions at once, depending on arbitrary defined parameters and to verify the compliance with the target energy indexes (generally heating, cooling and primary energy demand).
- The support obtained by fast and clear statistical analyses that can lead to a safe choice satisfying all the design constraints and requirements, besides the definition of the optimum variables values.
- The repeatability of the methodology for any kind of building (to be simulated in PHPP) both for new building and retrofit projects and for any geometry.
- The possibility to manage multi-objectives problems.

Moreover, the authors are going to add the possibility to apply the parametric approach also at the production systems using renewable energy sources (in particular through PV and ST) and at the operative energy costs.

In case of high grade of complexity and the need of more detailed energy assessments (e.g. switching from a steady-state model as PHPP to a dynamic simulation programs as Energy Plus or TRNYS) and/or of more a powerful tool for the data input and for the data post processing, optimization and statistical analyses can be performed with ModeFRONTIER. The effort to be put in the use of such simulation and optimization tools has to be well balanced with the design needs and complexity.

The parametric tool can be applied for any geographic location, but it needs adequate climate data as required by the mathematical model (PHPP or TRNYS).

The limitations from the numerical results point of view are the same as the calculation model (PHPP or TRNYS). From the usability of the parametric tool itself, the input and output management is still not very user friendly. Especially the output values need adequate and still not automate procedures in order to be evaluated.

7. REFERENCES