Guidelines for residential zero energy buildings by an integrated design approach with a support toolbox

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ABSTRACT: Buildings nowadays are increasingly expected to meet higher and more complex performance requirements, to play an important role reducing the energy use of the built environment. But even if the best design practices are widely adopted and zero-energy or even positive-energy buildings are becoming a high priority for many sectors involved, there are no ready-to-use applications that support the designer in the architectural practice. There is a need for a decision support tool that integrates energy strategies into early design of zero energy buildings in the traditional building design process. The aim of the paper is to present the Integrated Design Approach (IDA) defined to provide informative support decisions to reach the zero energy building target. The IDA is developed into a support toolbox (Zero Energy Homes in Temperate Climate = ZEHTeC Toolbox) that allows professionals to consider the energy performance from the early stage of the design process. The proposed approach was tested on two case studies, but the analyses are discussed in other publication, being the main purpose of the paper to provide an overview of the research and to present its outcomes. In conclusion strengths and limitations of the research are identified and future improvements are suggested.

Keywords: zero energy building; integrated design process; toolbox; matrix; energy simulation.

INTRODUCTION

Climate change mitigation and sustainable practices are now at the top of political and technical agendas towards the goal of low carbon cities with new low energy buildings and the reuse of the existing ones [1]. In particular, the topic of Zero Energy Buildings (ZEBs) has received increasing attention in recent years, until becoming part of the energy policy in several countries [2-3]. In the coming years, the building design community at large will be galvanized by mandatory codes and standards that aim to reach neutral or zero-energy built environments [4].

This energy "revolution" is a clear warning of the rapidly growing demand for better energy performance in buildings without compromising on comfort, performances, aesthetics and costs. This fact is leading to an ongoing development of technologies and innovations to improve energy efficiency in construction and, at the same time, the designer is faced with a variety of possible design options that are difficult to select. Choosing an appropriate combination of design options is now a complexity task and there is a risk of missing opportunities, which could have positive or negative effects if the design process is not properly informed.

It is therefore essential for the building construction industry to achieve sustainable development in the society. Sustainable development is viewed as development with low environmental impact, and high economical and social gains. To achieve the goals of sustainability it is required to adopt a multi-disciplinary approach covering a number of features such as energy saving, improved reuse and recycling of materials and emissions control [5].

At the same time, lessons from practice show that designing a robust ZEB is a complex, costly and tedious task. The uncertainty of decision making for ZEBs is high. The ZEBs objective has raised the bar of building performance, and will change the way buildings are designed and constructed[4].

In the last ten years, the Building Performance Simulation (BPS) discipline has reached a high level of maturation, and the use of computer-based appraisal tools to solve these energy design problems within buildings has grown rapidly, offering a range of tools for building performance evaluation.

Investigating the historical role of BPS in building design, the main theories and researches on the design concept development have been considered and studied to arrive at the ZEHTeC toolbox definition.

The objective is to define an Integrated Design Approach (IDA)[1] with a decision support tool (ZEHTeC Toolbox) that firstly provides practical guidelines at each step of the design process and secondly it permits constantly feedback regarding the possible sustainable strategies adopted to design a ZEB. This methodology will allow architects, building engineering consultants building firms and contractors to reach the goal of Zero

[1]*ABBREVIATIONS: Integrated Design Approach = IDA*

Energy Homes (ZEHs) ensuring comfort, performances, aesthetics and low costs during early stages.

The IDA approach was tested on two case studies: an Italian new residential building and a German refurbishment multifamily house. The analyses are conducted with BPS software both steady state (according to the building standard code available in the context of analysis) or dynamic. The results are omitted in this paper being discussed in others publications.

The paper structure is organized as following: the second paragraph discusses the need for new design practices to involve the use of an Integrated Design Approach (IDA) and it presents the ZEHTeC ToolBox structure, the methodology to assess building analyses, the design path and the instruments provide by the tool. The third paragraph provides an overview on the case *studies* used to validate the IDA approach. After the conclusion, open questions and suggestions for further development of ZEHTeC are proposed.

ZEHTeC ToolBox

Design tools have normally been constructed by reducing the complexity of the underlying system equations in an attempt to lessen the computational load and the corresponding input burden placed on the user. Traditionally, designers have relied on a range of disparate calculation techniques to quantify and assess building performance at the design stage [6]. It is only after the design has been finalized that external energy analysts have been involved to analyze the final design solution. Many of the decisions that affect energy demand are taken during the early design phases when simulation is not currently used.

There is a growing consensus within the literature of the need for integrated design and building performance simulation software [6-11]. This is seen as a necessity to enable the replacement of traditional sequential processes with interactive concurrent design [12].

In order to define a decision support tool for the early design phase, avoiding the creation of an inadequate model in which the tool is decoupled from the building design process and it requires the designer translation for the data model, the ZEHTEC ToolBox has been developed with the starting point to use an Integrated Design Approach (IDA). The idea is to propose to designer, consultants or building firms a design path (from the basic path to the optimized ones) to follow step by step, using the instruments which composed the ZEHTEC: the matrix tool, the guidelines and the residential ZEH atlas. All this components are finally collected in an informatics way and they became a website actually available on the web only for the members of the Milan Building Firm Association (Assimpredil) which funded this research.

THE INTEGRATED DESIGN APPROACH VERSUS THE TRADITIONAL

The Integrated Design Approach (IDA) is a method of intervention in early stages of the design process that supports the development and design team to avoid sub-optimal design solutions. IDA is not a new concept, and may in fact have been applied in the past by some design teams on an ad-hoc basis; but the formal definition and implementation of the process is the main goal of the work. In order to understand what the IDA is, it is useful to first characterize the more conventional design process [13].

The traditional design process has a mainly linear structure due to the successive contributions of the members of the design team. There is a limited possibility of optimization during the traditional process, while optimization in the later stages of the process is often troublesome or even impossible.

The IDA contains no elements that are radically new, but integrates well-proven approaches into a systematic total process. The skills and experience of all the actors involved can be integrated at the concept design level from the very beginning of the design process. When carried out in a spirit of co-operation among key actors, this results in a design that is highly efficient with minimal, and sometimes zero, incremental capital costs, along with reduced long-term operating and maintenance costs. The benefits of the IDA process are not limited to the improvement of environmental performance. Experience shows that the multidisciplinary synergistic approach will often lead to improvements in the functional program, in the selection of structural systems and in architectural expression.

Although this may seem obvious, it is a fact that most clients and designers have not followed up on the implications. The aim of this research is in fact to skip this obstacle presenting the IDA methodology and provide all the instruments necessary to adopt it.

The following Figures show the main screen of the ToolBox, e.g. Figure 1 is the WebMap, or rather the ZEHTeC structure. The choice of this name derives from the meaning of the noun WEB.

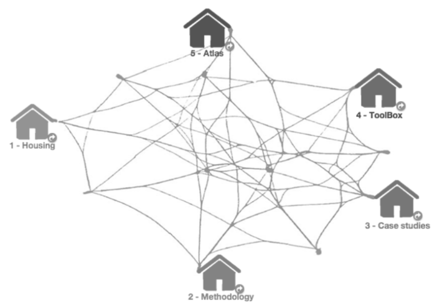

Figure 1: Webmap, ZEHTeC ToolBox structure

The tool has been developed for Internet to be accessible for all and everywhere and above all to be easily updated. Secondly the ZEHTeC would promote the diffusion of an IDA for ZEHs and the web, considered as a “spider’s web”, seems the best image to represent the interaction of many disciplines.

From the Webmap it is possible to enter in the five main pages of the ToolBox: 1 - Housing, 2 – Methodology, 3 – Case studies, 4 – ToolBox, 5 – Atlas.

The first page provides an overview on the housing market underlying the keywords of the building sector subdivided into the main topic spheres linked: social, architecture, regulation, energy and economy.

The second page describe the methodology followed for the application of the IDA approach on the case studies described in the third page.

The fourth page is the core of the project with the ZEHTeC ToolBox and its structure: genesis and strength points, IDA methodology and guidelines (Figure 2).

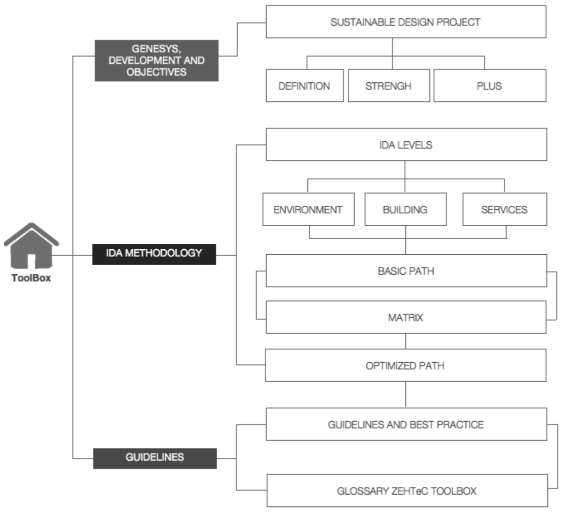

Figure 2: ZEHTeC ToolBox webpage and its components.

Finally the fifth page provides a Residential ZEH Atlas subdivided into European projects, technical solutions and sustainable strategies (Figure 3).

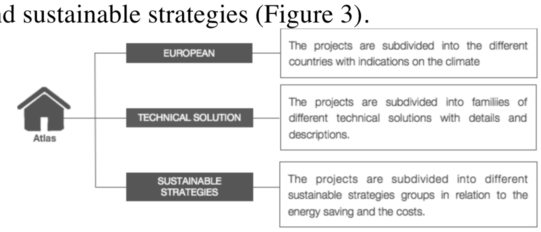

Figure 3: ZEH Atlas structure.

IDA: METHODOLOGY AND DESIGN PATHS

The architectural design is an iterative process with cycling through alternative solutions, testing, analyzing and refining their solution as it is developed [14] represents it as a process against time where the use of thermal simulation in this iterative design process causes many interruptions, and effectively halted at intervals. The IDA is the focus of the tool: it is based on a specific design path, which has the objective to support the ZEHTeC users during the design process. The path proposed has been structured according to specific phases to permit an easily comprehension of the whole process. The design process has been called “path” intentionally to emphasize its non-uniqueness and non-linearity. Path as a journey that all actors involved in the project follow up from the beginning to the construction site. The basic path is used mainly to inform users of the element families, which composed the design process: environmental, building and services and their main sub-elements. For each of these a detailed tree structure is presented in the toolbox with characteristics and details. In this paper is showed in Figure 4 only the tree of the Environment as an example.

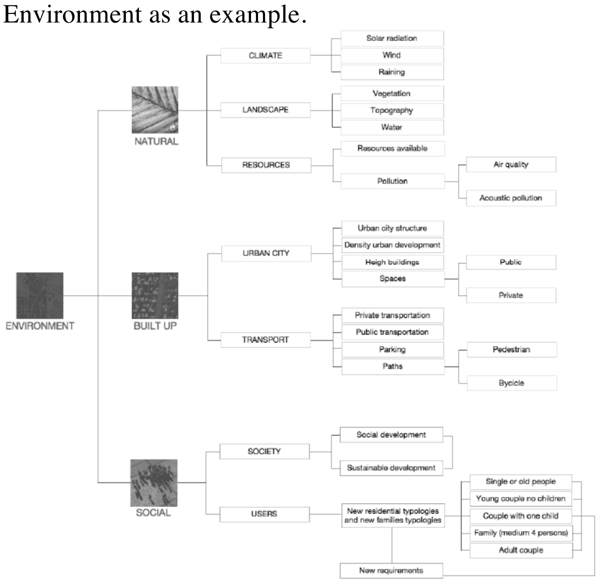

Figure 4: Environment element tree model of the of Basic path

All these information feed a clear overview on all the variables involved in the IDA path and through it users are able to read correctly also the other important instrument provide by ZEHTeC: the matrix of interrelations.

THE MATRIX AS A SUPPORT DECISION INSTRUMENT

The matrix (Figure 5) is composed by the most relevant parameters to achieve energy efficient building. Each of the 13 elements (orientation; spaces/distribution; opaque envelope insulation; transparent envelope; lodges, sunspace and other spaces; shadings; natural ventilation; mechanical ventilation; heating/cooling systems; renewable energies – PV; renewable energies – solar collectors; renewable energies – water and wind; economic aspects and users) are listed in the first rough of the matrix by their name, in the last rough by number (from 1 to 13) and in the second column by their respective icon to support the user for an immediate identification. The novelty of this instrument is the numerical identification of the energy saving for each parameter and also in relation to the others. It is a kind of roadmap for energy efficiency building, where each element is represented by hypothetical footprint according to a rating scale (from poor to excellent) and the percentage of potential savings on yearly energy demand.

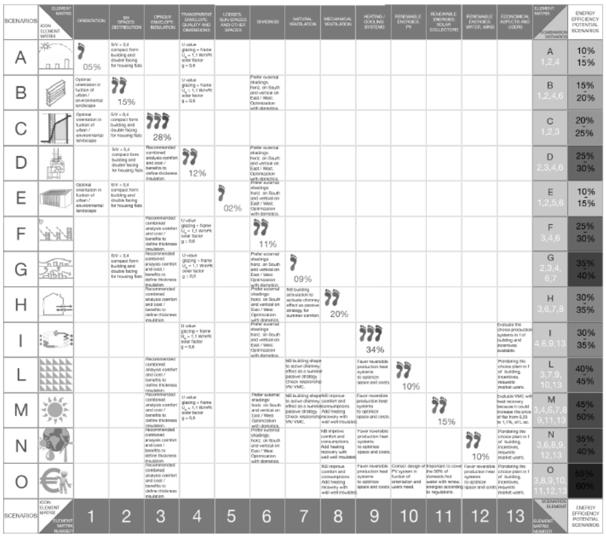

Figure 5: Matrix of the ZEHTeC ToolBox

The matrix has two orders of reading. The first is along the diagonal line where the user could easily individuate the potential energy saving of the element itself. The second order is along the horizontal line: in this case the user could read the scenarios created combining some matrix elements to reach the goal of ZEBs. These scenarios are analyzed in order to individuate the different energy saving which the combination of the elements could provide and also to identify the elements should be more convenient to adopt with another to find the most suitable and worthwhile combination in term of energy efficiency.

The name of the scenarios are listed in the first column from A to O and in the second last column of the matrix the scenario is summarized by the letter and the numbers of elements which composed it. For example the scenario G is summarized by the code G 2,3,4,6,7 because it is composed by the optimization of the following elements: 2 = S/V <0,4 compact form building and double facing for housing flats; 3 = opaque envelope: recommended combined comfort analysis and cost/benefit to define thickness insulation; 4 = transparent envelope: U value glazing + frame = 1,1 W/m2K and solar factor g = 0,6; 6 = shadings: prefer external shadings – Horizontal on south and Vertical on East/West and possible optimization with home automation; 7 = Natural ventilation. In the last column the user could read the percentage ranges (from 10% until 60%) of energy efficiency considering the respective scenarios. These data refer to the potential energetic efficiency obtainable putting into effect the scenarios elements considering a flat of 100 m2 with an energy consumptions that belongs to the range of 30 - 50 Kwh/m2 year. These data derive largely from some case studies analyzed and they must be intended as trend lines, so each case will require a specific refining because the values provided are not directly replicable.

THE OPTIMIZED PATH

The optimized path (Figure 6) represents the route to be followed throughout the design process to check all the decisions and to enhance the interactions between components. This path, if followed, will achieve higher levels of performance and energy savings, or in case of retrofitting; it will help to choose the more suitable strategies in term of energy efficiency.

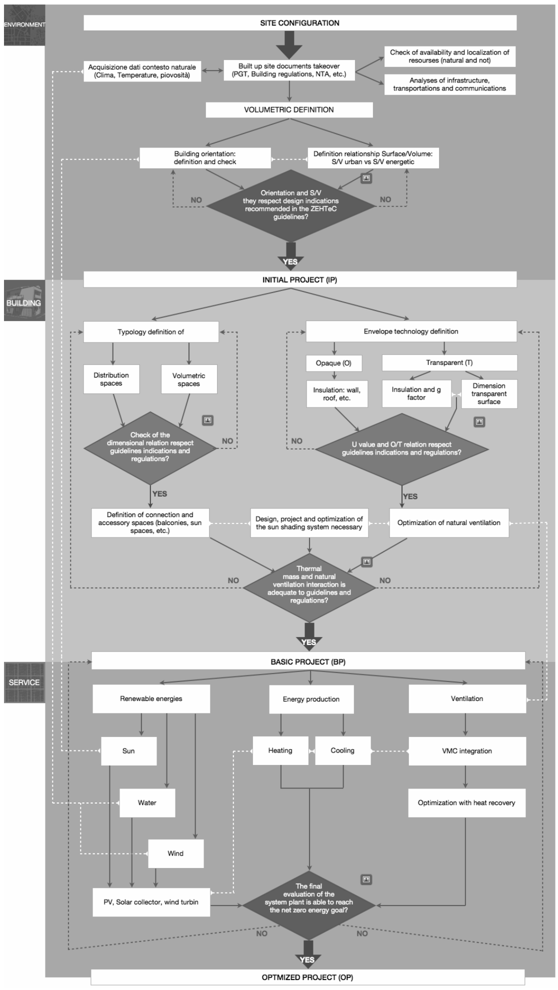

Figure 6: Optimized path of the IDA approach.

It is the roadmap of the IDA approach presented in the ZEHTeC ToolBox. It is structured into three sections: environmental, building and system and for each of them it provides practical questions and suggestions to keep in mind during the design process. The tool supports professionals step by step from the site configuration through the project definition to arrive at the final project with specific validation steps. It is important to remark that being an IDA, the path is an iterative process, and not linear. Simulating for example to use the optimized path tool, once that the tool user has defined the initial project (PI) which corresponds at the first validation step, it requests specific check about the building typology definition or the envelope technology to allow at the definition of the basic project. In case of negative response, the user must come back at previous steps and restart the path. Only with positive reply user can access at the next step and also at this level there is a new check to conclude the process with the optimized project definition. The novelty of this IDA is the systematization of the approach, which often is considered only for few parts by professionals and often not simultaneously during the design process. The tool would like to offer this support being a summary if the main steps to facilitate a holistic approach to design ZEHs.

RESIDENTIAL ZEH ATLAS

The Residential Atlas is a sort of database on Residential Zero Energy Home realized in Europe. The Atlas is divided into 3 sections: European, technical solutions and sustainable strategies. The projects are analysed and summarized by cards, icons, details in the three sections to assess all aspects of the context in climate, technology and innovations used and the economic viability and sustainable. An alphanumeric code has been assigned to each project to simplify the identification and comparisons: the number is sequential and the letters are the abbreviations of the country where the project is located (for example IT means Italy). The user may search project for example for construction technology to see details about wall or roof details of the housing or for economic range. in this second case the tool's user, choosing from different ranges of costs per m^2, can visualize all the projects belonging to the range chosen with more details about the housing: main keyword describing the project, localization, users typology, owners and a technical solutions summary.

GUIDELINES AND BEST PRACTICES

During the design path the user could consult the guidelines and best practice which ZEHTeC provides on 20 main topics: climate, vegetation, orientation, surface/volume, users, architectural disposal, opaque envelope, transparent envelope, connections, shadings, greenhouse, inertia factor, natural ventilation, thermal bridge, heating, cooling, mechanical ventilation, PV, solar collectors and renewable energies. For each topic a practical report is provided with the following information: definition, strength points, weakness points, examples and a special box with the energy saving potentiality information.

CASE STUDIES

In this paragraph only a brief description of the case studies are presented in order to provide a complete overview of the work with the main consideration about their choice and their importance for the validation of the ToolBox. The IDA was, in fact, tested coupling sensitivity analysis modeling and IDA ICE software on a retrofitting multifamily houses in Germany and a new residential tower building in Milan.

The German case was a pilot case of the city of Freiburg studied during the author's collaboration with the team of Fraunhofer ISE at the subtask C (analysis and concepts) of the IEA project SHC Task 37 - Advanced Housing Renovation with Solar and Conservation [15].

The Italian case study was provided by Assimpredil to directly apply the ZEHTeC ToolBox to a real case under construction during the analysis.

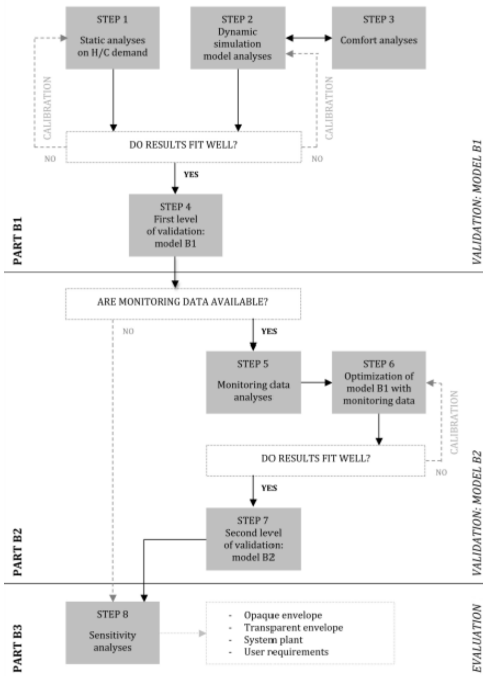

Figure 7: Clear line drawings are essential.

The comparison between Germany and Italy, even if they have different climate and technical construction, was useful to underline the advantages and sometimes the disadvantages related to the localization, the know-how, the policies and the market requirements on the topic for the two countries. The method followed to study these cases foresees two phases: the evaluation and the validation (Figure 7). For both cases, German and Italian, the first level of validation (MODEL B1) is achieved. The tools used in this phase are: PHPP worksheet from Passivhaus Institute and Cened Plus from Regione Lombardia for the static analyses and IDA ICE for the dynamic ones.

The German case study is analysed, considering the technological construction before and after the refurbishment, as a unique thermal model zone in IDA ICE; while for the Italian case study the analyses regard not the whole building, but only one flat.
The detailed analyses carried on and the results are omitted being discussed in other publication [16] being the main objective of this paper the presentation of the Toolbox and its IDA approach.

CONCLUSIONS

This paper underlines the strong influence that decisions at the early stages of building design have on the performance of the building throughout the rest of the process and the importance to adopt an IDA to reach the objectives set by the EU directive on energy building performance. The EPBD 2010/31/EU, in fact, requires that all new European building construction by 31/12/2020 are nearly zero energy (NZEB). The relevant requirements of forthcoming implementation require a substantial re-evaluate the logic of the design and construction of new buildings, adoption of tools and technologies that can effectively meet this goal.
The sustainability assessment methods are often sets of economic, social and environmental indicators assessed in isolation to each to other without energy efficiency, material efficiency and resources sustainability. However, in this paper, it was found that, in order to realize ZEBs, sustainable indicators must be assessed together, and for this reason the ZEHTEC ToolBox has been developed. The proposed IDA facilitates the definition of useful criteria and indicators for each level of the project design, with the attempt to transform the generic concept of sustainability and measurable elements into comparable indicators.

OPEN QUESTIONS

An interesting proposal for further work to apply directly the results of this research, could be the realization of a prototype of "NZEHouse", which could be a paradigm for similar interventions in temperate climate. This could become an opportunity for the practical application of design strategies and innovative technology components investigated in the ToolBox, and a realistic example of "best practice" in Lombardia region.

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