CONTEMPORARY TECHNOLOGIES IN INDIVIDUAL DWELLINGS PRESENT AND FUTURE

Doctoral thesis - Summary
for obtaining the scientific title of Phd in Architecture at
Politehnica University Timişoara
in the field of ARCHITECTURE by

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Chapter 1, introductory chapter presents the importance of sustainable development in the field of architecture and the built environment, highlighting the significant impact of the construction sector on energy consumption [1]. It is emphasized that the approach to the problem can no longer be ignored and requires the involvement of a complex group of specialists for its solution. It also mentions the efforts of the European Union and research in the field to reduce the impact of buildings on the environment.

The author justifies his choice of the theme of the paper, emphasizing his passion for designing energy efficient and financially accessible houses in Romania, where there is an opportunity for development. The paper aims to verify intuitive decisions in the design of environmentally friendly housing through analysis, calculations and multicriteria comparisons, taking into account financial and energy efficiency aspects.

The structure of the thesis is presented, including the main chapters:

1. Introduction
2. Directions in the evolution of the global, European and national strategy
3. Definition of the proposed calculation methodology
4. Defining and optimizing the analyzed model
5. Evaluation of the energy performances of the studied building in different scenarios
6. Conclusions and future directions of study

This thesis mainly explores the aspects related to the energy efficiency of buildings and their impact on the environment, focusing on the European and national context, calculation methodology, analyzed models and results obtained in relation to the criteria of constructions with almost zero energy consumption (nZEB).

The main objective of the present work is to fulfill the nZEB standard regarding a single-family house with a configuration specific to the suburbs of Timișoara, Romania. The aim is to determine the most efficient parameters in terms of the final cost of the building, considering an operating period of 30 years and low maintenance costs.

Chapter 2 highlights the importance of the transition to renewable energy sources and sustainable development in the context of climate change. The author highlights that fossil and nuclear resources have a negative impact on the environment and are becoming more and more expensive, emphasizing the need for a migration to green energy. Although this transition involves financial difficulties and changes to existing infrastructure, in the long term it brings significant benefits by reducing carbon emissions and increasing energy efficiency.

Next, we discuss the **Kyoto Protocol** [2], an international treaty signed in 1997, which introduced measures to reduce greenhouse gas emissions. The Protocol recognized that climate change is a global problem and set out a commitment for member states to reduce emissions over the period 2008-2012, known as the First Commitment. However, while some countries have been successful in reducing emissions, individual targets have not been entirely met.

In the current political and economic context, the European Union faces challenges related to environmental protection and energy independence, including reducing dependence on external resources such as gas from Russia. To achieve these goals, the EU has developed and implemented several directives aimed at improving energy efficiency in the construction sector.

European Directive 2002/91/EC [3], adopted in December 2002, establishes a legislative framework for improving the energy performance of buildings. The main purpose of this directive is to take into account external climatic conditions, local peculiarities and internal air conditioning needs in order to achieve an optimal cost-effectiveness ratio. This directive also follows the principles of the Kyoto Protocol aimed at increasing energy efficiency.

To assess the energy performance of buildings, it is important to use a methodology that takes national and regional specifics into account. This methodology must include the thermal characteristics of buildings, air conditioning systems, use of renewable energy sources, passive heating and cooling components, envelope, indoor air quality and natural lighting.

Each EU Member State sets its own minimum standards for the energy efficiency of buildings and their components, taking into account the balance between investment costs and energy savings over the lifetime of buildings. In order to assess the energy efficiency of buildings, energy performance certificates are issued that attest to the level of energy consumption of the building.

Directive 2010/31/EU [4], adopted in May 2010, focuses on the energy efficiency of buildings and aims at the efficient and prudent use of energy from fossil fuel sources, such as oil and natural gas, to reduce CO2 emissions of carbon. One of the main objectives of this directive is to reduce global greenhouse gas emissions by at least 20% by 2020 compared to 1990 levels.

The directive encourages the construction of near-zero energy buildings (NZEBs), which have very high levels of energy efficiency. These buildings must meet a large part of their energy needs from renewable sources such as solar or geothermal energy.

European directives also provide clear commitments regarding new buildings and those occupied by public authorities, in order to achieve these energy efficiency objectives.

These European directives represent significant efforts by the European Union to reduce energy consumption in the construction sector and to contribute to the protection of the environment and to ensuring the energy independence of the EU.

European Directive 2012/27/EU [5], adopted in October 2012, was developed to promote energy efficiency and help the EU achieve its target of reducing energy consumption by 20% by 2020 compared to 1990 levels The directive requires member states to establish obligation schemes to ensure cumulative end-use energy savings by the end of 2020.

To achieve energy efficiency targets, the directive encourages the use of technological innovations, including intelligent control systems. It is predicted that at least 80% of consumers should be equipped with such systems by 2020. These systems allow energy demand management and billing based on actual consumption.

Directive 2012/27/EU also promotes energy audits by qualified experts for end-users to assess and improve the energy efficiency of buildings and other systems. At the same time, the importance of improving the efficiency of the electricity transformation, transport and distribution infrastructure is emphasized.

The European Directive 2018/2001 [6], adopted in December 2018, emphasizes the use of renewable energy sources to achieve the objectives of reducing carbon emissions and increasing their share in the energy mix of the European Union. The directive states that by 2030, at least 32.5% of the Union's total annual energy consumption must come from renewable sources.

The directive also requires renewable energy sources to be taken into account in the calculation of Member States' gross final energy consumption and promotes the use of innovative technologies such as heat pumps, geothermal and solar thermal technologies in the building sector for heating and cooling. The directive also recognizes the right of consumers to produce energy from renewable sources for personal use, store it and sell the surplus.

These directives reflect the European Union's commitment to promote energy efficiency and reduce carbon emissions in the energy sector, including heating and cooling, to help protect the environment and ensure a sustainable and renewable energy source for the future.

The Romanian legislation regarding energy efficiency in the construction sector and the implementation of near-zero buildings (nZEB) is regulated by several regulations and laws. These include:

Norm C107/2005 [7]: This norm establishes the methodologies for the thermotechnical calculation of the construction elements of buildings. It has been republished and focuses on the energy performance of building elements and how to calculate them.

Law 372/2005 [8]: Law on the energy performance of buildings, which was later republished and amended by several normative acts, including Law 101/2020 [9]. This law introduced, for the first time, the concept of near-zero building (nZEB) and established rules for the energy performance certificate and near-zero energy consumption.

MC001/2022 [10]: Methodology for calculating the energy performance of buildings, reference Mc 001-2022, which details the requirements for calculating the energy performance of buildings. This document sets the limits for final primary energy consumption and CO2 equivalent emissions for nZEB buildings by climate zone.

TRC 4 – 2022 [11]: Guide on the implementation of measures to increase the energy performance applicable to new buildings, in the stages of design, execution and reception, operation and monitoring of behavior over time to meet the requirements of nZEB. This guide provides recommendations for the design and construction of nZEB buildings, as well as for tracking their performance over time.

To meet nZEB requirements, several design and construction measures and principles are recommended, such as:

- The use of quality heat-insulating materials with appropriate thicknesses for walls, floors and facades;
- Ensuring an interior plaster with adequate air permeability;
- Use of thermally efficient exterior joinery, with exterior shading systems (if applicable);
- Correct management of air infiltration to maintain indoor air quality and thermal comfort;
- Optimizing the geometry and orientation of the building to maximize solar inputs and reduce energy consumption for heating;
- Reduction of thermal bridges to minimize heat losses;
- Use of mechanical ventilation systems with high efficiency heat recovery;
- Integration of solar panels to generate energy from renewable sources.

All these measures and rules are intended to lead to the construction of buildings with high energy performance, which significantly reduce energy consumption and carbon emissions associated with their operation.

Chapter 3 begins with the definition of the program theme as well as the specific starting data for the studied situation, a single-family house for a family composed of 4 members for the Banat area near the Municipality of Timișoara. The information taken into account to define the theme will be based on the data extracted from a questionnaire made by the author as well as starting from an average encountered in the current real estate market. The purpose of this analysis is to define a situation as close as possible to reality.

Next, the paper analyzes the opportunities of non-polluting, solar energy for Romania, noting that it has a good geographical positioning with great potential for development, with areas that have solar energy production rates of over 1400 kWh/m2 per year in the Sea Coast

Negre and Dobrogea, as well as in some southern areas. In most regions of the country, solar energy production rates are higher than 1250-1350 kWh/m2 annually [12].

The next section examines recent green energy production technologies, focusing on photovoltaic panels and solar panels. Thus, a considerable evolution of these technologies over time can be seen, which through proper use can significantly contribute to the reduction of energy consumption as well as carbon dioxide emissions in the construction sector.

The next sub-chapter emphasizes the importance of orienting buildings and land to the cardinal points to efficiently exploit solar energy. Urban planning does not always take these aspects into account, which can lead to design difficulties and additional costs [13]. The analysis starts from the principles of passive houses that take into account the orientation of the buildings, the glazed area and the solar factor of the glass. It also mentions the importance of shadows and points out that urban planning must consider the orientation of buildings to ensure efficient use of solar energy and reduce costs and carbon emissions.

It highlights that incorrect urban planning can lead to additional costs to meet energy requirements and that the balance between the interests of developers, the community and the environment must be prioritized. In addition, it is stated that urban planning should facilitate the installation of solar and photovoltaic panels under economical conditions. It is also pointed out that urbanization can have a significant impact on the environment and subsequent costs, which requires a complex analysis to achieve nZEB energy efficiency standards [14].

To properly assess how a building fits into an urban environment, it is crucial to analyze the urban configuration. In the case of Timisoara, the city has a radial-concentric configuration, starting from the second half of the 20th century, which can affect the optimal orientation of the buildings. Solar exposure studies must take into account street forms, building heights and the position of the sun at different times of the day and year to determine the best orientation of each plot and maximize sunlight, essential for low-energy buildings.

In the peri-urban area around Timișoara, the development of the neighboring communities has increased significantly, and this has been observed through the increasing number of building permits issued in these municipalities. The interaction between the city and peri-urban communes has become an important theme, especially in the absence of a coherent urban strategy that addresses this issue at the macro level and details it at the neighborhood level.

In order to be able to understand the problem presented previously, a critical analysis of some existing situations encountered in real design is carried out. This analysis will study several cases of zonal urban plans intended for individual homes, in which the typologies of the plots and their orientation with respect to the cardinal points will be identified. The purpose of the analysis is to understand the causes of generation and possible solutions to improve solar exposure for future constructions. The analysis will focus on some urban plans in the vicinity of the city of Timișoara in the peri-urban area (Moșnița Nouă and Dumbrăvița).

Following the analysis, the following aspects are found:

• lack of an urban development plan for the entire urbanization area;

• The P.U.Z.'s limit is the former agricultural areas;

• situations that are randomly unfavorable due to this practice have been highlighted;

• the location of the constructions on the plot is proposed by P.U.Z.s according to customs without them being adapted to the actual situation regarding the sunshine.

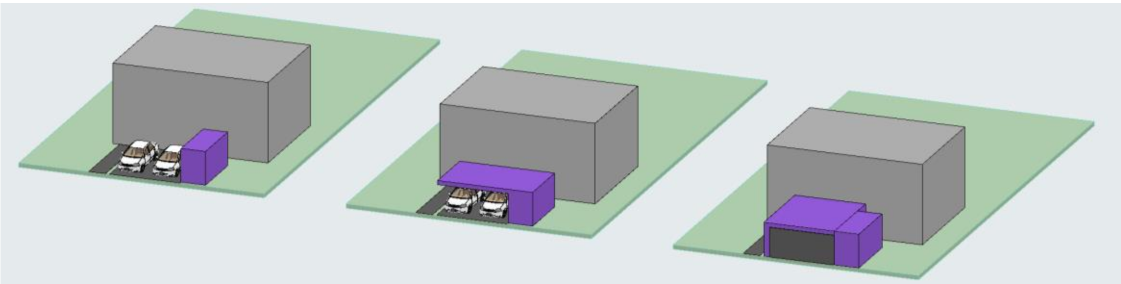
In conclusion, currently there is no specific custom or clear regulations to improve the situation of parcels in peri-urban localities in terms of orientation and solar exposure. However, increased awareness of environmental impact and energy efficiency may change this situation, and regulations and practices may need to be revised to promote more sustainable urban development.

Next, the various existing construction systems for the construction of a single-family house are analyzed, going through structures with continuous reinforced concrete foundations with load-bearing masonry [15] (Porotherm Robust 25 and Ytong Clasic 25) and reinforced concrete floors, structures in reinforced concrete frames [16], reinforced concrete infrastructure and wooden superstructure (skeletal structure, large prefabricated panels, large wooden panels) and reinforced concrete infrastructure and metal superstructure (rolled profiles, cold bent profiles). Advantages and disadvantages are identified for each constructive system. The purpose of this analysis being the identification of the most economical constructive system for the pursued objectives.

The next subchapter looks at the form, envelope, and HVAC systems needed to make a single-family home. It was thus found that the most economical solution is a house developed on the ground floor and first floor, having the most favorable ratio between the envelope area and volume. The components of the tire and their contribution in terms of energy efficiency are analyzed.

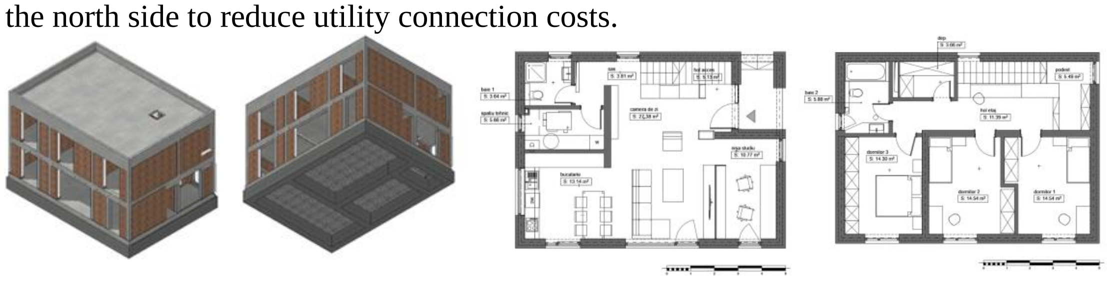
For HVAC systems, the study considers two energy scenarios, namely one on gas and the second on electricity, the systems most used in current practice. This is how condensing gas plants and air-to-water heat pumps are analyzed, proven to be the most economical in terms of initial investment.

In Chapter 4 the architectural project took into account the preferences and requirements of the beneficiaries defined in Chapter 2, respecting also the local planning regulations and the characteristics of the location. A favorable orientation was adopted with the courtyard facing south to maximize passive solar gain and reduce heating costs. In terms of phasing, flexibility in development has been proposed, with the possibility of adding a carport or garage later, but the analysis focuses on the main volume of the house.



The proposed house has a height regime on the ground floor and one floor, a cost-effective and efficient solution in terms of construction costs. The main goal was to create a compact volume that maximizes solar exposure in the interior spaces.

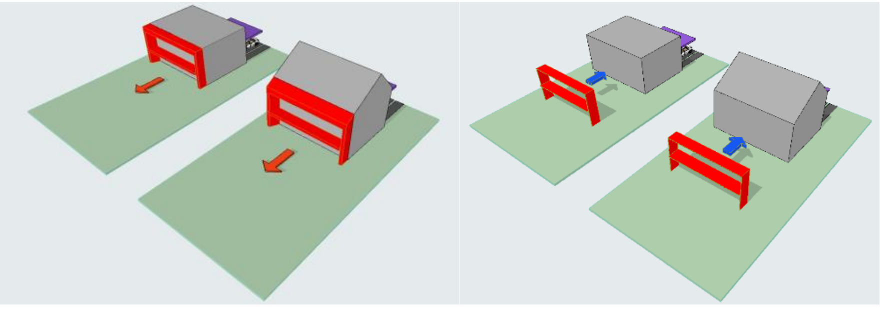
The structure of the house consists of continuous reinforced concrete foundations, load-bearing masonry and reinforced concrete floors, chosen for its low cost compared to other options. The internal configuration of the house is efficient, with the living rooms and bedrooms facing the courtyard to benefit from the sunlight. Wet spaces and vertical circulation are placed on the north side to reduce utility connection costs.



To maximize energy efficiency, the southern facade features extensive glazing, which allows sunlight to penetrate in the winter, but requires a shading system to prevent overheating in the summer.

As for the shading structure, there are several options to approach, such as integrating it into the structure of the house or making a separate metal structure. The project aims to create an energy-efficient house with a compact and flexible design that maximizes solar input and minimizes construction and operating costs.

In order to identify the most economical solution, two scenarios are taken into account for the realization of the shading system on the southern facade of the house:



- Model A – fixed shading system from the house structure for the chosen plan variant (M01)
- Model B – thermally decoupled shading system for the chosen plan variant (M02)

For each situation analyzed, two situations were taken into account, a variant with a terraced roof (M01-1, M02-1) and a variant with a gable roof (M01-2, M02-2).

The first variant considered involves a solar protection on the southern facade by extending the structure of the house. This extension consists of cantilevers made of reinforced concrete that provide shading both on the ground floor and on the first floor. The visual protection from the side neighbors is proposed to be achieved by vertical masonry piles placed at the ends of the volume on the southern facade.

First of all, this solution increases the built area of the house and the surface of the thermal envelope, which leads to additional costs. Moreover, the last floor will have a minimum thermal resistance according to the MC001 standard, and an increase in its surface implies higher costs. At the same time, this expansion can create additional thermal bridges, which should be managed to reduce the impact on energy consumption.

In conclusion, this option may be more expensive due to the increase in built-up area and may have poorer energy performance due to potential additional thermal bridges.

The second option is an exception on the real estate market in Romania, focusing on creating a continuous thermal envelope by eliminating thermal bridges, inspired by the concept of passive houses. In this vision, the house is designed to be as compact as possible, thus reducing energy consumption, and the shading system is added later through point fasteners, minimizing the impact of thermal bridges on the final energy consumption.

The structure intended for the shadow of the southern facade will be made of metal profiles of the rectangular pipe type with the dimensions 80x80x5 mm, forming a frame on the southern facade. In addition, a horizontal structure will be created fixed in the beam between the ground floor and the first floor, which will ensure the shading of the ground floor area, being anchored in the structure of the house by means of spacers integrated in the thickness of the thermal envelope.

This solution has the advantage of reducing thermal bridges and eliminates the need for wet steps for its finishing. Although it is estimated that this option may be more expensive than reinforced concrete and masonry, due to the reduction in the amount of materials and related labor, it is considered a more suitable option.

In order to choose the most appropriate option to satisfy the objectives of this research, i.e. cost minimization for a given situation, it is important to consider both initial and subsequent costs. Sometimes a solution that seems more economical in the initial phase can become more expensive in the long term due to later problems, such as the management of thermal bridges or the need for additional interventions.

Centralizing the data obtained for each analyzed solution, we can make a preliminary assessment of them. However, we must bear in mind that the M02-1 variant, which did not take into account the additional shading system and subsequent costs, is the most economical in terms of material consumption for the actual construction.

However, there are other solutions or sub-variants to consider. One of them could be the use of mobile raffstore systems for shading the southern facade, applied to the carpentry in that area. This approach could eliminate the need for the metal structure of the M02-1 variant, but would incur additional costs for the purchase and installation of the raffstore systems. It would also generate additional thermal bridges at the top of the joinery.

Another economical option for shading the southern facade would be the use of solar control glass. This option would completely abandon the shading systems and only change the parameters of the glass. However, it should be considered that this solution could lead to the loss of solar gain advantages in winter and overheating problems in summer.

To make a wise decision, you need to carry out a detailed analysis of the costs and benefits of each solution, taking into account both initial and long-term costs, as well as the energy efficiency and thermal comfort offered by each option. It's important to also consult building and energy efficiency experts to help you make the best decision based on your specific needs and goals.

Chapter 5 begins with the presentation of the calculation programs used for the energy evaluation of the models, mentioning as the main calculation program "Passive House Planning Package" (PHPP) and "designPH", both programs made by the "Passive House Institute" [17]. For the evaluation of the thermal bridges necessary for the calculation, the HTflux calculation program [18] was used, which provided the necessary information for the evaluation of the thermal bridges identified and analyzed in the different scenarios.

The study focuses on identifying tire and HVAC system configurations that meet nZEB standards for energy efficiency and carbon emissions. Initial and long-term costs are analyzed to identify cost-effective options.

For thermal insulation of facades, graphite expanded polystyrene is recommended, due to its superior performance and low cost per square meter. Different envelope configurations are evaluated (5 different variants and two additional variants) and those based only on increasing thermal efficiency do not reach the nZEB standards.

Two types of load-bearing masonry (Porotherm Robust 25 and Ytong Clasic), with different thermal resistances, are also compared to determine their influence on meeting the MC001 standard.

Regarding energy use, two different scenarios are analyzed for heating, domestic hot water, cooling and artificial lighting.

Thus, in the first variant, a gas thermal power plant is used for heating and hot water. Several scenarios are examined, including mounting joinery on pre-frames and using mechanized ventilation for maximum energy efficiency.

In the natural gas version, 30% of the required energy comes from renewable sources, i.e. solar panels and a 300l storage tank for hot water.

The second option uses electricity and heat pumps for heating and hot water. 30% of the energy requirement is provided by renewable sources, especially heat pumps. Photovoltaic (3.28kW, 5.33kW and 8.2kW) and solar panels are also taken into account, with different capacities, to cover the energy requirement, but without injecting excess energy into the grid.

In order to assess the energy consumption of the building accurately, the specific thermal bridges of the envelope were identified and calculated. These represent areas where heat transfer is significantly affected in a uniform thermal flowThe second option uses electricity and heat pumps for heating and hot water. 30% of the energy requirement is provided by renewable sources, especially heat pumps. Photovoltaic (3.28kW, 5.33kW and 8.2kW) and solar panels are also taken into account, with different capacities, to cover the energy requirement, but without injecting excess energy into the grid.

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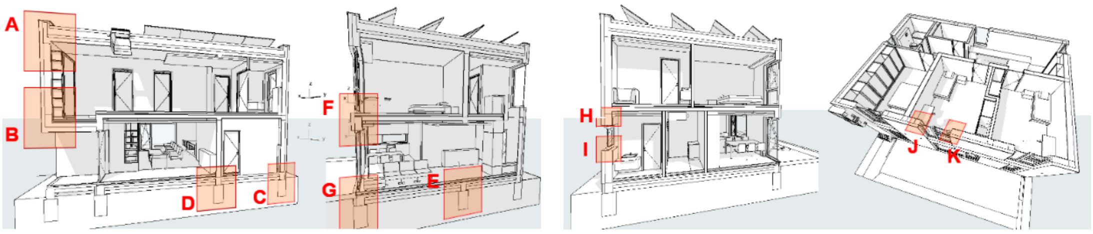


Even though the house design was designed to minimize thermal bridges and ensure a continuous envelope, we identified the following thermal bridges for analysis:

A. The attic area within the non-circular terrace.
B. The soffit area above the access.
C. The outer wall in the plinth area.
D. The inner wall in contact with the ground.
E. Interior foundation in floor area on ground.
F. Exterior carpentry between levels.
G. Exterior carpentry in the plinth area.
H. Reinforced concrete lintel in relation to exterior joinery.
I. Carpentry in the area of Solbanc.
J. Carpentry connection to a reinforced concrete core within an exterior wall.
K. Connection of joinery to an external wall.

The calculation of the thermal bridges was performed on the outer face of the tire for the two variants, one with Porotherm Robust masonry and the other with Ytong Classic.

To ensure adequate indoor air quality, it is essential to comply with ventilation requirements. According to the new standard MC001, non-mechanically ventilated residential buildings during the heating season must ensure a minimum flow of fresh air, corresponding to an hourly number of air exchanges of 0.5 times per hour.

In this context, two calculation scenarios for the ventilation of interior spaces were considered:

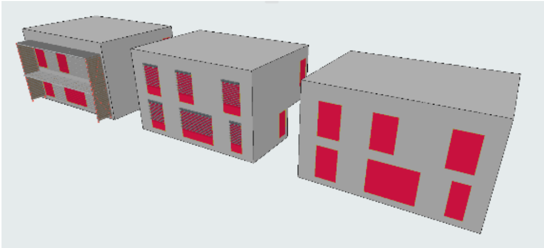
• Natural ventilation to ensure fresh air, with an air exchange of 0.5 times per hour in winter and additional ventilation in summer;

• Mechanical ventilation with heat recovery, with an efficiency of 90% in winter, with an air exchange of 0.3 times per hour, and additional natural ventilation in summer.

In the first variant, the internal air volume for the analyzed building was 386 m3, while for the variant with mechanical ventilation system, the internal air volume was 375 m3. The difference is due to the use of the false ceiling for the distribution of the ventilation system, which was installed locally in certain areas to avoid reducing the clear height below 2.6 meters, according to legislative requirements.

For both variants, the air permeability coefficient of the building envelope was considered n50 = 1.00 changes per hour at 50 Pa. To obtain this coefficient, special attention was paid to the tightness of the joinery, using vapor barriers on the inside and wind barriers on the outside around them. Also, in order to achieve the desired results, the sealing of the window gaps was an essential element, and the external plastering of the entire surface of the masonry contributed to the increase of the sealing coefficient.

Regarding the shading scenarios, three possible study options were identified:



• Fixed passive shading, with a structural system that completes the volume of the building with glass, without solar protection;
• Shading with mobile "raffstore" type systems, with glass without solar protection;
• Without shading systems, with solar control glass.

All the studies carried out considered passive shading as the most economical solution, as it allows the capture of passive solar energy in the winter season. In order not to create an excessive number of sub-categories in the analysis, the critical evaluation focused on the most economical option that meets the nZEB criteria. Thus, the impact of the three equipment options on energy consumption, solar input in winter and avoiding overheating in summer was analyzed. The shading scenarios influenced both the interior thermal regime and the construction costs.

Regarding the cooling of interior spaces, two possible scenarios have been identified:

• The first scenario is based on natural cooling, which requires fixed or mobile shading systems. From the calculation of the frequency of overheating, it was found that in less than 10% of the time the indoor temperature exceeds 25°C, the upper limit of comfort established by the Institute of Passive Houses;

• The second scenario involves the use of a split air conditioning system, with two units, one on each level.

The calculation revealed that in most of the analyzed situations, the comfort conditions can be met by natural cooling, with an overheating period limited to 10%. However, an increase in indoor temperature is observed in July and August. In this context, the use of complementary air conditioning systems can be considered an additional, optional comfort, since the comfort norms are respected without them. The implementation of these systems involves an additional cost in the case of split systems and can lead to higher energy consumption.

However, in the context of the increase in average summer temperatures in recent years, the use of air conditioning systems is becoming more and more necessary in the case of single-family homes as well. In this sense, the study proposes to analyze the impact of the use of such systems on energy consumption in an economic variant with a gas plant, which respects the criteria of net zero emission buildings (nZEB). Also, their influence will be evaluated in the case of a variant with a heat pump.

To ensure the interior lighting that will be included in the calculation of energy consumption according to the methodology in force, LED lighting fixtures with a consumption of 65lm/W have been provided, which correspond to lighting fixtures with warm white light.

Following the calculations, it is found that out of the 24 Porotherm masonry variants and the 20 Ytong variants equipped with a gas boiler and the 80 Porotherm masonry variants equipped with an air-water heat pump, only 58 meet the conditions to be nZEB. For these, an initial investment cost is realized.

Next, an analysis of the global cost is made for a period of 30 years, which aims to identify an optimal solution from the point of view of costs (initials, maintenance, equipment changes occurring over time) [19].

Therefore, it is found that the variant var_1_PR_ctg_vr represents the variant with the lowest initial cost, and var_3_PR_PCaa_f8kw the variant whose cost is optimal after the 30 years of exploitation.

Chapter 6 contains an additional evaluation for the evaluation of cooling on the two variants identified with the lowest initial cost and the one with the optimal cost. It is found that the use of split cooling systems can contribute to the increase of the RER value and have an insignificant influence on the additional CO2 emissions generated. In both variants, the introduction of additional cooling systems does not greatly influence the overall cost (2.96% for the thermal plant solution and 4.42% for the heat pump solution).

An additional analysis is carried out for the shading of the southern facade which finds that the passive solution with fixed shading systems is not the most efficient. In the version with raffstore, there is a higher solar input, which can thus reduce energy consumption in winter. However, this option will influence the initial cost of the analyzed building (+1.74% for var_1_PR_ctg_vr).

The variant with glass with solar control will have the weakest result in terms of solar input, but this is also the most economical variant in terms of the initial investment price.

In conclusion, this paper examined the fulfillment of the nZEB (nearly Zero Energy Building) standard in the context of a single-family home, with a structure proposed in this thesis. The study assessed initial costs, energy costs, and maintenance and upkeep over a 30-year period.

For the variants with gas-fired thermal plants, it was found that the nZEB standard cannot be reached by improving the thermal envelope alone, because the heat losses through natural ventilation are too high. Thus, these variants do not meet the requirements for the minimum percentage of renewable energy.

It was also observed that the differences between the two types of masonry (Porotherm and Ytong) did not have a significant impact on energy performance.

Mechanical ventilation systems with heat recovery were required to meet the nZEB standard for gas-fired power plants, even though they are not mandatory under MC001. Regarding renewable energy, solar panels have been used to produce domestic hot water, but their sizing may require further investigation.

In the case of heat pumps, it has been observed that they can easily reach the nZEB standard due to their energy efficiency and ability to extract energy from the environment. However, proper sizing of PV systems was crucial to avoid renewable energy surplus.

In conclusion, heat pump systems and medium thermal envelopes, combined with appropriately sized PV systems, are an effective option for achieving the nZEB standard. Gas-fired systems can be difficult to optimize in this regard due to energy requirements and CO2 emissions.

The main personal contributions are:

• The analysis is based on an individualized project, designed by the author with the aim of responding as best as possible to the studied issue;

• Taking into account the complexity of the studied situations (different types of tires, analysis of thermal bridges, different types of load-bearing masonry, different HVAC systems) to fulfill the nZEB criteria;

• In the absence of a calculation model for thermal bridges, a calculation system was developed that can become a database for the 25cm Porotherm and Ytong constructive system;

• Obtaining real prices from the market for each situation studied in order to reflect the conclusions obtained as accurately as possible (the prices of related materials and labor were taken into account at the date of the preparation of the financial calculation);

• Analysis and interpretation of the data obtained for a significant number of building compositions, envelope systems, HVAC systems, etc., resulting in 124 variants where the results obtained were interpreted through original tables and figures developed by the author;

• Highlighting through graphs and tables the advantages and disadvantages for each variant

analyzed;
• Complex analysis of the initial cost compared to the overall cost compared to the achieved energy performances;
• Design guide and future decision-making directions on the subjects studied;
• The calculations presented in the thesis and appendices are entirely the credit of the author.

As a result of the research carried out, the following directions for future study are specified:

• Taking into account some automation systems to optimize the studied solutions;
• Making calculations with more efficient, but more expensive heat pumps and comparing the results obtained;
• Carrying out a research to investigate the issue of the tightness of load-bearing external walls - additional plaster on the outside, Porotherm vs. Ytong.

The research results presented in this paper have been published in conference proceedings:

2 Web of Science indexed papers;
1 Paper in International Database Proceedings.

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