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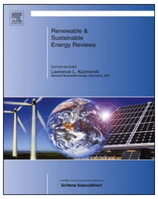

Energy efficiency in the Romanian residential building stock: A literature review

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ABSTRACT

The building sector in Romania is dominated by residential buildings that are old and have poor thermal performance. As a member of the European Union, Romania has to reach the objectives imposed by the Directive 2009/28/EC and to fulfill the requirements of the Energy Performance of Buildings Directive (EPBD) by year 2020. The implementation of these concepts in Romania consists into thermal rehabilitation of the existing buildings, applying the latest thermal performance characteristics in new buildings and establishing the certificate of energy performance. The following paper presents the literature review of the state of building energy performance in Romania. The purpose of the literature review analysis is to provide a snapshot on the existing building energy efficiency and future perspectives on the implementation of high performance buildings in Romania. The implementation of concepts such as the Passive House (PH), nearly Zero Energy Buildings (nZEB) and Net Zero Energy Buildings (NZEB) are discussed in order to help the decision makers to achieve the 2020 objectives. The results of the reviewed publications and case studies are classified under three categories: policy and regulations, technology and feasibility. Finally a holistic perspective on the Strength, Weakness, Opportunities and Threats (SWOTs) of energy efficiency in Romania's residential building sector is presented.

1. Introduction

Romania has to reach the objectives imposed by the European Union to reach nearly zero energy buildings by year 2020. The directive mentioned previously states that the share of renewables in the total gross of Romania's energy consumption should be 20%, the emissions of CO^2, greenhouse gases and the final energy consumption must decrease by 20% and all the new buildings must be passive. The Energy Performance of Buildings Directive (EPBD) requires all European member states, including Romania, to introduce minimum energy performance requirements for all buildings, building elements and technical building systems. The energy performance requirements must be set based on a cost-optimal methodology taking into account life time costs of the building. From 2020 onwards, all European member states will have to construct only nearly Zero Energy Buildings (nZEBs) [1]. In Romania, the implementation of these concepts consists into thermal rehabilitation of the existing buildings, into applying the latest thermal performance requirements for building elements from both new and renovated constructions and into establishing the certificate of energy performance of the building [7].

In Romania about 80% of the buildings need to be renovated in order to stop the heat losses through the building's envelope and to decrease energy consumption (reference). At the moment, it is difficult to renovate all the buildings to make them performant because of the costs involved. Most of Romania's national building stock have residential function and the costs are supported by the indwellers. Fig. 1 shows the distribution of the residential floor area by building type and urbanization according to the Buildings Performance Institute Europe (BPIE) report [7].

Therefore, the aim of this study is to review literature and to provide a general snapshot about the energy efficiency status in Romania and to document the current state-of-the-art regarding the potential and challenges of implementation of passive house, nZEB and ZEB concepts. This is a fundamental step in order to help decision makers for designing programs to achieve the EU's 2020 objectives. The objectives of this research are to review and analyze publications found in literature related mainly to energy performance in Romanian residential building sector. The work entails the categorization of major publications in sub-topics for a detailed analysis and better understanding of the current Romanian status of buildings and to identify the key findings and the gaps found in literature. The literature review presents the current state-of-the-art of the building energy perfor-

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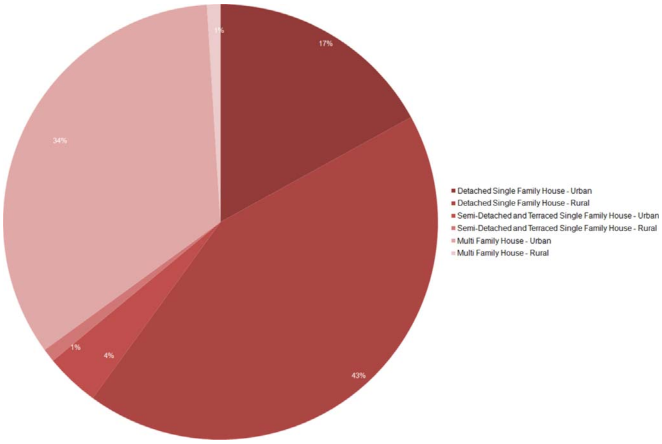

Fig. 1. The distribution of the residential floor area by building type and urbanization according to the Buildings Performance Institute Europe [7].

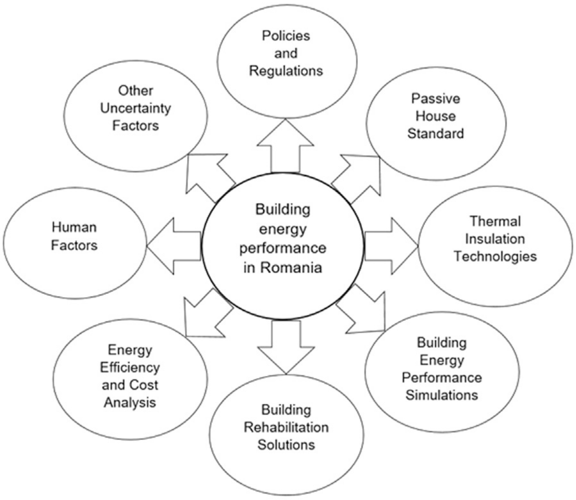

Fig. 2. The key elements that have significant impacts on building energy efficiency, including policies and regulations, technologies, feasibility, human factors and other uncertainty factors.

mance in Romania and the aspects that need to be improved in order to achieve the 2020 objectives. The categorization in sub-topics helps highlighting the levels of building energy performance where Romania has made progress and where it needs to improve. The study reviewed pilot projects in Romania and compared them with similar projects outside Romania.

The methodology consisted of screening the available resources related to building energy performance in Romania and finding a logical classification. These topics describe Romanian design codes, energy consumption in Romanian buildings, energy prices and climate. The publications related to these topics were arranged in a literature survey list in which the title, authors, publisher and the number of citations of the publication could be traced. Then a SWOT analysis was conducted to have a better understanding of energy efficiency issues and provide perspective on improvements that need to be addressed in the future to dismantle the barriers to the implantation of energy efficiency targets among households in Romania.

This paper is organized into seven sections. In the first section it is identified the research problem, the objective and the significance. The second section describes the methodology of the literature review. The third section describes the findings of the publications related to policies and regulations in energy performance. The fourth section presents the findings about sustainable technologies. The fifth section describes cost analysis in the context of building energy performance. The sixth section presents the human factors and the uncertainty factors that influence the implementation of nZEB in Romania. The seventh section discusses the outcomes of the literature review and presents the conclusions of the study.

2. Methodology

The literature review analysis was elaborated by browsing through resources which offer topics related to building energy performance in Romania. These topics include publications related to building energy performance national regulations, to energy consumption of the Romanian building stock and to cost analysis in the context of energy efficiency. The publications gathered in the literature survey list were organized based on their main topic into the following categories: policies and regulations, technology, feasibility and human factors. The publications were sorted into the topics mentioned previously to highlight both the current state-of-the-art and the aspects that need to be improved on different levels of building energy performance in Romania (i.e. policy and regulations, technology and feasibility). The following sections describe the main findings of the reviewed publications from each level of building energy performance in Romania.

The final step of the literature review analysis is the creation of the literature review matrix to summarize the key findings from the previous studies. The paper also includes a SWOT analysis which evaluates the strengths, the weaknesses, the opportunities and the

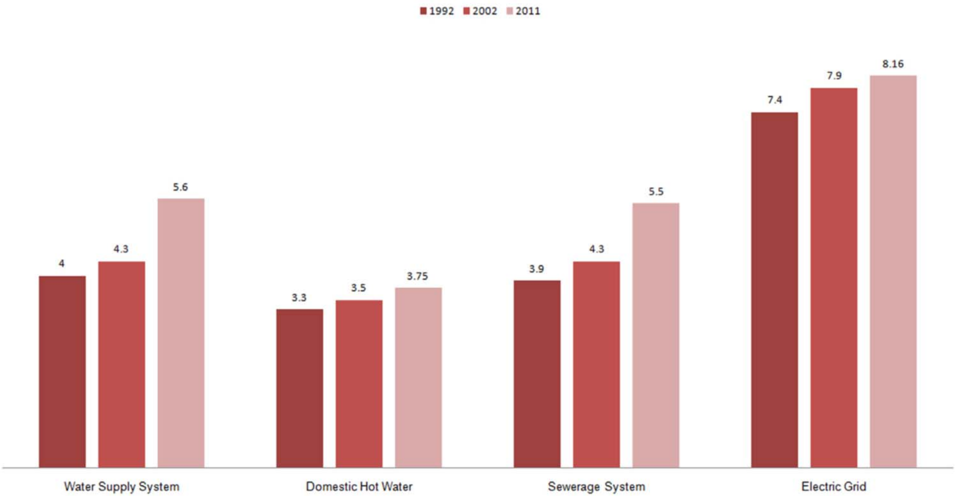

Fig. 3. The number of housing units from Romania based on endowment with the main building services [33,34].

Table 1
The literature review matrix of the reviewed studies.

	REFERENCE	STUDY PARAMETERS	FOCUS	GAPS	FINDINGS
1. Policy and Regulations	I. Nolte, O. Rapf, D. Staniaszek, and M. Faber [1]	The energy performance of buildings. Cost - Optimal calculations. Cost - Optimal calculations.	Implementing the Cost - Optimal Methodology in the EU countries. Rules for applying the Cost - Optimal Methodology.	The publication states that at the moment there is no data base about the price of energy at EU level.	The publication establishes the rules for selecting the reference buildings and for the packages of measures (variants). The three case studies made for the building stock from Germany, Austria and Poland emphasizes the difference in choosing the optimal solution between the three countries.
	B. Atanasiu, L. Kranzl, and A. Toleikyte [7]	The objective of the ENTRANZE project is to provide the required data, analysis and guidelines to achieve a fast and strong penetration of nZEB and RES-H & C within the national building stocks.	The document focuses on the building stocks from Romania. Recommendations for implementing the nZEB and RES-H & C in Romania.	–	For modeling was used Invert/EE-Lab, a simulation tool of different scenarios: price, insulation, consumer behavior and their impact on future trends of energy demand and mix of renewable and conventional energy sources on national and regional level.
	I. Nolte, N. Griffiths, O. Rapf, and A. Potcoava [6]	Implementing the concept of Nearly Zero Energy Buildings in Romania for the existing and new buildings.	The building stock of Romania. The roadmap of implementing the nZEB concept for Romanian buildings.	The report about Romanian building stock concentrates only on the urban areas and not on rural areas too. There isn't a detailed report about the areas with renewable energy. The cities are only mentioned.	The Cost-Optimal Methodology was applied for 3 different reference buildings from Romania: a single family house, a multifamily house and an office building. In the application of the Cost-Optimal Methodology, for each reference building were chosen at least 10 variants.
2. Technologies	C. Tanasa, C. Sabău, D. Dan, and V. Stoian [8]	The measure of energy consumption and the variation of the comfort parameters of the passive house built in the city of Timisoara in Romania.	The characteristics of the passive house built in Timisoara, Romania. Implementation of the monitoring system and measured energy consumption. Analysis of the thermal comfort parameters. Analysis of the final results.	The results of the monitoring system show that the passive house from Timisoara doesn't fulfill the passive house standard.	A monitoring system was used on the house from Timisoara that registers and collects data which is uploaded to a web server. On the web server diagrams are created for online visualization.
	V. Badescu, N. Laaser, R. Crutescu, M. Crutescu, A. Dobrovicescu, and G. Tsatsaronis [9]	The time depending simulation of the first Romanian passive house building using the model Passive House Thermal Transient (PHTT).	The description of the Passive House Thermal Transient model applied on the building. The description of the heating and ventilation system with which the building is provided. The analysis of the results of the PHTT simulation.	The study is limited to one climate area.	The simulation using PHTT was done with a time lag of 10 min leading to more accurate results than the PHPP model using monthly method. In order to compare the results from the PHPP and from the PHTT, the monthly average of the results from PHTT was computed.
	V. Badescu and B. Sicre [11]	Model to compute the heating demand for a three-zone passive house. The model is time dependent in order to take into account properly the thermal inertia of the very thick walls of the passive house's envelope.	The building's thermal load model. The thermal model for the ventilation/heating system. The thermal model for the solar collectors. Thermal targets and operation control. Preliminary results and discussions.	As the article states, the detailed information about the meteorological parameters at Pirmasens PH location were missing. For the research it was used the meteorological data from Chemnitz, Saxony, containing information measured in year 2000.	The definition of the space heating/cooling demand depends on the following parameters: the heat flux escaping the building envelope, the heat loss due to air circulating through the walls, the heat gain due to solar irradiation passing through the windows and the heat released by the building occupants or by household appliances. The time dependent heat transfer through walls was modeled by 1 dimensional time dependent heat transfer equation which was solved numerically by using a standard Netlib solver.
	N. Rotar and V. Badescu [12]	The comparison of the same passive house built in different climate zones from Germany and Romania.	The passive house energetic requirements and the European climate. The passive house energetic variation in the European climate. The analysis of the final results.	–	11 towns from Romania and Germany which are considered representative for the development of the passive house were chosen for the study. The towns are almost evenly distributed on the two territories between the limits of the longitude and latitude. The heating demand was computed

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Table 1 *(continued)*

REFERENCE	STUDY PARAMETERS	FOCUS	GAPS	FINDINGS
				by the means of PHPP.
S.B. Sadineni, S. Madala, and R.F. Boehm [13]	The most important building envelope elements and their latest development.	Walls, fenestration and roofs. Thermal insulation, thermal mass and phase change materials. Infiltration and air tightness. Building simulation software programs. Building envelope diagnosis. Building envelope maintenance.		There are methods for building envelope diagnosis like infrared thermography, fenestration diagnosis, infiltration and air tightness diagnosis and envelope moisture diagnosis.
B.P. Jelle [14]	Investigate and compare the various properties, requirements and possibilities for traditional, state-of-the-art and possible future thermal building insulation, materials and solutions, their weaknesses and strengths, disadvantages and advantages.	Traditional thermal building insulation. State-of-the-art thermal building insulation. Nanotechnology and thermal insulation. Possible future building thermal insulation. Comparison of weaknesses and strengths.	–	The high thermal conductivity of the traditional thermal insulation materials lead to very thick building elements in cold climate areas in order to achieve the passive house and ZEB standard. The traditional thermal insulation materials are vulnerable to humidity and perforations. The conceptual thermal insulation materials have been designed to have very low thermal conductivity and to be robust with respect to aging, perforation, building site adaptions.
A.R. Vasiu [15]	Active thermal insulation solution for the rehabilitation of the old buildings.	The description of the active thermal insulation solution.	There is no information regarding practical application of the active thermal insulation system on residential or non-residential buildings.	The active thermal insulation system has the following components: the cellulose honeycomb, glazed panel and a layer of passive thermal insulation positioned on the existent wall's side. The cellulose honeycomb is made of recycled carton and paper placed inside the panel. Between the glazed panel and the cellulose honeycomb is a layer of ventilated air which stimulates convection and avoids the overheating of the panel during summer season.
J.S. Sage-Lauck and D.J. Sailor [16]	A newly constructed passive house duplex was thoroughly instrumented to monitor indoor environmental quality metrics and building energy use. The use of phase change materials (PCMs), which store heat as they melt and release heat as the solidify.	PCM applications in buildings. The methods used in the study. The analysis of the result.	–	The 3 scenarios used to evaluate the behavior of the house with PCM material were: simulation of the building with no PCM installed simulation of the building with PCM having different melt temperatures and simulation of the building with PCM layer at the interior surface of the interior wall.
I. Hazyuk, C. Ghiaus, and D. Penhouet [25]	A possible way to obtain a low order model of the building's thermal behavior. Generate input/output data records by simulating a detailed model of the building instead of measuring them on a real building.	The dynamic modeling of a building. The model inputs characterization. The model parameter identification.	–	The building's thermal behavior is modeled as a linear electric circuit and the state-space equations are obtained by solving the circuit. To guarantee the optimality of the solution, the initial values need to be close to the optimal solution and the constrains need to be included in the algorithm in order to bound the physical values of the parameters.
S.A. Memon, T.Y. Lo, and H. Cui [17]	Form-stable composite PCM was developed by utilizing waste glass powder as container for n-octadecane.	Experimental program. Results and discussion.	–	The selected PCM was n-octadecane because its phase transition temperature is in the human comfort zone and has high latent heat of fusion. The container of the PCM was soda-lime glass which represents 80% by weight of waste glass. The composite PCM was prepared by using vacuum impregnation method. The PCM with n-octadecane-GP (glass powder) is effective in reducing the indoor temperature and the temperature fluctuations, improving the indoor thermal

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Table 1 *(continued)*

REFERENCE	STUDY PARAMETERS	FOCUS	GAPS	FINDINGS
				environment.
V. Badescu, N. Laaser, and R. Crutescu [9]	The analysis of cooling requirements of a passive building in Romania during summer season. The analyzed passive building is the headquarters of SC AMVIC SRL from Bragadiru, near Bucharest.	The description of the passive office building, the headquarters of SC AMVIC SRL from Bragadiru town, near Bucharest. The steady state analysis for cooling requirements during summer season. The time dependent models used. The analysis of the results of the time dependent models used.	Even though the analysis was done on a passive office building, the problem of overheating in the summer can occur also in passive residential buildings.	The cooling requirements for a passive house are larger than in a standard building. The internal heat sources have significant influence in the summer months on the cooling load. In the design of a passive building in Romania, it is important to take into consideration the overheating during summer season and the heat demand during winter season. These two aspects are equally important when it comes to energy performance and fulfilling the passive house standard.
I. Ballarini and V. Corrado [19]	The thermal characteristics of a building for summer performance with the focus on thermal insulation. A new methodology for the analysis of the parameters which influence space cooling energy performance.	The methodology of the building's thermal analysis. The ways of representing obtained results. Potential applications of the proposed methodology. The methodology applied using parametric analysis for two case studies. Sensitivity analysis and discussion of output.	–	The study presented in the article was applied in 3 phases. The first phase of the study involved the effect of the whole building envelope on the building's thermal behavior in summer which is assessed as a function of boundary conditions of the indoor and outdoor environment, of the building's typology and of the building's geometry. In the second phase, the effect of the opaque building envelope was analyzed which is influenced by the size of the transparent surfaces, the glazing thermo-physical parameters and the solar properties of the external opaque surfaces. In the third phase was studied the effect of the thermal insulation level of the opaque envelope which depends on the dynamic thermal properties of the structure. The proposed methodology can be applied for the energy design of a new building, the energy audit of an existing building or for the validation of simplified calculation models of building energy performance through a comparison with a detailed dynamic model.
N. Petrasincu and L. Fara [20]	The analysis of the bioclimatic elements from traditional Romanian houses. The analysis is meant to emphasize the characteristics of the traditional Romanian houses in order to adjust them to the new social and economic conditions.	The analysis of the bioclimatic elements of traditional Romanian houses from the rural environment. The analysis of the bioclimatic elements of the traditional Romanian houses from the urban environment.	–	The Romanian houses are characterized by the following: the orientation relative to the shining of the sun and to the direction of the dominant winds, solar energy collection for heating by greenhouse effect, minimizing the quantity of conventional fuels used through a proper design of the house and of the stoves and the use of shading elements in the warm season. The main factors that influence traditional Romanian houses are the natural environment with an excessive continental climate and the human creative nature.
V. Iordache, I. Nastase, A. Damian, and I. Colda [22]	Mathematical models and the adapted experimental protocol for four different parameters that describes the permeability.	The proposed mathematical model for permeability. The adjusted experimental protocol. The experimental study on a Romanian residential building. The analysis of the results.	The experimental study of the air permeability in the individual dwelling was limited because of the following reasons: the size of the house and the large number of rooms, the low probability of having favorable weather	The experimental study was done on an individual dwelling built in 1998, in the Sub Carpathian village Homoraciu from Prahova county. In the experimental study was used the Blower Door method.

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Table 1 *(continued)*

	REFERENCE	STUDY PARAMETERS	FOCUS	GAPS	FINDINGS
				conditions on a long duration necessary during a large number of measurements and the similarity between the ground floor area and a common Romanian apartment. There were errors of measurements for the wooden first level because of the numerous joints and of the flexibility of the wood during the measurements under the action of the indoor-outdoor pressure difference.	
	M.G. Baldi and L. Leoncini [23]	The description of the thermal exergy model of a building. The application of the exergy model on a real building.	Exergy as environmental impact value. Building impact on the environment. The thermal exergy model. The computational model. Discussion of the obtained results.	–	Exergy represents the thermodynamic potential measure of energy or material flux with respect to an equilibrium state assumed as the reference state. The exergy analysis application as an evaluation parameter allows a complete thermodynamic assessment of a building energy use because it accounts the potential of energy carriers that cross the system boundary and their degradation in addition to the energy conservation equations. Each of the sectors of the energy flow receives an exergy input from the sector placed upstream and provides an exergy output to the sector placed downstream. The irreversibility due to energy conversion and transport or temperature differences leads to exergy destruction of each sector and of the corresponding exergy efficiency.
	C. Ghiaus and I. Hazyuk [24]	Methodology for estimating the heating load of buildings with variable zone temperature set-point.	The outline of the proposed methodology. A possible thermal model for a building. The compensation of the weather conditions. Methodology for heat load calculations based on model predictive programming.	–	The problems of the current procedures of the heat load calculation are the non-physical variation of the heat load temperature, the dependence on the peak load value on sampling time and the non-optimal control. The methodology aims to transform heating load calculation into a control problem.
	M. Comsit, L. Isac, and M. D. Moldovan [26]	Relevant issue related to the architectural integration of active solar technologies in the facades. Concepts of interest for architects, engineers and designers working on the implementation and integration of solar energy conversion systems in the built environment.	The problem of the solar technology integration into the building facades. The solar collector and the array units. The multifunctional solar thermal facades.	The solar thermal façade has not been applied practically on a residential building yet.	The problems of the solar technology integration into the building's façade are shape, aesthetics and functional demand. The concepts of integrating solar energy conversion systems are the following: hiding the components in the façade, mounting the components of the façade without drawing attention and outlining the solar components in the building design. The vertical implementation of the solar collectors will lead to increased surface available for mounting and a better distribution of the heat production.
3. Feasibility	D. Popescu, E. Cerna Mladin, R. Boazu, and S. Bienert [27]	A new methodology to be considered in the sales comparison approach of real estate valuation.	The building energy efficiency linkage to its market value. The building valuation methodology including energy efficiency input. Case study on a residential building from Romania built in 1992 which suffered	–	The procedures of real estate appraisal: cost approach, income capitalization approach and sales comparison approach. In the case study was used the sales comparison approach. The sales comparison approach is

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Table 1 *(continued)*

REFERENCE	STUDY PARAMETERS	FOCUS	GAPS	FINDINGS
		only current maintenance since then. Perspectives of the methodology.		applied if similar properties have recently been sold or are currently on sale in the subject property's market. The methodology must be applied on at least 3 comparable buildings, one of them being the reference building. The method leads to good results if the subject property and comparable buildings are built on the same standards.
A. Badea, T. Baracu, C. Dinca, D. Tutica, R. Grigore, and M. Anastasiu [28]	The analysis of the life cycle cost of a passive house including its technical design variations. The analyzed passive house is located in the campus of the University Politechnica of Bucharest.	The description of the method. The description of the passive house "Politehnica". The model of analysis. Discussion of the obtained results.	–	The general model of the life cycle cost involves the variability of the bank interest rates, inflation and price escalation. The utilities, the staff, tax, the residual value and the cost of the decommissioning at the end of the life cycle are not taken into consideration in the analysis because they tend to have the same value throughout the change of the design of the house involved. In the study presented in the article the rate of inflation was not considered and for analyzing the variable economic environment was used the deterministic approach which involves the variation of one or of a combination of variables around the predicted point.
V.G.E. Ionescu and H. Necula [10]	Promote the energy efficiency of buildings in Romania. Simulation in TRNSYS of two houses located in the campus of University Politechnica of Bucharest.	The description of the two houses from the campus of University Politechnica of Bucharest. The simulation of the houses in TRNSYS. The analysis of the simulation results.	–	2 models were simulated in TRNSYS: the building provided with simple flux ventilation system and the building provided with MVHR system. The results of the first simulation: energy consumption of the building decreases with the increase of the thermal insulation layer and the efficiency of windows have influence on the thermal load. Result of the second simulation: the power consumption of the building used as lab is greater than of the building used as a 4 member family house. Also energy consumption decreases if MVHR system is combined with EAHX system.
B. Diaconu M. and M. Cruceru [30]	Proposal of a Phase Change Material (PCM) enhanced wall system. The development of a model for the heat exchange between the indoor heated environment and ambient. Assess the effect of occupancy pattern and ventilation on energy savings for heating that the Phase Change Material wall system is capable of achieving.	The description of the PCM wall system. The analysis of the effect of occupancy pattern and ventilation on energy efficiency of a room with PCM walls. The analysis of the results.	The article doesn't describe which exactly the occupancy patterns used in the model are. All it is known that the patterns were denoted as A, B, C, D.	The analysis was run on a test room with the dimensions 6.5×4.5×2.5 m, having the walls exposed to heat transfer and 1 window with the opening area 2 sqm. The floor and ceiling are not considered into the analysis. The energy demand for heating was calculated for several values of the PCM melting point in the case of each occupancy pattern and ventilation situation considered.
M. Păcesilă [5]	Describes different types of renewable energy sources. Reveals the importance given by Romania, Bulgaria and Greece regarding the investment and technologies in the field.	The renewable energy potential maps for Bulgaria, Greece and Romania. The analysis of the current situation of renewables in Bulgaria, Greece and Romania.	–	Romania is the 14th most attractive country regarding renewable energy markets in the top 40 made by Ernst and Young in 2012. Romania has very good potential for solar energy, hydropower, biomass and geothermal energy.
M. Shahbaz, M. Mutascu, and P. Azim [2]	The relationship between energy consumption, economic growth and CO2 emissions, in case of Romania. The	The Literature Review on Environmental Kuznets Curve. The economic specifications and methodology. Empirical results and	–	The Environmental Kuznets Curve shows the relationship between per capita GDP and measures of environmental degradation as

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Table 1 *(continued)*

	REFERENCE	STUDY PARAMETERS	FOCUS	GAPS	FINDINGS
		existence in Romania of the environmental Kuznets curve's effects over the period of 1980–2010.	discussions.		inverted U-shape. The determinants of the Environmental Kuznets Curve are: the financial development, the energy consumption, and economic growth and CO2 emissions.
4. Human Factors	V. Musatescu and M. Comănescu [4]	The problem of energy consumption and climate change in Europe. The problem of climate change in Romanian urban areas.	The renewables target impact. The possible barriers in energy - climate change package implementation in Romania. Greenhouse gases emission reduction. Energy consumption reduction.	–	Regarding the reduction of GHG emissions, in Romania a large number of intelligent measures could be used. The fact that the majority of towns are not properly developed in connection with GHG emissions reduction is at the same time a challenge and an opportunity.
	M. Sharp [3]	A report on energy, housing and energy services in Romania.	Energy sector in Romania. The Romanian building stock. The energy consumption of Romanian households. The energy service in Romania.	–	Romania is one of the EU member states which is the least dependent on energy import. After the fall of the communist regime, the total energy consumption has been decreasing in Romania. Even though the majority of dwellings from the Romanian building stock are relatively new, most of the buildings are in bad condition.

threats involved in reaching the EU's 2020 energy efficiency targets in Romania. The success of a building energy efficiency program depends on many issues. Fig. 2 shows the key elements that have significant impacts on building energy efficiency, including policies and regulations, technologies, feasibility, human factors and other uncertainty factors.

3. Policies and regulations

Romania is a country member of the European Union since 2007. Romania has an upper-middle income and a dynamic economic development. Between the years 1948 – 1989, when Romania was under the communist regime, the economy was centralized. After the fall of the communist regime in 1989, the economy of Romania had a period of instability [2]. The communist regime causes Romania to have excessive industrial consumption of energy and overstaffed, inefficient energy production systems. The modernization of the energy sector did not start until the late 1990s. It was held up by the continuation of the state-owned monopolies, by high levels of consumer subsidy and by the resistance to privatization of the coal, electricity and gas industries [3].

Romania is one of the European states which is the least dependent on energy imports according to the National Institute of Statistics Romania, 2005. In 2006 only 29% of Romania's energy supply was imported. Most of its imported energy resources are oil and gas. The energy sector in Romania encountered the specific problems faced by countries with economies in transition. The problem specific to transition countries are: high energy intensity combined with low energy efficiency, low level of legislation, institutional and regulatory infrastructure which lead to high transaction costs, consistent energy price increase above the rate of inflation and poor record on energy conservation and compliance with environmental requirements [3]. According to Eurostat, the energy price in Romania in 2015 was 0.13 euros/kWh [4] and the natural gas price was 27.11 Euro per Gigajoule [5].

The first Environment Department in Romania's history was established in the early 1990s. Its main objectives were the limitation of the pollution phenomena and establishing the responsibility regarding environmental damage. The first official document for environment conservation and protection based on EU regulations was called National Strategy of Environment Protection and was signed in 1992. The National Strategy of Environment Protection was updated in 1996 and 2002. Since Romania became member of the European Union, the environmental policy focused on increasing the share of renewable energy in the total energy production [2].

In 2007 the Convenant of Mayors was established which is a part of the EU's energy and climate protection package. The local authorities who are a part of the Convenant of Mayors are committed to go beyond EU objectives for 2020 in terms of CO2 emissions, energy efficiency and climate change measures and they must draw up a sustainable energy plan and share experience with other territorial units. There are 11 towns from Romania which are members of the Convenant of Mayors: Aiud, Baia Mare, Brașov, Bucharest, Craiova, Giurgiu, Mizil, Râmnicu Vâlcea, Slobozia, Târgoviște and Târgu Jiu [6].

Romania proposed the target for renewable energy share has to be 24% by year 2020 [6]. In 2010, by applying EU's policies, the share of renewable energy in Romania was 23.4% that year. In June 2010, the Government of Romania released Law no. 139/2010. This law, which modified and completed the Law no. 139/2010, established a system to promote the use and production of renewable energy. The law included the following aspects: new rules regarding issuing green certificates for 1 MW h of renewable energy (i.e. biomass, solar, geothermal) and overcompensation for renewable technologies. This overcompensation was given if the internal rate of return is 10% higher than the value considered by the promotion system and if the producer had accreditation from the Romanian National Energy Regulatory Authority [7].

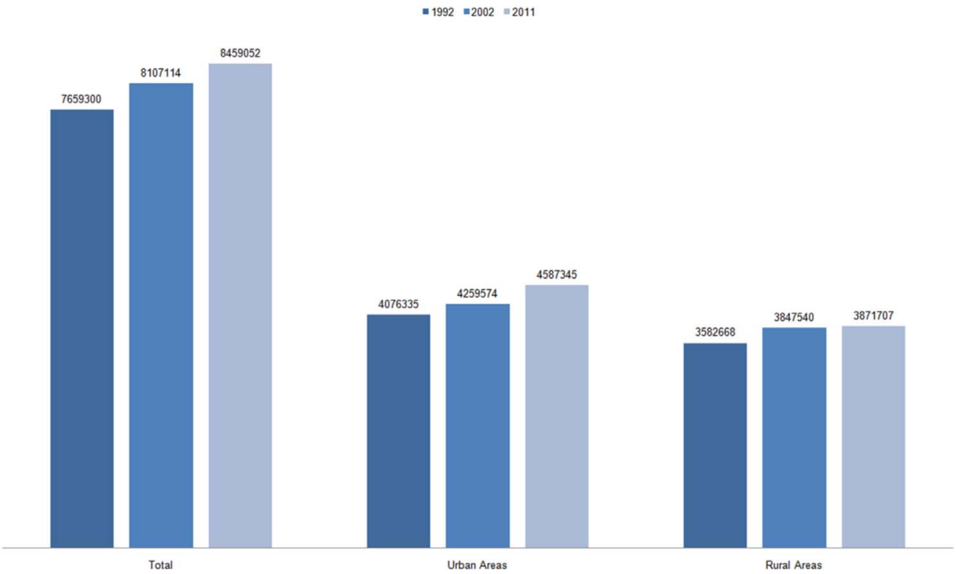

Fig. 4. The number of residential dwellings from Romania [36,37].

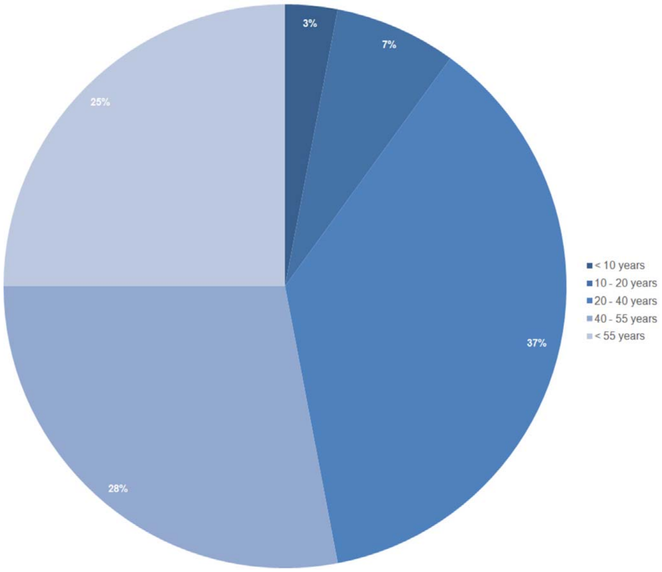

Fig. 5. The distribution of the Romanian buildings depending on their age [39].

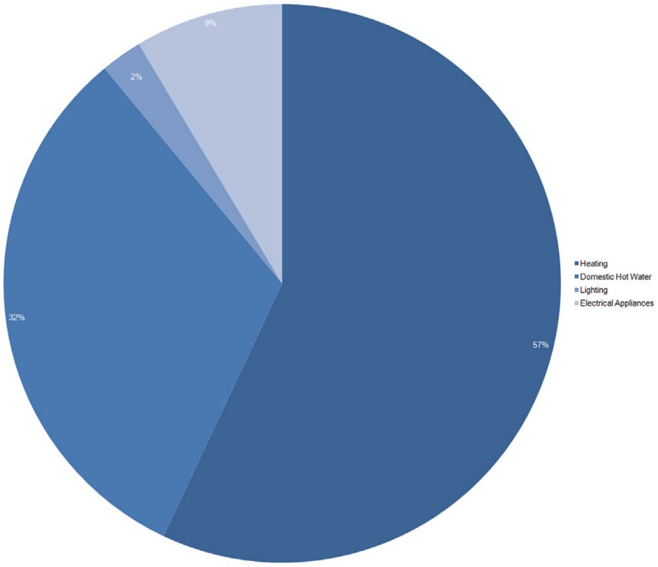

Fig. 6. The distribution of the total energy consumption of a Romanian household [3].

In a report written in year 2012 about Romania's level of nZEB implementation, BPIE states that in the national standards there are no specific requirements for primary energy use or CO2 emissions, there are no holistic policy packages and no long term programs for new buildings. Also there isn't a specific mechanism to promote Renewable Energy Sources – Heating and Cooling except for the existence of co-financing of some projects within programs such as European Structural Funds or the Environment Fund. The National Renewable Energy Action Plans (NREAP) issued mid 2010 did not sufficiently address biomass utilization although the biomass potential is large and biomass for heating is expected to be the main heating contributor of the 24% renewable energy share by 2020 [8].

Between September 2012 and April 2014 was developed a project called ENTRANZE where Romania, along with other 8 countries from the European Union, was analyzed for implementation of nZEB and RES & H/C. This was done by establishing three policy sets based on the pace of implementing the nZEB regulations until 2030, with special focus on year 2020. Two energy price scenarios and three renovation packages were analyzed. The policy scenarios, along with the energy price scenarios and the renovation packages were modeled in the

Table 2
SWOT analysis for improving energy efficiency in Romanian residential buildings.

SWOT Analysis for Improving Energy Efficiency in Houses	
Strengths ● **Reduced energy costs.** [10,28–30] ● **Comfortable interior environment.** [20–22] ● **Sustainable cities and villages.** [2,4,5,7], ● **Better indoor air quality.** [20,21]	Weaknesses ● The average income of Romanian families. [3,6] ● The availability of new thermal insulating materials. [14] ● Not enough skilled people for thermal rehabilitations. [3,6,7] ● Design codes require updates. [6] ● There are problems with the housing conditions in Romania. [3]
Opportunities ● **Increased values of buildings on the real estate market.** [7,27] ● **Socio-economic influence.** [7] ● **Market for new innovations.** [15–17,23,26] ● **New specialization for engineers and architects.** [6,7]	Threats ● Increase of house insurance costs. [27] ● Climate hazards such as floods or earthquakes. [3]

software named Invert/EE-Lab [9].

4. Technology

In the following section are presented the key findings in building energy performance technology from the previous studies. These findings include studies conducted on passive houses, on thermal insulation materials, on the thermal behavior of the building during cold season and warm season and, respectively, on other building energy performance technologies. The findings are briefly presented in the following paragraphs.

4.1. Passive houses

The previous studies state that in Romania were built four passive houses as follows: the AMVIC office building from Bragadiru, near Bucharest, a passive house from Timişoara, part of a duplex and two passive houses belonging to the campus of University Politechnica of Bucharest. Reference [10] mentions that in Romania are 5 passive houses, but it doesn't mention the location and the function of the other four passive houses besides the one from Timişoara. The information about the 5th passive house built in Romania is currently unknown, because there hasn't been found any information about it in the literature.

The passive office building AMVIC was simulated using the following models: building thermal load model, the model of the ventilation/ heating system, the thermal target and the operation control. The simulation was done using PHTT (Passive House Thermal Transient) model with a time lag of 10 min and the PHPP (Passive House Package Protocol) model with the monthly method, resulting that the office building fulfills the passive building standard [11].

For the passive house in Timişoara was installed a monitoring system that registers and collects data. The data is uploaded to a web server where diagrams are created for online visualization. The results of the monitoring system installed on the passive house from Timişoara show that the house doesn't fulfill the passive house standard because the annual heat demand exceeds 15 kW h/m^{2}*yr. So technically, the house from Timişoara cannot be classified as passive house [10].

The two passive houses located in the campus of the University Politechnica of Bucharest were tested for energy efficiency using the software TRNSYS. The designers created two models to use in the simulation with TRNSYS: one model is the building provided with simple flux ventilation system and the second model represents the building provided with MVHR system [12].

In Germany, a building named Pirmasens Passive House was simulated by using a one dimensional time dependent heat transfer equation solved numerically using Netlib. The model used on Pirmasens Passive House can be applied to any passive house with arbitrary number of rooms and arbitrary space orientation [13]. The same model could be applied to the passive houses built in Romania.

There was also a comparison of the same passive house built in different climate zones from Germany and Romania, where the heating demand was computed by the means of PHPP. The results state that for the same passive house constructive structure, the heating demand in Romania is latitude dependent and more reduced comparative to Germany. In the same climate zone, but at different latitudes, the variation of the specific heat demand is higher in Romania than in Germany [14]. The comparison of the heat demand between a passive house built in Romania and the same one built in Germany was made for the office building AMVIC from Bragadiru, near Bucharest [14]. The study would have been more accurate if the same comparison would have been made between a residential passive building from Romania and the same one from Germany.

4.2. Thermal insulation materials

In order to design a building that fulfills the passive house standard, the choice of materials is important. Besides the traditional building materials, there are also advanced technologies for the building envelope such as advanced wall systems (passive solar walls, lightweight concrete walls, ventilated or double skin walls, walls with latent heat storage), advanced glazing (aerogel glazing, vacuum glazing, switchable reflective glazing, suspended particle devices film, holographic optical elements) and roof systems (ventilated and micro-ventilated roofs, solar reflective/cool roofs, green roofs, photovoltaic roofs) [15]. The traditional thermal insulation materials are vulnerable to humidity and perforations. Their high thermal conductivity lead to very thick building elements in cold climate areas to be able to achieve the passive house and ZEB standard. The Polyurethane foam has the smallest thermal conductivity among the traditional thermal insulation materials, but it has the disadvantage of being very toxic in case of fire, because Polyurethane releases hydrogen cyanide [16]. Therefore designers try to find thermal insulating materials that have low thermal conductivity, do not allow air leakages, ensure thermal comfort and thermal stability and are not harmful to the indwellers' health.

An example of new technology in thermal insulation is the active thermal insulating system composed of a cellulose honey comb, made from recycled carton and paper placed inside the panel, a glazed panel and a layer of passive thermal insulation positioned on the existent wall's side. Between the glazed panel and the cellulose honeycomb is a layer of ventilated air which stimulates convection and avoids the overheating of the panel during summer season [17]. Another innovative thermal insulating material suitable for a passive building is the Phase Change Material (PCM) which reduces fluctuations in air temperature, shifts cooling loads to off-peak periods and has the ability to store energy characterized by its latent heat of fusion. The PCM can be fabricated of organic compounds, inorganic compounds or eutectic mixtures. The PCM can be applied on building elements by direct impregnation into building materials or by encapsulation [18].

Another example of thermal insulating materials suitable for the passive buildings or nZEB are the state-of-the-art materials. The most promising state-of-the-art thermal insulation materials are the vacuum insulation panels (VIP) and the aerogels due to their very low thermal conductivity. The VIP's drawback is that its thermal conductivity increases with age because of water vapors and humidity penetration into the pores. The gas filled panels (GFP) are doubtful solution because their thermal conductivity is higher than of the VIP [23].

There are also conceptual thermal insulation materials which have been designed to have very low thermal conductivity and to be robust with respect to aging, perforation, building site adaptations [23]. One of the conceptual thermal insulation material is the PCM with waste glass powder which is made of n-octadecane, because its phase transition temperature is in the human comfort zone and has high latent heat of fusion, and soda-lime glass which represents 80% by weight of waste glass. The composite PCM was prepared by using vacuum impregnation method and was tested for surface morphology, chemical compatibility, phase change behavior, thermal properties, thermal stability and thermal performance. The results of the tests show that the melting and freezing temperatures are for *n*-octadecane 27.4 °C and 25.15 °C and for n-octadecane-GP (glass powder) are 26.93 °C and 25.03 °C, which are close to the range of human comfort zone and the thermal conductivity of the n-octadecane-GP is 0.62 W/ m K [19].

4.3. Building energy performance during summer

The disadvantage of the passive houses is overheating due to the high air tightness. The internal heat sources and solar radiation have significant influence in the summer months on the cooling load. Therefore, PHPP recommends additional cooling measures if the overheating exceeds 10% [20]. Designers try to study the effect of thermal insulation on the building in summer conditions to be able to find solutions for interior thermal comfort and low cooling demand.

The application of an adequate thermal insulation to improve building energy performance in summer has only been analyzed in few case studies outside Romania. The case study presented in the reference [21] was made on a residential building and an office building located in Rome, Italy. The case study went through 3 phases: the first phase involved the effect of the whole building envelope on the building's thermal behavior in summer, in the second phase was analyzed the effect of the opaque building envelope and in the third phase was studied the effect at the thermal insulation level of the opaque envelope. Both building models went through 5 simulations where they were subjected to the same conditions, but with a different driving force each time. The detailed numerical simulation was done by EnergyPlus.

Another case study related to thermal insulation for building energy performance during summer was conducted in Portland, Oregon, USA. The efficiency of the PCM in ensuring thermal comfort in the building was studied on a duplex house. The model was analyzed by the following three scenarios: simulation of the building with no PCM installed, simulation of the building with PCM having different melt temperatures and simulation of the building with PCM layer at the interior surface of the interior wall. The results of the simulations showed that using PCM with 25 °C melting point may reduce the zone hours overheated by 50% and reducing the melting point of the PCM below 25 °C may have an adverse effect on thermal comfort [18].

The energy performance of the building during summer season can be improved by taking into account the bioclimatic elements, as in the traditional Romanian houses. The traditional houses from Romania have the following features: their orientation is relative to the shining of the sun and to the direction of the dominant winds, the solar energy for heating is collected by greenhouse effect, the quantity of conventional fuels is minimized by a proper design of the house and of the stoves and shading elements are used in the warm season [22].

4.4. The simulation of the thermal behavior of the building

The thermal behavior of the building was studied in many reviewed papers by simulations using different models and by experimental studies. The purpose of the thermal behavior simulations is to help decision makers find solutions for creating comfortable indoor environment in the buildings. The simulations were done to determine the indoor air quality, the air permeability of the building and the heat transfer through the building elements.

One of the reviewed studies describe a simulation done on the building's indoor comfort using the following models: the mathematical model for the analysis of thermal comfort in buildings based on the energy balance equation and the simulation model of indoor air quality. The simulation model of indoor air quality is based on the general equation for the time evolution of a contaminant concentration, on the equilibrium concentration and on the computation of the metabolic CO2. The numerical application was done on a room with the dimensions 4.4×6×2.7 m and with the indoor air temperature 24 °C [23].

Another study describes a simulation done for the evaluation of the building's permeability using 4 models in case of large buildings: model I, the calculation of the permeability as the air flow divided by the volume, model II, the calculation of the permeability as the air flow divided by the façade surface, model III, the calculation of the permeability as the air flow divided by the wind surface and model IV, the calculation of the permeability as the air flow divided by the joint length. The experimental study was done on a single family residential building, built in 1998, located in the village Homoraciu, Prahova County, in Romania. The method used in the experimental study was the Blower Door. The experimental analysis using Blower Door method is hard to apply in a multi-family residential building because it requires the cooperation of the indwellers. The experiment made on the single family house from Homoraciu village had limitations because of the size of the house and the large number of rooms, of the low probability of having favorable weather conditions on a long duration necessary during a large number of measurements and of the similarity between the ground floor area and a common Romanian apartment [24].

An interesting study is about a multi-family residential building model from Florence, Italy which went through exergy analysis. The exergy analysis allows a complete thermodynamic assessment of a building's energy use by taking into account the potential of energy carriers that cross the system boundary and their degradation in addition to the energy conservation equations. The building is an open thermodynamic and transient system which exchanges energy and material flow with the environment and it is modeled as a “black box” that needs exergy, while the surrounding is a closed system and the environment is a closed system in thermodynamic equilibrium with the surrounding [25]. Even though the thermal exergy analysis was done on a residential building from Italy, the same building exergy model could be applied on a residential building from Romania. For Romanian residential buildings it would be useful to have an exergy analysis in order to find out how much of the building's exergy is destroyed and how much is lost. This way can be established the impact of the building on the surrounding environment.

Reference [26] proposes a methodology for the calculation of the optimal thermal load of intermittently heated buildings which aims to transform heating load calculation into a control problem. The current procedures of the heat load calculation have the following problems: the non-physical variation of the heat load temperature, the dependence on the peak load value on sampling time and the non-optimal control. The intermittently heated building was also modeled using the state-space modeling in which is applied the principle of analogy between two different physical domains that can be described by the same mathematical equations. The building's thermal behavior is modeled as a linear electric circuit and the state-space equations, in which it can be applied the superposition theorem of the electric circuits, are obtained by solving the circuit. The methodology for the calculation of the optimal thermal load of intermittently heated buildings was applied on a detached house located in France [27]. The methodology of the calculation of optimal thermal load of intermittently heated buildings could also be applied on Romanian residential buildings, especially on multi-family residential buildings connected to the district heating plant.

4.5. Other technologies for improving the energy efficiency of buildings

There are other ways of improving the building's energy performance found in previous studies. For example, the building can be provided with architecturally integrated multifunctional solar thermal facades. The vertical implementation of the solar collectors having the shapes as equilateral triangle and isosceles trapeze, will lead to increased surface available for mounting and a better distribution of the heat production. The first practical application of the multifunctional solar thermal facades was done on the Research and Development Institute of Transylvania University of Brasov. The solar thermal facades were applied experimentally on the building mentioned previously [28]. The same multifunctional solar thermal facades can be applied experimentally on residential buildings from Romania.

5. Feasibility

In this section are presented the key findings of the studies related to the economical part of the building energy performance. These studies refer to the analysis of the cost and energy efficiency in buildings, to the potential for renewable energy sources and to the reduction of CO2 emissions. The following paragraphs summarize the key findings related to feasibility.

5.1. Cost analysis in building energy performance

In the previous studies were used different methods to analyze the cost of the energy used for buildings. A calculation methodology for cost and energy efficiency analysis is presented in reference [29]. The methodology is used for the real estate appraisal of green value. This involves the use of the sales comparison approach applied if similar properties have recently been sold or are currently on sale in the subject property's market. The element of comparison between the buildings is the wasted/saved energy (WSE). The methodology is applied on at least 3 comparable buildings, one of them being the reference building. The methodology leads to good results if the subject property and comparable buildings are built on the same standards. The methodology for the real estate appraisal of green value is important to apply for Romanian residential buildings that go under energy audit. Based on the results of the real estate appraisal of green value and on the energy certificate of the residential building is established the price of the apartment, respectively of the house according to its energy efficiency. For example, a house with the energy class D will have a smaller price than a house with the energy class B.

Another study related to cost analysis presents the passive house belonging to University Politechnica of Bucharest. The passive was analyzed using the general model of the life cycle cost. This life cycle cost model involves the variability of the bank interest rates, inflation and price escalation. The utilities, the staff, tax, the residual value and the cost of the decommissioning at the end of the life cycle are not taken into consideration in the analysis because they tend to have the same value throughout the change of the design of the house involved [30].

5.2. Simulations of energy efficiency in buildings

In order to determine the energy efficiency of the buildings, building models were created and were simulated using different software. In this section are presented examples of previous case studies where building models were simulated for energy efficiency in the context of thermal insulation, respectively of building services.

The first example of case study is the passive house Politechnica from Bucharest, Romania. The passive house was simulated in TRNSYS using two models. The first building model was provided with simple flux ventilation system, where the fresh air had the outdoor temperature. Also the thickness of the thermal insulation of the walls was reduced to half from the initial value. The second building model was provided with MVHR system. The building model had two different functions: laboratory and house for a family composed of 4 members [12].

Another case study is represented by an office building from Transylvania University of Brasov. The building model was simulated in TRNSYS to determine the most effective methods to improve the energy performance and to have optimal energy costs. In the simulation the office building was modeled using 6 building variants. The building variants had 3 types of insulation materials with different thickness for the exterior walls, with different types of windows and with 2 types of thermal insulation for the roof [31].

There is also a case study about a building having PCM as thermal insulation. The building model was simulated to determine its energy efficiency and the energy costs. The analysis was run on a test room with the dimensions 6.5×4.5×2.5 m, having the walls exposed to heat transfer and 1 window with the opening area of 2 m^2. In the analysis were used 4 occupancy patterns which were denoted with A, B, C, respectively D. Each occupancy pattern was analyzed for two cases: when the room doesn't have mechanical ventilation and when the room has mechanical ventilation. The energy demand for heating was calculated for several values of the PCM melting point in the case of each occupancy pattern and ventilation situation considered and the results show that the PCM with the melting point 19 °C has the highest potential for energy savings [32]. In this case study is not specified which exactly are the four occupancy patterns used in the simulation. Therefore the information is incomplete since it isn't known exactly what kind of occupancy pattern leads to the result mentioned previously.

5.3. The renewable energy potential and CO2 emissions

According to the analysis made by Ernst & Young in 2012 on the most attractive 40 countries worldwide regarding renewable energy market, Romania ranks on the 14th position, because the country has very good potential mix of solar energy, hydropower, biomass and geothermal energy. Romania has a significant potential for solar energy because more than half of the country's territory has an annual energy flow between 1000 and 1300 $\mathrm{kW\,h/m^2*yr}$ and has 210 days of sunshine per year. Also, Romania has great potential in hydropower. But the current generating capacity does not satisfy its power needs because the buildings are in bad conditions and the technology is outdated [7].

A study on Romania's CO2 emissions history used the Environmental Kuznets Curve. The Environmental Kuznets Curve shows the relationship between per capita GDP and measures of environmental degradation as inverted U-shape. The CO2 and greenhouse gas emissions from Romania were evaluated using the time reference data from 1980 to 2010. The existence of the Environmental Kuznets Curve in Romania, in the presence of energy consumption, was tested by using a series having natural logarithm form which is superior and provides consistent empirical findings. Also, for the analysis was used the ARDL (Autoregressive-Distributed Lag) bounds testing approach [2].

6. Human factors and other uncertainty factors

The implementation of passive house and nZEB standards in Romania also incurs barriers related to human factors and other uncertainty factors. The other uncertainty factors may refer to the availability of modern thermal insulation materials on the market, the degree of training in the field of building energy performance of specialists, the availability of programs for training specialists into building energy audit and building energy performance technologies, the funds that the authorities allocate for sustainability sector etc.

For example, in the implementation of the energy – climate change package in Romania the following barriers step in: the lack of information about the package requirements, the lack of coherent development plans and the lack of financial means. The lack of financial means may not be an excuse since there are a lot of EU financial instruments that could be used in Romania. In Romania, a large number of intelligent measures could be used to reduce CO2 emissions. The fact that the majority of the towns are not properly developed in connection with CO2 and greenhouse gas emissions cutting constitutes at the same time a challenge and an opportunity. In order to overcome the barriers, the authorities must ensure that resources are allocated on the basis of detailed knowledge instead of political trends and they must have a more in-depth understanding of the present situation and the future trends in Romanian towns [6].

At the current moment, implementing solutions for Zero Energy Buildings in Romania is difficult due to the costs involved in the process. The costs of nZEB implementation are high because of the low average income in Romania compared to other Member States. There is also uncertainty of using innovative thermal insulating materials, such as PCM, because of their availability on the market and of their high costs. So in order to achieve the 2020 targets in Romania, the

Romanian Government or the European Union has to provide higher financial support in form of subsidies [8].

In 25 years of transition, the average living conditions from Romania have not improved. Although the building stock is relatively recent (see Fig. 4), the general quality is low and deteriorating because of the lack of repair. In the Romanian building stock, 30% of the buildings have rotting windows, 29% have problems with damp and leaks, while 40% of dwellings are not connected to the sewerage system. The average dwelling in Romania is small with 27% of indwellers living in houses up to 50 m^2, while 23% live in houses with the surface over 100 m^2. This indicates a polarization in terms of living space. There is also a relatively high proportion of multi-generational dwellings, where children, parents and grandparents live together. Due to the high percentage of unemployment (5.5% in 2005) and of the high price of households on real estate market, many young families cannot afford to live independently. Romania's average household number is 2.92 and is one of the highest in EU (the average in EU is 2.46) [3].

In Fig. 3 [33] is presented the number of housing units from Romania based on endowment with the main building services. The data is taken from the census made by the Romanian National Institute of Statistics [34]. From Fig. 6 can be observed that the number of housing units endowed with water supply system, domestic hot water, sewerage and electric grid has increased from 1992.

The problems of the Romanian building stock come not only from economic problems. Romanian buildings have high risk factor because of earthquakes (especially in Vrancea area) and of flooding (in field areas) [3].

In order to solve the problems of the Romanian building stock, the Romanian authorities have initiated different support programs for the population. There are subsidies for heating given according to the family income, to the size of the family (i.e. a family with 4 members) and to the size of the household. The subsidies are given for electricity, natural gas and liquefied fuels [35]. In year 2000, the Romanian government started a social housing construction program with international funds. There is also a program for the rehabilitation of old buildings that do not meet earthquake safety standards [3].

The Romanian Government made available support programs for implementing nZEB in residential buildings such as The National Program for Thermal Rehabilitation of block of flats and the Green House ("Casa Verde") Program. The National Program for Thermal Rehabilitation of block of flats is a very good measure and is known by the owners and stakeholders. But in the actual structure, the program isn't sustainable and is not able to target the complete renovation of almost all blocks of flats. It is necessary to secure appropriate multi-annual budgets such as local, respectively central budgets and EU funds and to define a gradual reduction of grant levels as the ENTRANZE report recommends [9]. The Green House ("Casa Verde") Program had the aim to support the use of renewable energy in residential and public buildings, but had an operational budget only for the years 2010 and 2011. The report made by ENTRANZE recommends to revive the Green House Program and to further tailor it on new buildings aiming at passive house, nZEB and ZEB levels [9].

In order to reach the 2020 objectives and to surpass the barriers that step in, the authorities should launch subsidies programs for the population. These subsidies programs will aid the indwellers to rehabilitate their houses and also to provide them with renewable technologies such as solar panels or biomass boilers. Table 1 presents the SWOT analysis regarding implementing houses with high energy performance in Romania.

7. Discussion

The following section discusses the outcomes of the literature review analysis. The outcomes discussed are the current state of the Romanian residential building stock, the level of nZEB target in Romania and the future perspectives. The outcomes are presented in the following paragraphs.

7.1. Current state of the Romanian residential building stock

According to a study made by Building Performance Institute Europe (BPIE) in 2012, in Romania are 8.2 million dwellings in about 5.1 million buildings. Fig. 4 [36] shows that the number of residential dwellings from Romania has been increasing since 1992. The data was taken from the census made by the Romanian National Institute of Statistics [37].

The highest shares of the population owning their dwelling in Europe is registered in Romania (with 96.1% of owners) were more than 50% of the population lives in overcrowded households. The overcrowding rates among the population at risk of poverty are among the highest in Europe reaching 66.6% [38]. The building stock from the urban area consists of 72% of blocks of apartments and the rest of 28% are single houses. In the rural area the situation is totally different in the building stock: 94.5% are individual dwellings, while only 5.5% are blocks of apartments. When it comes to the age of the buildings, BPIE states that 53% of the buildings from Romania were constructed before 1970 and 37% of the buildings were made 1970–1989. The high percentage of the buildings constructed before 1989 is because the authorities had to keep up with the high urban migration from the rural areas. In the BPIE report is also stated that Romania has high rate of ownership in the residential sector. 97% of the residential dwellings are privately owned, while only 3% are rented. This situation is due to the fact that after the Romanian Revolution (after 1989), the residential buildings which were owned by the state were sold to the current residents or they were returned to the previous owners whose properties were confiscated by the communists [8]. The buildings from the Romanian housing stock have relatively young age, with 37% of the buildings having between 20 and 40 years. Fig. 5 shows the distribution of the Romanian buildings depending on their age according to Reference [39]:

According to the Romanian National Institution of Statistics, in year 2014, the volume of construction works from Romania decreased with 6.7% compared to year 2013. The general maintenance works made on buildings decreased in year 2014 with 17.9%, the current maintenance works of buildings decreased with 9% and the new construction works decreased with 3.2% compared to year 2013. Also, in year 2014, the number of new residential and non-residential buildings has increased with 32.6%, respectively with 16.6% compared to year 2013 [40].

From the energy performance point of view, the vast majority of buildings in Romania are in the range of C to D classes, but in reality most buildings could be closer to E class or even F. The energy performance level of the buildings ranges between 150 and 400 kW h/m^2. In Romania the demand of heating energy is 55% for apartments and 80% for individual houses. In the Romanian urban area most of the residential apartment buildings are connected to the district heating networks. Most of these district heating networks which date from communist times are inefficient [8]. Fig. 6 shows the distribution of the total energy consumption of a Romanian household according to Reference [3]:

7.2. The nZEB target in Romania

Regarding the implementation of passive house, nZEB and, respectively ZEB concept, Romania is in an early stage. In Romania there are 3 case studies of passive houses: the AMVIC office building from Bragadiru, the passive house from Timisoara which is a part of a duplex and the two passive houses from the campus of University Politechnica of Bucharest. Also in Romania there is a potential application of the PHTT (Passive House Thermal Transient) model for new residential buildings located in different Romanian climate areas. The PHTT model was already applied on an office building (i.e. the AMVIC building from Bragadiru) located in the Bucharest climate area. Therefore the PHTT algorithm can be used for residential buildings too.

Romania has very good potential mix of renewable energy sources: there is solar energy potential, geothermal energy, biomass potential due to the large agricultural activity and hydro energy potential which is also the dominant renewable energy source in the country [7]. By having a very good potential for renewables, Romania has the possibility to develop the necessary technology to produce energy from renewable sources. For example, Romania has the potential to integrate multifunctional solar panels into facades. The first practical application was done on the Research and Development Institute of Transylvania University of Brasov [28].

7.3. Future perspectives

The Romanian standards for energy performance have been changed along the time in order to try to align to the European standards. The latest versions of the Romanian standards were released in the year 2002 (C107/6-02 and C107/7-02), 2005 (C107-2005), 2006 (Mc001-2006) and, respectively 2011 (the annex C107-2011). Even though the annex C107-2011 brings changes to U-values for the elements of the building envelope and to certain parameters related to the global insulation coefficient and to the annual heat demand, the Romanian requirements for building energy performance are far from the passive house standard.

Because Romania's climate is inland, with hot summers and cold winters, there is no balance between the heating and cooling estimation regarding the passive house requirements and its impact on the seasonal interior comfort. Also, in Romania there is no climatic variation in implementing passive house, nZEB and, respectively ZEB requirements. The application of passive house, respectively nZEB is done in only one climatic area (i.e. Bucharest). Since Romania has 4 climate areas defined by the national standards, the implementation of the passive house and nZEB requirements should be studied for all the climate areas in order to come with adaptive technical solutions.

8. Conclusion

The study presented in this paper cannot be comprehensive, since the number of reviewed publications is modest. Therefore the paper presents an overview of the state-of-the-art of building energy performance in Romania. The study parameters, the major findings and the gaps from the previous studies are summarized in Table 2. The final remarks and the recommendations for future works in this field are presented as follows:

(1) In order to implement the passive house, nZEB and ZEB standards, Romania has to update the national building codes to align them with the passive house requirements.
(2) The authorities should give more financial support in the field of green technology.
(3) Detailed studies and research should be conducted in the area of thermal behavior of buildings, of building services energy performance and renewable technology.
(4) The Romanian codes for building energy performance should have prescriptive regulations. The performance based regulations may be optional, since building performance simulation is new in Romania and not all specialists (architects, civil engineer, service engineers) have the possibility to purchase the software.
(5) The Romanian Government should offer financial support not only for the rehabilitation of the residential buildings, but also for the training of specialists in building energy performance and renewable technology.
(6) The current studies made on passive houses and nZEB should not limit to one climate area, they should be applied to all the climate areas from Romania in order to create adaptable technical solutions.

Acknowledgements

None.

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