Development Of The Benchmark Model For A Romanian Multi-Storey Residential Building

Master Thesis written during Erasmus + Program

Supervisor in Belgium:
Prof. Dr. Shady Attia

Supervisor in Romania:
Prof. Dr. Eng. Mircea Petrina

Graduate:
Adina – Ana Mureșan

LIEGE
2015
# TABLE OF CONTENTS

**ABBREVIATIONS**

**CHAPTER I: INTRODUCTION**

1. General ideas about sustainable buildings................................. 7
2. The State of the Art in Romanian sustainable buildings design.......... 8
3. The objectives of study................................................................. 10
4. Methodology ................................................................................. 10
5. Expected results........................................................................... 11

**CHAPTER II: LITERATURE REVIEW ANALYSIS**

1. Introduction ..................................................................................... 15
2. The Literature Review Matrix.......................................................... 16
   2.1. Policy ...................................................................................... 16
   2.2. Governments .......................................................................... 18
   2.3. Technology .............................................................................. 18
   2.4. Feasibility ............................................................................... 24
3. Literature review analysis: findings and gaps.................................. 27
   3.1. Findings .................................................................................. 27
   3.2. Gaps ....................................................................................... 28
4. Open research questions................................................................. 29
5. The list of publications included in the Literature Review Matrix ........ 31

**CHAPTER III: ROMANIAN BUILDING STOCK AND nZEBs**

1. Climate analysis of Romania............................................................ 35
2. Romania’s vernacular and bioclimatic architecture........................... 38
   2.1. The vernacular architecture of rural areas ................................ 38
   2.2. The vernacular architecture of urban areas............................... 44
3. Romania’s energy and building sector............................................. 50
   3.1. Romania’s primary and renewable energy potential and consumption 50
   3.2. CO2 emissions in Romania........................................................ 53
   3.3. Energy prices in Romania......................................................... 54
4. The Romanian building stock for residential buildings.................... 57
   4.1. Energy Use Intensity in Romania............................................. 57
4.2. The Romanian building stock and energy performance .............................................................. 59

5. Current state of the energy efficiency of the residential buildings .............................................. 62
   5.1. Romania’s current practice in building energy performance ..................................................... 62
   5.2. Summary of the Cost – Optimal Methodology applied for residential buildings .................. 64
   5.3. Measures and recommendations regarding implementation of the nZEB concept .......... 66

6. Conclusions ................................................................................................................................ 69

CHAPTER IV: BUILDING PERFORMANCE SIMULATION .............................................................. 70

1. Introduction ................................................................................................................................ 70

2. Building performance simulation input data .............................................................................. 71
   2.1. Data on the building’s location .............................................................................................. 72
   2.2. Data on the building’s geometry .......................................................................................... 72
   2.3. Data on the building’s opaque construction elements ......................................................... 72
   2.4. Data on the glazing surfaces ............................................................................................... 73
   2.5. Data on the building’s activity ............................................................................................ 73
   2.6. Data on the HVAC system ................................................................................................. 74
   2.7. Data on the lighting system .................................................................................................. 75

3. The stages of building performance simulation ......................................................................... 75
   3.1. The 3D building model .......................................................................................................... 75
   3.2. Internal heat gains ................................................................................................................. 75
   3.3. HVAC plant .......................................................................................................................... 76
   3.4. Non-HVAC energy consumption .......................................................................................... 76
   3.5. Accuracy and validation of the building performance simulation ....................................... 76

4. The modeling protocol and the model resolution ....................................................................... 78

5. Simulation engine and weather data files ................................................................................... 82
   5.1. Summary about EnergyPlus ................................................................................................ 82
   5.2. The weather data files ......................................................................................................... 83

6. The choice of DesignBuilder ...................................................................................................... 85
   6.1. General description of DesignBuilder software .................................................................. 85
   6.2. Thermal zoning in DesignBuilder ....................................................................................... 87

CHAPTER V: THE BENCHMARK MODEL FOR THE ROMANIAN MULTI STOREY RESIDENTIAL BUILDING ................................................................................................. 90

1. Introduction ................................................................................................................................ 90

2. The description of the multi storey residential building .............................................................. 90

3. Energy characteristics of the reference building ...................................................................... 92
4. The description of the Romanian benchmark model

4.1. The description of the building elements and their U-values

4.2. The characteristics of the glazed surfaces

4.3. The general characteristics of the HVAC system

4.4. The characteristics of the lighting system

4.5. The description of activity in the building

5. The simulation and calibration of the Romanian benchmark model

5.1. The calibration of the input parameters

5.2. The final results after the calibration of the Romanian benchmark model

5.3. Model validation by error analysis

CHAPTER VI: THE ROMANIAN STANDARD MODEL

1. Introduction

2. The description of the Romanian Standard model

2.1. The description of the building elements and their U-values

2.2. The characteristics of the glazed surfaces

2.3. The general characteristics of the HVAC system

2.4. The characteristics of the lighting system

2.5. The description of activity in the building

3. Results of the simulation of the Romanian Standard model

4. Conclusion

CHAPTER VII: DESIGN RECOMMENDATIONS FOR ACHIEVING PASSIVE BUILDING, RESPECTIVELY nZEB STANDARD

1. The analysis of the final results of the building performance simulation

2. Comparing the research outcomes with the literature review

3. The implementation of Cost – Optimal Methodology in Romania

3.1. General ideas about the Cost – Optimal Methodology

3.2. The steps and rules of the methodology

4. Design recommendations for the Romanian benchmark model

CHAPTER VIII: CONCLUSION

1. Lessons learnt

2. Future research work

APPENDIX I: RESOURCES SCREENING LIST

APPENDIX II: LITERATURE SURVEY LIST

APPENDIX III: LITERATURE REVIEW MATRIX
ABBREVIATIONS

ARDL: Autoregressive-Distributed Lag
BPIE: Building Performance Institute Europe
CUSUM: Cumulative Sum
CUSUMSQ: Cumulative Sum of Squares
GDP: Gross Domestic Product
GFP: Gas Filled Panel
GP: Glass Powder
LRM: Literature Review Matrix
MVHR: Mechanical Ventilation Heat Recovery
nZEB: nearly Zero Energy Buildings
PCM: Phase Change Material
PH: Passive House
PHPP: Passive House Package Protocol
PHTT: Passive House Thermal Transient
VIP: Vacuum Insulation Panel
WSE: Wasted/Saved Energy
ZEB: Zero Energy Buildings
CHAPTER I: INTRODUCTION

1. General ideas about sustainable buildings

The main problem of this decade is trying to create a healthy environment for the current population and also for the future generation. This long term purpose is achieved only by preserving or limiting the energy based on fossil fuel and trying to use renewable sources of energy as much as possible. By limiting the energy which comes from burning fossil fuel like natural gas or oil, the greenhouse gas emissions are also limited and thus, global warming might not take place at fast pace. This long term goal may come true if measures are taken for saving the energy.

Besides industry and transport, buildings are also source for greenhouse gas emissions because they also consume energy. Buildings, depending on their function and geographical location, use lots of energy to heat or cool the space, for domestic hot water, for mechanical ventilation, for artificial lighting and for other activities. In order to save energy and limit the greenhouse gas emissions, the current problem of architects and civil engineers is to design new buildings or to upgrade the existing ones into buildings which have less to zero energy consumption. And this is how the concept of Zero Energy Building was born. This concept may sound ideal at the moment. To achieve the Zero Energy Building standard, the building’s envelope must be provided with a very efficient thermal insulation layer, the infiltrations through cracks must be zero and the energy provided for the activity in the building must come from renewable sources.

The study of high performance buildings from the energy consumption point of view is something new in Romania. Like all the other countries from the European Union, Romania has to reach the objectives imposed by the Directive 2009/28/EC, which states that by year 2020, the share of renewables in the total gross of Romania’s energy consumption should be 20%, the emissions of CO2 and greenhouse gases must be reduced with 20%, the final energy consumption must decrease by 20% and all the new buildings must be passive. Also, the Energy Performance of Buildings Directive (EPBD) requires all European Member States to (Nolte, Rapf, Staniaszek, & Faber, 2013):

1. Introduce minimum energy performance requirements for all buildings, building elements and technical building systems.
2. Set these requirements based on a cost – optimal methodology taking into account the lifetime costs of the building.
The implementation of these concepts in Romania have started with small steps and consists into thermal rehabilitation of the existing buildings, with applying the latest thermal performance characteristics for building elements in new buildings and with the classification of buildings into energy classes and establishing the certificate for energy performance.

In Romania there are a lot of buildings which need to be renovated in order to stop the heat losses through the building’s envelope and to decrease the energy consumption. At the moment it is difficult to renovate all the buildings to make them performant because of the costs involved. Most of these buildings from Romania’s national building stock have residential function and the costs are supported by the indwellers. Also, establishing the energy class of the buildings is at the beginning which means that there are a lot of houses and apartment buildings without energy certificate. If the energy certificate becomes mandatory for each building, it might have a large economical impact in the Romanian real estate field, because the energy class of the building may dictate its price.

2. The State of the Art in Romanian sustainable buildings design

The State of the Art from the Romanian sustainable buildings design area is analyzed through the Literature Review. Sustainable buildings design is a recent concept in Romania, which is why most of the reviewed publications were issued 1-5 years ago. The purpose of the Literature Review was to study the available information regarding the implementation of the passive house, nZEB and ZEB requirements in Romania. By studying the available information, the foundation of the research for the Master Thesis was created. After creating the list of resources, the information was distilled as following:

- The publications related to energy performance in buildings from Romania.
- Romanian design codes for energy performance
- The energy consumption in Romania
- The price of energy in Romania
- The climate of Romania.

In the Literature Review, along with the publications related to sustainable design and energy performance in buildings in Romania, were also included the Romanian standards for energy performance. In the field of building energy performance Romania uses the following standards: C107 – 2005, Mc001 – 2006, C107/6 – 2002: “The general standard for the calculation of the mass transfer (humidity) through the building elements” (C107/6-02: Normativ general privind calculul transferului de masă (umiditate) prin elementele de construcție, 2002) and C107/7 – 2002:
“Standard for designing the building envelope for thermal stability” (C107/7-02: Normativ pentru proiectarea la stabilitate termica a elementelor de inchidere ale clădirilor, 2002).

C107 – 2005 is divided in the following parts:


Mc001 – 2006 (The Methodology) is divided in the following 3 parts:


The Romanian standard SR1907: “Heating plant. Design heat requirements computation for buildings. Computation specifications” (SR1907-1: Instalații de încălzire. Necesarul de căldură de calcul. Prescripții de calcul, 1997) is used both for designing the heating system of buildings and for establishing the set point temperature of the rooms with respect to their function. The location and the effects of the thermal bridges are analyzed with the help of the thermal bridge catalogue called ”Catalogue with specific thermal bridges in buildings – Annex to Decree no. 1590/24.08.2012” (Ordin pentru modificarea reglementării tehnice ”Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor” indicativ C107 – 2005, aprobată prin Ordinul ministrului transporturilor, construcțiilor și turismului nr. 2.055/2005, 2010).

The Literature Review Analysis is described in detail in Chapter II.

3. The objectives of study

The following Master Thesis presents the development of the benchmark model for a multi-storey residential building in Romania. The benchmark model is created by assigning the architecture and energy characteristics of an existing building. The first objective of the study is to choose an existing multi storey residential building from the Romanian building stock and to determine its energy characteristics (i.e. electricity and natural gas consumption) by survey. The second objective is to create a benchmark model by using the data gathered from the existing building. The building elements of the benchmark model will use the current practice in Romanian construction works. Also, the benchmark model will have the energy characteristics similar to the existing building. The benchmark model will be developed with the aid of a building performance simulation tool.

The aim of the energy consumption estimation of the Romanian benchmark model is to be able to take future measures in the structure of the building envelope, in the HVAC system and in the share the renewables from the final energy consumption. These measures are taken to create a passive multi storey residential building or an nZEB one.

4. Methodology

The Master Thesis describes the development of a benchmark model for a multi storey residential building from Romania. The methodology followed is inspired by the study made in Reference (Shady Attia, Evrard, & Gratia, 2012) where benchmark model was created for multi storey residential buildings from Egypt. The development of the benchmark model starts with
choosing an existent building from the Romanian building stock and with establishing the energy characteristics of the real building. The purpose of developing the benchmark model of an existing building is to estimate the energy consumption of the common building (i.e. without passive building requirements) and after that to undergo a Parametric Analysis in which different variants of measures are applied to the building. The energy consumption, energy savings and the costs of the proposed variants are analyzed and then they are compared with the benchmark model. In the end the solution which fulfills the passive building requirements and which is optimal from the cost point of view is chosen. The method of analysis is known as Cost – Optimal Methodology and was introduced by Building Performance Institute Europe.

In the Master Thesis, the Romanian Benchmark model was determined in the following steps:

- An existing multi-storey residential building from Romania was chosen based on the age and current energy performance level. The chosen multi-storey residential building is located in Blaj, Alba County, Romania, was built in the 1980s like most of the multi-storey residential buildings in Romania, and is poorly insulated.
- A survey was carried out by gathering the electricity and natural gas bills from year 2014 for 54 apartments from the chosen building. The bills were provided by the companies S.C. Electrica S.A. and E.ON Gaz Romania.
- The building sectors which include the 54 surveyed apartments were introduced in the simulation tool DesignBuilder and their energy consumption was estimated.
- After the calibration of the results, the Romanian Benchmark model was developed.

After establishing the Romanian Benchmark model, the Romanian standard requirements were introduced and then the simulation was run. The final results of the building model which fulfills the Romanian standard of energy performance were compared to the results obtained in the case of Romanian Benchmark. For the passive house and nZEB requirements were proposed a series of variants as future work.

5. Expected results

The building model was simulated in DesignBuilder tool, a software that uses as simulation engine EnergyPlus. The weather data file used in the simulation was the one from the Romanian city Cluj-Napoca, which contains hourly recorded weather data. The weather data file was downloaded from the official website of U.S. Department of Energy. When introducing the geometry of the building sectors, each apartment was modeled as one block and in each block were
defined the thermal zones equivalent to the rooms of the apartment. To each of the thermal zone was assigned an activity according to the function of the room (i.e. the thermal zone specific to living rooms, bathrooms, kitchens etc.)

In order to have results similar to the monitored energy consumption, the Romanian Benchmark model had to be calibrated. The calibration of the model consisted into adjusting certain input parameters and running the simulation several times until the final results of the model are close to the monitored values of energy consumption of the real building. In the benchmark model developed in the Master Thesis, the following input parameters had to be adjusted to obtain a calibrated model:

- The efficiency of the heating system.
- The lighting energy
- The operation schedule of the heating system
- The operation schedule of the lighting system

After calibration, the benchmark model had to be validated by doing error analysis. The validation measures used in for the Romanian Benchmark model were the Annual Percentage Error and the Root Mean Square Deviation. The Annual Percentage Error analyzes the difference in percentage between the simulated annual energy consumption and the measured annual energy consumption. The Root Mean Square Deviation measures the differences between the values predicted by a model and the values actually observed and it applies to monthly or hourly data. The results of the validation measures applied to the Romanian Benchmark model are presented in detail in Chapter V.

With the benchmark model calibrated and validated, the Romanian standard requirements were applied to the building model and the simulation in DesignBuilder was run again. The final results of the simulations were compared by using bar charts for the annual energy consumption and line charts for the monthly energy consumption. The final results are explained in detail in Chapters V and VI.

6. Master Thesis outline

Chapter II: Literature review analysis

Chapter II presents the review of previous publications from the building energy performance field which are related to Romania. The aim of literature review analysis is to find out the state-of-the-art of building energy performance in the Romanian context. The literature review analysis was done in three steps: (1) establish the resources screening list where publications can be
found, (2) create the literature survey list which contains publications from the building energy performance field written about Romania and (3) create the literature review matrix where the most relevant publications are reviewed.

Chapter III: Romanian building stock and implementation of nZEB

Chapter III presents aspects about the Romanian building stock and the level of implementation of nZEB standard. The chapter describes the climate of Romania, the energy sector of Romania and the country’s renewable potential, the Romanian building stock and the projects and programs ran to reach the 2020 targets. The projects which are summarized in this chapter are the application of the Cost – Optimal Methodology on Romanian residential buildings made by the BPIE and the ENTRANZE project.

Chapter IV: Building performance simulation

Chapter IV describes how the building performance simulation tools work, the advantages of building performance simulation, the stages of the building performance simulation and what are weather data files and how they are used in the simulation. The chapter also presents the modeling protocol according to Reference (Shady Attia, 2015) which is used in the case study of the Master Thesis. The building performance simulation tool DesignBuilder is presented and its choice is motivated.

Chapter V: The benchmark model for the Romanian multi storey residential building

Chapter V presents the development of the benchmark model for the Romanian multi storey residential building following the methodology from References (Shady Attia et al., 2012) and (Shady Attia, 2012). The chapter describes the geometrical characteristics of the chosen building, its energy characteristics, the model input data for the benchmark model and the process of simulation, calibration and model validation. The results of the simulation are also discussed here.

Chapter VI: The Romanian standard model

Chapter VI describes the application of the Romanian standard requirements for building energy performance. The geometric characteristics, the model input data for the standard model and the process of simulation are presented. The final results are compared to the benchmark model and discussed.
Chapter VII: Design recommendations for achieving passive building, respectively nZEB standard

Chapter VII discusses the final results of the two case studies presented in the Master Thesis: the Romanian benchmark model and the Romanian standard model. The research outcomes are compared to the literature review from Chapter II and design recommendations are proposed.

Chapter VIII: Conclusion

In the final chapter of the Master Thesis are presented the lessons learned from the research work. The future work in research is proposed.
CHAPTER II: LITERATURE REVIEW ANALYSIS

1. Introduction

In order to review the state-of-the-art of the energy performance of the buildings in Romania, a number of publications were analyzed. The purpose of the literature analysis was to study the available information regarding the implementation of the passive house, nZEB and ZEB in Romania. By studying the available information, I created the foundation of the research for the Master Thesis.

At first, a Resources Screening List was elaborated which contains the resources from where the following information was distilled:

1. The publications related to energy performance in buildings from Romania.
2. Romanian design codes for energy performance
3. The energy consumption in Romania
4. The price of energy in Romania
5. The climate of Romania.

The Resources Screening List can be found in the Appendix I where are shown all the resources from where the publications were taken. After establishing the list of resources, publications were searched using the following keywords: “Romania”, “nZEB”, “implementing”, “passive buildings”, “passive house”, “thermal comfort”, “building stock”, “Romanian house”. The found publications were gathered all in the Literature Survey List where we can find information about the title, authors and publisher of the paper, the number of citations and observations which contain the classification of the publication. The Literature Survey List contains 80 publications related to sustainable buildings design in Romania. These publications were classified as following:

- **No new information.** This means that the publication doesn’t bring anything new.
- **Not related to my subject.** This means that the publication is not related to the subject of the Master Thesis, even though the title might appear like it is. The reason might be because the title may contain one of the keywords used to search for publications.
- **Not clear.** The publication which was classified as not being clear and had gaps that made the understanding difficult or it was too detailed and the information was poorly systemized to be easily understood.
- **Should be cited in the LRM.** This classification means that the publication will be included in the Literature Review Matrix (LRM) because the information contained is new or original,
but the number of citations is 0. Therefore the publication included in the Literature Review Matrix that doesn’t have any citations should be cited in the future.

- **In the LRM.** This means that the publication will be included in the Literature Review Matrix because it has new or original content.

The Literature Survey List can be found in the Appendix II. After establishing the Literature Survey List and after sorting the publications by the originality of the content, the Literature Review Matrix was elaborated. The Literature Review Matrix, which can be found in the Appendix III, contains 35 publications which were selected according to their study parameters, focus, gaps and findings which represent the main ideas of the publications.

2. The Literature Review Matrix

Based on occurrence of major topics in the LRM, the publications are divided into the following four categories: policy, governments, technology and feasibility. In this paragraph, the publications classified in each of the four categories are summarized. The concluding remarks from each category are grouped in Section 3.

2.1. Policy

In this category are the findings from the Romanian standards for energy efficiency C107 – 2005, Mc001 – 2006, C107/6-02 and C107/7-02, the European standards for energy efficiency and documents about the implementation of the nZEB policy in Romania. (See references [1], [2], [3], [4], [5], [10], [34] and [35] from the Literature Review Matrix, Appendix III).

From the standard C107 – 2005 [1], it was found that there are two different formulae for calculating the global thermal insulation coefficient for residential, respectively non-residential buildings and that it influences the result of the annual heating demand. Also, to analyze the building elements which are in direct contact with the terrain, there are new parameters such as the temperature of the ground at the invariable layer level, the thermal conductivity of the soil and the influence of the ground water table. It was found that the steps of the analysis of the energy performance of the buildings in heating from C107 – 2005 are quite simple which might put in doubt the accuracy of the final results. Mc001/1 – 2006 [2] has similar content with C107 – 2005 with upgraded information. The second part of Mc001 – 2006 [2] presents the evaluation of the energy performance of the building services using advanced methods of calculation such as iterative
methods or step by step integration and the third part contains templates for energy audit and energy performance certificate.

C107/6-02 [34] states that in order to satisfy the requirements for hygiene and interior comfort and also for the performance of the building envelope, the building must fulfill the following technical requirements: the relative humidity of the building materials due to water vapor condensation inside the envelope’s structure should not exceed a maximum value and avoid accumulation of water due to condensation in the building envelope. C107/7-02 [35] states that the thermal stability during summer and winter is evaluated for the room positioned in the most unfavorable direction and it will be considered by the designer as a reference room, by analyzing different parameters such as the thermal stability of the boundary element. According to the limitations imposed by the thermal stability, the rooms or the building sectors are divided into 3 groups (“a”, “b” and “c”) taking into account the endowment or necessity of the ventilation and air conditioning system.

Reference [4] from the Literature Review Matrix established the rules for selecting the reference buildings and the packages of measures in order to apply the Cost – Optimal Methodology and it presents three case studies made for building stocks from Germany, Austria and Poland, in which this methodology was applied. The differences between the three case studies are based on the reference building, weather conditions, design codes and energy prices typical for each analyzed country. The Cost – Optimal Methodology was applied in case of Romania by using 3 different reference buildings and at least 10 variants [3]. Reference [5] emphasizes the key changes that have to be done to the Energy Performance of Buildings Directive and it explains the Cost – Optimal Methodology in a simple and easily understanding manner.

In September 2012 – April 2014 was developed the project called ENTRANZE where Romania, along with other 8 countries from the European Union, was analyzed for the 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 software named Invert/EE-Lab [10].

After analyzing the publications related to policy we find out that the Romanian standards regarding the energy efficiency have a clear structure and are easy to use by the specialist, but they haven’t been updated since 2011. The Romanian standards need to be aligned with the European standards so that Romania could reach the 2020 target. Besides the Romanian regulations for
energy performance, there are also reports about implementing the nZEB concept in Romania and both of the reports conclude that Romania has potential for designing sustainable buildings and for using energy from renewable sources.

2.2. Governments

Reference [8] and reference [11] from the Literature Review Matrix (See Appendix 3) reflect the implications of the Romanian Government into the implementation of the energy saving and climate change policies. The energy efficiency and CO2 emission reduction target imposed by EPBD must be achieved by all Member States, including Romania, by year 2020. Reference [8] from the LRM gives information about the variation of the Romanian standards in the field of energetic efficiency between the years 1973 – 2009 and the structure of the Romanian building stock according to the age of the buildings.

Regarding the reduction of greenhouse gas emission in Romania, a large number of intelligent measures could be used and the fact that the majority of towns are not properly developed in connection with greenhouse gas emissions reduction is, at the same time, a challenge and an opportunity. The barriers in combating the climate change in Romania are the lack of information regarding the package requirements, the lack of coherent development plans and the lack of financial means. The lack of financial means is not an excuse since there are a lot of EU instruments that could be used in Romania [11].

2.3. Technology

The findings in the technology of passive houses, nZEB and ZEB are reflected in the references [6], [7], [9], [13], [16], [17], [18], [22], [23], [24], [25], [27], [28], [29], [30], [31], [32], [33] from the Literature Review Matrix (See Appendix III). References [6], [7], [9], [13], [29] and [30] concentrate on the passive houses, references [18], [22], [27], [32] and [33] present the traditional, innovative and the future thermal insulation materials, simulations of the building’s thermal behavior are described in the references [23], [24], [25], [28] and [31] and other technologies related to building sustainability are found in references [16] and [17].

2.3.1. Passive houses

In Romania there are 5 passive houses, one of them being the AMVIC office building from Bragadiru and a house which is a part of a duplex from Timișoara [9]. The passive office building
AMVIC was simulated using the 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 minutes and the PHPP (Passive House Package Protocol) model with the monthly method, resulting the fact that the office building fulfills the passive building standard [6]. The largest problem of the passive office building is overheating and that’s why PHPP recommends additional cooling measures if the overheating exceeds 10%. The internal heat sources and solar radiation have significant influence in the summer months on the cooling load [7]. For the passive house from Timișoara was installed a monitoring system that registers and collects data which is uploaded to a web server where diagrams are created for online visualisation [9]. In Bucharest, 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 [13].

Another passive house that has gone through simulation was Pirmasens Passive House from Germany in which was used a one dimensional time dependent heat transfer equation solved numerically by using Netlib. The model used on the house from Germany can be applied to any passive house with arbitrary number of rooms and arbitrary space orientation [30].

The four passive houses built in Romania are the following: AMVIC office building from Bragadiru, near Bucharest, the passive house from Timișoara which is a part of a duplex and the two passive houses belonging to the campus of University Politechnica of Bucharest. Reference [9] 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 Timișoara. The results of the monitoring system installed on the passive house from Timișoara show that the house doesn’t fulfill the passive house standard because the annual heat demand exceeds $15 \text{ kWh/m}^2 \cdot \text{yr}$ [9]. So technically, the house from Timișoara can not be classified as passive house. 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.

2.3.2. 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 building envelope such as advanced wall systems: passive solar walls, lightweight concrete walls,
ventilated or double skin walls and 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 [29].

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 in order 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 [32]. That’s why 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 thermal insulating material 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 [18]. Another thermal insulating material which may be 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 have the ability to store energy which is characterized by its latent heat of fusion. The PCM can be made of organic compounds, inorganic compounds or eutectic mixtures and on buildings can be applied by direct impregnation into building materials or by encapsulation [27].

Another example of thermal insulating materials which might be 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, but VIP’s drawback is the fact that it's thermal conductivity increases with age because of the 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 whose thermal conductivity is low due to the vacuum from the pores. 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 [32]. 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 [33].

The application of an adequate thermal insulation to improve building energy performance in summer has only been analyzed in few studies. The study presented in the reference [22] 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, in the second phase the effect of the opaque building envelope was analyzed and in the third phase was studied the effect of the thermal insulation level of the opaque envelope. Two case studies were analyzed: a residential building and an office building, both of them being located in Rome, Italy. The residential building, respectively the office building went through 5 simulations where the model is subjected to the same conditions, but has a different driving force each time. The detailed numerical simulation was done by EnergyPlus [22].

The efficiency of the PCM in ensuring thermal comfort in the building was studied on a duplex house from Portland, Oregon, in the USA. 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 show 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 [27].

In order to design a house with low energy consumption, the designers are trying to develop thermal insulation materials which have very lower thermal conductivity than the traditional materials such that they do not require large thicknesses. Also designers try to develop thermal insulation materials which ensure air tightness and which are not sensible to humidity or perforations. Because the problem of the passive houses is overheating due to the high air tightness, designers try to study the effect of thermal insulation on the building in summer conditions in order to find solutions for thermal comfort and low cooling demand. Even though the case studies from reference [22], respectively reference [27] were done in Italy, respectively in the USA, the methods of thermal analysis during summer applied on the three case studies (the residential and office building from Rome, the duplex from Portland, Oregon) can also be applied in Romania. In the
reference [7] from Section 2.3.1 is mentioned the fact that the largest problem of the passive houses in Romania is overheating and this is the reason why the analysis methods applied in the case studies from Italy, respectively from the USA could be useful in Romania.

2.3.3. 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. One of the simulations was done on the building’s interior 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 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 4.4x6x2.7 meters and with the indoor air temperature 24°C [23].

Another simulation was 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 [24].

The building went through exergy analysis which 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. The building model used in the exergy analysis was a multi-family residential building located near Florence, in Italy [31].

Reference [25] 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 [28].

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]. 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. Also 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.

2.3.4. Other technologies for improving the energy efficiency of buildings

There are other ways of improving the building’s energy performance found in the reviewed literature. For example, on the building can be applied architecturally integrated multifunctional solar thermal facades. 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 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 [16]. 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 [16]. The same multifunctional solar thermal facades can be applied experimentally on a residential building from Romania.
The energy performance of the building can also be improved by taking into account the bioclimatic elements, as in the traditional Romanian houses which are characterized by 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 [17].

2.4. Feasibility

In this category are classified the references [12], [13], [14], [15], [19], [20], [21] and [26] from the Literature Review Matrix (See Appendix III) which reflect cost analysis on the energy performance and energy consumption of the buildings and on the potential of renewable energy in Romania and reduction of CO2 and greenhouse gas emissions.

2.4.1. The analysis of cost and energy efficiency in buildings

Different methods can be used to analyze the cost of the building from the energy point of view. Reference [12] presents a methodology for the real estate appraisal of green value which uses 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 must be applied on at least 3 comparable buildings, one of them being the reference building and leads to good results if the subject property and comparable buildings are built on the same standards. The passive house belonging to University Politechnica of Bucharest was analyzed using the general model of the life cycle cost which 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 [21].

Some buildings were simulated with softwares in order to determine their energy efficiency. For example, the passive house Politechnica was simulated in TRNSYS using two models: the building provided with simple flux ventilation system, where the fresh air had the outdoor temperature and the thickness of the thermal insulation of the walls was reduced to half from the initial value and the building provided with MVHR system. Two functions of the building were simulated: the house as laboratory and the house used for a family composed of 4 members [13].
An office building from Transylvania University of Brasov was simulated in TRNSYS to determine the most effective methods to improve the energy performance of a building 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 [15].

A building having PCM as thermal insulation went through a simulation in order to determine its energy efficiency and the energy costs. The analysis was run on a test room with the dimensions 6.5x4.5x2.5 meters, having the walls exposed to heat transfer and 1 window with the opening area $2 m^2$. 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 [20].

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 [19].

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. Therefore a house with the energy class D will have a smaller price than a house with the energy class B. In the study presented in reference [20] is not specified which exactly are the four occupancy patterns used in the simulation. Therefore the information stated in reference [20] is incomplete since we don’t know exactly what kind of occupancy pattern leads to the result mentioned above. 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 [19]. 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.
2.4.2. The renewable energy potential and CO2 emissions

In the references which fall in the feasibility category there were also information about renewable energy in Romania and CO2 and greenhouse gas emissions reduction. Reference [14] from the Literature Review Matrix states that Romania is the 14th most attractive country regarding renewable energy markets in the top 40 made by Ernst and Young in 2012, because the country has very good potential mix of solar energy, hydropower, biomass and geothermal energy. Using the Environmental Kuznets Curve, which 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 between 1980-2010. 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. [26].

The results of the Environmental Kuznets Curve from Romania are shown in table form in Reference [26]. In Figure 2.1 is represented the plot of the cumulative sum of recursive residuals (CUSUM). The plot is not consistent after the 4th quarter of year 2005 because there was a structural break in Romania’s economy. In that period, the Romanian Government introduced the flat tax rate of 16% for the revenues of companies and individuals [26]. In Figure 2.2 is represented the cumulative sum of squares of recursive residuals (CUSUMSQ). The curves of the cumulative sums are taken from Reference [26].

Figure 2.1 – The plot of the cumulative sum of recursive residuals in Romania, between 1980 – 2010. The plot is not consistent after the 4th quarter of 2005. This indicates structural break in the Romanian economy [26].
Figure 2.2 – The plot of the cumulative sum of squares of recursive residuals in Romania, between 1980 – 2010. The plot shows that the ARDL parameters are stable [26].

3. Literature review analysis: findings and gaps

The publications suitable for the Literature Review Matrix (See Appendix III) were selected from the Literature Survey List (See Appendix II). The publications included in the LRM were reviewed on their study parameters, focuses, gaps and findings. In the following paragraphs are presented the concluding summaries of the findings, respectively of the gaps from the reviewed publications.

3.1. Findings

The most important findings from the publications included in the Literature Review Matrix are the following:

- The traditional Romanian houses are built using bioclimatic elements which take into account the amount of solar radiation with respect the cardinal points, the direction of the dominant winds and the microclimate of the area (i.e. the annual average rainfall, the annual average temperature in summer, respectively in winter, the local wind produced by the orographic conditions of the landscape, the climatic influences).

- Currently designers develop innovative thermal insulation materials, such as the Phase Change Materials (PCM), in order to reach the passive house, nZEB, respectively ZEB standard without being necessary to use large thicknesses for the thermal insulating layer of the building envelope.
• 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.

• The buildings from the Romanian housing stock have relatively young age, 37% of the buildings have between 20 – 40 years.

• Romania has the potential to integrate multifunctional solar panels into facades, the first practical application being done on the Research and Development Institute of Transylvania University of Brasov.

• In Romania was determined the Environmental Kuznets Curve, which shows the relationship between per capita GDP and measures of environmental degradation as inverted U-shape, for the time reference date 1980 – 2010. The same time reference shows how the CO2 and greenhouse gas emissions decreased in Romania.

• In Romania there were 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.

• 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.

3.2. Gaps

The major gaps found in the publications reviewed in the Literature Review Matrix are as follows:

• The bioclimatic strategies on urban planning level and on the buildings level are not applied in Romanian modern buildings.

• There is uncertainty of using innovative thermal insulating materials, such as PCM, because of their availability on the market and of their high costs.

• There is no balance between the heating and cooling estimation regarding the passive house requirements and its impact on the seasonal interior comfort.

• In Romania there is no climatic variation in implementing nZEB and the application is done in only one climatic area out of four.
Most of the case studies from Romania were done for office buildings, other case studies were analyzed outside Romania.

4. Open research questions

Based on the findings and gaps from the publications reviewed in the Literature Review Matrix, the current state-of-the-art on sustainable buildings design and energy performance in Romania was established. Therefore, open questions can be formulated in order to fill the major gaps and improve the current state-of-the art of the sustainable buildings design in the Romanian context..

One of the open question focuses on creating a new house model that uses the bioclimatic elements of the traditional Romanian house mentioned in Section 2.3.4. The new house will be provided with a porch which is a part of the main structure of the house. The porch’s depth will be designed such that the sun rays penetrate the rooms under different incident angles at winter solstice, summer solstice, respectively spring and fall equinox. In front of the house could be planted deciduous trees to be used as natural shading elements. Therefore, the overheating of the house could be avoided naturally. The house model designed by using bioclimatic elements will be combined with the passive house, nZEB, respectively ZEB standards.

Another open question refers to the analysis of the energy efficiency of the house model by parametric study. The house will be tested for different types of thermal insulating materials (i.e. traditional thermal insulating materials, PCM) with different thicknesses. The house model will also be provided with different types of glazed surfaces used for fenestration. The parametric study will be done for each climate area from Romania. Therefore, the impact of the passive house, nZEB, respectively, ZEB requirements on cooling, heating, interior comfort and energy efficiency could be investigated accurately. The accurate investigation of the model for all the Romanian climate areas would lead to more varied results, which will bring particular solutions for residential buildings at energy efficiency level for each climate area.

In Table 2.1 is the short summary of the concluding findings and gaps from the reviewed publications, along with open questions.
<table>
<thead>
<tr>
<th>Findings</th>
<th>Gaps</th>
<th>Open research questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Romanian houses use bioclimatic elements in their design.</td>
<td>The new buildings from Romania don’t use bioclimatic elements.</td>
<td>Create accessible benchmark models for Romanian residential buildings in order to be able to implement the PH, nZEB or ZEB standard.</td>
</tr>
<tr>
<td>Innovative thermal insulation materials are tested (i.e. PCM).</td>
<td>The lack of bioclimatic elements is also observed at urban level.</td>
<td>Apply the Cost – Optimal Methodology by EPBD on the benchmark models in order to determine the optimal technical solution.</td>
</tr>
<tr>
<td>Romania has potential of mixed renewable energy sources (i.e. geothermal, biomass, solar, hydro).</td>
<td>The practical application innovative thermal insulation materials (i.e. PCM) on new or existing building is uncertain due to their availability and costs.</td>
<td>Create a new house that integrates in its design the bioclimatic elements of the Romanian traditional house combined with the passive house, nZEB and ZEB requirements.</td>
</tr>
<tr>
<td>Most of the buildings from the Romanian housing stock have relatively young age.</td>
<td>In Romania, the application of passive house and nZEB requirements is done for one climate area.</td>
<td>By using bioclimatic elements, the balance between heating demand and cooling demand may be achieved because overheating is avoided naturally.</td>
</tr>
<tr>
<td>The Environmental Kuznets Curve from Romania shows the evolution of CO2 and greenhouse gas emissions reduction, along with the environmental measures.</td>
<td>There is no climatic variation in implementing these requirements.</td>
<td>In the parametric study of the model, test the energy efficiency of the innovative thermal insulation materials (i.e. PCM) for each Romanian climate area.</td>
</tr>
</tbody>
</table>
In the Romanian literature are 3 case studies of passive house simulation. The impact of the passive house, nZEB, respectively ZEB requirements on heating, cooling, thermal comfort, energy consumption and cost should be investigated for all the climate areas from Romania.

The PHTT model can be applied for new residential buildings because in Romania it was already applied on an office building. Therefore the literature on PHTT algorithm is available. This parametric study will establish whether the innovative materials are feasible.

| **Table 2.1 – The concluding findings and gaps from the reviewed publications and the summary of the research proposal.** |
| In this Master Thesis, the study will focus on developing an accessible benchmark model of a Romanian residential building, on applying the Romanian standards for energy performance on the benchmark model and on comparing the final results. The study focuses only on developing the benchmark model because the available time was not enough to concentrate also on the parametric study. The parametric study of the Romanian benchmark model of residential buildings will be a future work. |

5. **The list of publications included in the Literature Review Matrix**

This section presents the list of the publications included in the Literature Review Matrix which are in the same order as they appear in the matrix. For more details about the publications, see Appendix III. The publications included in the LRM and cited in this chapter are as follows:


[34] Normativ general privind calculul transferului de masă (umiditate) prin elementele de construcție. 2002. C107/6-02

[35] Normativ pentru proiectarea la stabilitatea termica a elementelor de inchidere ale clădirilor. 2002. C017/7-02
CHAPTER III: ROMANIAN BUILDING STOCK AND nZEBs

1. Climate analysis of Romania

Romania is a country situated in the South-Eastern part of the European continent and due to its position, Romania has a climate which is a transition from temperate to continental having different climatic influences as following (Administrația Națională de Meteorologie, n.d.-a):

- **Oceanic influences in the West and Central Romania:** these are occurring as low pressure systems generated above the Atlantic Ocean resulting in moderated temperatures and high rainfalls.

- **Continental influences in the East and Southeast Romania:** with extreme temperatures between summer and winter and low to moderate rainfalls.

- **Scandinavian influences in the North Romania:** these influences occur in Maramureș and Bucovina regions and result in a humid and cold climate.

- **Sub-Mediterranean influences in the Southwest Romania:** these influences are felt in Banat and Oltenia regions and is characterized by warm winters and high rainfalls, especially during fall season.

- **Influences on the coast of the Black Sea:** which occur in Dobrogea region resulting in rare rainfalls, but torrential ones.

The climatic conditions are also influenced by the varied topography: the temperature is decreasing with altitude, while the rainfalls increase with altitude (“Clima României,” 2008).

The average annual temperature decreases with altitude as following (“Clima României,” 2008):

- In the Danube Delta: 11°C.
- In the plains: 10 – 11°C.
- In the hills and plateaus: 8 – 9°C.
- In the mountains up to 2000 meters altitude: 0 – 6°C.
- In the mountains above 2000 meters altitude: −2 – 0°C.

The average annual rainfall increases with altitude as following (“Clima României,” 2008):

- In the Danube Delta: 350 mm/year.
- In the plains: 500 – 600 mm/year.
- In the hills and plateaus: 700 – 800 mm/year.
- In the mountains: 1000 – 1200 mm/year.
The absolute minimum temperature was $-38.5^\circ C$ registered near Brașov on January 24th, 1942, while the absolute maximum temperature was $+44.5^\circ C$ recorded at Ion Sion, Brăila County on August 10th, 1951 (“Clima României,” 2008).

In Figure 3.1 and Figure 3.2 are the mean monthly temperature from July and January, respectively the mean rainfall amount recorded between the years 1961 – 1990, by the Romanian National Administration of Meteorology (Asociația Națională de Meteorologie in Romanian).

![Figure 3.1](image1.png)  
**Figure 3.1 – The mean monthly temperature recorded in July, respectively in January between the years 1961 – 1990 in Romania** (Administrația Națională de Meteorologie, n.d.-a).

![Figure 3.2](image2.png)  
**Figure 3.2 – The mean rainfall amount recorded in July, respectively in January between the years 1961 – 1990 in Romania** (Administrația Națională de Meteorologie, n.d.-a).

Each climatic zone of Romania is also characterized by a type of local wind caused by the geographical position of the area and by its orographic characteristics. Most of the names of the local winds that occur in Romania are not translated into English in this paper since they don’t have
an English equivalent, thus they will be kept in the original form. The local winds that appear in Romania are the following (Administrația Națională de Meteorologie, n.d.-b):

1. **Crivățul**

   *Crivățul* is a wind that occurs in Moldova, Dobrogea and in the South and East of Muntenia mostly during winter season, but also during summer, on the direction Northeast – Southwest. The velocity of the wind may sometimes exceed 108 – 126 km/hr resulting into the strongest blizzards in Romania. During summer season, *crivățul* is a dry and warm wind which may sometimes ruin the crops from East and Southeast Romania.

2. **Austrul**

   *Austrul* is a wind that blows from West direction and occurs in the Romanian regions Crișana, Banat and Oltenia, resulting in dryness during summer, because *austrul* is a hot and dry wind. During winter, *austrul* is a cold and dry wind which brings dry and freezing winters.

3. **Nemirul**

   *Nemirul* is a wind that occurs in the valleys of the Eastern Transylvania, being typical for Brașov area. It can be considered a form of *crivăț* which slips through the valleys of the Eastern Carpathians and brings strong winter storms at the foot of the mountains in which the velocity of the wind may exceed 72 – 90 km/h.

4. **Băltărețul**

   *Băltărețul* is a warm and humid wind that blows from the Southwest direction and occurs in the South of Muntenia region. This wind has a lower area of influence, but it is good in the agricultural activities because it brings heavy rainfalls.

5. **Vântul negru (The black wind)**

   The black wind occurs in the South part of the Dobrogea region and it is a hot and dry wind which affects the crops. Sometimes its influence is also felt in the Bărăgan Plain.

6. **The foehn**

   The foehn is the most known wind that occurs in Romania and it is a descendent, dry and hot wind, similar to the Swiss foehn, which results from the difference between the atmospheric pressures on the mountains’ sides. The direction of the foehn is from the peaks of Făgăraș Mountains (Middle Carpathians) to the Olt Valley from Transylvania and it occurs at the end of the winter season. This wind is responsible for the melting of the snows at the foot Făgăraș Mountains and its influence extends to the North, up to the Târnavele Plateau.

7. **Cosava**

   *Cosava* is an extremely strong wind, similar to the foehn, which occurs in the Southwest Romania, in the Valley of the Danube called in Romanian *Dunărea la cazane* and in the Southwest
of Banat. The wind blows mostly from Southeast to Northwest and even from East to West. The reason why the velocity of the wind \textit{cosava} is about $72 - 90 \ km/h$ is due to the local orographic conditions: the direction of the air masses is normal to the mountain sides. \textit{Cosava} is a dry and warm wind which melts the snows and keeps the minimum temperatures in the area during nighttime higher than in the rest of Romania.

2. Romania’s vernacular and bioclimatic architecture

The style of the Romanian vernacular architecture comes mainly from agricultural economy and from the variation of the climatic zones across the Romanian territory (See Section 1 of the paper). The main characteristics of the Romanian houses are the orientation relative to the shining of the sun and to the direction of the dominant winds (i.e. front façade is in South direction and back façade is in the North direction), collecting solar energy for heating by greenhouse effect, minimizing the quantity of conventional fuels used through a proper design of the house and of the stove and the use of shading elements in the warm season. These characteristics have been included into Romanian houses since the 19\textsuperscript{th} century, but the primary ideas of their conception are a few centuries older (Petrasincu & Fara, n.d.).

2.1. The vernacular architecture of rural areas

The main factors that influence the Romanian vernacular architecture from rural areas are the local environment conditions and the human creative nature. The social environment of Romanian rural areas is defined mainly by the agricultural character. The rural habitat is the product of an anonymous collective creation, consequence of a long evolution and accumulation of existential experiences. The social background of the Romanian rural areas is defined by a limited division of labor which means that the products result from the effort of the entire family where the individuals have a complex development, by the relative isolation which ensures a unitary character to the handmade creation and by the interdependence of various occupations such as sheep and cattle husbandry, agriculture, fruit and vine growing (Petrasincu & Fara, n.d.).

The main façade of a Romanian rural house is always oriented towards South, being a strictly observed rule. On the South façade there are the entrance doors, the windows and the porch all along the house. The porch is architecturally and structurally integrated into the house. The North façade which is facing the dominant winds is either opaque and completely closed or has very small windows. (See Figure 3.3) As consequence of this orientation rule, the house positioning is
free because it does not take into account the access way infrastructure or the slope of the terrain (Petrasincu & Fara, n.d.).

Figure 3.3 – Rural house from the village Câinelul de Sus, Hunedoara County.

Source: www.meteo-europ.com

The porch represents the intermediary space between the interior and exterior of the house both from the functional and bioclimatic point of view. Because it is orientated into South direction, during the cold season, the porch is closed with removable glass panels having the function of a greenhouse, while in the warm season it is opened and has shading function. The depth of the porch is designed based on the Sun’s annual revolution such that the rays of sunshine could penetrate into the house during the cold season and stop them during the warm season (Petrasincu & Fara, n.d.). Figure 3.5 shows the way the sun rays penetrate a Romanian rural house from the hill area. The porch is also a part of the aesthetics of a Romanian traditional rural house.
Figure 3.4 – Rural house from the mountain resort Cheia, on the Prahova Valley. This house has the porch partially covered with glass panels. The glass panels are not removable.

Source: http://turistintaramea.blogspot.ro
Ray (a) is the Sun ray that penetrates the room at winter solstice, ray (b) is the Sun ray that penetrates the porch at spring and fall equinox and ray (c) is the Sun ray which falls outside the house at summer solstice (Petrasincu & Fara, n.d.).

Even though the architecture of the Romanian rural house is different from region to region, the plan composition is the same all over the country. On the South façade protected by the porch there is the front door leading to the “entrance hall” which is usual without ceiling being integral with the attic. On the both sides (i.e. on the East and West side) of the “entrance hall” are the inhabitable rooms. The room on the East side is in constant use, while the room on the West side is called “the big” or “the clean room” which is used as guest room. The inhabitable rooms have ceilings. On the North side, with the access from “the entrance” hall is the pantry which runs on the entire length of the house. In the hill regions, the pantry is at the partially buried basement level with the entrance on the South side. It is built from natural stone masonry and serves as storage for wines, fruits and vegetables (Figure 3.5, room no. 5). This kind of layout allows the endowment of a single fireplace (Petrasincu & Fara, n.d.). In Figure 3.6 is the plan and front façade elevation of a Romanian rural house from Zăland Valley, Covasna County.
The thermal insulation is achieved by using materials with good thermal inertia. Depending on the region, the walls are built from burnt or un-burnt bricks or massive timber trunks and as interior rendering it is used a layer of clay. For ceilings and floors, the thermal insulation is achieved by a layer of clay reinforced with twigs and straws which is placed directly on the timber structural joists of the ceiling and floor.

The attic has a complex thermal insulation function because the chimneys that come from the fireplace do not penetrate the roof so they end up in the attic. The smoke is evacuated through the roof’s covering made by reed, straws, shingles, clapboards or ceramic roof tiles such that the
entire attic is covered in a halo of smoke during winter season. The common space between the attic and the “entrance hall” evens out the temperature. The attic is not only a thermal buffer is also a place where the smoked meat is stored. The smoke which passes through the organic material covering helps protecting against moisture. The chimney is intentionally bent in order to radiate heat on a as long as possible surface (Petrasincu & Fara, n.d.).

The slope of the roof varies between $30^\circ - 60^\circ$ according to the type of covering used on the roof and to the rainfall regime of the area, thus the houses which are located in a climate zone with low rainfalls, like Dobrogea, have the slope of the roof low while the houses located in the mountains have the slope of the roof high. In Figure 3.7, respectively Figure 3.8 is presented the difference between a rural house located in Dobrogea, where the annual average rainfall is about 350 mm/year, and a rural house located in the West Carpathians, where the annual average rainfall is about 1000 – 1200 mm/year.

![Figure 3.7 – Romanian rural house from Dobrogea.](http://www.igloo.ro/)
2.2. The vernacular architecture of urban areas

Based on the same principles on which the Romanian rural houses are built, the Romanian houses in the urban area built in the 19th century and the beginning of 20th century represent an enhancement and adaptation of the rural houses. This happened mainly due to merchants’ class who moved from the countryside and brought with them the tradition of rural houses together with the
local craftsmen. The main similarities between the rural houses and the urban houses from Romania are the porch oriented in the South direction, closed in the cold season by removable glass panels which generate the greenhouse effect, and in summer acting as a shading element, the tendency of the North facades to be closed as possible against dominant winds, planting trees in front of the south side to block the Sun rays during summer (Petrasincu & Fara, n.d.). There are also differences between the Romanian rural houses and Romanian urban houses like the ever increasing complexity and variety of architectural solutions adopted in residential areas and the adaptation to the system of roads (Petrasincu & Fara, n.d.). Figures 3.9, 3.10, 3.11, 3.12 and 3.13 present examples of Romanian urban houses built in the 19th century and in the first half of the 20th century.

Figure 3.9 – Romanian urban house from Bucharest built in the 19th century by the Romanian architect Alexandru Săvulescu (1847-1904). Even though it is considered an historical monument, unfortunately it was demolished.

Source: http://jurnalul.ro/
Figure 3.10 – The house of Vasile Pogor (1833 – 1906), Romanian poet, which was built in the 19th century, in the city of Iași.

Source: http://jurnalul.ro/

Figure 3.11 – A German style villa built by the Romanian architect Nicu Georgescu in 1927, in the city of Sibiu.

Source: http://www.capital.ro/
Figure 3.12 – The residential house belonging to the famous Brătianu family, built in 1912, in Bucharest.

Source: [http://www.capital.ro/](http://www.capital.ro/)

Figure 3.13 – Romanian house built in Art Deco style located in Bucharest.

Source: [http://bucharestunknown.blogspot.ro](http://bucharestunknown.blogspot.ro)
When the urban areas started to develop, in Romania were built multi-family residential buildings, especially during the communist era, when there was a huge migration of the population from the countryside to the cities due to the communist policy of making people work in the factories. Figures 3.14 and 3.15 present the multi-family houses built in the interwar period using the Art Deco style and in Figures 3.16 and 3.17 are multi-family houses from the communist period.

Figure 3.14 – Multi-family residential building from Romania built in the Art-Deco style in the interwar period

Source: http://photos.wikimapia.org/
Figure 3.15 – Another Romanian multi-family house from the interwar period
Source: http://photobucket.com/

Figure 3.16 – Romanian multi-family houses built during the communist period.
Source: www.spatiulconstruit.ro
3. Romania’s energy and building sector

3.1. Romania’s primary and renewable energy potential and consumption

Romania is a country member of the European Union since 2007 with an upper-middle income and a dynamic economic development. Between the years 1948 – 1989, Romania was under the communist regime, therefore its economy was centralized. After the fall of the communism in 1989, the economy of Romania became unstable, the GDP of the country decreased seriously and the unemployment rate and inflation became high. The inefficient public administration, the corruption and the lack of real structural reforms were the main reasons of the economic instability from post-communist Romania. Today, Romania’s economy is based on services which represent 55% of the GDP, while the industry represents 35% and agriculture is 10% of the country’s GDP (Shahbaz, Mutascu, & Azim, 2013).

Romania has the largest energy consumption among the South Eastern European countries (Shahbaz et al., 2013). Also, according to the International Energy agency, in 2006 Romania used for the residential sector around 30% of its total energy consumption (Musatescu & Comănescu, 2009). The Romanian company SC Electrica SA has published on their official website the
structure of energy production of Romania in 2012 which is presented in Figure 3.18 and Figure 3.19 and in Table 3.1 and Table 3.2 (S.C. Electrica S.A., n.d.). According to the charts from Figure 3.18, respectively Figure 3.19, most of the primary energy from Romania comes from coal, while most of the renewable energy comes from hydropower.

![Primary energy production in Romania in year 2012](image1)

*Figure 3.18 – Primary energy production in Romania in year 2012 (S.C. Electrica S.A., n.d.).*

![Renewable energy production in Romania in year 2012](image2)

*Figure 3.19 – Renewable energy production in Romania in year 2012 (S.C. Electrica S.A., n.d.).*
Primary energy

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>32.76%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>19.59%</td>
</tr>
<tr>
<td>Gas</td>
<td>13.79%</td>
</tr>
<tr>
<td>Oil</td>
<td>0.58%</td>
</tr>
<tr>
<td>Other conventional sources</td>
<td>0.51%</td>
</tr>
</tbody>
</table>

Table 3.1 – Primary energy production in Romania in year 2012 (S.C. Electrica S.A., n.d.).

Renewable energy

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>22.17%</td>
</tr>
<tr>
<td>Wind</td>
<td>5.35%</td>
</tr>
<tr>
<td>Biomass</td>
<td>0.35%</td>
</tr>
<tr>
<td>Solar</td>
<td>0.02%</td>
</tr>
<tr>
<td>Other renewable sources</td>
<td>0.03%</td>
</tr>
</tbody>
</table>

Table 3.2 – Renewable energy production in Romania in year 2012 (S.C. Electrica S.A., n.d.).

Even though Romania is an important producer of natural gas, oil and coal in Europe, just like the other European countries, Romania also relies on natural gas and oil imported from Russia and Middle East countries. U.S. Energy Information Administration states that Romania, Bulgaria and Hungary have a great potential of shale gas reserves which are about 538 billion cubic meters (Shahbaz et al., 2013). Since 2010, the Romanian government has offered as concession 870,000 ha of terrain in the Eastern plains and Black Sea coastal area for the exploitation of the shale gas. Despite of several civil protests, the Romanian Parliament has overwhelming rejected a motion to ban shale gas exploitation and exploitation by hydraulic fracturing (Shahbaz et al., 2013).

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. Romania has a significant potential for solar energy because more than half of the country’s territory has an annual energy flow between 1000 – 1300 kWh/m² · yr. Also Romania has 210 days of sunshine per year. 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. Romania is the 4th country in Europe with the highest geothermal potential, after Island, Italy and Greece. Researches and explorations made in the 1960s discovered low enthalpy resources in the range 40 – 1200°C. Five discovered sites have temperatures over 1000°C (Păcesilă, 2013).
Biomass potential in Romania is huge and 60% comes from agricultural waste, while 20% comes from wood waste. Therefore Romania could develop a successful biomass industry. The biomass potential also relies on using the land, having the surface about 1 – 2 million ha, for energy crops. The exploitation of biomass in Romania would generate 300,000 new jobs in rural areas by the end of 2020, but also in other sectors of renewable energy (Păcesilă, 2013).

Romania’s proposed target for renewable energy by 2020 is 24% (Musatescu & Comănescu, 2009). In 2010, Romania almost reached its target by applying EU policies and the production of renewable energy in Romania was 23.4% that year. Also, 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 (Păcesilă, 2013):

- New rules regarding issuing green certificates for 1 MWh of renewable energy (i.e. biomass, solar, geothermal).
- 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.

3.2. CO2 emissions in Romania

In the communist period, in Romania the CO2 emissions registered high levels, over 200,000 Gg CO2. After the fall of communism, the CO2 emissions from Romania start to decrease from 161,343 Gg CO2 registered in year 1990 to 61,329 Gg CO2 in 2010. The same decrease is registered in the greenhouse gas emissions: from 264,495 Gg CO2 in 1989 to 95,545 Gg CO2 in 2010. (Shahbaz et al., 2013) SC Electrica SA also states that in 2012, the amount of CO2 emissions in Romania was 408.67 g/kWh and of the radioactive waste was 0.004 g/kWh (S.C. Electrica S.A., n.d.).

The democratic regime has a significant influence in the decline of CO2 emissions through effective implementation of economic policies and financial development improves the environment reducing the CO2 emissions by redirecting the resources to environment friendly projects. In the early 1990s it was established the first Environment Department in Romania’s history and its main objective was the limitation of pollution phenomena and establishing the responsibility regarding environmental damage. Unfortunately, the Romanian government of that period did not concentrate on a coherent environment policy. The first official document for environment conservation and protection based on EU regulations was called National Strategy of
Environment Protection and it was signed in 1992 and then it 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 (Shahbaz et al., 2013).

In 2007 was established the Convenant of Mayors 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 (Musatescu & Comănescu, 2009).

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 is not an excuse because 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 and 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 (Musatescu & Comănescu, 2009).

To combat pollution from energy consumption, the Romanian authorities could use other policy instruments like restructuration of the environmental taxes or incentive for population behaviour in the environmental area. Romania is the country with the lowest environmental taxes as percent of the GDP from the EU. That’s why the Romanian authorities have to revise the taxation rates for energy, transport and, respectively, pollution. Also, to decrease energy pollution, the Romanian authorities must ensure a strong cooperation between the main public actors: the government, the companies, the educational institutions, the non-governmental organisations and the citizens (Shahbaz et al., 2013).

3.3. Energy prices in Romania

By the order of the National Authority for Energy Regulation (Autoritatea Națională de Reglementare în Energie), the Romanian natural gas provider E.ON Energie Romania and the Romanian electricity provider ELECTRICA S.A. have published on their official websites the
On December 23rd, 2014 the company ELECTRICA S.A. publishes in the report the following prices on energy which are applied starting year 2015. The established prices are according to each regional supplier as follows (Societatea de Distribuție și Furnizare a Energiei Electrice - ”ELECTRICA” S.A., 2014):

1. **ELECTRICA S.A. Muntenia North supplier**
   - Low voltage: 138 lei/MWh (31.19 euros/MWh)
   - Medium voltage: 42.84 lei/MWh (9.64 euros/MWh)
   - High voltage: 18.47 lei/MWh (4.16 euros/MWh)

2. **ELECTRICA S.A. Transilvania North supplier**
   - Low voltage: 112.15 lei/MWh (25.23 euros/MWh)
   - Medium voltage: 47.34 lei/MWh (10.65 euros/MWh)
   - High voltage: 21.10 lei/MWh (4.75 euros/MWh)

3. **ELECTRICA S.A. Transilvania South supplier**
   - Low voltage: 122.39 lei/MWh (27.54 euros/MWh)
   - Medium voltage: 46.85 lei/MWh (10.54 euros/MWh)
   - High voltage: 23.41 lei/MWh (5.27 euros/MWh)

The established prices for year 2015 according to each type of domestic consumer are the following (Societatea de Distribuție și Furnizare a Energiei Electrice - ”ELECTRICA” S.A., 2014), (CEZ România, 2012):

- **a. For domestic consumers with the monom CR price with reservation (CR – monom cu rezervare):** domestic consumers with permanent energy consumption, if the energy consumption is greater than 45 kWh/month.
  - For low voltage: 0.3716 lei/kWh (0.08 euros/kWh)
  - For medium voltage: 0.2889 lei/kWh (0.07 euros/kWh)

- **b. Domestic consumers with the monom CD price:** domestic consumers with small energy consumption that doesn’t exceed 45 kWh/month.
  - For low voltage: 0.4956 lei/kWh (0.11 euros/kWh)
  - For medium voltage: 0.3854 lei/kWh (0.09 euros/kWh)

- **c. For domestic consumers with the monom CR2 price with reservation on two hour zones (CR – monom cu rezervare, diferențiat pe 2 zone orare):** domestic consumers with high energy consumption during nighttime and in the weekend.
• For low voltage: 0.5920 lei/kWh (0.13 euros/kWh) – during daytime, 0.1925 lei/kWh (0.04 euros/kWh) – during nighttime.

• For medium voltage: 0.4769 lei/kWh (0.11 euros/kWh) – during daytime, 0.1514 lei/kWh (0.03 euros/kWh) – during nighttime.

d. For domestic consumers with the CS social price: domestic consumers in which the family’s net monthly income is smaller than the minimum wage. The energy consumption is calculated for 3 consumption installments. If the monthly energy consumption exceeds 110 kWh/month, then the CS social price is not available.

• For low voltage, installment I (0-2 kWh/day): 0.2065 lei/kWh (0.05 euros/kWh)
• For low voltage, installment II (2-3 kWh/day): 0.4956 lei/kWh (0.11 euros/kWh)
• For low voltage, installment III(3 kWh/day): 0.9770 lei/kWh (0.22 euros/kWh)

On December 1st, 2014 the company E.ON Energie Romania publishes in the report the following prices on natural gas which are applied starting year 2015 for the following types of domestic consumers (E.ON Energie România, n.d.):

1. Domestic consumers connected to the national natural gas supply network

• Domestic consumers with an annual consumption up to 1.162,78 MWh: 82,33 lei/MWh (18.52 euros/MWh). The annual price is up to 21,530 euros/year.

• Domestic consumers with an annual consumption between 1.162,79 MWh and 11.627,78 MWh: 82,23 lei/MWh (18.50 euros/MWh). The annual price is between 21,510 – 215,100 euros/year.

• Domestic consumers with an annual consumption between 11.627,79 MWh și 116.277,79 MWh: 81,94 lei/MWh (18.44 euros/MWh). The annual price is between 214,400 – 2,144,000 euros/year.

2. Domestic consumers connected in the natural gas supply system

• Domestic consumers with an annual consumption up to 23.26 MWh: 116.50 lei/MWh (26.21 euros/MWh). The annual price is up to 609,645 euros/year.

• Domestic consumers with an annual consumption between 23.26 MWh and 116.28 MWh: 113.26 lei/MWh (25.48 euros/MWh). The annual price is between 592,665 – 2,963 euros/year.

• Domestic consumers with an annual consumption between 116.28 MWh și 1.162,78 MWh: 112.57 lei/MWh (25.33 euros/MWh). The annual price is between 2,945 – 29,450 euros/year.
• Domestic consumers with an annual consumption between 1.162,79 MWh and 11.627,78 MWh: 111.90 lei/MWh (25.18 euros/MWh). The annual price is between 29,280 – 292,800 euros/year.

• Domestic consumers with an annual consumption between 11.627,79 MWh și 116.277,79 MWh: 111.13 lei/MWh (25 euros/MWh). The annual price is between 290,700 – 2,907,000 euros/year.

• Domestic consumers with an annual consumption over 116.277,79 MWh: 109.35 lei/MWh (24.6 euros/MWh). The annual price is over 2,860,000 euros/year.

The energy prices in euro presented in this paper were evaluated for the exchange price of March 11th, 2015, when 1 euro = 4.4444 lei, with the VTA being 24%, the value from Romania. The exchange price was established by the National Bank of Romania (Banca Națională Română). The prices of the natural gas expressed in lei are without the VTA.

4. The Romanian building stock for residential buildings

4.1. Energy Use Intensity in Romania

International organizations and national agencies use energy intensity as an indicator for the energy efficiency of a country. Due to the large number of member-states in the European Union, the assessment of the energy sector typically takes the form of scenario analysis using energy intensities so that the members can develop cohesive energy policies. Therefore, the countries which have joined or intend to join the EU must adjust their energy consumption and energy sector to reduce the energy intensity to levels comparable to those of the full members (Iorgulescu & Polimeni, 2009).

The revolution of 1989 started the transition of the Romanian command economies towards an open market system. As the vital link in the economic chain, the energy sector experienced a large change in structure as well. The energy intensive industrial sector, with high levels of energy consumption per unit of output, was the focus of economic development by the communist regime in power at the time. Romania was the only Eastern European country to undergo a violent revolution which ended with the execution of its then leader, Nicolae Ceausescu. Since that time, however, the Romanian transition, while not completely painless, had been relatively smooth with a steadily improving economy (Iorgulescu & Polimeni, 2009).

The inherited energy problems in Romania included subsidized prices, the lack of incentives and of mechanisms for energy conservation, and centralized control of electricity generation,
encouraging inefficient energy use. Therefore in 1989, Romania used 56 MJ per dollar produced in the industrial sector compared to West Germany which used 8 MJ per dollar in the same year. This problem was further exacerbated by the dependence of Romania on imported energy resources. In 2002, more than 10 years after the fall of the communist regime, the dependence on energy imports for Romania was 30% (Iorgulescu & Polimeni, 2009).

Energy intensity does not provide the most descriptive analysis of an energy sector. By analyzing the graph of energy intensity from Figure 3.20, we notice that it does not provide any additional understanding. In case of Romania, from 1995 to 1999, the country reduced its energy intensity by 8%. However, from 2000 to 2004 additional reductions were experienced when Romania reduced its energy consumption by 7%.

Figure 3.20 – The energy intensity of Romania, Bulgaria, Hungary and Poland between 1995 – 2004 (Iorgulescu & Polimeni, 2009).
59

Figure 3.21 – The household consumption as a percentage of total final energy consumption from Romania, Bulgaria, Hungary and Poland between 1990 – 2004 (Iorgulescu & Polimeni, 2009).

In Figure 3.21 is represented the household consumption as a percentage of total final energy consumption from Romania along with Bulgaria, Poland and Hungary. The share of household sector in final energy consumption has a slightly similar pattern in Romania and Bulgaria (Iorgulescu & Polimeni, 2009). The overall energy intensity (EI) in Romania declined in the early years of transition, but started to climb back between 1995 and 1997, before beginning to drop again. In 1998, energy intensity was down 14% compared to 1992. Non-industrial energy use and structural change contributed to a reduction in energy intensity. Industrial energy intensity, on the other hand, increased by 19% over the study period, a reflection of the slow pace in privatisation and restructuring which Romania experienced over much of the decade (Cornillie & Fankhauser, 2004).

4.2. The Romanian building stock and energy performance

According to the study of BPIE done in 2012, in Romania there are 8.2 million dwellings in about 5.1 million buildings. 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 before 1989. The high percentage of the buildings constructed before 1989 is due to the authorities who had to keep up with the high urban migration from the rural areas. In Romania the demand of heating energy is
55% for apartments and 80% for individual houses (Nolte, Griffiths, Rapf, & Potcoava, 2012). (Nolte, Rapf, Griffiths, & Potcoava, 2012).

![Figure 3.22 – The distribution of the residential floor area by building type and urbanization (Nolte, Griffiths, et al., 2012).](image)

BPIE states 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, because when the communist regime was established in Romania, lots of private proprieties were confiscated by the state (Nolte, Griffiths, et al., 2012), (Nolte, Rapf, et al., 2012).

In Figure 3.23 is represented the structure of the Romanian building stock according to the age of the buildings (F. Prada, Brata, F. Tudor, & E. Popescu, n.d.). According to the chart, most of the buildings have the age between 20 – 40 years, while in the Romanian building stock there are very few buildings with the age less than 10 years.
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 – 400 kWh/m². 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 (Nolte, Griffiths, et al., 2012), (Nolte, Rapf, et al., 2012).

The continuous increase of the price of Giga calorie is most of the times beyond the household affordability limit. According to the National Agency for Financial Administration (Agenția Națională de Administrare Fiscală), the average wage in Romania, in year 2015, is 2382 lei (536.97 euros) without the taxes and 1684 lei (379.62 euros) after subtracting the taxes. Also, according to the same institution, the minimum wage in Romania is 975 lei (219.79 euros) which will be increased to 1050 lei (236.7 euros) starting July 1st, 2015. The exchange from lei to euros was done for the exchange price from March 12th, 2015 when 1 euro = 4.436 lei, the exchange price being established by National Bank of Romania (Banca Națională Română), with the VTA of 24% in Romania. That’s why, in order to save money, most of the dwellers are forced to close their radiators during cold season and to live inside their apartments below the comfort limit. This means that if the standard room temperature is 20°C, in order to save money, a Romanian with average income will live at the temperature of 17 – 18°C during the cold season.

BPIE states that in Romania there are some cities which have renewable district heating systems which exploit the local potential and from that it results lower prices in the energy for

Figure 3.23 – The structure of the Romanian building stock depending on the age according to ref. (F. Prada et al., n.d.).

The structure of Romanian housing stock depending on the age
heating than in case of gas and oil. The report gives example the following cities: Giurgiu, Beiuș and Huedin. About Huedin I have no knowledge about renewable district heating systems. Actually Huedin, a town with less than 10,000 inhabitants is located at the edge of Cluj County and its situation is not quite good from the energy efficiency point of view. Huedin is a town without gas supply system because for unknown reasons the main gas pipe doesn’t cross Huedin area. This means that the inhabitants rely on wood as source of energy for heating and in a decade when we try to focus on finding alternative sources of energy and to try to save as much as possible the forests, this is a major problem to be focused on. BPIE also reports that Oltenița has thermal plants with high efficiency in production and distribution, combined with additional solar collector and pellet boiler (Nolte, Griffiths, et al., 2012), (Nolte, Rapf, et al., 2012).

If in the urban area the situation of the buildings from the energy performance point of view isn’t good, in the rural area the situation is even worse, especially in the rural areas which are far from the cities or important roads. Romanian villages which are close to cities and towns, at maximum 10 – 20 kilometers, or they are near an important road (like National Roads or European Roads) are more developed than villages who are far from the cities or from important roads. The dwellings of the villages close to cities are connected to the water supply system, to the sewerage system and gas supply system. The villages far from the cities have no gas supply system, which means that heating is done using wood, there is no water supply system so this means that there is no domestic hot water, there is also no sewerage system. Most of the houses in the rural area are old, some of them being built before 1930 and this makes them inefficient from the energy performance point of view.

5. Current state of the energy efficiency of the residential buildings

5.1. Romania’s current practice in building energy performance

At the current moment, implementing solutions for Zero Energy Buildings in Romania is a bit hard due to the costs involved in the process because of the low average income of Romanians compared to other Member States. So in order to apply the solutions for Zero Energy Buildings by year 2020 in Romania, the Romanian Government or the European Union has to provide higher financial support in form of subsidies (Nolte, Griffiths, et al., 2012), (Nolte, Rapf, et al., 2012).

Even though the average Romanian lives on small income compared to other Member States, in Romania some buildings have started to improve their energy performance. Some apartment buildings have started to add on the exterior walls thermal insulation made of polystyrene with the
average thickness of 10 cm. The choice of this material is done first because its thermal conductivity is very low and second, because is quite cheap compared to other thermal insulating materials. Romania is taking small steps at improving the buildings energy performance, but at the same time it also manages to fail. Applying thermal insulation on the block of apartments involves the costs of all the dwellers of the buildings. In every block of apartments there is at least one family who refuses the improvement of the building where they live because the cost involved in the thermal rehabilitation of the building might be higher than their income. And this is how some Romanian blocks of apartments become partially thermal insulated which leads to almost 0 energy performance because the heat inside the building tends to find thermal balance by every possible means. This leads to heat losses through the bare areas.

Also the Romanian standards for energy performance have been changed along the time in order to try to align to the European standards. The latest version of the Romanian standards were released in the year 2002 (C107/6-02 and C107/7-02), 2005 (C107-2005), respectively 2006 (Mc001-2006) and, unfortunately, they haven’t been upgraded since then. Figure 3.24 represents the variation of the standards number in the field of energetic efficiency in Romania (F. Prada et al., n.d.). From the chart it can be seen that the highest variation of the Romanian energy performance standards was between 1997 – 2009.

![Variation of the energy performance standards in Romania](image)

*Figure 3.24 – The variation of the number of energy performance standards in Romania* (F. Prada et al., n.d.).

Another disadvantage for Romania is the fact that the EU demands that the regular gas central heating should be removed from the market because of their high CO2 emissions and
polluting potential and to be replaced with central heating based on gas condensation which is less polluting. Romanian citizens having the average or minimum wage refuse this upgrade because the central heating based on gas condensation is two times expensive than the regular gas central heating. The replacing of the regular gas heating central with the one based on gas condensation requires the replacement of the entire central heating installations with one special for the gas condensation and that increases even more the costs which are too much to bear for such a small family income.

5.2. Summary of the Cost – Optimal Methodology applied for residential buildings

To analyze the energy performance level in Romania, the Cost – Optimal Methodology was applied for 2 residential reference buildings having the specific Romanian climatic conditions. The analysis was run on a Single Family House and on a Multi Family House which are most representative for the Romanian building stock. The Cost – Optimal Methodology was applied by the Building Performance Institute Europe (Nolte, Griffiths, et al., 2012), (Nolte, Rapf, et al., 2012).

According to the BPIE document, the reference Single Family House (SFH) is described as being an individual detached house with two floors in accordance with the current practice in construction. The house has simple architecture with sloped roof facing South. The reference Multi Family House (MFH) is a building having 6 floors in accordance with the current practice in construction from Romania. The roof is flat in this case. The average standard interior temperature of the buildings is 20°C. The basement and the attic are assumed to be unheated spaces in both cases.

The reference SFH has central gas boiler heating system with radiators. The domestic hot water system uses a 250 liters tank and is connected to the heating boiler. There is no mechanical ventilation in the house besides the natural ventilation provided by opened windows. For the general cooling there is a split system. There is no solar thermal system and no PV system installed on the roof. The MFH uses a central gas boiler heating system with radiators. The domestic hot water system uses a 2400 liter tank and is connected to the heating boiler. There is no mechanical ventilation system as in the previous case. For general cooling there is a split system for each apartment. And as in the previous case, there is no solar thermal system and no PV installed on the roof (Nolte, Griffiths, et al., 2012), (Nolte, Rapf, et al., 2012).

After establishing the reference buildings, the next step in applying the Cost – Optimal Methodology was the selection of packages of measures. For the Single Family House were selected 5 packages of measures and for the Multi Family House were selected 4 packages of
measures. The packages of measures referred to improved building envelope combined with improved building services such as solar collectors, mechanical ventilation with heat recovery or wood pellet boiler. The improvement of the building envelope was made first by applying the national standard and then by applying the passive house standard.

According to BPIE, the following parameters were analyzed for the chosen reference buildings:

- Specific final energy demand detailed by building services (i.e. heating, domestic hot water, cooling, ventilation and auxiliary energy)
- Specific primary energy demand
- Share of renewable energies
- Specific CO2 emissions

The financial impacts of the Single Family House, respectively Multi Family House were analyzed by assuming the extra investment costs and related cost savings, which reflect energy savings of nZEB solutions as compared to the reference buildings according to the current standard. All the calculations for Romania were based on an 8% interest rate.

The simulations done by BPIE on the Romanian reference buildings demonstrate that nZEB solutions can be achievable in Romania even without major changes in the common building shapes. After applying the Cost – Optimal Methodology on Romanian SFH and MFH, BPIE has found the following conclusions:

- Rooftop PV systems for residential buildings are sufficient to reach full CO2 compensation and high share of renewable energy.
- The most economic solutions for SFH and MFH with specific CO2 emissions below $3 \text{ kg/m}^2 \cdot \text{yr}$ are those with wood pellet boilers.
- The lowest annualized costs compared to the reference buildings are about $7.7 \text{ Euros/m}^2/\text{yr}$ for SFH and $1.6 \text{ Euros/m}^2/\text{yr}$ for MFH.
- The most economic solutions for MFH are the ones with CO2 emissions below $3 \text{ kg/m}^2 \cdot \text{yr}$ combined with PV compensation. The annualized additional cost is estimated at $1.7 \text{ Euros/m}^2/\text{yr}$ compared to the reference building.
- The most economic solutions for SFH are the air heat pump solutions with PV compensation which lead to annualized additional cost of $3.6 \text{ Euros/m}^2/\text{yr}$. Also the CO2 emissions threshold is fulfilled if the PV compensation is used.
Details about how the Cost – Optimal Methodology was applied for the residential buildings from Romania and, also, for office buildings are found in the reports written in English, respectively in Romanian from the References (Nolte, Griffiths, et al., 2012) and (Nolte, Rapf, et al., 2012).

5.3. Measures and recommendations regarding implementation of the nZEB concept

5.3.1. The Building Performance Institute Europe report on Romania

In the report written about Romania’s level of nZEB implementation BPIE states the following problems (Nolte, Griffiths, et al., 2012), (Nolte, Rapf, et al., 2012):

- In the national standards there are no specific requirements for primary energy use or CO2 emissions.
- There are no holistic policy package and no long term programs for new buildings.
- 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.

To overcome the problems mentioned above and to reach the nZEB standard by 2020, BPIE offers the following solutions (Nolte, Griffiths, et al., 2012), (Nolte, Rapf, et al., 2012):

- The national regulations should be changed in order to secure the path to nZEB in the future. These changes should reflect the structure of the regulation and its ambition level.
- The structure should be adapted by including minimum requirements in the use of primary energy, in CO2 emissions and the use of renewable energy.
- The ambition level of the obligations should be tightened.
- Create financial instruments for Energy Efficiency and Renewable Energy in new buildings that are embedded in a holistic policy package and which should include regulatory and communication elements.
- Make the energy efficiency measures affordable by offering loans or grants.
Facilitate the use of renewable technology by removing existing barriers and by introducing market support schemes for local technology like financial support, knowledge transfer, and for technology to be imported, where necessary, from other EU countries.

5.3.2. The ENTRANZE project

Between April 2012 – September 2014, Romania was a part of ENTRANZE project which focused on providing the required data, analysis and guidelines to achieve a fast and strong penetration of the nZEB and RES – H&C within the national building stocks. Along with Romania in the ENTRANZE project have participated other 8 countries which are Austria, Bulgaria, Czech Republic, Germany, Spain, Finland, France and Italy, each having, just like Romania, an available report regarding implementation of nZEB and RES – H&C. The reports of the participant countries can be found on their official website: http://www.entranze.eu/. The ENTRANZE project was co-funded by the Intelligent Energy Europe Programme of the European Union. The basic conditions that had to be fulfilled by the ENTRANZE policy were the following: dynamic building regulations, longer term predictability of support programs, quality of works in construction, information and technical advice, measures in primary energy, support research, technology and development and supply chain industry.

The impacts of different policy instruments on the diffusion process and the building related energy demand were investigated taking into consideration economical, technical, non – technical, institutional barriers and rebound effects. The scenarios were developed until year 2030 with a particular focus on year 2020, according to the target setting of EPBD. In the project were developed 3 policy scenarios and 2 energy price scenarios.

The methodology of the ENTRANZE report was based on the following 3 pillars:
1. Selection and description of policy sets based on a participatory stakeholder process.
2. Modeling the potential impact of these policy sets with Invert/EE – Lab.
3. Deriving recommendations.

Invert/EE – Lab is a simulation tool for different scenarios: price, insulation, consumer behavior and their impact on future trends of energy demand and the mix of renewable and conventional energy sources on national and regional level. The input data of the model simulated in Invert/EE – Lab were the disaggregated description of the building stock, the cost data of heating, domestic hot water and cooling systems, as well as renovation options and the definition of renovation packages and the link to the cost – optimality calculations.

The policy sets were defined according to the following rules:
• The instruments should be designed as to address the main barriers that hamper investments in the efficiency of the buildings.
• If a certain barrier is addressed by two or more instruments at the same time, then this should be adequately justified.
• It should be avoided that instruments are simply redundant, because this will lead to high administrative costs.

During the ENTRANZE project, Romania was evaluated for only one climate zone represented by Bucharest. The results of the analysis would have been more accurate if in the project would have been analyzed one representative city from each of Romania’s 4 climate zones. In this way the set of measures would have been more varied. Details on the report made by the ENTRANZE project on Romania can be found in Reference (Atanasiu, Kranzl, & Toleikyte, 2014).

5.3.3. Support programs for implementing nZEB

The support programs for implementing nZEB for residential buildings which are available in Romania and also modeled by the ENTRANZE project (See Reference (Atanasiu et al., 2014)) are the following:

1. The National Programme for Thermal Rehabilitation of block of flats

   It is a very good measure and is already 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. This way it will be secured a higher investors’ confidence and at the same time a constant pressure on the market. This means that the decision of building owners to undertake renovation will be fostered by the imminent grant reduction timely announced.

2. The preferential credit line with subsidized interest for the renovation of residential buildings

   This is a more commercial instrument and a good measure even though the actual market impact is still low. Its attractiveness is likely to increase in time according to the modeling done by the ENTRANZE project and may have a significant impact by 2030, especially for single family houses, but with some adaptations. For maximizing its impact, it might be effective an extension of the payback period for the loans from 5 years to 10 – 15 – 20 years, in order to align financing to the payback period of more deep renovation. The subsidy should be also adjusted to the energy
savings generated by renovation as it appear to be effective from the model of the ENTRANZE project. As in the previous case, a multi-annual budget will increase its predictability, will reduce the investors’ risks and may secure the transformation of the actual credit line into a self-sustainable revolving fund.

3. **Green House (Casa Verde) Programme**

   This 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. According to the model performed in the ENTRANZE project, such a support program can significantly contribute to foster the market adoption of ambitious nZEB, mainly for new buildings. The report made by ENTRANZE indicates that it is recommended to revive the Green House Programme and to further tailor it on new buildings aiming at passive house levels with renewables, nZEB and ZEB.

6. **Conclusions**

   In terms of energy use intensity and CO2 and greenhouse gas emissions reduction, Romania has registered progress. During the communist period, Romania experienced high CO2 and greenhouse gas emissions along with subsidized prices, the lack of incentives and of mechanisms for energy conservation, and centralized control of electricity generation which resulted in inefficient energy consumption. From 1990, when Romania’s economical transition period started, until present, the energy use and CO2 emissions have reduced. This success is due the fact that Romania has slowly started to adopt environmental policies. Romania’s entry in the European Union in 2007 had also a huge influence in the reduction if energy use intensity and CO2 emissions, because Romania had to align with the European standards for environment protection.

   In Romania the level of implementation of passive house and nZEB requirements in buildings is at beginning. The current economic situation of Romania is a barrier in achieving this target. The economical barrier could be overcome if the Romanian Government could aid the population with subsidized programs by using European grant. In this way, the 2020 targets could be achieved easier.
CHAPTER IV: BUILDING PERFORMANCE SIMULATION

1. Introduction

The study of the building’s thermal behavior and energy performance is complex. Each location has its own particularities in terms of climate and geography. Each building material has its own thermal properties. Each equipment for heating, cooling and ventilation has different functions and powers. In order to see which building material and HVAC system is suitable for a building such that it fulfills the passive house, nZEB or ZEB standard, we need to elaborate the building performance simulation.

Building performance simulation is a fundamental component of sustainable buildings design. It is a powerful tool used on many new building and refurbishment projects. The building performance simulation is a computational model that approximates the performance of the actual building in practice for energy consumption, thermal comfort, daylight or ventilation. It has inherent limitations, functions as a valuable tool to inform the design process and assesses a building design for benchmarking, rating and compliance (The Australian Institute of Refrigeration, Air Conditioning and Heating, 2015). Building performance simulation can be combined with building performance optimization becoming a promising solution to use in the evaluation of different design options and obtain the optimal or near optimal objective (Shady Attia et al., 2015).

In the building performance simulation we create a model of the most representative building from a certain location (i.e. from a certain country, from a certain city) which is endowed with thermal insulation materials on its envelope, HVAC system and Photovoltaic panels eventually. Then the model is tested for heat losses through thermal bridges, air tightness, energy performance and energy costs. Also, in the building performance simulation we can also create a prototype of a building that fulfills the passive house, nZEB or ZEB requirements.

The advantages of building performance simulation are the following (The Australian Institute of Refrigeration, Air Conditioning and Heating, 2015):

- Enables quick evaluations of the thermal and energy scenarios to provide reliable comparisons between design options.
- Variables in a building simulation are much more easily controlled than in real world full or part scale models.
- Is far more cost effective than fixing a bad design post construction.
Other advantages of building performance simulations are related to the decision making of designers. These advantages are, according to Reference (Shady Attia, Andre, Elisabeth, & M., 2013), as follows:

- The knowledge of the design problems and options is improved. The modeler knows about the design parameters which influence the energy performance of a building, their range of influence and their impact on energy performance.
- The decision uncertainty is reduced. The uncertainty may refer to advantages or disadvantages of different design strategies or alternatives and the influence of the design option on nZEB standard.
- The design robustness is increased. This means that the buildings designed as nZEB meet the desired performances and are less influenced by external forces such as environment, climate change and tenant behavior.

2. Building performance simulation input data

Building performance simulation is complex due to the fact that it uses large amounts of input data. The input data used to run the building performance simulation falls into the following categories:

1. Data on the building’s location
2. Data on the building’s geometry
3. Data on the building’s opaque construction elements
4. Data on the glazing surfaces
5. Data on the building’s activity
6. Data on the HVAC system
7. Data on the lighting system

These input data are gathered by the modeler during the detailed design and certification phase from the following documents (The Australian Institute of Refrigeration, Air Conditioning and Heating, 2015):

- A full set of plans, sections and elevations including perspective or renders in CAD format or vector PDF.
- Full services specifications if defined or contact for mechanical/electrical/façade consultants.
- Part load performance characteristics or contacts for services equipment from suppliers.
- Materials schedules, window and door schedules and wall construction schedules.
Where tenant is known and where the modeling protocol allows it, tenant’s occupancy profiles and fit out plans.

The following paragraphs describe briefly each type of input data necessary to run the building performance simulation.

2.1. Data on the building’s location

The input data on the building’s location are very important in a building performance simulation. The input data on the location must contain information about the location’s climate and about the location’s geography. This information is important in establishing the annual heating and cooling demand of the building model. The data about the location’s climate is taken from the weather files which are available on the internet for every major city in the world. The weather files contain information about outdoor temperatures measured every hour, about rainfalls, about snowfalls and about the winds that occur within that location.

The data about the location’s geography contains information about the latitude and longitude of the location or about the elevation above sea level. The latitude and longitude are important for simulating the amount of daylight that a certain location has. The amount of daylight is important, for example, if the building is endowed with solar panels. The data on the location’s geography also contains information about the site such as the ground texture, the presence of ground water table, the ground monthly temperatures and so on, which are important for the envelope’s elements in contact with ground.

2.2. Data on the building’s geometry

After establishing the location of the building model, the next set of input data are on the building’s geometry. The building’s geometry is defined by the shape and size of the building’s footprint on the ground, by the shape and size of the openings for windows and doors and also by the shape of the roof. The building may have pitched roof at different angles, flat roof, vaulted roof or dome. The size of the openings are chosen according to the function of the rooms. Also, the partitions of the building are established depending on the building’s function. Residential buildings have different types of partitions from the non-residential buildings.

2.3. Data on the building’s opaque construction elements
After the building’s geometry is known, we need input data on the structure of the opaque construction elements. The data on the structure of the opaque construction elements contain information about the component material layers. The opaque construction elements are the walls, the floors and the roofs. The set of data must include the type of material from the layers, the thermal conductivity of the component materials, its thickness and its apparent density. These material properties are very important in establishing the heat flow through the building’s envelope and the thermal inertia of the building elements.

2.4. Data on the glazing surfaces

Besides the structure of the opaque construction elements, in order to build the model we also need data on the glazing surfaces of the windows and doors (if the building is provided with glazed doors). The data on the glazing surfaces must contain information on the type of glazing (i.e. simple glazed, double glazed or triple glazed), on the glazing surface solar transmittance and emissivity and on the type of frame (i.e. wooden frame, PVC frame or aluminum frame). In this set of data we also include information about the shading elements, i.e. the type of shading, the solar absorption and solar transmittance.

2.5. Data on the building’s activity

After the building’s geometry and structure (i.e. the structure of the opaque building elements, the glazing surfaces and shading elements) is establish, we also need input data on the building’s activity to be able to run the simulation. The data on the building’s activity contains information about the internal heat gains, about the occupancy, about the domestic hot water consumption and about the environment.

The internal heat gains in a building occur from human activity, from electrical devices, from the use of the domestic hot water and from lighting. The values of the internal heat gains are taken from the building performance standards and depend on the building’s function and on the degree of occupancy. When establishing the occupancy pattern of the building, we need information about the occupancy level, about the occupancy schedule and about the metabolic rate. The occupancy level is a standard value which is found in building performance standard. The value of the occupancy level represents the number of people reported to the surface of the room. The occupancy schedule depends on the building’s function and the metabolic rate depends on the type
of human activity. The metabolic rate is also a standard value measured in “met” and is also found in building performance standards.

The input data on the environment must contain information on the heating/cooling/ventilation set-point temperature, on the required luminance levels and on the required fresh air levels per person. The required luminance level depends on the building’s function and on the type of activity from the building. The required fresh air levels for each person depends also on the building’s function, on the level of occupancy and on the presence of smokers and non-smokers.

2.6. Data on the HVAC system

In order to be able simulate the energy performance of the building and to obtain accurate results, we must provide the model with HVAC system. The input data on the HVAC system must include information about ventilation, about the system and about the air distribution.

When describing the ventilation of the building, we must introduce information about the maximum natural ventilation rate and about the maximum mechanical ventilation rate. The value of the maximum natural ventilation rate depends on the position of the windows and on the time of the day (i.e. natural ventilation rate at daytime, respectively at nighttime). The value of the maximum mechanical ventilation rate depends on the building’s function and on the room’s function. For example, the mechanical ventilation rate is different in the kitchen and in the bathroom. Also, the mechanical ventilation rate has different value in a normal kitchen and in a kitchen from a restaurant. The two values (the maximum natural ventilation rate and the maximum mechanical ventilation rate) can be found in the building performance standards.

The input data about the HVAC system used in the building model must include information about auxiliary energy, about the efficiency of the heating/cooling system and about the efficiency of the boiler/chiller. The value of the heating/cooling system efficiency, respectively of the boiler/chiller efficiency are included in the simulation only if the building is provided with one of these systems. Also, the information about auxiliary energy is included in case the building is provided with it. The value of the heating system efficiency depends on the type of heating system, on the type of fuel used for heating (i.e. wood, natural gas, biomass) and on the type of heating devices (i.e. radiator). The value of the cooling system efficiency depends on the type of the building.

The data about air distribution must include the outdoor temperature, the indoor temperature, the difference between the indoor and outdoor temperature and the heating and cooling loads.
2.7. Data on the lighting system

The building model which undergoes an energy performance simulation is also provided with lighting system. The data on the lighting system describes information about the output and about the type of control. The output of the lighting system can be task lighting or general lighting. The choice of the output depends on the building’s function and on the types of activities from the rooms.

3. The stages of building performance simulation

After gathering and inserting the large amount of input data, the building performance simulation goes through 4 different stages defined by Reference (The Australian Institute of Refrigeration, Air Conditioning and Heating, 2015). These stages of simulation are briefly described in the following paragraphs.

3.1. The 3D building model

In this stage, the modeler defines the shape and layout of the building, the position of the windows and shading, the construction materials, the surface finishes and the ventilation openings. The location of the building must be set using the correct geographical position and climate with the aid of the weather data file. The weather data file can be taken for the test reference year (TRY) or for the meteorological reference year (MRY).

In this step can be calculated the daylight, shading and glare for the building model. Also the façade loads can be predicted.

3.2. Internal heat gains

In this stage of the building performance simulation, the building model is filled with people, equipment and lighting, usually using set default profiles determined by the modeling protocol. The modeler must ensure that the values used accurately reflect the known tenant loads if the model is to be used to predict actual energy or comfort. Depending on the software used for the simulation of the model, the operation of the windows may be included.

In this part of the simulation, the thermal comfort of naturally ventilated buildings can be predicted. Also, the building fabric performance can be predicted and optimized.
3.3. **HVAC plant**

Within this stage, the building’s HVAC system is modeled. The level of output depends on the modeler, on the tools used and on the level of detail required. In this stage the thermal comfort can be predicted. The HVAC energy consumption can also be predicted and the design and/or equipment selection can be optimized.

Generally it is necessary to calculate the capacity of the building service equipment prior to doing the energy simulation. These calculations are usually done by building services consultants. The calculations of the capacity of building service equipment may lead to a number of recalculation or iterations depending on the results of the energy simulation.

3.4. **Non-HVAC energy consumption**

In this stage of building performance simulation is calculated the energy consumption of non-HVAC equipment such as lighting, domestic hot water, lifts or ventilation fans. The calculations are usually done on a spreadsheet. However some modeling packages perform these calculations automatically.

In this stage the complete building energy consumption can be calculated. Also, the design of auxiliary systems can be optimized. The analysis of the non-HVAC energy consumption can often be done independently, although the interactions between all the building systems must be simulated.

3.5. **Accuracy and validation of the building performance simulation**

The accuracy of the building performance simulation depends on the following factors (The Australian Institute of Refrigeration, Air Conditioning and Heating, 2015):

- The purpose of the simulation.
- The simulation software used.
- The weather data used.
- The accuracy of the model’s geometry and input data.
- The assumptions made regarding building operation compared to actual use.

All building performance simulation models must apply certain assumptions and simplifications around the following parameters (The Australian Institute of Refrigeration, Air Conditioning and Heating, 2015):
• Occupancy and operation schedules.
• External features and adjacent structures.
• Local climate conditions.
• Building services specifications, construction and fit outs.

The level of accuracy of the end result is directly proportional to the information provided and to the detail of the model. The further developed the design, the more accurate the model can be. The level of accuracy of the model is also proportional to the need at that design stage, which means that the model can be created even though the necessary documentation is incomplete. When the simulation is used as comparison tool, the numerical accuracy may not be as important as developing an understanding of the impact of various measures (The Australian Institute of Refrigeration, Air Conditioning and Heating, 2015).

At the end of construction, with a formal rating in sight, the building performance model needs to predict the energy consumption of all building systems as accurately as possible. It must be considered the fact that no simulation tool or model can be absolutely accurate because of the complexity of heat transfer calculations. The results of the heat transfer calculations can always be regarded as an estimate (The Australian Institute of Refrigeration, Air Conditioning and Heating, 2015).

Besides the accuracy of the building performance simulation, it is extremely important to validate the energy models during the building tuning period. The validation of the building thermal and energy model is done in order to identify (The Australian Institute of Refrigeration, Air Conditioning and Heating, 2015):

• Whether the thermal and energy model needs to be altered to reflect tenant behavior and usage of facility.
• Whether the sub-metering has issues such as calibration or faulty.
• Whether the control strategies implemented are providing the expected outcome.
• Whether the predicted energy targets are likely to be achieved.

In order to validate the building performance model and simulation, the modeler has to take into consideration three very important aspects (S. Attia, 2015):

1. The building survey

   The modeler must have adequate knowledge of building occupancy and use, of HVAC function and use and some measures for all electrical demand in the building (S. Attia, 2015). This can only be achieved by obtaining the necessary documentation listed in Section 1.1.

2. The simulation program
The modeler must ensure that the simulation tool he has chosen to use for the building model has passed the ASHRAE BESTest. The BESTest’s aim is to compare the results of different simulation tools for a series of attributes (U.S. Department of Energy, 2014b). Also the modeler must make sure that he has the adequate documentation presented in Section 1.1. The modeler’s experience and knowledge of the simulation tool is also a very important factor in the validation of the building performance simulation.

3. Output critique

After the simulation of the building model, the modeler must critically interpret the output data. He has to check on the thermal loads, on the annual energy use and on the hourly profile. The modeler must ensure that the simulation makes sense by figuring out if the final results are close to reality or not. He also must ensure that the overall savings level is plausible and if not, then the modeler must check for possible errors in the input data or in the model settings (S. Attia, 2015).

4. The modeling protocol and the model resolution

The following Master Thesis presents the building performance simulation of a Multi Storey Residential Building which is a reference building from Romania located in the urban area. The reference building from Romania is simulated by considering the following case studies:

- Romanian Benchmark.
- Romanian Standard.

The building performance simulation of the Romanian Multi Storey Residential Building will follow the modeling protocol from Reference (Shady Attia, 2015) which consists into the following steps:

- **Step 1 – Information gathering:** gather information from different field surveys about in order to create a model benchmark.
- **Step 2 – Data collection:** collect the input data by creating a model template suitable for the simulation tool.
- **Step 3 – Identification of modeling goals:** establish the purpose of the building performance simulation like efficient thermal insulation, establishing a certain annual energy demand, calculate the energy costs.
- **Step 4 – Model building:** create the building model by using the input data from the model template which contains information about the weather data, building geometry, thermal zoning, constructions, lighting, occupancy, plug loads, HVAC systems and utility rates.
- **Step 5 – Run the simulation**
• **Step 6 – Debug**: to check if there are certain errors from inserting the input data or creating the building model’s geometry.

• **Step 7 – Verification and accuracy**: check if the building model is accurate, if the input is valid, check the calibration of the unit of measurements and of the robustness of the model. The purpose of this step is to avoid having unrealistic results.

• **Step 8 – Optimization**: which can be done by Parametric Analysis, Uncertainty Analysis and Automated Optimization.

• **Step 9 – Visualization of results**

• **Step 10 – Interpretation of results**

• **Step 11 – Design recommendations**: based on the results of the simulation establish technical solutions such that the building model fulfills the passive house, nZEB or ZEB standard.

In the Figure 4.1 is represented the flow chart adapted to the modeling protocol from Reference (Shady Attia, 2015).

The model resolution is a mathematical and physical modeling detail used in each design stage to represent the following: the process of energy transfer or conversion in the building envelope and inside the building, generation of electricity and useful heat from PV panels, heating, ventilation and cooling and artificial lighting and daylight. Generally, the model resolution is different within the stages of design because it reflects the availability and certainty of design details.

In the stage of conceptual design, when the geometric parameters of the building are chosen, there isn’t enough information to perform a detailed dynamic thermal simulation of the building’s response. Therefore, in the conceptual phase is used a simplified model that captures the essential dynamic thermal characteristics of the building. In this phase, the modeler must determine the appropriate level of resolution which is necessary to model the building performance accurately to be able to make basic decision such as window area or thermal mass. Early stage design tools are often unable to analyze overheating and other passive phenomena. The PCM integrated into the building envelope require special modeling approaches to be represented (Athienitis, A. et al., 2010).

In the detailed stages of design the following methods are used (Athienitis, A. et al., 2010):

• **Transfer function based methods**. The building is modeled as a linear system. The dynamic building response is obtained by using time domain or frequency domain functions.
Finite difference methods. The energy balance equations are discretized with respect space and time. From this discretization results algebraic equations that are solved simultaneously for variables like nodal temperatures or heat flows. The finite difference methods are generally more flexible and allow modeling nonlinear processes as heat storage in PCMs. Also, in the final stages of the design the HVAC system is fully detailed.
Figure 4.1 – Flow chart adapted to the modeling protocol from Reference (Shady Attia, 2015).
5. Simulation engine and weather data files

5.1. Summary about EnergyPlus

EnergyPlus is a software developed by the U.S. Department of Energy and used for energy analysis and thermal load simulation. EnergyPlus calculates the heating and cooling loads necessary to maintain the indoor comfort of the building throughout a secondary HVAC system and coil loads and the energy consumption of the primary plant equipment. These calculations are based on the user’s description of a building model from the perspective of physical make-up and associated mechanical and other systems. The simultaneous integration of the input data described in Section 1 of Chapter IV verifies that the EnergyPlus simulation performs as would the real building (U.S. Department of Energy, 2015).

EnergyPlus has the following functions (U.S. Department of Energy, 2015):

- The solutions are integrated and simultaneous such that the building’s response and the building’s systems are tightly coupled.
- The sub-hourly time steps are user definable. These time steps are used to describe the interaction between the thermal zones and the environment, respectively the HVAC systems.
- The weather data input and output files are based on ASCII text. The weather data files include hourly and sub-hourly weather conditions, respectively standard and user definable reports.
- The solutions are based on heat balance. The heat balance is a method to determine the radiant and convective heat at the same time, on both the interior and exterior surface for each time step.
- The heat flow through the building envelope is described by conduction transfer functions.
- EnergyPlus uses 3D finite difference method and simplified analytical techniques to model the ground heat transfer.
- The absorption/desorption of humidity into building elements is taken into consideration by two methods: layer by layer integration into conduction transfer function and by Effective Moisture Penetration Depth model (EMPD model).
- The thermal comfort models are based on activity, inside dry bulb temperature, humidity etc.
- The diffuse solar radiation on tilted surfaces is calculated using the anisotropic sky model.
- The calculations of the glazing surfaces include layer by layer heat balances. These allow proper assignment of solar energy absorbed glazing surfaces.
• The day lighting controls include interior luminance calculations, glare simulation and control, luminaire controls and the effect of reduced lighting on heating and cooling loads.

• EnergyPlus simulation engine runs calculations which predict CO2, SOx, NOx and CO emissions, particulate matter and hydrocarbon production for a certain location and remote energy conversion.

In order to develop EnergyPlus, U.S. Department of Energy runs several tests using industry standard methods. The purpose of the tests is to make EnergyPlus as bug free as possible. The tests which are currently conducted on EnergyPlus are the following (U.S. Department of Energy, 2014b):

1. **Analytical tests**
   - HVAC tests based on ASHRAE Research Project 865.
   - Building fabric tests based on ASHRAE Research Project 1052.

2. **Comparative tests**
   - International Energy Agency Solar Heating and Cooling Programme (IEA SHC), BESTest (Building Energy Simulation Test) methods which are not included yet in Standard 140.
   - EnergyPlus HVAC Component Comparative tests
   - EnergyPlus Global Heat Balance tests

3. **Release and executable tests**

5.2. **The weather data files**

Civil engineers and architects who perform building performance simulation have a wide variety of weather data available from locally recorded weather data to pre-selected typical years. There are over 2,100 locations available on the official website of U.S. Department of Energy. The weather data files provided by U.S. Department of Energy have the EPW extension which comes from EnergyPlus Weather format.

The thermal and energy simulation users may have special needs for different locations. So the official website of U.S. Department of Energy also lists other websites that may provide user locations which may not be found on the official website. If a user decides to find weather data files on other websites than of U.S. Department of Energy, they are advised to check if the existing weather data file with the EPW extension is within 30 – 50 km and within 100 meters of elevation.
Also users are advised to avoid using single year, Test Reference Year (TRY) type weather data files. The reason why modelers must avoid these weather data files is because one year can not represent the typical long term weather patterns. U.S. Department of Energy recommends complete methods for creating artificial years that represent the temperature, the solar radiation and other parameters from the recorded period. The methods recommended by U.S. Department of Energy are more suitable because the predicted energy consumption and energy costs will be closer to the long term average. The methods are used for Typical Meteorological Year 2 (TMY2) and Weather Year for Energy Calculations 2 (WYEC2). TMY2 and WYEC2 have improved solar models and are closer to the long-term average climatic conditions (U.S. Department of Energy, 2014a).

The sources which supply appropriate weather data files for simulation are the following (U.S. Department of Energy, 2014a):

- **Weather Bank**: maintains hourly and daily historical data records on a real time basis from every National Weather Service reporting station in the United States, as well as other locations around the world. The hourly archiving has been active since late November, 1994 (U.S. Department of Energy, 2014a).

- **National Climatic Data Center**: is located in the U.S.A. and is the world’s larges active archive of weather data which produces numerous climate publications and responds to data requests from all over the world (U.S. Department of Energy, 2014a).

- **Weather Source**: provides historical and real-time digital weather information for more than 10,000 locations across the United States and around the world (U.S. Department of Energy, 2014a).

- **Weather Analytics**: it provides site specific weather files in EnergyPlus format based on the user’s choice of the most current 30, 15, or 10 years of hourly data for any official weather station on more than 650,000 35-km grid tiles across the globe. Both Typical Meteorological Year (TMY) files and individual, Actual Meteorological Year (AMY) files are available, as are files constructed from the previous 12 months (U.S. Department of Energy, 2014a).

- **Meteonorm**: contains files in EnergyPlus format for specific locations which can be purchased. Meteonorm extrapolates hourly data from statistical data for a location. Where statistical data aren't available, Meteonorm interpolates from other nearby sites (U.S. Department of Energy, 2014a). The drawback of this source is the fact that weather files generated from statistics will not demonstrate the normal hour-to-hour and day-to-day variability seen in measured data (U.S. Department of Energy, 2014a).
• **White Box Technologies:** provides instant web access to the following weather data sets: ASHRAE IWEC2 (International Weather for Energy Calculations) "typical year" weather files for 3,012 international locations outside of US and Canada and historical year weather files from 2006 through 2012 for over 10,000 stations around the world, including over 1,500 in the U.S.A. and 300 in Canada, earlier years being available upon request.

In the simulation ran for the Master Thesis research, the weather data files used are the ones from Cluj-Napoca city. The weather data files of Cluj-Napoca contain information about the weather in the area (i.e. temperatures, rainfalls, humidity) which were recorded in year 2002. The hourly weather data files for Cluj-Napoca were taken from the official website of U.S. Department of Energy.

6. The choice of DesignBuilder

6.1. General description of DesignBuilder software

The building performance simulation of the Multi Family House from Romania is done using the software DesignBuilder. DesignBuilder was chosen for this research because it is a user friendly modeling environment which works with virtual building models. DesignBuilder provides a range of environmental performance data such as energy consumption, carbon emissions, comfort conditions, daylight luminance, maximum summer time temperatures and HVAC component sizes. The typical functions of DesignBuilder are the following (DesignBuilder Software, n.d.-f):

- Calculation of the building’s energy consumption.
- Evaluation of façade options for overheating and aesthetics.
- Thermal simulation of naturally ventilated buildings.
- Reports of savings in artificial lighting due to use of daylight.
- Prediction of natural daylight distribution through radiance simulations.
- Visualization of site layouts and solar shading.
- Calculating the heating and cooling equipment sizes.
- Detailed simulation and design of HVAC and natural ventilation systems including the impact of supply air distribution on temperature and velocity distribution within a room using CFD.
- ASHRAE 90.1 and LEED energy models.
- Economic analysis based on construction costs, utility costs and life cycle costs.
- Design optimisation with multiple objectives, constrains and design variables.
In DesignBuilder, the environmental performance data is displayed without the need to run external modules and import data. Any simulation required to generate the data is started automatically. DesignBuilder software shows the simulation data in annual, monthly, daily, hourly or sub-hourly intervals. The simulation data shown by DesignBuilder are the following (DesignBuilder Software, n.d.-a):

- Energy consumption broken down by fuel and energy use.
- Indoor temperatures.
- Weather data.
- Heat transmission through building elements.
- Heating and cooling loads.
- Generation of CO2 emissions.

DesignBuilder generates EnergyPlus .IDF files. The EnergyPlus .IDF files are necessary to work outside DesignBuilder in order to access EnergyPlus system functionality. The EnergyPlus system functionality is not provided by DesignBuilder and that’s why these .IDF files need to be generated. DesignBuilder is also provided with parametric analysis screens which allow the user to investigate the effect of variations in design parameters on a range of performance criteria (DesignBuilder Software, n.d.-a).

The models created in DesignBuilder are organised in a simple hierarchy (DesignBuilder Software, n.d.-c). Figure 4.2 shows the hierarchy of the model.

![DesignBuilder model hierarchy](DesignBuilder Software, n.d.-c).

The data is inherited from the level above in the hierarchy. For example, the data from the Block level is inherited from the Building level, the data from the Zone level is inherited from the Block level and the data from the Surface level is inherited from the Zone level. This hierarchy allows the user to make settings or changes at Building level which become active throughout the whole building. Also, the user can make changes or settings at Block level which are inherited by all the zones and surfaces from the block.
The DesignBuilder hierarchy mechanism allows the user to set the data globally in a fast way into the building model. It is recommended that the amount of input data should be minimum in order to have an efficient inheritance system. For example, if all the zones from a block have the same activity, then the activity should be set at Block level and not multiple times at Zone level (DesignBuilder Software, n.d.-c).

The DesignBuilder software is provided also with templates which allow the user to load the data quickly and in bulk into the building model. When working with similar types of buildings, the user may create his own templates. By creating custom model templates, the user is able to load any data into any building models he will work with in the future (DesignBuilder Software, n.d.-d).

For the Master Thesis research was created a model template of the Romanian Multi Storey Residential Building for DesignBuilder. The model template contains input data for the two cases of simulations presented in Section 2. The details about the model template can be found in Appendix IV.

6.2. Thermal zoning in DesignBuilder

After introducing the geometric data of the building in the simulation tool described in the previous section, the building model must be divided into thermal zones before the simulation is run. The thermal zoning of the building model depends on the following criteria (Shady Attia, 2014):

- **Usage**: the rooms which have the same thermal loads and occupancy schedules.
- **Temperature control**: the rooms which have the same heating/cooling temperature set-point.
- **Solar gains**: the perimeter zones which have glazed surfaces. There should be at least one thermal zone for each cardinal point. The opaque exterior surfaces can be combined in this case. Also, when dividing the building model into thermal zones according to solar gains, it is important to take into consideration the shading elements.
- **Perimeter or interior locations**: there are perimeter zones having 30 – 38 cm length which require heating during cold season, resulting into a separate thermal zone. Also, there are core spaces which can require cooling during warm seasons, which is also a separate thermal zone.
- **The type of the distribution system**: the rooms which are served by the same type of distribution system may be included into one thermal zone.
- **Conditioned room**: if the room is cooled or heated.
• **Unconditioned room:** if the room is neither heated or cooled. Unconditioned rooms may be the space between the false ceiling and soffit, which is not used as returned air plenum, the attic, the crawl space and the garage.

• **The plenum:** it is a room used for the return air. An example of space used for return air is the atrium. Besides the circulation of return air, in the plenum also takes place the heat transfer.

The simplest way to divide a building model into thermal zones is by taking in consideration the orientation of the rooms with respect the compass directions. For example, the rooms which are directed to South are considered to be a part of the same thermal zone, while the rooms which are directed with respect North are included in a different thermal zone. The number of thermal zones in the building model has an influence in the simulation time. If the number of thermal zones in the building model is high, then the simulation of the building takes longer than in case of lower number of thermal zones. But a detailed thermal zoning of the building model may offer more accurate results than in case of simple thermal zoning.

In DesignBuilder, thermal zoning is done at Block level. The building model is automatically divided into thermal zones by drawing partitions. In case of large building models, this default automatic thermal zoning may be postponed in order to avoid mistakes (DesignBuilder Software, n.d.-g). If the partition doesn’t connect at both ends with the exterior walls or other partitions, then DesignBuilder simulation tool defines it as “hanging partition”. The hanging partitions do not create thermal zones and are modeled non-geometrically in EnergyPlus as internal thermal mass (DesignBuilder Software, n.d.-b).

If the modeler has to sub-divide the space into two different thermal zones and in the real building there is no partition wall, DesignBuilder offers the user the option of “virtual partitions”. The virtual partitions are used for separating perimeter zones from core zones in case there is a different HVAC provision and when carrying out day lighting or overheating studies in situations where a large open plan space is subjected to a high level of solar gains around the perimeter. The virtual partitions are placed to create separate perimeter and core zones such that the local effect of the solar gains in the perimeter zone may be calculated. If the virtual partitions are not used in the overheating studies of the building, then the risk of overheating may be underestimated due to the distribution of the solar gains throughout the open plan space (DesignBuilder Software, n.d.-e).

The virtual partitions are modeled using a hole that fills the whole surface area. The DesignBuilder user can not draw custom openings on a virtual partition (DesignBuilder Software, n.d.-e).
The way the building model is divided into thermal zones, by taking into account the criteria mentioned above, and the choice of the number of thermal zones in the building, depends on the modeler and on the accuracy of the expected results. These two aspects may also depend on the time available for building performance simulation. This means that a short deadline of the results may require a simple thermal zoning of the building, while a longer deadline, combined with high exigency, may require a detailed thermal zoning.
CHAPTER V: THE BENCHMARK MODEL FOR THE ROMANIAN MULTI STOREY RESIDENTIAL BUILDING

1. Introduction

The following chapter describes the development of the Romanian benchmark model of a Multi Storey Residential building located in Blaj, Alba County, Romania. The reasons why that building was chosen is because it is representative for the Romanian building stock and because I had access to data on its architecture and energy consumption. The steps in developing the benchmark model are:

1. Establishing the energy characteristics of the building by survey
2. Create the geometry of the building.
3. Introduce the input data templates into the simulation tool.
4. Run the simulation.
5. Calibrate the model such that the final results will match with the real energy consumption from the survey.
6. Validate the model by using validation measures.
7. Comparison and interpretation of the final results.

The simulation tool used in the research is DesignBuilder which is a user friendly interface for EnergyPlus simulation engine. The survey of the building was done by gathering energy bills from the companies S.C. Electrica S.A. and E.ON Gaz Romania which operate in Blaj. The validation measures used for the model are the Annual Percentage Error and the Root Mean Square Deviation.

The following sections are describing in detail the steps of developing the benchmark model of an existing building.

2. The description of the multi storey residential building

The first step in developing the benchmark model is to choose an existing building from the Romanian building stock. For the Master Thesis research, the subject of study is a Multi Storey Residential Building, located in the town of Blaj, Alba County, in Romania and which was built at the beginning of 1980s. The building’s height regime consists of technical basement, ground floor and four levels. The planar shape of the building is “L” and it is composed of 5 different sectors: sector A, B, C, D, and, respectively E. Sector A is the building directed with the main facades to East and West, sector B is the building located in the corner of the “L” and sectors C, D and E have
the main facades directed to South and North. The total built area of the building is $1811 \text{ m}^2$. In Figure 5.1 is the satellite imagine of the existing building captured from Google Maps.

Figure 5.1 – The satellite imagine of the real building as seen in Google Maps. From left to right: sector A, sector B (the corner of the “L”), sector C, sector D and sector E.

Sector A, directed East – West, has the built area 427.61 $\text{m}^2$ and includes the apartments numbered from 1 to 20. On the ground floor has 4 apartments with the following surfaces:

- One 2 room apartments with the area 65.02 $\text{m}^2$.
- Two 1 room apartments with the areas 50.16 $\text{m}^2$, respectively 51.06 $\text{m}^2$.
- One 3 room apartment with the area 91.12 $\text{m}^2$

On the current floor, sector A has 4 apartments with the following surfaces:

- One 3 room apartment having the area: 91.12 $\text{m}^2$.
- Three 2 room apartments having the areas 73.56 $\text{m}^2$, respectively 75.81 $\text{m}^2$.

Sector B, located in the corner of the “L”, has the built area 382.61 $\text{m}^2$. It contains the apartments numbered from 21 to 35. On the ground floor it has 3 apartments with three rooms with the areas 90.28 $\text{m}^2$, 98.53 $\text{m}^2$ and respectively 86.58 $\text{m}^2$. On the current floor, sector B has 3 apartments with the following surfaces:

- Two 3 room apartments, with the areas 90.28 $\text{m}^2$, respectively 98.53 $\text{m}^2$.
- One 4 room apartments, with the area 106.64 $\text{m}^2$. 

91
Sectors C, D and E, directed South – North, have the same architecture and their area is 332.56 m². On the ground floor they have three 2 room apartments with the areas 66.04 m², respectively 63.06 m². On the current floor, these sectors have four 2 room apartments with the area 66.04 m². Because sectors C, D and E have similar layouts, only sector C was simulated. Also, the data on energy bills obtained from the providers SC Electrica SA and E.ON Romania are only for sector C. Sector C includes the apartments numbered from 36 to 54.

The layouts of the apartments from sector A, sector B and, respectively sector C are represented in Appendix V.

The five sectors of the building not only have different orientations and apartment layouts, but they also have different sizes of openings. Sector A has the following sizes of openings:

- Room windows: 1.50 m × 1.50 m = 2.25 m²
- Doors from balconies: 0.80 m × 2.10 m = 1.68 m²
- West façade entrance door: 0.80 m × 2.10 m = 1.68 m²
- East façade entrance door: 1.30 m × 2.10 m = 2.73 m²

Sector B is provided with the following openings:

- Room windows: 1.20 m × 1.20 m = 1.44 m²
- Kitchen windows: 1.30 m × 1.20 m = 1.56 m²
- Stair case windows: 0.80 m × 1.20 m = 0.96 m²
- West façade bedroom windows: 2.00 m × 1.20 m = 2.40 m²
- West façade bathroom windows: 0.60 m × 0.60 m = 0.36 m²
- Doors from balconies: 0.80 m × 2.10 m = 1.68 m²
- North façade entrance door: 0.80 m × 2.10 m = 1.68 m²

Sectors C, D, E have the following types of openings:

- Living room windows: 1.80 m × 1.20 m = 2.16 m²
- Bedroom windows: 1.30 m × 1.20 m = 1.56 m²
- Kitchen and inner balcony windows: 2.00 m × 1.20 m = 2.40 m²
- North façade entrance door: 1.00 m × 2.10 m = 2.10 m²
- South façade entrance door: 0.80 m × 2.10 m = 1.68 m²

3. Energy characteristics of the reference building

The energy characteristics of the existing building was established by survey. For the first 54 apartments from the chosen Multi Storey Residential Building located in Blaj, Alba County, the
energy consumption was surveyed by gathering the electricity and natural gas bills from year 2014. The electricity bills were provided by the distributor S.C. Electrica S.A. and the gas bills were provided by the company E.ON Romania. These two companies operate in Blaj. The surveyed apartments belong to sectors A, B and, respectively C.

The real behavior of the tenants was not studied in the Master Thesis. The study of the activity in the existing building required the agreement of tenants and my presence in the town of Blaj, in Romania, because the research was elaborated from Liege, Belgium. My presence in the town of Blaj required extra costs related to transport and more available time for the research.

In the figures below are represented the average monthly electricity, respectively natural gas consumption for sector A, sector B and, respectively sector C in year 2014, measured in $kWh/m^2/month$. The monthly energy consumption was calculated with the help of Excel sheets and using the numerical data provided by the electricity, respectively gas bills.

![Monthly Electricity Consumption for Sector A](image)

*Figure 5.2 – The monthly electricity consumption for Sector A.*

In Figure 5.2. is the bar chart of the monthly electricity consumption of Sector A. It can be observed that the highest electricity consumption is recorded in January, while the lowest electricity consumption is in June. The high electricity consumption from August is probably related with the use of air conditioning system from some apartments. In August 2014 were recorded high temperatures which made the tenants use the air conditioning from their apartments.
In Figure 5.3, is the monthly electricity consumption of Sector B. As in the previous case, the highest consumption is recorded in January, but the lowest consumption is recorded in February. This might be related to the fact that some of the apartments of the building were not occupied in that period.

Figure 5.4 – The monthly electricity consumption for Sector C.
Figure 5.4 presents the monthly electricity consumption of Sector C. As in Sector A and Sector B, the highest electricity consumption is in January. The lowest energy consumption is recorded in December in this case. This may be related to the fact that most apartments from Sector C were not occupied in that month. In December is also the Christmas season so this might be another reason for having unoccupied apartments and low electricity consumption.

Figure 5.5 – *The monthly natural gas consumption for Sector A.*

Figure 5.5 describes the monthly energy consumption of Sector A. It is observed that in January and November, the natural gas consumption is high, while in March, June and September is low. A similar situation is also in Figure 5.6 which shows the monthly natural gas consumption for Sector B. The lowest natural gas consumption are recorded in March and in September. This situation may be due to the fact that March 2014 had an unusual warm weather or some apartments were not occupied.
In Figure 5.7, which shows the monthly natural gas consumption of Sector C, the situation is very different from the other two sectors. The lowest natural gas consumption is in September. The reason might be that September 2014 had mild weather so tenants didn’t require heating or the use of more domestic hot water or in that period most of the apartments were unoccupied.
As it can be observed in Figures 5.2, 5.3 and, respectively 5.4, the highest electricity consumption is registered in January. The highest value of natural gas consumption is also registered in January as it shows in Figures 5.5, 5.6 and, respectively 5.7. This means that January is the coldest month in Romania, so the heating demand was high in that period. The high values of the natural gas consumption of all the three sectors during the summer season (i.e. June, July, August) doesn’t come from heating, it comes from the use of domestic hot water. Because June, July and August are very hot in Romania, the domestic hot water demand is also high.

The values of the electricity, respectively of the natural gas consumption taken from the bills of the surveyed apartments are influenced by the following factors:

- The local weather of Blaj.
- The winter holidays, when most of the indwellers are home.
- The summer holidays, when most of the indwellers are out from the city.
- The national holidays from Romania.
- Some apartments are most of the times unoccupied.
- Some tenants take measures to save energy such as low heating set point temperatures, lights turned off when watching television etc.

The real buildings sectors have an average annual energy consumption as following:

- Sector A: 57.70 kWh/m²/year
- Sector B: 50.38 kWh/m²/year
- Sector C: 60.96 kWh/m²/year

These values show that the existing buildings are far from being passive. Even though the tenants take measures to reduce the energy consumption, these values are influenced by the structure of the building’s envelope. The real building doesn’t have a uniform thermal insulation on the exterior wall, which means that some apartments are insulated, some are not insulated with a layer of polystyrene. To reach the passive building standard, the first measures that have to be taken are in improving the structure of the building’s envelope.

4. The description of the Romanian benchmark model

4.1. The description of the building elements and their U-values

The Romanian benchmark model of the chosen Multi Storey Residential Building has the structure formed by ACC masonry walls. The structural walls have the thickness 40 cm. The slabs of the building are made of reinforced concrete and have the thickness 15 cm, except the slab from
the technical basement which has the thickness 20 cm. In the Romanian Benchmark, the exterior walls are provided with a layer of thermal insulation made of extruded polystyrene, with the thickness 10 cm.

The floors from inside the apartments, the cold floor, respectively the warm floor, have a layer of thermal insulation made of rigid mineral wool, with the thickness 3.5 cm. The floors from the stair well and entrance halls, having the finishing layer made of mosaic, have no thermal insulation in the Romanian Benchmark. The roof of the building is flat and is not occupied. The layer of thermal insulation of the flat roof is made of extruded polystyrene and has the thickness 15 cm.

In the following figures are presented the interior structure of the building elements in the Romanian Benchmark. The figures represent screen caps from the simulation tool DesignBuilder.
Figure 5.8 – The structure of the (a) exterior wall, (b) interior wall, (c) cold floor, (d) warm floor, (e) stair well floor and (f) flat roof in the Romanian benchmark as seen in DesignBuilder simulation tool.

The exterior doors of the apartments are opaque doors, swinging U-0.500 (2.839) and the interior doors are solid hardwood door (normally hung). Both apartment doors, interior and exterior, are not glazed.

In the Romanian benchmark, the permeability class is set to be medium. This means that the building is provided with exterior joinery with sealing elements. The values of the infiltrations through cracks which correspond to medium permeability were chosen according to Table 9.7.3 from Mc001/1 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea I – Anvelopa clădirii, 2006). The value of the infiltrations through cracks is 0.5 h⁻¹.

The U-values of the building elements from the Romanian Benchmark were calculated according to C107 – 2005, Part 3 (C107 – 2005: Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor. Partea a 3-a – Normativ privind calculul performanțelor termotehnice ale elementelor de construcție ale clădirilor, 2005) and were compared to the maximum allowed values from the standard C107 – 2011, the annex with modifications (Ordin pentru modificarea reglementării tehnice ”Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor” indicativ C107 – 2005, aprobată prin Ordinul ministrului transporturilor, construcțiilor și turismului nr. 2.055/2005, 2010). These values are not corrected by taking into consideration the thermal bridges. The U-values of the elements of the building envelope are as following:
- Exterior wall: 0.263 $W/m^2K$. Maximum value imposed by the Romanian standard C107 – 2011, the annex with modifications: 0.56 $W/m^2K$.
- Interior wall: 0.933 $W/m^2K$. Maximum value imposed by the Romanian standard C107 – 2011, the annex with modifications: 0.56 $W/m^2K$.
- Cold floor: 0.988 $W/m^2K$. Maximum value imposed by the Romanian standard C107 – 2011, the annex with modifications: 0.35 $W/m^2K$.
- Warm floor: 0.916 $W/m^2K$. Maximum value imposed by the Romanian standard C107 – 2011, the annex with modifications: 0.35 $W/m^2K$.
- Cold floor for stairs: 2.770 $W/m^2K$. Maximum value imposed by the Romanian standard C107 – 2011, the annex with modifications: 0.35 $W/m^2K$.
- Non-trafficable flat roof: 0.252 $W/m^2K$. Maximum value imposed by the Romanian standard C107 – 2011, the annex with modifications: 0.20 $W/m^2K$.

In DesignBuilder, the U-values of the elements of the building envelope in the Romanian Benchmark model are the following:

- Exterior wall: 0.263 $W/m^2K$.
- Interior wall: 0.614 $W/m^2K$.
- Cold floor: 0.894 $W/m^2K$.
- Warm floor: 0.867 $W/m^2K$.
- Cold floor for stairs: 2.370 $W/m^2K$.
- Non-trafficable flat roof: 0.261 $W/m^2K$.

The U-values provided by DesignBuilder simulation tool are close to the values computed according to the standard C107 – 2005, Part 3 (C107 – 2005: Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor. Partea a 3-a – Normativ privind calculul performanțelor termoelmatiche ale elementelor de construcție ale clădirilor, 2005) and they also exceed the maximum value accepted by standard C107 – 2011, the annex with modifications (Ordin pentru modificarea reglementării tehnice “Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor” indicativ C107 – 2005, aprobată prin Ordinul ministrului transporturilor, construcțiilor și turismului nr. 2.055/2005, 2010).

4.2. *The characteristics of the glazed surfaces*

In the Romanian Benchmark, the building is provided with double glazed thermopane windows, having normal emissivity and the solar transmittance $g = 0.75$. The joinery is made of
UPVC. The double glazed window has the dimensions 4-12-4 mm and has a layer filled with air. The value of the total solar energy transmittance \( g_i \) is taken from Section I.9.6.1. from Mc001/1 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea I – Anvelopa clădirii, 2006). The U-value of this type of glazing is 2.9 \( W/m^2K \) and is taken from Table 9.4.3, from Mc001/1 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea I – Anvelopa clădirii, 2006). The U-value calculated by DesignBuilder is 2.897 \( W/m^2K \).

4.3. The general characteristics of the HVAC system

4.3.1. Natural ventilation

The building is not provided with mechanical ventilation in this case, therefore the ventilation is ensured by natural means. The values of the maximum natural ventilation rate are chosen according to the air exchange done through windows on two facades according to Table 2.6, Section 2.3.4 from Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006), as following:

- During daytime: 4 \( h^{-1} \)
- During nighttime: 7.5 \( h^{-1} \)

The values were also chosen according to the opening surface of the window \( S_{fd} \), which is the ratio between the effective opening surface of the window and the total surface of the window. In this case the value taken is \( S_{fd} = 0.5 \).

In DesignBuilder, the maximum natural ventilation rate was set 5 ac/h.

4.3.2. The heating system

The use of auxiliary energy and air temperature distribution are not available for this case. Also, the building is not endowed with air conditioning system in the Romanian Benchmark model. The building is provided with central heating system which runs on natural gas and which has the average efficiency \( \eta = 0.85 \). The central heating system is based on radiators with water.

Besides the type of the heating system and the fuel used, the building model was also provided with heating schedules. The heating schedule depends on the occupancy and on the
function of the room. In the following figures are presented an example of a heating schedule from a conditioned space and a heating schedule from an unconditioned space. In the rooms which are conditioned, the heating schedule was set as following: from January until March, the heating system is on, from April until September the heating system is off and from October until December the heating system is on again.

4.4. The characteristics of the lighting system

The task lighting is not available in this case. In residential buildings, the presence of task lighting is not always necessary. For residential buildings, the general lighting is uniformly distributed and the type of control used is manual light switch. As in the case of the heating system, the lighting system also has a schedule set according to the occupancy and function of the room. In the figures below are a few examples.

The lighting schedule of the bathroom is different during the weekdays and during the weekend. During the weekdays, the lighting is set on from 7:00 – 9:00 and 18:00 – 23:00, because between 9:00 – 18:00 the tenants are considered to be out of the room. During weekends, the lighting is set from 7:00 – 23:00, because the tenants are considered to be home all day. The entrance hall is a space which is occasionally occupied, which means that the tenants pass there as they enter, respectively exit the building. The lighting is set to be on only between 18:00 – 7:00, because the entrance hall is supposed to use the daylight from 7:00 – 18:00. Also, since most of the stair wells don’t have windows, the lighting is set on all day long.

4.5. The description of activity in the building

The activity of the building is described by the internal heat gains, by occupancy, by the quantity of domestic hot water used and by the environmental parameters.

4.5.1. The internal gains

The values of the internal gains were evaluated for a family composed of 2 adults and 2 children according to Annex II.5.E from Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006). The value of the internal gains from cooking activity is a standard value given by Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor.)
Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006), in the Annex II.5.E. The internal heat gains have the following values:

- Internal gains from human activity: 260 W
- Internal gains from the use of domestic hot water: 80 W
- Internal gains from cooking: 100 W
- Internal gains from equipment: 430 W
- Internal gains from lighting (Table E.2, Annex II.5.E, Mc001/2 – 2006):
  - For a large sized apartment with children (> 100 m²): 60 W
  - For an average sized apartment with children (50 – 100 m²): 45 W

In DesignBuilder simulation tool, the value of the internal gains was introduced as an average between the values presented above for each type of zone as following:

- Bathroom: 68.75 W/m²
- Bedroom: 44.82 W/m²
- Hall: 25.63 W/m²
- Kitchen: 76.25 W/m²
- Living room: 44.82 W/m²
- Unconditioned occupied spaces (stair well, entrance hall): 16.95 W/m²
- Interior balcony (available for sector C): 49.52 W/m²

4.5.2. The occupancy of the building

In DesignBuilder, the input value for the density of people per surface is 0.050 person/m² in order to have 4 people in one apartment. The metabolic rate has different values for adult males, adult females and, respectively, children so the input value is an average between the values mentioned before. The average value of the metabolic rate is 0.87 met.

Along with the level of occupancy in the building and the metabolic rate, was established the occupancy schedule. The occupancy schedule for the Multi Storey Residential Building was set as follows:

- During weekdays: 7:00 – 9:00 and 18:00 – 23:00.
- During weekends: 7:00 – 23:00.
4.5.3. The environmental parameters of the building

Because in the Romanian benchmark the building is not provided with mechanical ventilation and air conditioning system, the cooling and the ventilation set point temperatures are not available in this case. The heating set point temperature depends on the function of the room. In the case of Romanian Benchmark model, the set point temperatures of the rooms are the following:

- Bedroom, kitchen, living room and hall: 18°C.
- Bathroom: 22°C.

The set point temperatures for heating were chosen according to the real set point temperature for heating established by the indwellers and according to the Romanian standard for designing heating plants SR 1907 (SR1907-1: Instalații de încălzire. Necesarul de căldură de calcul. Prescripții de calcul, 1997). Besides the heated rooms, the Multi Storey Residential Building has semi-exterior and unconditioned spaces and also unoccupied rooms. The rooms from the building which are not heated are: the stair well, the entrance halls, the dryer rooms and the inner balconies specific to sector C. The rooms which are unoccupied are the dressing, the storages and the technical basement.

The values of the required luminance levels were taken from Annex 13.1 of Mc001/1 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea I – Anvelopa clădirii, 2006) and are the following:

- Lateral: 100 lx
- Lateral and downwards: 200 lx

In DesignBuilder, the level of luminance was set at 200 lx.

The values of the required fresh air level per person were taken from Table 2.20, Section 2.6.9 from Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006) and depend on the presence of smokers in the room:

- Non smokers: 22 – 36 m³/s · person
- Smokers: 43 – 72 m³/s · person

In DesignBuilder simulation tool the fresh air level required per person was set to 8 l/s/pers.

5. The simulation and calibration of the Romanian benchmark model

The Romanian benchmark model was simulated in DesignBuilder. The weather data file used in the simulation was the from the city of Cluj-Napoca and it was downloaded from the
official website of U.S. Department of Energy. Each of the three sectors, A, B and, respectively C, were modeled separately since they are 3 separate buildings with different apartment layouts, a different geometry and different position with respect the cardinal directions. The neighbor sector which is attached to the modeled sector was represented as an adiabatic block. Also, to simplify the model, the second and the third floors were modeled as one adiabatic block because their thermal zoning is similar to the first floor. The zones from the first floor were multiplied.

Each of the apartment from the sector was modeled as one block and the block was divided into thermal zones corresponding to the rooms of the apartment. Each of the thermal zone was assigned with an activity specific to the function of the room. For example, there is a thermal zone for living rooms, for kitchens, for bedrooms et cetera. In Appendix V are represented the layouts of the apartments from sectors A, B and C and the thermal zones inside them as captured from DesignBuilder simulation tool.

In the figures below are captures from DesignBuilder which show the geometry of sector A, B and respectively C.

![Figure 5.9 – The model of Sector A.](image-url)
The geometry of the three building sectors was modeled with the help of plans of the existing buildings. These plans were converted from .DWG format to .DFX format and then they were imported into DesignBuilder. The building plans were provided by the design office for gas installations S.C. Proinstal S.R.L. from Alba Iulia, S.C. Pro Ex Florin S.R.L from Cugir and S.C. Cris Flor Gaz S.R.L. from Blaj. The original architecture plans of the existing building could not be found because the building was designed before 1989. Due to the communist regime, there were no private design offices that could archive the drawings properly.
5.1. The calibration of the input parameters

The use of building performance simulation softwares for creating benchmark models is based on post-decision trial and error approach. This means that the final results of the simulation are compared to a desired value (Shady Attia, 2012). In the case study elaborated for the Master Thesis, the results of the simulation are compared to the monitored energy consumption of each building sector (i.e. Sector A, Sector B and Sector C). If the final results are not satisfactory, then the benchmark model must be calibrated and the simulation is repeated.

After the first simulation of the benchmark model, the resulted values of the annual electricity, respectively of the natural gas consumption at building level were larger than the monitored values at the same level. So to obtain values of annual fuel consumption at building level close to the monitored values, the benchmark model had to be calibrated. The calibration of the Romanian benchmark model meant the adjustment of the input parameters such that the annual fuel consumption per surface at building level is close to the monitored annual fuel consumption per surface (i.e. \( kWh/m^2/yr \)). The input parameters which had to be adjusted to calibrate the Romanian benchmark model were:

- The efficiency of the heating system.
- The lighting energy
- The operation schedule of the heating system
- The operation schedule of the lighting system

The first adjustments were made in the operation schedules of the heating system, respectively of the lighting system. Initially, the operation schedules of the heating and lighting system were set by default at 100%. This was the main reason why the simulated annual fuel consumption at building level was larger than the monitored annual fuel consumption. The operation schedule of heating was reduced gradually at 50% and then at 30% for all the sectors, and after each reduction the simulation was run. It was noticed that the annual natural gas consumption at building level has decreased, but it wasn’t close to the monitored value. The same steps were followed also in the case of lighting energy: the lighting operation schedule was reduced at first to 50% and after running the simulation, the annual electricity consumption at building level was also reduced, but the value was not close to the monitored one.

Reducing the operation schedule of the heating system was not enough to bring the annual natural gas consumption close to the monitored value. So another adjustment was made at the heating system CoP. The initial value of the heating system CoP was 0.85 for all the three sectors. For sector A, the value of the heating system CoP was adjusted at 0.93, for sector B at 0.90 and for
sector C at 0.80. At the same time, the operation schedule of the heating was reduced to 10% for sector A and, respectively to 20% for sectors B and C.

In case of the lighting energy, the initial value was 5 \( W/m^2 \). To calibrate the value of the annual electricity consumption, the operation schedule of the lighting was reduced to 30%, while the lighting energy was increased. For sector A the lighting energy was increased to 7 \( W/m^2 \), for sector B to 8 \( W/m^2 \) and for sector C to 10 \( W/m^2 \).

After adjusting the parameters (the heating system CoP, the lighting energy, the operation schedule of the heating, respectively the lighting) the simulation was run again. The resulted annual fuel consumption at building level was finally close to the monitored annual fuel consumption. The final results and the comparison between the existing building sectors and the Romanian benchmark model are presented in the next paragraph.

5.2. The final results after the calibration of the Romanian benchmark model

The adjustment of the heating system CoP, the lighting energy, the operation schedule of the heating, respectively the lighting in DesignBuilder simulation tool brings the following results listed in Tables 5.1 and 5.2:

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Annual Electricity Consumption [kWh/m2/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monitored Consumption</td>
</tr>
<tr>
<td>Setor A</td>
<td>17.90</td>
</tr>
<tr>
<td>Setor B</td>
<td>16.11</td>
</tr>
<tr>
<td>Setor C</td>
<td>19.83</td>
</tr>
</tbody>
</table>

*Table 5.1 – The annual electricity consumption.*
<table>
<thead>
<tr>
<th>Building Name</th>
<th>Annual Natural Gas Consumption [kWh/m2/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monitored Consumption</td>
</tr>
<tr>
<td>Setor A</td>
<td>97.50</td>
</tr>
<tr>
<td>Setor B</td>
<td>84.64</td>
</tr>
<tr>
<td>Setor C</td>
<td>102.08</td>
</tr>
</tbody>
</table>

*Table 5.2 – The annual natural gas consumption.*

The difference between the monitored annual fuel consumption and the simulated annual fuel consumption can be observed better in the charts from the Figures 5.12 and 5.13:

*Figure 5.12 – The difference between the monitored annual electricity consumption and the simulated annual electricity consumption.*
At the annual level, the difference between the monitored energy consumption and the simulated energy consumption at building level is not very large. At monthly level, the situation is different. The monthly electricity consumption and the monthly natural gas consumption are represented in the charts from the Figures 5.14 and 5.15.
Figure 5.14 – The difference between the monitored monthly electricity consumption and the simulated monthly electricity consumption.

In Figure 5.14 is observed that at Sector B between the monitored monthly electricity consumption and the simulated monthly electricity consumption is a large difference. Large differences between the monitored monthly natural gas consumption and the simulated monthly natural gas consumption are observed in Figure 5.15 in case of all sectors. These large differences between the monitored values of the monthly energy consumption and the simulated values come from the weather data files and the surveyed data. The values of the energy consumption which come from the bills are from year 2014. The weather data files of Cluj-Napoca used in the simulation contain information about the recorded weather from 2002, as displayed in DesignBuilder in the monthly energy consumption. This means that the weather recorded in 2002 was different from the weather recorded in 2014.
A solution to reduce the large differences between the monitored values and the simulated values at the monthly level is to create a new weather data file for year 2014, but this aspect does not fall into one of the milestones of the Master Thesis. Creating a new weather data file is a long and complicated process because it requires gathering and processing of hourly weather data recorded in Blaj or Cluj-Napoca weather station. So a simple and fast solution is to analyze the errors between the simulated values and measured values and to establish if the errors are fulfilling an imposed tolerance. The analysis of the errors is described in the next paragraph.

**5.3. Model validation by error analysis**

The validation of the Romanian benchmark model is done by error analysis. In the error analysis is established whether the differences between the simulated values and monitored values of the energy consumption are fulfilling an imposed tolerance. The imposed tolerance for this simulation is 15%. The error analysis was done using the following model validation measures:

- The Annual Percentage Error
• The Root Mean Square Deviation

The formulae must be used with caution because they often differ slightly from one published source to another within the field of building performance simulation.

5.3.1. The Annual Percentage Error

The Annual Percentage Error analyzes the difference in percentage between the simulated annual energy consumption and the measured annual energy consumption. The Annual Percentage Error is calculated with the following formula:

\[ APE = \frac{y_{simulated} - y_{measured}}{y_{measured}} \cdot 100 \]  

Where:

APE: Annual Percentage Error.

\( y_{simulated} \): The value of the simulated annual energy consumption.

\( y_{measured} \): The value of the measured annual energy consumption.

After applying the formula 5.1, the following results were obtained:

<table>
<thead>
<tr>
<th>Sector A - The Annual Percentage Error</th>
<th>Electricity</th>
<th>0.084</th>
<th>8.352 %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural Gas</td>
<td>0.015</td>
<td>1.523 %</td>
</tr>
</tbody>
</table>

*Table 5.3 – The annual percentage error for sector A.*

<table>
<thead>
<tr>
<th>Sector B - The Annual Percentage Error</th>
<th>Electricity</th>
<th>0.126</th>
<th>12.608 %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural Gas</td>
<td>0.009</td>
<td>0.875 %</td>
</tr>
</tbody>
</table>

*Table 5.4 – The annual percentage error for sector B.*

<table>
<thead>
<tr>
<th>Sector C - The Annual Percentage Error</th>
<th>Electricity</th>
<th>0.034</th>
<th>3.381 %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural Gas</td>
<td>0.004</td>
<td>0.392 %</td>
</tr>
</tbody>
</table>

*Table 5.5 – The annual percentage error for sector C.*
As seen in Tables 5.3, 5.4 and, respectively 5.5, the differences between the measured annual consumption and the simulated annual consumption are not exceeding the 15% limit. The largest percentage difference between the measured energy consumption and simulated energy consumption is in Sector B, in the electricity and is 12.608% (See Table 5.4). The smallest difference between the measured energy consumption and simulated energy consumption is in Sector C, in the natural gas and is 0.392% (See Table 5.5). At the annual level, the Romanian benchmark model is valid.

5.3.2. The Root Mean Square Deviation

The Root Mean Square Deviation measures the differences between the values predicted by a model and the values actually observed. This measure is applied to monthly or hourly data. In this case, the values predicted are the values resulted from the simulation of the Romanian benchmark building model and the values actually observed are the values taken from the electricity, respectively the natural gas bills. The formula of the Root Mean Square Deviation used in this case study is the following:

\[
RMSD = \sqrt{\frac{\sum_{t=1}^{n}(x_{1,t} - x_{2,t})^2}{n}}
\]  

(5.2)

Where:

**RMSD**: Root Mean Square Deviation

\(x_{1,t}\) : The value of the measured monthly energy consumption from the first time series.

\(x_{2,t}\) : The value of the simulated energy consumption from the second time series.

\(n\) : The number of data points.

After applying formula 5.2, the following results were obtained:
<table>
<thead>
<tr>
<th>Sector A</th>
<th>Sector B</th>
<th>Sector C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00004</td>
<td>0.00015</td>
<td>0.01842</td>
</tr>
<tr>
<td>0.01520</td>
<td>0.34073</td>
<td>0.00124</td>
</tr>
<tr>
<td>0.01028</td>
<td>0.00036</td>
<td>0.00011</td>
</tr>
<tr>
<td>0.00039</td>
<td>0.00449</td>
<td>0.00477</td>
</tr>
<tr>
<td>0.00188</td>
<td>0.10225</td>
<td>0.00102</td>
</tr>
<tr>
<td>0.00520</td>
<td>0.00713</td>
<td>0.00018</td>
</tr>
<tr>
<td>0.00267</td>
<td>0.01418</td>
<td>0.00367</td>
</tr>
<tr>
<td>0.02626</td>
<td>0.18694</td>
<td>0.00014</td>
</tr>
<tr>
<td>0.02145</td>
<td>0.01226</td>
<td>0.01087</td>
</tr>
<tr>
<td>0.03667</td>
<td>0.02346</td>
<td>0.01608</td>
</tr>
<tr>
<td>0.06429</td>
<td>0.19439</td>
<td>0.02257</td>
</tr>
<tr>
<td>0.43555</td>
<td>0.77315</td>
<td>0.57049</td>
</tr>
</tbody>
</table>

| Sum      | 0.61986  | 1.65949  | 0.64958  |
| Average  | 0.05166  | 0.13829  | 0.05413  |
| RMSD     | 0.22728  | 0.37187  | 0.23266  |

*Table 5.6 – The RMSD of the monthly electricity consumption.*

<table>
<thead>
<tr>
<th>Sector A</th>
<th>Sector B</th>
<th>Sector C</th>
</tr>
</thead>
<tbody>
<tr>
<td>87.36185</td>
<td>71.49148</td>
<td>54.88050</td>
</tr>
<tr>
<td>39.90052</td>
<td>29.84493</td>
<td>14.55790</td>
</tr>
<tr>
<td>77.45711</td>
<td>62.99851</td>
<td>4.12392</td>
</tr>
<tr>
<td>4.51494</td>
<td>6.20024</td>
<td>0.00006</td>
</tr>
<tr>
<td>0.16503</td>
<td>0.06271</td>
<td>5.00470</td>
</tr>
<tr>
<td>27.13248</td>
<td>2.16256</td>
<td>19.02216</td>
</tr>
<tr>
<td>3.63471</td>
<td>0.82410</td>
<td>11.10096</td>
</tr>
<tr>
<td>2.96723</td>
<td>0.38732</td>
<td>10.86019</td>
</tr>
<tr>
<td>24.06837</td>
<td>7.93550</td>
<td>40.15396</td>
</tr>
<tr>
<td>8.18905</td>
<td>9.64190</td>
<td>0.14047</td>
</tr>
<tr>
<td>106.58643</td>
<td>34.84878</td>
<td>13.67230</td>
</tr>
<tr>
<td>6.82630</td>
<td>5.56947</td>
<td>31.23123</td>
</tr>
</tbody>
</table>

| Sum      | 388.80400| 231.96748| 204.74835|
| Average  | 32.40033| 19.33062| 17.06236 |
| RMSD     | 5.69213  | 4.39666  | 4.130661 |

*Table 5.7 – The RMSD of the monthly natural gas consumption.*

In Table 5.6 is observed that the Root Mean Square Deviation has small values which means that the difference between the simulated monthly electricity consumption and the measured
monthly electricity consumption isn’t large. In case of the monthly natural gas consumption, shown in Table 5.7, there Root Mean Square Deviation has larger values than in case of the monthly electricity consumption, which means that the differences between the measured and simulated data are larger in case of natural gas consumption. This difference is, as explained before, due to the fact that the measured data is taken from the bills issued in year 2014, while the weather data file used in the simulation has weather data recorded in year 2002. Still, the differences are not large enough to state that the monthly natural gas consumption of the Romanian benchmark model is far from reality. Therefore, the Romanian benchmark model is also valid at the monthly level.
CHAPTER VI: THE ROMANIAN STANDARD MODEL

1. Introduction

The Romanian benchmark model was created, was calibrated and was validated using the model validation measures. After going through these processes, the Romanian benchmark model was completed and the next step is to apply the requirements of the Romanian standard C107 – 2011, the modified annex (Ordin pentru modificarea reglementării tehnice ”Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor” indicativ C107 – 2005, aprobată prin Ordinul ministrului transporturilor, construcțiilor și turismului nr. 2.055/2005, 2010) and Mc001 – 2006. In this case study, two situations are taken into consideration: the Romanian standard model only with heating system and the Romanian standard model with air conditioning system. The differences between the Romanian standard model and the Romanian benchmark model are reflected in the building envelope and in the endowment with mechanical ventilation and air conditioning system. The calibrations are taken from the Romanian benchmark.

2. The description of the Romanian Standard model

2.1. The description of the building elements and their U-values

The Romanian Standard model of the Multi Storey Residential Building has the same structure in the building envelope, but the difference from the Romanian Benchmark is in the thickness of the thermal insulation layer. In DesignBuilder, the thickness of the thermal insulation layer is set such that the U-value is close to the values from the Romanian standard C107 – 2011. In the Romanian Standard, the exterior walls are provided with a layer of thermal insulation made of extruded polystyrene, just like in the previous case, but this time with the thickness 1.5 cm. The interior floors, the cold floor, respectively the warm floor, have the layer of thermal insulation made of rigid mineral wool, with the thickness 12 cm. The floors from the stair well and entrance halls have a layer of thermal insulation with the thickness 12 cm in the Romanian Standard model. Also, the layer of thermal insulation of the unoccupied flat roof, made of extruded polystyrene, has the thickness 20 cm in this case.

In the following figures are presented the cross sections of the building elements in the Romanian Standard model. The figures represent screen caps from the simulation tool DesignBuilder.
Figure 6.1 – The structure of the (a) exterior wall, (b) cold floor (c) warm floor, (d) stair well floor and (e) flat roof in the Romanian Standard as seen in DesignBuilder simulation tool.

The exterior and interior doors of the apartments are similar with the Romanian Benchmark model (See Chapter V, Section 2.1).

In the Romanian Standard model, the permeability class is set to be low. This means that the building is provided with mechanical ventilation and the exterior joinery has special sealing elements. The values of the infiltrations through cracks which correspond to medium permeability...
were chosen according to Table 9.7.3 from Mc001/1 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea I – Anvelopa clădirii, 2006).

The U-values of the building elements from the Romanian standard are the maximum allowed U-values from the standard C107 – 2011, the annex with modifications (Ordin pentru modificarea reglementării tehnice "Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor" indicativ C107 – 2005, aprobată prin Ordinul ministrului transporturilor, construcțiilor și turismului nr. 2.055/2005, 2010). The U-values of the elements of the building envelope are presented below:

- Exterior wall: 0.56 $W/m^2K$.
- Interior wall: N/A.
- Cold floor: 0.35 $W/m^2K$.
- Warm floor: 0.35 $W/m^2K$.
- Cold floor for stairs: 0.35 $W/m^2K$.
- Non-trafficable flat roof: 0.20 $W/m^2K$.

In DesignBuilder, the U-values of the elements of the building envelope in the Romanian standard model are the following:

- Exterior wall: 0.536 $W/m^2K$.
- Interior wall: 0.614 $W/m^2K$.
- Cold floor: 0.355 $W/m^2K$.
- Warm floor: 0.351 $W/m^2K$.
- Cold floor for stairs: 0.354 $W/m^2K$.
- Non-trafficable flat roof: 0.201 $W/m^2K$.

The U-values provided by DesignBuilder simulation tool are close to the values from standard C107 – 2011, the annex with modifications (Ordin pentru modificarea reglementării tehnice "Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor" indicativ C107 – 2005, aprobată prin Ordinul ministrului transporturilor, construcțiilor și turismului nr. 2.055/2005, 2010).

2.2. The characteristics of the glazed surfaces

The building model from the Romanian standard is provided with double glazed thermopane window, having one surface provided with a reflecting layer against infrared rays and with the solar transmittance $g = 0.50$. The joinery is made of UPVC, as in the Romanian benchmark. The double
glazed window has the dimensions 4-12-4 mm and has a layer filled with Argon. The value of the total solar energy transmittance \( g_t \) is taken from Section I.9.6.1. from Mc001/1 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea I – Anvelopa clădirii, 2006). The U-value of the glazing is 1.7 \( W/m^2K \) which is taken from Table 9.4.3, from Mc001/1 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea I – Anvelopa clădirii, 2006). The U-value calculated by DesignBuilder is 1.142 \( W/m^2K \).

2.3. The general characteristics of the HVAC system

2.3.1. Natural ventilation

The values of the maximum natural ventilation rate are chosen according to the air exchange done through windows on two facades according to Table 2.6, Section 2.3.4 from Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006), as following:

- During daytime: 4 \( h^{-1} \)
- During nighttime: 7.5 \( h^{-1} \)

As in the case of the Romanian benchmark, the values were chosen according to the opening surface of the window \( S_{fd} \), which is the ratio between the effective opening surface of the window and the total surface of the window, and the value taken is \( S_{fd} = 0.5 \).

In DesignBuilder, the maximum natural ventilation rate was set 5 ac/h.

2.3.2. Mechanical ventilation

In the Romanian standard, the building is provided with mechanical ventilation. According to Table E.2, Annex II.2.E from Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006), the maximum mechanical ventilation rate depends on the room’s function and has the following values:

- For kitchens: 108 \( m^3/h \)
- For bathrooms: 36 \( m^3/h \)

In DesignBuilder, the mechanical ventilation rate was set to be 2 ac/h in the kitchens and in the bathrooms of the apartments.
2.3.3. The heating and the cooling system

The use of auxiliary energy and air temperature distribution are also not available in the case of Romanian Standard. The efficiency of the air conditioning system is $\eta = 0.17$. The value of the cooling CoP is taken from Annex II.2.L from Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006) with respect to the building function. To keep the calibration of the Romanian benchmark model, for the Romanian standard model was used the average efficiency $\eta = 0.85$ for the air conditioning system, the same as the heating system. The building is provided with central heating system which runs on natural gas and which has the efficiency $\eta = 0.85$, as in the Romanian benchmark model. The central heating system is based on radiators with water.

The building’s heating schedule is similar with the one from the Romanian Benchmark (See Chapter V, Section 2.3.2). The unconditioned spaces (i.e. the stair case, the entrance halls) are not endowed with air conditioning system. Also, the bathrooms are not endowed with air conditioning systems.

As in the previous case, the heating schedule was set as following: from January until March, the heating system is on, from April until September the heating system is off and from October until December the heating system is on again. The cooling schedule is set to be on from May until August. The operation schedule of the cooling system was reduced to 10%, as for the heating system, in order to maintain the calibration.

2.4. The characteristics of the lighting system

As in the Romanian benchmark model, the task lighting is not available because in residential buildings, the presence of task lighting is not always necessary. For residential buildings, the general lighting is uniformly distributed and the type of control used is manual light switch. The lighting schedule is set as in the Romanian benchmark. For more details, see Chapter V, Section 2.4.

2.5. The description of activity in the building

2.5.1. The internal gains
As in the previous case, the values of the internal gains were evaluated for a family composed of 2 adults and 2 children according to Annex II.5.E from Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006). The value of the internal gains from cooking activity is a standard value given by Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006) in the Annex II.5.E. The chosen values are found in Chapter V, Section 3.5.1. As in the previous case, in DesignBuilder simulation tool, the value of the internal gains was introduced as an average between the values presented above for each type of zone as following:

- Bathroom: 68.75 W/m²
- Bedroom: 44.82 W/m²
- Hall: 25.63 W/m²
- Kitchen: 76.25 W/m²
- Living room: 44.82 W/m²
- Unconditioned occupied spaces (stair well, entrance hall): 16.95 W/m²
- Interior balcony (available for sector C): 49.52 W/m²

### 2.5.2. The occupancy of the building

The occupancy level and occupancy schedule are similar to the Romanian benchmark model. For details regarding occupancy, see Chapter V, Section 2.5.2.

### 2.5.3. The environmental parameters of the building

In the Romanian Standard model, the building is provided with mechanical ventilation and air conditioning system. Therefore, besides the heating set point temperature, there is also a cooling, respectively a mechanical ventilation set point temperature. The cooling set point temperature is 25°C, while the mechanical ventilation set point temperature is 18°C. The heating set point temperature depends on the function of the room and in the case of Romanian Standard model, they are the following:

- Bedroom, kitchen, living room and hall: 20°C.
- Bathroom: 22°C.
The heating set point temperatures were chosen according to the Romanian standard for designing heating plants SR 1907 (SR1907-1: Instalații de încălzire. Necesarul de căldură de calcul. Prescripții de calcul, 1997). As in the Romanian Benchmark model, the Multi Storey Residential Building has semi-exterior and unconditioned spaces and also unoccupied rooms, which are the stair case, the entrance hall, storages and dressings.

The values of the required luminance levels were taken from Annex 13.1 of Mc001/1 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetic ale clădirilor. Partea I – Anvelopa clădirii, 2006) and are the following:

- Lateral: 100 lx
- Lateral and downwards: 200 lx

The values of the required fresh air level per person were taken from Table 2.20, Section 2.6.9 from Mc001/2 – 2006 (Mc001 – 2006: Metodologie de calcul al performanței energetic ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri, 2006) and depend on the presence of smokers in the room:

- Non smokers: $22 - 36 \text{ m}^3/\text{s} \cdot \text{person}$
- Smokers: $43 - 72 \text{ m}^3/\text{s} \cdot \text{person}$

In DesignBuilder simulation tool the fresh air level required per person was set to 8 l/s/pers.

3. Results of the simulation of the Romanian Standard model

After running the simulation for both the Romanian standard model only with heating system and the Romanian Standard model with air conditioning system, the annual energy consumption is shown in Tables 6.1 and 6.2 and in the charts from Figures 6.2 and 6.3. The Romanian standard model is compared only with the Romanian benchmark model.
<table>
<thead>
<tr>
<th>Building Name</th>
<th>Annual Electricity Consumption [kWh/m²/yr]</th>
<th>Romanian Benchmark Simulated</th>
<th>Romanian Standard Heated Simulated</th>
<th>Romanian Standard Cooled Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setor A</td>
<td></td>
<td>19.39</td>
<td>19.91</td>
<td>19.98</td>
</tr>
<tr>
<td>Setor B</td>
<td></td>
<td>18.14</td>
<td>18.97</td>
<td>18.98</td>
</tr>
<tr>
<td>Setor C</td>
<td></td>
<td>20.50</td>
<td>21.33</td>
<td>21.33</td>
</tr>
</tbody>
</table>

*Table 6.1 – The annual electricity consumption.*

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Annual Natural Gas Consumption [kWh/m²/yr]</th>
<th>Romanian Benchmark Simulated</th>
<th>Romanian Standard Heated Simulated</th>
<th>Romanian Standard Cooled Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setor A</td>
<td></td>
<td>98.98</td>
<td>106.82</td>
<td>106.82</td>
</tr>
<tr>
<td>Setor B</td>
<td></td>
<td>85.38</td>
<td>94.09</td>
<td>94.09</td>
</tr>
<tr>
<td>Setor C</td>
<td></td>
<td>102.48</td>
<td>109.73</td>
<td>110.32</td>
</tr>
</tbody>
</table>

*Table 6.2 – The annual natural gas consumption.*
In Figures 6.2 and 6.3 is observed that by applying the maximum allowed U-values from the Romanian standard, the energy consumption has increased compared to the benchmark model. This
increase is due to the layer of thermal insulation from the exterior walls which had to be decreased in order to reach the U-value $0.56 \, W/m^2K$. In Figure 6.2 can be observed that in the Romanian standard model with air conditioning system, the annual electricity consumption has increased compared to the Romanian standard model without heating system. This variation is clearly observed in Sector A and in Sector B. The increase in the electricity consumption in the Romanian standard model with air conditioning system is due to the fact that the air conditioner uses electricity from the grid. Therefore, in the hot season months (i.e. May, June, July, August), when the air conditioning system is functioning, the electricity consumption increases.

In Figures 6.4 and 6.5 is the monthly electricity consumption in the Romanian standard model without the air conditioning system, respectively with the air conditioning system. In Figure 6.6 is the monthly natural gas consumption for the Romanian standard generally. The presence or absence of air conditioning system doesn’t influence the natural gas consumption because the air conditioning system uses electricity from the grid.

![Monthly Electricity Consumption](image)

*Figure 6.4 – The monthly electricity consumption for Romanian Standard without air conditioning system.*
Figure 6.5 – The monthly electricity consumption for Romanian Standard with air conditioning system.

Figure 6.6 – The monthly natural gas consumption for Romanian Standard.
The final results of the simulation of the Romanian benchmark and of the Romanian standard models and the design recommendations are discussed in the next chapter.

4. Conclusion

As seen from the results listed, by applying the values of the Romanian national standard, the energy consumption of sectors A, B and respectively C has increased. In Table 6.3 are the differences in percentage between the energy consumption of the benchmark model and the energy consumption of the standard model with and without air conditioning system. In the natural gas consumption can be observed a difference between 7 – 10% between the benchmark model and the standard model. In the electricity consumption, between the benchmark model and the standard model is a difference between 2 – 4%.

The reason behind the increase in natural gas consumption lies in the structure of the building envelope. The exterior walls of the benchmark model have 10 cm extruded polystyrene and a U-value of $0.263 \ W/m^2\ K$. In the Romanian standard model, the maximum U-value is $0.560 \ W/m^2\ K$ and to reach this value, the layer of thermal insulation of the exterior wall had to be decreased.

<table>
<thead>
<tr>
<th>Setor</th>
<th>Electricity</th>
<th>Natural Gas</th>
<th>Electricity</th>
<th>Natural Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setor A</td>
<td>2.66%</td>
<td>7.92%</td>
<td>3.00%</td>
<td>7.92%</td>
</tr>
<tr>
<td>Setor B</td>
<td>4.59%</td>
<td>10.20%</td>
<td>4.61%</td>
<td>10.20%</td>
</tr>
<tr>
<td>Setor C</td>
<td>4.04%</td>
<td>7.07%</td>
<td>4.07%</td>
<td>7.64%</td>
</tr>
</tbody>
</table>

Table 6.3 – The differences in percentage between the energy consumption of the benchmark model and energy consumption of the standard model.
The differences in energy consumption between the benchmark model and the Romanian standard model are quite large. This means that the Romanian standard requirements are not as strict as the Passive House requirements. The Romanian standard hasn’t been upgraded since year 2011. Therefore, the Romanian standard for energy performance needs to be tighten by reducing the maximum allowed U-values for the building elements.
CHAPTER VII: DESIGN RECOMMENDATIONS FOR ACHIEVING PASSIVE BUILDING, RESPECTIVELY nZEB STANDARD

1. The analysis of the final results of the building performance simulation

After the simulation of the Romanian Benchmark model, respectively Romanian Standard model described in Chapter V, respectively Chapter VI, the average annual energy consumption of each building sector (i.e. Sector A, Sector B and Sector C) is presented in the Table 7.1 and, respectively, in Figure 7.1:

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Average Annual Energy Consumption [kWh/m²/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monitored Consumption</td>
</tr>
<tr>
<td>Setor A</td>
<td>57.70</td>
</tr>
<tr>
<td>Setor B</td>
<td>50.38</td>
</tr>
<tr>
<td>Setor C</td>
<td>60.96</td>
</tr>
</tbody>
</table>

Table 7.1 – The average annual energy consumption for Sector A, B, and respectively C for each case study
Figure 7.1 – The average annual energy consumption for Sector A, B, and respectively C for each case study

As seen in Table VII.1 and Figure VII.1, the real building and the benchmark model have high annual energy consumption compared to the Romanian Standard model. The average annual energy consumption decreased for the Romanian Standard model because improvements were done to the structure of the building envelope. The improvements were increasing the thickness of the thermal insulation layer for the external walls, cold floor, warm floor and, respectively the roof, and adding a layer of thermal insulation for the floor outside the apartments (i.e. the stair well, the dryer rooms, the entrance halls). With these improvements made to the building envelope such that it fulfills the Romanian standard requirements, Sector A, B and C are still far from being passive buildings.

To reach the passive building standard, Sector A, B and, respectively C, must fulfill the following conditions, according to the Passive House Planning Package 2007 (Dr. Wolfgang Feist, n.d.):

- The annual heat demand must be lower than $15 \text{ kWh/m}^2\text{yr}$.
- The heat load must be lower than $10 \text{ W/m}^2$.
- The excessive temperature frequency must be lower than 10% (higher than 25°C).
• The annual primary energy demand must be lower than 120 \( \text{kWh/m}^2 \text{yr} \). This also includes energy for the electrical appliances.

To classify the buildings studied in the Master Thesis as Zero Energy Buildings, then the energy used for their activity must come from renewable sources.

To achieve the passive house standard, Sector A, B and respectively C must undergo the following improvements (Dr. Wolfgang Feist, n.d.):

• The building envelope must be provided with very good thermal insulation which will be carefully executed in detail.

• The building must have high level of air tightness. Practically, the building is completely sealed from the exterior environment.

• The heat losses through windows must be low. This means that the window frames must be well sealed such that there will not be thermal bridges. Also, the glazed surface of the windows must have high heat gains.

• The building should be provided with an efficient mechanical ventilation system with heat recovery.

• The building must be provided with efficient services, electrical devices and lighting.

Reaching the nearly Zero Energy Building standard, even Zero Energy Standard is more difficult because implementing the nZEB standard requires parametric analysis. In the parametric analysis, different building variants are discussed and compared to the benchmark model from the energy efficiency and cost point of view. In the end, the building variant which offers an optimal solution is chosen. This type of parametric analysis is also known as Cost – Optimal Methodology and was introduced in the Energy Performance of Buildings Directive (EPBD) by the European Union.

2. Comparing the research outcomes with the literature review

Out of the research questions presented in the literature review analysis from Chapter II, in Table 2.1, only the development of an accessible benchmark model for residential buildings was achieved. The benchmark model was developed for multi storey residential buildings. The reason for answering only one research question was the available time. Developing a benchmark model for any type of building requires a lot of time because it involves gathering data about the existing building, calibration of the model to obtain satisfactory results and the validation of the model.

Applying the cost – optimal approach described in Section 3 of this chapter to obtain an optimal solution for achieving the nZEB standard is also a long process. It involves the simulation
of at least 10 building models each provided with its own package of measures. The package of measures contains solutions regarding the building envelope, HVAC system and the use of energy from renewable sources.

Adding bioclimatic elements to the building also takes times. Designing a house according to the annual revolution of the Sun, as the traditional Romanian houses from the rural areas, involves daylight simulations and overheating analysis. Also the benchmark model can not be used because adding bioclimatic elements involves the design of a new architecture for the building.

3. The implementation of Cost – Optimal Methodology in Romania

3.1. General ideas about the Cost – Optimal Methodology

The Cost – Optimal Methodology is a parametric analysis method introduced by the Energy Performance of Buildings Directive (EPBD) which helps architects, civil engineers and building service engineer determine the optimal solution such that a new or an existing building fulfills the passive house or nZEB standard. The Cost – Optimal Methodology has the following principles (Boermans, Bettgenhäuser, de Vos, & Constantinescu, 2010):

- Analyzing economic and environmental benefits.
- The optimum is determined from the lowest part of the cost curve for a combination of packages of measures.
- Setting of minimum performance requirements which are represented by the area of the curve that delivers the lowest cost for the end-user and/or for the company or society.

Romania and all the other Member States have to integrate the following elements into the national legislation in order to align to the EPBD requirements (Boermans et al., 2010):

- A methodology for calculating the energy performance of buildings.
- A definition of minimum energy efficiency requirements for Romania in this case.
- Energy performance certificates for new and existing buildings.
- Regular inspection of heating and air conditioning systems.

There are certain challenges in implementing the Cost-Optimal Methodology in Romania and in the other Member States. The challenges of the implementation are the following (Boermans et al., 2010):

- When the costs are analyzed, the future environmental targets should not be ignored.
- The technical requirements of the building and its thermal comfort must be taken into consideration.
• To ensure the success of the Cost – Optimal approach, several details of the methodology must be fixed and taken into consideration properly.
• All the stakeholders must be commonly understood such that the calculations and interpretations of the final results are done in a uniform and comparable way.
• The European Commission must supply its data base with energy price forecasts and their updates.
• Further elaboration needs to be done in the distinction between private and societal perspective.
• For the comparison with greenhouse gas reduction targets, CO2 emissions could be used as additional indicator.

3.2. The steps and rules of the methodology

According to “Cost – Optimal Regulation Guidelines”, the calculation of the buildings energy performance should consider the following (Nolte et al., 2013):
• The thermal and electrical energy from renewable sources, generated and used onsite, have to be subtracted to calculate the building’s net energy demand.
• The energy which is generated on site and then exported to the market is deducted and calculated from primary energy which is associated to the energy delivered to the building.
• The characteristics of generation, distribution, emission and control systems must be taken into consideration when calculating the energy uses.
• Cost – optimal calculation is done by considering all climatic zones across the country.

The Cost – Optimal Methodology is done by going through the following steps (Nolte et al., 2013):

2. Selection of variants for thermal insulation and equipment.
3. Primary energy demand calculation.
5. Cost – optimal calculation from the financial perspective.

When choosing the reference building, the following rules must be taken into account (Nolte et al., 2013):
The reference building must be similar with a building from the existing building stock or the new buildings stock of each country and must be defined according to the building’s characteristics and analysis purpose.

In order to define reference buildings with simple and common geometries, realistic and easy to be reproduced in practice, modelers must have close consultations with architects and contractors.

The reference buildings should be designed based on the plans of existing buildings with simplifications or adaptations if necessary.

The conditions at the construction market and urban planning levels must be set properly to realize the assumption from the Cost – Optimal Methodology.

Also, when establishing the packages of measures, we have to take into consideration the following aspects (Nolte et al., 2013):

- The number of packages of measures for a reference building should be at least 10.
- The reference package must contain the current requirements of national standards as benchmark for energy and cost analysis.
- The packages of measures should be elaborated as much as possible based on well established official or voluntary building standards. An example would be the on-going support programs or internationally accepted standards.
- Create ambitious packages of measures to identify the remaining performance and financial gaps. The results of the ambitious packages of measures will be further used to shape policies and market support programs.

An example of applying the Cost – Optimal Methodology in the Romanian contest is presented as summary in Chapter III of the Master Thesis and in detail in References (Nolte, Rapf, et al., 2012) and (Nolte, Griffiths, et al., 2012).

4. Design recommendations for the Romanian benchmark model

Now that the benchmark model of the multi-storey residential building from the town of Blaj, Romania, was developed, the next step will be to apply the Cost – Optimal Methodology described in the previous section in order to find solutions for the passive building or nZEB standard. In the Master Thesis, I have developed benchmark models for 3 sectors of the real building: Sector A, Sector B and Sector C. Each sector has differences regarding site orientation, apartment layout and size of the openings. Also, these three buildings are representative for the
town of Blaj, since most of the multi-storey residential buildings from the town were built around 1980s, have 4 floors and the average surface of one apartment is between 60 – 80 m².

The first design recommendation is to create a weather data file only for the town of Blaj, which will contain hourly measured weather data from recent years, like 2014 or 2015. It is necessary to have weather data files from the exact location to be able to determine accurately the heat and cool loads or the annual energy demand of the buildings. In the simulation ran for the Master Thesis research, the weather data file used were the ones from Cluj-Napoca which contained hourly measured weather data from year 2002. Even though Cluj-Napoca and Blaj are geographically in the same region (i.e. the centre of Romania) and the same climatic influences occur on their site (i.e. oceanic influences), Cluj-Napoca is at North from Blaj, which brings differences between the measured weather data from Blaj and the ones measured in Cluj-Napoca by 2 – 3°C. So to create a weather data file with EnergyPlus format, the measured weather data must be taken from Blaj’s local weather station.

Another recommendation is to create variants for thermal insulation and equipment. These variants will be created by taking into consideration the price of the thermal insulation layer per square meter and the price of the HVAC equipment. To reach the nZEB standard, we also have to study the potential for renewables of the town of Blaj. This means that we have to study whether in Blaj is efficient to provide the buildings with solar panels or if it is suitable to use biomass.

After all the solution variants were created, the buildings will be simulated again with DesignBuilder tool or any other simulation tools for energy models, the final results will be compared and the optimal solution will be determined.
CHAPTER VIII: CONCLUSION

1. Lessons learnt

After finishing the development of the Romanian benchmark model of a multi storey residential building there were three main lessons that I have learnt. These lessons are related to establishing the energy characteristics of the existing building, to the calibration of the benchmark model and to the weather data files used in the simulation tool DesignBuilder.

The first lesson learnt is about establishing the energy characteristics of the existing building. As mentioned in Chapter V, the energy characteristics of the chosen building was established by survey. The energy bills of 54 apartments which belong to the first 3 sectors of the building were gathered from the electricity provider S.C. Electrica S.A. and, respectively, from the natural gas provider E.ON Gaz Romania. In the Reference (Shady Attia et al., 2012) and (Shady Attia, 2012), the energy characteristics of the chosen buildings were also established by gathering utility bills. But unlike in the case study from the Master Thesis, besides gathering utility bills, the tenants behavior was also studied. Therefore, the energy characteristics of the multi storey residential building from Blaj would have been more accurate if there was a possibility to study the occupancy of the building. But studying the occupancy of the chosen building required returning from Liege, Belgium to the town of Blaj, which was not possible because of the rules of the Erasmus + Programme. Also, to study the occupancy of the building requires the cooperation of the tenants.

The second lesson learnt while elaborating the research is about the calibration of the model. The calibration of the benchmark models is a long process and involves the adjustments of more than four design parameters. In the case study of the Master Theses there were adjusted four design parameters. According to the References (Shady Attia et al., 2012) and (Shady Attia, 2012), the calibration of the benchmark models lasted for one year. The benchmark models were larger because there were 1500 survey responses and the representative buildings were from three different locations. In the Master Thesis there were only 54 survey responses and the building was from a single location. The time assigned for calibration depends on the size of the model, but also on the time available for research.

The third lesson learnt is that weather data files have a huge influence in the model calibration. As mentioned in Chapter IV and Chapter V, the weather data files used for the building performance simulation of the Master Thesis are from Cluj-Napoca. These weather data files were taken from U.S. Department of Energy. Even though Blaj has weather conditions similar to Cluj-Napoca because they belong to the same microclimatic region of Romania, there are still
differences in hourly temperatures. These temperature differences are due to the position of these two Romanian cities with respect to the latitude: Cluj-Napoca is located at 46°46′N 23°35′E, while Blaj is located 46°10′31″N 23°54′52″E. The U.S. Department of Energy has weather data files available only for the following cities from Romania: Cluj-Napoca, Galati, Timisoara, Constanta and Bucharest. Therefore, weather data files for EnergyPlus have to be created specially for Blaj.

2. Future research work

In Chapter II, in Table 2.1, based on the literature review about building energy performance in Romania, are formulated research open question. The Master Thesis has answered to only one of the research questions: the development of benchmark model for Romanian residential buildings. The rest of the open question which were not answered due to the short time available for writing the Master Thesis are mentioned in this section as future research work.

The first future research work is to create a new house that integrates in its design the bioclimatic elements of the Romanian traditional house mentioned in Chapter III combined with the passive house, nZEB and ZEB requirements. By using bioclimatic elements, the balance between heating demand and cooling demand may be achieved naturally. The bioclimatic elements may be as following: setting the position of the building with respect to the cardinal points (i.e. front facade to the South, back facade to the North), provide the building with a porch that is designed according to the Sun’s revolution as seen in Figure 3.5 from Chapter III or plant deciduous trees in front of the house which will be used as natural shading elements. The South – North position of the new residential buildings will also imply the urban planning of the neighborhood. The access way infrastructure must be designed such that this position can be easily achieved.

The second future work is to elaborate a parametric study of a residential building model with bioclimatic elements. In the parametric study, the energy efficiency of the innovative thermal insulation materials (i.e. PCM) is tested for each Romanian climate area. The climate variation is necessary in the parametric study because the Romanian climate is different for each area so to implement the PH, nZEB and ZEB requirements we need a variety of results. The variety of results of the parametric study applied in all the climate areas will lead to solutions particular for each climate zone from Romania.

The last future work is about upgrading the Romanian standards for energy performance in buildings in order to align them with the 2020 targets.
# APPENDIX I: RESOURCES SCREENING LIST

<table>
<thead>
<tr>
<th>No.</th>
<th>Source</th>
<th>Link</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Universitatea de Arhitectură și Urbanism „Ion Mincu” – București</td>
<td><a href="https://www.uauim.ro/">https://www.uauim.ro/</a></td>
<td>Str. Academiei nr. 18-20, 010014, București, Romania, Tel: 0040 21 307 71 12, Fax: 0040 21 307 71 09</td>
</tr>
<tr>
<td>2</td>
<td>Institutul de Cercetări în Construcții și Economia Construcțiilor INCERC – București (The Institute for Research in Civil Engineering and Economy of Constructions – Bucharest)</td>
<td><a href="http://www.incerc.ro/">http://www.incerc.ro/</a></td>
<td>Șos. Pantelimon, 266, 021652, Sector 2, București, România, Tel: 0040 21 255 00 62</td>
</tr>
<tr>
<td>3</td>
<td>Universitatea Tehnică de Construcții – București (Technical University of Civil Engineering – Bucharest)</td>
<td><a href="http://utcb.ro/">http://utcb.ro/</a></td>
<td>Bd. Lacul Tei, nr. 122 - 124, cod 020396, Sector 2, București, România, Tel.: +40 21 242.12.08, Fax: +40 21 242.07.81</td>
</tr>
<tr>
<td>4</td>
<td>Ministerul Transporturilor, Construcțiilor și Turismului (The Ministry of Transport, Constructions and Tourism)</td>
<td><a href="http://www.mt.ro/">http://www.mt.ro/</a></td>
<td>Bulevardul Dinicu Golescu nr. 38, Sector 1, București, România, Cod poștal 010873, România</td>
</tr>
<tr>
<td>5</td>
<td>Buildings Performance Institute Europe</td>
<td><a href="http://www.bpie.eu/">http://www.bpie.eu/</a></td>
<td>Rue de la Science 23, 1040 Brussels, Belgium</td>
</tr>
<tr>
<td>6</td>
<td>Scopus</td>
<td><a href="http://www.scopus.com/">http://www.scopus.com/</a></td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>SC Electrica Furnizare SA (Romanian electricity supply provider – data on energy consumption and energy price)</td>
<td><a href="http://www.electricafurnizare.ro/">http://www.electricafurnizare.ro/</a></td>
<td>The main headquarters: București, str. Grigore Alexandrescu nr. 9, Sector 1, Tel. 021.208.59.99, Fax. 021.208.59.98</td>
</tr>
<tr>
<td>8</td>
<td>Google Scholar</td>
<td><a href="https://scholar.google.com/">https://scholar.google.com/</a></td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>Science Direct</td>
<td><a href="http://www.sciencedirect.com/">http://www.sciencedirect.com/</a></td>
<td>N/A</td>
</tr>
<tr>
<td>No.</td>
<td>Source</td>
<td>Website</td>
<td>Contact Information</td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>---------</td>
<td>---------------------</td>
</tr>
<tr>
<td>10</td>
<td>CES Working Papers</td>
<td><a href="http://ceswp.uaic.ro/">http://ceswp.uaic.ro/</a></td>
<td>N/A</td>
</tr>
<tr>
<td>11</td>
<td>WSEAS</td>
<td><a href="http://www.wseas.us/">http://www.wseas.us/</a></td>
<td>N/A</td>
</tr>
<tr>
<td>12</td>
<td>Central and East European Online Library</td>
<td><a href="http://www.ceeol.com">www.ceeol.com</a></td>
<td>N/A</td>
</tr>
<tr>
<td>13</td>
<td>ENTRANZE project</td>
<td><a href="http://www.entranze.eu/">http://www.entranze.eu/</a></td>
<td>N/A</td>
</tr>
<tr>
<td>14</td>
<td>Scribd</td>
<td><a href="https://www.scribd.com/">https://www.scribd.com/</a></td>
<td>N/A</td>
</tr>
<tr>
<td>15</td>
<td>Administrația Națională de Meteorologie (The National Meteorology Administration from Romania – for weather data)</td>
<td><a href="http://www.meteoromania.ro/">http://www.meteoromania.ro/</a></td>
<td>Sos. București-Ploiești nr.97, Sector 1, Cod postal: 013686 București, Romania /Tel: +40 21 318 32 40; Fax: +40 21 316 31 43</td>
</tr>
<tr>
<td>16</td>
<td>E.ON Energie România (Romanian natural gas supply provider – data energy price for residential buildings)</td>
<td><a href="http://www.eon-energie-romania.ro/">http://www.eon-energie-romania.ro/</a></td>
<td>Sediul social: Mureș, Tîrgu Mureș, Justiției nr.12, 540069, Romania</td>
</tr>
</tbody>
</table>
## APPENDIX II: LITERATURE SURVEY LIST

<table>
<thead>
<tr>
<th>No.</th>
<th>Publication</th>
<th>Citations</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Keywords: Romania, Nzb, ZEB, implementing, passive buildings, passive house, thermal comfort, thermal insulation, building stock, Romanian house</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No.</td>
<td>Reference</td>
<td>Citation Status</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>---------------------------------------------------------------------------</td>
<td>-------------------</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Catalog cu punți termice specifice clădirilor. 2012, p. 836.</td>
<td>0</td>
<td>It should be cited.</td>
</tr>
<tr>
<td>21</td>
<td>G. Teodorescu, “Climate change impact on urban ecosystems and sustainable development of cities in Romania,” <em>WSEAS TRANSACTIONS on ENVIRONMENT and DEVELOPMENT</em>, vol. 6, no. 2, pp. 103–112, Feb. 2010.</td>
<td>12</td>
<td>Not in my subject.</td>
</tr>
<tr>
<td>No.</td>
<td>Reference</td>
<td>Information Note</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>V. Musatescu and M. Comănescu, “Energy – Climate change package impact on Romanian urban areas,” <em>CCASP TERUM</em>, vol. 4, no. 13, pp. 194–213, Nov. 2009.</td>
<td>7 In the LRM.</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Reference</td>
<td>Page</td>
<td>Notes</td>
</tr>
<tr>
<td>-----</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>38</td>
<td>I. Nolte, O. Rapf, D. Staniaszek, and M. Faber, Eds., “Implementing the Cost – Optimal Methodology in EU countries. Lessons learned from three case studies.” The Buildings Performance Institute Europe (BPIE), Mar-2013.</td>
<td>2</td>
<td>In the LRM.</td>
</tr>
<tr>
<td>40</td>
<td><strong>Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a II-a – Performanța energetică a instalațiilor din clădiri.</strong> 2006, pp. 167–481, Mc001/2-2006.</td>
<td>0</td>
<td>Should be cited in the LRM.</td>
</tr>
<tr>
<td>41</td>
<td><strong>Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea a III-a – Auditul și certificatul de performanță a clădirii.</strong> 2006, pp. 482–577, Mc001/3-2006.</td>
<td>0</td>
<td>Should be cited in the LRM.</td>
</tr>
<tr>
<td>42</td>
<td><strong>Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea I – Anvelopa clădirii.</strong> 2006, pp. 2–162, Mc001/1-2006.</td>
<td>0</td>
<td>Should be cited in the LRM.</td>
</tr>
<tr>
<td>45</td>
<td><strong>Normativ general privind calculul transferului de masă (umiditate) prin elementele de construcție.</strong> 2002. C107/6-02.</td>
<td>0</td>
<td>Should be cited in the LRM.</td>
</tr>
<tr>
<td>46</td>
<td><strong>Normativ general privind calculul transferului de masă (umiditate) prin elementele de construcție.</strong> 2002. C107/7-02.</td>
<td>0</td>
<td>Should be cited in the LRM.</td>
</tr>
<tr>
<td>No.</td>
<td>Reference</td>
<td>Cited</td>
<td>Notes</td>
</tr>
<tr>
<td>-----</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>51</td>
<td>B. Atanasiu, L. Kranzl, and A. Toleikyte, “Policy scenarios and recommendations on Nzeb, deep renovation and RES-H/C diffusion: the case of Romania. Deliverables D4.3 and D5.6 from Entranze Project.” EntraNZE, Sep-2014.</td>
<td>0</td>
<td>Should be cited in the LRM.</td>
</tr>
<tr>
<td>52</td>
<td>D. Constantinescu, “Proposition of updating the method used in calculating the heat demand based on a new concept of design outdoor temperature and of building – soil boundary heat transfer,” * Construcții*, no. 1, pp. 27–52, 2010.</td>
<td>0</td>
<td>Not related to my subject.</td>
</tr>
<tr>
<td>---</td>
<td>------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>65</td>
<td>M. C. Dascălu, “Studiul de caz privind posibilitatea de transformare a unei clădiri existente într-o casa pasiva energetic.”</td>
<td>Not related to my subject.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Authors</td>
<td>Title</td>
<td>Page Range</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>78</td>
<td>D. Constantinescu, C.-P. Stamatiade, H. Petran, and G. Caracas</td>
<td>“Validation of the software used in determining the energy performance of buildings (EPB),” Constructii</td>
<td>no. 2, pp. 3–26</td>
</tr>
<tr>
<td>79</td>
<td>V. Badescu, N. Laaser, and R. Crutescu</td>
<td>“Warm season cooling requirements for passive buildings in Southeastern Europe (Romania),” Energy</td>
<td>vol. 35, no. 8, pp. 3284–3300</td>
</tr>
</tbody>
</table>
**APPENDIX III: LITERATURE REVIEW MATRIX**

<table>
<thead>
<tr>
<th>No.</th>
<th>REFERENCE</th>
<th>STUDY PARAMETERS</th>
<th>FOCUS</th>
<th>GAP</th>
<th>FINDINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C107 – 2005: Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor. Partea 1-5. vol. I. 2005</td>
<td>The global thermal insulation coefficient of residential and non-residential buildings</td>
<td>Calculation of the thermal characteristics of the building envelope</td>
<td>The energy performance design code concentrates only on the heating of residential and non-residential buildings.</td>
<td>There are 2 different formulae for establishing the global thermal insulation coefficient for the residential, respectively non-residential buildings. In the analysis of the building elements in contact with the ground, new parameters appear: the temperature of the ground at the invariable layer level, the thermal conductivity of soil and the influence of the ground water table.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The standard global thermal insulation coefficient of residential and non-residential buildings</td>
<td>Analysis of the thermal bridges in the building envelope</td>
<td>The mechanical ventilation, domestic hot water or artificial lighting are not included.</td>
<td>The steps of the analysis of the energy performance of the building in heating are quite simple which might put in doubt the precision of the final results.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The annual heat demand</td>
<td>Special analysis of building elements in contact with ground</td>
<td>Very few mentions about the interior climate of the building.</td>
<td>The annual heat demand is influenced by the global thermal insulation coefficient, which means that in case the condition $G &lt; G_N$ is not fulfilled, then the modifications should be done in the initial calculations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The standard annual heat demand</td>
<td>The thermal inertia of non-residential buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The thermal resistances of the building elements</td>
<td>The temperatures balance sheet</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The thermal bridges</td>
<td>The calculation of the annual heat demand and of the global insulation coefficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The elements of the building envelope</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#</td>
<td>Source</td>
<td>Description</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>--------</td>
<td>-------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Mc001 – 2006: Metodologie de calcul al performanței energetice ale clădirilor. Partea I-III. 2006</td>
<td>Thermal performance, energy performance and air permeability analysis of the building envelope and its elements. Functions of the buildings and their influence on their energy performance. Performance requirements and thermal, energy and air permeability performance levels of the building envelope and its elements. The energy performance of the building services: heating, domestic hot water, mechanical ventilation, lighting. The energy audit and energy performance certificate of buildings. The calculation of the parameters of thermal and energy performance and air permeability of the building envelope. The calculation of the parameters of thermal and energy performance and air permeability of the building envelope in contact with ground. The architectural and constructive design of the building for energy efficiency. Calculation of the energy performance of the building services: heating, domestic hot water, mechanical ventilation, lighting. Alternative methods for the evaluation of the energy performances of building services. The energy audit of residential and non-residential buildings. The energy grading and energy certificate of buildings. There aren't so many details regarding the interior comfort of the buildings. Some of the calculation methods described in the code lead to results with errors. (i.e. monthly method for energy demand for cooling) Some of the formulae seem to be unclear. (i.e. the number of degree - days for the evaluation of the annual energy demand for the AC systems) Few information regarding the energy certification of the new buildings. Mc001/1 has similar content with C107-2005, Parts 1-5 with upgraded information. In the evaluation of the energy performance of the building services are used advanced methods of calculation such as iterative methods or step by step integration. Contains templates for energy audit and energy performance certificate.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>I. Nolte, N. Griffiths, O. Rapf, and A. Potcoava, Eds., “Implementing Nearly Zero-Energy Buildings (nZEB) in Romania – Towards a definition and roadmap.” The Building Performance Institute Europe (BPIE), Aug-2012.</td>
<td>Implementing the concept of Nearly Zero Energy Buildings in Romania for the existing and new buildings. State of the art Gaps in the Romanian design codes Financial analysis of nZEB solutions. The building stock of Romania. The roadmap of implementing the nZEB concept for Romanian buildings. Current regulations and practice for new buildings Current support schemes for buildings. The report about Romanian building stock concentrates only on the urban areas and not on rural areas too. There isn't a detail report about the areas with renewable energy. The cities are only mentioned. The cities: Beius, Huedin, Giurgiu are mentioned as having renewable energy, but don't have certain facts or data to prove its implementation. The Cost-Optimal Methodology was applied for 3 different reference buildings from Romania: a single family house, a multi family house and an office building. In the application of the Cost-Optimal Methodology, for each reference building were chosen at least 10 variants.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The energy performance of buildings
Cost - Optimal calculations
Implementing the Cost - Optimal Methodology in the EU countries.
The algorithm of the Cost - Optimal Methodology applied for 3 case studies:
Germany, Austria and Poland.
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 presented emphasize the
mistakes in the application of the Cost - Optimal
Methodology.
The three case studies made for the building stock
from Germany, Austria and Poland emphasize the
difference in choosing the optimal solution between
the three countries.
The differences between the 3 studied cases are
based on the reference buildings typical for the
studied country, weather conditions, design codes
and energy price.

I. Nolte, O. Rapf, D. Staniaszek, and M. Faber,
Eds., “Implementing the Cost – Optimal
Methodology in EU countries. Lessons learned
from three case studies.” The Buildings
Performance Institute Europe (BPIE), Mar-
2013.

The Cost - Optimal Methodology
The challenges of the Cost - Optimal
Methodology.
Requirements of the Cost - Optimal
Methodology.
Measures to improve the energy
performance of the buildings.
The steps of the Cost - Optimal calculations.
Changes to be done in the Energy
As the publication states, the Cost - Optimal
Methodology needs further development
The Cost - Optimal Methodology is fully
developed if all the Member States and other
stakeholders such as industries or scientific
organisations are actively involved.
The publication emphasizes the key changes that
have to be done to the Energy Performance of
The calculations using Cost - Optimal
Methodology are explained in a simple and easily
understanding manner.
The steps of the calculations are listed in a manner
such that the Cost - Optimal calculations can be
applied easily.

T. Boermans, K. Bettgenhäuser, R. de Vos,
and T. Constantinescu, Cost Optimality.
Discussing methodology and challenges
within the recast Energy Performance of

The first Romanian passive office building.
The time depending simulation of the first
Romanian passive house building using the
model Passive House Thermal Transient
(PHTT).
The description of the passive office
building, the headquarters of SC AMVIC
SRL from Bragadiru town, near Bucharest.
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 meteorological data base of the climate
zone near Bucharest.
The time dependent models used.
The analysis of the results of the PHTT
simulation.
The simulation was done on an office building.
This type of analysis can be applied also to a
passive residential building.
In the simulation of the passive office building
were used the following models: building thermal
toad model, the model of the ventilation/heating
system, the thermal target, the operation control.
The simulation using PHTT was done with a time
lag of 10 minutes 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.
According to the results given by PHTT, PHPP
monthly method and PHPP annual method, the
passive office building fulfills the passive house
standard imposed by Passivhaus Institute from
Darmstadt, Germany.

V. Badescu, N. Laaser, R. Crutescu, M.
Crutescu, A. Dobrovicescu, and G.
Tsatsaronis, “Modeling, validation and time-
dependent simulation of the first large passive
building in Romania.” Renewable Energy.,
The analysis of cooling requirements of a passive building in Romania during summer season.

The description of the passive office building, the headquarters of SC AMVIC SRL from Bragadiru, near Bucharest.

The meteorological data base of the climate zone 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.

The analysis of the cooling requirements during summer season was done on a passive office building.

Opening the windows to decrease the rate of overheating can be done in a standard building too. It is nothing new here.

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.

PHPP recommends additional cooling measures in passive buildings if the overheating exceeds 10%.

A common technique to decrease the rate of overheating is opening the windows at night during summer time and this technique was not included in the analysis.

Opening the windows to decrease the rate of overheating can be done in a standard building too. It is nothing new here.

The cooling requirements for a passive house are larger than in a standard building.

Changing the thickness of thermal insulation in the range of -20% to +20% has no influence on the cooling load.

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.


The problem of the energy saving in the existing buildings from Romania.

The thermal insulation and energy saving problem in Europe and in the world.

The thermal insulation and energy saving problem in Romania.

Case study for existing buildings in Romania.

The buildings from the case study are not residential buildings, they are schools.

The buildings from the case study are not residential buildings, they are schools.

The article states at the beginning the energy efficiency and CO2 emission reduction target imposed by EPBD and which must be achieved by all Member States by year 2020.

The variation of the Romanian standards in the field of energetic efficiency between the year 1973 - 2009.

The structure of the Romanian building stock according to the age of the buildings.

Case study presents 6 buildings from Romania which were expertized, have energy performance certificates and a part of them have been rehabilitated from the thermal point of view.

None of the buildings from the case study have renewable energy sources.

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The measure of energy consumption and the variation of the comfort parameters of the passive house built in the city of Timisoara in Romania.</td>
</tr>
<tr>
<td>The characteristics of the passive house built in Timisoara, Romania.</td>
</tr>
<tr>
<td>The results of the monitoring system show that the passive house from Timisoara doesn't fulfill the passive house standard.</td>
</tr>
<tr>
<td>In Romania there are 5 passive houses.</td>
</tr>
<tr>
<td>Implementation of the monitoring system and measured energy consumption.</td>
</tr>
<tr>
<td>Analysis of the thermal comfort parameters.</td>
</tr>
<tr>
<td>The paper states that in Romania there are 5 passive houses. One of the passive houses is the one from Timisoara which, according to the analysis results, doesn't fulfill the PH standard.</td>
</tr>
<tr>
<td>Analysis of the final results.</td>
</tr>
<tr>
<td>The paper doesn't give information about which are the other 4 passive buildings from Romania, which are their functions and where they are located on the Romanian territory.</td>
</tr>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>
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.

3 policy sets were used in case of Romania: “BaU+” (smooth but continuous tightening of building regulations until 2030), “Growing-up” (a consistent tightening of the building regulations introducing nZEB for both new and existing buildings undertaking major renovations) and “Market transformation” (supporting a fast adoption of strict nZEB requirements for new and existing buildings undertaking renovations).

2 energy price scenarios were used: the reference scenario (only on going and already planned climate policies are taken into account and that no consensus is reached at the international level) and the ambitious climate scenario (the implications of more stringent policies and reinforced support for renewables at world level driven by successful negotiations between advanced and emerging economies on climate change).

For modeling it 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.

3 renovation packages were defined: the standard package (current practice of thermal building renovation), the good package (set of measures near the cost-optimality point), the ambitious package (level of renovation near the minimum primary energy level).

<table>
<thead>
<tr>
<th>Page</th>
<th>Text</th>
</tr>
</thead>
</table>
| 11   | 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.  
11 towns from Romania are members of Convenant of Mayors, established in 2007 as a part of EU's energy and climate protection package. |
| 12   | 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 only current maintenance since then.  
Perspectives of the methodology.  
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 applied if similar properties have recently been sold or are currently on sale in the subject property's market.  
In the sales comparison approach, the wasted/saved energy (WSE) is the element of comparison between the buildings.  
If WSE is positive, then the building is highly efficient. If WSE is negative, then energy is wasted when opposed to the current legal standards.  
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. |


Romania's proposed target for renewable energy is 24% by year 2020. 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. In 2006 Romania used for the residential sector around 30% of its total energy consumption. The barriers in combating the climate change: lack of information regarding the package requirements, lack of coherent development plans and lack of financial means. The lack of financial means is not an excuse since there are a lot of EU instruments that could be used in Romania.  

<table>
<thead>
<tr>
<th>Page</th>
<th>Description</th>
</tr>
</thead>
</table>
| 13   | **Promote the energy efficiency of buildings in Romania.**  
Simulation in TRNSYS of two houses located in the campus of University Politehnica of Bucharest.  
The description of the two houses from the campus of University Politehnica 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.  
In the first model, the fresh air had the outdoor temperature and the thickness of the thermal insulation of the walls was reduced to half from the initial value.  
In the second model, two functions of the building were simulated: the house as laboratory and the house used for a family made of 4 members.  
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.  
The two analyzed houses fulfill the passive house standard. |
| 14   | **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.  
Romania has almost reached the 2020 target of renewables production. In 2010 the production of renewables was 23.4%. The target set is 24%. |
<table>
<thead>
<tr>
<th>15</th>
<th>The analysis of the most effective methods to improve the energy performance of a building.</th>
<th>Possibilities to increase the energy efficiency of a building.</th>
<th>The analysis was done for an office building from Transilvania University of Brasov.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case study on a multi-zone building from Brasov, in Romania.</td>
<td>The thermal insulation of the exterior walls and roof.</td>
<td>The advantages and disadvantages of the following thermal insulation materials are presented: expanded polystyrene, extruded polystyrene and polyurethane foam. These also apply to residential buildings.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Providing windows with triple pane insulation glass.</td>
<td>The simulation was done using TRNSYS with the weather data file from Brasov.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The computation methods.</td>
<td>In the simulation were used 6 building variants having 3 types of insulation materials with different thickness for the exterior walls, different types of windows and 2 types of thermal insulation for the roof.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energetic simulation of the building.</td>
<td>The polyurethane foam has the best insulation during cold season, but increased demand for space cooling. If the thickness of the layer increases from 10 to 15 cm, the heating demand decreases by 3.4% and the cooling demand decreases by 1.3%.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analysis of the results of the simulation.</td>
<td>The expanded polystyrene has the worst insulation during the cold season. If the thickness of the layer increases from 10 to 20 cm, the heating demand decreases by 6.1%, but the cooling demand increases by 2.1%.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The expanded polystyrene has the lowest values of space cooling demand.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Page</th>
<th>Relevant issue related to the architectural integration of active solar technologies in the facades.</th>
<th>The problem of the solar technology integration into the building facades.</th>
<th>The article shows the implementation of the solar thermal façade on a non-residential building: The Research and Development Institute of Transilvania University of Brasov.</th>
<th>The problems of the solar technology integration into the building's façade are shape, aesthetics and functional demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The concepts of interest for architects, engineers and designers working on the implementation and integration of solar energy conversion systems in the built environment.</td>
<td>The multifunctional solar thermal facades.</td>
<td></td>
<td>The suggested shapes of the solar collectors are the equilateral triangle and the isosceles trapeze. The equilateral triangle has great flexibility in development of various patterns with direct applications for small and medium facades, with various openings and volumetric structures. The isosceles trapeze offers cost effective larger arrays and facilitates an easier connection and mounting.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The vertical implementation of the solar collector will lead to increased surface available for mounting and a better distribution of the heat production.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Page</th>
<th>Relevant issue related to the architectural integration of active solar technologies in the facades.</th>
<th>The problem of the solar technology integration into the building facades.</th>
<th>The article shows the implementation of the solar thermal façade on a non-residential building: The Research and Development Institute of Transilvania University of Brasov.</th>
<th>The problems of the solar technology integration into the building's façade are shape, aesthetics and functional demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>N. Petrasincu and L. Fara, “Bioclimatic Elements for Traditional Romanian Houses,” <em>PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 6-8 September 2006</em>.</td>
<td>The analysis of the bioclimatic elements from traditional Romanian houses.</td>
<td>The analysis of the bioclimatic elements of traditional Romanian houses from the rural environment.</td>
<td>The vertical implementation of the solar collector will lead to increased surface available for mounting and a better distribution of the heat production.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>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.</td>
<td></td>
<td>The suggested shapes of the solar collectors are the equilateral triangle and the isosceles trapeze. The equilateral triangle has great flexibility in development of various patterns with direct applications for small and medium facades, with various openings and volumetric structures. The isosceles trapeze offers cost effective larger arrays and facilitates an easier connection and mounting.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The vertical implementation of the solar collector will lead to increased surface available for mounting and a better distribution of the heat production.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Page</th>
<th>Relevant issue related to the architectural integration of active solar technologies in the facades.</th>
<th>The problem of the solar technology integration into the building facades.</th>
<th>The article shows the implementation of the solar thermal façade on a non-residential building: The Research and Development Institute of Transilvania University of Brasov.</th>
<th>The problems of the solar technology integration into the building's façade are shape, aesthetics and functional demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>A. R. Vasiu, “Sistem inovativ de termoizolare activă a clădirilor vechi,” <em>A XI-a Conferință Națională Multidisciplinară cu participare internațională “Profesorul Dorin Pavel - fondatorul hidroenergeticii românești”</em>, Sebeș, pp. 247–252, 2011.</td>
<td>Active thermal insulation solution for the rehabilitation of the old buildings.</td>
<td>The description of the active thermal insulation solution.</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The vertical implementation of the solar collector will lead to increased surface available for mounting and a better distribution of the heat production.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The suggested shapes of the solar collectors are the equilateral triangle and the isosceles trapeze. The equilateral triangle has great flexibility in development of various patterns with direct applications for small and medium facades, with various openings and volumetric structures. The isosceles trapeze offers cost effective larger arrays and facilitates an easier connection and mounting.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The vertical implementation of the solar collector will lead to increased surface available for mounting and a better distribution of the heat production.</td>
</tr>
<tr>
<td>19</td>
<td>N. Rotar and V. Badescu, “Romanian climate data impact on passive buildings design,” <em>U.P.B. Sci. Bull.</em>, vol. 73, no. 3, pp. 287–290, 2011.</td>
<td>The comparison of the same passive house built in different climate zones from Germany and Romania.</td>
<td>The passive house energetic requirements and the European climate.</td>
<td>The passive house energetic variation in the European climate.</td>
</tr>
<tr>
<td>20</td>
<td>B. Diaconu M. and M. Cruceru, “Building envelope with phase change materials inclusions: factors influencing thermal energy savings,” <em>Annals of the „Constantin Brâncuși” University of Târgu Jiu</em>, no. 3, pp. 76–84, 2010.</td>
<td>Proposal of a Phase Change Material (PCM) enhanced wall system.</td>
<td>The description of the PCM wall system.</td>
<td>The analysis of the effect of occupancy pattern and ventilation on energy efficiency of a room with PCM walls.</td>
</tr>
<tr>
<td>21</td>
<td>The analysis of the life cycle cost of a passive house including its technical design variations.</td>
<td>Literature reviews of the life cycle cost analysis.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
|----|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------
|    | The analyzed passive house is located in the campus of the University Politehnica of Bucharest.                                    | The description of the method.                  |
|    | 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. | The general model of the life cycle cost involves the variability of the bank interest rates, inflation and price escalation. |
|    | The description of the passive house ‘POLITEHNICA’.                                                                             | 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. |
|    | The thermal loads of the passive house were evaluated using the PHPP software and the thermal balances were determined by creating a VBA programming code in order to achieve a conservative balance of the thermal loads supplied by the PHPP by using conditional Boolean functions and threshold functions. | The results of the life cycle cost analysis show that the payback time in case the passive house uses for heating gas fuel is 16-26 years, in case it uses electricity is 9-16 years and in case the house is connected to the District Distribution is 16-28 years. |
|    | Discussion of the obtained results.                                                                                            |                                                  |

<table>
<thead>
<tr>
<th>The thermal characteristics of a building for summer performance with the focus on thermal insulation.</th>
<th>The methodology of the building's thermal analysis.</th>
<th>The residential building and the office building used in the case study were located in Rome.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A new methodology for the analysis of the parameters which influence space cooling energy performance.</td>
<td>The ways of representing obtained results.</td>
<td>The same methodology could be used on buildings located in Romania since they also experience the same problem with energy performance in cooling because of the climate.</td>
</tr>
<tr>
<td></td>
<td>Potential applications of the proposed methodology.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The methodology applied using parametric analysis for case studies.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sensitivity analysis and discussion of results.</td>
<td></td>
</tr>
<tr>
<td>I. Ballarini and V. Corrado, “Analysis of the building energy balance to investigate the effect of thermal insulation in summer conditions,” <em>Energy and Buildings</em>, vol. 52, pp. 168–180, Sep. 2012.</td>
<td></td>
<td>The application of an adequate thermal insulation to improve building energy performance in summer has only been analysed in few studies. The study presented in the article was applied in 3 phases.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>There were 2 cases studies: a residential building and an office building.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The detailed numerical simulation was provided by Energy Plus.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>There were 5 simulations for the same model subjected to the same conditions and they were done by adding a different driving force each time.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td>23</td>
<td>The numerical prediction of thermal comfort in closed spaces on the basis of PMV-PPD model. Computation and testing model of thermal comfort in buildings. A computational model for indoor air quality numerical simulation.</td>
<td>The prediction of the thermal comfort. The thermal comfort criteria used for the design of the heating system. The relationship between thermal environment and human performance. The evaluation of the olfactory comfort. The indoor quality simulation model. The computation of the outside air flow rate and indoor air quality control. The influence of CO2 concentration on human performance and productivity.</td>
</tr>
</tbody>
</table>

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.

As the publication states, 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 favourable weather 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.

The experimental study could not be done on a multifamily residential building because it required the cooperation of the indwellers and obtaining the approval of the indwellers is a difficult task.

For the evaluation of the permeability of large buildings there are 4 models.

Model I is about the calculation of the permeability as the air flow divided by the volume. In this case, the permeability is the air change rate.

Model II is about the calculation of the permeability as the air flow divided by the façade surface.

Model III is the calculation of the permeability as the air flow divided by the wind surface.

Model IV is the calculation of the permeability as the air flow divided by the joint length.

The experimental study was done on an individual dwelling built in 1998, in the Subcarpathian village Homoraciu from Prahova county. In the experimental study was used the Blower Door method.

The Blower Door consists in the following equipment: false door, radial fan with variable speed, variable voltage device, dual differential micromanometer, computer and software.

<table>
<thead>
<tr>
<th>Page</th>
<th>Methodology for estimating the heating load of buildings with variable zone temperature set-point.</th>
<th>The outline of the proposed methodology. A possible thermal model for a building. The compensation of the weather conditions. Set point tracking. Methodology for heat load calculations based on model predictive programming. Case studies and the analysis of results.</th>
<th>The article could be provided with the summary of the method for better understanding.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>C. Ghiaus and I. Hazyuk, “Calculation of optimal thermal load of intermittently heated buildings,” <em>Energy and Buildings</em>, vol. 42, no. 8, pp. 1248–1258, Aug. 2010.</td>
<td></td>
<td>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.</td>
</tr>
</tbody>
</table>

| 26   | The relationship between energy consumption, economic growth and CO2 emissions, in case of Romania. The existence in Romania of the environmental Kuznets curve’s effects over the period of 1980–2010. | The Literature Review on Environmental Kuznets Curve. The economic specifications and methodology. Empirical results and discussions. | Kuznets Curve expresses the relationship between per capita income and income inequality as inverted U-shape. The hypothesis is that if per capita income increases, the income inequality increases too, but starts declining after a turning point. The Environmental Kuznets Curve shows the relationship between per capita GDP and measures of environmental degradation as inverted U-shape. The determinants of the Environmental Kuznets Curve are: the financial development, the energy consumption, economic growth and CO2 emissions. The hypothesis of the Environmental Kuznets Curve is that the economic growth increases the energy emissions initially, but after a certain level of per capita income, the economy starts to adopt environment friendly technology due to the rising demand of cleaner environment. To test the existance of the Environmental Kuznets Curve in the presence of energy consumption it is used a series having natural logarithm form which is superior and provides consistent empirical findings. The time reference data used for Romania was 1980-2010. It was used the ARDL bounds testing approach. |
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.

Motivation and background.

Overview of the phase change materials (PCM).

PCM applications in buildings.

The goals of the study.

The methods used in the study.

The analysis of the result.

The case study was made on a duplex house located in Portland, Oregon, in the USA.

The standard used for the evaluation was ASHRAE.

 PCM can be made of organic compounds, inorganic compounds or eutectic mixtures.

The PCM properties desired in a passive house are: high thermal conductivity, high latent heat fusion, non-flammable and a melting point that is approximately equal to room temperature.

On buildings, the PCM can be applied by direct impregnation into building materials or by encapsulation.

The 3 scenarios used to evaluated 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.

Results state that using PCM with 25°C melting point may reduce the zone hours overheated by 50%.

Reducing the melting point of the PCM below 25°C may have an adverse effect on thermal comfort.

Placing the PCM on the interior surfaces of the interior wall will result in a reduction of the zone hours overheated by 60%.


The PCM reduce fluctuations in air temperature and shift cooling loads to off-peak periods and they have the ability to store energy which is characterized by its latent heat of fusion.
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.

In the state-space modelling is applied the principle of analogy between two different physical domains that can be described by the same mathematical equations.

In the parametrical identification method used for the reference building, the model is represented as a nonlinear correlation between its parameters. To guarantee the optimality of the solution, the initial values need to be close to the optimal solution and the constraints need to be included in the algorithm in order to bound the physical values of the parameters.

The representation of the model is obtained by time discretization of the continuous transfer function model. To identify the transfer function model, the system must be in stationary initial conditions before applying the excitation.

The most important building envelope elements and their latest development.

|--------------------------------|-------------------------------------------------------------|-----------------------------|---------------------------------------|-----------------------------|--------------------------------|

The advanced wall technologies presented are: passive solar walls, lightweight concrete walls, ventilated or double skin walls and walls with latent heat storage. The types of glazing for fenestrations are presented: aerogel glazing, vacuum glazing, switchable reflective glazing, suspended particle devices film and holographic optical elements. The types of roofs discussed are: masonry roofs, lightweight roofs, ventilated and micro-ventilated roofs, solar reflective/cool roofs, green roofs, vaulted and domed roofs and photovoltaic roofs. There are methods for building envelope diagnosis like infrared thermography, fenestration diagnosis, infiltration and air tightness diagnosis and envelope moisture diagnosis.


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 analyzed building is Pirmasens Passive House from Rhineland Palatinate, Germany. 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 thermal model for the ventilation/heating system. The paper states that there are 2 ideal hypothesis regarding interconnection between various elements of the heating/ventilation system which turn out to be 3. The 3rd ideal hypothesis refers to the heat provided by the solar collector to the heating/ventilation system.

The thermal model for the solar collectors. The time dependend heat transfer through walls was modeled by 1 dimensional time dependend heat transfer equation which was solved numerically by using a standard Netlib solver.

Thermal targets and operation control. In the model for the heat transfer through doors the thermal inertia of the doors was neglected.

Preliminary results and discussions. The heat transfer through windows has two components: the solar energy flux transmitted inside the building and absorbed there and the heat flux transferred by conduction through the window.

The energy balance of the room takes into account the following: the heat fluxes transferred through separating elements of high thermal inertia, the heat fluxes through windows and doors, the thermal fluxes associated with internal heat sources and the energy fluxes entering and escaping the room through the air moved by the ventilation system. The model can be used to analyze the space heating demand for passive houses with arbitrary number of rooms and arbitrary space orientation.
<table>
<thead>
<tr>
<th></th>
<th>The description of the thermal exergy model of a building.</th>
<th>Exergy as environmental impact value.</th>
<th>The analyzed building was a multi-unit residential building located near Florence, Italy.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The application of the exergy model on a real building.</td>
<td>Building impact on the environment.</td>
<td>Exergy represents the thermodynamic potential measure of energy or material flux with respect to an equilibrium state assumed as the reference state.</td>
</tr>
<tr>
<td></td>
<td>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.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The thermal exergy model.</td>
<td>Equations.</td>
<td>The building is an open thermodynamic system which exchanges energy and material flow with the environment and it is modeled as a &quot;black box&quot; that needs exergy.</td>
</tr>
<tr>
<td></td>
<td>The computational model.</td>
<td>The building is a transient open system, while the surrounding is a closed system and the environment is a closed system in thermodynamic equilibrium with the surrounding.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Discussion of the obtained results.</td>
<td>The results of the building exergy analysis performed in the article state that 95% of the building’s exergy is destroyed while 5% of the exergy is lost.</td>
<td></td>
</tr>
<tr>
<td>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.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional thermal building insulation.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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 HCN (hydrogen cyanide).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State-of-the-art thermal building insulation.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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. VIP's drawback is the fact that it's thermal conductivity increases with age because of the water vapours and humidity penetration into the pores. The gas filled panels (GFP) are a doubtful solution because their thermal conductivity is higher than of the VIP whose thermal conductivity is low due to the vacuum from the pores. 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 adaptations. |
| Nanotechnology and thermal insulation. |
|Possible future building thermal insulation. |
|Comparison of weaknesses and strengths. |

Form-stable composite PCM was developed by utilizing waste glass powder as container for n-octadecane.

Experimental program.

Results and discussion.

The ideal PCM has the following properties: high storage density, good heat transfer, small volume change, low vapour presence, no super cooling, long term chemical stability, non-toxic, non-flammable, self nucleating behavior and should have phase change temperatures in the human comfort zone.

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 form stable composite PCM was tested for surface morphology, chemical compatibility, phase change behavior, thermal properties, thermal stability and thermal performance.

The results show that the melting and freezing temperatures are for n-octadecane 27.4°C and 25.15°C and for n-octadecane-GP are 26.93°C and 25.03°C, which are close to the range of human comfort zone.

The latent heat for melting and freezing for unit weight are for n-octadecane 229.9 J/g and 228.5 J/g and n-octadecane-GP 18.97 J/g and 18.95 J/g.

The thermal conductivity of the cement paste with n-octadecane-GP is 0.62 W/mK and without n-octadecane-GP is 0.90 W/mK.

The PCM with n-octadecane-GP is effective in reducing the indoor temperature and the temperature fluctuations, improving the indoor thermal environment.

This material can be used in buildings for thermal energy storage purpose to reduce energy cost, scale air-conditioning and flatten the fluctuation of indoor temperature.
Methods for calculation of the water vapors diffusion in the building elements in order to choose the optimal solution to ensure normal relative humidity of the building elements during the life cycle of the building.

Technical conditions and performance level of building elements in case of humidity.

The standard C107/6 was released in year 2002 and since then there is no knowledge of being upgraded.

Calculation of the diffusion of the water vapors through the building elements.

Some of the formulae presented in the standard seem to have mistakes at indexes leading to confusion of the designer who uses it.

Constructive measures in order to avoid increasing the humidity inside the building elements.

The calculation method is based on the following hypothesis: 1. The thermal transfer takes place in a steady regime and is unidirectional. 2. All the thermal and physical properties of the materials are independent from temperature and humidity. 3. The air flow inside the building element or from the indoor environment to outdoor environment through the building element is not taken into consideration. 4. The superficial air layer from the building elements is taken into consideration as stated in the standard C107/3.

In order to satisfy the requirements for hygiene and interior comfort in the building and to ensure the performance of the exterior and interior building elements, they should satisfy the following technical and performance conditions: the increase of mass relative humidity of the materials from the building envelope’s structure due to water vapors condensation and avoid the progressive accumulation of water inside the building envelope every year due to condensation phenomenon.

Prescriptions regarding the design of the opaque elements of the building envelope and of the separation elements in the residential buildings for thermal stability taking into account their thermal inertia and the thermal stability of the rooms.

Criteria and performance levels for appreciating the thermal stability in the building.

The standard C107/7 was released in year 2002 and since then there is no knowledge of being upgraded.

Constructive measures in order to ensure thermal stability in the room.

The thermal stability during summer and winter is evaluated in the room which has the most unfavorable direction and which is considered by the designer as a reference room inside the building.

According to the limitations imposed by the thermal stability, buildings are classified into 3 groups as following: “a”, “b”, “c”, depending on the endowment or necessity of the ventilation and air conditioning system.

In the calculation of the thermal stability of the building, the following parameters are analyzed: the damping coefficient of the amplitude of the outdoor temperature oscillation, the dephasing coefficient of the outdoor temperature oscillation and the thermal stability coefficient of the boundary element.
## APPENDIX IV: MODEL DATA INPUT

<table>
<thead>
<tr>
<th>DesignBuilder Template Category</th>
<th>Template Type</th>
<th>Parameter</th>
<th>Romanian Benchmark</th>
<th>Romanian Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sectors A, B, C</td>
<td>Sectors A, B, C</td>
</tr>
<tr>
<td>Construction</td>
<td>Walls</td>
<td>Exterior wall</td>
<td>Interior cement-lime mortar rendering: 1.5 cm</td>
<td>Interior cement-lime mortar rendering: 1.5 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ACC masonry GBN 35: 40 cm</td>
<td>ACC masonry GBN 35: 40 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extruded polystyrene: 10 cm</td>
<td>Extruded polystyrene: 20 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Exterior cement-lime mortar rendering: 0.5 cm</td>
<td>Exterior cement-lime mortar rendering: 0.5 cm</td>
</tr>
<tr>
<td></td>
<td>Interior wall</td>
<td></td>
<td>Interior cement-lime mortar rendering: 1.5 cm</td>
<td>Interior cement-lime mortar rendering: 1.5 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ACC masonry GBN 35: 40 cm</td>
<td>ACC masonry GBN 35: 40 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interior cement-lime mortar rendering: 1.5 cm</td>
<td>Interior cement-lime mortar rendering: 1.5 cm</td>
</tr>
<tr>
<td></td>
<td>Floors</td>
<td>Cold floor</td>
<td>Ceramic tile flooring: 1 cm</td>
<td>Ceramic tile flooring: 1 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Equalizing layer: 4.2 cm</td>
<td>Equalizing layer: 4.2 cm</td>
</tr>
<tr>
<td>Layer</td>
<td>Thickness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sound proof layer, rigid mineral wool</td>
<td>3.5 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reinforced concrete slab</td>
<td>15 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interior cement-lime mortar rendering</td>
<td>1.5 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em><strong>Warm floor</strong></em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oak flooring</td>
<td>2.2 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equalizing layer</td>
<td>3 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sound proof layer, rigid mineral wool</td>
<td>3.5 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reinforced concrete slab</td>
<td>15 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Another Example:**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound proof layer, rigid mineral wool</td>
<td>20 cm</td>
</tr>
<tr>
<td>Reinforced concrete slab</td>
<td>15 cm</td>
</tr>
<tr>
<td>Interior cement-lime mortar rendering</td>
<td>1.5 cm</td>
</tr>
<tr>
<td></td>
<td>Interior cement-lime mortar rendering: 1.5 cm</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Cold floor for stairs</td>
<td>Mosaic: 2.5 cm</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Equalizing layer: 3 cm</td>
</tr>
<tr>
<td></td>
<td>Reinforced concrete slab: 15 cm</td>
</tr>
<tr>
<td></td>
<td>Interior cement-lime mortar rendering: 1.5 cm</td>
</tr>
<tr>
<td>Roofs</td>
<td>Non-trafficable flat roof</td>
</tr>
<tr>
<td></td>
<td>Sand protection layer for waterproof: 4 cm</td>
</tr>
<tr>
<td></td>
<td>Protection layer for thermal insulation: 4 cm</td>
</tr>
<tr>
<td></td>
<td>Extruded polystyrene: 15 cm</td>
</tr>
<tr>
<td></td>
<td>Plain concrete pitching layer: 12 cm</td>
</tr>
</tbody>
</table>

176
<table>
<thead>
<tr>
<th>Reinforced concrete slab: 15 cm Interior cement-lime mortar rendering: 1.5 cm</th>
<th>Reinforced concrete slab: 15 cm Interior cement-lime mortar rendering: 1.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Doors</strong></td>
<td><strong>Exterior doors</strong></td>
</tr>
<tr>
<td><strong>Interior doors</strong></td>
<td>Solid hardwood door (normally hung)</td>
</tr>
<tr>
<td><strong>Airtightness</strong></td>
<td><strong>Cracks</strong></td>
</tr>
<tr>
<td><strong>Infiltrations</strong></td>
<td><strong>Medium</strong></td>
</tr>
<tr>
<td><strong>Glazing</strong></td>
<td><strong>Glazing</strong></td>
</tr>
<tr>
<td><strong>Frame</strong></td>
<td><strong>UPVC window frame</strong></td>
</tr>
<tr>
<td><strong>Opening Area</strong></td>
<td>A1 = 2.25 m2</td>
</tr>
<tr>
<td></td>
<td>A2 = 1.68 m2</td>
</tr>
<tr>
<td></td>
<td>A3 = 1.68 m2</td>
</tr>
<tr>
<td></td>
<td>A4 = 2.73 m2</td>
</tr>
<tr>
<td></td>
<td>B1 = 1.56 m2</td>
</tr>
<tr>
<td></td>
<td>B2 = 1.44 m2</td>
</tr>
<tr>
<td></td>
<td>B3 = 1.68 m2</td>
</tr>
<tr>
<td></td>
<td>B4 = 0.96 m2</td>
</tr>
<tr>
<td></td>
<td>B5 = 2.40 m2</td>
</tr>
<tr>
<td></td>
<td>B6 = 0.36 m2</td>
</tr>
<tr>
<td>Shading</td>
<td>Type</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Exterior wall</td>
<td>0.263</td>
</tr>
<tr>
<td>Interior wall</td>
<td>0.614</td>
</tr>
<tr>
<td>Cold floor</td>
<td>0.897</td>
</tr>
<tr>
<td>Warm floor</td>
<td>0.867</td>
</tr>
<tr>
<td>Mosaic floor</td>
<td>2.37</td>
</tr>
<tr>
<td>Non-trafficable flat roof</td>
<td>0.261</td>
</tr>
<tr>
<td>Double glazed termopane window g=0.75, normal emissivity</td>
<td>2.897</td>
</tr>
<tr>
<td>Double glazed termopane window with 1 reflectant layer against infrared rays, g=0.50</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**HVAC**

<p>| Ventilation | Maximum natural ventilation rate | 5 ac/h | 5 ac/h |</p>
<table>
<thead>
<tr>
<th></th>
<th>Maximum mechanical ventilation rate</th>
<th>N/A</th>
<th>2 ac/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>Auxiliary energy</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Heating/cooling system CoP</td>
<td>Heating CoP: 0.83</td>
<td>Heating CoP: 0.83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N/A</td>
<td>Cooling CoP: 0.83</td>
</tr>
<tr>
<td></td>
<td>Boiler/chiller CoP</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Air temperature distribution</td>
<td>Air temperature distribution</td>
<td>Mixed</td>
<td>Mixed</td>
</tr>
<tr>
<td>Lighting</td>
<td>Output</td>
<td>Task lighting</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>General lighting</td>
<td>8 W/m²</td>
<td>8 W/m²</td>
</tr>
<tr>
<td></td>
<td>Control Type</td>
<td>Linear</td>
<td>Linear</td>
</tr>
<tr>
<td>Activity</td>
<td>Gains</td>
<td>Bathroom</td>
<td>68.75 W/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bedroom</td>
<td>44.82 W/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hall</td>
<td>25.63 W/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kitchen</td>
<td>76.25 W/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Living Room</td>
<td>44.82 W/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unconditioned spaces</td>
<td>16.95 W/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inner Balcony</td>
<td>49.52 W/m²</td>
</tr>
<tr>
<td></td>
<td>Occupancy</td>
<td>Occupancy level</td>
<td>0.05 pers/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Occupancy time</td>
<td>Monday - Friday 7:00 - 9:00</td>
</tr>
<tr>
<td></td>
<td>18:00 - 23:00</td>
<td>18:00 - 23:00</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Saturday - Sunday</td>
<td>Saturday - Sunday</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7:00 - 23:00</td>
<td>7:00 - 23:00</td>
<td></td>
</tr>
<tr>
<td>Metabolic activity</td>
<td>0.87 met</td>
<td>0.87 met</td>
<td></td>
</tr>
<tr>
<td>Domestic hot water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bathroom</td>
<td>22.85 l/m2/day</td>
<td>22.85 l/m2/day</td>
<td></td>
</tr>
<tr>
<td>Kitchen</td>
<td>10.67 l/m2/day</td>
<td>10.67 l/m2/day</td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating set-point temperature</td>
<td>18°C</td>
<td>20°C</td>
<td></td>
</tr>
<tr>
<td>Cooling set-point temperature</td>
<td>N/A</td>
<td>25°C</td>
<td></td>
</tr>
<tr>
<td>Ventilation set-point temperature</td>
<td>N/A</td>
<td>18°C</td>
<td></td>
</tr>
<tr>
<td>Illuminance levels required</td>
<td>200 lx</td>
<td>200 lx</td>
<td></td>
</tr>
<tr>
<td>Fresh air levels required per person</td>
<td>8 l/s/pers</td>
<td>8 l/s/pers</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX V: THE LAYOUT OF THE APARTMENTS

The figures presented in Appendix V represent screen captures from the simulation tool DesignBuilder. The rooms are colored differently because each one represents a different thermal zone, with different activity assigned to it. Each apartment was modeled in DesignBuilder as a single Block.

In the Figure 1, 2 and, respectively, 3 are presented the layouts of the apartments from sector A.

Figure 1 – The layout of a 1 room apartment from the ground floor of sector A.
Figure 2 – The layout of a 3 room apartment from sector A.

Figure 3 – The layout of a 2 room apartment from the sector A.
Figure 4 – The layout of a 2 room apartment from the current floor of sector A

The Figures 5, 6, 7 and, respectively 8 represent the layouts of the apartments located in sector B.

Figure 5 – The layout of the 3 room apartment from the ground floor of sector B.

Figure 6 – The layout of a 3 room apartment from sector B.
Figure 7 – The layout of a 3 room apartment from sector B.

Figure 8 – The layout of a 4 room apartment from the current floor of sector B.

In the Figure 9, 10, 1, 12 and, respectively, 13 are shown the layouts of the apartments located in sector C.
Figure 9 – The layout of a 3 room apartment from the ground floor of sectors C, D, E.

Figure 10 – The layout of a 2 room apartment from the ground floor of sectors C, D, E.
Figure 11 – The layout of a 2 room apartment from the ground floor of sectors C, D, E.

Figure 12 – The layout of a 2 room apartment from the current floor of sectors C, D, E.

Figure 13 – The layout of a 2 room apartment from the current floor of sectors C, D, E.
Figure 2.1 – The plot of the cumulative sum of recursive residuals in Romania, between 1980 – 2010. The plot is not consistent after the 4th quarter of 2005. This indicates structural break in the Romanian economy (Shahbaz, Mutascu, & Azim, 2013).

Figure 2.2 – The plot of the cumulative sum of squares of recursive residuals in Romania, between 1980 – 2010. The plot shows that the ARDL parameters are stable (Shahbaz, Mutascu, & Azim, 2013).

Figure 3.1 – The mean monthly temperature recorded in July, respectively in January between the years 1961 – 1990 in Romania (Administratia Nationala de Meteorologie, n.d.-a).

Figure 3.2 – The mean rainfall amount recorded in July, respectively in January between the years 1961 – 1990 in Romania (Administratia Nationala de Meteorologie, n.d.-a).

Figure 3.3 – Rural house from the village Câinelul de Sus, Hunedoara County. Source: www.meteo-europ.com

Figure 3.4 – Rural house from the mountain resort Cheia, on the Prahova Valley. This house has the porch partially covered with glass panels. The glass panels are not removable. Source: http://turistintaramea.blogspot.ro

Figure 3.5 – The angles of the Sun rays that penetrate a Romanian rural house from the hill area. Ray (a) is the Sun ray that penetrates the room at winter solstice, ray (b) is the Sun ray that penetrates the porch at spring and fall equinox and ray (c) is the Sun ray which falls outside the house at summer solstice (Petrasincu & Fara, n.d.).

Figure 3.6 – The plan and the elevation of a house from Zăland Valley, Covasna County. Source: www.bnab.ro

Figure 3.7 – Romanian rural house from Dobrogea. Source: http://www.igloo.ro/

Figure 3.8 – Romanian rural house from West Carpathians. It is the memorial house of Avram Iancu (1824 – 1872), a Transylvanian Romanian lawyer who played an important role in the local chapter of the Austrian Empire Revolutions of 1848–1849, located in Vidra de Sus, Alba County. Source: http://www.ro.tezaur-romanesc.ro/

Figure 3.9 – Romanian urban house from Bucharest built in the 19th century by the Romanian architect Alexandru Săvulescu (1847-1904). Even though it is considered an historical monument, unfortunately it was demolished. Source: http://jurnalul.ro/

Figure 3.10 – The house of Vasile Pogor (1833 – 1906), Romanian poet, which was built in the 19th century, in the city of Iași. Source: http://jurnalul.ro/
Figure 3.11 – A German style villa built by the Romanian architect Nicu Georgescu in 1927, in the city of Sibiu. Source: [http://www.capital.ro/](http://www.capital.ro/)

Figure 3.12 – The residential house belonging to the famous Brătianu family, built in 1912, in Bucharest. Source: [http://www.capital.ro/](http://www.capital.ro/)

Figure 3.13 – Romanian house built in Art Deco style located in Bucharest. Source: [http://bucharestunknown.blogspot.ro](http://bucharestunknown.blogspot.ro)

Figure 3.14 – Multi-family residential building from Romania built in the Art-Deco style in the interwar period. Source: [http://photos.wikimapia.org/](http://photos.wikimapia.org/)

Figure 3.15 – Another Romanian multi-family house from the interwar period Source: [http://photobucket.com/](http://photobucket.com/)

Figure 3.16 – Romanian multi-family houses built during the communist period. Source: [www.spatiulconstruit.ro](http://www.spatiulconstruit.ro)

Figure 3.17 – Romanian multi-family residential building built before 1989. Source: [www.hotnews.ro](http://www.hotnews.ro)

Figure 3.18 – Primary energy production in Romania in year 2012 (S.C. Electrica S.A., n.d.).

Figure 3.19 – Renewable energy production in Romania in year 2012 (S.C. Electrica S.A., n.d.).

Figure 3.20 – The energy intensity of Romania, Bulgaria, Hungary and Poland between 1995 – 2004 (Iorgulescu & Polimeni, 2009).

Figure 3.21 – The household consumption as a percentage of total final energy consumption from Romania, Bulgaria, Hungary and Poland between 1990 – 2004 (Iorgulescu & Polimeni, 2009).

Figure 3.22 – The distribution of the residential floor area by building type and urbanization (Nolte, Griffiths, et al., 2012).

Figure 3.23 – The structure of the Romanian building stock depending on the age according to ref. (F. Prada et al., n.d.).

Figure 3.24 – The variation of the number of energy performance standards in Romania (F. Prada et al., n.d.).

Figure 4.1 – Flow chart adapted to the modeling protocol from Reference (Attia, 2015).

Figure 4.2 – DesignBuilder model hierarchy (DesignBuilder Software, n.d.-c).

Figure 5.1 – The satellite imagine of the real building as seen in Google Maps. From left to right: sector A, sector B (the corner of the “L”), sector C, sector D and sector E.

Figure 5.2 – The monthly electricity consumption for Sector A.

Figure 5.3 – The monthly electricity consumption for Sector B.

Figure 5.4 – The monthly electricity consumption for Sector C.

Figure 5.5 – The monthly natural gas consumption for Sector A.
Figure 5.6 – The monthly natural gas consumption for Sector B.
Figure 5.7 – The monthly natural gas consumption for Sector C.
Figure 5.8 – The structure of the (a) exterior wall, (b) interior wall, (c) cold floor, (d) warm floor, (e) stair well floor and (f) flat roof in the Romanian benchmark as seen in DesignBuilder simulation tool.
Figure 5.9 – The model of Sector A.
Figure 5.10 – The model of Sector B.
Figure 5.11 – The model of Sector C.
Figure 5.12 – The difference between the monitored annual electricity consumption and the simulated annual electricity consumption.
Figure 5.13 – The difference between the monitored annual natural gas consumption and the simulated annual natural gas consumption.
Figure 5.14 – The difference between the monitored monthly electricity consumption and the simulated monthly electricity consumption.
Figure 5.15 – The difference between the monitored monthly natural gas consumption and the simulated monthly natural gas consumption.
Figure 6.1 – The structure of the (a) exterior wall, (b) cold floor (c) warm floor, (d) stair well floor and (e) flat roof in the Romanian Standard as seen in DesignBuilder simulation tool.
Figure 6.2 – The annual electricity consumption.
Figure 6.3 – The annual natural consumption.
Figure 6.4 – The monthly electricity consumption for Romanian Standard without air conditioning system.
Figure 6.5 – The monthly electricity consumption for Romanian Standard with air conditioning system.
Figure 6.6 – The monthly natural gas consumption for Romanian Standard.
Figure 7.1 – The average annual energy consumption for Sector A, B, and respectively C for each case study.
APPENDIX VII: LIST OF TABLES

Table 2.1 – The concluding findings and gaps from the reviewed publications and the summary of the research proposal.

Table 3.1 – Primary energy production in Romania in year 2012 (S.C. Electrica S.A., n.d.).

Table 3.2 – Renewable energy production in Romania in year 2012 (S.C. Electrica S.A., n.d.).

Table 5.1 – The annual electricity consumption.

Table 5.2 – The annual natural gas consumption.

Table 5.3 – The annual percentage error for sector A.

Table 5.4 – The annual percentage error for sector B.

Table 5.5 – The annual percentage error for sector C.

Table 5.6 – The RMSD of the monthly electricity consumption.

Table 5.7 – The RMSD of the monthly natural gas consumption.

Table 6.1 – The annual electricity consumption.

Table 6.2 – The annual natural gas consumption.

Table 6.3 – The differences in percentage between the energy consumption of the benchmark model and energy consumption of the standard model.

Table 7.1 – The average annual energy consumption for Sector A, B, and respectively C for each case study.
APPENDIX VIII: THE MASTER THESIS POSTER

ABSTRACT
The following Master of Science Thesis was written during the Erasmus + Program for exchange students at Université de Liege, Belgium, which is in bilateral agreement with Technical University of Cluj-Napoca, Romania, available between 2014-2020. The research for this work was elaborated in the Sustainable Buildings Design Lab, from the Faculty of Applied Sciences. The work describes the current situation of the buildings energy performance in Romania and the development of a benchmark model for a Romanian residential building in order to implement the passive house or nZEB requirements. The case study presented is a Multi Storey Residential Building from 1980s, located in Biaș, Alba County, Romania.

KEYWORDS
Romania, nZEB, ZEB, implementing, passive buildings, passive house, thermal comfort, thermal insulation, building stock, Romanian houses, benchmark model

PROBLEM
1. There aren't accessible benchmark models for residential buildings in Romania.
2. The bioclimatic elements of the traditional Romanian houses are not integrated into the new buildings.
3. The practical application of the innovative thermal insulation materials on new or existing buildings is uncertain due to their availability and costs.
4. There is no climatic variation in implementing passive house or nZEB requirements in Romania.
5. There is no balance between heating and cooling estimation regarding the passive house requirements and its impact on the seasonal interior comfort.

OBJECTIVE/HYPOTHESIS
1. The development of an accessible benchmark model for Romanian multi storey residential building.
2. Estimation of the energy consumption of the Romanian benchmark model and of the model complying with the Romanian standards for energy performance.

AUDIENCE
Architecture Students, Civil Engineering Students, Architects, Civil Engineers, Building Services Engineers

RESEARCH QUESTION
1. Which is the methodology for developing the benchmark model for Romanian multi storey residential buildings?
2. Are the current Romanian standard requirements close to the 2020 targets?

ORIGINALITY
1. Survey of the energy consumption in Romanian Multi Storey Residential Buildings built in the 1980s by gathering the electricity and natural gas bills from 54 apartments.
2. Create the benchmark model after the Multi Storey Residential Building located in Biaș, Alba County, Romania.
3. Simulate the model using the tool DesignBuilder.

METHODOLOGY
1. Literature Review Analysis.
2. Choice of an existing multi storey residential building and establish its energy characteristics by surveying 54 apartments.
3. Create the Romanian Benchmark model by introducing the model input data in the simulation tool DesignBuilder.
4. The building performance simulation of the Romanian Benchmark model.
5. Calibration and validation of the model.
6. Apply the current Romanian standards to the benchmark model.
7. Discussion of the final results.

RESULTS

CONCLUSION
1. The differences between the monitored monthly energy consumption and the monthly energy consumption of the Romanian Benchmark model come from the fact that the energy bills from the surveyed apartments are from year 2014 and the weather data file used in the simulation tool DesignBuilder has recorded hourly weather from year 2002.
2. The Romanian Benchmark model was validated using Annual Percentage Error and Root Mean Square Deviation.
3. The annual energy consumption of the Romanian Standard model has increased. This is due to the maximum U-values from the Romanian Standard which lead to decrease in the layer of thermal insulation compared to the benchmark model.
4. The Romanian standard for energy efficiency needs to be upgraded.

Resources
2. The Institute for Research in Civil Engineering and Economy of Construction, Bucharest, Romania.
3. Technical University of Cluj-Napoca, Romania.
5. The National Agency for Regional Development, Bucharest, Romania.
7. The National Bank of Romania, Bucharest, Romania.
8. ECO Ecological Romania.
10. The National Bank of Romania, Bucharest, Romania.
REFERENCES


http://doi.org/10.1016/j.apenergy.2012.01.065


192

C107/6-02: Normativ general privind calculul transferului de masă (umiditate) prin elementele de construcție, C107/6-02 (2002).

C107/7-02: Normativ pentru proiectarea la stabilitate termica a elementelor de inchidere ale clădirilor, C107/ 7-02 (2002).


DesignBuilder Software. (n.d.-b). Hanging And Outline Partitions. Retrieved from http://www.designbuilder.co.uk/helpv4.3/#Hanging_Partitions.htm%3FTocPath%3DBuilding%2520Models%7CBuilding%2520Geometry%7CWorking%2520at%2520Block%2520Level%7C_____2

DesignBuilder Software. (n.d.-c). Model Data Hierarchy & Data Inheritance. Retrieved from http://www.designbuilder.co.uk/helpv4.3/#_Model_data_hierarchy_and_data_inheritance.htm%3FTocPath%3DCore%2520Concepts%7C_____1

DesignBuilder Software. (n.d.-d). Templates. Retrieved from http://www.designbuilder.co.uk/helpv4.3/#Template_Data.htm%3FTocPath%3DTemplates%7C_____0

DesignBuilder Software. (n.d.-e). Virtual partitions. Retrieved from http://www.designbuilder.co.uk/helpv4.3/#Virtual_Partitions.htm%3FTocPath%3DBuilding%2520Models%7CBuilding%2520Geometry%7CWorking%2520at%2520Block%2520Level%7C_____3

DesignBuilder Software. (n.d.-g). Working at Block Level. Retrieved from http://www.designbuilder.co.uk/helpv4.3/#Working_within_Blocks___Block_Level_.htm%3FTocPath%3DBuilding%2520Models%7CBuilding%2520Geometry%7CWorking%2520at%2520Block%2520Level%7C_____0


196


