UNIVERSITY OF CRAIOVA
FACULTY OF POWER ENGENEERING

DOCTORATE THESIS

STUDY OF ENERGETICALLY AND ECONOMICALLY EFFICIENT BUILDINGS

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-2009-

CHAPTER 1
PAPER SCOPE AND OBJECTIVES

Our planet life is based exclusively on perusable fossil energetic resources. The dispose time for these resources, while the science have to find others resources, can be longer threw energy economy, taking into account the fact that the cheap energy is the save energy. To save energy is not only a conscience problem, is more a imperative problem because the energy prices are more and more expensive.

Figure 1.1 presents the energetically consume structure for the residential and tertiary sectors for the European Union countries.

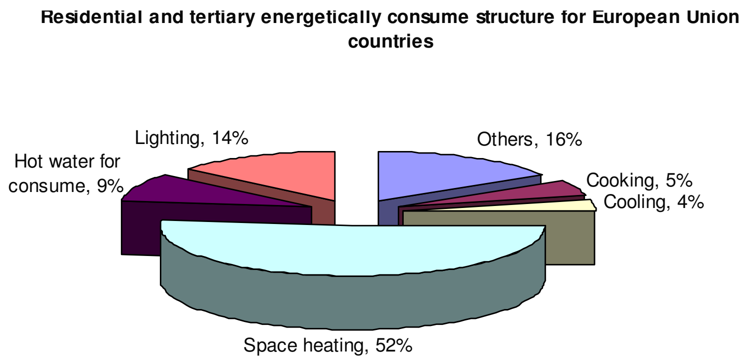


Figure 1.1. *Residential and tertiary energetically consume structure for European Union countries, [26]*

The present paper scope is to analyze some efficient methods for existing and future buildings.

The first part of the paper include an analyze of the buildings domain actual situation, regarding the envelope elements and the possibilities to optimize the heat consume for Romania and European Union buildings.

The paper first chapter presents some mathematical and physical models in order to describe the transitorily thermal transfer phenomena which occur in buildings. Are described thermal transfer phenomena as radiant, convective and conductive transfers threw the buildings enclosed component elements.

The second paper part describes some improvement methods and solution for the buildings envelope comparing different buildings construction materials, with or without thermal insulation.

The last two chapters presents methods and solutions for improving buildings energetically and economical efficiency.

CHAPTER 2.
THE ENERGETICALLY ACTUAL SITUATION ANALIZE OF THE BUILDINGS

2. 1. BUILDINGS STRUCTURE EVOLUTION

2.1.1. <u>Introduction</u> [26], [70]

Most of the buildings from Romania are old buildings between 15 and 55 years old, characterized by a low thermal insulation level and advanced depreciation. The living buildings structure depending on oldness is presented in the figure 2.1.

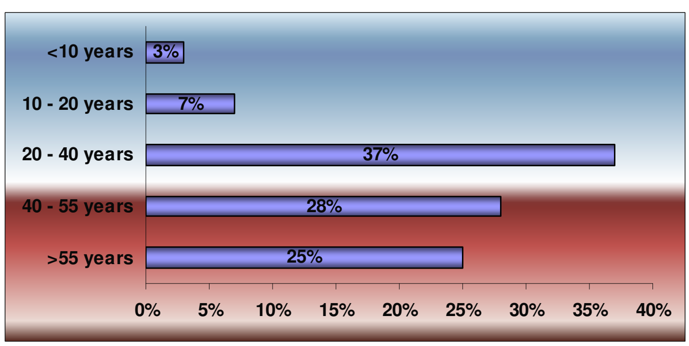


Figure 2.1. *Living buildings structures from Romania*

Before the year 1973 in Romania were implemented some thermal protection regulation, as for the thermal transfer total resistance, $\mathbf{R}_t$ the prescribed values were:

- 0,88… 1,06 $m^2 \cdot K/W$ for walls;
- 1,18…1,73 $m^2 \cdot K/W$ for roofs.

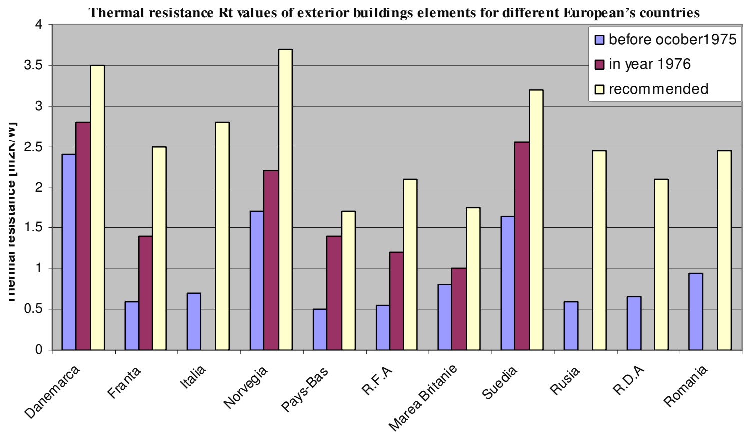


Figure 2.3. *Thermal resistance R_t values of exterior buildings elements for different European's countries*

In present the thermal protection level R_t are growing up:

- 2,5…3,2 $m^2 \cdot K/W$ for exterior walls;
- 3,60…4,20 $m^2 \cdot K/W$ for ceiling above the unheated basements;
- 3,0…5,0 $m^2 \cdot K/W$ inferior floors and ceilings;
- 0,62 $m^2 \cdot K/W$ for exterior carpentry.

Conclude

The actual buildings situation is analyzed by presenting the buildings structure evolution problems taking into account the European standards evolution. Still form the beginning of the paper are presented some aspects regarding the buildings thermal hydro dynamic characteristics starting with mathematical and hydro thermal calculation models based on differential equations that can conclude some practical solution regarding rehabilitation process especially for the buildings envelopes

The protection against water penetration can be realized using:

- water proof insulation, using hydro insulated materials structure;
- envelope and exterior carpentry water proof insulation;
- protection structure for insulation elements for the hydro materials, air tight and no air leakage for the building envelope;
- avoiding excessive humidity for the insulated elements, using a correct water proof for the construction elements;
- drying the wet construction elements as a precondition for the insulation supplementary elements.

CHAPTER 3.
BUILDINGS COMPONENT ELEMENTS THERMAL ANALIZE

3.1.1. Heat transfer threw the building component elements

- Convection and radiation heating transfer Q_{cv}, Q_r from the hot air threw the walls surface and surrounding surface;
- Conduction heating transfer at the walls surface Q_{cd};
- Convection and radiation heating transfer Q_{cv}, Q_r at the walls surface threw the outside and surrounding air surface [58]

Table 3.11. Material type- R value and U value for the wall structure analyzed

Walls structure	**Thickness,[cm]**	**Rt [m^{2}K/W]**	**U [W/m^{2}K]**
Brick structure without insulation	42	0.46	2.16
Brick with polystyrene insulation 5 cm	47	1.71	0.58
Brick with polystyrene insulation 10 cm	52	2.96	0.34
Brick with polystyrene insulation 15 cm	57	4.21	0.24
Autoclaves concrete without insulation	42	1.17	0.86
Autoclaves concrete with polystyrene insulation 5 cm	47	2.42	0.41
Autoclaves concrete with polystyrene insulation10 cm	52	3.67	0.27
Autoclaves concrete with polystyrene insulation15 cm	57	4.92	0.20
Concrete without insulation	42	0.31	3.25
Concrete with polystyrene insulation 5 cm	47	1.56	0.64
Concrete with polystyrene insulation 10 cm	52	2.81	0.36
Concrete with polystyrene insulation 15 cm	57	4.06	0.25
Efficient brick without insulation	42	0.81	1.23
Efficient brick with polystyrene insulation 5 cm	47	2.06	0.49
Efficient brick with polystyrene insulation 10 cm	52	3.31	0.30
Efficient brick with polystyrene insulation 15 cm	57	4.56	0.22

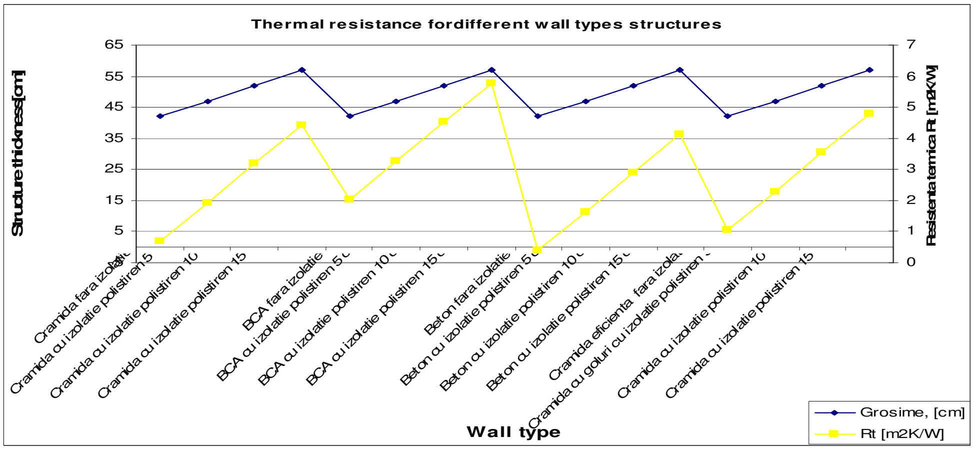


Figure 3. 33. *Thermal resistance variation at the brick walls structure, with different thickness for the insulation, with a value of the exterior temperature Te=-20℃*

3.3.5. <u>Conclude</u>

Chapter 3 are present the main heating transfer for the buildings elements. A part of this chapter is dedicated to a complex analyze of different types of walls regarding the heat transfer to there surface, the characteristic thermal parameters, thermal transmittance, thermal bridges and the temperature gradient. In the end of the chapter is establish the thermal insulation influence for walls structure, and is presented the theoretical concept of the equivalent walls. Also is established the windows influence for the heating consume and heating looses threw those surface that include windows.

<u>Author contributions</u>

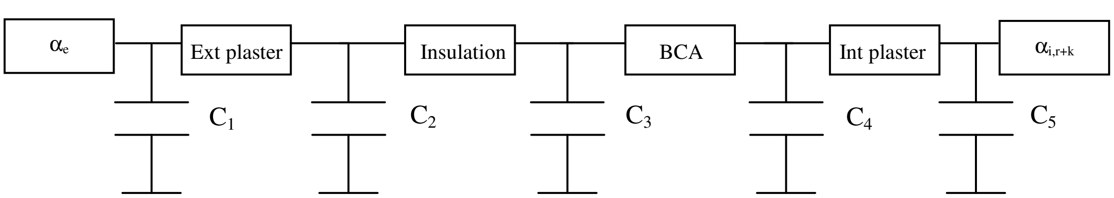
- Buildings energy consumes analyze and study with annual and average annual buildings thermal energy consumes, graphical representations for different climatic zones buildings: Central and Est Europe, Scandinavian countries and European Union countries;
- Graphical representations of thermal resistance and transmittance variation for different walls structures depending on the walls materials thickness;
- Comparations for transparent and opaque buildings elements determining the windows surface influence for the building heat loose;
- Different windows types' performance parameters analyze and evaluation using the thermal transmittance values;
- determine the heat looses threw the windows surface.
- Tables and graphical comparative analyze for the main important thermal characteristics: thermal resistance and transmittance, heat flux for walls structures: concrete walls, cellular expanded concrete, brick walls.

CHAPTER 4.
MATHEMATICAL MODELS FOR BUILDINGS COMPONENT ELEMENTS ANALIZE

4.3. DYNAMIC AND MATHEMATICAL SYMULATIONS FOR BUILDINGS

4.3.1. <u>Efficient building exterior wall mathematical model</u>: [36],[47]

α[W/(m^{2}K)]	25.000	0.289	0.291	11.314	9.106	7.7
1/α[(m^{2}K)/W]	0.04	3.456	3.438	0.088	0.110	0.130
d[m]	0	0.015	0.175	0.275	0.020	0



C [Wh/(m^{2}K)]	8.788	1.375	21.163	40.950	25.155
τ[h]	0.347	2.370	1.824	2.005	2.762

For a minimal value of the time thermal constant, τ =0.347 [h], the values obtained are:

C= 8.788 +1.375+21.163+40.950+25.155 = 97.430 Wh/(m^{2}K)

$$R = \frac{1}{\alpha_i} + \sum_{i=1}^{n} \frac{d_i}{\lambda_i} + \frac{1}{\alpha_e} = 9.64 \qquad m^2K/W$$

$$U = \frac{1}{R} = 0.10 \qquad W/(m^2K)$$

In the next paragraphs are presented the mathematical models results for the analyzed buildings walls, using the buildings dynamic simulation program Dynbil [36],[47].

4.3. Efficient building exterior wall characteristics dates obtained after the simulation process

Efficient building exterior wall characteristics						
Material	δ [cm]	rho [kg/m^3]	c [J/kgK]	λ [W/mK]	factor diffuse	k[W/m ^{2} °C]
Exterior plaster	2	1200	840	0,87	0,0096	2
Cellular expanded concrete	17,5	750	840	0,21	0,0085	17,5
Polystyrene	30	20	1460	0,04	0,0171	30
Interior plaster	1,5	1200	840	0,87	0,0145	1,5
U value [W/m^2 K]	0,10					
Total capacity, [kJ/m^2 K]	536,49					
Effective thermal capacity left [J/m^2 K]	259,2					
Effective thermal capacity right [kJ/m^2 K]	68,08					
Time thermal constant, τ [min]	53,174					

4.3.9. <u>Conclude</u>

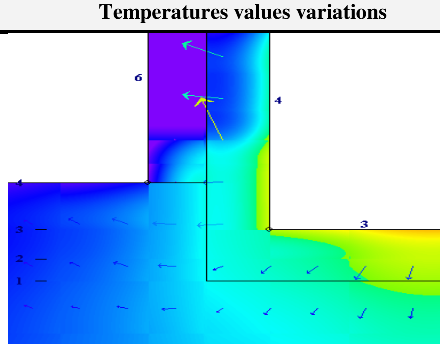
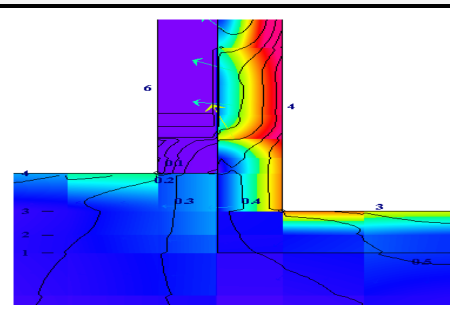
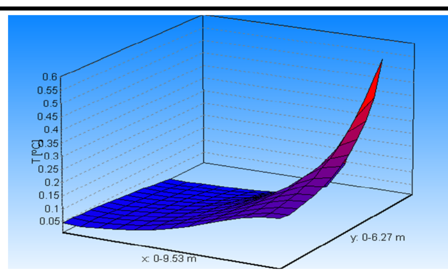
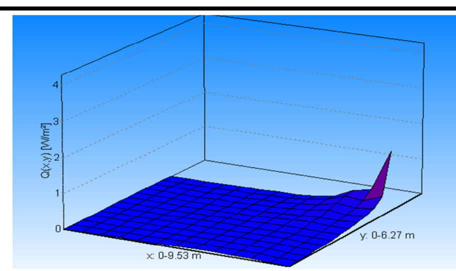
This chapter presents mathematical models used to calculate the thermal balance of the rooms and building zones, resulting the necessity of using the numerical methods to resolve the partial derivate equations systems (implicit and explicit differential methods), taking into accounts the specific stability criteria. Are presented some simplify methods for thermal balance general equations that must be done especially when is used the dedicated programs, the programs size, calculation time, and the input dates quantities and quality.

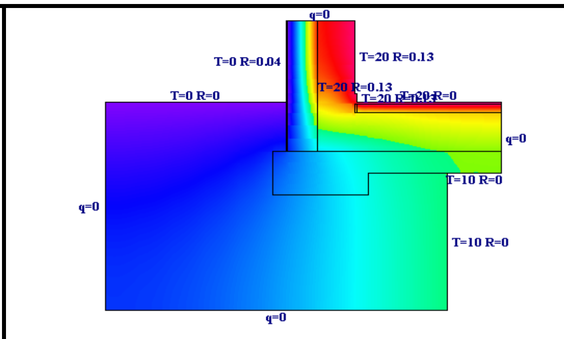
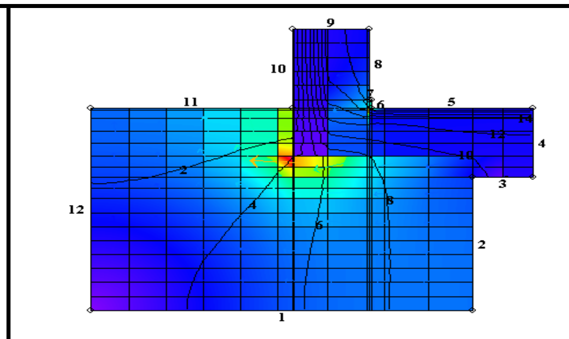
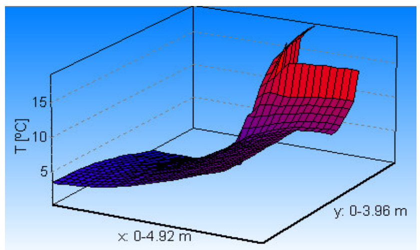
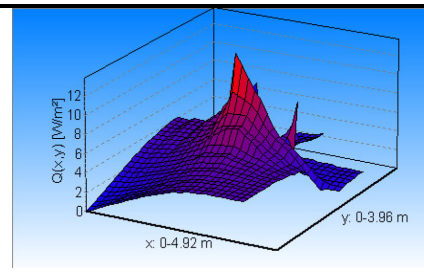
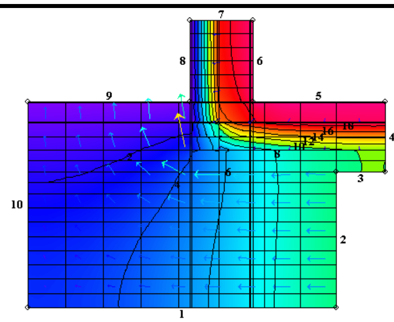
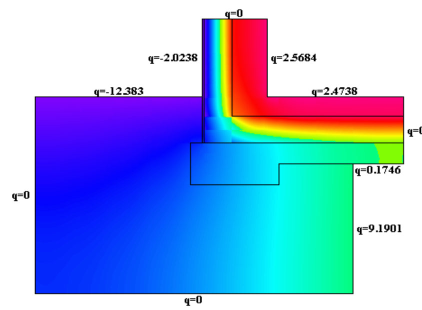
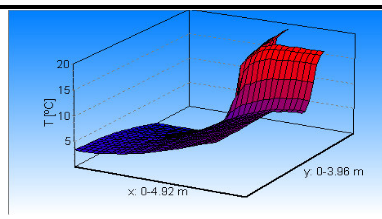
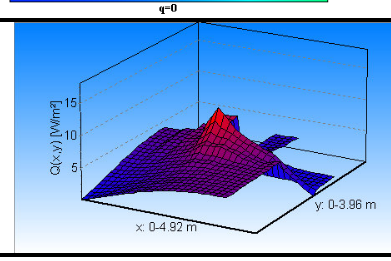
The end of the chapter present in the same scientific manner the obtained results using the building dynamic simulation program (DYNBIL) for ceiling, roof, exterior wall, base structure for each type of analyzed buildings (energetically efficient building and less efficient building).

CHAPTER 5.
THERMAL BRIDGES CALCULATION AND HEAT FLUXES SIMULATIONS

5.3. THERMAL BRIDGES EFFECTS DINAMIC SIMULATION AND DETERMINE THE THERMAL BRIDGES HEAT LOOSES COEFFICIENT

Table 5.19. Different structure types comparation for the analyzed walls

Structure type	**Temperatures values variations**	**Heat fluxes variations**
Exterior wall at the base structure with less insulation layer		
		

Exterior wall at the base structure with exterior insulation layer Heating looses total coefficient **Ψa =0,526**		
		
Exterior wall at the base structure with exterior insulation layer and ceiling insulation Heating looses total coefficient **Ψa =0,037**		
		

<u>Conclude</u>

Can be observed a big difference for the heat looses for the different analyzed elements, for the first wall that has a less thermal insulation only on exterior layer , the heat looses coefficient is, Ψa =0,526 comparing to Ψa =0,037 for the wall that has thermal insulation on exterior and over the ceiling above unheated basement. Also thermal transmittance for the first element structure is U=0,219 W/m^2K, and for the second structure U=0,134 W/m^2K.

CHAPTER 6.
DYNAMIC SYMULATION OF THERMAL TRANSFER PHENOMENS WITCH OCCURS IN BUILDING.CASE STUDY

6.2.1. <u>Introduction</u>

The dynamic simulations for the two analyzed buildings were effectuated using the specialized dynamic simulation program de DYNBIL (Dynamic Building Simulation). This program was special concept to allow a dynamic for different buildings types and structures the main advantage is that it ca take into account the climate dates specific to different zones fact that is very useful especially because can give real information about buildings behavior with different structure and in different climate zones, using the exterior temperature variations over a year, for each day and every minute [36], [42], [47].

6.3. INTERIOR TEMPERATURES AND HEATING REQUIREMENTS VARIATION ANALIZES FOR BUILDINGS

In this chapter is presented a heating requirements analyze for the two buildings type, for each zone of the building for every month and day of the year [36].

The two analyzed buildings had the same surface and volume but the materials and structure is different, and also the climate zones are different in order to determine and analyze the obtained differences between looses, heat gains, heat requirements and overheating effect for each climate zone (Mediterranean and temperate climate).

In the next graphics are presented the heat requirements for each building type depending on climate characteristic: the less energetically efficient building and the energetically efficient building: the specific climate dates are for Craiova, Cluj, Bucharest (Romania) and Frankfurt (Germany) zone.

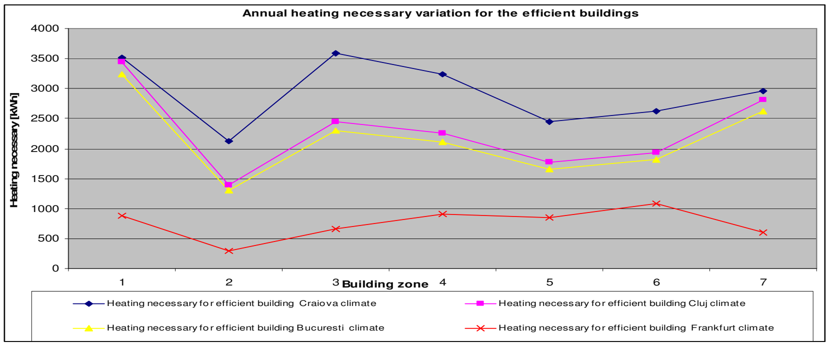


Figure 6.39. *Total heating requirements for each 7 zones depending on the 4 climate zones from Romania and Germany (Frankfurt), for all year,*

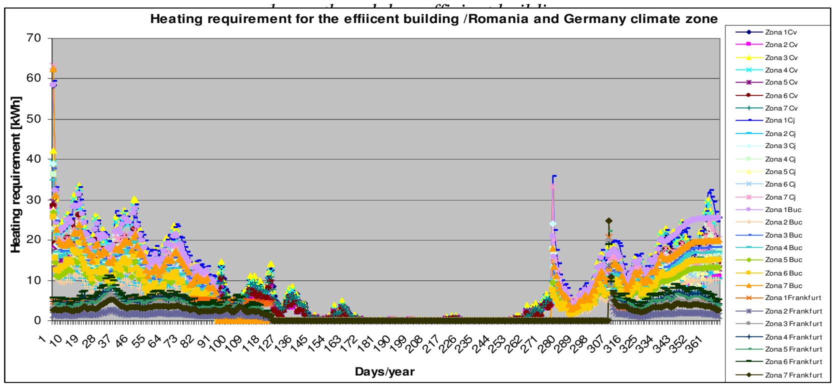


Figure 6.40. *Total heating requirements for each 7 zones depending on the 4 climate zones from Romania and Germany (Frankfurt), for all year, each month and day, efficient building case*

6.4. INFLUENCES ON THE THERMAL BALANCE OF THE BUILDINGS

6.4.1. <u>Climate dates influences</u>

A special importance for building energetically efficiency study is given by the climate dates characteristics to different zones where is consider that the house is to be built. The exterior temperature influences the interior temperature heat requirement and heat looses over the cold season. In this chapter were analyzed the climate dates for different zones from Romania (Craiova, Cluj, Bucharest) and South West of Germany, more precisely Frankfurt climate zone [74], [81].

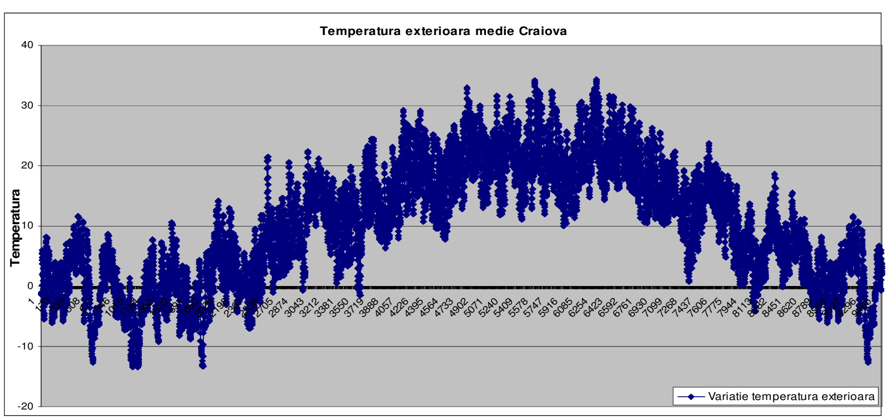


Figure 6.5. *Exterior temperature dates for Craiova climate zone, obtained with climate program Metronorm 6.0.*

Conclude

In figure 6.5 is presented the daily temperatures variations for Craiova climate zone

Figures 6.39. and 6.40 present the total heating requirements for each 7 zones depending on the 4 climatic zones from Romania and Germany (Frankfurt), for a year period, every day, efficient building case. In the 6.40 figure, it can be observed the fact that the heat requirement maximum value is 60 kWh/m^2year, value that is less that for the less energetically efficient building case.

CHAPTER 7.
DESCRIBING THE ENERGETICALLY EFFICIENT BUULDING CONCEPT. PASSIVE HOUSE

7.3. BUILDINGS THERMAL BEHAVIOUR IMPROVEMENTS

7.3.1.2. Heating requirements and costs analyze for a passive house

Table 7.8. Heat requirements for less energetically efficient building

	Heat necessary [kWh]	
Building zone	**Climate zone 1 (Romania)**	**Climate zone 2 (Germany)**
Zone 1	5000	1905,43
Zone 2	1555	835,93
Zone 3	3602	1926,59
Zone 4	4417	3950,35
Zone 5	2404	1475,78
Zone 6	2052	1727,43
Zone 7	7064	1399,8
Total	**26094**	**13221,31**

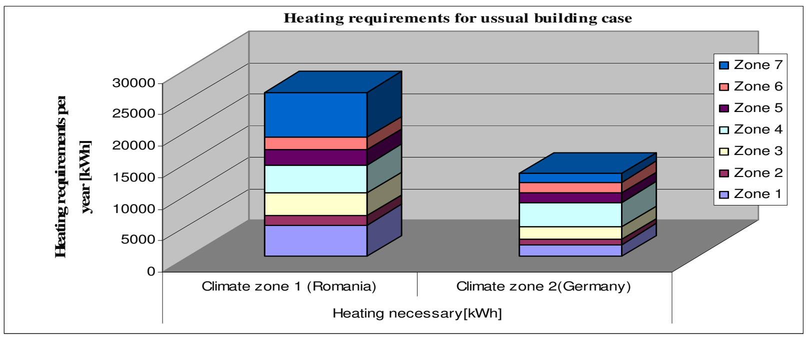


***Figure 7.14**.Heat requirements for both climate zones, less energetically efficient building case*

Table 7.9. Heat requirements for energetically efficient building

	Heat necessary [kWh]	
Building zone	**Climate zone 1 (Romania)**	**Climate zone 2 (Germany))**
Zone 1	3523,23	878,28
Zone 2	2131,60	296,03
Zone 3	3584,80	663,36
Zone 4	3242,23	901,93
Zone 5	2450,04	849,64
Zone 6	2625,14	1083,60
Zone 7	2956,78	595,51
Total	**20513,82**	**5268,34**

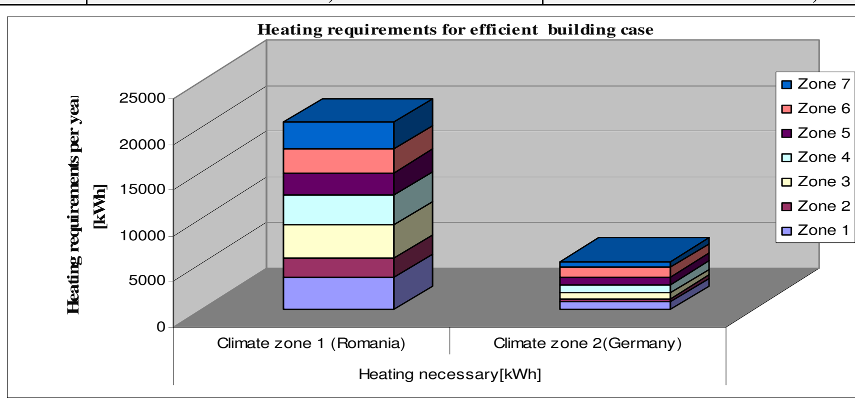


***Figure 7.15**. Heat requirements for both climate zones, energetically efficient building case*

Conclude

Chapter 7 presents a efficient building detailed concept, and a comparation between a less efficient building and a efficient building.

In this chapter are presented some technical solutions with a strong accent on optimizing the energy consumes, using performing insulations materials and growing up the thermal buildings behavior, ia context of energetically efficient strategies for Romania buildings in accordance with the European Union energy politics. It is demonstrated that the energetically efficient buildings allows to obtain a high thermal comfort with low costs.

CHAPTER 8.
ECONOMICALLY INVESTMENTS ANALIYE FOR DIFERENT BUILDINGS TYPES

8.2. BUILDINGS ECONOMICAL EFFICIENCY

8.2.1. Energetically improvements measures economical analyze for buildings [111]

Energetically improvements measures economical analyze for an existing buildings is realized using investments economical indicators. The most import ants indicators are: net present value, ΔVNA (m) [lei]; *investment cycle lifetime* after energetically increase process, **TR** [years]; energy economy unit cost, **e** [lei/Gcal].

Table 8.11. Net present for both building depending on the 4 climate zones

Climate zone	**Cm[lei]**	**ΔCk**[lei/an]	**VNA**
Craiova	4567,27	200766,01	**2.074,43 lei**
Bucharest	4053,73	286851,91	**2.739,20 lei**
Cluj	4295,85	267502,42	**2.601,30 lei**
Frankfurt	2314,15	250563,62	**2.281,15 lei**

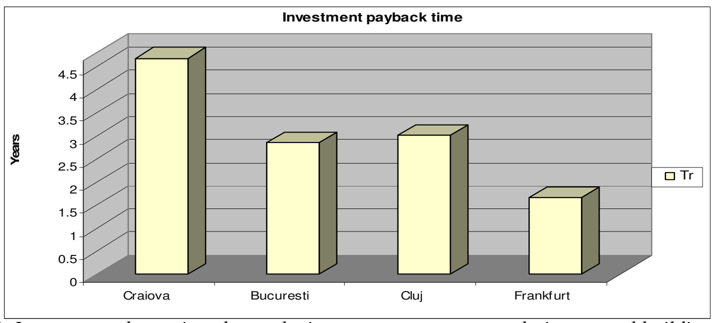


Figure 8.23. *Investments decay time due to the improvements process solutions, usual building case*

Table 8.17. Investments cycle lifetime due to the improvements process solutions

Climate zone	**Ck**	**ΔEk**	**Tr**
Craiova	3590,56	976,71	3,68
Bucharest	2632,28	1421,45	1,85
Cluj	2809,72	1486,12	1,89
Frankfurt	922,13	1392,02	0,66

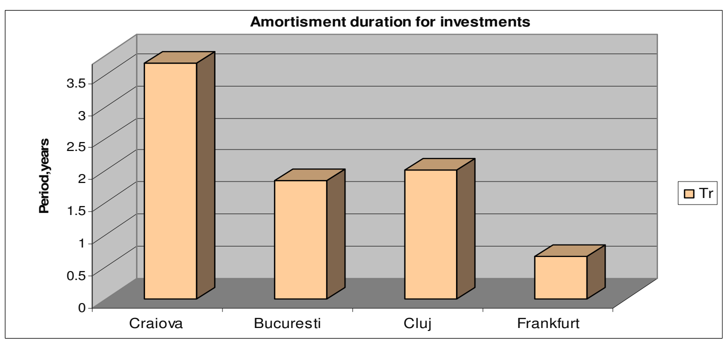


Figure 8.24. *Investments cycle lifetime due to the improvements process solutions, energetically efficient building case*

8.3.3. Conclude

This chapter contains an economical analyze for the energetically improvements process of a building using economic indicators for investments processes. The analyze include: graphical representation for net present value (VNA) for different climate zone for both analyzed buildings, economical efficiency study for energetically performance growing up technical solutions, buildings thermal insulation investments costs analyze. In addition, it is presented the cost prices decrease due to rising the energetically performance, investment capital cost for different buildings types. So a energetically efficient building it must by also economically efficient, fact that can be describe and analyzed using investments decay time and exploitation costs reduction.

CHAPTER 9.

CONCLUDE, PERSONAL CONTRIBUTIONS AND FUTURE PERSPECTIVES

9. 1. Conclude

The buildings domain is very vast, so the buildings economical and energetically analyze include a lot of aspects, starting with the physical design of the buildings constructions, energetically aspects, exterior climate were the building is to be placed so that in final to can determine the life time period and decay time of the building and the ways to reduce the costs decrease as a result of reducing the consume.

The present paper purpose is to analyze the energetically and economically efficient methods of the buildings. The special scope was to determine the heat requirements and heat looses for the two analyzed placed in different climate zones.

Chapter 1: „The paper scope and objectives" present the scientific theme and objective of this paper, the thematic justification witch constitute the study purpose of the study regarding the efficiency development methods for the building structure.

Chapter 2: „Buildings domain actual situation analyze" is concretize threw the buildings structures evolutions in the context of the European buildings standards.

Chapter 3: „Buildings component elements analyze", presents the most important buildings elements, thermal transfers processes threw the buildings elements and there influence over the total thermal energy balance

Chapter 4: „Component element buildings mathematical models study and analyze" in the first part are presented the buildings thermal balance mathematical models, with a special attention for the numerical models necessity to resolve the partial derivation systems equations (explicit and implicit differential methods), taking into account the stability criteria's. In the last part of the chapter are presented the obtained results using the buildings dynamic simulation program (DYNBIL- Dynamic Building Simulation) board above unheated basements, roof, and exterior walls for the two analyzed buildings.

Chapter 5: „Thermal bridges calculation and heat fluxes simulation" this chapter is dedicated to define the thermal bridge concept for a building envelope. (standard definition) and the solution to avoid the thermal bridges and the heat looses that are caused by the thermal bridges presence.

In the last part of the chapter are presented some dynamic thermal bridges simulations, including heat fluxes and heat variations and some technical measure to reduce the thermal bridges effects.

The last subchapter is dedicated to the thermal bridges solutions and ways to reduce the thermal bridges effects.

Chapter 6: „Buildings dynamic heat transfer simulations for buildings. Case study" present the two analyzed buildings dynamic simulations (energetically efficient building and respectively usual building) those buildings are considered to be realized from different construction elements together with there behavior in different climate zones.

Chapter 7: „Energetically efficient building concept. Passive house" describes the energetically efficient concept for building, with a special attention on passive house concept, the design principles for a passive house, are presented some solutions o reduce the thermal bridges effects. Is simulated the thermal bridges effects over the annual heat requirement and is described the mineral wool thermal insulation effect due to the heat looses.

Chapter 8: „Buildings rehabilitation and investments economical analyze „ contain a complex economical analyze of the energetically modernization processes using specific economical indicators for buildings investments projects.

Chapter 9: Conclude, author contributions, perspectives.

9. 2. Personal contributions

-Buildings dynamic simulation using a calculation algorithm inside the dedicated program DYNBIL- Dynamic Building.

- Simulations obtained results analyze with the dynamic simulation dedicated program (DYNBIL- Dynamic Building) for floors above the unheated basements, roof, and exterior walls for the two analyzed buildings.

- Using specialized programs to compare the obtained results, PHPP (Passive House Planning Package), program that allow certificating the passive houses design projects.

- Simulations and determination the climate dates for different zones using the real time simulation program Metronorm 6.0.

- Two and three-dimensional thermal bridges and heat flows dynamic simulations using the program HEAT 5.2, analyzing three different walls structures. Determining the heat looses threw the thermal, temperatures and heat fluxes dynamic simulations for those three walls structures.

- Heat looses simulations and evaluation due to thermal bridges effects that can appear into the buildings characteristic, those obtained values are compared to standard values in order to describe the differences between the values obtained with the simulations programs and specialized standard values.

- Heat looses evaluation for the surfaces at the ground level, according to the calculation standard algorithm EN 13370. This standard algorithm takes into account the thermal bridges and the under ground water effects.

- Temperatures, heat fluxes, heat flows and isothermal curves graphical representations for the analyzed buildings structures.

- Heat flows and heat fluctuations due to the thermal bridges effects 3D dynamic simulations, determining the limit surface temperatures.

- Ultraviolet radiations value at the windows surfaces taking into account the windows geometry, orientation and thermal properties for frame and window glaze, heat looses due to the thermal bridges and climate zone effects.

- Calculations and graphical representations of the additional capital investments costs, additional costs due to the energetically increasing effects, annual heat requirements decrease, and investments decay time and buildings live time cycle, considering different climate zones for the two different analyzed buildings.

- Energetically and economically increasing technical solutions, analyzing concrete cases, with obtained results comparisons using energetically and economical specific indicators.

- Energy costs calculations, investments costs, and economical indicators evaluation using graphical methods.

9.3. Perspectives

Taking into account the complexity of the thesis, the buildings analyzed problems will open new perspectives for future in order to continue the new directions like:

- different Romanian buildings types analyze and comparing the heat requirements and losses for different buildings types, including the rehabilitate buildings characterized the most efficient thermal factors.

- comparative analyze for the buildings main component elements, for Romania buildings comparing to other countries, the main focus is to describe the differences registered regarding the characteristics thermal coefficients values: thermal resistance, thermal transmittance, thermal insulation global factor, etc.

- realizing performing simulations programs for buildings and comparing those with the already build programs.

- realizing the possibilities to realize efficient buildings, like passive houses, using the climate dates for different zones from our countries and establishing the main solutions witch can achieve to build those types of buildings together with establishing the characteristics for each analyzed climate.

- precise and concrete measures and solutions in order to realize energetic efficient buildings with characteristics details for each type of building.

- analyzing different passive houses or energetically efficient building for the case for witch those how contain supplementary ventilations and heating systems.

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