"Politehnica" University of Timisoara
Universitatea "Politehnica" din Timişoara

HABILITATION THESIS
TEZĂ DE ABILITARE

HABILITATION IN RESEARCH / ABILITARE ÎN CERCETARE

Research field / Specialitatea

CIVIL AND INSTALLATIONS ENGINEERING / INGINERIE CIVILĂ ŞI INSTALAŢII

Contributions regarding the use of hybrid energies from renewable sources in the construction field and the rehabilitation of water supply systems /
Contribuții cu privire la utilizarea energiilor hibride din surse regenerabile în construcții și la reabilitarea sistemelor de alimentare cu apă

PhD. Eng. Ioan AŞCHILEAN

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A. REZUMAT

Prezenta teză de abilitare include rezultatele activităţii de cercetare a candidatului după susţinerea tezei de doctorat în anul 2010, teză intitulată „Contribuţii teoretice şi experimentale la reabilitarea şi modernizarea sistemelor de alimentare cu apă a localităţilor urbane”.

Teza de doctorat a angajat o temă de cercetare de mare importanţă şi actualitate pentru domeniul fundamental *Ştiinţe Inginereşti,* specializarea: *Inginerie Civilă*. Începând cu semnificaţia globală, istorică, culturală şi tehnică a resursei de apă, în teza de doctorat, pe lângă explicitarea noţiunilor de specialitate esenţiale, se oferă o privire de ansamblu asupra prevederilor normelor şi standardelor în vigoare, la nivel naţional şi internaţional. Deasemenea, se oferă, cu luarea specială în considerare a rapoartelor tehnice bazate pe experienţa practică, invenţii şi inovaţii aplicate la nivel mondial, prezentarea posibilităţilor tehnice şi relaţii de calcul în domeniile: captarea apei, înmagazinarea apei, tratarea apei, distribuţia apei. Sunt prezentate materialele folosite la fabricarea conductelor montate în sistemele de distribuţie a apei, defectele din reţelele de conducte constatate prin diagnosticarea imagistică, dar şi tehnologiile de reabilitare şi modernizare a conductelor - metode clasice şi moderne - tehnologiile de reabilitare a conductelor fără săpătură. În finalul tezei este prezentat un studiu de caz pentru evidenţierea conceptului de reabilitare şi modernizare a sistemelor de alimentare cu apă. Principalele rezultate ale tezei au fost prezentate la mai multe conferinţe naţionale sau internaţionale şi au fost diseminate prin publicarea unor articole în reviste indexate în baze de date internaţionale.

Activitatea post-doctorală s-a axat pe următoarele direcţii principale de cercetare:

1. Dezvoltarea durabilă în domeniul construcţiilor privind utilizarea energiilor hibride alternative în aplicaţii staţionare;
2. Reabilitarea şi modernizarea sistemelor de alimentare cu apă.

Într-o primă etapă, în vederea continuării activităţii desfăşurate în cadrul studiilor doctorale, activitatea de cercetare s-a orientat pe rezolvarea, în mod ştiinţific prin utilizarea metodelor de analiză multicriterială în scopul fundamentării deciziilor, problematica reabilitării sau modernizării sistemelor de distribuţie a apei.

În general, analiza multicriterială trebuie să fie organizată după cum urmează: obiectivele trebuie să fie exprimate în variabile măsurabile; odată ce este construit “vectorul obiectivelor” trebuie găsită o tehnică pentru agregarea informaţiei şi pentru a face o alegerea; definirea criteriilor de evaluare; analiza impactului; estimarea efectelor investiţiei exprimate în criteriile selectate; identificarea tipologiei subiecţilor implicaţi în investiţie şi colectarea preferinţelor respective (pondere) acordată diferitelor criterii; agregarea scorurilor diferitelor criterii pe baza preferinţelor relevate – fiecare scor poate fi agregat dând o evaluare numerică a investiţiei comparabilă cu alte investiţii similare.

În contextul celor precedent enunţate au fost efectuate studii de caz asupra reţelei de distribuţie a apei din cadrul Municipiului Cluj-Napoca, România, cu privire la alegerea momentului optim al reabilitării conductelor de apă; analiza privind stabilirea priorităţilor de reabilitare a reţelelor de distribuţie a apei şi alegerea tehnologiei optime de reabilitare a conductelor din sistemele de distribuţie a apei.

Ca urmare a realizării studiilor de caz s-a constatat că sistemul de alimentare cu apă al municipiului Cluj-Napoca este unul neomogen, atât din punct de vedere al materialelor utilizate, cât şi în privinţa vechimii. La iniţierea programului de reabilitare va trebui să se ţină cont de creşterea numărului de defecte din sistem şi de coeficienţii de regresie ce se vor stabili în funcţie de lungimea tronsoanelor planificate a fi reabilitate. S-a constatat o depăşire a pierderilor de apă, ceea ce duce la costuri ridicate de producţie şi implicit la o ineficienţă economică a societăţii. Se recomandă o monitorizare mai atentă a pierderilor şi implementarea de programe pentru reabilitarea cu prioritate a sectoarelor cu pierderi mari în zona conductelor de azbociment. Analizele multicriteriale au fost aplicate cu succes pentru alegerea conductelor ce urmează a fi reabilitate şi ulterior pentru stabilirea tehnologiei de reabilitare. Prin realizarea studiului s-a arătat că prima măsură care trebuie adoptată de companie este reabilitarea conductelor de azbociment. Conform studiului, aceasta se poate realiza cu metoda Slipline, prin introducerea unei conducte de polietilenă în conducta veche, fără a fi necesară scoaterea din pământ sau distrugerea acesteia.

Deasemenea, în cadrul activităţii de cercetare a fost analizată legatura dintre defecţiunile apărute la sistemul de alimentare cu apă şi traficul rutier în Cluj-Napoca, România. Calculele din cadrul studiului de caz au fost realizate cu ajutorul softului Autodesk Robot Structural Analysis Professional 2011. În cadrul studiului de caz au fost analizate următoarele tipuri de conducte: din oţel, din fontă cenuşie, din fontă ductilă şi din polietilenă de înaltă densitate (HDPE). Pe baza rezultatelor obţinute în urma efectuării calculului analitic s-a constatat că traficul rutier greu afectează în primul rând conductele având diametru nominal mic, respectiv conductele cu diametrul nominal de pănă la 300 mm. Rezultatele cercetării sunt utile pe de o parte în faza de proiectare a reţelelor de distribuţie a apei, astfel că în funcţie de tipul materialului conductelor se poate indica adâncimea minimă de montaj a acestora, astfel ca să fie evitată defectarea conductelor din cauza traficului rutier. În perspectivă ar putea fi efectuate studii asemănătoare şi cu privire la influenţa negativă a traficului rutier asupra reţelelor de canalizare, a reţelelor de gaz şi a reţelelor termice.

A fost manifestat interes şi s-a realizat o activitate de cercetare semnificativă şi în domeniul eficientizării energetice a construcţiilor prin studierea posibilităţilor de utilizare a energiilor hibride alternative în aplicaţii staţionare.

Într-o primă etapă a fost realizat un studiu privind selecţia soluţiilor tehnice pentru modernizarea/reabilitarea termică şi energetică a clădirilor existente în vederea creşterii performanţelor energetice a acestora. Practic, studiul vine să completeze lipsurile existente în legislaţia privind auditarea energetică a clădirilor privind selectarea măsurilor optime de reabilitare a clădirilor existente, precum şi în chestiuni legate de efectuarea studiilor de fezabilitate a proiectelor de auditare energetică, folosind în acest scop metoda de analiză multicriterială TOPSIS.

Succesul implementării eficienţei energetice în domeniul aplicaţiilor staţionare depinde în mod direct de soluţiile de valorificare a energiilor alternative prin intermediul diverselor sisteme de generare a energie care vor fi adoptate în vederea susţinerii energetice a acestor construcţii.

O primă direcţie în domeniul energiilor alternative abordată spre analiză şi cercetare tratează aspecte particulare şi specifice ale producerii electrolitice a hidrogenului prin utilizarea unor sisteme energetice care folosesc ca sursă primară de energie iradiaţia solară. Scopul studiului este de a identifica şi dezvolta un model ştiinţific pentru alegerea documentată privind producerea sustenabilă şi eficientă a hidrogenului cu ajutorul radiaţiei solare concentrate. Lucrarea se adresează inginerilor din domeniul energiei, cercetătorilor, dezvoltatorilor de sisteme solare şi producătorilor de combustibili alternativi. Totodată, lucrarea are menirea de a prezenta specialiştilor din domeniul energiei potenţialul sistemelor cu poli-generare de energie prin conversia radiaţiei solare concentrate şi de a stabili noi direcţii de cercetare în acest domeniu, precum şi în domeniile adiacente.

Principală preocupare specifică în domeniul sistemelor hibride de generare a energiei pentru clădirile eficiente energetic este sintetizată în teza de abilitare prin prezentarea succintă a rezultatelor unui studiu amplu privind soluţiile alternative de energie (soare, vânt, hidrogen) pentru alimentarea cu energie a unei casei pasive amplasată în Cluj-Napoca, România. În cadrul studiilor au fost optimizate şi analizate cinci scenarii pentru diferite combinaţii de energii hibride. Sistemele hibride au fost proiectate şi simulate virtual în funcţionare, iar principalele concluzii formulate sunt: cele mai bune performanţe energetice şi de mediu sunt obţinute de către tehnologia hidrogenului şi celula de combustibil, de asemenea, utilizarea energiei pe bază de hidrogen este mai eficientă şi mai puţin costisitoare decât stocarea sezonieră a energiei primare regenerabile de către baterii.

Un alt studiu se referă la proiectarea şi conceperea unui sistem energetic având la bază surse de energie regenerabile pentru o seră agricolă sustenabilă. Studiul de caz care a fost abordat arată modalitatea de dezvoltare a unui concept de seră agricolă sustenabilă, care implementează un sistem integrat de energie bazat exclusiv pe surse regenerabile, cum ar fi energia solară, energia pe bază de hidrogen biomasa, cu posibilă aplicabilitate în viitor.

Studiile, analizele şi rezultatele cercetărilor realizate, dar şi problemele, limitările tehnice întâmpinate permit identificarea şi stabilirea unor direcţii viitoare de cercetare în domeniul tematicilor abordate:

- continuarea direcţiilor de cercetare în domeniul sustenabilităţii alimentării cu apă;

- realizarea activităţilor de cercetare pentru obţinerea unor produse, tehnologii noi de tratare a apelor cu material absorbant obţinut pe bază de material zeolitic;

- extinderea cercetărilor privind implementarea soluţiilor de sisteme hibride de generare a energiei pentru susţinerea energetică a consumatorilor rezidenţiali standard, dar şi pentru aplicaţii civile comerciale şi industriale eficiente energetic;

- realizarea unui studiu care să contureze percepţia socio-economică, viabilitatea şi acceptarea publică din partea României privind utilizarea hidrogenului ca alternativă energetică şi tranziţia regională înspre sisteme de generare a energiei durabile şi ecologice bazate pe hidrogen;

- realizarea unei baze de date în vederea creării premiselor utile pentru elaboarea unor proceduri, normative şi standarde cu privire la proiectarea, executarea şi exploatarea în condiţii de siguranţă a sistemelor energetice alternative, având ca domeniu aplicaţiile staţionare, dar şi elementele referitoare la producţia, stocarea, transportul şi distribuţia - infrastructura necesară dezvoltării unei economii bazate pe energii alternative.

A. ABSTRACT

This thesis includes the results of the candidate's research activity after the defence of the Ph.D. thesis in 2010, entitled "Theoretical and Experimental Contributions to the Rehabilitation and Modernization of Water Supply Systems in Urban Localities".

The Ph.D. thesis has addressed a major research theme for the field of fundamental Engineering Sciences, specialization: Civil Engineering. Starting with the global, historical, cultural and technical significance of the water resource, in the Ph.D. thesis, besides explaining the essential specialty concepts, we provide an overview of the norms and standards in force at national and international level. Also, with special consideration to the technical reports based on practical experience, inventions and innovations applied worldwide, we provide a presentation of technical possibilities and computational relations in the areas of: water catchment, water storage, water treatment, and water distribution. The materials used in the manufacture of pipelines fitted in the water distribution systems, the failures in the pipeline networks found through imaging diagnostics, as well as the pipeline rehabilitation and modernization technologies - classic and modern methods, such as the rehabilitation technologies of the pipelines without excavation -, are also presented. In the end of the thesis, we present a case study in order to highlight the concept of rehabilitation and modernization of water supply systems. The main results of the thesis were presented at several national or international conferences and were disseminated by publishing articles in journals indexed in international databases.

The post-doctoral activity focused on the following main research directions:

1. Sustainable development in the field of construction regarding the use of alternative hybrid energies in stationary applications;
2. Rehabilitation and modernization of water supply systems in urban localities.

As a first step, in order to continue the work carried out in the doctoral studies, the research activity focused on scientifically solving the issues of rehabilitation or modernization of the water distribution systems using the multi-criteria analysis methods for grounding decision-making.

In general, the multi-criteria analysis should be organized as follows: objectives must be expressed in measurable variables; once the "vector of objectives" is built, a technique must be found to aggregate information and make a choice; definition of evaluation criteria; impact analysis; estimation of the effects of the investment expressed in the selected criteria; identification of the typology of the subjects involved in the investment and collection of the respective preferences (weight) given to the different criteria; aggregation of the scores of different criteria based on their relevant preferences - each score can be aggregated by giving a numerical appraisal to the investment, comparable to other similar investments.

In the context of the foregoing, case studies have been carried out on the water distribution network of the City of Cluj-Napoca, Romania, regarding the choice of the optimal moment of rehabilitation of water pipelines; the analysis of setting priorities for the rehabilitation of water

distribution networks and the choice of the optimal technology of rehabilitation of pipelines in the water distribution systems.

As a result of the case studies, it was found that the water supply system of the City of Cluj-Napoca is inhomogeneous both from the point of view of the materials used and their age. When initiating the rehabilitation program, it will be necessary to take into account the increase in the number of faults in the system and the regression coefficients to be determined depending on the length of the sections to be rehabilitated. An excess of water loss has been found, which leads to high production costs and, implicitly, to the economic inefficiency of the company. Better tracking of losses and implementation of programs for the priority rehabilitation of high loss sectors, in the asbestos pipeline area, is recommended. Multi-criteria analyses have been successfully applied for the choice of pipelines to be rehabilitated and subsequently for the establishment of the rehabilitation technology. The study has shown that the first measure to be adopted by the company is the rehabilitation of asbestos pipelines. According to this study, it can be done with the Slipline method, by introducing a polyethylene pipe into the old pipe, without having to be removed or destroyed.

Also, within the framework of the research activity, the link between the failures in the water supply system and the road traffic in Cluj-Napoca, Romania, was analysed. The calculations in the case study were made using the 2011 Autodesk Robot Structural Analysis Professional software. In the case study, the following types of pipes were analysed: made of steel, grey cast iron, ductile cast iron and high density polyethylene (HDPE). On the basis of the results obtained from the analytical calculation, it was found that heavy road traffic affects primarily the pipes with a small nominal diameter, i.e. pipes with a nominal diameter of up to 300 mm. The results of the research are useful on the one hand in the phase of design of the water distribution networks, so that depending on the type of material in the pipes, the minimum fitting depth can be indicated, so as to avoid pipeline failure due to road traffic. Further, similar studies could also be carried out with regard to the negative influence of road traffic on sewer networks, gas networks and thermal networks.

Interest has been shown and significant research has been carried out in the field of energy efficiency of buildings by studying the possibilities of using alternative hybrid energies in stationary applications.

In the first stage, a study was conducted on the selection of technical solutions for the thermal and energy modernization/rehabilitation of existing buildings in order to increase their energy performance. In fact, the study aims to fill the existing gaps in the laws on energy audit of buildings regarding the selection of optimal measures for the rehabilitation of existing buildings as well as on feasibility studies of energy audit projects, using the TOPSIS multi-criteria analysis method.

The success of implementing energy efficiency in the field of stationary applications depends directly on the solutions to capitalize on the alternative energies through the various energy generation systems that will be adopted for the energetic support of these buildings.

A first direction in the field of alternative energies addressed for analysis and research deals with particular and specific aspects of electrolytic hydrogen production by using energy systems that use solar irradiance as the primary source of energy. The aim of the study is to identify and develop a scientific model for the documented choice of sustainable and efficient hydrogen production using concentrated solar radiation. The paper is addressed to energy engineers, researchers, solar system developers and alternative fuel manufacturers. At the same time, the paper aims to present to the specialists in the energy field the potential of energy poly-generation systems by converting concentrated solar radiation and to establish new research directions in this field, as well as in the adjacent fields.

The main specific concern in the field of hybrid power generation systems for energy-efficient buildings is synthesized in the habilitation thesis by synthetically presenting the results of a comprehensive study on alternative energy solutions (sun, wind, hydrogen) for powering a passive house located in Cluj-Napoca, Romania. Five scenarios for different combinations of hybrid energy have been optimized and analysed in the studies. Hybrid systems have been designed and virtually simulated in operation, and the main conclusions are: the best energetic and environmental performances are achieved through hydrogen and fuel cell technology, and the use of hydrogen energy is more efficient and less costly than the seasonal storage of primary renewable energy by batteries.

Another study concerns the design and development of an energy system based on renewable energy sources for a sustainable agricultural greenhouse. The case study that has been addressed shows how to develop a sustainable agricultural greenhouse concept to implement an integrated energy system based exclusively on renewable sources such as solar energy, hydrogen energy, and biomass, possibly applicable in the future.

The studies, the analyses and the results of the researches, as well as the problems, the technical limitations encountered allow identifying and establishing future directions of research in the field of the themes approached:

- continuing research directions in the field of water supply sustainability;

- conducting research activities for obtaining new products, new technologies for water treatment with absorbent material obtained from zeolite material;

- expanding research on the implementation of hybrid power generation solutions for the energetic support of standard residential consumers, but also for energy-efficient commercial and industrial applications;

- carrying out a study outlining socio-economic perception, viability and public acceptance by Romania on the use of hydrogen as an energy alternative and the regional transition to hydrogen-based sustainable and green energy generation systems;

- developing a database to create the necessary premises for the elaboration of procedures, norms and standards regarding the design, execution and safe operation of alternative energy systems, having as field the stationary applications, as well as the elements regarding the production, storage, transmission and distribution - the infrastructure needed to develop an economy based on alternative energies.

B. RESEARCH RESULTS

1. Introduction. Relevant Publications

The habilitation thesis presents a synthesis of the main scientific results obtained from the research activity, after obtaining the degree of Ph.D. in the fundamental field of *Engineering Sciences, Civil Engineering*, following the Ph.D. thesis defence in 2010 at the Technical University of Cluj-Napoca.

The development of our professional, scientific and academic career after the Ph.D. programme was focused on sustainability issues in the field of *Civil Engineering* by addressing interdisciplinary research directions, as follows: water supply systems in localities, energy efficiency in buildings, alternative energy resources, alternative energy conversion technologies, hybrid energy generation systems for stationary applications, quality management in construction.

The multidisciplinary and complex concept of *sustainable development* was first discussed globally in response to the negative consequences of human activity on the environment at the United Nations Environment Conference, Stockholm, June 5th -16th, 1972, which was attended by delegates from 114 states, including Romania, the conference being held under the slogan *"One Earth"*. The main document of this conference is the *Final Environmental Statement*, which highlights the link between environmental protection and economic and social progress in the context of eliminating the negative effects of human development. The issue of the quantitative and qualitative assurance of resources for the human activities and the high price volatility, through their topicality and their triggering effects, are important topics on the agenda of all world scene actors.

With the generic themes, *water and energy*, the research activity is within a framework of major interest for the society, it falls within the current national and international context, the importance of the themes being topical both from the scientific and technological point of view, but also from the socio-economic or cultural point of view.

The activity selected to be synthesized in the habilitation thesis proves the achievements and relevance of the original contributions to the two main research directions, namely: **Use of Alternative Hybrid Energies in Stationary Applications,** presented in Chapter 2, and **Rehabilitation of the Water Supply Systems in Urban Localities,** presented in Chapter 3.

The 10 selected papers (publications and patents), considered to be relevant to the professional, scientific and academic achievements supporting the activities presented in the habilitation thesis, are as follows:

01 - Ioan Aşchilean, Ioan Giurca, *Choosing a Water Distribution Pipe Rehabilitation Solution Using the Analytical Network Process Method.* MDPI, Water (ISSN 2073-4441), April, 2018, 10(4), 484; doi:10.3390/w10040484.

02 - Ioan Aşchilean, Mihai Iliescu, Nicolae Ciont, Ioan Giurca, *The Unfavourable Impact of Street Traffic on Water Distribution Pipelines.* MDPI, Water (ISSN 2073-4441), August, 2018, 10(8), 1086; https://doi.org/10.3390/w10081086.

03 - Ioan Aşchilean, Gabriel Rasoi, Maria Simona Raboaca, Constantin Filote, Mihai Culcer, *Design and Concept of an Energy System Based on Renewable Sources for Greenhouse Sustainable Agriculture*. MDPI, Energies (ISSN 1996-1073), May 2018, 11, 1201; doi:10.3390/en11051201.

04 - Ioan Aşchilean, Gheorghe Badea, Ioan Giurca, George Sebastian Naghiu, Florin George Iloaie, *Determining Priorities Concerning Water Distribution Network Rehabilitation.* Energy Procedia 112 (2017). Sustainable Solutions for Energy and Environment, EENVIRO 2016, October 26th – 28th, 2016, Bucharest, Romania. Ed. ELSEVIER. ISSN 1876-6102, pp. 27 – 34. DOI: https://doi.org/10.1016/j.egypro.2017.03.1055.

05 - Ioan Aşchilean, Gheorghe Badea, Ioan Giurca, George Sebastian Naghiu, Florin George Iloaie, *Choosing the Optimal Technology to Rehabilitate the Pipes in Water Distribution Systems Using the AHP Method.* Energy Procedia 112 (2017). Sustainable Solutions for Energy and Environment, EENVIRO 2016, October 26th – 28th, 2016, Bucharest, Romania. ELSEVIER Publishing House. ISSN 1876-6102, pp. 19 – 26. DOI: https://doi.org/10.1016/j.egypro.2017.03.1109.

06 – Invention Patent no. 126695/30.12.2013 - Granted according to the provisions of the Law no. 64/1991 in patents for inventions, republished in the Official Gazette of Romania, Part I, no. 541, dated August 8th, 2007.

Title of the invention: **ACTIVE SYSTEM FOR THE PROTECTION OF PIPES RELATED TO FLUID STORAGE TANKS**

Inventors: Badea Gheorghe, Cluj-Napoca, **AŞCHILEAN IOAN**, Cluj-Napoca, Romania.

07 - Invention Patent no. 126490/ 30.08.2013 - Granted according to the provisions of the Law no. 64/1991 in patents for inventions, republished in the Official Gazette of Romania, Part I, no. 541, dated August 8th, 2007.

Title of the invention: **ACTIVE SYSTEM FOR FUNCTIONAL INSULATION OF FLUID STORAGE TANKS**

Inventors: Badea Gheorghe, Cluj-Napoca, **AŞCHILEAN IOAN**, Cluj-Napoca, Romania.

08 - Gheorghe Badea, George Sebastian Naghiu, Raluca - Andreea Felseghi, Maria Simona Răboacă, **Ioan Aşchilean,** Ioan Giurca, *Multi-criteria Analysis on How to Select Solar Radiation Hydrogen Production System.* Proceedings of the 10th Int. Conference on Processes in Isotopes and Molecules - PIM 2015. https://doi.org/10.1063/1.4938449.

09 - Gheorghe Badea, Raluca - Andreea Felseghi, **Ioan Aşchilean,** Andrei Bolboacă, Dan Mureşan, Teodora Melania Şoimoşan, Ioan Ştefănescu, Maria Simona Răboacă, *Energen System for Power Supply of Passive House. Case Study*. 2nd Int. Conference on Mathematics and Computers in Sciences and Industry, Sliema, Malta, 2015, IEEE Explore 2016, doi: 10.1109/MCSI.2015.31.

10 - Ioan Giurca, **Ioan Aşchilean**, George Sebastian Naghiu, Gheorghe Badea, *Selecting the Technical Solutions for Thermal and Energy Rehabilitation and Modernization of Buildings.* 9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, October 8th – 9th, 2015, Târgu Mureş, Romania. Procedia Technology Volume 22, 2016, Pages 789-796. http://www.sciencedirect.com/science/article/pii/S2212017316000517.

2. Use of Hybrid Energies in Stationary Applications

2.1. Introduction. General Background.

A defining characteristic of the 21st century is the increasing dependence of the world economy on energy resources. The issue of the energy dimension of economic growth and development has become today a very sensitive topic, both at national and global level, and energy paradigms will become more acute in the future. The global economic trends of the modern man dependent on massive energy consumption have raised the issue of energy security, namely the issue of fuel sufficiency assurance in all industrial fields.

The topic of scarcity of the traditional energy resources, that of the high price volatility, as well as that of energy security, by their topicality and driving effects, are important subject matters on the agenda of all world scene actors.

The spectrum of depletion, in a not too far-off future, of fossil fuels, that is, oil, coal and natural gas, which are in limited quantities, many of the deposits once very profitable, starting to diminish their production, turned the attention of modern society towards the creation new energy resources, superior capitalization of raw materials, diversification of products, improvement of life quality through the creation and implementation of new performant processes and technologies (Duma S.I., 2009)

The coverage of energy needs under the circumstances of protecting the natural environment and meeting economic and social constraints are some of the major challenges that need to be taken. At the same time, the reduction of pollutant emissions is a necessity, considering that more than half of the noxae released in the environment are the effect of the production of electric and thermal energy from the classical thermoelectric power plants.

Starting from these considerations defining the *energy drama* of mankind, the only solution today is searching, finding and implementing new, theoretically inexhaustible and non-polluting energy resources that, over the next 50 years, would replace the current traditional resources based on fossil fuels (Badea G., et al. 2013).

At a time when energy, environmental, economic and social concerns become more and more important, being represented by climate changes or those that jeopardize energy security, resource depletion or human health, the reduction in energy consumption *along with human comfort and well-being* in the building sector is of strategic importance, both at national and international level. Besides the efforts to development of new high quality buildings which assures a high level of comfort to the building's occupants while complying with the conditions of energy and environmental efficiency, it is essential to address an attitude to human well-being and healthy environments along with the drop in high levels of energy consumption.

By making a significant contribution to the EU's energy consumption, the use of conventional energy resources and the carbon dioxide emissions, as well as to a series of factors that can adversely affect occupants' health, the building sector is the subject of many medium and long term policies and objectives to reduce the negative impact on the environment. The objectives phrases by the "20-20-20" target by 2020 are the set of three key objectives for:

- reduction by 20% of greenhouse gas emissions in EU, as compared to 1999 levels;

- increase by 20% in the share of energy produced from renewable sources in the EU;
- improvement by 20% in energy efficiency in the EU. (MDRAP, 2017b)

As the European energy system faces an increasingly pressing need for sustainable, affordable and competitive energy supply for all citizens, the European Commission adopted on November 30th, 2016 the legislative package "Clean Energy for All Europeans", through which it is aimed to implement the strategies and measures to achieve the objectives of the energy union for the first ten-year period (2021-2030), in particular for the EU's energy and climate objectives for 2030, and refers to: energy security, energy market, energy efficiency, decarbonisation , research, innovation and competitiveness.

In a remote future perspective, the EU established a set of long-term objectives in roadmaps to 2050. Regarding the building sector, the main three roadmaps are:

- The EU's objective of moving to a low-carbon, competitive economy by 2050 (COM, 2011a), which identified the need to reduce by 88% to 91% the carbon dioxide emissions from the residential sector and the services sector (collectively, the real estate sector) by 2050 as compared to 1990 levels;
- The 2050 Energy Perspective (COM, 2011b), whereby "the increase in the energy efficiency potential of new and existing buildings is essential" for a sustainable future;
- The Energy Efficient Europe Plan (COM, 2011c), identifying the real estate sector as one of the top three sectors responsible for 70% to 80% of the overall negative impact on the environment. Achieving better constructions and optimizing their use within the EU would reduce by over 50% the amount of raw materials extracted from the underground and could reduce water consumption by 30%.

These roadmaps are a long-term aspiration that is not only desirable from a social and economic point of view, but also essential in terms of ecology and human health, safety and well-being in buildings.

Currently, there are more opportunities in the world to meet the challenges of sustainable development in the field of energy consumption and primary and secondary energy resources. Efficiency in the use of energy and resources is an essential objective, a challenge for the global community of researchers, focusing on tackling phenomena that have unfavourable consequences, taking action to achieve world policy goals in energy efficiency driven by the many benefits of efficient consumption that will contribute favourably to the economic and social development, natural resource preservation, greenhouse gas emission reductions and contribute significantly to reducing the impact of economic activity at a global level.

The extensive use of fossil energies, the threatening increases in the prices of these energies and, last but not least, the global climate change require the rapid imagining of concrete solutions that meet our contemporary requirements but which operate under the umbrella of important environmental challenges. Energy efficiency and decarbonisation of the real estate sector attracts particular attention because the residential and tertiary habitat alone accounts for 43% of the final energy consumption and 25% of the greenhouse gas production, in particular carbon dioxide emissions (Puiu O., 1996, European Commission of Energy, FNME, Romanian Energy Strategy).

The development of the *nearly Zero Energy Building (nZEB)* concept, and in particular the concept of *passive house*, as standards of energy efficiency in the construction sector, has made important contributions in terms of reducing the energy demand for buildings and greenhouse gas emissions, but the success of implementing this concept directly depends on the solutions for the capitalization of alternative energies through the various energy generation systems that will be adopted to energetically support these buildings.

In this context, alternative hybrid energies along with their specific conversion technologies can play an important role in streamlining and decarbonising power generation systems in the field of stationary applications.

As a result, the specific concerns regarding the use of hybrid energy systems in buildings, approached for analysis and research after the completion of doctoral studies, fall within the current national and international context, the importance of the issue being topical both from a scientific, technological point of view, but also from a socio-economic or cultural point of view.

The main focus of the research on alternative energies is to identify solutions for the use and applicability of hybrid systems in the generation of green electricity for energy-efficient buildings. It also aims at analysing the energy, economic and environmental performances of these energy generation systems by capitalizing on domestic alternative resources.

2.2. Energy-Efficient Buildings

Energy needs in terms of protecting the natural environment and meeting economic and social restrictions, are some of the major challenges that need to be undertaken. At the same time, reducing polluting emissions is a necessity, given the fact that over half of particulate matter released into the environment are the effect of the production of electricity and heat from conventional power plants. Based on these considerations, worldwide have outlined various energy strategies for sustainable development.

2.2.1. General Considerations on Energy-Efficient Buildings

2.2.1.1. nZEB - nearly Zero Energy Building

At the level of European Union, the building sector has emerged mandatory implementation of the *Plan to increase the number of buildings whose energy consumption is nearly zero* (MDRAP, 2014). The building with energy consumption nearly zero is defined as a building with a very high energy performance, where energy requirements from conventional sources are nearly zero or very low and is covered in mostly by energy from renewable sources, including renewable energy produced on-site or nearby (MDRAP, 2014; Ferrara M., et al. 2014).

Romania has important heritage buildings made mainly during 1960 ÷ 1990 with low thermal insulation consequence of the fact that before the energy crisis of 1973, there were no regulations on thermal protection of the buildings and items perimeter closure and are no longer suitable for the purpose for which they were built. Final energy consumption in these buildings varies widely, recording values of the range 150÷400 kWh/m^2 yr. It also notes that buildings constructed in the early years after 1990 have low energy performance (150÷350 kWh/m^2 yr), but was improved energy performance in buildings that were constructed after 2000 (120÷230 kWh/m^2 yr). The final energy consumption for nonresidential buildings is between 120÷400 kWh/m^2 yr depending on the category of building (education, culture, health, etc) (MDRAP, 2014).

According to the recommendations of the experts, are proposed these levels to be taken into account when defining *nZEB* for Romania (table 1).

Table 1. Limits proposed to define Romanian nZEB (MDRAP, 2014).

Building category	**Minimum requirements**	**Year**	
		2016	**2020**
Individual buildings	Primary energy [kWh/m^2 yr]	100	30-50
	Renewable energy [%]	>20	>40
	Emission CO_2 [kgCO_2 /m^2 yr]	<10	<3-7
Collective buildings	Primary energy [kWh/m^2 yr]	70	30-50
	Renewable energy [%]	>20	>40
	Emission CO_2 [kgCO_2 /m^2 yr]	<10	<3-7
Office buildings	Primary energy [kWh/m^2 yr]	100	40-60
	Renewable energy [%]	>20	>40
	Emission CO_2 [kgCO_2 /m^2 yr]	<13	<5-8
Public administration buildings	Primary energy [kWh/m^2 yr]	100	40-60
	Renewable energy [%]	>20	>50
	Emission CO_2 [kgCO_2 /m^2 yr]	<13	<5

The limits above-suggested for defining nZEB in Romania are ambitious but accessible taking into account that for some countries in Western Europe need to be accomplished by 2020 of some new buildings that are neutral in terms of climate parameters, independent of fossil fuels or even buildings that produce energy.

Principles and constructive solutions to achieve buildings nZEB with reference to the thermal insulation envelope, the global coefficient of heat transfer or material with features thermal improved are already technical regulated, internationally standardized and used or under implementation in new buildings (MDRAP, 2014; Ferrara M., et al. 2014; MC 001/2-2006). In contrast, solutions, implementation practices and techniques for analyzing the energy efficiency systems and facilities that serving functions of this buildings and ensures the comfort of occupants are elusive addressed.

2.2.1.2. Passive House

The comfort and availability of the energy have in the meantime generated the increase of the requirements in parallel with the technical progress and it certainly mankind will not give up this way of life in the future. The passive use of solar irradiation, which is possible without the use of integrated systems, has led to the concept of a building that uses itself, directly, the solar energy, due to location, architectural geometry, construction solutions and materials used. Such a building designed based on this principle can adapt and connect the building to the natural energy potential of the area. The concept of *passive house* can be defined as the most efficient form of storage and conservation of energy in buildings. The energy demand for heating is reduced, so the building also has a considerable contribution to protecting the environment through low CO_2 emissions (Ivan B., et al., 2012).

Passive House is the top concept in terms of energy-efficient constructions, a global concept for building houses that consume by 90% less energy than an existing building and even by 75% less than a new European standard-built house. Generally, the value of standardized energy consumption for the passive house (Passive House Institute) is as follows:

- Energy demand for heating ≤ 15 kWh/m² · year;
- Total demand for primary energy ≤ 120 kWh/m² · year.

The *passive house* standard offers an interesting way to minimize the energy demand of new buildings, thus achieving sustainability and improving the comfort of the inhabitants (Catalina T., 2013), based on the two main principles (Grobe C., 2002):

- the optimization of basic requirements by increasing the performance of components that are indispensable, i.e. the building envelope, windows and ventilation.
- the maximum loss reduction.

This minimum energy demand can be satisfied exclusively from renewable sources (Bădescu V., Sicre B., 2006) and the passive house can make the most of all the available energy resources.

Specifically for the *passive house*, the energy efficiency can be synonymous with maintaining a comfort interior temperature, both in winter and summer, without additional energy in support of thermal comfort. Given that the energy requirement for heating a building is equal to its energy losses, diminishing these losses also leads to a decrease in heat demand and a decrease in energy demand. The same principle is valid in summer, when the building envelope plays the role of protection against overheating in interior spaces (Guerriat A., 2008).

Higher energy efficiency, characteristic of passive houses, is ensured by meeting the five basic requirements: efficient thermo-insulation, thermal bridge removal, envelope tightness, ventilation with heat recovery and, last but not least, the orientation and shading of the building. The thermal insulation of the building is considered the optimal solution for reducing heat loss through a building envelope. Under current laws, for Romania, the maximum value of the heat transfer coefficient for external walls is set at U = 0,56 W/m²K (C107/2010), while the *passive house* standard has a maximum value of U = 0.15 W/m²K (Passive House Institute). This normative act sets out all the mandatory maximum values of the "U" thermal transfer coefficient for different envelope components, including for doors and windows components (U = 1.3 W/m²K).

The thermal bridges are in two variants: the structural thermal bridges, which perforate the building's thermal insulation, thus creating a way of passing the heat outwards and the geometric thermal bridges that take place in the corners of the building. The largest losses are high-area thermal bridges (e.g., a reinforced concrete floor in contact with soil without thermal insulation), followed by linear bridges (e.g. a balcony). The lowest losses are recorded by the point thermal bridges.

The next condition to be achieved is the tightness of the building envelope, otherwise 10-15% of the input energy will be lost through various cracks, through the electrical cable protection tubing, through other gaps considered thermally negligible in the case of conventional buildings.

Heat recovery ventilation is essential not only to ensure increased thermal efficiency, but also to create a healthy indoor space, providing a continuous air exchange, controlling the concentration of NOx (CO, CO_2, COV, etc.) and relative humidity in the air. Besides, the dust and pollen filter in the ventilation system with heat recovery also provides a cleaner and more comfortable interior space.

The last condition, of essential importance, is the orientation and shading of a *passive house*. From this point of view, the most important construction elements are the glazed surfaces that ensure the solar input, which must overcome the heat losses occurring through these surfaces. Otherwise, it is difficult to achieve the values imposed in the *passive house* standard. Depending on the possibilities and climatic conditions, the glazed surfaces must be oriented to the south or east. Those on the western side may pose a risk of overheating, especially during the summer season. Those on the northern side are areas that lose heat. Thus, minimizing them is recommended. By shading glazed surfaces it is possible to avoid overheating of interior spaces during the summer. (Heiduk E., 2009; Passive House Association; International Passive House Association; Passive House Institute)

The energy performance of buildings, respectively the energy actually consumed or estimated to meet the needs for its normal use, includes the following functions: heating during the cold season, respectively cooling during the hot season, preparation of the hot water for consumption, air ventilation / air conditioning, lighting and electrical energy required for the operation of household appliances, office equipment and auxiliary electrical equipments for heating, ventilation / conditioning and domestic hot water preparation systems.

2.2.2. The selection of the technical solutions in case of energy audit of buildings

For this research direction, a study was conducted on the selection of the technical solutions in case of energy audit of buildings, using TOPSIS, being supported by the paper: Ioan Giurca, **Ioan Aşchilean**, George Sebastian Naghiu, Gheorghe Badea, *Selecting the Technical Solutions for Thermal and Energy Rehabilitation and Modernization of Buildings.* 9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, 8-9 October 2015, Târgu Mureş, Romania. Procedia Technology Volume 22, 2016, Pages 789-796. http://www.sciencedirect.com/science/article/pii/S2212017316000517.

The English word "audit" stands for book keeping review, balance sheet or finding. Within the framework of the sustainable development commitments, the energy audit was introduced in the USA in 1997, as a requirement for obtaining State subsidies granted within the Energy Conservation Project (SSEP), and then in order to guarantee loans. At present, the energy audit means the identification and the quantification of the energy consumption from a certain physical unit (industry, building, installation) (Radu A., 2006).

The acronym comes from the initials of its name: **T**echnique for **O**rder **P**reference by **S**imilarity to **I**deal **S**olution (Şuteu S., 2007). TOPSIS method was developed by C.L. Hwang and K. Yoon, in 1981, as an alternative to the Electre method (Ciocalteu S.C.F., 2006; Jantea D., et. al., 2009; Ravesh M.H.S., et. al., 2012). This method is based on the concept that the optimal decision must be as closed to the most advantageous solution as possible and as distant to the most disadvantageous solution as possible. The closeness or the distance is taken into account as the geometric distances between the characteristics. For a maximizing characteristic, the most advantageous value is the greatest one, and the most disadvantageous value is the smallest one. For a minimizing characteristic, things are the other way around (Şuteu S., 2007). TOPSIS method has been largely used in the foreign scholarly literature: (Abo-Sinna M.A., Amer A.H., 2005; Jee D.H., Kang K.J., 2005; Olson D.L., 2004; Opricovic S., Tzeng G.H., 2004; Rouhani S., et. al., 2012).

Low thermal protection of Romanian buildings leads to about a double energy consumption as compared to the EU States, with direct consequences on the high level of pollutants (Marusciac D., Pleșa S., 2011; Giurca I., 2009). In this context, Romania officials started a thermal and energetic rehabilitation and modernization program, for buildings constructed before 1990, and this program must be finalized by 2030 (MDRAP, 2016). If the thermal and energetic rehabilitation and modernization works for buildings are financed from public funds, then the specific energy consumption of heating systems must decrease under 100 kWh/m^2/year (MDRAP, 2017a; MDRAP, 2017b).

In Romania too, several works approaching the TOPSIS method have been published, and we would like to mention the following (Ciocalteu S.C.F., 2006; Jantea D., et. al., 2009; Dolga V., 2011; Prejmerean V., 2012). Considering the important amounts of money budgeted by the State for the rehabilitation of the residential buildings as well as of the administrative buildings, one must use a scientific method in order to select the energy audit solutions for buildings.

This study aims at filling in the emptiness on the building energy audit, when it comes to selecting the building energy modernization and rehabilitation solutions, as well as in relation with the performance of the sensitivity analysis of energy audit projects, using TOPSIS. Therefore, the purpose of the analysis was to help the designer, the beneficiary and the public authorities in selecting the technical solutions during the design stage of the energy audit of buildings. Based on the conclusions, we are making proposals in order to improve the actual legislation in the field of building energy audit.

2.2.2.1. Calculation methodology

TOPSIS method provides the normalization of the consequence matrix and the determination of the distances to the ideal solution and to the most unfavourable alternative; the decision alternative with the smallest distance to the ideal solution and to the greatest distance to the most unfavourable solution is considered to be the multicriterial optimum (Jantea L., et al., 2009). The TOPSIS method is carried out as follows:

Step 1: Create the alternatives matrix. Basically, the alternative matrix comprises a list of the technical solutions proposed by the designer.

Step 2: Create the criteria matrix. Basically, the criteria matrix comprises the list of the chosen criteria in order to select the optimal technical solution.

Step 3: Create the consequences matrix. The consequence matrix shall practically contain the results of the technical alternatives for each decision criterion.

Step 4: Determine the weight of the performance assessment criteria. In order to determine the criteria weight, one shall use the matrix method.

Step 5: Create the normalized matrix. The calculations specific to the TOPSIS method, namely steps five to nine, shall be performed based on the calculation relations presented in the literature (Şuteu S., 2007; Ciocalteu S.C.F., 2006; Jantea D., et. al., 2009; Rouhani S., et al., 2012; Dolga V., 2011; Ashtiani B., et al., 2009; Mazza A., Chicco G., 2012; Vahdani B., et al., 2011; Wedagama D.M.P., 2010).

At step five, one shall determine the normalized table by converting the Cij consequences in the CNij normalized values, according to the formula:

$$CNij = \frac{Cij}{\sqrt{\sum_{j=1}^{n} C_{ij}^{2}}} \tag{1}$$

where: i = 1, m (m representing the total number of assessment criteria); j = 1, n (n representing the total number of alternatives to analyse).

Step 6: Create the weighted normalized matrix. At step six, one shall make the weighted normalized table by multiplying the normalized values with the importance weights (pj) awarded by the decision-maker to each characteristic:

$$CNP_{ij} = p_j \cdot CN_{ij} \quad (2).$$

Step 7: Determine the ideal alternative and the negative ideal alternative. At step seven one shall determine, for each characteristic used for taking the decision (j from 1 to n), the most advantageous characteristic (the ideal positive one) Cj+, namely the most disadvantageous characteristic (the ideal negative one) Cj-. In order to do this, one shall take into account the type of that respective characteristic (a maximizing one or a minimizing one):

- for maximizing characteristics:

$$C_j^{+} = \max_{1 \le i \le m}\{CNP_{ij}\}$$
$$C_j^{-} = \min_{1 \le i \le m}\{CNP_{ij}\} \tag{3}$$

- for minimizing characteristics:

$$C_j^+ = \min_{1 \le i \le m}\{CNP_{ij}\}$$
$$C_j^- = \max_{1 \le i \le m}\{CNP_{ij}\} \quad (4)$$

Step 8: Determine the square deviation of the characteristics as opposed to the most advantageous characteristic and to the most disadvantageous characteristic respectively. At step eight, for each decision alternative one must determine the square deviation of the characteristics towards the most advantageous characteristic and towards the most disadvantageous one respectively:

$$S_i^+ = \sqrt{\sum_{j=1}^{n}\left(CNPij - C_j^+\right)^2} \quad (5)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}\left(CNPij - C_j^-\right)^2} \quad (6)$$

Step 9: Calculate the relative exactness in relation with the ideal solution. At step nine, one shall rank each decision alternative in relation with the ideal solution. The best alternative is the one obtaining the best Ci* score.

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \quad (7)$$

The alternative relation shows that any alternative located at the shortest distance to the ideal solution is certainly located at the longest distance to the ideal-negative solution. Since $Si^- \ge 0$ and $Si^+ \ge 0$, then, clearly, Ci Є [0, 1] (Chamodrakas I., et al., 2009; Gumus A.T., 2009).

Step 10: Perform the sensitivity analysis, by modifying the consequences of the weights. The sensitive analysis is based on the fact that at a certain point, only one coefficient of the objective function varies, while the other ones remain at the initial values (Rusu A., 2007). The sensitivity analysis is made by modifying the values of the consequences corresponding to the alternatives as well as the weight of the decision criteria, in order to determine how well is the optimum technical solution resisting to the successive changes of consequences or of importance coefficients.

Step 11: Determine the solutions ranking. The rank of the technical solutions shall be made according to the decreasing order of the values Ci* (Ciocalteu S.C.F., 2006; Prejmerean V., 2012).

2.2.2.2. Case Study

Further on, we shall present a multicriterial analysis application on the energy audit of a block of flats, located in Cluj-Napoca City. The construction consists of underfloor, first floor and 4 floors, it is composed of 2 buildings, it has 30 apartments, and the useful heated area is of 1778.92 square meters.

Step 1: Create the alternatives matrix. In order to determine the effects of the construction's energy rehabilitation and modernization measures, the solutions were taken into account both individually and as sets of measures. We proposed three sets of measures, namely: a minimal one; an average one; a maximal one.

The list containing the proposed measures is synthetically presented in the table 2.

Table 2. Alternatives' matrix.

Variant Name	**Package's**	**Work Category**		
		Construction Works	**Plumbing Works**	**Connective Works**
V1	Minimal package of measures	- Supplementary thermal insulation for front side, using 10 cm cellular polystyrene; - New exterior windows with climate comfort glass; - New exterior doors with climate comfort glass.	- Repairing the thermal insulation of the heating agent distribution pipes from the basement; - Repairing the thermal insulation of the hot water distribution pipes from the basement; - Obtaining and installing thermostatic mixing valves for static heating units; - Obtaining and installing heat cost allocators for static heating units; - Automating apartment heating units so that they can function in idle mode during the night or when the owners are not at home.	- Taking out and re-installing natural gas pipes located on the front sides of buildings; - Taking out and re-installing telephone, cable and internet network located on the front sides of buildings.
V2	Average package of measures	- Supplementary thermal insulation for front side, using 12 cm cellular polystyrene; - New exterior windows with climate comfort glass; - New exterior doors with climate comfort glass.	- Repairing the thermal insulation of the heating agent distribution pipes from the basement; - Repairing the thermal insulation of the hot water distribution pipes from the basement; - Obtaining and installing thermostatic mixing valves for static heating units; - Obtaining and installing heat cost allocators for static heating units; - Automating apartment heating units so that they can function in idle mode during the night or when the owners are not at home.	- Taking out and re-installing natural gas pipes located on the front sides of buildings; - Taking out and re-installing telephone, cable and internet network located on the front sides of buildings.

V3	Maximal package of measures	- Supplementary thermal insulation for front side, using 15 cm cellular polystyrene; - New exterior windows with climate comfort glass; - New exterior doors with climate comfort glass.	- Repairing the thermal insulation of the heating agent distribution pipes from the basement; - Repairing the thermal insulation of the hot water distribution pipes from the basement; - Obtaining and installing thermostatic mixing valves for static heating units; - Obtaining and installing heat cost allocators for static heating units; - Automating apartment heating units so that they can function in idle mode during the night or when the owners are not at home. - Installing low flow mixer showers; - Installing low flow basin mixer taps; - Installing low flow sink mixer taps.	- Taking out and re-installing natural gas pipes located on the front sides of buildings; - Taking out and re-installing telephone, cable and internet network located on the front sides of buildings.

Step 2: Create the criteria matrix. In the case study, its set the following objectives: minimizing total investment expenses, criterion C1; maximizing the reduction of the updated net value (ΔVNA) corresponding to the investment, criterion C2; minimizing the period of recovery of the supplementary investment "Tr", criterion C3; minimizing the cost of saved unit of energy "e", criterion C4; minimizing the monthly instalment "rc", criterion C5.

In table 3 it is presented the decision-making criteria proposed for choosing the technical solutions concerning the thermal and energetic rehabilitation and modernization of the building and its installations, object of this study.

Table 3. Criteria matrix.

No.	Criterion	Criterion's name	Optimization is done by	M.U.
1	**C1**	Total investment expenses	**minimization**	euro
2	**C2**	VNA discount	**maximization**	euro
3	**C3**	Investment recovery period	**minimization**	year
4	**C4**	Cost of saved unit of energy	**minimization**	euro/kWh
5	**C5**	Beneficiary affordability of the monthly instalment	**minimization**	lei/month ap.

2.2.2.3. Results and discussions

After performing the calculations, we obtained the following values (table 4) for the consequences of the analysed alternatives. Then it go through steps 4 to 7, and then at step 8 it calculate the squared deviation of characteristics compared with the most advantageous characteristic using the formula 5, and then the results are presented in table 5. At step 8 it calculate the squared deviation of characteristics compared with the most disadvantageous characteristic using the formula 6, and then the results are presented in table 6.

Table 4. Consequence matrix.

Variants	**Criteria**				
	C1	**C2**	**C3**	**C4**	**C5**
V1	160,172	92,679	13.55	0.03843	78.01
V2	164,503	95,714	13.53	0.03835	80.12
V3	181,643	115,205	13.14	0.03712	88.47

Table 5. Square deviation of the characteristics towards the most advantageous characteristic.

No.	**Variants**	**Si+**
1	V1	0.0151
2	V2	0.0134
3	V3	0.0141

The relative exactness in relation with the idea solution is determined with formula 6, and afterwards we rank each decision alternative in relation with the ideal solution, and the result is the one presented in table 7.

Table 6. Square deviation of the characteristics towards the most disadvantageous characteristic.

No.	**Variants**	**Si-**
1	V1	0.0141
2	V2	0.0115
3	V3	0.0151

According to the data presented in the table 7, alternative no. 3 is on the 1st place, alternative no. 1 is on the 2nd place and alternative no. 2 is on the 3rd place. Now, one can decide which alternative is the most suitable, based on the order of the priority rank of Ci*.

Consequently, the best alternative is the one placed at the shortest distance towards the ideal solution. The alternative report shows that any alternative placed at the shortest distance to the ideal solution is certainly placed at the longest distance to the ideal-negative solution (Ciocalteu S.C.F., 2006).

Table 7. Relative exactness in relation with the idea solution.

No.		Average	Place
1	C1* =	0.4842	2
2	C2* =	0.4616	3
3	C3* =	0.5158	1

The solution ranking is as follows: V3, V1, V2. Therefore, alternative 3 is on the first place, alternative 1 is on the second place and alternative 2 is on the third place.

Practically, the analysis comes to fill in the emptiness existent in the legislation on the building energy audit, in matters related to the selection of building energy rehabilitation and modernization, as well as in matters related to the performance of the sensitivity analysis of energy audit projects, using for this purpose the TOPSIS method.

The conclusions of this study are useful both for the specialists who want to obtain the energy auditor license for buildings as well as for elaborating energy audit projects for buildings. From the above facts, it results that the TOPSIS method may be used for building energy audit projects. In order to automate the calculations, we recommend the use of Excel sheets or of specialized software dedicated to TOPSIS method. Based on the study conclusions, we are making proposals in order to improve the actual legislation in the field of building energy audit.

2.3. General Considerations on Alternative Energies

The success of implementing energy efficiency in the field of stationary applications depends directly on solutions to capitalize on the alternative energies through the various energy generation systems that will be adopted to energetically support these buildings.

Unconventional energy sources have gained and will continue to gain an increasing share of energy systems around the world, both due to the research efforts and the political volition involved in their development, and due to the increase in the price of energy obtained through traditional methods. Renewable primary energy sources are those sources in the natural environment, available in virtually limitless quantities or regenerating through natural processes at a faster rate than they are consumed.

The officially recognized renewable energies originate from the sun’s rays, the internal temperature of the earth, or the gravitational interactions of the sun and the moon with the oceans (Bălan M., 2007). In addition, nowadays hydrogen is recognized as a non-polluting energy carrier because it does not contribute to global warming if it is produced from renewable sources.

All these forms of energy are capitalizable, as they can be used to generate electricity and produce thermal energy. At present, these alternative energy sources are not fully exploited, but there is a clear and concrete trend that shows that important amounts of money are invested heavily in this relatively new direction, representing a new energy branch.

Specific concerns in the area of alternative energies approached for analysis and research after the completion of doctoral studies are related to the practical applicability of solar, wind and hydrogen energy in the building sector.

2.3.1. Romanian Solar Energy Potential

Solar energy is the most important resource of renewable energy, being virtually an inexhaustible source of energy. The potential for solar energy in Romania is relatively important, our country being in the second (B) sunny area from Europe. Thus, for Romania, it is possible to define 5 sunny zones, from a maximum of the annual solar energy flux that can reach values of 1450÷1600 kWh/m^2/year in the area Black Sea Coast, Dobrogea and in most southern areas, up to a minimum of 1100÷1200 kWh/m^2/year in mountainous areas and north of the country. In most regions of the country, annual solar energy exceeds 1250÷1350 kWh/m^2/yr. (MDRAP, 2016)

Due to geographical areas and climatic conditions, the potential of solar energy is characterized by an average irradiation. Romanian Global Horizontal Irradiation map and Photovoltaic Power Potential map are presented suggestively in the figure 1.

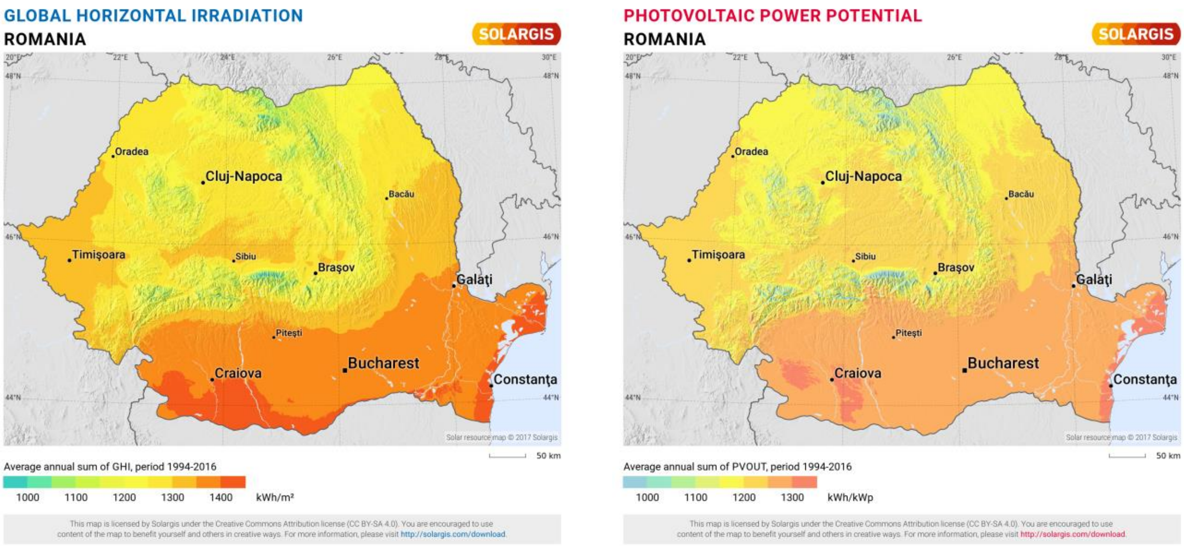


Figure 1. Romanian solar energy potential

2.3.2. Romanian Wind Energy Potential

In Romania, five wind farm potential areas were identified, depending on environmental and topogeographical conditions, taking into account the level of energy potential of such resources at an average height of 50 meters and above. The results of the recorded measurements show that Romania is in a temperate continental climate with a high energy potential, especially in seashore and coast line areas (gentle climate) as well as in alpine areas with mountain plateaux and valleys (severe climate).

Preliminary assessments of the Black Sea coastline, including in the offshore area, show that the convertible wind potential in the short and medium term is high, with the possibility of obtaining an appreciable amount of energy.

The average annual wind speed is directly influenced by orography and thermal stratification of the air, which can intensify or attenuate it. In the mountainous area there are average annual speeds that decrease with the altitude from 8-10 m/s on the Carpathian heights (2,000-2,500 m) to 6 m/s in the areas with altitudes of 1,800-2,000 m, on the sheltered slopes the annual speeds decrease to 2-3 m/s, and in the intramontane depression these reach 1-2 m/s. Within the Carpathian arc, the average annual speeds fluctuate between 2-3 m/s, and on the outside of the Carpathians, in Moldova, they reach 4-5 m/s, the highest annual average being in the eastern part of the country, in the Lower Siret Plain (5-6 m/s), on the Black Sea coast (6-7 m/s), in Dobrudja and Bărăgan regions (4-5 m/s). The lowest annual mean values (1-2 m/s) are recorded in the closed intra-Carpathian depressions. (MDRAP, 2016)

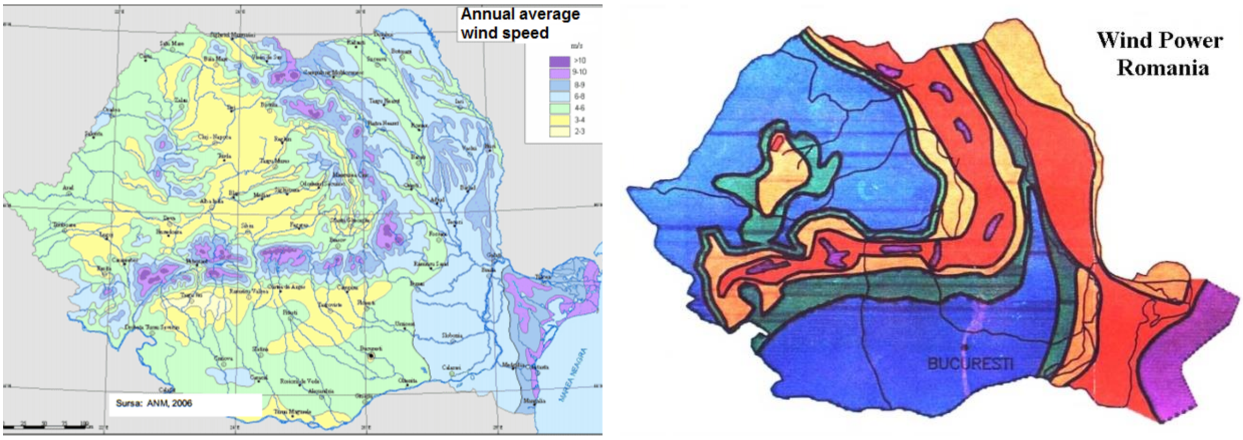


Figure 2. Romanian wind energy potential

Figure 2 shows the Romania Wind Speed map and the Wind Power Romania map, and the table 8 highlights wind speed and potential power values for the main 5 wind areas of Romania.

Table 8. Romanian wind resources

area	high mountain		large open		seaside		flat land		hills and plateaus	
	m/s	w/m^2	m/s	w/m^2	m/s	w/m^2	m/s	w/m^2	m/s	w/m^2
I	>11.5	>1800	>9.0	>800	>8.5	>700	>7.5	>500	>6.0	>250
II	10.0-11.5	1200-1800	8.0-9.0	600-800	7.0-8.5	400-700	6.5-7.5	300-500	5.0-6.0	150-250
III	8.5-10.0	700-1200	7.0-8.0	400-600	6.0-7.0	250-400	5.5-6.5	200-300	4.5-5.0	100-150
IV	7.0-8.5	400-700	5.5-7.0	200-400	5.0-6.0	150-250	4.5-5.5	100-200	3.5-4.5	50-100
V	<7.0	<400	<5.5	<200	<5.0	<150	<4.5	<100	<3.5	<50

The results of the measurements confirm that Dobrudja is, along with North Scotland, the most promising wind farm exploitation area in Europe. Besides the average wind intensity of 7.2 m/s at the level of the whole year, Dobrudja has a relatively flat territorial profile and also has a low population density, which allows the installation of a large number of wind turbines, preserving the technological distances needed between them. (MDRAP, 2016)

2.3.3. Hydrogen Energy

Hydrogen is the only secondary energy vector that fits a wider application on the market, focusing on the fact that hydrogen can be obtained from a wide range of primary energies. It can be used advantageously for a wide range of applications, ranging from transport and portable to stationary applications (Balat M., 2008). In addition, hydrogen can also be used in decentralized energy generation systems without carbon dioxide emissions. Hydrogen is already part of the current chemical industry, but as an energy source, its rare advantages can only be obtained with the help of technologies (Badea G., et al. 2012; Bockris J.O'.M., 2013).

T. N. Veziroğlu, editor of the journal specializing in hydrogen technology and energy, *International Journal of Hydrogen Energy,* synthetically presents some peculiarities (Momirlan M., Veziroğlu T.N., 2005) recommending the use of hydrogen as a secondary energy vector produced by nonconventional technologies:

- hydrogen concentrates primary energy sources and makes them available to the consumer in a convenient form;
- it offers the possibility of transformation into various other forms of energy through highly efficient conversion processes;
- it is an inexhaustible source, if electrolytically produced from water; hydrogen production and consumption is a closed cycle, the source of production - water - is kept constant and represents a classic cycle of recirculation of this type of raw material;
- it is the easiest and cleanest fuel; burning of hydrogen is almost entirely free from pollutant emissions;
- it has a higher gravimetric energy density compared to other fuels;
- hydrogen can be stored in various ways, such as: normal or high pressure gas, in the form of liquid hydrogen or in the form of solid hydrides;
- it can be transported over long distances stored in the form or in one of the ways outlined above;
- the equipment for hydrogen conversion in electric power, of fuel cell-type, has an efficiency of over 60%. (Afgan N., Veziroğlu A., 2012; Momirlan M., Veziroğlu T.N., 2005; Veziroğlu T.N., Şahin S., 2008).

Hydrogen condenses at -252.77°C and the specific weight of liquefied hydrogen is 71 g/L, giving it the highest energy density per unit of mass amongst all fuels and energy carriers: 1 kg of hydrogen contains as much energy as 2.1 kg of natural gas or 2.8 kg of petroleum (Badea G., Felseghi RA, et al., 2012). This feature has made hydrogen the fuel used in propulsion and energy supply of space crafts. Unlike other fuels such as petroleum, natural gas and coal, hydrogen is renewable and non-toxic when used in fuel cells. Hydrogen has a very high energy potential as environment-friendly fuel and in reducing the import of energy resources.

Etymologically, the word hydrogen is a combination of two Greek words, meaning "to make water" (Wikipedia). Produced from non-fossil sources and raw materials, using different forms of alternative energy (solar, wind, hydro/electrical, geothermal, biomass, etc.), hydrogen is considered to be a prime fuel in delivering the so-called "green energy" (Duma S.I., 2009). Thus, systems that run with hydrogen as fuel can be considered to be the best solution for accelerating and ensuring global stability. Hydrogen is expected to play an important role in the future energy scenarios of the world, the most important factor that will determine the specific role of hydrogen will likely be the demand for energy. At the same time, hydrogen can replace fossil fuels to a certain extent and become the preferred clean, non-toxic energy carrier / transmission operator in the near future.

To highlight the advantages of hydrogen compared to other fuels, the main properties of the various fuels currently used are presented in Table 9 (Mekhilef S., Saidur R., Safari A., 2012).

Table 9. Comparison of the main properties of hydrogen and other fuels

Fuel type	Energy / mass unit (J/kg)	Energy / volume unit (J/m³)	Energy reserve factor	Specific carbon emission (kgC/kg comb.)
Liquid hydrogen	141.90	10.10	1.00	0.00
Gas hydrogen	141.90	0.013	1.00	0.00
Black oil	45.50	38.65	0.78	0.84
Gasoline	47.40	34.85	0.76	0.86
Jet fuel	46.50	35.30	0.75	-
LPG	48.80	24.40	0.62	-
LNG	50.00	23.00	0.61	-
Methanol	22.30	18.10	0.23	0.50
Ethanol	29.90	23.60	0.37	0.50
Bio diesel	37.00	33.00	-	0.50
Natural gases	50.00	0.04	0.75	0.46
Coal	30.00	-	-	0.50

Analysing the information contained in the table, it can be concluded that the main arguments in favour of using hydrogen as synthetic fuel, obtained from renewable sources, are the following: it has the highest energy / mass unit of all fuel types; it is environmentally friendly, its *burning* resulting in water vapours, as it is noticed that the amount of carbon emissions for hydrogen is zero; it has the largest energy reserve factor, respectively the largest conversion factor in electricity, being considered for this reason the best of the fuels presented, and the energy efficiency is very high. Hydrogen is expected to play an important role in future global energy scenarios (Mekhilef S., Saidur R., Safari A., 2012).

The procedures and processes for producing, capturing, storing or converting these types of alternative energies are being refined, high investment costs and reduced conversion process yields have made renewable energy sources a small part of the global demands. Optimistic forecasts estimate alternative energy production at a share of 30-50% of the total energy market around the 2050s, but this depends on reducing production costs and finding massive electricity storage capacities (European Commission of Energy). In addition, all these forms of energy could also supply the demand for fuel in satisfactory quantities for various industrial uses (Midilli A., Dincer I., 2007).

2.4. Analysis on the Solutions of Hydrogen Production Using Solar Energy

At present, hydrogen is mostly entirely produced out of fossil fuels, such as: natural gas, petroleum and coal, based on a well-established conversion processes. In these cases, the carbon dioxide released into the atmosphere during the hydrogen-production process is slightly lower than that resulted from the direct combustion of these fuels, if equal amounts of energy are produced. On the other hand, the use of hydrogen produced from renewable sources, substantially reduces the amount of CO_2 released into the atmosphere (Pasculete E., 2008).

A first direction in the field of alternative energy we have approached for analysis and research addresses particular and specific aspects of hydrogen production by using energy systems that use solar energy as the primary source of energy. The results of the studies for this field were disseminated within the international specialized conferences, supported by the following works:

Gheorghe Badea, George Sebastian Naghiu, Raluca - Andreea Felseghi, Maria Simona Răboacă, **Ioan Aşchilean,** Ioan Giurca, *Multi-criteria Analysis on How to Select Solar Radiation Hydrogen Production System,* Proceedings of the 10th Int. Conference on Processes in Isotopes and Molecules - PIM 2015. https://doi.org/10.1063/1.4938449;

George Sebastian Naghiu, Ioan Giurca, **Ioan Aşchilean,** Gheorghe Badea, *Comparative analysis on the solutions of hydrogen production using solar energy with and without connection to the power network* – 9*th* International Conference Interdisciplinarity in Engineering, INTER ENG, Targu-Mures, Romania, October 8-9, 2015. DOI: https://doi.org/10.1016/j.protcy.2016.01.049.

2.4.1. Advanced Multi-Criteria Analysis based on the FRISCO formula

The purpose of this work is to present a method of selecting hydrogen-production systems using the electric power obtained in photovoltaic systems, and as a selecting method, it suggest the use of the Advanced Multi-Criteria Analysis based on the FRISCO formula.

Multi-criteria methods are well known in Romania (Roman M., 2012), but their use in the field of construction installation works is less studied. Starting with 1996, in Romania also were published several papers on the use of multi-criteria methods in the field of construction installation works, such as: doctoral theses (Aşchilean I., 2010; Aşchilean I., 2014; Badea G., et al., 2015; Bobancu S., 2009; Boomer J., 2004; Cruceru R. and Ciobanu I., 2008; Giurca I., 2009), books (Aşchilean I., 2014) and articles (Badea G., et al., 2015; Giurca I., 2013; Giurca I., 2010; Naghiu G.S. and Giurca I., 2015a; Naghiu G.S. and Giurca I., 2015b).

Its wish that the presented method may be used as a research and innovation tool, useful for selecting the optimal system in the stage of technological development of hydrogen-production systems and in the stage of elaboration of opportunity and feasibility studies and business plans for the development of new hydrogen energy production plants.

2.4.1.1. Materials

It was analysed the following technical solutions:

- **Alternative A1,** hydrogen production system by water electrolysis at room temperature and electrical power obtained using crystalline photovoltaic panels. These systems convert non-concentrated solar radiation. The efficiency of these systems is between 13 % and 16 %;

- Alternative A2, hydrogen production system by water electrolysis at room temperature and electrical power obtained using concentrating photovoltaic systems. These systems convert non-concentrated solar radiation. The efficiency of these systems is between 12 % and 14 %;

- Alternative A3, hydrogen production system by water vapour electrolysis obtained with a part of the solar radiation spectrum and electrical power obtained using concentrating photovoltaic systems. The efficiency of these systems is between 26 % and 34 %;

- Alternative A4, hydrogen production system by water vapour electrolysis obtained with concentrated solar thermal systems and electrical power obtained using concentrating photovoltaic systems. These systems are only in the research stage, but a development in this direction is foreseen once with the technological development of the multi-junction photovoltaic cells and of the high precision concentrating optical systems. The efficiency of these systems is between 26 % and 34 %.

Considering that various hydrogen production systems have various components, that they have advantages and disadvantages, they bear different investment and operation costs, depending on the system, in practice, both designers and beneficiaries are facing problems with selecting the right hydrogen production system.

In this context, when selecting the hydrogen production system, it was intended:

- to minimize hydrogen production cost (€/kWh), criterion C1;
- to minimize investment cost (€/kg H_2/year), criterion C2;
- to minimize the surface of land dislocated to the system installation (m^2/kg H_2/year), criterion C3;
- to maximize the system efficiency (%), criterion C4.

2.4.1.2. Methods

As a multi-criteria analysis method, it was used the Advanced Multi-criteria Analysis. This Advanced Multi-criteria Analysis is based on the FRISCO formula, an empiric formula developed by a well-known research team from San Francisco - the U.S.A., internationally recognized as the most efficient formula and a widely used formula too. In order to apply the Advanced Multi-criteria Analysis, one must take the following steps:

Step 1*:* Determining the purpose. At this stage, one must identify the problem that must be practically solved or to determine the purpose.

Step 2*:* Establishing the decision-making variants. In this stage, the set of alternatives that can be applied shall be identified, while the data shall be written in the alternatives matrix A = [Ai]. Where i = 1...n, represents the number of alternatives.

Step 3*:* Establishing the decision-making criteria. Here it was identified the criteria (objectives) that shall be used for the selection of the alternatives, while the data shall be written in the decision criteria matrix C = [Cj]. Where j = 1...m, represents the number of criteria.

Step 4*:* Filling in the performance matrix, where the performance of the alternatives shall be identified for each criterion, and the data shall be written in the performance matrix P = [Pij].

Step 5*:* Establishing the importance coefficients for the decision-making criteria. The criteria established for the comparative analysis of objects, objectives, projects or activities do not have the same importance, generally speaking. In order to quantify the criteria importance (weight), one calculates certain "weight coefficients" Kj. It was started from the qualitative analysis of the criteria, comparing two criteria at a time and establishing which one of them is the most important.

When establishing the importance coefficients for the decision-making criteria one shall bear in mind, by a simple mathematical expression, that the relative position of two criteria may only know three situations: one criterion is more important than the other one, one criterion is just as important as the other one and one criterion is less important than the other one.

For instance, the criteria weight may be established using a "3 values grid", namely "0", "0.5" and "1". Thus, one makes a square table, where the number of rows equals the number of columns and the number of criteria. Each criterion from a row is compared with each criterion in the column, granting them a coefficient directly related to their qualitative importance (Bobanacu S., 2009; Boomer J., 2004):

- if the criterion placed on the row is more important than the one from the column, one shall assign the value "1" in the table;

- if the criterion from the row is just as important as the one from the column, one shall assign the value "0.5";

- if the criterion from the row is less important than the one from the column, one shall assign the value "0".

- when a criterion is compared to itself, one shall assign the value "0.5".

On each row, one adds up the points corresponding to each criterion, thus establishing the total number of points obtained. Further on, one must calculate the weight coefficients. The weight coefficients "Kj" may be calculated using various formulas. In this study, it was used the FRISCO formula, namely (Cruceru R. and Ciobanu I., 2008):

$$Kj = \frac{p + |\Delta p| + m + 0{,}5}{\frac{NCRT}{2} + |\Delta p'|} \tag{8}$$

where: "Kj" represents the weigh coefficients, "p" represents the sum of the points obtained by that specific element, "Δp" stands for the difference between the score of the element taken into account and the score of the element that ranked the last, "m" stands for the number of outranked criteria, namely those criteria that scored lower than that specific element, "NCRT" represents the number of criteria taken into account, and "Δp" represents the difference between the score of the element taken into account and the score of the element that ranked first (a negative value shall result).

The criteria ranking is made taking into account that the criterion that obtained the highest score shall rank the first and the criterion that obtained the lowest score shall rank last.

In order to determine the importance level in relation to the other criteria, one shall rank the criteria according on their score. One shall assign an importance level number, which corresponds to the place it obtained in the ranking. If two or more criteria obtained the same score, their place in the ranking is the same and it is calculated as the arithmetical average of the places occupied by these criteria.

Step 6: Determining the marks for the performances of alternatives for each criterion. In this stage of the multi-criteria analysis, one shall grant "Nji" marks for the alternatives analysed according to the accomplishment of each analysis criterion. We shall analyse the alternatives one by one (index "i") and one shall grant a mark according to each criterion (index "j"), until one finished up all variants. For grading, one shall choose, for instance, a scale of 10 points. In the advanced multi-criteria analysis, the mark 10 shall be granted for the most advantageous value of performances.

Depending on the nature of the criterion, the marks are calculated according to the following formulas:

Maximizing criteria:

$$Nji = \frac{aji}{a\max\ j} \cdot 10 \tag{9}$$

Minimizing criteria:

$$Nji = \frac{a\min\ j}{aji} \cdot 10 \tag{10}$$

where: "Nji" represents the mark granted to alternative "i" according to the "j" criterion, "aij" represents the performance of the alternative "i" according to the "j" criterion, "aminj" represents the minimal performance according to the "j" criterion, and "amaxj" represents the maximum performance according to the "j" criterion.

A mark corresponds to each performance. Some authors (Cruceru R. and Ciobanu I., 2008) say that the marks must be an integer from 1 to 10, while some other authors (Aciu C., 2013) say that the marks must be anywhere in the range 0...10 and they also say that the marks must not be rounded to integers.

Step 7: Determining the total value factor. For each variant, according to each criterion, one shall calculate a final factor "Fji" (performance factor) representing the product between the weight coefficient of the criterion "Kj" and the mark granted "Nji", according to the formula (Cruceru R. and Ciobanu I., 2008):

$$Fji = Kj \cdot Nji \tag{11}$$

Therefore, for each variant one calculated the sum of these factors obtaining the total value factor "FVi", according to the formula (Cruceru R. and Ciobanu I., 2008):

$$FVi = \sum_{j=1}^{j=m} Fji \tag{12}$$

Step 8*:* Determining the ranking of alternatives. The optimal alternative is the one for which the total value factor “FVi” has the maximal value, namely:

$$Aopt = \max FVi \tag{13}$$

Step 9*:* Selecting the optimal variant. Based on the values of this total value factor “FVi” one shall determine the final ranking of the analysed variants. It is obvious that the alternative that obtains the highest value for the total value factor “FVi” (Cruceru R. and Ciobanu I., 2008) shall rank the first.

2.4.1.3. Results and Discussions

It was proposed a case study about how to select the hydrogen production systems, starting from the alternatives and decision-making criteria identified at chapter 2.4.1.

Step 1*:* Determining the purpose. At this stage, one must identify the problem that must be solved in practice or to determine the purpose. The purpose of this study was to present a method of ranking hydrogen-production systems, using multi-criteria methods.

Step 2*:* Elaborating the alternative matrix. For this case study the alternatives (A1-A4) were identified in chapter 2.4.1.

Step 3*:* Elaborating the criteria matrix. For this case study the criteria (C1-C4) were identified in chapter 2.4.1.

Step 4*:* Drafting the performance matrix. The performance was identified for each alternative and for each decision criterion and the results are presented in table10.

Table 10. Performance matrix

No.	**Alternative’s symbol**	**Alternative**			
		A1	**A2**	**A3**	**A4**
1	C1	0.1870	0.1801	0.1812	0.1653
2	C2	81.2400	77.9400	78.4500	70.8700
3	C3	0.7993	0.1579	0.1316	0.1311
4	C4	8.2600	19.3100	33.9500	27.1400

Step 5*:* Determining the importance coefficients for decision criteria. The weights of criteria were calculated based on FRISCO formula (formula 8) and the results are presented in table 11.

Step 6*:* Determining the marks according to the performances of alternatives for each criterion. The marks were calculated based on formula 9 and formula 10, using the data from the performance matrix, and the results are presented in table 11.

***Step 7**:* Determining the total value factor. The value of performance coefficients Fji was calculated based on formula 11, white the value of total value factor FVi was calculated based on formula 12. The results of the calculations are presented in table 11.

Table 11. The value of performance coefficients Fji and total value factor FVi

No.	Alternative's symbol	Kj	A1		A2		A3		A4	
			N	Kj * N	N	Kj * N	N	Kj * N	N	Kj * N
1	C1	3.50	8.840	30.941	9.179	32.127	9.125	31.936	10.000	35.000
2	C2	3.50	8.723	30.531	9.093	31.824	9.033	31.616	10.000	35.000
3	C3	1.80	1.640	2.952	8.305	14.949	9.959	17.926	10.000	18.000
4	C4	0.43	2.433	1.043	5.689	2.438	10.000	4.286	7.996	3.427
5	Sum			65.467		81.338		85.764		91.427
6	Place			4		3		2		1

***Step 8**:* Determining the ranking of alternatives based on formula 13, while the results are presented in Table 11. Analysing the results and the final ranking presented in Table 11, one may notice that: the alternative **A4** ranks first, the alternative **A3** ranks second, the alternative **A2** ranks third, and the alternative **A1** ranks fourth.

***Step 9**:* Selecting the optimal variant. It was recommended the practical implementation of the alternative which ranked first, namely the alternative obtaining the highest value for the total value factor "FVi", this being the alternative **A4**, that refers to the hydrogen production system by water vapour electrolysis obtained with concentrated solar thermal systems and electrical power obtained using concentrating photovoltaic systems.

This study provides for designers, beneficiaries and public authorities a method for the selection of technical solutions for the production of hydrogen using the hybrid systems, namely the production of hydrogen using the photovoltaic energy. The advanced multi-criteria analysis is a very objective method allowing to process easily an unlimited number of alternatives and decision criteria.

2.4.2. Comparative Analysis on the Solutions of Hydrogen Production Using Solar Energy

2.4.2.1. Context

The transition to a hydrogen-based economy involves the creation of an infrastructure for hydrogen production and distribution by pipeline systems, but also the development of pressurized hydrogen fuelling stations for mobile applications and transport. System efficiency and hydrogen production cost depend, directly proportionally, to the distance between the place of production and the place of use of the hydrogen.

Conventional solar systems, either photovoltaic or thermal solar ones, generate only one type of energy. Lately, there is a tendency in the development of co-generation solar systems, namely the simultaneous production of electricity and heat.

Latest developments in the solar field reveal tendencies of developing tri-generation systems that are producing electricity, heat and refrigeration. Production of refrigeration using average temperature heat (90-95ºC) is possible by using an absorption lithium-bromide chiller. These technologies are suitable for commercial or residential applications.

Modular development of concentrated hybrid solar systems will allow the development of systems which generate several types of energy. These will be able to produce several types of energy simultaneously or depending on the technical needs or economic advantages, in a fully automated and programmed process.

In 1980 was published in Romania a first PhD thesis regarding the production of hydrogen based on nuclear energy (Ibrahim A., 1980) and more recently were published other papers regarding the production of hydrogen (Iordache I., Ştefãnescu I., 2010; Iordache I., Ştefãnescu I., 2011; Vaszilcsin N., et al., 2013), as well as regarding the photovoltaic systems (Fara L., et al., 2005).

The purpose of this study was the comparative analysis of hybrid systems for hydrogen production by water electrolysis, hydrogen being produced using energy supplied by a photovoltaic system. The work meets the European Union's policy whose target is the transition to an economy based on hydrogen produced from renewable sources by the middle of the 21st century (Iordache I., Ştefãnescu I., 2010).

This analysis develops for the first time in the field of the solar technologies, the concept of a system that can simultaneously produce more than three types of energy. This is possible due to the modular conception, namely the conception of standardized modules as a solution for attracting and concentrating the solar radiation, but also different depending on the component which converts the energy.

This study focuses on the financial analysis of the hydrogen production system using the solar energy. It was analysed the latest technical solutions regarding the production of hydrogen by water electrolysis, hydrogen being produced using energy supplied by a photovoltaic system. It have to mention that most of the studies approach only the financial analysis of the hydrogen production systems by means of solar energy using the standard technical solutions and doesn't approach the financial analysis in relation with the latest technologies in this field. According to this study, starting with 2030 it is possible that the price of hydrogen may be competitive as compared to the price of heavy oil.

2.4.2.2. Materials

Scientific concept:

- production and bottling station for pressurized hydrogen obtained using renewable energy and photovoltaic energy respectively;
- hydrogen production capacity: 36,500 kg/year, 100 kg/day yearly average respectively;
- bottling pressure: 300 atm;
- network connection method: without/with network connection.

General data about the project:

- station location: Romania, centre of the country, semi-urban area;
- project financing: bank credit;
- subventions for renewable energy: 3 green certificates/MWh.

It was analysed 4 variants of producing hydrogen using solar energy:

- a system of producing hydrogen by water electrolysis at ambient temperature and electricity obtained using crystalline photovoltaic panels, system S1;

- a system of producing hydrogen by water electrolysis at ambient temperature and electricity obtained using concentrated photovoltaic systems, system S2;
- a system of producing hydrogen by the electrolysis of vapour obtained using a part of the solar radiation spectre and electricity obtained using concentrated photovoltaic systems (hybrid system), system S3;
- a system of producing hydrogen by the electrolysis of vapour obtained using concentrated thermal solar systems and electricity obtained using concentrated photovoltaic systems (hybrid system), system S4.

The table 12 presents the components of the systems considered for the hydrogen production.

Table 12. The components of the systems considered for the production of hydrogen.

No.	System's component	Hydrogen production solution			
		S1	S2	S3	S4
1	Photovoltaic panels	Crystalline	Concentrating	Plane	Concentrating
2	Type of the system used for the mounting of photovoltaic panels	Fixed mounting system for photovoltaic panels	Sun position tracking system with 2 axles for concentrating photovoltaic panels	Mounting system for the photovoltaic panels	Mounting and sun position tracking system for concentrating photovoltaic panels
3	Type of the system used for the wiring of photovoltaic panels	DC electric system for wiring the panels in series and parallel	DC electric system for wiring the panels in series and parallel	DC electric system for wiring the panels in series and parallel	DC electric system for wiring the panels in series and parallel
4	Steam generator with concentrated solar radiation	No	No	No	Yes
5	Steam distribution system	No	No	No	Yes
6	Type of electrolyser	For liquid water	For liquid water	For liquid water	For high temperature steam
7	Compressor for increasing the hydrogen pressure	Yes	Yes	Yes	Optional

From the above table it may notice that different solutions of hydrogen production have different components, thus resulting in different investment costs, as well as different operating costs.

2.4.2.3. Methods

The financial analysis details the aspects related to the investment value and the forecasts concerning the price decrease of these systems by 2030, based on the studies performed at European level (Bertuccioli L., et al., 2014). The main steps of the financial analysis are: assessment of total cost of investment, assessment of operating costs, assessment of yearly total costs, calculation of the global cost, calculation of the specific investment, calculation of the hydrogen production cost, calculation of other indices, specific to the hydrogen production systems by means of solar energy.

The main financial indices specific to such investments are presented as follows:

a) *Total cost of investment*.

The first logical step in financial analysis is the assessment of the total cost of investment (Massimo Florio, Silvia Maffii, 2008). The total cost of investment can be calculated as the sum of direct costs and indirect costs, where:

$$I = Id + Ic \tag{14}$$

where I represents the total investment cost; Id - direct investment; Ic - indirect investment, namely costs related to design, project's check, authorizations and permits, unforeseeable expenses, etc. (Ciolan I., 1981).

In order to assess the value of the direct investment, it was used the calculation method of the investment value based on price indices.

b) *Yearly total costs.*

The second step in financial analysis is the calculation of the operating costs and of the total incomes (if necessary) (Massimo Florio, Silvia Maffii, 2008). The yearly total costs can be calculated using the following formulas:

$$Ctotale = \frac{I}{Ds} + Cp \tag{15}$$

where Ctotale represents the yearly total costs; Ds - the study length, in years; Cp - the production cost (Mareş D., 1977).

In the energy field, the yearly production costs can be assessed using the formula:

$$Cp = Ccomb,t + Cee + OM\ \&\ R \tag{16}$$

where Ccomb,t represents the yearly expenses with fuel purchasing; Cee - the yearly expenses with electrical power purchasing; OM&R - operating, maintenance and repairs costs which doesn't involve the use of fuel.

c) *Total cost*.

The total cost is calculated based on the following formula:

$$C = I + Cp \cdot Ds \tag{17}$$

where C represents the total cost (Mareş D., 1977).

d) *Cost of hydrogen*.

The cost of hydrogen is calculated as a ratio between the yearly total costs and the production capacity in physical measuring units, namely:

$$c = \frac{Ctotale}{Qf} \tag{18}$$

where c represents the yearly cost of hydrogen; Qf - the production capacity in physical measuring units.

e) Specific investment.

The specific investment is calculated as a ratio between the total investment and the production capacity in physical measuring units, namely:

$$is = \frac{I}{Qf} \quad (19)$$

where is represents the specific investment (Mareş D., 1977).

f) Surface area covered by the entire investment objective refers to the entire surface taken out of agriculture or being decommissioned on which the investment objective shall be built (Postăvaru N., Băncilă Ş., Icociu C-V, 2006).

2.4.2.4. Results and discussions

The results and discussions related to the case study analysed in *Materials* Chapter are presented as follows. When calculating the yearly total costs it took into consideration the recommendations from literature (Massimo Florio, Silvia Maffii, 2008), in which the study length for the investments in energy field must be up to 25 years, while in our study we considered a 15 years period.

Results

Based on the mathematic model presented above, as well as on the data provided by the literature, it was performed the calculations for each of the four technical solutions, for the solutions S1, S2, S3 and S4 respectively.

When making the calculations it took into consideration the evolution in time of the technical performances of the systems proposed as well as of the specific investment. The calculations were made for three different scenarios, namely for 2014, for 2020 and for 2030.

It also made the calculations for two different situations, namely:

- without the connection of the photovoltaic system to the power supply network;
- with the connection of the photovoltaic system to the power supply network.

In present case study, the subsidization of renewable energy was analysed as follows:

- case 1, without subsidization of the renewable energy;
- case 2, with subsidization of the renewable energy by means of green certificates, according to the regulations in force in Romania.

a) Solution without wiring the photovoltaic system to the power network.

Figure 3 presents the evolution of the cost price of hydrogen during the years 2014-2030, for the case without wiring the photovoltaic system to the power network, and without the subsidization of the renewable energy by means of green certificates.

Figure 4 presents the evolution of the cost price of hydrogen during the years 2014-2030, for the case without wiring the photovoltaic system to the power network, and with the subsidization of the renewable energy by means of green certificates.

Figure 5 presents the evolution of heavy oil price. The heavy oil price was considered to follow the evolution of oil's price increase of about 2.25% p.a. between the years 2010-2035 (Muşatescu V., et al., 2012).

Analysing the data presented in figure 3, in relation with the data presented in figure 5, we may notice that starting with the year 2030 it is possible that the hydrogen price to be competitive compared to heavy oil price.

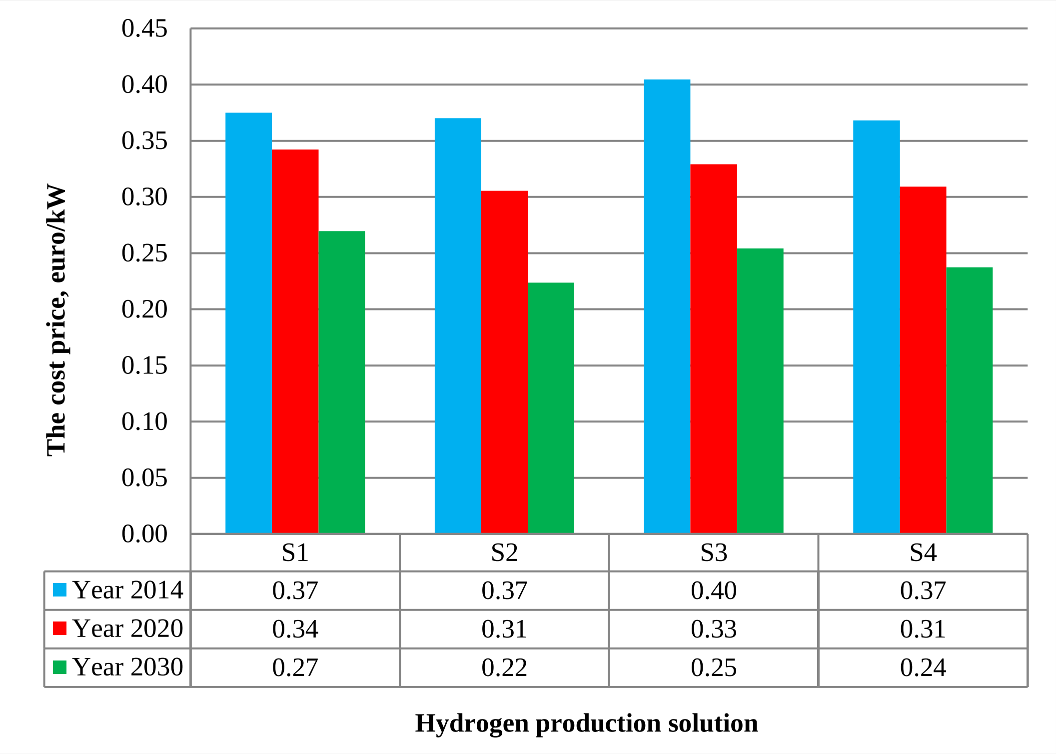


Figure 3. The cost price of hydrogen considering the solution without wiring to the power network, without subsidies, in Euro/kWh.

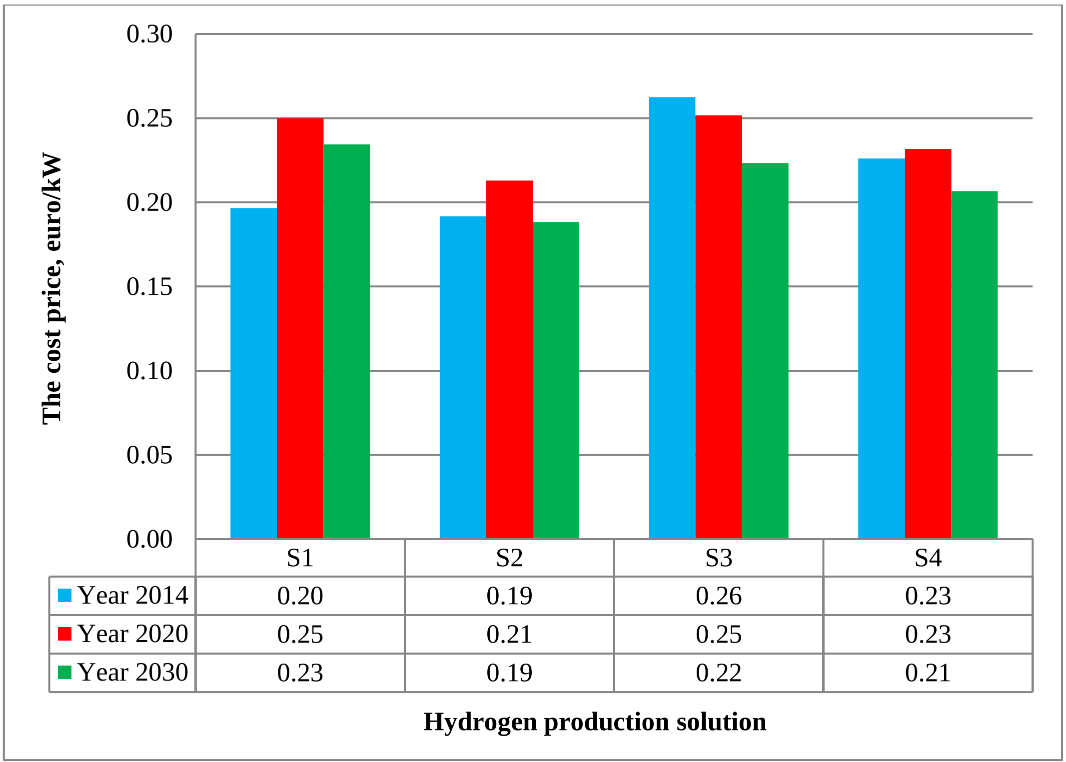
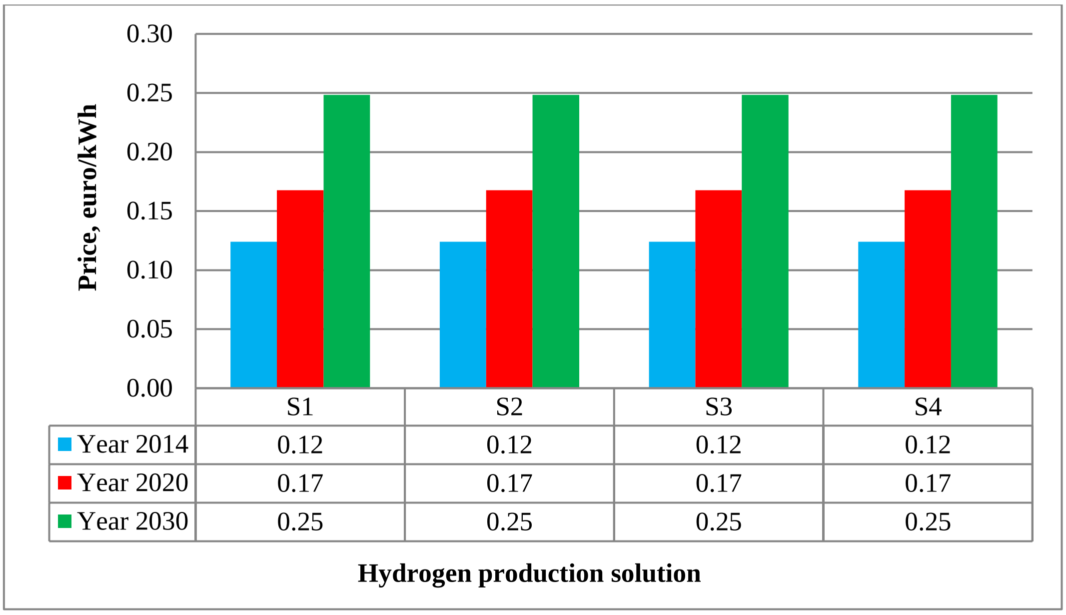


Figure 4. The cost price of hydrogen considering the scenario without wiring to the power network, with subsidies, in Euro/kWh.



	S1	S2	S3	S4
Year 2014	0.12	0.12	0.12	0.12
Year 2020	0.17	0.17	0.17	0.17
Year 2030	0.25	0.25	0.25	0.25

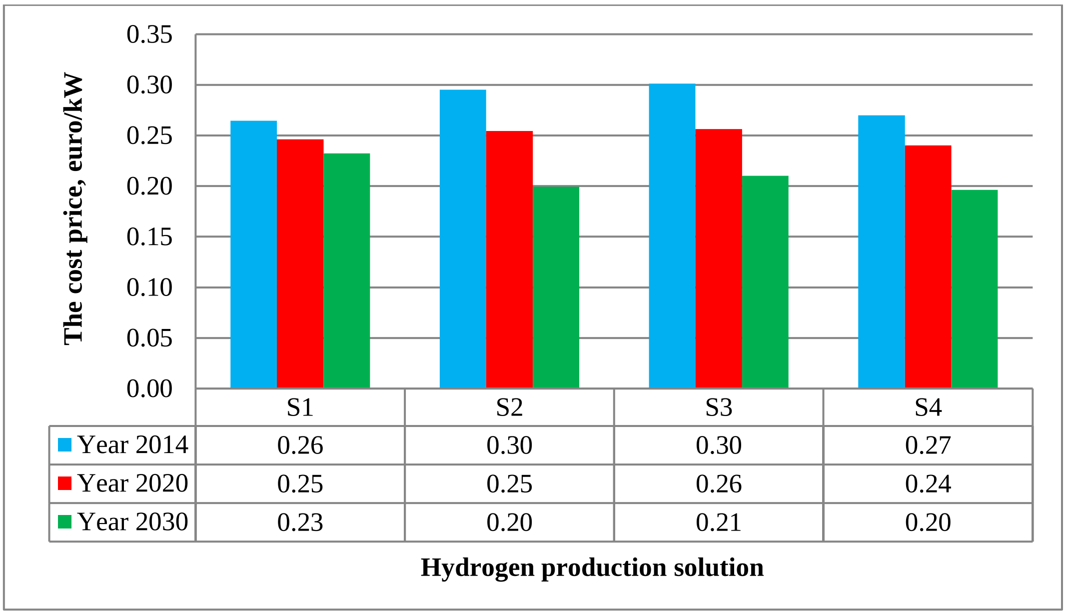
Figure 5. Evolution of heavy oil price, in Euro/kWh.

Analysing the data presented in figure 4, in relation with the data presented in figure 5, we may notice that starting with the year 2020 it is possible that the hydrogen price to be competitive compared to heavy oil price.

Based on the results obtained, we recommend the implementation of S2 system, in the case of the solution without wiring to the power network.

b) Solution with wiring the photovoltaic system to the power network.

Figure 6 presents the evolution of the cost price of hydrogen during the years 2014-2030, for the case with wiring the photovoltaic system to the power network, and without the subsidization of the renewable energy by means of green certificates.

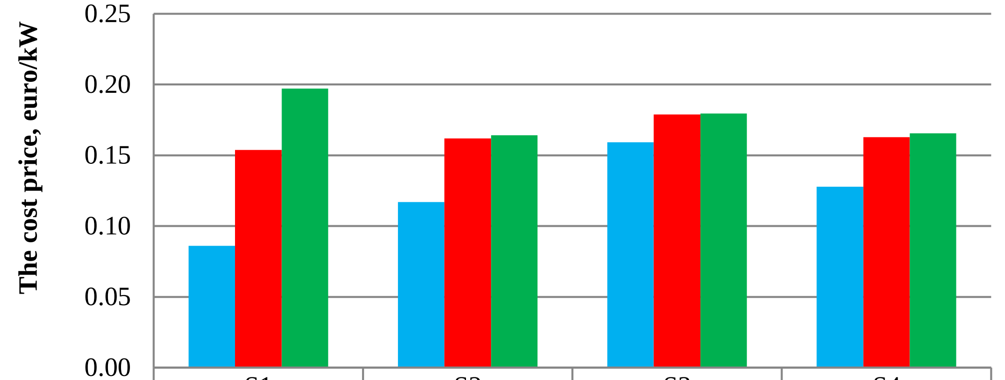


	S1	S2	S3	S4
Year 2014	0.26	0.30	0.30	0.27
Year 2020	0.25	0.25	0.26	0.24
Year 2030	0.23	0.20	0.21	0.20

Figure 6. The cost price of hydrogen considering the solution with wiring to the power network, without subsidies, in Euro/kWh.

Analysing the data presented in figure 6, in relation with the data presented in figure 5, we may notice that starting with the year 2020 it is possible that the hydrogen cost price to be competitive compared to heavy oil price.

Figure 7 presents the evolution of the hydrogen cost price between the years 2014-2030, for the solution with wiring the photovoltaic system to the power network, and with the subsidization of the renewable energy by means of green certificates respectively.



	S1	S2	S3	S4
Year 2014	0.09	0.12	0.16	0.13
Year 2020	0.15	0.16	0.18	0.16
Year 2030	0.20	0.16	0.18	0.17

Figure 7. The cost price of hydrogen considering the scenario with wiring to the power network, with subsidies, in Euro/kWh.

Analysing the data presented in figure 7, in relation with the data presented in figure 5, we may notice that starting with the year 2014 it is possible that the hydrogen cost price to be competitive compared to heavy oil price, and with the subsidization of the renewable energy by means of green certificates respectively.

Based on the results obtained, we recommend the implementation of S4 system, in the case of the solution with wiring to the power network.

Discussions

Based on this study performed we recommend the implementation of one of the following technical solutions:

- the system S2, if the system is not to be connected to the power supply network;
- the system S4, if the system is to be connected to the power supply network.

We recommend the implementation of these technical solutions as a result of the advantages of these technical solutions as compared to the other analysed technical solutions.

According to the study performed, it seems that the most advantageous solution is to connect the photovoltaic system to the power supply network. Also, the technical solutions presented are more desirable in case of subsidization of renewable energy by means of the green certificates. Also, according to this study, starting with 2030 it is possible that the price of hydrogen may be competitive as compared to the price of heavy oil.

2.4.3. Conclusions

The need to increase renewable energy in the global energy balance is an acute problem of present days. Innovative technical solutions attempt to meet this need depending on the region and the available natural resources. Of the renewable energies, solar energy is supposed to have the largest contribution to the global energy balance due to the enormous potential for exploiting this resource.

At present, hydrogen production using conventional (non-concentrated) photovoltaic systems is not a technically feasible solution due to the very low efficiency of these hydrogen production systems (less than 10%) and the need to use very large areas of land to meet the energy needs of the system. Hybridization of hydrogen production systems by efficient conversion of solar radiation into both electricity by using photovoltaic systems with concentrated radiation as well as thermal energy in the form of steam, and the production of hydrogen by steam electrolysis seems to provide a viable solution.

The aim of the study is to identify and develop a scientific model for the documented choice of sustainable and efficient hydrogen production using concentrated solar radiation. The paper is addressed to engineers in the field of energy, researchers, solar system developers and alternative fuels manufacturers. At the same time, the paper aims to present to the specialists in the field of energy the potential of energy poly-generation systems by converting concentrated solar radiation and to establish new research directions in this field, as well as in the adjacent fields of research.

2.5. Specific Concerns in the Field of Hybrid Power Generation Systems for Energy-Efficient Buildings

The main specific concern in the field of hybrid energy generation systems for energy-efficient buildings is supported by the paper: Badea G., Felseghi R.A., **Aşchilean I.,** Bolboacă A., Mureșan D., Șoimoșan T.M., Ștefănescu I., Răboacă M.S., *Energen System for Power Supply of Passive House. Case Study*, 2nd International Conference on Mathematics and Computers in Sciences and Industry, Sliema, Malta, 2015, IEEE *Explore 2016*, doi: 10.1109/MCSI.2015.31. The following is a synthetic presentation of the results of a large study regarding the alternative energy solutions (sun, wind, hydrogen) for power supply of passive house placed on Cluj-Napoca, Romania. Five scenarios for different combinations of hybrid energy system were optimized and analysed.

2.5.1. General Context

Energy efficiency is a top priority in the international agenda towards a more sustainable energy future. Buildings are one of the most important sectors where there is significant potential for improving energy efficiency. The residential sector alone currently accounts for 30 % of all electricity consumed in developed countries, corresponding to 21 % of energy related CO_2 emissions.

According to the World Business Council for Sustainable Development (WBCSD) energy use in buildings can be cut by 60 percent by 2050 if immediate actions to transform the building sector are taken (Milo A., et. al., 2010). In this context, Passive House Institute developed, promoted and implemented Passive House Standard. Passive Houses performances consists in reducing energy consumption and energy waste in buildings, interests in the field are found in the majority of the European Union energy strategies.

Sustainable development requires the implementation of measures to reduce negative impacts on the ecosystem of the planet, and minimize dependence on fossil fuels by emphasizing energy production from alternative sources. Passive House standard is globally recognized as the main standard designed to reduce energy load in the building sector. Based on this principle can be adopt and connected the building to the natural energy potential of the area (Audenaert A., et. al., 2008).

Depending on weather conditions, renewable energy sources are fluctuating, being necessary to store the energy produced in the interval where is no consumption or for periods in which excess energy is produced (Sevencan S., Ciftcioglu G.A., 2013). The solution used for short-term energy storage is the battery. The batteries can be recharged, but the major problem is the continuing trend of decreasing their load capacity during use. Long-term energy storage is done by producing hydrogen in the process of electrolysis. Hydrogen - energy vector - is energy storage medium in tandem with the fuel cell stack that generates the electricity needed by the consumer (Cano A., et al., 2014). Hydrogen can be stored seasonally, on medium and long periods, also has a practical universality application, having various uses (Cano A., et al., 2014; Gahleitner G., 2013).

This analysis presents results of the comparative study in which were analyzed five different energen hybrid systems in virtual operating conditions. The aim of this work was to identify the optimal solution able to support with energy a passive house, considering the main features of performance it produces in one year of operation: energy performance - amount of energy supplied by alternative energy and excess energy resulted, its storage, the amount of CO_2 emissions and financial aspect. Although it follows the functioning of these systems in stand-alone operation, in the study was kept the grid connection of the consumer to ensure the start-up in case of some equipment components and to count unmet load, coverage of the energy demand from RES, but also the excess energy resulted from the operation energy systems, which can be outsourced by centralized electricity network as green energy.

So, were configured, optimized and simulated in operation following energy hybrid systems (Felseghi R., 2015):

S_1 – PV + Battery. In this case the system is composed of photovoltaic panels as the main equipment for converting solar irradiation, batteries as a storage medium and inverter for converting DC/AC. Energy demand of passive house was supplied by photovoltaic panels, while ensuring energy needs at night, during periods of peak load and fluctuations due to weather conditions, the excess energy generated by photovoltaic panels was stored in batteries.

S_2 - Wind turbine + battery. In the second case, the system is composed of wind turbines, batteries and inverter. In this scenario the energy demand of passive house was supplied by wind turbines, to provide the necessary power during periods of peak load and fluctuations due to weather conditions, the excess energy generated by the turbine was stored in batteries.

S_3 - Fuel cell + hydrogen. In this case study is tracked the performance of an energy system in operation composed of fuel cell supply with hydrogen and inverter. Hydrogen, used as the first and only source of power generation is fed to the system from a centralized distribution network in anticipation of a future hydrogen economy. It was noted that currently, worldwide, are in use energy systems with fuel cell that operating with natural gas reformed catalytic in supply in advance of fuel cell. This study assesses, only pure hydrogen consumption required to generate energy according with load of Passive House.

S_4 – PV + WT + FC + hydrogen. The hybrid system consists of photovoltaic panels, wind turbine, fuel cell supply with hydrogen from outside of the system and inverter. Photovoltaic panels and wind turbines provide energy demand as primary sources and fuel cell serves as back-up for peak load periods and flicker weather.

S_5 – PV + WT + FC + electrolyser - hydrogen. The hybrid system of this case study is composed of photovoltaic panels, wind turbine, fuel cell, electrolysis and inverter. The system uses both solar energy and wind power as a renewable primary source for covering peak load and weather flicker uses fuel cell that consume hydrogen (secondary source of energy), the hydrogen is local electrolytic obtained into the system by capitalization of renewable energy sources available, so the stored energy obtained from solar and wind primary sources through hydrogen.

2.5.2. Problem Formulation

Comparative study on the five proposed systems requires data input to define the following: energy demand and hourly energy demand; solar irradiation and wind speed; energy conversion equipment particularities.

2.5.2.1. Consumer Profile

This study was performed for a category of building with residential destination, which has an economic power consumption, type "passive house", placed in Cluj-Napoca, Romania, with total annual needed by 6759 kWh/yr and 42,24 kWh/m²•yr. Studied building has a total area of 160 m^2 usable area and the expected number of residents equal to 4.

Energy demand determined by mathematical calculation in compliance with the standards, regulations and legislation, reported to the developed area of the building is:

- heating demand: 2106 kWh/yr and 13,16 kWh /m² • yr;
- DHW: 2020 kWh/yr and 12,63 kWh/m² • yr;
- lighting: 2088 kWh /yr and 13,05 kWh /m² • yr;
- auxiliary: 545 kWh /yr and 3,41 kWh /m² • yr. ((Felseghi R., 2015; Mc 001/2-2006)

Graph of variation hourly energy demand shown in figure 8, illustrating the waveforms characteristic of energy demand that are specific to consumer, refers to alternative current with 50 Hz frequency, 230 V voltage and cos φ = 0,9.

The most unfavourable situation may be observed during of December, when the hourly maximum load – active is by 1695,00 W, between 21 ÷ 23 hours and the hourly minimum load – active is by 360,00 W realize between 4 ÷ 6 hours.

The most favourable situation may be performed during of June, when the hourly maximum load – active is by 920,00 W, between 22 ÷ 23 hour and the hourly minimum load – active is by 310,00 W realized between 4 ÷ 6 hours. For the remaining months is recording the intermediate values of two limits described above.

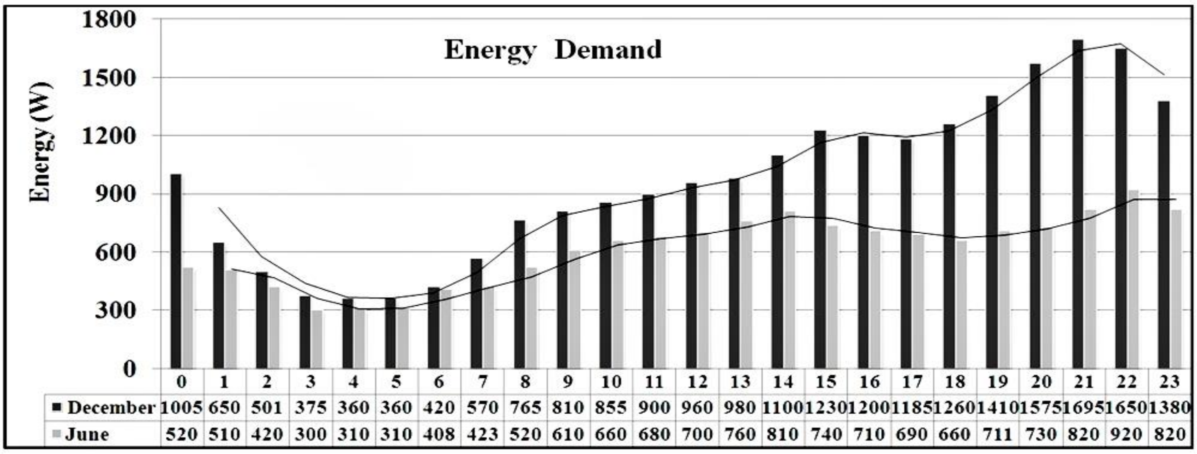


Figure 8. Hourly energy demand

2.5.2.2. Solar and wind energy

The coordinates of the selected location for the simulation of the suggested systems are (45°6′17″N, 24°22′32″E). Solar irradiation, clearness index and wind speed were taken from "NASA Surface Meteorology and Solar Energy" (RETScreen Data, 2014). Based on these factors the energy generated by the PV and WT was calculated. The main advantage of primary RES consists in the production of electricity without polluting effects.

In present case Cluj-Napoca, the solar irradiation, clearness index and wind speed were identified, being presented schematically in figure 9 (RETScreen Data, 2014). Was observed that in July is recorded the highest value of solar irradiation and December the lowest value. The determination of the energy supplied by the wind system depends on the wind speed in the system's location taking into account the monthly average of wind speed measured at a distance of 14 meters above the ground. For the studied location, the winter season it is relatively the most favourable, in the summer were obtained minimum values.

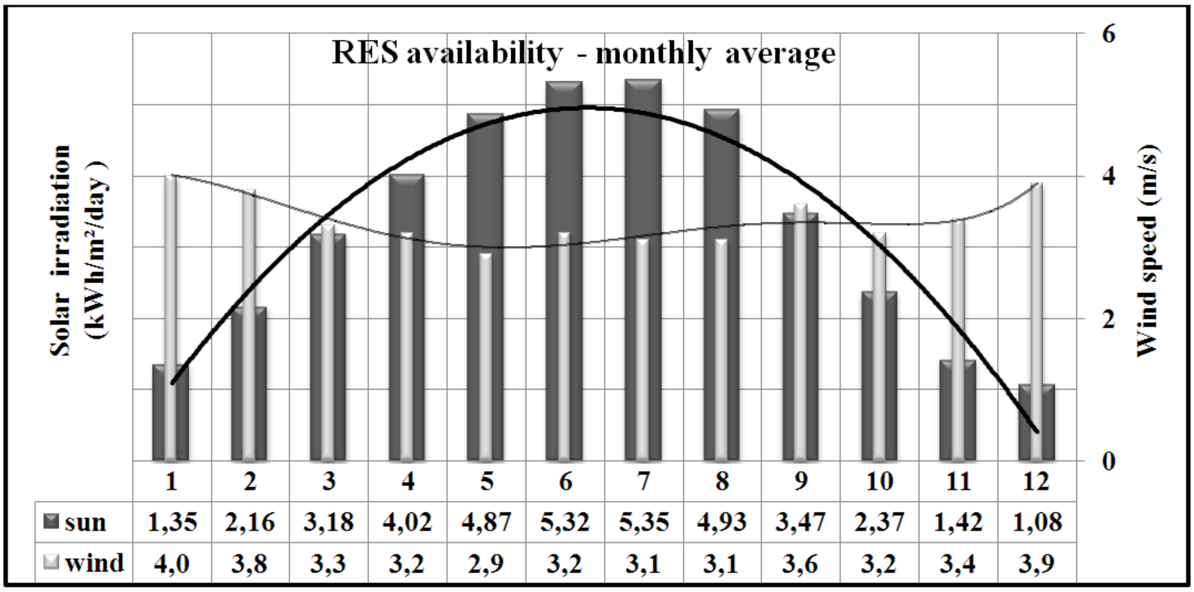


Figure 9. RES availability - characteristic of Cluj-Napoca site

2.5.2.3. Equipment components of the hybrid system

The main equipment's (Dufo - López R., Bernal - Augustin J.L., 2012) that do the conversion of various forms of energy are shown in table 13.

Photovoltaic panels (PV): solar energy conversion equipment into electricity; Wind Turbine (WT) wind energy conversion equipment into electricity; Fuel Cell (FC): electrochemical hydrogen conversion equipment; fuel cell technology presents a particular interest for the research area, being considered a potential candidate through clean energy solutions; Electrolyser (Ely): equipment which allows water splitting under the action of excess energy obtained from primary sources, to generate hydrogen; Battery (B) storage medium of energy produced by PV and WT. Inverter (I): continuous current conversion equipment generated from energy hybrid system in the current alternative useful to consumer.

Table 13. Energy conversion equipment

Equipment	Nominal/rated power	Lifespan	CO_2 emission	Cost (€)
Photovoltaic panels (PV)	24 (V) /280 (Wp)	25 (yr)	800 (kgCO_2/kWp)	350
Wind Turbine (WT)	1500 (1660W at 14 m/s wind speed)	15 (yr)	(900 kg)	4875
	3000 (3471W at 14 m/s wind speed)	15 (yr)	(1800 kg)	7555
	6000 (6345W at 14 m/s wind speed)	15 (yr)	(3500 kg)	12056
Fuel Cell (FC)	2 (kW)	40.000 (h)	330 (kgCO_2/kW)	12000
	3 (kW)	40.000 (h)	330 (kgCO_2/kW)	15000
Electrolyser (Ely)	3 (kW)	25 (yr)	330 (kgCO_2/kW)	17000
	5 (kW)	25 (yr)	330 (kgCO_2/kW)	24000
Battery (B)	3360 (Ah), SOCmin = 20%	18 (yr)	55 (kgCO_2/kWh capacity)	1010
	2240(Ah), SOCmin = 20%	18 (yr)	55 (kgCO_2/kWh capacity)	1200
Inverter (I)	1800 (VA)	10 (yr)	-	1200

2.5.2.4. Virtual simulation conditions

Computational simulations conducted with *iHOGA* software (Dufo - López R., Bernal - Augustin J.L., 2012), and supply information regarding economical and energetic performances of system works during one year of operations and financial performances for 25 year lifetime.

Optimization Type (Dufo - López R., Bernal - Augustin J.L., 2012) was multi-objectives and were imposed conditions to minimize of the following criteria: uncovered load, carbon dioxide emissions, total system cost, excess energy and power nominal/equipment components reported la ensuring energy demand.

Control Strategies adopted for present case study was the *Load following* type (Felseghi R., 2015; Dufo - López R., Bernal - Augustin J.L., 2012)

In the first case (S_1), the principle of operation of the system is based on two conditions: (a) if the power generated from renewable sources with PV is greater than energy demand of the consumer, then the excess energy will be stored in battery; (b) if the power generated from RES is less than energy demand, the energy from battery will be used. The battery is used for energy storage and in the case when energy produced from renewable sources is not sufficient to meet the entire load, the battery is the back-up for this system.

In the second case (S_2), also the principle of operation of the system is based on two conditions: (a) if the power generated from renewable sources with WT is greater than energy demand of the consumer, then the excess energy will be stored in battery; (b) if the power generated from RES is less than energy demand, the energy from battery will be used.

In the next case (S_3), the principle of operation of the system is based on one condition: in this case the fuel cell supply with hydrogen represent the unique source to provide energy , so the total energy demand to supply the passive house is ensure by fuel cell.

In case (S_4), the principle of operation of the system is based on one condition: energy demand is ensure with priority by PV and WT and if the power generated from RES is less than energy demand, then the hydrogen outside will be used by the fuel cell to produce electrical energy.

In the last case (S_5), also the principle of operation of the system is based on two conditions: (a) if the power generated from renewable sources with PV and WT is greater than energy demand of the consumer, then the electrolyser integrated into the system produces hydrogen which will be stored in the tank of hydrogen; (b) if the power generated from RES is less than energy demand, then the hydrogen stored will be used by the fuel cell to produce electrical energy.

2.5.2.5. Elements of Calculation.

Power generated by PV is calculated by the formula:

$$P_{PV} = G_i \cdot I_{sc} \cdot F_p \cdot U_{DC}, \tag{20}$$

P_{PV} is power generated by photovoltaic panels (kWp),

G_i - hourly solar radiation (kW/m²),

I_{SC} - short – circuit current (A),

F_p - factor of losses compensation by power due to shading,

U_{DC} - voltage DC generated by PV (V) (Dufo-López R., Bernal-Augustin J.L., 2008; Yilanci A., et al., 2009).

The power generated by wind turbines is calculated (Zhou W., et al., 2010) depending on wind speeds, power curves of each typology and data supply by manufacturer after formula:

$$P_{WT} = v_{data\_i} \cdot \frac{\ln \frac{z_{hub}}{z_0}}{\ln \frac{z_{data}}{z_0}}, \tag{21}$$

where: P_{WT} is power supplied by wind turbine (kW),

v_{data_i} - wind speed measured at “i” (m/s),

z_{hub}- slope difference of turbine rotor shaft above ground (m),

z_0- length of elements with uneven surfaces (m),

z_{data}- the level difference to anemometer from the ground measuring (m).

Calculation of electricity consumption in the electrolytic production of hydrogen is based on formula (22) and is directly proportional to the flow rate and the actual flow of hydrogen produced by the electrolyser.

$$C_E = B_E \cdot Q_{N\_E} + A_E \cdot Q_E , \tag{22}$$

where: C_E is power consumption of the electrolyzer (kW),

Q_{N_E} - nominal flow of hydrogen produced in the electrolysis process (kg/h),

Q_E - real flow of hydrogen produced in the electrolysis process (kg/h),

A_E şi B_E – consumption curve and efficiency coefficients (kW/kg/h) (Dufo-López R., Bernal-Augustin J.L., 2008).

For determining the energy efficiency level of an electrolyser, which is given by the ratio of energy usable generated by hydrogen and consumed energy can be utilized relationship

$$\eta_{energetic} = \frac{E_{hidrogen}}{E_{electric}} = \frac{V_{H_2} \cdot H_u}{U \cdot I \cdot t} \cdot 100 , \qquad (23)$$

where: V_{H_2} volume by hydrogen produced electrolytic (m³)

H_u - lower heating value of hydrogen ($9{,}9 \cdot 10^6$ J/m³),

U - voltage applied to the electrolyzer (V),

I - current- carrying electrolyzer (A),

t - operating time of the electrolyser (s) (3600) (Sopian K., et al., 2009; Ghribi D., et al., 2013).

Consumption of hydrogen within the fuel cells depends on its rated power and actual power generated in the system (Ural Z., Gencoglu M.T., 2013; Kelly N.A., 2014). This calculation is based on hydrogen consumption following formulas:

In the situation where: $\frac{P_{FC}}{P_{N\_FC}} \leq P_{max\_ef}$,

fuel cell consumption is calculated with formula:

$$C_{FC} = B_{FC} \cdot P_{N\_FC} + A_{FC} \cdot P_{FC} , \qquad (24)$$

where: $\frac{P_{FC}}{P_{N\_FC}} > P_{max\_ef}$,

then fuel cell consumption is calculated with formula:

$$C_{FC} = B_{FC} \cdot P_{N_{FC}} + A_{FC} \cdot P_{FC} \cdot \left[1 + F_{ef} \cdot \left(\frac{P_{FC}}{P_{N_{FC}}} - P_{max\_ef}\right)\right], \qquad (25)$$

where: C_{FC} is hydrogen consumption of the fuel cell (kg/h),

P_{N_FC} - nominal power of fuel cell (kW),

P_{FC} - real power generated in system by fuel cell (kWh),

A_{FC} and B_{FC} - consumption curve and efficiency coefficients (kg/kWh),

F_{ef} - consumption factor over the limit of the power generated at maximum efficiency,

$P_{\max\_ef}$ - generated power into the system at maximum efficiency of fuel cell (kWh) (Dufo-López R., Bernal-Augustin J.L., 2008; Segura F., et al., 2004).

For determining the energy efficiency of fuel cells, which is given by the ratio of the energy generated by the fuel cell and hydrogen product of its consumption and lower heating value of hydrogen can be utilized relationship (26).

$$\eta_{energetic} = \frac{E_{electric}}{E_{hidrogen}} = \frac{U \cdot I \cdot t}{V_{H_2} \cdot H_u} \cdot 100 , \qquad (26)$$

where: $\eta_{energetic}$ is the energy efficiency of fuel cell,

V_{H_2} - volume of hydrogen consumed by the fuel cell (m³),

H_u - lower calorific value H_2 ($9{,}9 \cdot 10^6$ J/m³),

U - voltage generated by fuel cell (V),

I - intensity of the current generated by the fuel cell (A),

t - time of consumption hydrogen (s) (3600) (Sopian K., et al., 2009;Segura F., 2004)

General data for batteries includes: Name, Nominal Capacity (Cn) in (A·h), Nominal Voltage (Vn), Acquisition Cost (€), Operation and Maintenance Costs (€/yr)

The number of life cycles of batteries between failures for each discharge depth percentage *iHOGA* calculates cycled energy throughout battery life (Dufo-López R., Bernal-Augustin J.L., 2008; Kaundinya D.P., et al., 2009):

$$C_{cycled\_i(kWh)} = C_n\ (Ah) \cdot Vn(V) \cdot Depthi(\%)/100 \cdot Cyclesi/1000, \quad (27)$$

Discharge Depth (Depthi in %)

Life Cycles ($Cycles_i$)

The number of equivalent cycles is calculated as:

$$Neq\_cycles = \Sigma\ Ecycled\_i\ (kWh) \cdot 1000\ /\ (Cn\ (Ah) \cdot Vn\ (V) \quad (28)$$

2.5.3. Results and Discussion

The results obtained after calculations, but and results generated after simulation were synthesized, presented tabular and illustrated graphically to highlight the energy performance, financial, and carbon dioxide emissions of each type of system. For a better visualization and analysis of the five studied cases, performance indicators have been presented and discussed in order to establish optimal configuration compared with high energy efficiency, which can be considered as a solution to support passive house with energy systems by harnessing available alternative energy.

2.5.3.1. System's components

Based on input data has been established optimum configuration of the energy hybrid system (table 14) for each of five simulated assumptions. Equipment of alternative energy conversion FC, Ely, WT, PV - panels with similar power characteristics, PV optimal number, PV geometrical positions - serial(s) * parallel(p) - and the slope were determined and indicated by *iHOGA* as the best option; also the Inverter (I), which has an average efficiency of 83%.

Depending on the particular case studied, in S_1, S_2 and S_3 are found storage equipment and capitalization of excess energy through via hydrogen (Cano A., et al., 2014), being dimensioned in this direction an hydrogen tank with a storage capacity 55 (kg H_2).

Table 14. System's components

Components	S_1	S_2	S_3	S_4	S_5
Photovoltaic panel (PV)	280 (Wp), 2s*17p	-	-	280 (Wp), 2s*6p	280 (Wp), 2s*25p
Wind Turbine (WT)	-	2 * DC 3000	-	1 * DC 1500	1 * DC 6000
Fuel Cell (FC)	-	-	3 (kW)	3 (kW)	3 (kW)
Electrolyser (Ely)	-	-	-	-	5 (kW)
Hydrogen tank	-	-	-	-	55 (kg capacity)
Battery (B)	3360 (Ah): 24s*8p	2240 (Ah): 24s*8p	-	-	-
Inverter (I)	1800 (VA)	1800 (VA)	1800 (VA)	1800 (VA)	1800 (VA)

2.5.3.2. Energy performances

In this study, with the goal to emphasize results obtained regarding the energy performance of these systems, data values were illustrated in a comparative chart of annual average energy generated by the five energy hybrid systems, were illustrated graphically, individual energy performance achieved by each system over one day in December, the period is considered the worst in terms of energy load. It noted that this case study is part of a detailed analysis aimed at multi-criteria selection of the optimal energy system that power supply of passive house. It is a starting point to establish general criteria to assess overall performance achieved by such energy systems and can be considered a model that can be used for various stationary applications, can also be useful in planning and design of energy systems based on alternative energies.

a) *Annual Average Energy*

The results of calculations and simulations in operation are illustrated graphically in figure 10 and represents the average annual values of the parameters that characterize each type of system.

S_1 - PV sustain with energy the consumer, generating a total of 7366 (kWh/yr) in one year of operation. From total energy production 36,88% is directly use to cover the energy need, and 63,12% is stored in batteries and used in deficient periods of solar irradiation. Energy balance highlights annual loss energy by 8.25% due to conversion efficiency DC/AC of invertor, and storage in batteries.

S_2 - WT sustain with energy the consumer, generating a total of 8174 (kWh/yr) in one year of operation. From total energy production 52% % is directly use to cover the energy need, and 48 % is stored in batteries and used in periods with low wind potential. Energy balance highlights an annual loss energy by 17.30% due to conversion efficiency DC/AC of invertor, and storage in batteries, and excess energy resulted.

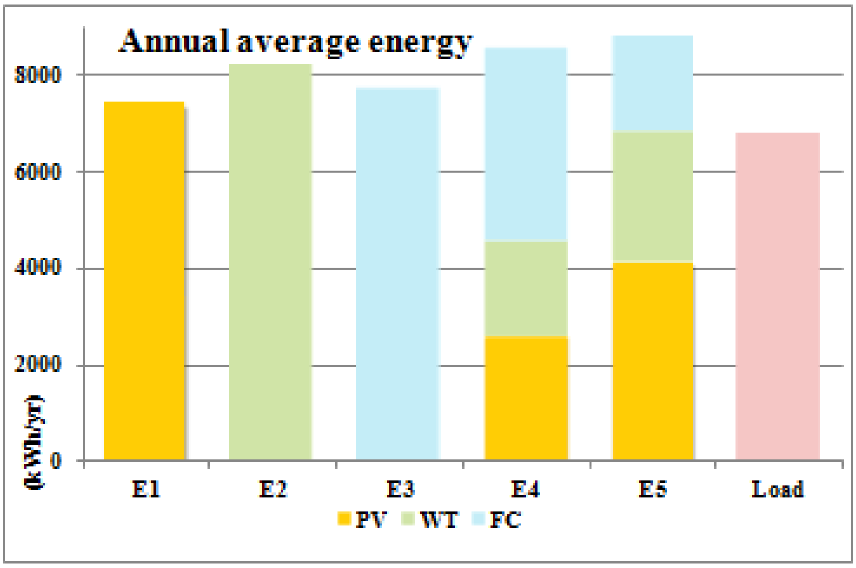


Figure 10. Energy Performance during one year

S_3 – fuel cell supply energy to consumer, total energy generated is 7680 (kWh/yr) hydrogen consumed is 549 (kg/yr) during one year in operation. Energy balance highlights an annual loss energy by 12% energy due the conversion efficiency DC/AC of invertor.

S_4 – total energy supply by system is 8503 (kWh/yr) during one year in operation. From the total energy supplied 30.56% is generated by PV, 23% by the WT and 46.44% by FC, having a hydrogen consumption by 297 (kg/yr) and operation time is 6459 (h/yr). Energy balance highlights an annual loss energy by 20.51 due to conversion efficiency DC/AC of invertor, also the excess energy.

S_5 - total energy supply by system is 19810 (kWh/yr during one year in operation. From the total energy supplied 54.67% is supply by PV, 35.63% by WT and 9.7% by FC, having a hydrogen consumption by 143 (kg/yr) and operation time is 3039 (h/yr). Primary energy is valorised through electrolyser 11080 (kWh/yr), having a hydrogen production by 180.6 (kg/yr) and operation time is 3858 (h/yr). Energy balance highlights annual loss energy by 9.95% due to conversion efficiency DC/AC of invertor, also the excess.

Detailed results obtained for one day in December on the worst situation was graphically illustrated as follows. Mentioned that values illustrated represents the maximum energy performance obtained during a year of operation of each system, other results are below the rang.

b) S1 - Energy Performance:

For this period the solar irradiation is available between 08:00 ÷ 17:00 hours, period in which photovoltaic panels supply energy for consumer, passive house, taking into account the availability and capacity equipment. It is noted that in this time take place and storage reserve energy in batteries. The time between 10:00 ÷ 14:00 building is supply 100% by energy generated by PV.

The rest of the period from the day energy demand of passive house is provided by discharging the battery of energy, storage in available favorable period of solar irradiation.

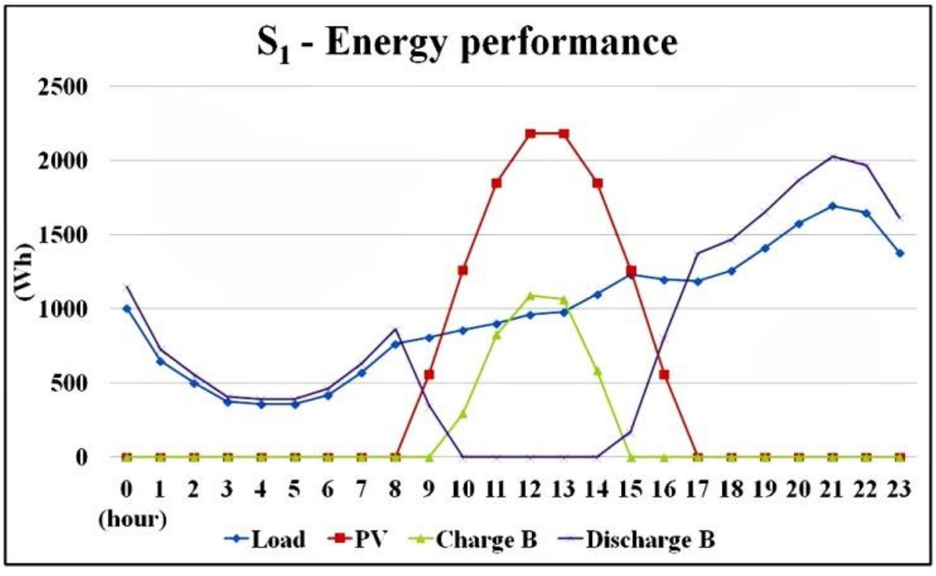


Figure 11. S_1 - Energy Performance during one day of December

c) S2 - Energy Performance

This system achieved better energy performance than first system during of one day in December.

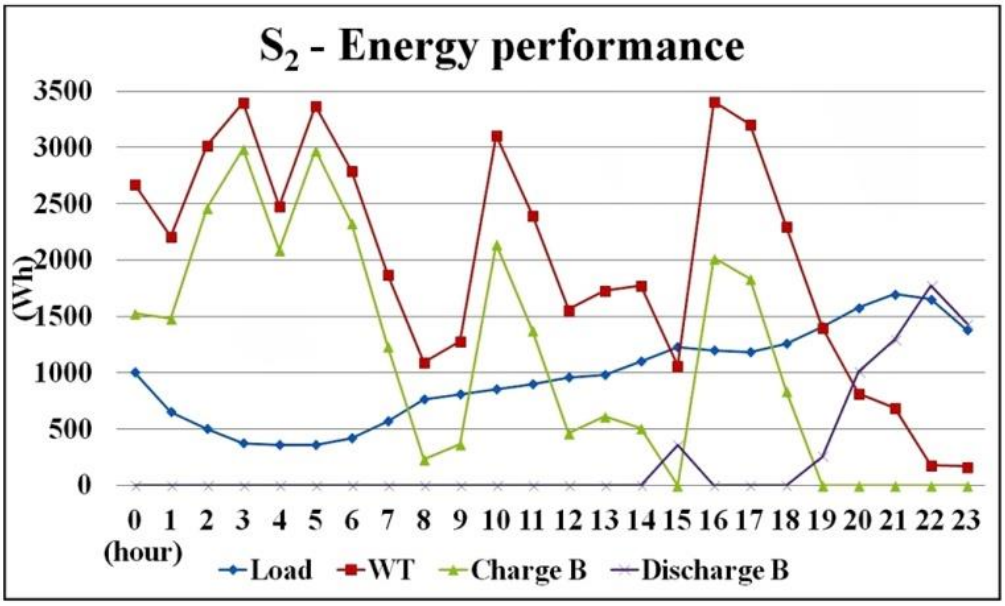


Figure 12. S2 - Energy Performance during one day of December

Availability of wind energy ensure the major energy needed to building, except during the peak load characteristic ÷ 18:00 to 24:00. It is noted that in this time the energy comes from discharging of battery, which storage energy between 00:00 ÷ 19:00 hours.

d) S3 - Energy Performance.

Fuel cell having the role of first and unique source energy in power supply of passive house generates 100% energy throughout the day depending on the load required.

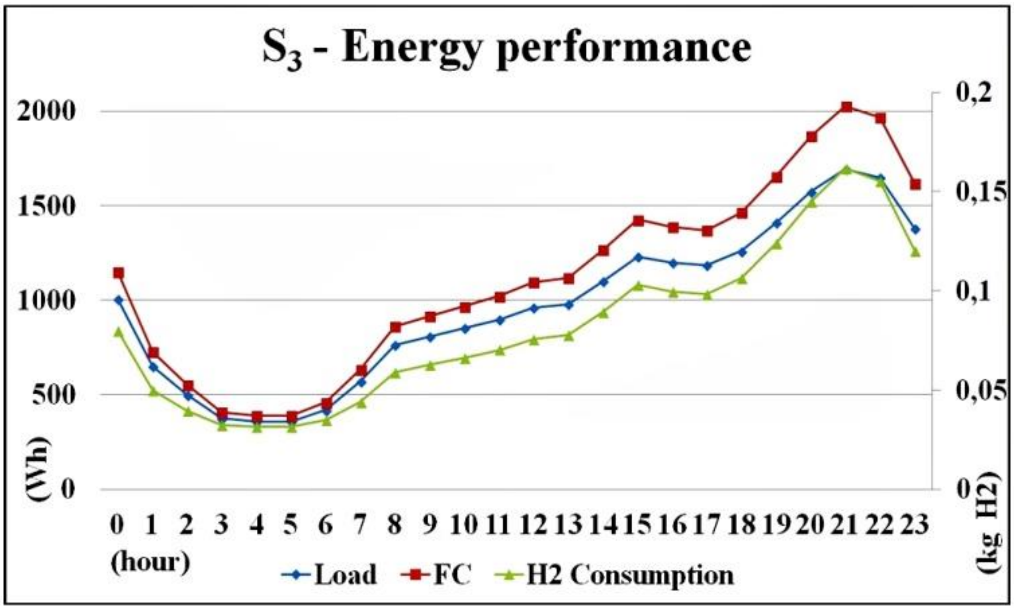


Figure 13. S3 - Energy Performance during one day of December

e) S4 - Energy Performance.

Unlike previous cases studied, the advantage of combining the two types of primary energies with hydrogen energy, removed the deficiencies due to the intermittent available character of RES, but remains available the aspect regarding the issue of whether power generation during 24 hours.

PV supply energy for passive house during period 08:00 ÷ 17:00, WT operate and supply energy all day. FC ensures back-up on period with peak load and on period with diminishes in intensity of solar radiation and lack of it.

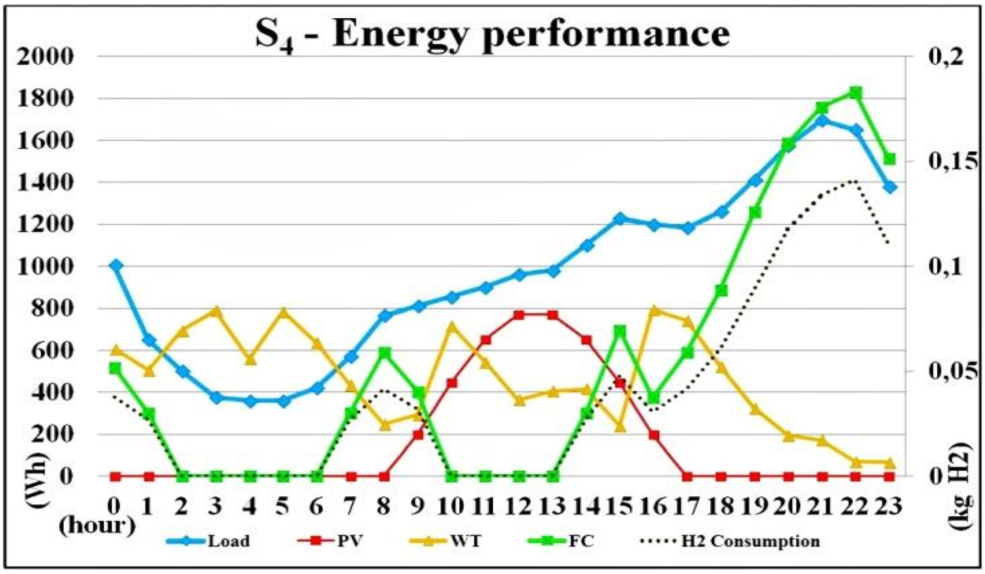


Figure 14. S4 - Energy Performance during one day of December

f) S5 - Energy Performance.

On December solar irradiation is available between 08:00÷ 17:00 hours, in this period photovoltaic panels supplu energy with a maxim by 3211 W recorded between 12:00÷14:00.

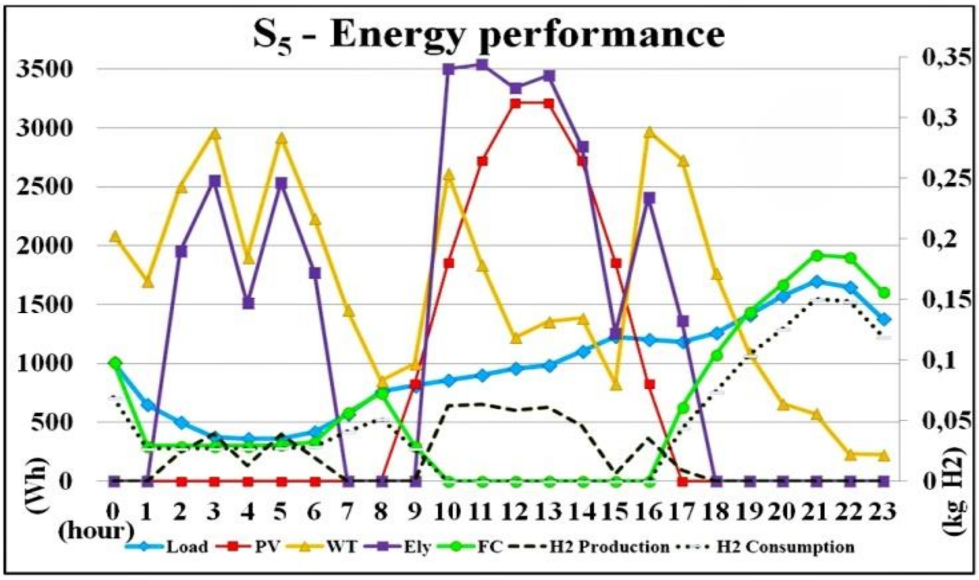


Figure 15. S5 - Energy Performance during one day of December

Also, is a favorable month to supply energy using wind speed, WT supply energy all day, with a maxim between 16÷18 hours, but in the rest period was obtained satisfacatory values taking into account by daily waveforms consumption.

Hydrogen electrolysis is done mainly between 09:00 ÷ 18:00 hours, when we have available a large amount of energy resulting from the conversion of the two types of primary energies. Electrolyser working at full capacity from 10:00 ÷ 15:00 and 02:00 ÷ 06:00 and FC have secured enough fuel to support with energy the consumer at night, especially peak load, respective 18:00 ÷ 24:00.

2.5.3.3. Sustainability Issues

Aspects regarding the environmental protection that are analyzed relate to emissions of carbon dioxide and excess energy, parameters realized by studied energy systems.

a) *Excess energy* realized in each energy system is illustrated comparative in figure 16.

In cases S_1 and S_2 was not obtained excess energy from system in operation during one year. In cases S_1 and S_3 was not obtained excess energy from systems in operation during one year. In change, in case S_2 was an excess by 233 (kWh/yr), that is useless for building and can be considerate lose or can be externalized through sending this in grid like green energy.

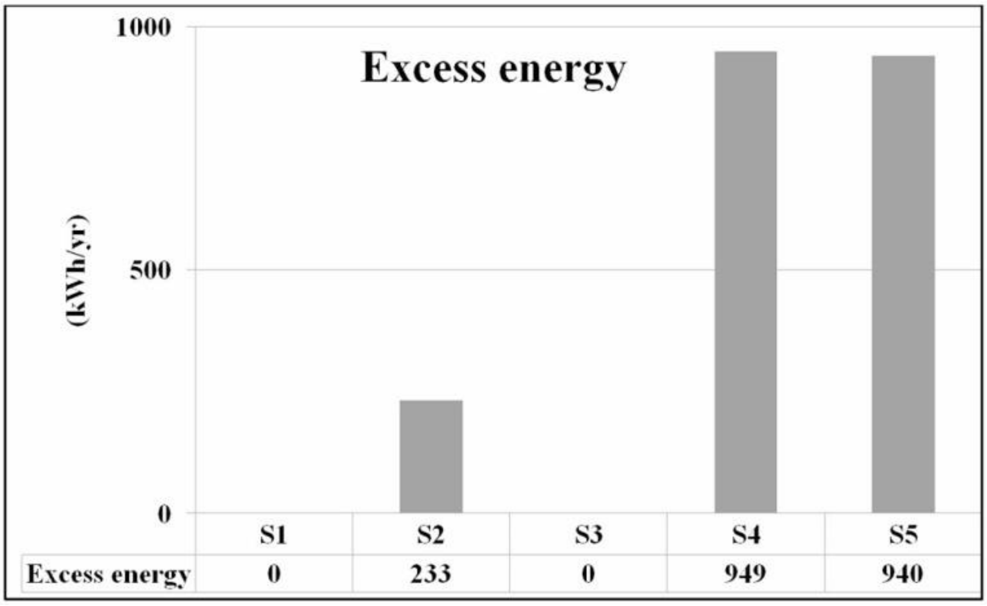


Figure 16. Excess Energy

In the S_4 is performed, the highest excess energy, closely followed by S_5. Also, it is useless for building and can be exploited through centralized outsourcing in electricity distribution network, or if the S_5 can be turned into hydrogen and used in other types of applications.

b) *CO_2 Emission.*

The calculation was used as inputs of CO_2 emission of the components, values presented in table 13 and also the total emissions of the hydrogen production. Then the total value of CO_2 emission of the life of the system is divided by the number of years of the system life (default 25 years), obtained in kgCO_2/yr, like in figure 17.

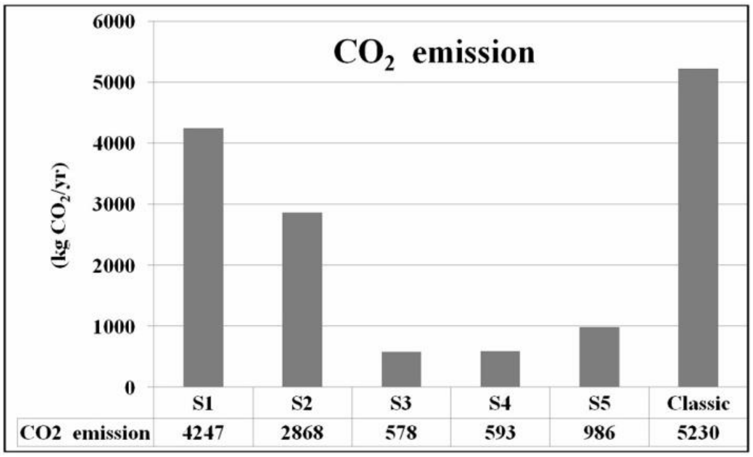


Figure 17. CO_2 Emission

The highest quantity of emission was realized by S_1, 4247 (kgCO_2/yr), being 18,80% lower than a classic system of generating energy for a standard building (Parra D., et al., 2014). S_3 - energy system with FC-based hydrogen generates the least amount of emissions, by 86.40% less than in S_1 and by 88.95% than the classic. The use of hydrogen in electricity production can make an essential contribution in the global decrease in emissions resulting from power generation more than energy systems based on solar and wind energy (Kothari R., et al., 2008; Veziroğlu T.N., Şahin S., 2008).

2.5.3.4. Financial Issues.

Total costs of the five systems were calculated based on the input data for each hypothesis is illustrated in the graph comparison of figure 18.

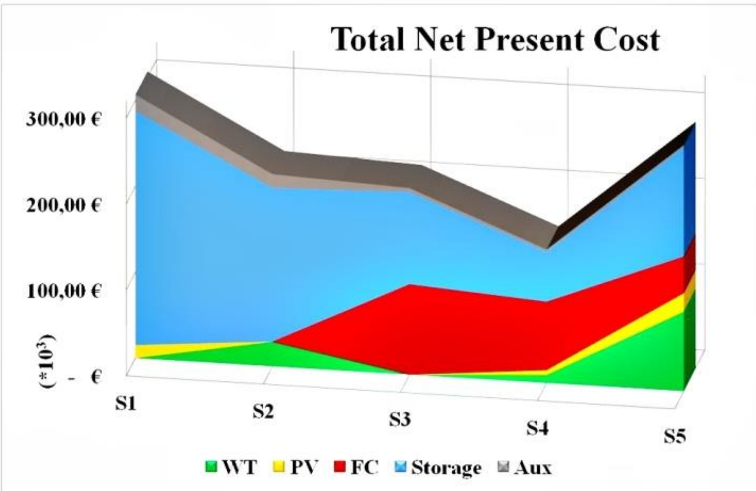


Figure 18. Total Net Present Cost

The largest share in total cost storage holds the storage unit for S_1 and S_2 respectively the cost of acquisition to hydrogen fuel in S_3 and S_4 cases or electrolytic production this in S_5. Photovoltaic panels have the lowest costs, followed by wind turbines.

The costs of hydrogen technology and purchase costs of hydrogen fuel have a higher share in the total costs diagram of these systems (Kothari R., et al., 2008; Veziroğlu T.N., Şahin S., 2008).

2.5.4. Conclusions

Through case study realized was create virtual condition of operation to energen system that sustain with energy a passive house which is within the standard of passive house, and then was determinate the performance in operation of this with the goal to demonstrate the global capabilities of this system, but also to equipment components.

By using these systems to supply energy can obtain an degree of autonomy by 100% in comparison with centralized network national that supply energy.

Primary renewable sources may be higher valorized, by total removal of the deficiencies in weather flicker but also aspects linked by storage in batteries, eliminating in totality of losses associated with these drawbacks through hydrogen technology.

The technology of power generation based on hydrogen, and production methods, storage and distribution of hydrogen make the object to continuous research and development, which will influence and lead to reduced costs in the near future.

2.6. Design and Concept of an Energy System based on Renewable Sources for Greenhouse Sustainable Agriculture

Bio-organic greenhouses that are based on alternative resources for producing heat and electricity stand out as an efficient option for the sustainable development of agriculture, thus ensuring good growth and development of plants in all seasons, especially during the cold season. Greenhouses can be used with maximum efficiency in various agricultural lands, providing ideal conditions of temperature and humidity for short-term plant growing, thereby increasing the local production of fruit and vegetables. This study presents the development of a durable greenhouse concept that is based on complex energy system integrating fuel cells and solar panels. Approaching this innovative concept encountered a major problem in terms of local implementation of this type of greenhouses because of the difficulty in providing electrical and thermal energy from conventional sources to ensure an optimal climate for plant growing. The work result consists in the design and implementation of a sustainable greenhouse energy system that is based on fuel cells and solar panels.

The study is supported by the article: **Ioan Aşchilean,** Gabriel Rasoi, Maria Simona Raboaca, Constantin Filote, Mihai Culcer, Design and Concept of an Energy System Based on Renewable Sources for Greenhouse Sustainable Agriculture. MDPI, Energies (ISSN 1996-1073), May, 2018, 11, 1201; doi:10.3390/en11051201.

2.6.1. Introduction

Development of renewable energy as a primary global resource of clean energy is one of the main objectives of energy policies worldwide, which, in the general framework of sustainable development, aimed at reducing energy consumption, increasing security of supply, environmental protection, and friendly and sustainable energy technology development (IDEA, 2010). Renewable sources represent good alternatives to fossil resources, which are limited in quantity and are prone to exhaustion.

In this context, the use of the proposed hybrid system can be successfully used in areas where the connection to the grid is not possible or where the development of the electrical infrastructure is not technically feasible or in terms of investment costs. The area of greenhouses in Romania is 922 hectares, of which, about 450 hectares are heated greenhouses. Agriculture is one of the most important sectors, which is characterized by the greatest potential for sustainable economic development (Odeim F., et al., 2015).

In order to reduce production costs, it is necessary to implement a hybrid thermal power that is based on renewable energy designed and dimensioned according to local demand, so that the production costs to be reduced significantly, while considering that heating accounts for about 30% of the total energy used in the greenhouse (Boulard T., Baille A., 1987; Kim M., et al., 2016). Integration of renewable sources-based hybrid system in the greenhouses to provide heat and electricity is an important objective for sustainability and efficiency of commercial systems in order to increase the production and reduce costs that are associated to heat production in order to ensure an optimal climate for plant growing (Nachidi M., et al. 2011; Lopez J.C., et al., 2008).

The concept of this project came as a result of the demand of a farming company that is specialized in greenhouse vegetable-growing, which has shown interest in developing a new greenhouse concept based on sustainable sources of energy-combustion piles and solar power. Major disadvantages for vegetable farmers occur in winter when it is necessary to provide specific environmental conditions: temperature (min 15 °C), humidity, sun exposure, water, and fertilizers. In this context, the design of a sustainable energy system is the first Romanian initiative to implement renewable energy sources in the agricultural field (Palander T., Kärhä K., 2016).

A combination of renewable sources by creating a mixed system is a sustainable and economic solution that could address these issues (Erdinc O., Uzunoglu M., 2012; Deshmukh M.K., Deshmukh S.S., 2008; Nema P., et al., 2009).

Reducing fossil fuel consumption by using solar energy can contribute to global climate change as a result of reducing greenhouse gas emissions and the impact of energy use on the environment (Ozgener O., Hepbasli A., 2005).

Photovoltaic energy is a valuable energy source that comes from renewable sources that are inexhaustible and non-polluting. To be used in a wide range of applications and to meet cost constraints, the implemented energy system must feature a good optimization of photovoltaic cells with a practical validation (Zerhouni F.Z., et al. 2008).

The total amount of solar energy received at ground level for one week exceeds the energy that is produced by oil, coal, natural gas, and uranium in the world.

In most cases, it is necessary to convert solar energy into electricity (Torres-Morenzo J.L., et al., 2018).

Solar energy is a source of green and inexhaustible energy and its production cost is zero, thus successfully replacing the conventional energy that we buy, and, consequently, reducing the production costs considerably (Ibrahim H., et al., 2008). These initiatives were adopted in some Smart Island north European (Cannistraro G., et al., 2017).

Photovoltaic energy is the product of direct conversion of solar light into electricity using solar cells that are connected to produce the desired electrical energy (Rosa C.B., et al., 2017). Using solar energy that is provided through solar panels and solar collectors is an efficient and environmentally friendly way that can help to reduce production costs in stand-alone greenhouses (Von Zabeltitz C., 2011; Sethi V.P., Sharma S.K., 2008; Carreno-Ortega A., et al., 2017).

Free energy of the sun can be used to heat greenhouses by collecting and storing heat during the hot summer season and using it during the cold season.

Moreover, solar energy can be used to generate electricity by integrating a system of photovoltaic panels that are mowing on the roof of the greenhouse (Carreno-Ortega A., et al., 2017).

As an alternative to fossil fuels that are expensive, farmers use renewable energy sources, such as solar heat pumps (Esen M., Yuksel T., 2013), geothermal heating systems, thermo-solar and photovoltaic panels, and biomass-derived fuels for greenhouse heating.

Greenhouses are covered with transparent materials since they mainly use solar energy, being designed to provide optimum growth conditions for plants (Panwar N.L., et al., 2011).

There are two types of greenhouses that use solar energy for heating.

First, passive greenhouses are designed to maximize solar heat gains by using special coating and structural materials that are used as solar collectors (Bot G.P.A., et al., 2005).

Secondly, there are active greenhouses that are equipped with solar systems using an independent heat collection and storage system, supplying the greenhouse with additional thermal energy when compared to the heat that is generated by direct heating (Sethi V.P., et al., 2013; Santamouris M., 1994).

The main objective of the research was to develop a functional and durable energy system that is aimed at greenhouse bio-organic farming.

2.6.2. Hybrid Energy System: A Case Study

This work identifies specific elements of a case study on the concept of sustainable development of organic greenhouses by integrating a hybrid energy system that is based on renewable sources (Nižetić S., et al., 2017).

In the warmer months, the excess energy that is produced by photovoltaic panels is stored in a hydrogen tank using an electrolyser, and in the cold season, hydrogen is used by the fuel cell to generate energy when the photovoltaic panels are unable to cover the demand energy.

This concept of hybrid energy system based greenhouse was designed, built, and implemented in a research project having ICSI as partner. The project beneficiary provided a greenhouse having the parameters that are specified in table 15.

Also, table 15 shows the calculation of heat demand of a modular greenhouse.

The hybrid energy system is able to produce cost efficient heat and electricity at any time, having good efficiency and a low level of environmental pollution.

An important requirement is to investigate the feasibility of the equipment installed in experimental greenhouse, and to evaluate the mutual benefits that are arising from this integration. The case study refers to a modular greenhouse with an area of 90 m^2, aerofoil shaped tunnel with steel structure and round arches.

Table 15. Calculation of greenhouse heat demand.

Calculation of Greenhouse Heat Demand			
Climatic Zone	II	Wind Area	II
Outside temperature	−15 (°C)	Wind speed	7.00 (m/s)
Sealed greenhouse		Outside the village	
Insulation material: double-layer polyethylene film			
Indoor temperature	18 (°C)		
1	d-the greenhouse wall thickness (mm)		
1000	ë-Thermal conductivity greenhouse walls		
3	Embodiment of the greenhouse		
90	Surface land that is located greenhouse (m^2)		
190	A-Total greenhouse area (m^2)		
284	V-Greenhouse volume (m^3)		
79.23	Q-heat requirement for calculating (kW)		
9.68	Kconv-total coefficient of heat transfer by convection through the surface (W/m^2 K)		
1.70	n-tightness coefficient greenhouse		
0.10	πn-penetration coefficient (kJ/kg K)		
0.32	ξ-coefficient that takes account of indoor and outdoor air enthalpy		
11.60	αi-heat transfer coefficient of surface to the inside (W/m^2 K)		
32.58	αe-heat transfer coefficient on the outside surface (W/m^2 K)		
8.48	KET-total coefficient of heat transfer by convection through the surface of the greenhouse, considered sealed (W/m^2 K)		
0.61	ΨA-coefficient that depends on the area of land that is located greenhouse		
10.00	L-greenhouse length (m)		
9.00	l-width greenhouse (m)		
4.00	H-maximum height (m)		
4.50	r_1-circle's radius = l/2 (m)		
4.00	r_2-circle's radius = H (m)		
90.00	S-greenhouse area (m^2)		
205	A1-total area when r_1 = l/2 (m^2)		
176	A2-total area when r_1 = H (m^2)		
190.4	A~total area (m^2): average between A1 and A2		
318	V1-greenhouse volume when r_1 = l/2 (m^3)		
251.3	V2-greenhouse volume when r_1 r_2 = H (m^3)		
284.6	V~greenhouse volume (m^3): average between V1 and V2		

Gauge dimensions of the greenhouse are: L = 10 m, l = 9 m, H = 4 m.

Figure 19 shows the concept and design of the greenhouse and figure 20 shows a functional greenhouse (seretransilvania, 2017).

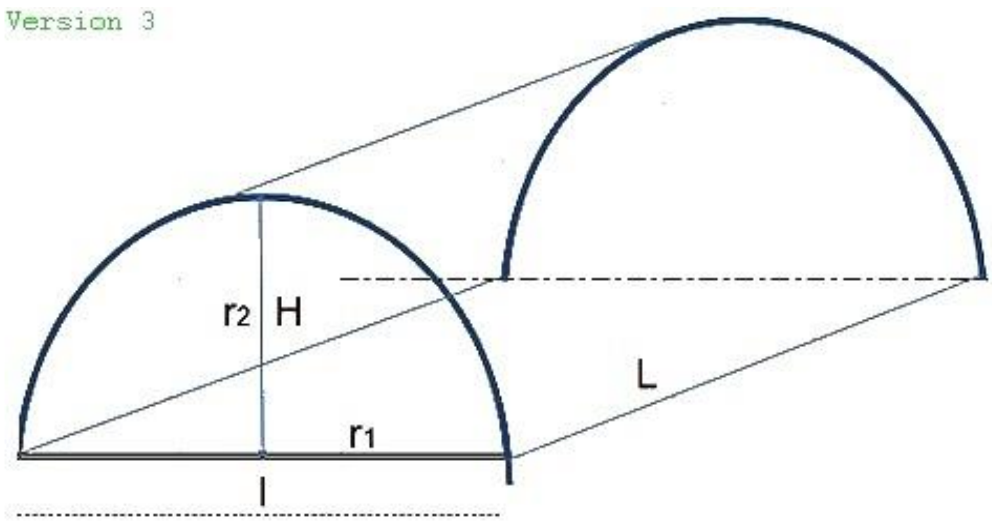


Figure 19. Elliptic design of the greenhouse.

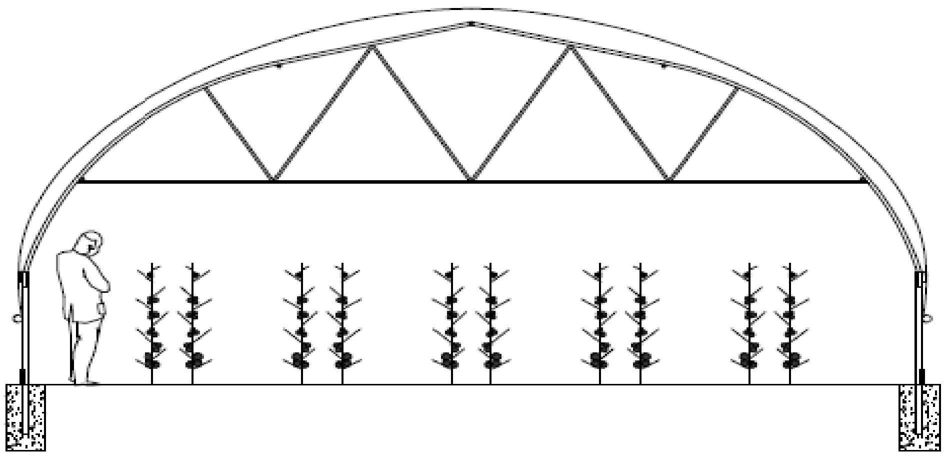


Figure 20. Functional greenhouse.

This greenhouse model was selected because it displays good strength and durability, being able to resist winds of 90 km/h and snow layer (80 kg/m^2 + 25 kg/m^2 internal load) (Short G.D., 2013).

According to Romanian standard SR 1907-3, the energy for heating the greenhouses was calculated, while considering the type of material that is used for insulation and coatings (Shen Y.; Wei, R., Xu L., 2018).

Efforts to decrease energy consumption have led the researchers to use alternative energy sources for greenhouse heating.

Several types of passive solar systems and techniques have been proposed and used for the substitution of conventional fuels with solar energy as available low-cost technology (Fabrizio E., 2012; Bargach M.N., 2000).

Because the sunlight may be insufficient in winter, then a combination of renewable energy sources is very useful to be used in this situation.

Table 16 shows the calculation of greenhouse heat loss.

Table 16. Calculation of greenhouse heat loss.

Calculation of Greenhouse Heat Loss	Data	U/M
Double-layer sheet losses	15.28	(kW)
Loss through ground	1.02	(kW)
Other losses	16.30	(kW)
Effective thermal calculation	41.1	(kW)
Thermal calculation for heat generator choosing	46	(kW)
Heat generator efficiency = 0.9	41.078	(kcal/h)
Overall thermal power	37	(kW)

Collecting solar radiation is more efficient when the greenhouse is oriented East-West, which may be performed both in summer and winter (Abdel-Ghany A.M., 2011; Castilla N., Hernandez J., 2007; Barbir F., 2005; Larminie J.; Dicks A., 2003; Nižetić S., et.al, 2016; Ay M., Midilli A.; Dincer I., 2006).

2.6.3. Hybrid Energy System Components

The project research team identified the following components of the hybrid energy system, in accordance with the specific technical requirements of the beneficiary.

The use of the fuel cell in the proposed hybrid system will have a high economic profitability, as it will be implemented by as many users as possible, thus reducing the cost of fuel cell production.

In the next level of this research, a multicriterial analyse taking into account economic criteria for all equipment from hybrid energy will be realized.

2.6.3.1. Thermal energy production system

- Thermal heating generator that is based on fuel wood and biomass is used to produce heat for the greenhouse needs. This equipment has a nominal heat output of 38 kW, it works very efficiently, gasification has low fuel consumption, and it shows superior performance, which is up to 93%.

From thermal calculation performed, it results that this model of power with thermal power of 38 kW is sufficient to provide the energy requirements of the greenhouse at a rate of up to 70%, when considering that its use is done mainly in winter.

- Thermal solar collector panels with vacuum tubes are a great alternative to produce hot water using solar energy in summer.

The total area is 3.5 m^2, P_{max} = 1260 kWh, 666.34 kWh/m^2 (63 kWh/tube), 67% optical efficiency, maximum temperature 239 °C.

Using thermal solar panels for a period of 4–6 months per year in the greenhouse can bring in significant savings on heat production.

Mixed hybrid heating system based on solar-hydrogen energy and biomass allows for a saving of up to 30% of annual fuel that is used for heating and domestic hot water (esolar, 2017).

2.6.3.2. Electricity generation system

- The assembly of photovoltaic panels, Off Grid.

- Polymer electrolyte membrane fuel cells, P_{max} = 9 kW, T = 14.4 V, I = 35 A, hydrogen consumption 6.5 L/min.

- Proton exchange membrane (PEM) electrolyser, with capacity of 1.05 Nm3H2/h at a pressure up to 30 bar, U = 230 V, P_{max} = 2 kW.

The hydrogen produced by the electrolyser is very efficient when it is converted into electricity using fuel cells with proton exchange membrane, which are actually electrochemical energy converters (Pascuzzi S., et al., 2016).

This equipment has the advantage that it can be used to produce electricity at any time using stored hydrogen, but only when it is necessary.

PEM fuel cells are the most promising type of power generation, due to its advantages, such as simplicity, low operating temperature, and easy maintenance (González I., et al., 2017; Rosa R., et al., 1989).

PEM fuel cells are the future of generators that provide electricity and portable station types, using renewable energy sources for this purpose.

The implementation of a combined electrolysis fuel system for the production and storage of hydrogen in a demonstration greenhouse is a good alternative to traditional power solutions, given that it provides reliable equipment and it generates electricity at all times (Mengelkamp E., et al., 2017).

2.6.3.3. Electrical and thermal energy storage system

- Mixed boiler for hot water heating and storage, with a capacity of 500 L and thermal energy storage power up to 42 kWh.

- Pressure hydrogen storage cylinders, with a capacity of 50 L and volume of 10 m^3.

- Solar batteries with gel solution, U = 12 V, I = 200 Ah, are designed for photovoltaic systems and kits, and they are used to store electricity.

This type of battery uses innovative technology “Absorbent Glass Mat”, which gives them the property to provide significant energy reserves that can feed many electrical consumers throughout its service life (Smaoui M., Krichen L., 2016).

A schematic diagram of the constructed experimental system is illustrated in figure 21.

The output power of a solar PV panel changes in accordance with change in solar radiation and temperature level.

This makes it impossible to use the direct-coupled method to automatically track the maximum power point.

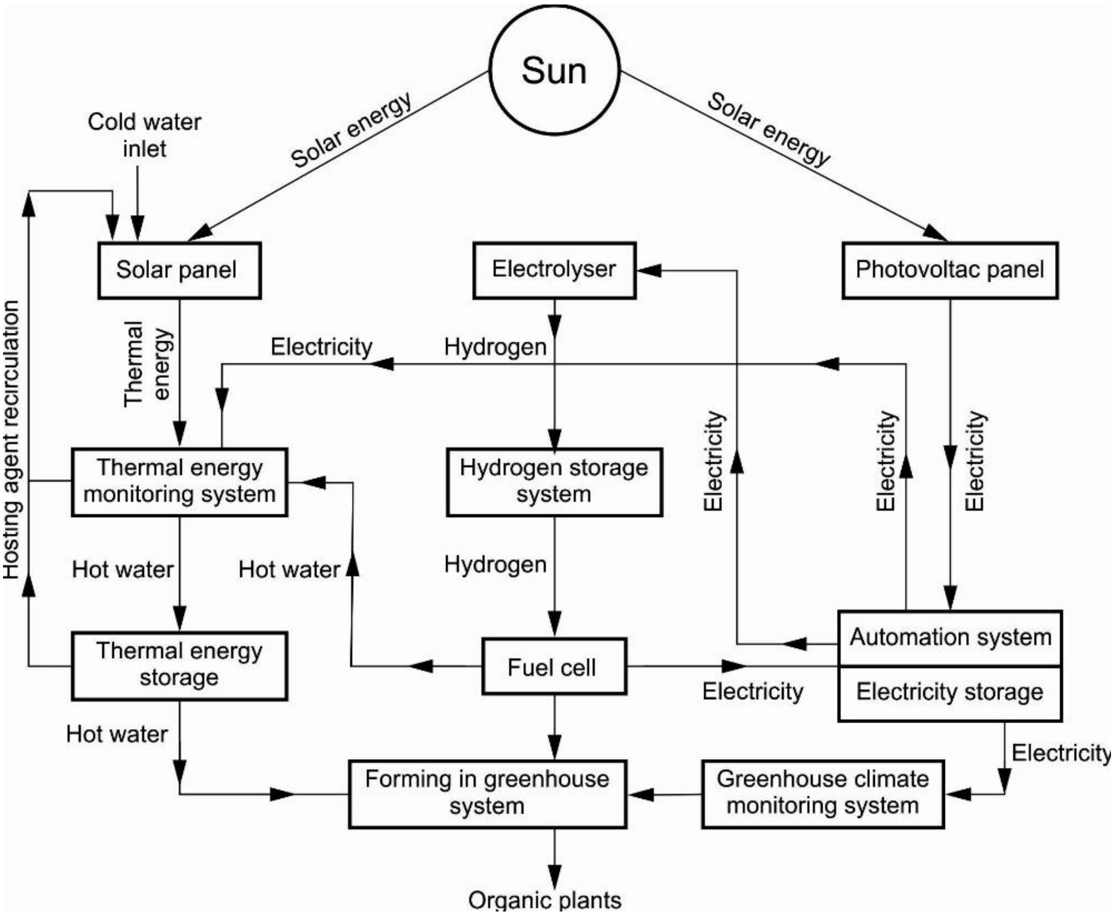


Figure 21. Schematic diagram of the hybrid greenhouse system.

These changes in weather conditions are shown by the P-V curves that are displayed in figures 22 and 23, respectively.

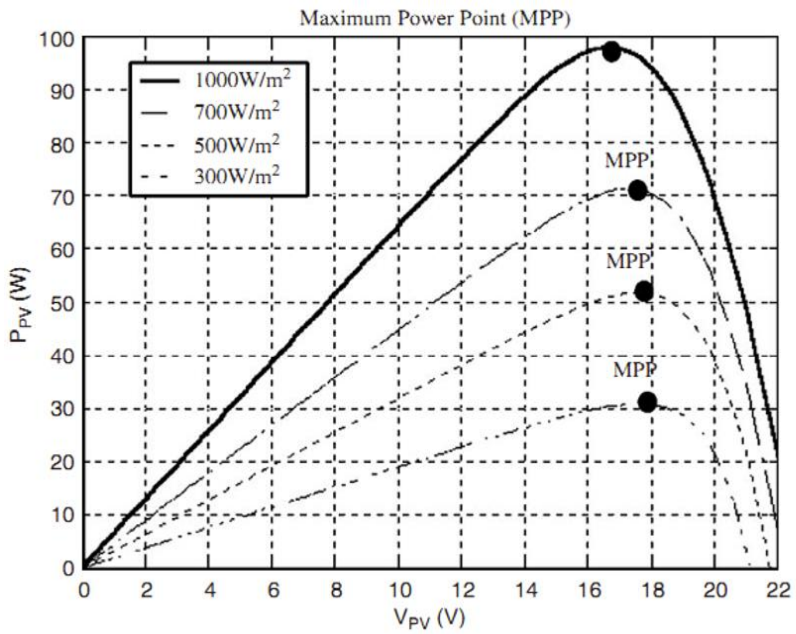


Figure 22. Characteristic curves at four different irradiances.

Figure 22 shows the characteristic curves at four different irradiances.

A Maximum Power Point Tracking (MPPT) system needs to be implemented in order to extract maximum power during the operation of solar panel and to be able to track the changes in power due to changes in the atmospheric conditions (Abbasi M.A.; Zia M.F., 2017).

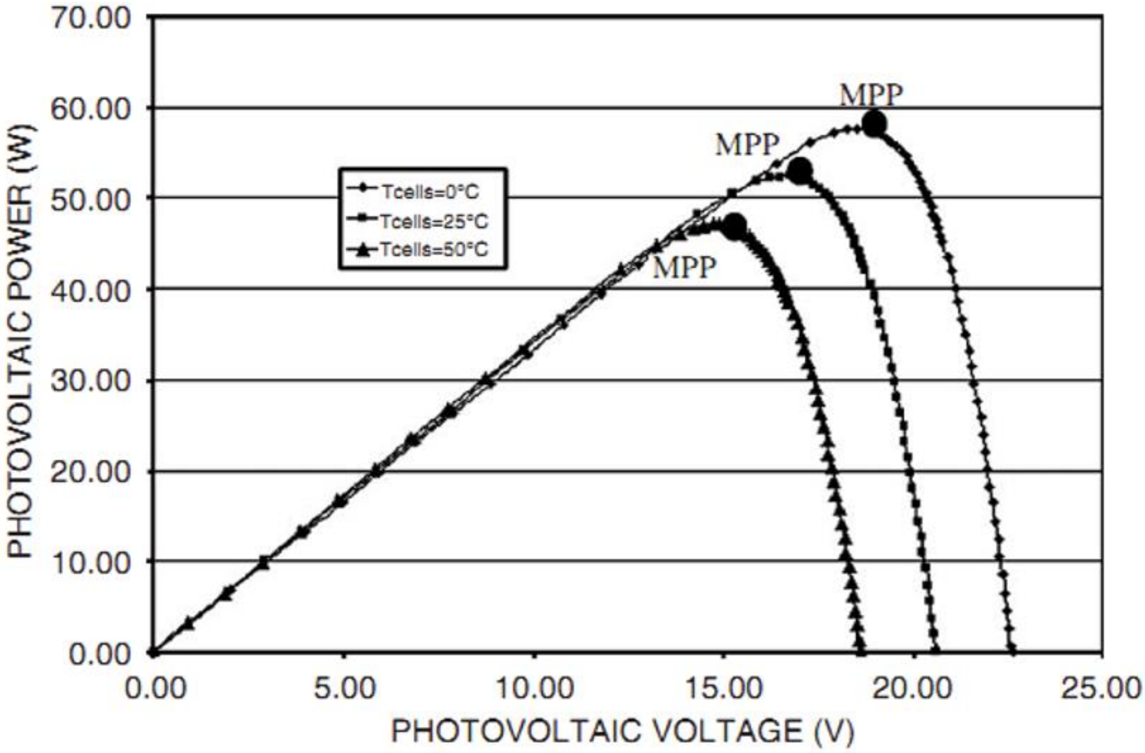


Figure 23. Characteristic curves at different temperatures.

Figure 23 presents the characteristic curves at different temperatures.

Modularity is one major advantage of this sustainable type of renewable sources based greenhouse. Once the hybrid system is sized and implemented by resizing individual components, an unlimited number of various constructive structural elements can be added: photovoltaic panels, thermal solar modules, fuel cells heating systems, ventilation systems, etc. (Luque A., Hegedus S., 2011).

In the event that there are conditions for biogas production to complement the energy requirement of the greenhouse, a small system to produce the fuel gas by decomposing organic matter can also be integrated.

Renewable energy resources, such as wind, sunlight, geothermal, and biomass are mostly used.

They are working together and their integration into the energy market can improve the sustainability and the reliability of the power systems (Whiteman Z.S., et al., 2015).

A microgrid is an autonomous electric distribution system that combines one or more energy resources with the loads, having its own management and control system, and working as an independent controllable entity (Ahmadi H., et al., 2014).

The communication and control responsible device collects the data from the microgrid and manages the system.

In Figure 24 is represented the functional scheme of biogas system.

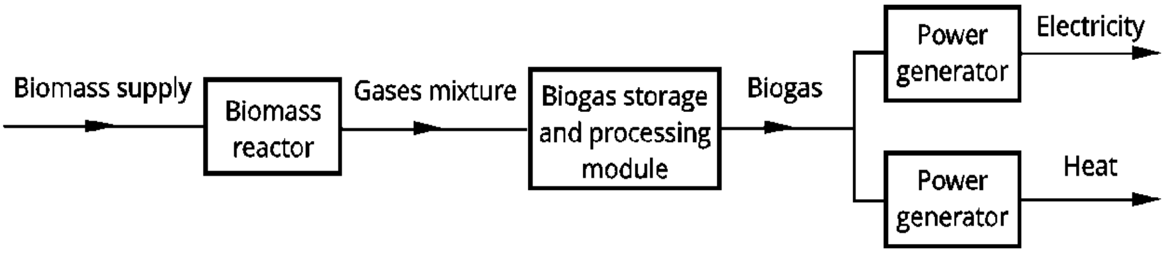


Figure 24. Schematic diagram of the biogas system.

The algorithm that is used to test the system is based on the state of charge of the batteries. The read values are the following: BatSoc, PacSI, ExtPwrAt, GnManStr, PacSB, and Pbio (power of the biomass generator).

The microgrid setup has emulators for the geothermal and biomass generators and a photovoltaic system with storage capability and two inverters, a grid forming capable, and a grid follower.

That proper energy production of the microgrids is also a substantial issue.

The balance between the energy flow and the load demands is their basic rule considering the availability of the resources.

A properly functioning energy management system can ensure the best solution and meet the load requirements continuously and in short time.

The gradient-based systems are too slow to be used in real-time energy management systems, so the articles from this area focus on the off-line application (Lazar E., et al., 2018).

The use of biogas to produce heat and electricity in the case of greenhouses is one of the most effective solutions to ensure their sustainability.

Heating and cooling systems are major costs involved in plant production in greenhouses.

Normally, heat-generating generators that imply the high consumption of energy are normally used to heat greenhouses, which are usually supplied by combustion of fossil fuels (diesel fuel, oil, oil, gas).

In view of the above, an effective solution for the sustainable development of greenhouse farming is the replacement of fossil fuels with alternative energy sources (Cannistraro G., et al., 2015a).

The main alternative energy sources to be implemented in the greenhouse for the supply of heat and power are the following:

- thermo-solar energy;
- energy from biomass and solid wood; and,
- energy from hydrogen energy.

The innovative combination of these renewable sources and the use of local air conditioning systems (Cannistraro G., et al., 2015a; Cannistraro G., et al., 2015b) will create an energy system that can meet the energy needs of an agricultural greenhouse, thus achieving an optimal climate for plant growing (Chai L., Ma C., Ni J.Q., 2012*)*.

2.6.4. Development and Perspectives

The greenhouse systems that are provided with heating systems which are usually used during cold nights and during the winter season have a significant advantage over the quality of the products that are obtained, as well as a significant reduction in the planting and harvesting time.

In order to maintain the ambient temperature at optimal parameters for plant growing, it is necessary to consume large amounts of heat, which is usually supplied by fossil fuel energy systems (Chinese D., et al., 2005).

As a result, the average temperature difference between the inlet and outlet of the earth-air heat exchanger (EAHE) was 8.29 °C.

The total electricity consumption of this system was 8.10 kWh, operating approximately 11 hours/day, when 34.55% of this energy demand was provided by photovoltaic cells (Yıldız A., et al., 2012).

An Indian study (Ganguly A., et al., 2010) analyzed and modeled an integrated energy system for a greenhouse consisting of solar PV, a PEM polymeric membrane electrolyzer, and fuel cell assemblies. This study demonstrated that 51 PV modules, each modulus with a power of about 75 W together with a 3.3 kW electrolyzer and two PEM fuel cell assemblies, each 480 W power unit can cover the energy requirement of a flower greenhouse of 90 m^2.

Solar radiation in the greenhouse depends on its orientation and positioning, but East-West orientation is more effective in collecting solar radiation in winter than in summer collection (Abdel-Ghany A.M., 2011; Rosa R., Silva A.M., Miguel A., 1989).

A key factor in the proper functioning of the greenhouses is the implementation of an efficient irrigation system to ensure the effective hydration of the plants.

In this respect, ensuring the supply of electricity for pumping, transport, and water storage equipment is one of the most important objectives. A solar water pumping system has many important advantages, for example, besides any fuel and maintenance costs; there is no environmental pollution hazard.

There are very frequent cases where rural settlements, which are made up of villages and communes, are not connected to the conventional power distribution lines because they are not located near them, being located at considerable and relatively isolated distances, so that it is almost impossible to connect them to classic energy distribution systems due to huge costs.

In this respect, the best solution to solve these problems is the use of small-scale energy applications consisting of combinations of photovoltaic panels with thermo-solar panels, which ensures the supply of greenhouses with heat, electricity, and water, representing an efficient and cost-effective solution for these isolated areas (Meah K., et al., 2008).

2.6.5. Conclusions

This work presents the case study of a research project that had as the main objective the development and implementation of an experimental model of functional greenhouse, an integrated energy system for the production of thermal and electric energy using low-pollution renewable sources.

The case study that was analysed shows that the development of a sustainable greenhouse concept that implements an integrated hydraulic energy system, based exclusively on renewable sources, such as solar energy, hydrogen energy, biomass with possible applicability in the future, along with the development of production technologies and the development of the production capacities of fuel cells.

The amount of additional energy that was produced by photovoltaic panels during the period 20 March–10 November, exceeding of technological consumption and lighting is 6775.84 kW, of this amount of energy between 20 March and 10 November, from using the electrolyser we produce 203.28 kg of hydrogen. During 11 November–19 March, from 203.28 kg of hydrogen using fuel cell, we produce 3374.44 kW, which we provide 3 kW of energy for lighting and technology per day, with a total consumption of 387 kW and the difference of 2997.44 kW is used for heating the greenhouse as an additional energy, to the thermal energy produced by the wood, covering the peak load in the days with temperatures lower than −3 °C, with an average of 31 days per year.

New energy generation systems use all of the systems at renewable sources contribute to reducing overall energy consumption, increasing energy supply security, and protecting the environment, thus reducing the polluting emission (Cannistraro G., et al., 2016a; Cannistraro G., et al., 2016b). In recent years, the use of food, water, and energy resources has become an essential issue, especially in rural areas, with some being unable to connect to electricity, water or gas networks but having very high potential for solar, wind and biomass renewable sources.

Due to different socio-economic obstacles, these renewable sources are under exploited and are poorly used by mankind. Globally, due to population growth, and, implicitly, food and water needs, significant increases in energy consumption in agriculture are estimated. The implementation of renewable energy sources, especially solar energy and biomass, will solve these problems by ensuring the provision of cheap and environmentally-friendly energy, especially for greenhouses, which use an appreciable amount of energy for the proper functioning of the cooling systems, heating, lighting, and irrigation.

Moreover, the use of green energy will lead to the sustainability of greenhouses, increased energy efficiency, increased food production, and the provision of cheap and clean energy.

2.7. Final Remarks

The theoretical and case studies included in this paper are supported by the processing, analysis and synthesis of a large amount of technical and scientific data and information obtained from the scholarly literature, namely: articles, journals, books, handbooks, scientific papers presented in national and international conferences, documents and reports of professional associations in the field of renewable energies, hydrogen and fuel cells, standards, engineering design normative acts, regulations and laws in force at national and international level. The studies, analyses and results of the researches, as well as the problems, the technical limitations encountered allow identifying and establishing future directions of research in the field of the approached topic.

3. Rehabilitation of the Water Supply Systems in Urban Localities

3.1. Introduction. General Background.

Water has been, is, and will be, an essential element in the development of human settlements, with civilization developing in the presence of water and often disappearing with its depletion or degradation. Being considered a means and occupational object, but also a renewable resource that can not be replaced, water is an important factor in the development of human society. With the development of centralized water supply systems, water has become a commercial good, in many cases having a very high price.

The problem of resources is growing in the world. In spite of scientific and technological progress, along with population growth and resource exploitation, pollution has perpetuated. The provision of water flows to a suitable quality for human collectivities at international level is far from being solved. In recent years, the importance of the environmental aspect by addressing the global and integrated development of water resource management has increased, to the detriment of past sectoral and technical treatment.

The World Summit on Sustainable Development, held in Johannesburg (South Africa) in 2002, sets new directions for action on the sustainable development of the contemporary world, where the focus is put on the upgrading of the sustainable management of fundamental natural resources, which include the WATER resource, as well as action goals to enhance the sustainable development of human society.

Coming down to the management of water resources, the expected objectives and actions are as follows:

- **objectives:**
  - sustainable exploitation of fresh water resources (water demand to be less than the available);
  - conservation of unpolluted groundwater;
  - avoidance of any situation of deterioration in the quality of already groundwater already polluted;
  - maintenance of the quality of the polluted groundwater at a level that will allow it to be made safe to drink;
- **actions:**
  - increase in the degree of knowledge of the water resource field and development of the corresponding database;
  - integrated water management and protection;
  - substantiation and operationalization of economic and tax instruments for the management of water resources;
  - reduction or elimination of polluting practices.

On 12.11.2008, the Government of Romania approved the National Strategy for Sustainable Development - Horizons 2013-2020-2030, which is a joint project of the Romanian Government, by the Ministry of Environment and Sustainable Development and the United Nations Development Program through the National Centre for Sustainable Development.

The strategic objectives adopted are the following:

- Horizon 2013 - reduction in the existing gap as compared to other EU Member States on environmental infrastructure, both quantitatively and qualitatively, by developing efficient public services in the field, in line with the concept of sustainable development and the observance of the ″polluter pays″ principle;
- Horizon 2020 - achievement of the current EU average level at key parameters for responsible management of natural resources;
- Horizon 2030 - significant gap recovery as compared to the other EU Member States' environmental performance of that year.

Regarding water, the national strategy provides for the promotion of integrated water and wastewater systems in a regional approach, to provide to the population and other water service consumers with the required quality, at acceptable tariffs.

The management of water supply systems involves at least two aspects:

- the development of a long-term rehabilitation / modernization strategy, so as to prevent the evolution of the system status and performances, as well as the construction and evaluation of the action strategy;
- the development of annual or multiannual rehabilitation / modernization programs, by which to establish a hierarchy of sections according to the priority of their rehabilitation, taking into account the strategy and budgets actually available.

To plan the rehabilitation or modernization of damaged elements in drinking water systems, the following questions must be answered at least:

- whether it is better to undertake rehabilitation or modernization;
- what is the optimal technology for rehabilitation / modernization;
- what is the optimal time for rehabilitation / modernization;
- what are the technical and economic criteria for rehabilitation / modernization;
- what are the elements to be rehabilitated / modernized with priority.

In the field of water supply systems, the state of installation is more difficult to diagnose, as the majority are buried, and the costs of assessing the degree of deterioration are high. Also, companies managing water supply systems do not have sufficient information on installation status and system performances. Thus, making a decision on rehabilitation or modernization can be a rather difficult process.

Efforts to adapt laws in force and their implementation should not be considered as being determined exclusively or predominantly by the factors mentioned, as they are valid in any domestic and international political, economic or social context. Water issues are serious and human communities and nature as whole need indispensable healthy and sufficient water, otherwise there is no real chance of sustainable development.

In this context, for the research activity having "WATER" as main direction, it was adopted as the main objective the establishment of technical and economic decision-making criteria regarding the methods of rehabilitation and modernization of water supply systems in urban localities, so that water is an asset accessible to everyone.

In order to support this goal, two of the most representative objectives have been adopted as secondary objectives, the first being to determine the optimal moment for the rehabilitation or modernization of water supply systems, a decision with multiple implications in the management of such a system and the second being the development of a general methodology for piping rehabilitation using non-digging methods, the piping being the most extensive component of a water supply system.

3.2. System Description and Analysis

3.2.1. Urban Water Supply Systems

The water supply system has the duty of making usable of the natural water capacity for the population, which means that the raw material, water, in terms of drinking water prescription requirements, must be provided and made available hygienically, physically and chemically and without restrictions, in sufficient quantity.

Water coverage refers in principle to drinking water supplies, industrial consumption, industrial machinery cooling, mining and industrial production, but also for irrigation, fish farming or aquaculture.

From the entire water supply system, only the ″drinking water supply system″ will be selected for a more in-depth analysis.

3.2.2. The Technical Concept of System

The word *system* comes from the ancient Greek language σύστημα (sýstema), currently sístima, which means the product, the combination, the connection. The system can be defined as a set of elements dependent on each other and interacting in a unit that makes a practical activity work according to the intended purpose. Thus, the concept of system can comprise both technical and organizational complexes.

Economic operation connections and economic systems can be considered up to technical structures (Figure 25). The costs and organizational processes that result from the design and maintenance of the technical water supply system are of major relevance to this analysis.

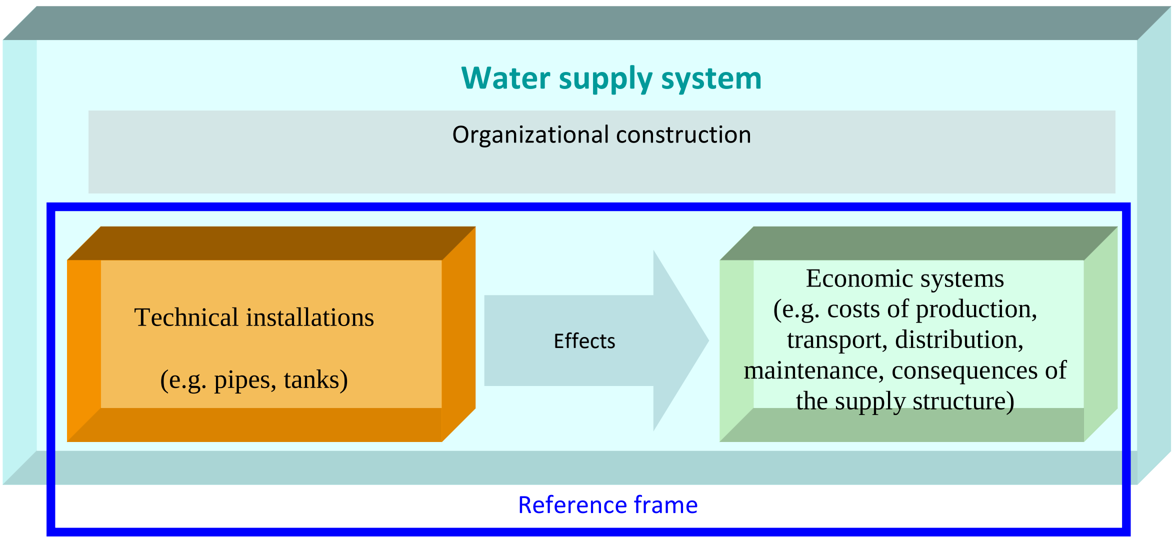


Figure 25. Reference frame inside the water supply system

The standard SR 1343-1:2006 defines the water supply system as a "Set of specific buildings, installations and construction measures that provide drinking water to the whole or most of the population of the locality. As a whole, the system ensures the catchment of water from a natural source, treatment to the quality required by the consumer in accordance with the legal requirements in force, transmission, storage and distribution to users in the quantity, quality and normal use pressure" (Figure 26).

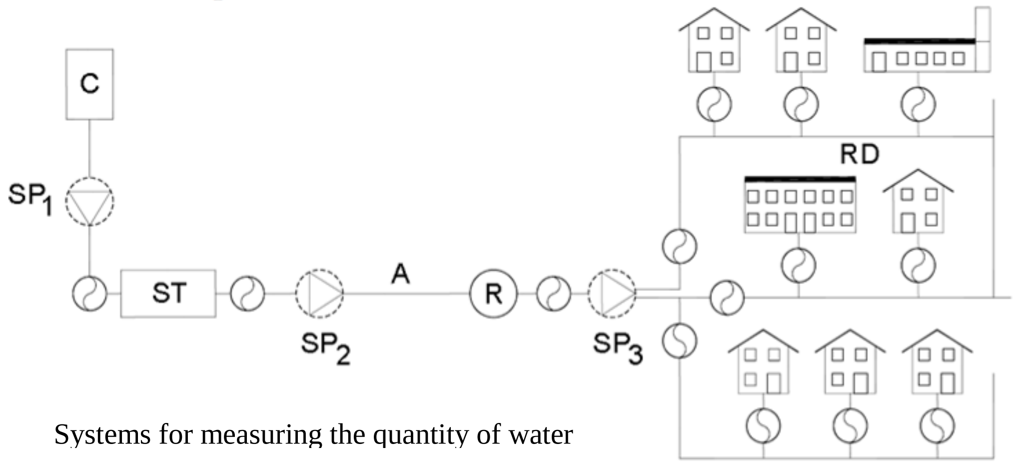


Figure 26. General scheme of a water supply system in a locality

The Law no. 241 of 2006 of the water supply and sewerage service defines the concept of public water supply system as "the assembly of constructions and land, technological installations, functional equipment and specific facilities, through which the public water supply service is provided. Public water supply systems typically include the following components: water catchments, penstocks, treatment stations, pumping stations without hydrophore, storage tanks, transmission and distribution networks, connections, up to the delimitation point."

According to the definition given by the same law, the water supply service is all the activities necessary for: the catchment of raw water, from surface or underground sources; treatment of raw water; transmission of drinking and/or industrial water; water storage; distribution of drinking and/or industrial water.

3.2.3. Water Supply in Urban Localities

Considering the complexity and extension of water supply systems, the study will only be limited to the drinking water supply in urban localities. Drinking water supply refers to all the hydroedilitary works required to meet the drinking water demands of the populated centres.

The city is a complex form of human settlement with variable dimensions and industrial facilities, usually having administrative, industrial, commercial, political and cultural functions. Water supply installations should not always be located within the territory of the urban locality, but only to economically and legally belong to it.

The water connection consists of connecting the distribution network with the customer’s facility. This starts at the connection point of the distribution network and ends with the metering element.

In this analysis, water supply installations will be treated up to the final user's connection, the end-user installation not being the subject of this research.

Briefly, the term "urban water supply" thus encompasses all technical installations in the waterway, from the bifurcation in the natural hydrological circuit from the first phase up to the consumer's connection.

3.2.4. Stages of Water Supply

How can water supply be structured inside this man-made system? In the following, the technical elements will be presented briefly and in general, as well as the areas where the important points of this paper fall.

Drinking water supply has always been at the forefront when new human settlements have been built or when existing ones have been extended. Where there was a house or a village, there must have been a spring or a fountain nearby. In the modern world, this rule is no longer strictly valid since centralized water supply systems have been made for entire localities or groups of localities with water from sources sometimes located hundreds of miles away. The supply of any dwelling or institution with drinking water remains a standard which can not be retracted.

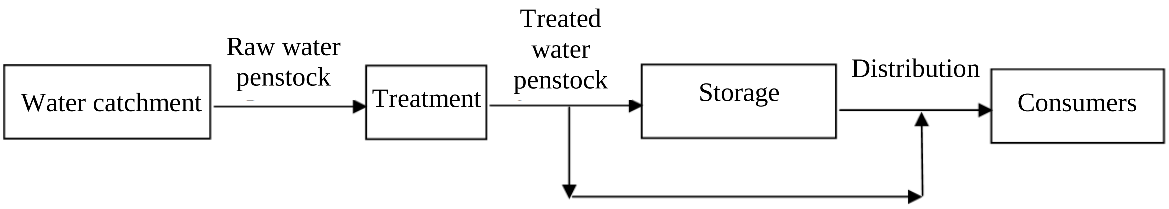


Figure 27. Stages of water supply

A drinking water supply system consists of different levels and technical elements, which can be divided into 4 stages: procurement (catchment), treatment, transmission and storage of water, as well as its distribution to consumers (Figure 27).

3.2.5. Rehabilitation and modernization of water supply systems

In the broadest sense is meant by rehabilitation the sum of all the measures having as main objective bringing of the water supply system to the technical stage provided by the law, and by modernization, bringing it to a higher level than the law requirements.

For the water supply system, this means that on the basis of rehabilitation and modernization, it may be possible to prepare the water resource in accordance with the provision of the laws and standards in force and under the influence of the highest economic, ecological and technical technology.

The development of water supply systems has been made progressively with the development of technology, both in terms of the structure of the materials and the mode of execution of the pipeline assembly technologies.

Water supply systems are designed and built at various stages with the knowledge, technologies, equipment and materials known at the respective stages, but over time some technologies and materials become obsolete, with new ones emerging.

Consequently, both globally and especially in Romania, where the efficiency of water supply systems is still low, modernization, reengineering and development are required. These actions call for important investments and qualified staff, so that the execution requires in most cases staging in time.

As a result, any action needs to be begun with a critical analysis of the existing system, highlighting its strengths and weaknesses, analysing the possibilities through an overall study comprising solution proposals considering the most advanced technologies, the most performing materials and equipment and the financial possibilities available. The adoption of compromise solutions between technical performance and financial possibilities often leads to resolutions that are viable for a short time, and background issues need to be resumed later in order to find an optimal solution.

Tubes and pipes for water pipelines from the current supply systems were made from the following materials: asbestos (currently banned, being considered as a source of cancer), reinforced concrete, plastics, grey cast iron, steel, etc.

At present, modernization-reengineering or development processes strive to introduce performance materials such as: ductile cast iron, high density polyethylene, polyester fibreglass reinforced polyester etc. The choice of pipeline material is made taking into account the need to meet both the technical and economic conditions required and imposed by the standards.

3.2.5.1. The Concepts of Rehabilitation and Modernization

In this paper, through rehabilitation is meant the execution of the works necessary to keep the system in the technical parameters of operation at which it was designed.

Modernization means the partial or total replacement of a system by a more advanced technical and modern one, resulting in an improvement in the technical parameters. Reporting to the water supply system, modernization means increasing ecological and economic efficiency through the set technical measures.

Due to very high costs, it is often necessary to rehabilitate pipelines and water supply systems, and only when sufficient financial resources are available, modernization is addressed by using more energy-efficient materials and more durable in terms of service life.

In order to rehabilitate the pipelines, taking into account the importance of existing technical solutions, it is necessary to deepen the technological alternative of the cleaning and coating of the interior surfaces. For the modernization of water supply systems, however, the pipeline expansion/replacement method is required.

For interventions on elements of water supply systems, other terms are also used, among which:

- replacement of pipelines - is the change and refurbishment of systems that can not be repaired by other new technological systems;
- change and renewal of pipelines - if by change is meant the process by which the old pipelines are destroyed and replaced with others without removing them from the ground, by renewal is meant the replacement of the old pipelines with new ones without destroying the old pipeline;
- reconstruction of parts of the water supply system may be a rehabilitation if the

reconstruction does not serve for new supply capacities;

- system rebuilding means the suspension and demolition if a rehabilitation or replacement no longer have any meaning.

3.2.5.2. Context of Triggering the Process of Rehabilitation or Modernization of Pipelines

The main reasons behind the commencement of pipeline rehabilitation or modernization processes are as follows:

- major interventions or restoration of other edilitary networks (gas, sewage);
- change in road traffic to a higher axle weight traffic and/or its intensification;
- high frequency of cracks or breakage of pipes;
- major damage to the soil (landslides, earthquakes, floods);
- age of pipelines.

There may also be adjacent reasons that come to support the commencement of these projects, among which we mention:

- the risk of soil flooding, caused by the breakage of a pipeline;
- the need to extend the network, if the main sections can not bear this;
- the increase in the number of consumers supplied by a section;
- the inadequate diameter of a pipeline due to the expansion of residential or industrial areas, etc.

As already mentioned, buried pipes in the earth are subjected to external and internal loads which produce stresses in the walls of the pipe both in the transverse direction and in the longitudinal direction.

In the transverse direction, M moments and N normal forces are born in the walls of the pipes, which come from the following loads:

- loading with earth;
- pushing the earth;
- loading from the upper field loads;
- own weight of the pipeline;
- weight of the water inside the pipe;
- water pressure inside the pipe;
- overpressure and underpressure in the pipe at the hydraulic stroke.

In the longitudinal direction, M_l moments and N_l normal forces are born in the walls of the pipe, which come from:

- temperature differences;
- pressures in bends;
- elastic deformations of the pipes due to the fixed and mobile loads and the elasticity of the foundation bed;
- seismic action.

In pipelines under road traffic areas, in underpasses of railways and roads, mobile loads are considered to be fundamental.

The actual P_{ef} pressure on the pipeline from the G_v and G_{v1} external loads that can form in the pipe will be

$$P_{ef} = \frac{G_v + G_{v1}}{10d} \quad (29)$$

where:

G_v represent external loads distributed due to the earth above the pipe;

G_{v1} - loads concentrated as a result of road traffic;

d - pipe diameter.

From the multitude of internal and external factors that adversely affect the stability of the pipeline from a static point of view and may lead to additional stresses in the pipe walls, leading to greater stresses than the admissible ones, we consider vertical loading from loads to the surface of the ground as the cause with major impact:

- increased traffic;
- changes from light traffic to heavy traffic;
- rehabilitation of the vertical systematization above the pipes and thus the change in the soil structure, including the technologies and machinery used to carry out these works;
- digging in adjacent areas.

These additional stresses do not necessarily take into account the age of the pipeline, with possibility of damage of both the new pipelines and pipelines that have been in operation for a long time.

In the current period, the replacement of water networks must be a priority, because their outdated service life is a reality.

National and local authorities need to develop an adequate strategy to plan the necessary financial investments in the field, support the exploitation of existing infrastructure, optimize operating and maintenance costs, limit losses and, last but not least, improve the quality of distributed water and services provided to consumers, all of which are being made in the context of lowering investment and operating expenses, ensuring all the parameters required by the safe functionality and maximum quality of the entire system.

In this context, choosing the optimal moment of rehabilitation, establishing the order in which the rehabilitation will be done, the theoretical substantiation regarding the choice of technical solutions for rehabilitation, materials for pipelines and equipment should be based on researches, scientifically documented and rigorous drawn analyses, established by their hierarchy based on multi-criteria analyses, the quality requirements being the minimum condition for the configuration of any water supply system.

3.3. Choice of the Optimal Moment for Rehabilitation or Modernization of Water Distribution Systems

3.3.1. Pipeline Damage Statistics

Statistics of the damage from the commissioning of the pipeline is the easiest help to know the weaknesses that may occur over time.

The information used for such statistics should be **static data**, such as pipe characteristics - diameter, material, quality, length, topographic / GPS coordinates, location (green spaces, normal traffic, heavy traffic, existence of tramways and railways in the proximity, water), commissioning, joints, land structure etc., but also **dynamic data**, on system performance, including a recall of the history of faults (date, pipe identification, pipeline location, type of fault, remediation time, remediation module), hydraulic test results, network pressure fluctuation, dynamic traffic load variation, extreme temperatures, groundwater level, etc.

From the repair cases, an annual fault rate can be calculated, which is the annual number of faults per km of pipeline. Often, faults will be related to other qualitative indices, such as the occurrence of water turbidity, stagnation and changes in the direction of flow.

For the rehabilitation and modernization strategy, it is necessary to establish a medium-term financial framework.

The rate of faults in a pipeline system drops strongly during the pipeline operation period. This can also be seen in Figure 28. Shortly after the pipeline is commissioned, there are early faults that can be deduced from building deficiencies. Then there is the main exploitation duration, which is stable. Towards the end of the pipeline operation, the faults are growing again in frequency, due to their obsolescence.

Statistical fault surveys usually focus on the last period of use. In order to forecast future fault rates for an area of a pipeline network, different forecasting models are available. The trend functions determine fault occurrence at this stage mainly depending on the age of the pipe elements. An extrapolation can be performed by linear, polynomial or exponential functions.

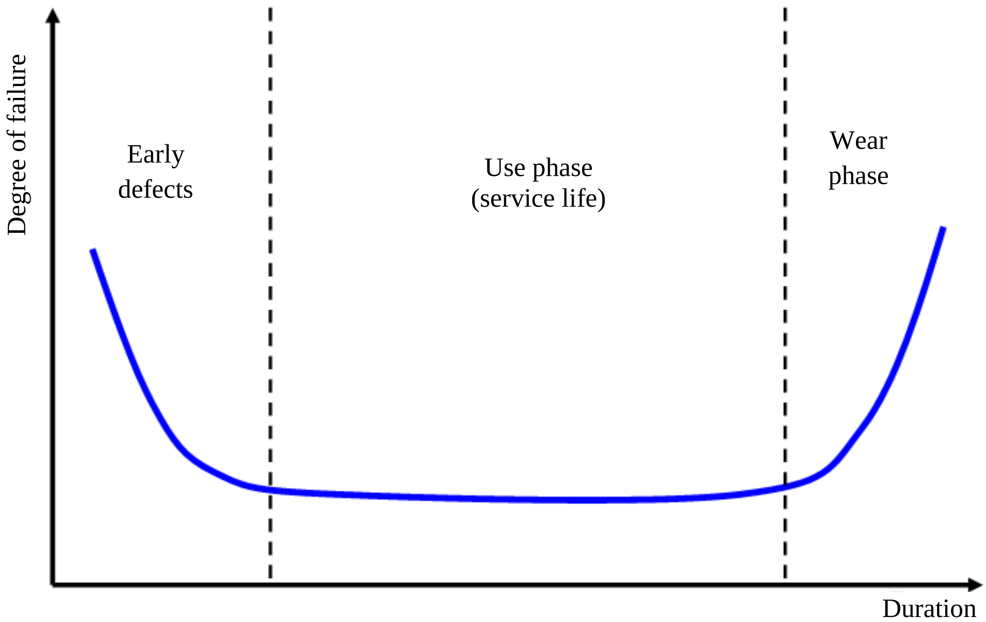


Figure 28. Curve of cases of faults in water pipelines during the period of use

The tendential function can be formulated after Shamir-Howard, 1979, as follows:

$$SR(t) = SR(t_0) \cdot e^{\alpha t} \tag{30}$$

where:

SR(t) is the number of faults or the rate of faults;

$SR(t_0)$ - initial value for the number of faults or the rate of faults at the beginning of the observation;

t - age of pipeline;

t_0 - initial moment;

α - constant regression coefficient for different pipeline groups.

This model of calculation leaves little space for consideration of other factors of influence over time, such as earth structure, construction activity.

More suitable for forecasting future faults are the survival models, among which we mention the Proportional Hazard Model (PHM)

$$SR(t,z) = h_0(t) \cdot e^{\beta_1 z_1 + \beta_2 z_2 + \dots \beta_n z_n} \qquad (31)$$

where:

z_i are explanatory factors (e.g. material, age, surrounding earth);

β_i - coefficients of regression.

$$h_0(t) = \lambda p(\lambda t)^{p-1} \qquad (32)$$

where:

p is a form parameter that determines whether $h_0(t)$ remains constant (p=1), increases (p>1) or decreases (p<1);

λ - parameters for classifying the event, so the fault occurrence at the t moment.

As can be seen from the computation relation, several explanatory factors will be analysed hereunder and introduced into the predicted fault rate. And the fault rate for the beginning of the observation will be adjusted according to the past events. A whole series of programs have been developed, among them CARE-W - Computer Aided Rehabilitation of Water Networks, developed in a European research project, that works with such survival models.

3.3.2. Forecast Using Survival Models

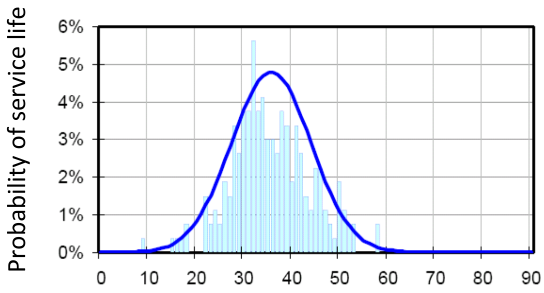
Over time, improvements to forecasting methods and techniques have been made by taking into account the assessments of the probability theory regarding the dynamic development of pipeline systems in the future. With the help of the probabilistic calculation, the future worsening of the pipeline condition must be foreseen so that the rehabilitation and allocation of financial funds for rehabilitation can be done before the serious damage to the pipeline system operating capacity.

The basis for such models is the record of time tracking of pipeline networks and the evaluation of the 0 moment of existing faults.

The inclusion of the research results before the 0 moment can provide information on previous development of faults in the pipeline network.

The entire pipeline system will now be divided into spatially or qualitatively delimited groups. The pipeline condition records, in individual pipeline areas or for different types of pipelines (e.g. cast iron pipes dating back the 1960s) will be systematized, including breakdown by fault categories. The worst possible fault of the observed one will serve as a standard for classification by categories, so that the remaining use time for that pipeline group can be deduced (Shultz J., 2007; Stein R., et al., 2006). The second hypothesis of the specialists is that, despite the fact that a pipeline belongs to a particular category, its durability can not be individually predicted, but the stability of the pipeline group follows a probabilistic distribution. This is illustrated by Figure 29.

The service life of each pipeline follows in this example Weibull's distribution. If these results accumulate over the service life, the survival function of the pipeline group is obtained. This gives the probability that at a *t* moment, a pipeline in the group is still intact. For different pipeline groups, survival curves with different slopes result. Statistically, uncoated cast iron pipes fail faster than double-walled PE pipes. Losses occur statistically earlier than a total breakage of the pipeline.



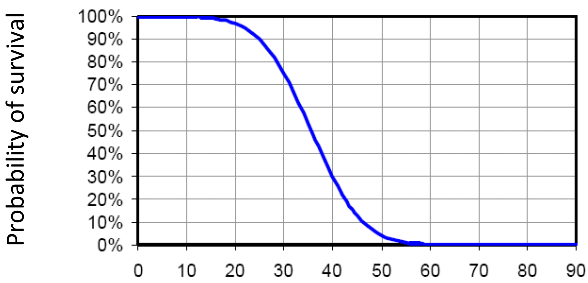


Figure 29. Statistical distribution of the service life of individual pipelines (left) and pipeline survival function (right) resulting from the Weibull's distribution

It can be considered that a defective and repaired pipeline has a probable survival distribution over one on which no interventions have been performed. This can be represented by the Markov chain, which iteratively comprises the changing state over a longer period of time. This model of technical calculation shows the forecast regarding the condition of individual pipeline types in the future. The condition will be expressed by the inclusion in the group of pipelines to a class of conditions. This is represented by Figure 30.

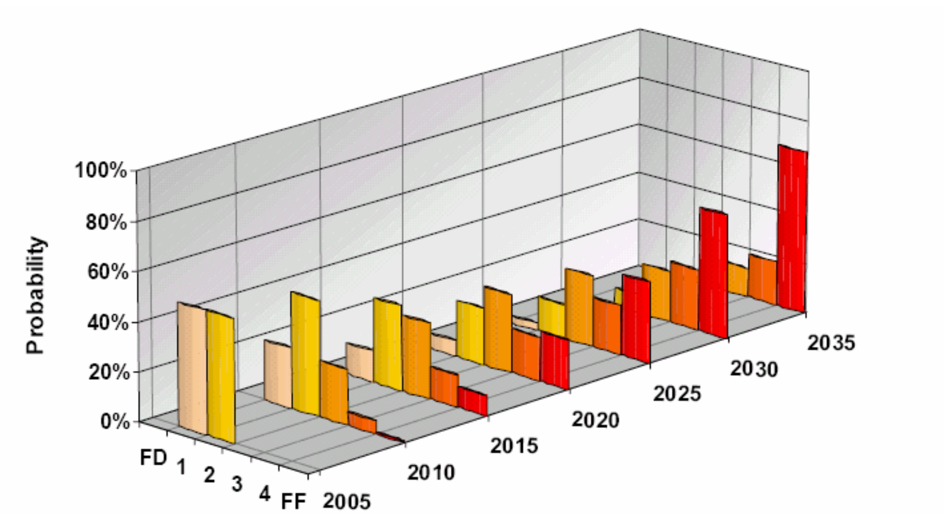


Figure 30. Future conditions of pipeline groups in the sense of a probability distribution

With the help of this forecast, it is possible to calculate how the condition of the pipeline will evolve and if to some extent through the rehabilitation efforts it will be directed in the opposite direction. The higher the annual rehabilitation costs, the better the condition of the pipeline system in the future. A sufficiently large short-term budget for rehabilitation can even lower the pressure of costs in the coming years. By comparing future investment costs with keeping the actual value, it can be seen that the sum of the resulting total costs decreases inversely in proportion to the investment in the pipeline network. The risk of a failure decreases regressively with the increase in investment because the probability of failure of the pipelines increases due to their aging throughout the whole system.

In the theoretical probability models the data is preserved as complete as possible in the present case and a probability distribution is accepted for forecasting a survival function for individual pipeline groups. From here, the investment needed to keep the system or improve it can be deduced.

It can be noticed that in the forecasting models based on the probability theory explained above, the models rely on individual instances of past failures. Recording all faults on pipe units at a given 0 time is not possible because the problem lies precisely in the fact that faults must be recognized. If it would be possible that faults are recognized at all times, then they might be remedied, which would be simpler than forecasting faults in the future. For the future, only the likely condition of the pipeline can be estimated.

For a pipeline group a probability distribution is determined - after Weibull, Gaussian or linear distribution. The chosen distribution will have a strong influence on the results, so there must be prior research on the pipeline at the base of the actual distribution.

In these models as well, pipeline network estimates vary subjectively, depending on the components.

3.3.3. Berliner Method: Combined Use of the Survival Function and the Settlement Method

In Berlin, electronic fault statistics have been prepared using the OptNet Software. It is a tool for collecting all available technical-hydraulic data, pipeline condition-oriented and financial data, for pipeline failures that allow for the development of an optimized rehabilitation strategy. For this, the materials were first divided into classes. There are 78 subgroups in Berlin, which can also be differentiated according to their age. By analysing the historical faults, a fault forecast is made in terms of pipeline classes for the respective year under review. Approximately 40 factors of influence will be used, such as time distribution of previous defects, earth aggression, earth type, load generated by circulation, pipe wall condition, and pipe sludging thickness. (Maler P., Ahrens J., 2009)

By fault ratios, for individual pipeline groups classified by nominal diameter and material, a fault function will be deduced:

$$S(f) = a_1 \cdot t^2 + a_0 \qquad (33)$$

where:

t is the age of the pipeline;

a_1, a_0 - parameters that will be iteratively calculated from the fault rate.

In the above case a_1 will be calculated in relation to a_0 after the following calculation relation:

$$a_1 = \frac{s - a_0}{t^2} \cdot \frac{Length}{1000} \quad (34)$$

The optimal duration of use of a pipeline in Berlin was determined by the minimum investment and repair costs. The remaining value of the first investment was represented by a depreciated value as a function of the duration of use. Repair costs are a progressive increasing function, dependent on the fault ratio (Figure 31). The optimum duration of use is up to the minimum sum of both functions (NUS Consult, 2009).

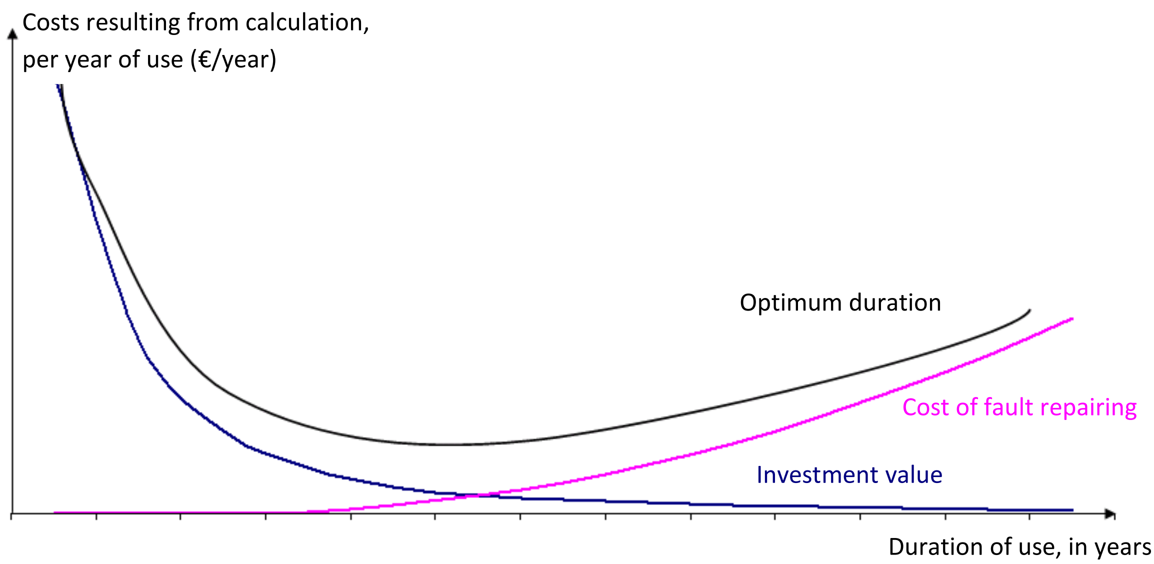


Figure 31. Evolution of costs during the service life and optimal duration of use

If a rehabilitation investment is to be made, the cost dependency of the new pipeline will be determined. The costs of the new pipeline are calculated from the investment costs and the average costs of repairs to the new pipeline. If existing pipeline costs are higher than average new pipeline costs, replacement is cost-effective.

According to the Berliner method, costs will not be determined by the method of calculation of the annuities, but by the updated value method. This means that all costs will be compared at the time of the investment. The average costs of future repairs will therefore be presumed at the ″present″ moment and their value in cash will be added to investment costs. (Roscher H., 2000)

In practice, these methods proved to be reliable: the number of pipeline faults predicted by the software deviates from 1997 to 2008 on average by only 3.7% of faults that actually occurred in a season. Based on the calculated risk of fault occurrence, the necessary renewal quotas per year and by network section were calculated, which is necessary to improve the pipeline condition. In Berlin, the increasing trend of faults has been possible to interrupt by a consistent rehabilitation strategy. The expected renewal quota is on average 30 km/year to keep the pipeline in good condition.

3.3.4. Proposed Method for Determining the Moment of Rehabilitation or Modernization (Aschilean Method)

As a result of the analysing of the methods presented above, it can be found that each of them has been applied at different times, related to the technological development and distribution network data at those times. It has to be critically noticed that the determination of the rate of economically acceptable faults can be subjective, so, in the absence of the budget, it can easily be argued that under the given conditions the level of the admissible economic fault rate must be set above.

In order to make decisions objectively and considering that none of the methods currently applied take into account the continuous water loss, which is an increasing cost element, it is introduced into the proposed calculation relation. In order to have a correct relationship between the depreciation of the investment and the growing expense, estimated for the entire duration of use, it is proposed that the depreciation be linear.

Hereunder, we propose a method for determining the optimal moment of rehabilitation or modernization, which takes into account previous observations; the two technological interventions being in a unitary coherence with certain types of procedures, as in Figure 32.

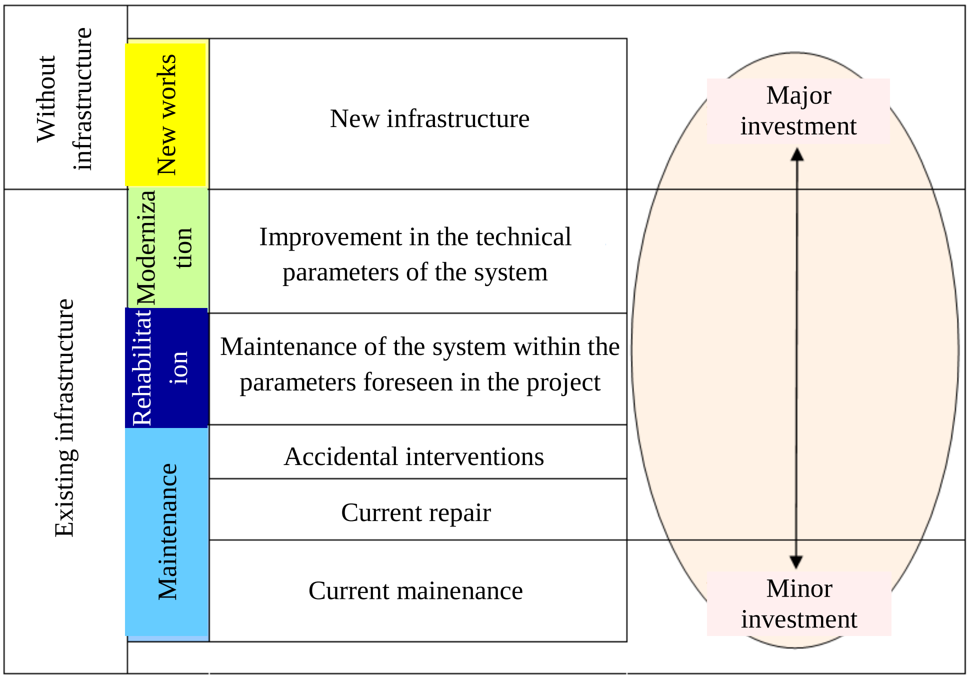


Figure 32. Rehabilitation and modernization in coherence with the various procedures in the field of water supply systems

At the core of the interest lies the maintenance of pipeline network operation capacity and cost reduction. The normal service life of an installation is often higher than the economically established normal service life. A water pipeline network must be in perfect working order, but when deciding on a rehabilitation strategy, consideration should also be given to economic aspects, making an overall assessment as to whether rehabilitation of the existing pipeline is appropriate or not.

It has been established that the probability of pipeline failure increases with aging, but also with the influence of external and internal factors.

The risk of pipe damage can theoretically be brought to near 0 faults / km, but with very high cost, economically unjustified. It is therefore appropriate to establish a balance between the costs of repairing and faults in the system and the costs involved in investments with the rehabilitation or modernization of the pipeline.

To calculate the depreciation value of the investment, the following calculation relation applies:

$$f(t) = v_i - t \cdot \frac{v_i}{t_a} \tag{35}$$

where:

v_i is the value of the depreciated investment;

t_a – normal duration of operation;

t – time.

For the graphical representation of the cost of repairs and system losses, one of the probabilistic methods of fault distribution described above or the like shall apply, adapted for water pipelines.

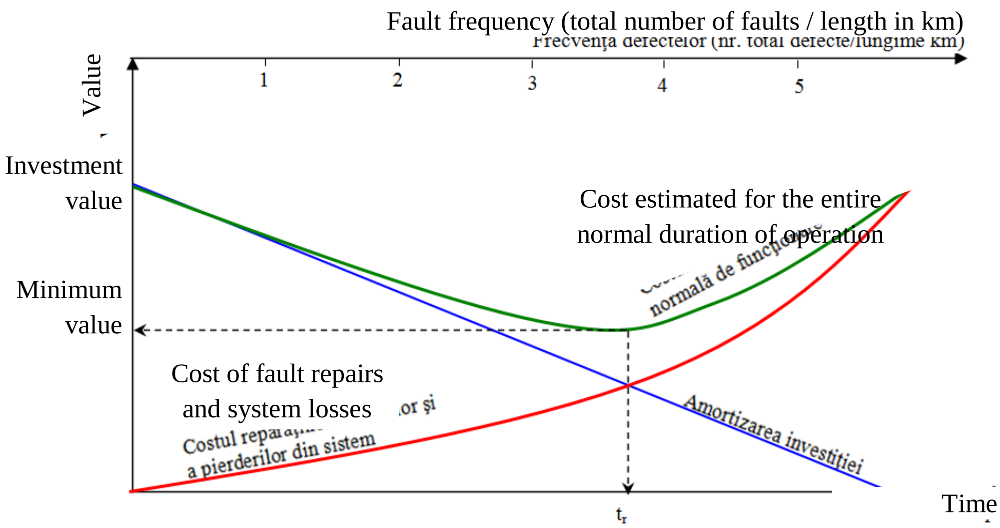


Figure 33. Choice of the optimal moment for rehabilitation of water pipelines

Estimated costs over the normal duration of operation are the result of the sum of the cost of fault repairs defects and system losses and the depreciation of the investment. The total value of these costs may be represented graphically in the form of a convex parabola.

The horizontal upper axis in Figure 33 presents a fault frequency scale showing that the optimal moment for the pipeline rehabilitation is achieved at a fault rate of n faults per km. This graph is representative for distribution pipelines, where Dn<400 mm and can be accepted to occur a number of n faults / km, given the low cost of their repair.

In the case of large diameter pipelines, the costs generated by faults, meaning that the direct, indirect and social costs, are very high. At the same time, the failure of these pipelines has far more serious implications for the consumer water supply safety. Due to these considerations it is proposed to approach a preventive management on the occurrence of faults.

When choosing the optimal moment it is necessary to take into account:

a) the maximum accepted threshold for the failure frequency per km/year, nmax being calculated with the following calculation relation:

$$n_{\max} = \frac{C_{TA}}{C_D} \tag{36}$$

where:

C_{TA} is the maximum cost of fault repairing, that is economically acceptable per year;

C_D - average cost per fault.

b) cost of losses in the system, considering the maximum permissible losses according to SR 1343/1:2006 to:

- 35% of the water distributed in the system, in the case of old systems;
- 22% for rehabilitated systems;
- 15% for new systems (less than 5 years).

System rehabilitation can also be done before the above threshold being reached, depending on the available funds and the return on investment, using annuity calculations or another similar method.

The proposed method thus shows that a continuous neglect of rehabilitation measures, in favour of higher short-term returns, has long-term negative effects on food safety, ecology and future costs.

3.4. Use of Multi-criteria Analysis Methods to Substantiate Decisions for Rehabilitation or Modernization of Water Distribution Systems

Making correct decisions is one of the most complex issues faced by those involved in the management and administration of installation infrastructure. Decision-making must be grounded with great accountability, using appropriate analysis tools and methods, such as multi-criteria methods.

The multi-criteria analysis simultaneously considers a variety of objectives in relation to the assessed investment. By using it, the investor will consider not only the economic and technical analysis, but also objectives such as social equity, environmental protection, etc.

Both the investor and the engineering designer have to choose the ″optimal″ solution from a multitude of alternatives that are available on the market. The investor will most certainly want the best materials and equipment with the smallest gauge, easy assembly, reliability and long service life, with long-term warranties and last but not least, at a minimum price.

In order to make a decision on the applicable solution, the multi-criteria analysis was developed in 1960. This is used for the comparative analysis of alternative projects or different criteria or objectives. With the help of the multi-criteria analysis, multiple objectives can be considered simultaneously, in complex situations.

The multi-criteria analysis is similar to the techniques used in the organizational development and information management systems.

Given that there is no perfect solution, the solution best suited to the investor’s needs must be chosen, being a compromise between all their requirements.

The solution to a multi-criteria problem can be found following two different approaches:

- by introducing restrictive / simplifying hypotheses in such a way that the problem can be reduced to a classical optimization problem - obviously, it has the disadvantage of a significant deviation from reality;

- by using a dedicated multi-criteria method based on models built partly on restrictive mathematical hypotheses, partly on information gathered from decision-makers.

Any multi-criteria analysis has as its main characteristic the formalization and modelling of the preparation of the decision. It has two decisive advantages:

- it improves the transparency of the decision-making process;
- it defines, specifies and underlines the responsibility of the person who makes the decision.

In general, multi-criteria analysis should be organized as follows:

- objectives must be expressed in measurable variables - they should not be redundant, but may be alternative;
- once the 'vector of objectives' is built, a technique must be found to aggregate information and make a choice; objectives must have a weight assigned reflecting their attributed relative importance;
- definition of the evaluation criteria - these criteria should refer to the priorities pursued by the different subjects involved or should refer to the particular aspects of the evaluation;
- impact analysis - this activity consists in analysing, for each of the chosen criteria, the effects it produces, and the results could be quantitative or qualitative;
- estimation of the effects of the investment expressed in the selected criteria; results that come from the previous stage are assigned a certain score;
- identification of the typology of the subjects involved in the investment and collection of the respective preferences (weight) given to the different criteria;
- aggregation of the scores of the different criteria based on the highlighted preferences - each score can be aggregated by giving a numerical evaluation score to the investment, comparable to other similar investments.

In the context of the foregoing, case studies have been carried out on the water distribution network of the City of Cluj-Napoca, Romania - presented hereunder.

3.4.1. Analysis on Setting Priorities for the Rehabilitation of Water Distribution Networks

For this research direction, for the ranking in priority in terms of the rehabilitation of the water distribution network, the use of multi-criteria methods, namely the Leader method, have been proposed. This study is supported by the paperwork: **Ioan Aşchilean,** Gheorghe Badea, Ioan Giurca, George Sebastian Naghiu, Florin George Iloaie, *Determining Priorities Concerning Water Distribution Network Rehabilitation.* Energy Procedia 112 (2017), EENVIRO 2016, Bucharest, Romania. Ed. ELSEVIER. ISSN 1876-6102, pp. 27 – 34.
DOI: https://doi.org/10.1016/j.egypro.2017.03.1055.

a) Context. It is necessary to rehabilitate pipes of the Romanian water supply systems due to the following reasons:

- works related to water distribution networks started at the end of the 19th century and as a result the water distribution networks are old;

• water losses in water distribution networks are up to 30 – 50%, an excessive percentage if one takes into consideration the important of drinking water at global level;
• emergence of new pipe manufacture and installation technologies for water networks;
• digital-controlled operation is not recommended for classic water supply systems.

Water distribution network is part of the water supply system consisting of the pipe network, fittings and complementary buildings, which assure water distribution to consumers (Aşchilean I., 2014).

Table 18. Software products used in the field of rehabilitation of water distribution networks (Large A., et al., 2015)

Software name (country)	Models				Software name (country)	Models			
	M1 deterioration	M2 risk	M3 economic	M4 decision		M1 deterioration	M2 risk	M3 economic	M4 decision
W-PIPER (USA)	X				Grille MS7 (F)				X
D-WARP (CDN)	X				NESSIE curve (AUS)			X	X
Q-WARP (CDN)	X				Patrimony expert (F)			X	X
I-WARP (CDN)	X				GAnetXls (GB)			X	X
T-WARP (CDN)	X				CARE-W-ARP (F)		X	X	X
PARMS priority (AUS)	X				SIROCO (F)		X	X	X
CARE-W-PHM (F)	X				WiLCO (GB)		X	X	X
CARE-W-Poisson (F)	X				PARMS planning (AUS)		X	X	X
CARE-W-NHPP (N)	X				MOSARE (F)	X	X		X
Casses (F)	X				Vision (F)	X		X	X
PRMS (USA)	X				KANEW (D)	X		X	X
CARE-W-RelNet (CZ)		X			PiReM Drinking Water (A)	X		X	X
CARE-W-FailNet (F)		X			PREVOIR Canalisation (F)	X	X	X	X
Criticité (F)		X			Aware-P (N) (P)	X	X	X	X
SynerGEE Rel. A. M. (USA)		X							

b) Present state of research in the world. The methods used worldwide for the selection of the technical solution for the rehabilitation of water distribution systems focus on the following main areas: predictive methods on the deterioration of pipes (Andreou S A., 1986), models for risks assessment (Marlow D, et al., 2015), economic analysis and financial analysis (Walski T.M., 1982; Elnaboulsi J, Alexandre O., 1998) as well as the multi-criteria methods.

Out of the multi-criteria methods used worldwide for substantiating the selection of technical solutions regarding the water distribution networks, one may consider: the AHP method (Ahmed Al-Aghbar, 2005), the Electre III method (Tlili Y, Nafi A., 2012) the Promethee method (Tlili Y, Nafi A., 2012; Fontana M.E., et al., 2013) , and the multi-attribute aggregation function method - MAVM (Scholten L., et al., 2014).

Several software products were designed in order to shorten the time required for substantiating the selection of technical solutions for the rehabilitation of water distribution systems. Thus, table 18 presents a synthesis of these software products used in the field of rehabilitation of water distribution networks. A. Large and his collaborators (Large A., et al., 2015) performed the ranking of these software products in four categories, namely: the model M1 for assessing the deterioration of pipes, the model M2 for assessing the risks, the model M3 for economic analysis and financial analysis, and the model M4 for the multi-criteria analysis.

c) Present state of research in Romania. In Romania there were a number of books (Aşchilean I., 2014), as well as guidelines (MDRAP - GP127-2014), on the rehabilitation of pipelines within the water supply systems.

d) Purpose of the study. In order to determine the priorities in terms of the rehabilitation of the water distribution network, the use of multi-criteria methods was proposed, and out of the multitude of multi-criteria methods, in this case it was proposed the use of the Leader method. In Romania, multi-criterial methods are well known, but few have studied their use in the field of construction installations.

e) Contributions. The study is useful for substantiating the decisions on the selection of the technical solutions regarding the water distribution systems.

3.4.1.1. Materials and methods

a) Materials

Along time, one used several types of materials for making the pipes of the water supply systems. One started with the stone and wood, later on one continued with prefabricated wooden items (staves), stone (masonry) and bricks (fitted in with lime and then with cement), lead and copper, and during the last 200 years people used the iron, first in the form of cast iron and afterwards in the form of steel. In the 20^{th} century, the plastics and composite materials industry developed (MDRAP - GP127-2014).

In table 19 it was synthetically presented the types of pipes traditionally used for water supply systems in Romania, and in figure 34 it was presented the total number of pipes of the water supply systems from Romania, in 2001 (Aşchilean I., 2014).

According to figure 34 it results that in 2001, in Romania, most pipes used for water supply systems were made out of asbestos cement, namely 46% of the pipes.

Table 19. Types of pipes traditionally used for water supply systems in Romania (Aşchilean I., 2014; MDRAP - GP127-2014; MDRAP - GP133-2013)

No.	Name of material	Nominal diameter	Nominal pressure	Delivery length	Lifetime	Method of connection
		mm	bar	m	years	
1	Grey cast iron/high pressure cast iron/second casting	80 ÷ 900	4; 6; 10; 16	4; 6	100	- flanged; - with plug and sealing with tarred rope and melted and pressed lead; - connection with fittings.
2	Carbon steel	up to 1400	up to 100	6; 12	30 ÷ 40	- by welding; - flanged.
3	Asbestos cement	50 ÷ 600	4; 6; 10	4; 5; 6	50	- with a sleeve made of asbestos cement and rubber gaskets; - with sleeve and metallic flanges (also known as Gibault couplings).
4	Prestressed concrete (PREMO)	400 ÷ 1400	2; 4; 6; 10	4; 5; 6	30 ÷ 40	- with plug and rubber ring.
5	Pipes made of plastic tubes, PEHD, PVC	50 ÷ 2400	2.5; 4; 6; 10; 16	- coils 100 m; - pipe 6; 12	50	- with prefabricated sleeve; - by butt welding; - with dismountable joints (at small diameters).
6	Pipes made of PGRP/ *sand-filled* and *glass-fibre reinforced* polyester tubes	200 ÷ 600	2; 4; 6; 10	6; 8	50	- with jack socket on the tube, the jack socket being made from the same material; - with elastomeric rubber rings.
7	Ductile (nodular) cast iron, third casting iron	80 ÷ 3000	up to 10	6	100	- flanged; - with plug.

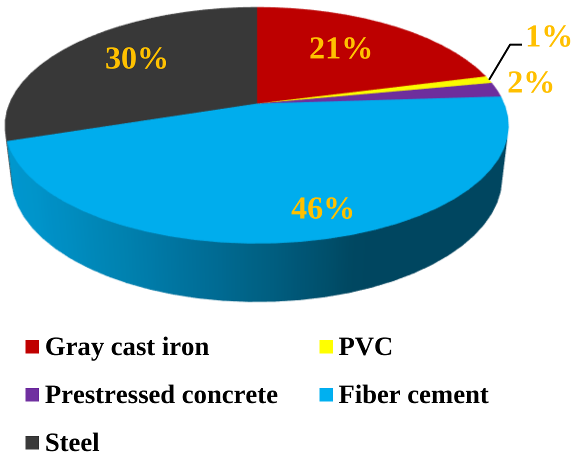


Figure 34. Total number of pipes in Romania in 2001 (Aşchilean I., 2014)

b) Methods

In order to determine the priorities in terms of the rehabilitation of the water distribution network, the use of multi-criteria methods was proposed, namely of the Leader method.

Stages to be completed in the case of Leader method are the following:

Step 1**:** Establishing the decision alternatives A = [*Ai*], where i = 1...n, n - number of alternatives.

Step 2**:** Establishing the decision criteria C = [*Cj*], where j = 1...m, m - number of criteria.

Step 3**:** Assessing each *Ai* alternative considering the *Cj* criterion, based on a matrix of performance P = [*aij*] (Dobre I., Bădescu A.V., 2002).

Step 4**:** Calculation of utilities and filling in the utility matrix. As there are several decision-making criteria, and therefore performances that might be expressed using various measuring units, one may use the utility to measure the extent to which one alternative is preferable to another one. So, one must transform all the performances in utilities, in order to correctly prioritize the alternatives.

Depending on the nature of the criteria, the utilities will be calculated according to the following formulas:

Maximizing criteria:

$$uij = \frac{aij - a\min\ j}{a\max\ j - a\min\ j} \qquad (37);$$

Minimizing criteria:

$$uij = \frac{a\max\ j - aij}{a\max\ j - a\min\ j} \qquad (38);$$

where: *uij* represents the usability of the *i* alternative according to the *j* criterion; *amax j* - the maximum performance obtained by the analyzed alternatives, according to the *j* criterion; *amin j* - the minimum performance obtained by the analyzed alternatives, according to the *j* criterion; *aij* - the performance obtained by the *i* alternative according to the *j* criterion.

One utility corresponds to each performance (Petca I., 2003). The usability shall take values comprised in the [0, 1] range (Naghiu G S, Giurca I. , 2015).

After calculating of the utilities, one shall write them down in a matrix.

Step 5**:** Preparing the matrix of dominance for each decision-making criterion. On the basis of the utilities one determines the dominance of alternative “*Aj*” towards the alternative “*Ai*” using, for this, the calculation formula (39), and results shall be transcribed in a matrix of dominance for each decision-making criterion.

$$dij = \begin{cases} 2, Aj > Ai \\ 1, Aj = Ai \\ 0, Aj < Ai \end{cases} \qquad (39).$$

Step 6**:** One calculates the total dominance matrix as a sum of determinant matrices from the previous step (Electre, 2013), using a formula such as:

$$MDT = \sum MDj \qquad (40);$$

in which: *MDT* represents the total dominance matrix; *MDji* - dominance matrix related to criterion *j*.

***Step 7*:** One calculates the total dominance vector, whose elements are determined by adding up the variables taken from the total dominance matrix line (Electre, 2013).

***Step 8*:** One shall prioritize the alternatives depending on the corresponding values from the total dominance vector (Electre, 2013). Obviously, the alternative that obtained the highest score within the total dominance vector shall rank on the first place.

3.4.1.2. Case study, results and discussions

a) Case study

Then it presented a case study on the rehabilitation of the drinking water distribution network in Cluj-Napoca, Romania. The rehabilitation of the drinking water distribution system in Cluj-Napoca was required due to high water losses occurred in the water distribution networks. Out of the many methods of selecting the alternatives regarding the rehabilitation of water distribution network we selected the multi-criteria methods, and out of them we selected the Leader method.

For this, one shall take the following steps:

***Step 1*:** Determining the decision-making alternatives. One went out in the land and made the inventory of the types of existent pipes, and the conclusion was that the water distribution network was 479 km long, and the nominal diameters ranged between 50 mm and 700 mm. The network is made of various materials, depending on the knowledge and the technology available at the time when the works were performed, namely grey cast iron, ductile cast iron, sand-filled and glass-fibre reinforced polyester, asbestos cement, steel, prestressed concrete and polyethylene (Aşchilean I., 2014).

On this basis one built the matrix of decision-making alternatives (see table 20).

***Step 2*:** Determining the decision-making criteria. Further on, one identified the criteria based on which one shall select the type of pipes to be rehabilitated first.

These criteria are the following: ductile cast iron, grey cast iron, polyethylene, prestressed concrete, fibre cement and steel.

Table 20. The set of alternatives (Aşchilean I.,2014)

No.	A_i	Alternative name
1	*A1*	Ductile cast iron
2	*A2*	Grey cast iron
3	*A3*	Polyethylene
4	*A4*	Prestressed concrete
5	*A5*	Fibre cement
6	*A6*	Steel

Table 21. The set of decision criteria (Aşchilean I., 2014)

No.	C_j	Criterion name	M.U.	Nature
1	C_1	Water loss	%/km	maximization
2	C_2	Pipe length	m	minimization
3	C_3	Pipe age	years	maximization
4	C_4	Rehabilitation cost	notes	maximization

Also, for each criterion, one established whether the optimization shall be made by maximization or by minimization. Based on this, we built up the decisional criteria matrix (see table 21).

b) Results and discussions

Step 3: Filling in the matrix of performances. After determining the set of decision-making alternatives and the set of decision-making criteria, one identifies the performances corresponding to the decision-making alternatives and the decision-making criteria, and then one makes the matrix of performances (see table 22).

Step 4: Calculating the utilities and filling in the utility matrix. Pursuant to the information from table 22 and using the calculation formulas (37) and (38), one obtained the partial utilities (see table 23).

Table 22. Matrix of performances (Aşchilean I., 2014)

A_i	Alternative name	*C1*	*C2*	*C3*	*C4*
A1	Ductile cast iron	3	14	9	5
A2	Grey cast iron	17	180	67.5	5
A3	Polyethylene	6	140	6	7
A4	Prestressed concrete	8	10	53.5	5
A5	Fibre cement	37	67	52	7
A6	Steel	29	68	51.5	6

Table 23. Matrix of partial utilities.

A_i	Alternative name	*C1*	*C2*	*C3*	*C4*
A1	Ductile cast iron	0.00	0.98	0.05	0.00
A2	Grey cast iron	0.41	0.00	1.00	0.00
A3	Polyethylene	0.09	0.24	0.00	1.00
A4	Prestressed concrete	0.15	1.00	0.77	0.00
A5	Fibre cement	1.00	0.66	0.75	1.00
A6	Steel	0.76	0.66	0.74	0.50

Water losses (criterion *C1*) were determined by measurements performed for the water supply system of Cluj-Napoca Municipality.

The price for the rehabilitation of the pipes belonging to the water supply system (criterion *C4*) was estimated using school grades, using a scale of grades ranging from 1 to 7.

Based on the data from table 22, were elaborated figure 35 and figure 36.

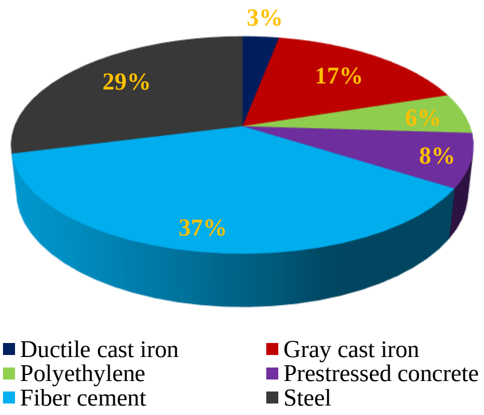


Figure 35. Water losses weight.

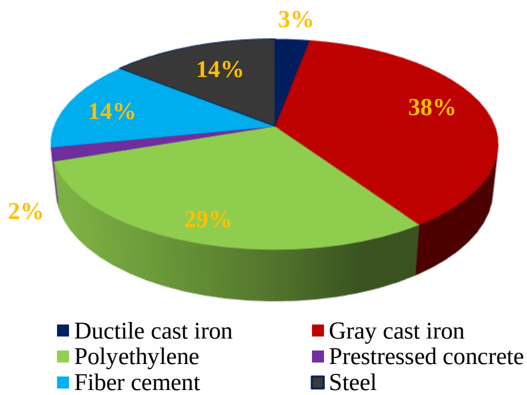


Figure 36. Pipe length weight.

From table 22 and figure 35 it results that water losses through water distribution networks with pipes made of asbestos cement are superior to the maximum acceptable losses specified in Romanian Standard 1343-1:2006, namely 35%.

Step 5: Further on, based on the utilities, one determined the dominance of the alternative "*Aj*" as opposed to the alternative "*Ai*" using for this the calculation formula (39), and the results were written in a matrix of dominance for each decision-making criterion:

MD Water loss =

2	0	0	0	0	0
2	2	2	2	0	0
2	0	2	0	0	0
2	0	2	2	0	0
2	2	2	2	2	2
2	2	2	2	0	2

MD Pipe length =

2	2	2	0	2	2	2
0	2	0	0	0	0	0
0	2	2	0	0	0	0
2	2	2	2	2	2	2
0	2	2	0	2	1	0
0	2	2	0	1	2	0

MD Pipe age =

2	0	2	0	0	0
2	2	2	2	2	2
0	0	2	0	0	0
2	0	2	2	2	2
2	0	2	0	2	2
2	0	2	0	0	2

MD Rehabilitation cost =

2	1	0	1	0	0
1	2	0	1	0	0
2	2	2	2	1	2
1	1	0	2	0	0
2	2	1	2	2	2
2	2	0	2	0	2

***Step 6*:** We shall calculate the total dominance matrix as a sum of the determinant matrices from the previous step (Electre, 2013), basically we apply the calculation formula (40), and thus the total dominance matrix results, and it is marked MDT.

***Step 7*:** One calculates the total dominance vector, whose elements are determined by adding up the variables taken from the total dominance matrix line, noted VDT (Electre, 2013).

MDT =

8	3	4	1	2	2
5	8	4	5	2	2
4	4	8	2	1	2
7	3	6	8	4	4
6	6	7	4	8	7
6	6	6	4	1	8

VDT =

20
26
21
32
38
31

***Step 8*:** One prioritizes the alternatives depending on the corresponding values within the vector of total dominance (see table 24 and figure 37) (Electre, 2013).

Table 24. Ranking of alternatives.

No.	A_i	Alternative name	Scoring	Place
1	*A1*	Ductile cast iron	20	6
2	*A2*	Grey cast iron	26	4
3	*A3*	Polyethylene	21	5
4	*A4*	Prestressed concrete	32	2
5	*A5*	Fibre cement	38	1
6	*A6*	Steel	31	3

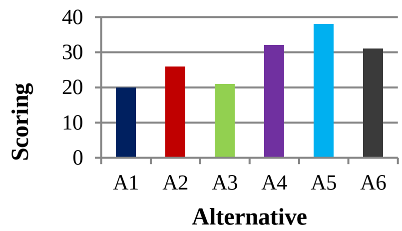


Figure 37. Ranking of alternatives.

From table 24 and figure 37, it results that alternative *A5*, namely the pipes made of asbestos cement, ranked on the 1st place, and the alternative *A4*, namely the pipes made of prestressed concrete, ranked on the 2nd place.

3.4.1.3. Conclusion

The result of this study shows that the rehabilitation of water distribution network in Cluj-Napoca, Romania has to begin with the substitution of asbestos cement pipes.

On the one hand, on those sections of the water distribution network made of asbestos cement pipes one recorded the most important water losses, and on the other hand, nowadays it is forbidden to use asbestos as a material for drinking water supply systems.

For the same case study, in work (Aşchilean I., 2014) it was used the Electre I method, and after analysing the results, the alternative *A5* was declared the winner. To conclude, both in accordance with the Leader method and in accordance with the Electre I method, we recommend rehabilitating the pipes made of asbestos cement first of all.

If one uses many decisional criteria, the problem solving becomes quite a difficult process, and in order to solve it more quickly we recommend the use of software or the realization of the computations using Excel computation sheets.

3.4.2. Choice of the Optimal Technology for the Rehabilitation of Pipelines in Water Distribution Systems

In order to choose the optimal rehabilitation technology of the water distribution network, the multi-criteria analysis methods, namely the AHP method, have been used. This study is supported by the paperwork: **Ioan Aşchilean,** Gheorghe Badea, Ioan Giurca, George Sebastian Naghiu, Florin George Iloaie, Choosing the Optimal Technology to Rehabilitate the Pipes in Water Distribution Systems Using the AHP Method. Energy Procedia 112 (2017). Sustainable Solutions for Energy and Environment, EENVIRO 2016, 26-28 October 2016, Bucharest, Romania. Ed. ELSEVIER. ISSN 1876-6102, pp. 19 – 26. DOI: https://doi.org/10.1016/j.egypro.2017.03.1109.

a) Context. In 2007, according to a report released by the National Statistics Institute, in Romania drinking water losses represented 40.9 % (Aşchilean I., 2014).

According to Romanian Standard 1343-1:2006, acceptable water losses in the existent distribution networks must not exceed 35 %, and in case of rehabilitated pipes, water losses must not exceed 22 %, while in case of networks newer than 5 years water losses must not exceed 15 % (Aşchilean I., 2014).

In this context, in Romania, one should make a priority out of replacing water networks, due to the fact that their normal lifespan was exceeded, and on the other hand water losses greatly exceed the accepted limits specified in Romanian Standard 1343-1:2006.

In order to select the technologies for the rehabilitation of the water supply systems one may use multi-criteria analysis. Out of the various multi-criteria methods available, in this work it was proposed the use of AHP method.

b) Present state of research in the world. Among the most relevant papers published internationally on the rehabilitation of pipelines of water supply systems of settlements, are the following (Shamir U., Howard Ch.D.D., 1979; Kleiner Y., et al., 2001; Park S.W., Loganathan G.V., 2002; Giustolisi O., et al., 2006).

The Analytic Hierarchy Process (AHP) was developed by Thomas L. Saaty (1977, 1980, 1982, 1988, 1995), as a method of analyzing decisions by structuring the decision's components (Bana C.A., Vansnick J-C., 2008; Turcksina L., et al., 2011).

The applicability of this method was successfully proved in decisional problems pertaining to the technical and economical field, namely for: the selection of the supplying variants, the selection of the investment projects, the selection of certain types of equipment that are to be bought through the modernization project, the division of the financial resources based on certain budgets, and so on (Dobrea R., 2006).

c) Present state of research in Romania. Although in Romania there were studies related to the rehabilitation of water distribution networks, until now, in the scholarly literature, there is no synthetic approach (Aşchilean I., 2014).

The AHP method proved to be one of the most applicable methods of multi-criteria analysis (MCA) and it is mentioned in most of the MCA manuals and guides (Roman M., 2012).

d) Purpose of the study. In this work it was intended to solve in a scientific way, using the AHP method, a problem faced by companies in the field of water supply in towns, and choosing the technology of pipe rehabilitation in water distribution systems.

e) Contributions of the study. The method presented may be used for the feasibility studies elaborated for water distribution networks.

3.4.2.1. Materials and methods

a) Materials

In order to perform the rehabilitation of the water distribution networks, one may use the classic methods with trenches or the trenchless technologies.

Some of the trenchless technologies widely used for the rehabilitation of water distribution systems are: Compact-Pipe, Sliplining, Subline, CIPP, GFK-Liner, Swagelining, Rolldown, Short Liner, Berstlining, Pilot Pipe and Microtunneling.

The technologies currently used for the rehabilitation of water distribution systems are the ones presented in table 25.

Table 25. Matrix of alternatives.

Alternative's symbol	Alternative name	Alternative's symbol	Alternative name
A1	Compact Pipe	*A6*	GFK Liner
A2	Slipline	*A7*	Berstlining
A3	Subline	*A8*	Pilot Pipe
A4	Swagelining	*A9*	Microtunneling
A5	CIPP (Cured in place pipe)	*A10*	Open cut

Up to 50 years ago, most of the pipes were placed in tranches while nowadays most of the works are performed using the trenchless technologies.

The water distribution systems require rehabilitation due to both damages and poor water quality (Aşchilean I., 2014).

b) Methods

In order to select the technologies for the rehabilitation of the pipes from the water distribution systems one shall use the AHP method. In our opinion, using the AHP method involves 11 steps, as following:

Step 1**:** Problem identification. In this step we shall identify the practical issue that has to be solved.

Step 2**:** Establishing the decision-making criteria. Here we shall identify the criteria (objectives) that shall be used for the selection of the alternatives, while the data shall be written in the decision criteria matrix C = [*Cj*]. Where j = 1...m, represents the number of criteria (Naghiu G.S., et al., 2016).

Step 3**:** Establishing the decision-making alternatives. In this stage, the set of alternatives that can be applied shall be identified, while the data shall be written in the alternatives matrix A = [*Ai*]. Where i = 1...n, represents the number of alternatives (Naghiu G.S., et al., 2016).

Step 4**:** Determining of relative weight of criteria by comparing the criteria in pairs.

In this step we shall determine the relative weight of the criteria c = [*cij*], and their importance in taking the decision (Prejmerean V., 2015), respectively. In order to determine the relative weight of the criteria, we shall perform a pairwise comparison.

The pair comparisons are made by the decision makers who assess the pairs subjectively (initially based on verbal assessments, such as “equally important”, “slightly more important”, “absolutely more important”, and so on, and then by assigning values on a scale from 1 to 9, which represents the importance degree of one attribute towards another attribute). If the comparison between two criteria is reversed, then the importance value equals the reverse of the direct comparison value (Dobrea R., 2006).

It was used the Thomas L. Saaty scale for this purpose. For further details, please see table 26.

Table 26. Fundamental scale of Thomas L. Saaty (Saaty T L., 1980)

Values/Rates	Description	Values/Rates	Description
1	Equally preferred or it does not matter (equal importance)	6	Strongly preferred towards obviously preferred
2	Equally preferred, but with certain moderate differentiation tendencies	7	Obviously preferred
3	Moderately preferred	8	Obviously preferred towards extremely preferred
4	Preferred towards strongly preferred	9	Extremely preferred
5	Strongly preferred		

Then we fill in the data into a square matrix with “*m*” elements, where “*m*” is the number of decisional criteria. The table shall contain the values resulted from the comparison between the criteria. Then, by performing the calculations for the ratios 1/2…1/9, the data shall be filled in a new matrix of pairwise comparisons between criteria. Also, this matrix shall contain the total on every column, which is calculated based on the following formula:

$$Sj = \sum_{j=1}^{m} cji \tag{41}$$

Step 5**:** Normalizing the comparisons between criteria. The normalized values ''*nij*''are obtained by dividing the value obtained as a result of comparison with the total value of their column (Dobrea R., 2006), calculation based on the following formula:

$$nij = \frac{cij}{Sj} \tag{42}$$

Then, the pairwise comparison between criteria is transformed in weights, these weights being calculated as an average of the normalized values on each row, based on the formula (43), as follows:

$$kj = \frac{\sum_{j=i}^{m} nij}{m} \tag{43}$$

where: *kj* represent the importance coefficients (weights) of the decision criteria.

Considering that we use normalized values, the following condition must be observed:

$$\sum_{j=1}^{m} kj = 1 \tag{44}$$

Step 6**:** Determining the consistency factor of the decision criteria matrix. In order to determine the consistency factor of the matrixes, we shall perform the following steps (Dobrea R., 2006):

i) Determining the vector of priorities - λmax. The vector of priorities is calculated as an average of multiplication between the matrix of relative weights of decision criteria and the average weight of decision criteria, based on the formula (45), as follows:

$$\lambda \max = \sum_{j=1}^{m} \frac{(c \cdot k)j}{m \cdot kj} \tag{45}$$

where: $(c \cdot k)j$ represent the elements of the matrix vector determined as a result of multiplying the "*c*" matrix with "*k*" vector (Dobrea R., 2006).

ii) Establishing the average stochastic uniformity coefficient. The average stochastic uniformity coefficient, marked ''*R*'', is determined depending on the rank of the analysed matrix, marked ''*m*'', based on the following table 27 (Dobrea R., 2006):

Table 27. Values of the average stochastic coefficient depending on the rank of the matrix (Winston W.L., 1994)

(Order of matrix)	1	2	3	4	5	6	7	8	9	10
R	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

iii) Determining the uniformity coefficient. The uniformity coefficient "*CI*" is calculated based on the formula (46), as follows:

$$CI = \frac{\lambda \max - m}{m-1} \quad (46)$$

iv) Determining the consistency factor of the matrixes. The consistency factor of matrixes "*CR*" is calculated based on the formula (47) and formula (48), as follows:

$$CR = CI, \text{ if } m = 1 \text{ or } 2; \quad (47)$$

$$CR = \frac{CI}{R}, \text{ if } m > 2 \quad (48)$$

When determining the consistency relation, one takes into account the following rule: if $CR < 0.10$, than the matrix is considered to be consistent, namely the vector of the weights is well determined.

Step 7**:** Determining the relative weight of the alternatives based on criteria. The procedure of comparing the alternatives is identical with the one related to criteria, and the results are recorded in a square matrix with "*m*" elements, where "*m*" is the number of alternatives. The number of matrixes is equal to the number of criteria (Dobrea R., 2006).

Step 8**:** Normalizing the comparisons between the alternatives in relation with each decisional criterion.

Practically, step 9 supposes the transformation into weights of the comparisons between alternatives, in relation with each criterion. The normalized values are obtained by dividing the value obtained out of the comparison to the total of the column to which it belongs (Dobrea R., 2006).

Step 9**:** Filling in the performance matrix, where the performance of the alternatives shall be identified for each criterion, and the data shall be written in the performance matrix P = [*Pij*] (Naghiu G.S., et al., 2016).

Step 10**:** Determining the total value for the priority of each alternative. In this step we shall multiply the weight of each alternative related to each criterion with the weight of each criterion and then we calculate their sum (Dobrea R., 2006):

$$Pi = \sum_{j=1}^{m} pij \cdot kj \quad (49)$$

where: *Pi* represent the total value for the priority of each alternative; *pij* – the weight of each alternative related to each criterion.

Considering that we use normalized values, the following condition must be observed:

$$\sum_{i=1}^{n} pij = 1 \tag{50}$$

Step 11**:** Making the decision. The optimum alternative is the one for which the sum of the multiplications between the weight of each alternative and the weight of each criterion has the highest value:

$$Aopt = \max \sum_{j=1}^{m} pij \cdot kj \tag{51}$$

3.4.2.2. Case study, results and discussions

a) Case study

In order to exemplify this, it shall present a case study concerning the rehabilitation of a drinking water distribution network from Cluj-Napoca Municipality, and as a method of determining the priorities concerning the rehabilitation of the water distribution network it shall use the AHP method.

Considering the important water losses from the water distribution system of Cluj-Napoca Municipality, one must set a rehabilitation and modernization plan, and when elaborating such a plan one must take into account the lack of homogeneity of the system (Aşchilean I., 2014).

Step 1**:** Problem identification. The purpose of this study is to select the optimum technology for the rehabilitation of the pipes from the domestic water supply system in Cluj-Napoca, Romania.

Table 28. The set of decision criteria.

No.	Criterion	Name of criteria	Type	Description
1	*C1*	Diameter of the pipe	maximized	It is advisable to select that alternative that can be used for the entire range of pipes used in water distribution networks.
2	*C2*	Length of the pipe	maximized	It is advisable to select that alternative that can be used for the longest possible pipelines.
3	*C3*	Period of time required for installation	minimized	It is preferable the installation to be as quick as possible.
4	*C4*	Lifespan ratio between the rehabilitated pipe and the not rehabilitated pipe	maximized	The lifespan of the rehabilitated pipe must be higher than the lifespan of the replaced pipe.
5	*C5*	Pressure losses	minimized	The pressure losses should be as low as possible.
6	*C6*	Price	minimized	The price for replacing the pipes should be as low as possible.
7	*C7*	Installation conditions	minimized	The alternative should not set special installation conditions.

Step 2**:** Determining the decision criteria. Identifying the decision criteria C = [*C1*, *C2*, ..., *Cm*], based on which we shall determine the performance of alternatives (Prejmerean V., 2015). For the case study analysed in this study we shall use seven decision criteria, as presented in table 28.

***Step 3*:** Determining the alternatives. In this step we shall determine the decision alternatives A = [*A1, A2, ..., An*] (Prejmerean V., 2015).

In order to establish the optimal technology of pipe rehabilitation in water distribution systems, initially the existing technologies on the market must be analysed and the ones compatible with the specific demands of the project must be established, followed by their ranking.

After a market analysis, in this study, detailed information about only 10 rehabilitation technologies, among the most representative ones, were chosen and obtained, specified as follows table 25.

b) Results and discussions

***Step 4*:** Determining of relative weight of criteria by comparing the criteria in pairs. In Step 4 we shall determine the relative weight of the seven decision criteria as compared to the next upper hierarchy rank, namely the goal of the study.

In the table 29 we presented the values of the comparisons between criteria, using the fundamental scale of Thomas L. Saaty (see table 26).

On the matrix' diagonal one assigns the value 1, because by comparing a criterion with itself one obtains the same comparison, namely the value 1 (Constantin S.L., Constantin B.V., 2010).

In order to fill in the entire matrix, one must note the following: if the criterion *C2* is third times more preferred than the criterion *C3*, then the criterion *C3* is 1/3 times less preferred than criterion *C2*. Thus, if the criterion *C2* receives the mark 3, then the criterion *C3* shall have the mark 1/3.

Table 29. Values of the comparisons between criteria.

	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
C1	1	1/3	1	1/3	1/5	1/5	1/3
C2	3	1	3	1	1/3	1/3	1
C3	1	1/3	1	1/3	1/5	1/5	1/3
C4	3	1	3	1	1/3	1/3	1
C5	5	3	5	3	1	1	3
C6	5	3	5	3	1	1	3
C7	3	1	3	1	1/3	1/3	1

Then we shall complete the matrix of pairwise comparisons of criteria based on data taken from the table 29, and the totals corresponding to each column are calculated based on formula (41).

***Step 5*:** Normalizing the comparisons between criteria. Then, the pairwise comparison between criteria is transformed in weights based on the formula (42) and formula (43), and the final result is presented in table 30. As one can see in table 30, the sum of columns equals to 1, hence the condition required by formula (44) is observed.

***Step 6*:** Determining the consistency factor of the decision criteria matrix. We have seven decision criteria in this case study, then according to table 27, if $m = 7$ then $R = 1.32$.

We shall further perform the calculations based on formula (45) – (48), and the results obtained are, as follows: $\lambda max = 7.16$; $CI = 0.014$; $RI = 1.410$; $CR = 0.011$. Considering that the calculated value of *CR* is lower than 0.10, then the decision criteria matrix is consistent, namely the weights vector is clearly defined.

Step 7: Determining the relative weight of the alternatives based on criteria is performed in the same manner as in Step 4. Due to the space restrictions, we shall go to the next step.

Table 30. Normalized for decision criteria matrix.

	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	Total	Medium value
C1	0.05	0.03	0.05	0.03	0.06	0.06	0.03	0.32	0.045
C2	0.14	0.10	0.14	0.10	0.10	0.10	0.10	0.79	0.113
C3	0.05	0.03	0.05	0.03	0.06	0.06	0.03	0.32	0.045
C4	0.14	0.10	0.14	0.10	0.10	0.10	0.10	0.79	0.113
C5	0.24	0.31	0.24	0.31	0.29	0.29	0.31	2.00	0.285
C6	0.24	0.31	0.24	0.31	0.29	0.29	0.31	2.00	0.285
C7	0.14	0.10	0.14	0.10	0.10	0.10	0.10	0.79	0.113
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	7.00	1.00

Step 8: Normalizing the comparisons between alternatives according to each decision criterion is performed in the same manner as in Step 5. Due to the space restrictions, we shall go to the next step.

Step 9: Completing the performance matrix. Step 9 consists of determining the performance of the ten alternatives in connection with the seven decision criteria.

Step 10: Determining the global priority value of each alternative. The values of each alternative's global priority are calculated based on formula (49), and the results obtained from the calculations performed are presented in table 31 and in figure 38.

Tabel 31. Global priority value of the alternatives.

Alternative's symbol	Alternative name	Total score	Place
A1	Compact pipe	0.1339	2
A2	Slipline	0.1527	1
A3	Subline	0.1134	3
A4	Swagelining	0.0733	10
A5	Cured in place pipe (CIPP)	0.0736	9
A6	GFK Liner	0.0819	8
A7	Berstlining	0.0872	6
A8	Pilot Pipe	0.0972	5
A9	Microtunneling	0.1007	4
A10	Open cut	0.0860	7

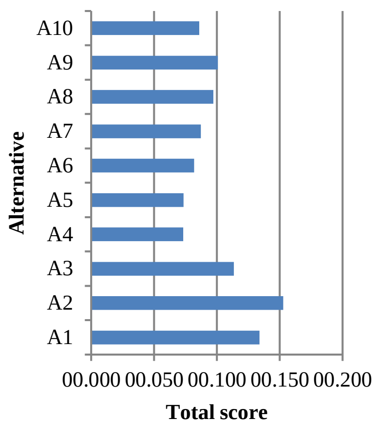


Figure 38. Global priority value of the alternatives.

Step 11: Making the final decision. Analyzing the table 31 and figure 38, one may notice that the alternative no. 2 has the highest global priority score, while the alternative no. 1 ranks second and the alternative no. 3 ranks third.

3.4.2.3. Conclusions

Based on this study, it was recommended that the rehabilitation of the Cluj-Napoca water distribution networks should be performed by implementing the alternative no. 2, by applying the Slipline method respectively.

Obviously, in the assessment process, one may take into account as many versions and as many criteria as he desires, and thus the selection of the pipes from the water distribution systems will be more precise, but at the same time one shall have to make more calculations.

The necessary calculations are quite complex. In practice, these calculations should be performed using a software program, such as Expert Choice (Roman M., 2010). The AHP method presented above may be analogously used in order to choose other types of construction installations too.

3.5. Verification by Calculation of the Solution for the Rehabilitation of Pipelines in the Water Distribution Networks

3.5.1. Introduction

3.5.1.1. Context

One of the main challenges facing water utilities worldwide is the high levels of water losses in the distribution networks. According to the World Bank study, about 32 billion m^3 of treated water is lost annually as leakage from urban water distribution systems around the world, while 16 billion m^3 is used but not paid for (Harrison E., et.al., 2011).

The main problems faced by urban water distribution networks are: old pipelines, frequent leakage, frequent failures, drinking water supply discontinuance, important water losses, high energy costs as well as high costs with the rehabilitation of water distribution networks (Puust R., et.al., 2010).

In this context, a smarter management of urban water distribution networks is needed to achieve higher levels of efficiency. Thus, the International Water Association (IWA) proposed to improve the leakage management process in three different stages, namely: assessment, detection and physical location (Candelieri A., at.al., 2014).

A percent of water that brings no revenue is indicated for Eastern European water supply systems and this percent ranges from 16 % to 61 % (Danilenko A., et.al., 2014; Chirica S., Luca A-L., 2017). In Romania, the maximum allowable water losses from a water distribution system must not exceed 20 % (SR 1343/1-2006).

Among the causes of water loss we would like to mention the following: pipe holes and longitudinal cracks, improper pipe fitting, gasket faults associated with the pipes used for the water distribution networks, old pipelines, road traffic, repairs to the road system, high water pressure in water distribution networks.

If water distribution networks are made of pipes tighten with gaskets, a considerable part of the water loss occurs either due to incorrect pipe assembly or due to fatigue and aging of the material used to tight the pipes (Covelli C., et.al., 2015).

Covelli et al. 2015 (Covelli C., et.al., 2015) states that most articles in the scholarly literature refer to the assessment of water losses through holes and longitudinal pipe cracks.

One of the methods of reducing water losses in water distribution networks is to install water pressure reducing devices. This purpose can be accomplished by means of flow or pressure control devices (Throttle Control Valves (TCVs) or Pressure Reduction Valves (PRVs) or by using small- or micro-turbines or Pumps as Turbines (PaT)), able to totally replace the PRVs or to be located in parallel or in series with them (Covelli C., et.al., 2016).

Determining the number of pressure reducing valves, positioning and setting them is a problem that requires optimization calculations (Covelli C.,et.al.,2016).

Candelieri et al. (2015) have conducted a study in which they have attempted to highlight the relationship between pressure variations and flow variations and pipeline sections that may be affected by leakage.

To locate leakage Candelieri et al. (2014) propose combining chart-based analysis with traditional machine learning techniques (e.g. regression) to estimate the severity of leakage, which leads to leakage location improvement and also helps water distribution network managers to define the intervention plan.

Several studies proposed to improve localization through the analysis of data collected by computer-based systems usually adopted in water distribution networks, such as Supervisory Control And Data Acquisition (SCADA), Automatic Metering Readers (AMR), GIS and hydraulic simulation software (Candelieri A., et.al., 2014).

In the field of drinking water production one can optimize the following: production costs, water losses, duration of water supply interruption, maintenance costs, and compliance with water quality requirements (Castro-Gama M., et.al., 2017).

Since the 1970s, several articles have appeared on optimizing water distribution networks. A first field of research relates to the operation of pumps, because pump operation costs are the biggest expense for water companies around the world. The second field of research concerns the optimization of water quality in the water distribution network. This research field emerged in the 1990s.

Optimal operation of pumps is often formulated as a cost optimisation problem. Pump operating costs comprise of costs for energy consumption due to pump operation and costs due to the maintenance of pumps. At their turn, the electricity costs have two components, namely the costs of the electricity actually consumed and the electricity consumption tax.

Castro-Gama et al. (2017) have implemented a pump operating program for the entire Milan water distribution system. The results show that there is a potential to reduce electricity costs by up to 26%.

Soldi et al. (2015) state that water distribution network managers can establish intervention / rehabilitation plans, even preventive ones, taking into account the vulnerability / resistance and damage chances of water distribution network components.

Resilience and vulnerability of networked infrastructures are strictly linked: while resilience is focused on a general evaluation of the robustness of the entire infrastructure, vulnerability is associated with a specific component, or set of components, to represent the possibility of being influenced by hazards/threats and the severity of the possible consequences (Soldi D., et.al., 2015).

When setting up the rehabilitation plan for water distribution networks, the concept of "water-smart society" can be taken into account. The new concept of “water-smart society”, where the true value of water is recognized and exploited, is transforming Water Distribution Networks (WDN) into “smart” water networks, with a widespread adoption of Advanced Metering Infrastructure (AMI), Automatic Metering Readers (AMR), data analytics, hydro-informatics and automation technologies, enhancing water efficiency operations and optimizing the supply and demand cycle through a growing availability of real time data from the process (Candelieri A., et.al., 2017).

The rehabilitation of drinking water distribution networks is a crucial aspect of sustainable urban development. The mismanagement of water systems can engender not only the disruption of supply but also the degradation of water quality and increased operating and capital expenditures (Tlili Y., Nafi A., 2012).

3.5.1.2. Current state of research

At international level, the methods of choosing technical solutions for the rehabilitation of water distribution networks are focused on the following main areas: predictive models on pipe degradation, models for risk estimation, economic analysis and financial analysis, social analysis, cost optimization, energy optimization, analysis of CO_2 emissions on life cycle (LCE / LCA), as well as multi-criteria methods.

Several software products were designed in order to shorten the time required for substantiating the selection of technical solutions for the rehabilitation of water distribution systems.

Large et al. (2015) performed the ranking of these software products in four categories, namely: the model M1 for assessing the deterioration of pipes, the model M2 for assessing the risks, the model M3 for economic analysis and financial analysis, and the model M4 for the multi-criteria analysis.

Due to difficult process of both the optimization and reliability assessment of water distribution networks, most of the researches focused only on the piping system, omitting other network components such as balancing tanks, pumps or valves (Abunada M., et.al., 2014).

State of-the-art projects in rehabilitation management for urban water networks focus mainly on one single network alone while an integrated multi-utility approach is still seldom used (Tscheikner-Gratl F., et.al., 2017).

Multi-criteria analysis methods can be defined as a set of techniques for assessing decisional options based on several criteria expressed in different measurement units. According to Xu and Yang (2001), multiple criteria decision making refers to making decisions in the presence of multiple and usually conflicting criteria. Recent review papers identify hundreds of MCA techniques for ranking or scoring options, weighting criteria and transforming criteria into commensurate units. Boran et al. (2008) say that one of the weaknesses of these traditional methods is that they do not take into account the relationship between the criteria used for the evaluation.

The main multi-criteria analysis methods used internationally in order to substantiate the decision in the field of water distribution networks are presented in table 32.

Analysing the data from table 32, one may note that the AHP method is one of the most popular multi-criteria methods used in the field of water distribution networks.

Harrison et al. (2011) have noticed that there is a gap between developed decisional theories and applications. The deficiency of knowledge is even greater in developing countries, where these methods and tools are difficult to apply and therefore they are not well understood and validated.

Following the bibliographic study performed, we have noticed that there are few articles in the scholarly literature using the AHP method in the case of drinking water distribution networks.

For easier calculations in case of multi-criteria methods, in practice it is customary to use software programs.

Table 32. Multi-criteria analysis methods used in the field of water distribution networks.

	Method
1	AHP
2	The hybrid method AHP (Analytic Hierarchy Process) and ANN (Artificial Neural Network)
3	Copeland
4	Electre II
5	Electre III
6	Electre TRI
7	Leader
8	Promothee I
9	Promothee II
10	Promethee III
11	Promothee GDSS (Group Decision Support System)
12	TOPSIS
13	Multiattribute value model (MAVM)
14	WSM (Weighted Sum Model)
15	Weighted Utopian Approach

Weistroffer et al. (2005) inventoried a number of 79 MCA software packages implementing a variety of MCA methods (Hajkowicz S., et.al.,2008; Weistroffer H.R., 2005).

3.5.1.3. The purpose and contributions of the study

The purpose of the study is to contribute to the more and more complex decision-making process concerning the water distribution networks in localities.

An important contribution of this work is to provide a methodology for choosing the best rehabilitation technology for water distribution networks.

3.5.2. Materials and methods

3.5.2.1. Description of study area

We shall analyse the possibility of rehabilitating the water distribution networks of Cluj-Napoca City, Romania.

Following the inventory of existing pipeline types, it was concluded that the water distribution network in the city of Cluj-Napoca has a length of 479 km, with nominal diameters between 50 mm and 700 mm. It is made of various materials, depending on the knowledge and technology that existed during the period of the works, namely ductile cast iron, grey cast iron, polyethylene, prestressed concrete, asbestos and steel.

Figure 39 shows the percentages of the pipeline types that compose the water distribution network in the city of Cluj-Napoca. Besides the inventory of pipeline types and their lengths, one also recorded water losses from the water distribution system of Cluj-Napoca City. Figure 40 shows the percentage of water losses broken down by pipeline types.

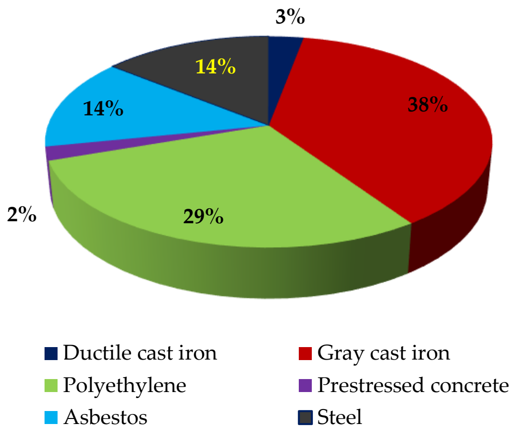


Figure 39. Pipe length weight.

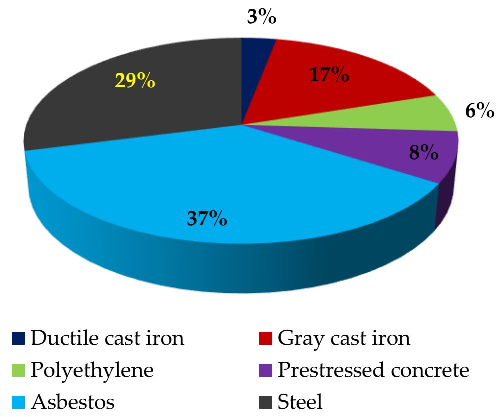


Figure 40. Water losses weight.

Figure 40 shows that the largest water losses are recorded in asbestos pipes. Also, Figure 39 shows that the asbestos pipes have only a 14% share.

Given the fact that water distribution networks are quite old, the materials used to make water distribution networks are of poor quality, pipelines break frequently, there are large water losses and frequent interruptions in the supply of drinking water in Cluj-Napoca, it is necessary to replace old pipes.

Considering the large water losses of the Cluj-Napoca water distribution system, a plan for the rehabilitation and modernization of water distribution networks must be established, starting with the asbestos pipes where the largest water losses are recorded.

3.5.2.2. Materials

Asbestos pipes started to be manufactured at the beginning of the 20^{th} century in Italy. The new type of pipe came with some advantages, so it began to spread rapidly in most European and North American countries. Between the 1950^{s} and the 1960^{s}, the asbestos pipes were the most used material for the construction of water supply networks. Nowadays, most asbestos water pipes are near the end of their lifespan (Marek C., et.al., 2014).

Asbestos pipes pose water quality problems, and according to European regulations these pipes have to be replaced (GP 127-2014).

Water loss reduction options are selected after carrying out a water balance/audit. The water balance reveals the nature and magnitude of the decision problem and provides guidance on which strategy options to adopt.

The strategy options can then be selected from a rich menu developed by the International Water Association (IWA) and the American Water Works Association (AWWA) based on many years of research (Harrison E., et.al., 2011).

Water distribution networks can be installed using open cut technologies or trenchless technologies. The open cut/trenching conventional method represents the technology of executing a new pipe at a depth of 1-6 m, or of replacing an existing pipe in the ground, by creating an open trench along the entire work route. The no dig/trenchless technology represents the technology of building or restoring a ground-based, water or water-free tubular work without opening a trench along the way. The excavations are local for the launch of the machine or of the new pipeline and for the rebuilding of the connection, the excavations representing less than 5% of the length.

In this study we shall analyse five alternatives, as follows: Compact Pipe, Slipline, Subline, Swagelining and Pilot Pipe (see table 33).

Table 33. Matrix of alternatives (Aşchilean I., 2010)

Alternative's symbol	Alternative name	Material of the pipe to be rehabilitated	Material of the rehabilitated pipe	The nominal diameter of the pipe [mm]	Distance [m]	Observations
A1	Compact Pipe	Concrete, asbestos cement, cast iron, steel, PVC	PE	100 ÷ 500	700	The PE inliner shall be delivered on site as molded in the form of "C". It is recommended for crowded urban areas.
A2	Slipline	Concrete, asbestos cement, cast iron, steel, PVC	PE, PVC	50 ÷ 1000	long	
A3	Subline	Concrete, asbestos cement, cast iron, steel, PVC	PE 80 or PE 100 with SDR 26 or SDR 80	75 ÷ 1600	long	The PE inliner shall be delivered on site as molded in the form of "U".
A4	Swagelining	Concrete, asbestos cement, cast iron, steel, PVC	PE, PVC	65 ÷ 1000	1000	
A5	Pilot Pipe	Concrete, asbestos cement, cast iron, steel, PVC	Steel, PE or other materials with high tensile strength	80 ÷ 1600	60 ÷ 80 m trenchless term	

In recent years, trenchless technologies have been used for construction and rehabilitation of buried utilities such as gas pipelines, water distribution systems, sewer collection systems and drainage culverts (Zhao J.Q., et.al., 2002).

Pipeline renewal technologies may be divided into repair, rehabilitation and replacement technologies. Obviously, water distribution network rehabilitation technologies may have their advantages, as well as their disadvantages.

Trojan and Costa (2012) say that alternatives can be assessed using different criteria which are usually in conflict.

3.5.2.3. Methods

We propose to use multi-criteria methods for choosing technical solutions for rehabilitation of water distribution networks.

Two of the most important methods of multi-criteria decision-making (MCDM) are the Analytical Hierarchical Process (AHP) and the Network Analysis Process (ANP). Because the ANP method (1996) is more recent than the AHP method (1980), there is a limited number of studies on this topic. However, there are studies that have shown that there are advantages of the ANP method to the AHP method (Nedjatia A., et.al., 2013).

Many decision problems cannot be structured hierarchically because they involve the interaction and dependence of higher level elements on a lower level element.

Saaty suggested the use of AHP to solve the problem of independence among alternatives or criteria, and the use of Analytic Network Process (ANP) to solve the problem of dependence among alternatives or criteria (Nedjatia A., et.al., 2013).

According to Cheng and Li (2005) the ANP method incorporates both qualitative and quantitative approaches of a decision-making problem.

Nedjatia and Izbirak (2013) assert that for the decision-making process, when using qualitative and uncertain values, the use of the ANP method is preferable to the AHP method, so for the choice of pipeline rehabilitation technologies in water distribution systems, we propose the use of the ANP method.

The ANP method was applied in many areas, such as quality, energy efficiency, civil engineering, renewable resources, environment, human resources, telecommunications, industry, health, finance, transportation, computer science, thermal energy supply systems (Erdoğmus S., et.al., 2016), wastewater treatment, methane gas systems, banking, government, marketing, tourism and so on.

In order to select the technologies for the rehabilitation of the pipes from the water distribution systems one shall use the ANP method. In our opinion, using the ANP method involves 14 steps, as following:

Step 1 Establishing the purpose and the objectives. Goals are broad statements of intent and desirable long-term plans. The goals and objectives are derived from the utility's vision and mission statements. The goals and objectives should include sustainability dimensions such as economic, environmental and social aspects. In practice, objectives are often conflicting and may be realized over a short, medium and long-term period.

Issues related to prioritisation of alternatives or general decision-making in water utility companies are always connected to conflicts of preference among managers who have different interests in attending to the company's goals.

Step 2 Identification of the decision-making criteria. At this stage, the decision-maker must identify a list of selection criteria for the evaluation of the alternatives.

Tscheikner-Gratl et al. (2017) assert that at the start of the decision-making process the decision-makers need to give enough time to define the decision-making criteria.

Tlili and Nafi (2012) assert that decision-making on the classification of alternatives to rehabilitate water distribution networks depends on the number of criteria used and the weighting assigned to each criterion, which makes the aggregation task more complicated.

Step 3 Identification of alternatives. At this stage, the options that may contribute to the accomplishment of objectives are identified.

Step 4 Forming the structure of the ANP network. Jayant et al. (2015) assert that many decision-making problems cannot be built as hierarchic problems because of the (interior / exterior) dependences, of the influences between and inside the clusters (criteria, alternatives). ANP is very useful for solving such problems.

Not only does the importance of the criteria determine the importance of the alternatives as in a hierarchy, but also the importance of the alternatives themselves determines the importance of the criteria. Feedback enables us to factor the future into the present to determine what we have to do to attain a desired future (Kroener M.U., 2014).

To structure detailed ANP models wisely, Saaty introduces clusters, which refer to grouping of homogenous elements together, such as alternatives, criteria, and subcriteria.

The objectives, criteria, subcriteria and alternatives are clustered.

Hence, in this model, one cluster for objective, one cluster for all the evaluation criteria and each of the evaluation criteria with their sub-criteria constitute clusters. The alternatives are grouped into one cluster (Thangamani G., 2012).

Relationships in a network are represented by arcs, and the directions of arcs signify dependence.

Step 5 Forming the pairwise comparison matrices. Similar to the AHP method, the priorities in case of the ANP method are directly assessed by pair comparison (Ozdemir Y., et.al., 2011).

There are two levels of pairwise comparisons in the ANP method: the cluster level, which is more strategic, and the node/element level, which is more specialized.

Cluster comparisons involve comparing clusters with another cluster. While pair comparisons on elements in clusters are made depending on their influence on each element in another group, they are related to elements in another cluster (external dependence) or elements in their own group (inner dependency) (Hussey L.K., 2014).

Should there be n elements to be compared, then the pairwise comparison matrix noted with A shall be defined as:

$$A = (a_{ij})_{nxn} = \begin{vmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{vmatrix}, \quad (52)$$

where: $a_{ii} = 1$, $a_{ji} = 1/a_{ij}$ and $a_{ij} \neq 0$ (Sakthivel G., et.al., 2015).

The a_{ij} score in the pairwise comparison matrix represents the relative importance of the element from row (i) compared with the element from column (j). The pairwise comparison matrices are square matrices, with n elements on the line and n elements on the columns. In this context, for the n criteria it is necessary to compare n (n-1) / 2 pairs.

As to this stage, one shall establish the relative importance of each criterion relative to the other criteria, in order to determine the level of contribution of each criterion to the achievement of objectives (Hussey L.K., 2014).

The pair comparisons are made by the decision makers who assess the pairs subjectively (initially based on verbal assessments, such as “equally important”, “slightly more important”, “absolutely more important”, and so on, and then by assigning values on a scale from 1 to 9, which represents the importance degree of one attribute towards another attribute). If the comparison between two criteria is reversed, then the importance value equals the reverse of the direct comparison value.

We used the Saaty scale for this purpose.

Step 6 Forming normalized matrices. Further on, the values recorded in the pairwise comparison matrix shall be normalized, and then the results shall be recorded in the normalized matrix.

Saaty proposes several algorithms for approximating the relative weights. There is still a continuous discussion on the approximation methods; this matter is still unsolved. A critical analysis of the weight calculation method can be taken from Bana and Vansnick (2008). In most articles, normalization is made by one of the following methods: arithmetic average method, geometric average method or the difference method.

Further on we present the arithmetic average method, which supposes three steps:

- one calculates the sum on each column of the pairwise comparison matrix, using the formula (53);
- one shall divide each element of the pairwise comparison matrix to the amount corresponding to its column, using the formula (54);
- the obtained values shall be recorded in the normalized matrix, using the formula (55).

$$Sj = \sum_{j=1}^{m} aji \ , \tag{53}$$

$$aji\_norm = \frac{aji}{Sj} \ , \tag{54}$$

$$A_{norm} = \begin{vmatrix} a11_{norm} & a12_{norm} & \dots & a1n_{norm} \\ a21_{norm} & a22_{norm} & \dots & a2n_{norm} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ an1_{norm} & an2_{norm} & \dots & ann_{norm} \end{vmatrix} , \tag{55}$$

Step 7 Establishing local priorities. Based on the information recorded in the normalized matrix, local priorities are established, using the formula (56), and the data are registered in a column matrix, according to the model presented in the formula (57). The respective matrix is called the local priority vector (Lahby M., et.al., 2017).

$$wi = \frac{\sum_{j=1}^{n} aij\_norm}{n} \text{ and } \sum_{j=1}^{n} wi = 1 , \tag{56}$$

$$W = \begin{vmatrix} w1 \\ w2 \\ \dots \\ \dots \\ wn \end{vmatrix} , \tag{57}$$

Step 8 Determining the consistency of the matrix. In order to determine the consistency factor of the matrixes, we shall perform the following steps:

a) Establishing the average stochastic uniformity coefficient. The average stochastic uniformity coefficient, marked ‘‘R’’, is determined depending on the rank of the analyzed matrix, marked ‘‘m’’, based on table 34 (Dobrea R., 2006):

Table 34. Values of the average stochastic coefficient depending on the rank of the matrix

(Order Of Matrix)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

b) Determining the uniformity coefficient. The uniformity coefficient “CI” is calculated based on the formula (58), as follows:

$$CI = \frac{\lambda \max - n}{n-1} , \quad (58)$$

where:

λmax > n;

n is the number of elements to be compared.

$$\lambda \max = \sum_{i=1}^{n} \frac{(A \cdot w)i}{n \cdot wi} , \quad (59)$$

c) Determining the consistency factor of the matrixes.

The consistency factor of matrixes “CR” is calculated based on the formula (60), as follows:

$$CR = \frac{CI}{R} , \quad (60)$$

When determining the consistency relation, one takes into account the following rule: if CR ≤ 0.10, than the matrix is considered to be consistent, namely the vector of the weights is well determined. When higher matrix consistency rations are found, it is necessary to resume comparisons for that respective matrix (Ünver S.B.S, 2015).

Step 9 Forming the unweighted supermatrix. After having established the local priorities based on the pairwise comparison matrices, the following step consists in progressively forming three supermatrixs, namely: the initial or unweighted supermatrix, the weighted supermatrix and the limit supermatrix.

The unweighted supermatrix, the weighted supermatrix and the limit supermatrix are square matrices and they all have the same number of elements.

The priority vectors obtained from the pairwise comparison matrix are recorded as column vectors relative to their control criterion, in a new matrix called unweighted supermatrix, whose form is according to the formula (60).

The unweighted supermatrix represents the influence priority of an element from the left part of the matrix on an element from the upper part of the matrix relative to a certain control criterion.

The resulted matrix must be a stochastic one, meaning that the sum of the values recorded in each column must be equal to for each cluster individually (Ünver S.B.S, 2015).

W =

		C_1	C_2	…	C_N
		e_{11} e_{12} … e_{1n_1}	e_{21} e_{22} … e_{2n_2}	…	e_{N1} e_{N2} … e_{Nn_N}
C_1	e_{11} e_{12} … e_{1n_1}	W_{11}	W_{12}	…	W_{1N}
C_2	e_{21} e_{22} … e_{2n_2}	W_{21}	W_{22}	…	W_{2N}
⋮		…	…	…	…
C_N	e_{N1} e_{N2} … e_{Nn_N}	W_{N1}	W_{N2}	…	W_{NN}

(61)

where CN represents the cluster N, Nn is the element n in the cluster N, and Wij is the vector of the element influence.

In the unweighted matrix, Wij virtually represents a local priority matrix and it results from a comparison of two clusters.

Each column of the Wij matrix is the priority vector resulted from a pairwise comparison matrix, virtually this matrix comprises the local priority vectors (Khademia N., et.al, 2012).

$$Wij = \begin{vmatrix} w11 & w12 & \dots & w1n \\ w21 & w22 & \dots & w2n \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ wn1 & wn2 & \dots & wnn \end{vmatrix}, \quad (62)$$

Step 10 Forming the weighted supermatrix. For each column block, the first entry of the local priority vector is multiplied with all the elements of the first block of the respective column, the second entry with all the elements of the second block of that column and so on. Thus, the blocks of each column of the supermatrix are weighted, and the result is known as the weighted supermatrix, which is a stochastic one.

This 'column stochastic' feature of the weighted supermatrix allows convergence to occur in the limit supermatrix (Peykarjou K., et.al., 2015).

Step 11 Forming the limit supermatrix. Finally, the weighted supermatrix is transformed into the limit supermatrix by raising itself to powers. The reason for multiplying the weighted supermatrix is because we wish to capture the transmission of influence along all possible paths of the supermatrix.

Raising the weighted supermatrix to the power 2k + 1, where k is an arbitrarily large number, allow convergence of the matrix, which means the row values converge to the same value for each column of the matrix. The resulting matrix is called the limit supermatrix, which yields limit priorities capturing all the indirect influences of each element on every other element (Peykarjou K., et.al., 2015).

The limit supermatrix has the same form as the weighted supermatrix, but all the columns of the limit supermatrix are the same.

The consistency of the element comparison is calculated as follos:

$$W'\infty = \lim_{k\to\infty} W^{2k+1}, \quad (63)$$

Step 12 Establishing the alternative ranking. The alternative ranking is established based on the global priority. Obviously, the alternative having the highest global priority shall rank on the first place.

Step 13 Sensitivity analysis. Sensitivity analysis refers to the question "what if" in order to see if the final answer is stable when entries modify, whether they are judgments or priorities (Abastante F., Lami I.M., 2012).

Step 14 Choosing the best alternative. Eventually the alternative with the highest global priority should be the selected one (Dağdeviren M., Yüksel İ., 2007).

3.5.3. Results

Step 1 Establishing the purpose and the objectives. The purpose of this study is to find the best technical solution for the rehabilitation of the asbestos pipelines in order to reduce water losses in the water supply system of Cluj-Napoca City, Romania.

Step 2 Identifying the decision-making criteria. After the study of the scholarly literature and based on the available data, the decision-making criteria were selected. Table 35 present the decision-making criteria used in the case study.

Table 35. The set of decision criteria.

Criterion	Name of criteria	Type	Description
C1	Diameter of the pipe	maximized	It is advisable to select that alternative that can be used for the entire range of pipes used in water distribution networks.
C2	Length of the pipe	maximized	It is advisable to select that alternative that can be used for the longest possible pipelines.
C3	Period of time required for installation	minimized	It is preferable the installation to be as quick as possible.
C4	Lifespan	maximized	The lifespan of the rehabilitated pipe must be higher than the lifespan of the replaced pipe.
C5	Pressure losses	minimized	The pressure losses should be as low as possible.
C6	Price	minimized	The price for replacing the pipes should be as low as possible.
C7	Installation conditions	minimized	The alternative should not set special installation conditions.

Step 3 Identifying the alternatives. In subchapter 3.5.2.2 five alternatives were identified, namely: Compact Pipe, Slipline, Subline, Swagelining and Pilot Pipe. The data concerning the selected alternatives are presented in table 35.

Step 4 Forming the structure of the ANP network. The problem is decomposed into a network where nodes correspond to clusters. The elements in a cluster may influence some or all the elements of any other cluster. These relationships are represented by arcs with directions. Also, the relationships among elements in the same cluster can exist and be represented by a looped arc.

The ANP network was drawn in the Super Decisions 2.6.0 software. In order to rank the five alternatives based on the seven criteria, the ANP method by Saaty and the Super Decisions 2.6.0 software were used. This software was chosen because the academic version of the Super Decisions 2.6.0 software is free.

Figure 41 represents the hierarchical structure of the process of choosing the technical solution for the rehabilitation of water distribution networks containing three clusters, namely the "Goal" cluster, the "Criteria" cluster and the "Alternatives" cluster. There is a feedback loop in the criteria cluster, indicating that the nodes in this cluster (the criteria) are compared to them. There is also a feedback loop in the alternative cluster and the cluster criteria, indicating that alternatives can influence the criteria.

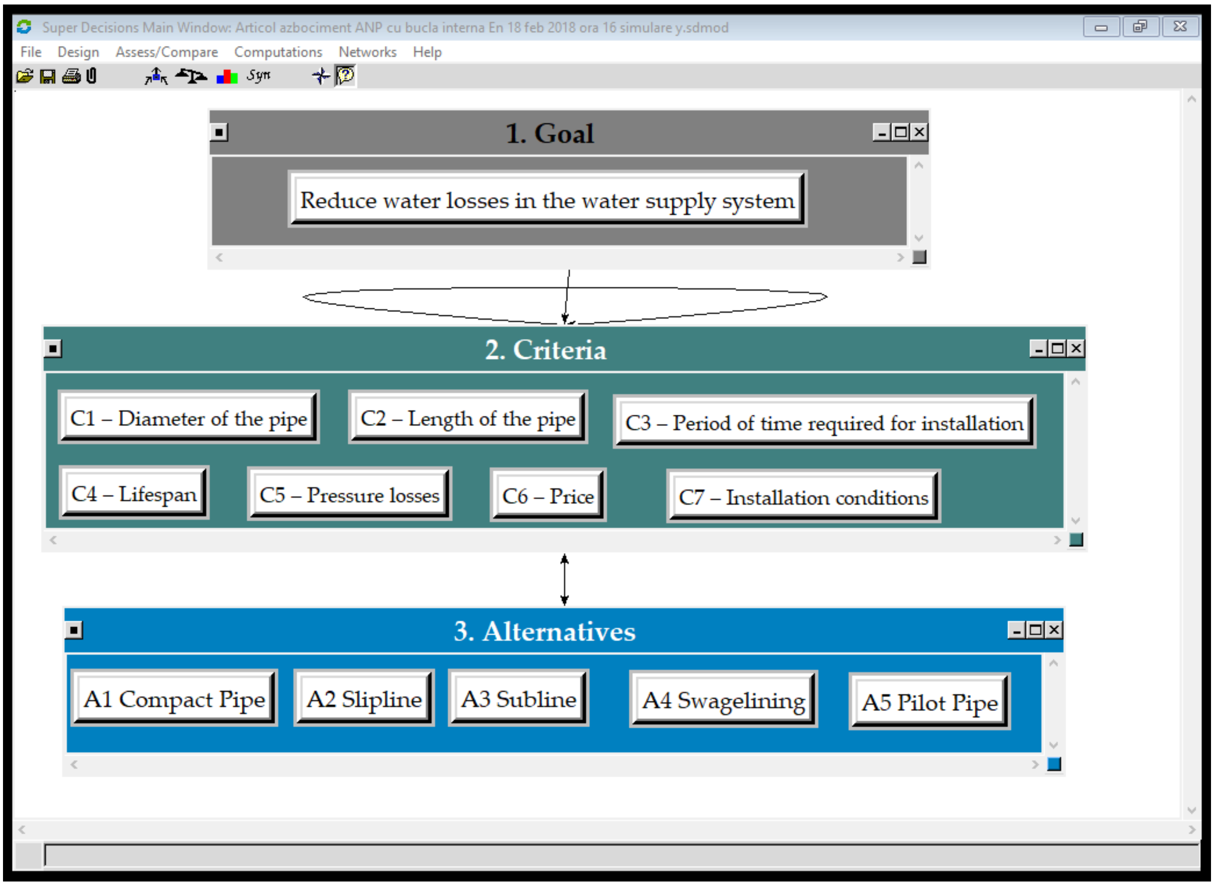


Figure 41. Ranking structure of the network analytical process for selecting the optimal alternative.

The hierarchical structure of the network analytical process for choosing the optimal alternative was drawn using the Super Decisions 2.6.0 software, based on the relationship between criteria and alternatives.

The relationships specified in figure 42 were identified between the decision-making criteria.

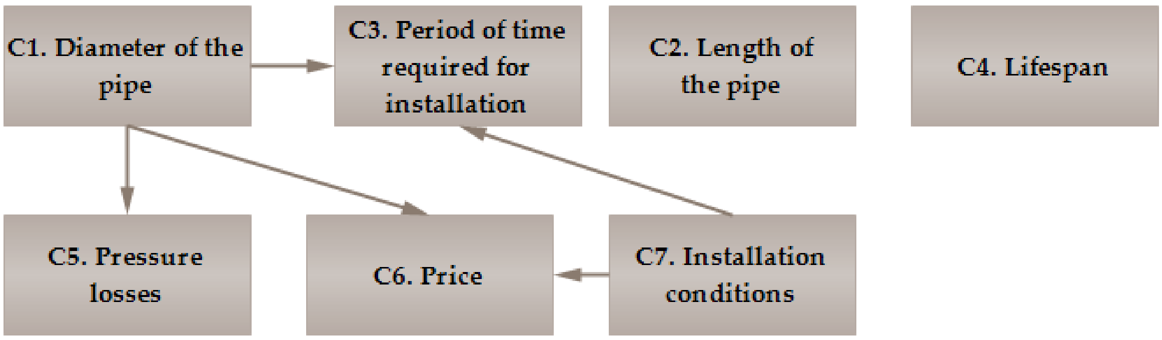


Figure 42. Relationships between the decision-making criteria.

Step 5 Forming the pairwise comparison matrices. In table 36 we present the interaction between the elements of the decision-making process.

Table 36. Interaction between the elements of the decision-making process.

		1. Goal	*2. Criteria*							*3. Alternatives*				
			C1	***C2***	***C3***	***C4***	***C5***	***C6***	***C7***	***A1***	***A2***	***A3***	***A4***	***A5***
1. Goal														
2. Criteria	*C1*	*x*												
	C2	*x*												*x*
	C3	*x*	*x*						*x*					
	C4	*x*												
	C5	*x*	*x*											
	C6	*x*	*x*						*x*					
	C7	*x*												*x*
3. Alternatives	*A1*		*x*	*x*	*x*	*x*	*x*	*x*	*x*					
	A2		*x*	*x*	*x*	*x*	*x*	*x*	*x*					
	A3		*x*	*x*	*x*	*x*	*x*	*x*	*x*					
	A4		*x*	*x*	*x*	*x*	*x*	*x*	*x*					
	A5		*x*	*x*	*x*	*x*	*x*	*x*	*x*					

Remark: The symbol x represents the interaction between the elements of the decision-making process.

According to table 36, for this case study we may have maximum 39 pairwise comparison matrices, namely:

- 13 pairwise comparison matrices between the goal cluster and the 13 elements of the decision-making process mentioned in table 36;

- 13 pairwise comparison matrices between the criteria cluster and the 13 elements of the decision-making process mentioned in table 36;
- 13 pairwise comparison matrices between the alternatives cluster and the 13 elements of the decision-making process mentioned in table 36.

For this case study we identified 11 pairwise comparison matrices, namely:

- one matrix for comparing the criteria cluster in relation with the goal;
- two matrices that highlight the relationships between the decision-making criteria, as presented in figure 42;
- one matrix that highlights the influence of alternatives on the criteria;
- seven matrices for comparing the alternatives in relation with the decision-making criteria, therefore one matrix was elaborated for each decision-making criterion.

Further on, the analysis of pair comparisons was done using the Super Decisions 2.6.0 software. Entering data for pair comparisons with the Super Decisions 2.6.0 software can be done through the following methods: direct data input, use of the questionnaire method, use of the matrix method, use of the verbal method, and use of the graphical method. For this case study the data input was made using the default data input option, respectively the questionnaire method.

As an example one presents the work algorithm to compare the decision-making criteria in relation with the purpose proposed in the case study. Thus, in figure 43 we present the questionnaire used for pair comparison between the seven decision-making criteria in relation with the goal.

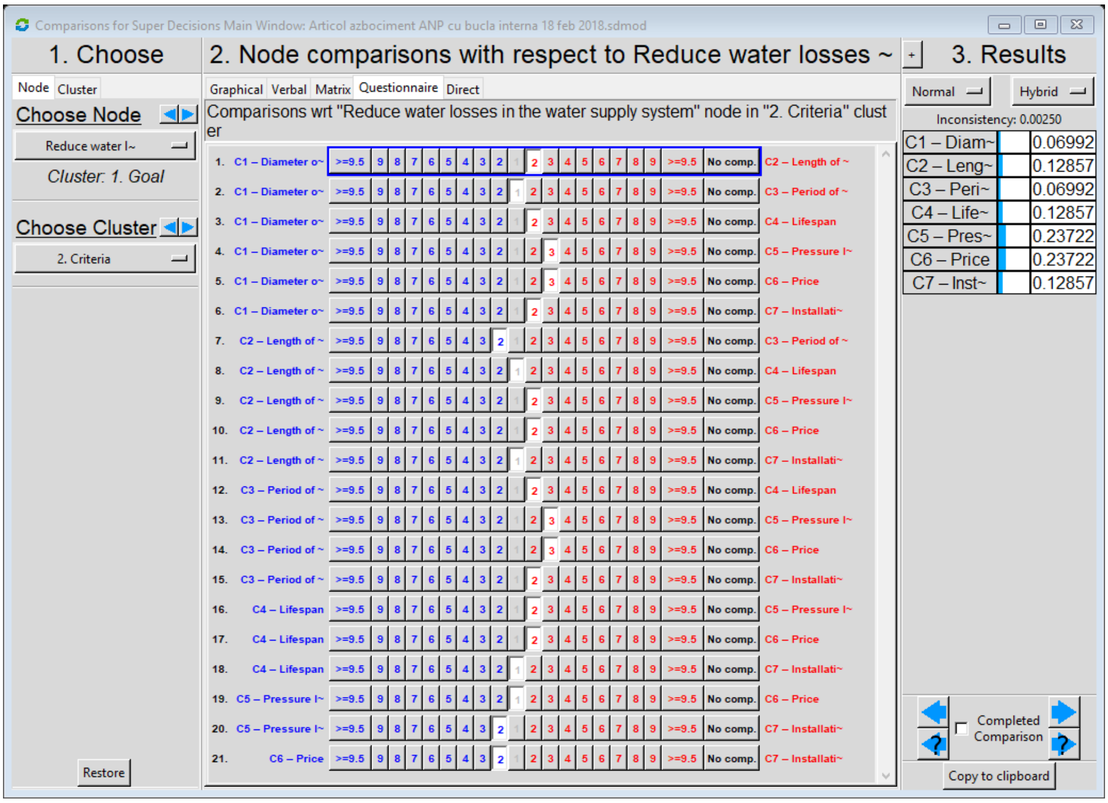


Figure 43. The questionnaire used for pair comparison between the seven decision-making criteria.

The pair comparisons are made based on the Fundamental Scale of Saaty.

In table 37 we present the values of the pair comparisons between the criteria in relation with the goal.

Table 37. Matrix of pair comparison between the criteria in relation with the goal.

Criteria code	C1	C2	C3	C4	C5	C6	C7
C1	1.00	1/2	1.00	1/2	1/3	1/3	1/2
C2	2.00	1.00	2.00	1.00	1/2	1/2	1.00
C3	1.00	1/2	1.00	1/2	1/3	1/3	1/2
C4	2.00	1.00	2.00	1.00	1/2	1/2	1.00
C5	3.00	2.00	3.00	2.00	1.00	1.00	2.00
C6	3.00	2.00	3.00	2.00	1.00	1.00	2.00
C7	2.00	1.00	2.00	1.00	0.50	0.50	1.00

In table 37 it is noticed that on the matrix diagonal the value one is entered because a criterion is compared to itself.

Step 6 Forming the normalized matrices. Further on the values of the criteria comparisons in relation with the purpose shall be normalized, using the Super Decisions 2.6.0 software.

Step 7 Establishing local priorities. After normalizing the values of the criteria comparisons in relation with the purpose, one shall establish the local priority vector W21 (see figure 44).

$$W21 = \begin{vmatrix} 0.069918 \\ 0.128572 \\ 0.069918 \\ 0.128572 \\ 0.237225 \\ 0.237225 \\ 0.128572 \end{vmatrix}$$

Figure 44. Local priority vector W21.

Step 8 Determining the consistency ratio of the matrix. Following the application of the calculation algorithm, eventually, for the pairwise comparison matrix of the decision-making criteria in relation with the goal, we obtained a matrix consistency ration of 0.00250 and therefore the matrix fulfils the consistency requirement ($CR \leq 0.1$). In this case study, local priorities as well as matrix consistency ration were both established using the Super Decisions 2.6.0 software.

Further on the calculations are made similarly for the other pairwise comparison matrices. After making the calculations it resulted that for all pairwise comparison matrices the consistency ratio is less than 0.1 and therefore the matrices fulfil the consistency requirement ($CR \leq 0.1$).

Step 9 Forming the unweighted supermatrix. Starting from the ranking structure of the process presented in figure 45, for this case study the supermatrix shall have the following form:

		1. Goal	2. Criteria	3. Alternatives
W =	1. Goal	0	0	0
	2. Criteria	W21	W22	W23
	3. Alternatives	0	W32	0

Figure 45. Supermatrix form for this case study.

Where W21 is a vector representing the impact of the objective established over the criteria, W22 is a vector representing the dependency between the criteria, W23 is a vector representing the dependency between the criteria and the alternatives, and W32 is the vector representing the impact of the criteria on each alternative.

For this case study, the unweighted supermatrix shall be a square matrix with 13 lines and 13 columns, namely:

- one line and one column reserved for the goal cluster, having only one objective, namely to reduce water losses in the drinking water distribution network;
- seven lines and seven columns reserved to the criteria cluster, namely one line and one column reserved for each criterion;
- five lines and five columns reserved to the alternative cluster, namely one line and one column reserved for each alternative.

Further on the unweighted matrix shall be elaborated based on the relative weights establish for each pairwise comparison matrix (see table A1). Thus, at the intersection between the line “2 Criteria” and column “1 Goal” one shall enter the relative weights obtained in the matrix of comparisons between the criteria in relation with the established purpose (see table A1). Then one shall proceed similarly with the local weights established through the other matrices of the pairwise comparisons.

Step 10 Forming the weighted supermatrix. Based on the unweighted supermatrix the weighted supermatrix shall be elaborated, and in order to do this the values from the unweighted supermatrix are multiplied with the weights corresponding to the cluster (see table A2).

Step 11 Forming the limit supermatrix. The limit supermatrix is calculated by rising to power the weighted supermatrix using the formula (63), see table A3.

Step 12 Establishing the alternative ranking. In table 38 the alternative ranking obtained using the ANP method is presented.

Table 38. Alternative Rankings.

Alternative name	Global priority	Place
A1 Compact Pipe	0.1804	3
A2 Slipline	0.1813	2
A3 Subline	0.3664	1
A4 Swagelining	0.1691	4
A5 Pilot Pipe	0.1028	5

3.5.4. Discussions

Step 13 Sensitivity analysis. A sensitivity analysis was performed to check the robustness of the model. For this the weight of each decision-making criterion is modified by ± 10 %. The sensitivity analysis was made for all the seven criteria, and the alternative preferences were the following: 0.180 for alternative A1, 0.181 for alternative A2, 0.366 for alternative A3, 0.169 for alternative A4 and 0.103 for alternative A5.

Super Decisions 2.6.0 software allows the establishment of the limit supermatrix to be carried out by a number of nine different variants, defined as: calculus type, scaling by scalar, new hierarchy (without limit), new hierarchy (with limit), identity at sinks, sinks formula (straight normalize), sinks formula (normalize limits), Pre-2001 Version, Pre-2000 Version.

In this context, we have made a simulation within the case study, using the nine variants for the establishment of the limit supermatrix, and after the simulation the same result was obtained. The limit supermatrix presented in table A3 was determined by the "calculus type" variant. As a conclusion, after performing the sensitivity analysis it was proved that the method used offered a very stable ranking of alternatives.

Step 14 Selecting the best alternative. The priorities obtained after assessing the alternatives (see table 38), are the following: 0.1804 for the alternative A1 (Compact Pipe), 0.1813 for the alternative A2 (Slipline), 0.3664 for the alternative A3 (Subline), 0.1691 for the alternative A4 (Swagelining) and 0.1028 for the alternative A5 (Pilot Pipe).

Based on the priorities obtained, as well as based on the sensitivity analysis, we recommend the alternative A3, namely the Subline technology, considering that this alternative obtained the highest global priority.

3.5.5. Conclusions

The work presented a case study on the choice of the best technical solution for the rehabilitation of the asbestos pipelines in the city of Cluj-Napoca, Romania. The ANP method was used as the method of selecting the technical solutions for the rehabilitation of the pipes, and the calculations were carried out using the Super Decisions 2.6.0 software.

In the case study five alternatives are analysed, based on seven decision-making criteria. The decision-making criteria taken into account to substantiate the decisions included pipeline diameter, pipe length, specific building duration, lifespan, pressure drops, price and mounting conditions, while the alternatives were Compact Pipe, Slipline, Subline, Swagelining and Pilot Pipe. Based on the maximum global priority, we recommend choosing the Subline alternative as a method of rehabilitating the water distribution networks made of asbestos pipes in the case of Cluj-Napoca City, Romania.

The mathematical model presented is a flexible one, allowing the entry of new criteria and subcriteria, as well as alternatives. The methodology described in this work may be modified and used depending on the specific situation in each town. In the future we also recommend the study of the ANP-GP method which, in addition to the ANP method, uses the objective programming. Also for the future, we recommend to combine the fuzzy approach with the ANP method, which better fits the style of human thinking, this approach seems to lead to reliable results.

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Appendix 3.5. A.

Table A1. The unweighted supermatrix.

		1. Goal	**2. Criteria**							**3. Alternatives**				
			C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**A1**	**A2**	**A3**	**A4**	**A5**
1. Goal		0	0	0	0	0	0	0	0	0	0	0	0	0
2. Criteria	C1	0.06992	0	0	0	0	0	0	0	0	0	0	0	0
	C2	0.12857	0	0	0	0	0	0	0	0	0	0	0	0.75
	C3	0.06992	0.24931	0	0	0	0	0	0.25000	0	0	0	0	0
	C4	0.12857	0	0	0	0	0	0	0	0	0	0	0	0
	C5	0.23722	0.15706	0	0	0	0	0	0	0	0	0	0	0
	C6	0.23722	0.59363	0	0	0	0	0	0.75000	0	0	0	0	0
	C7	0.12857	0	0	0	0	0	0	0	0	0	0	0	0.25
3. Alternatives	A1	0	0.07909	0.16649	0.18432	0.23077	0.34632	0.23077	0.19829	0	0	0	0	0
	A2	0	0.13673	0.16649	0.34908	0.23077	0.34632	0.23077	0.16278	0	0	0	0	0
	A3	0	0.24440	0.43320	0.18432	0.23077	0.13500	0.23077	0.24351	0	0	0	0	0
	A4	0	0.13673	0.16649	0.18432	0.23077	0.13500	0.07692	0.24351	0	0	0	0	0
	A5	0	0.40305	0.06734	0.09796	0.07692	0.03736	0.23077	0.15191	0	0	0	0	0

Table A2. Weighted supermatrix.

		1. Goal	**2. Criteria**							**3. Alternatives**				
			C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**A1**	**A2**	**A3**	**A4**	**A5**
1. Goal		0	0	0	0	0	0	0	0	0	0	0	0	0
2. Criteria	C1	0.06992	0	0	0	0	0	0	0	0	0	0	0	0
	C2	0.12857	0	0	0	0	0	0	0	0	0	0	0	0.75000
	C3	0.06992	0.06233	0	0	0	0	0	0.06250	0	0	0	0	0
	C4	0.12857	0	0	0	0	0	0	0	0	0	0	0	0
	C5	0.23722	0.03926	0	0	0	0	0	0	0	0	0	0	0
	C6	0.23722	0.14841	0	0	0	0	0	0.18750	0	0	0	0	0
	C7	0.12857	0	0	0	0	0	0	0	0	0	0	0	0.25000
3. Alternatives	A1	0	0.05931	0.16649	0.18432	0.23077	0.34632	0.23077	0.14872	0	0	0	0	0
	A2	0	0.10255	0.16649	0.34908	0.23077	0.34632	0.23077	0.12209	0	0	0	0	0
	A3	0	0.18330	0.43320	0.18432	0.23077	0.13500	0.23077	0.18263	0	0	0	0	0
	A4	0	0.10255	0.16649	0.18432	0.23077	0.13500	0.07692	0.18263	0	0	0	0	0
	A5	0	0.30229	0.06734	0.09796	0.07692	0.03736	0.23077	0.11393	0	0	0	0	0

Table A3. Limit supermatrix.

		1. Goal	2. Criteria							3. Alternatives				
			C1	C2	C3	C4	C5	C6	C7	A1	A2	A3	A4	A5
1. Goal		0	0	0	0	0	0	0	0	0	0	0	0	0
2. Criteria	C1	0	0	0	0	0	0	0	0	0	0	0	0	0
	C2	0.16718	0.16718	0.16718	0.16718	0.16718	0.16718	0.16718	0.16718	0	0	0	0	0.16718
	C3	0.01026	0.01026	0.01026	0.01026	0.01026	0.01026	0.01026	0.01026	0	0	0	0	0.01026
	C4	0	0	0	0	0	0	0	0	0	0	0	0	0
	C5	0	0	0	0	0	0	0	0	0	0	0	0	0
	C6	0.03077	0.03077	0.03077	0.03077	0.03077	0.03077	0.03077	0.03077	0	0	0	0	0.03077
	C7	0.05572	0.05572	0.05572	0.05572	0.05572	0.05572	0.05572	0.05572	0	0	0	0	0.05572
3. Alternatives	A1	0.13282	0.13282	0.13282	0.13282	0.13282	0.13282	0.13282	0.13282	0	0	0	0	0.13282
	A2	0.13343	0.13343	0.13343	0.13343	0.13343	0.13343	0.13343	0.13343	0	0	0	0	0.13343
	A3	0.26967	0.26967	0.26967	0.26967	0.26967	0.26967	0.26967	0.26967	0	0	0	0	0.26967
	A4	0.12445	0.12445	0.12445	0.12445	0.12445	0.12445	0.12445	0.12445	0	0	0	0	0.12445
	A5	0.07570	0.07570	0.07570	0.07570	0.07570	0.07570	0.07570	0.07570	0	0	0	0	0.07570

3.6. Impact of Street Traffic on Water Distribution Pipelines

The work analyses the relation between the failures occurred in the water supply network and the road traffic in the city of Cluj-Napoca in Romania. The calculations in the case study were made using the Autodesk Robot Structural Analysis Professional 2011 software. In the case study, the following types of pipes were analysed: steel, grey cast iron, ductile cast iron and high density polyethylene (HDPE). While in most studies only a few sections of pipelines and several types of pipelines and certain mounting depths have been analysed, the case study presented analyses the entire water supply system of a city with a population of 324,576 inhabitants, whose water supply system has a length of 479 km. The results of the research are useful in the design phase of water distribution networks, so depending on the type of pipe material, the minimum depth of installation can be indicated, so as to avoid the failure of the pipes due to road traffic. In the perspective, similar studies could also be carried out regarding the negative influence of road traffic on sewerage networks, gas networks and heating networks.

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3.6.1. Introduction

3.6.1.1. Context

The pipelines of the water distribution systems must withstand ground loading, groundwater loading and road traffic loading. In this case, the pipeline is treated as a structure as well as a fluid transport pipe and it is designed to fulfil these two functions throughout its lifetime (Chaallal O., et.al., 2014)

The frequency of breakage and failure of pipes in water distribution networks is increased over time mainly due to deterioration; when pipes deteriorate, the operation and maintenance costs typically increase, and the hydraulic network capacity and the quality of service decrease (Al-Barqawi H., Zayed T., 2008).

Al-Aghbar (2014) stated that the four main reasons for the deterioration of the water distribution networks are:

- the aging of water distribution infrastructure due to environmental factors;
- inadequate preventive maintenance and asset management programmes;
- inappropriate funds and changed municipal priorities;
- lack of information and staff.

3.6.1.2. Literature Review

During the construction and service period, pipes must support pressures from soil and vehicle loads applied at the soil surface (Al-Aghbar A., 2005).

Xu et al. (2017) conducted a study on the influence of road load on a reinforced concrete pipe with an inner diameter of 1400 mm, and the study showed that the unfavourable influence of road load depends on the pipe mounting depth.

Li et al. (2015) conducted a study analysing the relationship between non-hydraulic factors and pipe failures. Thus, the following factors were taken into account: the type of material from which the pipes are made, the diameter of the pipeline and the type of materials used for the roads in the urban environment. The types of pipes used in the water distribution system were the following: galvanized pipes, glass fibre reinforced polymer (GFRP) pipes, polyethylene (PE), other plastics, ductile cast iron, grey cast iron, steel, multi-layer steel-plastic pipe and concrete pipes. Following the study, the authors concluded that most of the faults occur in the area of concreted roads, these failures being caused by road traffic.

Alzabeebee et al. (2017) state that the scholarly literature does not provide clear conclusions about the effect of the pipe diameter and pipe mounting depth on the pipeline behaviour, that most studies have focused on certain types of pipes, certain pipe diameters and certain pipe mounting depths. So they conducted a study on the effect of pipe diameter and pipe mounting depth, the study was conducted for rigid concrete pipes and flexible PVC pipes, and the traffic loads were considered to be those specified in BS 9295/2010. The study showed that the effect of road traffic loading becomes insignificant for a pipe mounting depth exceeding 2 m for concrete pipes and 3 m for PVC pipes, respectively.

Rajeev et al. (2014) conducted a study on large diameter pipeline defects, and the study showed that most of the failures occurred in the case of steel pipes, cast iron pipes and ductile cast iron pipes. Among the causes of defects the authors identified corrosion, water pressure in pipelines, as well as road traffic.

Pislarasu et al. (1970) presented a nomogram on establishing the thickness of the pipe wall in the case of steel pipes used in a water supply system, the pipes being mounted buried at depths of 1 m and 7 m and the pipes having the diameter between 500 mm and 1,400 mm.

The nomogram was drawn up for mobile loads, namely 10 t trucks, as well as for 30 t tracked vehicles.

In the study (Luleh va Mashinsazi Iran., 2018), a graph on the minimum depth and maximum depth of the ductile iron pipe mounting is presented by a pipeline manufacturer. The graph is designed for pipes with a diameter of 700 mm and for pipes with a diameter of 2000 mm, and the recommended mounting depth is between 0.8 m and 7 m, depth recommended according to the pipe diameter and the pipe nominal pressure.

3.6.1.3. Purpose and Contributions of the Study

This study seeks to analyse the impact of street road traffic on water distribution network pipelines.

The necessity of this study results from the critical analysis of the scholarly literature on the impact of street road traffic on water distribution pipelines. Currently used water network failure patterns commonly take into account the characteristics of the pipes, but they often overlook the impact of road traffic. The need to make calculations about the impact of street traffic on pipelines in the local water supply systems is arises to the fact that pipeline manufacturers usually indicate the minimum and maximum pipe mounting depths for only certain road traffic loads and for certain calculation hypotheses, and in practice both road traffic loads and other calculation hypotheses can vary considerably.

The results of the research are useful on the one hand in the phase of water distribution networks design and on the other hand in the phase of water distribution networks exploitation.

3.6.2. Materials and Methods

3.6.2.1. Studied Area

This article analyses the relation between the failures in the water supply network and the road traffic in the case of the city of Cluj-Napoca, Romania. Following the field inventory of existing pipeline types, it was concluded that the water distribution network of the city of Cluj-Napoca has a length of 479 km and serves 324,576 inhabitants.

The work represents a continuation of the research conducted by the authors within a doctoral thesis (Aşchilean I., 2010), as well as within a research grant (Aşchilean I., 2014).

Figure 46 shows the annual evolution of the number of failures in the water supply network of the city of Cluj-Napoca, by connecting pipes, by distribution pipes (DN 80 ÷ 400 mm), by lanes (DN 400 ÷ 600 mm) and by adductions (DN 600 ÷ 1400 mm), the analysis period being the years 2002 ÷ 2010.

An analysis of the data in figure 46 reveals that the number of water supply network failures in the city of Cluj-Napoca increased by 37 % in 2008 compared to 2007 and increased continuously until 2009. We mention that the road system in the city of Cluj-Napoca was rehabilitated and modernized during the period 2007 ÷ 2009. Figure 46 shows that in 2010 the number of failures in the water supply network in Cluj-Napoca decreased, due to the fact that in 2009 the road system rehabilitation process was completed.

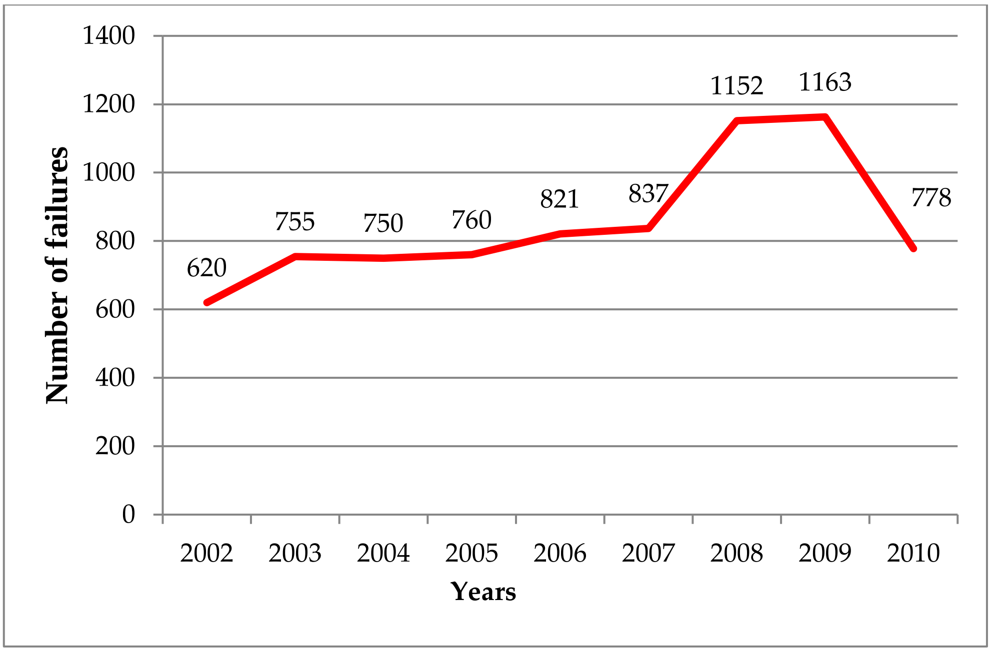
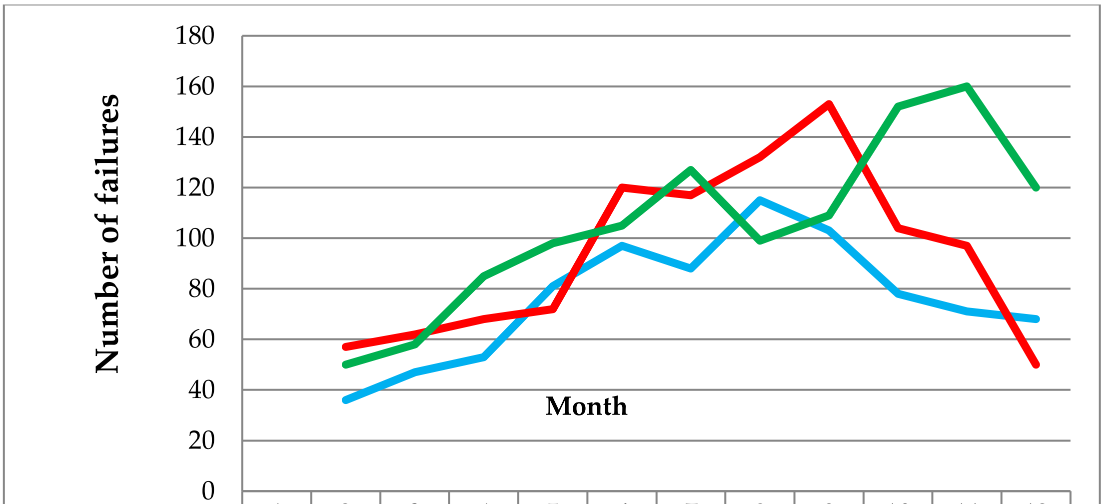


Figure 46. The annual evolution of the number of failures occurred in the water supply network of Cluj-Napoca during 2002 ÷ 2010.

Figure 47 shows the monthly evolution of failures in the water supply network of the city of Cluj-Napoca for the period February 2007 ÷ December 2009.



	1	2	3	4	5	6	7	8	9	10	11	12
Year 2007		36	47	53	81	97	88	115	103	78	71	68
Year 2008		57	62	68	72	120	117	132	153	104	97	50
Year 2009		50	58	85	98	105	127	99	109	152	160	120

Figure 47. Monthly evolution of failures occurred in the water supply network of Cluj-Napoca, February 2007 ÷ December 2009.

Most pipelines for the water supply system of Cluj-Napoca are located under the road system, and repairs to the road system in Cluj-Napoca are usually carried out in April - December. Analysing the data in figure 47, there can be notices an increase in the number of failures in the water supply system during the period from May to October, so there is a correlation between the number of failures in the water supply system of the city of Cluj-Napoca and the period to carry out repairs to the road system.

3.6.2.2. Materials

a) Materials used for building the water distribution networks

Over time, several types of materials were used for making the pipes of the water supply systems. It began with the stone and wood, continued with prefabricated wooden items (staves), stone (masonry) and bricks (fitted in with lime and then with cement), lead and copper, and during the past 200 years, the iron was used, first in the form of cast iron and afterwards in the form of steel. In the 20th century, the plastics and composite materials industry developed.

The main materials currently used for water distribution networks are the following: steel, grey cast iron, ductile cast iron, asbestos cement, reinforced concrete, plastics, polyethylene (PE), glass fibre reinforced polymer (GFRP), other materials.

A study of the pipeline types used for the 1.5 million km distribution network in the Netherlands, Belgium, Japan, South Africa, Spain, Switzerland, France, Norway, Australia, USA and Germany provides the following data on the share of pipeline types, which are presented in table 39 (Aşchilean I., 2014).

Table 39. Share of water distribution pipelines depending on the pipe diameter and material type.

Pipe diameter [mm]	Pipe material					
	Plastics [%]	Concrete [%]	Asbestos cement [%]	Cast iron [%]	Steel [%]	Other materials [%]
< 200	29.2	0.1	24.7	40.6	4.4	1
200 ÷ 400	17.9	0.4	15.2	56.6	4.6	5.3
> 400	0	8.4	8.2	64.2	19.2	0

Following the analysis of data in table 39, it can be noticed that one of the most used materials for building the water distribution networks was cast iron. Also, for pipes with a diameter under 400 mm, the plastics are ranked second place.

In the United States, the reason why cast iron was the most used material is because most of the water distribution system was built during the Second World War and good quality pipe materials were not quite available during the war. Due to this fact, a large number of cheaper and lower quality pipes (Saadeh M., et.al, 2013) were used for the water distribution system.

This may also explain the increasing use of new materials, such as PVC and PE, for water distribution networks (Van Zyl J.E., 2014).

Grey cast iron and ductile cast iron represent more than two-thirds of the length of existing water networks in Canada. Steel, polyvinyl chloride (PVC), high density polyethylene (HDPE), asbestos cement and concrete pressure pipe (CPP) are also used for Canada water pipelines (Saadeh M., et.al., 2013).

As a result of the analysis carried out by the Romanian Water Association, 30 % of the length of the water distribution networks in Romania was found to be represented by steel pipes (see table 40).

Table 40. Romanian water distribution pipelines.

Pipeline Material	Length [km]	Percent out of the total length [%]
Plastics	390	1
Concrete pressure pipe (CPP	779	2
Grey cast iron	818	21
Steel	11686	30
Asbestos cement	17918	46

b) Road Traffic and Road Types inside Urban Areas

Among the main defects affecting the components of a water distribution network are also pipe cracks and breaks or other constituents. One of the causes that lead to these defects is represented by external loadings that affect the constituents of the network.

The occurrence of defects as a result of the action of external factors (road traffic, works, earthworks, etc.) leads to chained effects, which include:

- road structure damage;
- possible dangers to the lives and safety of citizens;
- interruptions of utility supply to the population and businesses;
- additional costs etc.

Nowadays, many streets and urban networks are undergoing rehabilitation and modernization processes. This is accompanied by an increase in the volume of road traffic and of the direct loading of vehicles. Consequently, the problem that arises is the avoidance of the occurrence of defects in the underground networks, caused by road traffic. At the same time, it is intended to optimize the process of modernization and rehabilitation of urban networks, so as to minimize the possibility of failure of the network constituents.

As a result, studying the unfavourable impact of street road traffic on water distribution pipelines and analysing possible solutions respond to the need of eliminating defects arising from the above-mentioned causes and affecting water distribution networks.

According to the Romanian laws, the streets are public roads inside the localities, arranged specifically for:

- vehicle and pedestrian circulation;

- placement of technical and municipal networks;
- ensuring access to adjacent buildings.

According to the Romanian laws there are four categories of streets, having the geometrical characteristics of the standard cross-sectional profile presented in table 41.

Table 41. Streets - geometrical constituents in cross-sectional profile.

Street category	Number of lanes	Lane width [m]	Roadway width [m]
I	6	3.50	21.00
II	4	3.50	14.00
III	2	3.00; 3.50	6.00; 7.00
IV	1	3.00; 3.50	3.00; 3.50

Obviously, the most intense traffic is in the case of the streets from the 1st category.

The main types of road structures that can be used for streets are:

- flexible road structures;
- rigid road structures;
- road structures with carved stone paving carpets;
- road structures with self-locking concrete paving carpets;
- road structures with crushed stone surface, macadam, penetrated macadam carpets;
- pavement of rough stone or cobble (recommended for streets in rural areas).

3.6.2.3. Methods

In this study, we are trying to determine the unitary stresses that take place in the walls of the pipelines of the water distribution networks, under the pressure of road traffic and filler earth. The software used to run the computations in this case study was Autodesk Robot Structural Analysis Professional 2011. This is a program for calculation by finite element structures that includes a wide range of design codes of all types of metal and concrete structures, with the possibility of contemplating other structural materials (Simão M., 2016).

Two basic hypotheses are considered in the calculation:

- pipeline in initial state, in ground free of groundwater;
- pipeline in running order, in ground with groundwater.

The general calculation model used in order to assess the loadings on the water distribution networks is presented in figure 48.

The meanings of the terms are the following:

p_0 - uniformly distributed pressure from the standard semi-axle;

l - width of the indentation of the standard semi-axle (l = 303 mm);

H – pipe coverage thickness / overlay + road structure thickness;

L - distributed width of the indentation of the standard semi-axle;

D - outer pipe diameter;

γ - volumetric weight of the filler earth above the pipe / pipe overlay density;

Ø - internal friction angle of the filler earth above the pipe;

c - cohesion of the filler earth above the pipe;

ka, k_0 - coefficient of lateral earth pressure;

γ_0 - volumetric weight of the filler earth around the pipe;

$Ø_0$ - internal friction angle of the filler earth around the pipe;

c_0 - cohesion of the filler earth around the pipe;

pvH - uniformly distributed vertical pressure from the standard semi-axle at depth H and 45°;

pv2 - uniformly distributed loading from the filler earth at depth H;

pah1, pah2 - active compression of the earth on the pipe's height;

Pah1, Pah2, Pah - resultants of the active compression of earth on the pipe's height;

paw - underground water lateral pressure.

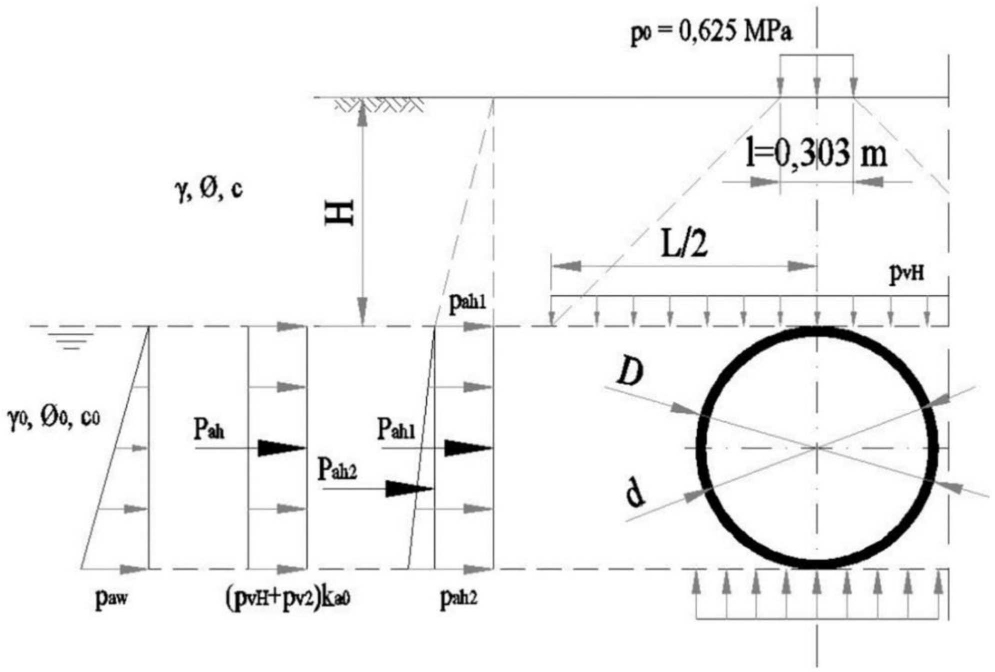


Figure 48. Pipeline loadings calculation model.

In Romania, the standard vehicle axle load is 115 kN. In the considered model, a local force representing a standard semi-axle load was applied. The real tyre-pavement contact surface is elliptical. However, the PD 177 standard states that it may be considered circular, with a radius of 171 mm and an applied uniform load p_0 = 0.625 MPa. For model convenience, the contact surface was modelled as a 303 x 303 mm square, with the same applied load.

The pressure p_0 of the standard semi-axle was assessed by equivalence of the 57.5 kN concentrated force with the loading distributed on the contour of a square surface having the side l = 30.3 cm. Thus it results p_0 = 0.625 MPa.

Considering that each layer of a road structure has a well-defined role, it has been studied how the road traffic loadings are distributed on the thickness of the road system. Thus, we made a calculation model consisting of a plate on elastic medium having the area of 1 m^2 and the deformability characteristics presented in table 42, centrically and vertically stressed with a concentrated force F = 57.5 kN.

As this study focuses on the impact of street traffic on water distribution pipelines, a common flexible road structure, modelled as a multi-layer system, was considered (see table 42). The design of such non-rigid pavements may be carried out using an analytical method, which consists of analysing the state of stresses and strains in the configured pavement, under the standard semi-axle load, using the Burmister model for different cases of multi-layered systems (Burmister D.M., 1945).

Table 42. Characteristics of the materials composing the flexible road structure.

Material	Dynamic elasticity modulus E [MPa]	Poisson's ratio μ
Asphalt mixture - wearing course	3600	0.35
Asphalt mixture - binder course	3000	0.35
Asphalt mixture - base course	5000	0.35
Intermediate aggregate - optimal mixture	500	0.27
Ballast	300	0.27

The calculation model for the plate is presented in figure 49.

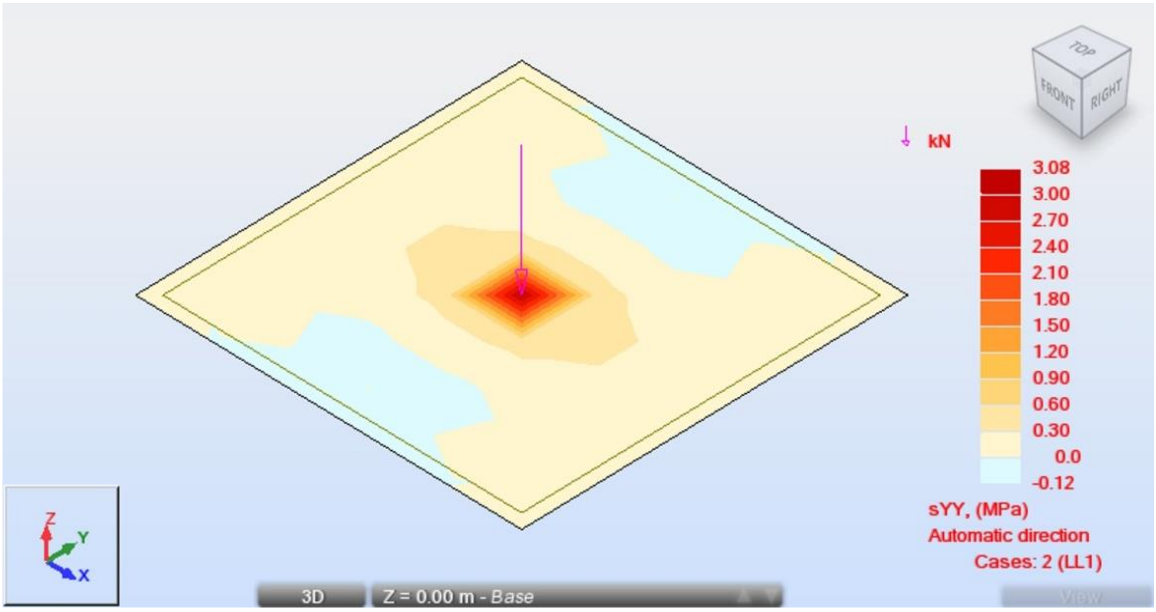
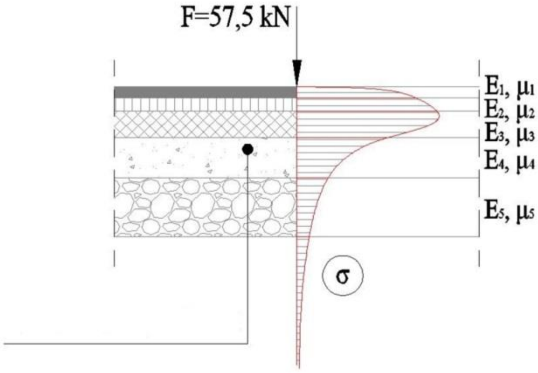


Figure 49. Plate calculation model.

Thus, a distribution of the stresses on the road structure thickness similar with the one presented in figure 50 is obtained.



Designed road structure

Figure 50. Distribution of stresses on the thickness of the road structure.

Considering a modernized street with a non-rigid road structure on the route of which water distribution networks are disposed, the distribution of road traffic loadings is therefore decreasing with the depth. The maximum values of stresses generated by road traffic are recorded at depths of 10 ... 25 cm from the surface of the wear layer. Thus, the essential structural role of the base course in a road system is justified.

Numerous defects of underground public networks occur during and following repair, rehabilitation or street modernization works, due to the reduction of piping coverage and the heavy machinery used in road works.

Thus, it should be considered the situation where the piping coverage is reduced to the minimum and significant dynamic actions are recorded. According to European standards, it is recommended to multiply the characteristic values of actions with dynamic coefficients with values up to 2.

This study considers a distribution to 45° of the uniformly distributed load from the standard semi-axle through the filler earth above the pipelines, a hypothesis which includes cases where road works are being carried out on the streets in question.

If groundwater is present, when assessing the earth compression, we took into account the density of the earth in submerged state as well as the hydrostatic pressure of the groundwater. At the same time, assuming that the water supply pipes are functional and full, the filler earth is subjected to a stress by the pipe's walls. Thus, the earth compression is considered as passive.

The earth active compression ratios were assessed using the Rankine theory:

$$ka = tg^2(45^o - \emptyset/2)\,, \tag{64}$$

$$ka0 = tg^2(45^o - \emptyset 0/2)\,, \tag{65}$$

Similarly, the ratios of the earth passive compression were assessed:

$$kp = tg^2(45^o - \emptyset/2)\,, \tag{66}$$

$$kp0 = tg^2(45^o - \emptyset 0/2)\,, \tag{67}$$

As a result of the comparative study of the calculation hypotheses, it was concluded that the maximum loadings arise when the pipes are filled with water and the filler earth exerts passive pressure on the walls of the pipelines.

To evaluate the stress, we grouped the actions according to the following formula:

$$Ed = \gamma G \cdot Gk + \gamma P \cdot \Phi \cdot \alpha P \cdot Pk \; + \; \alpha Q \cdot (\gamma Q1 \cdot Qk1 + \gamma Q2 \cdot Qk2) \; , \qquad (68)$$

where:

Ed - calculation value of the effect of the actions;

Gk - characteristic value of the permanent actions (own weight);

Pk - characteristic value of the temporary action of the road traffic;

Qk1 - characteristic value of the permanent action from the earth filler;

Qk2 - characteristic value of the permanent action from the earth compression;

γG - partial ratio for permanent actions (own weight); γG = 1.35;

γP - partial ratio for the temporary action of the road traffic; γP = 1.35;

γQ1 - partial ratio for the permanent actions from the earth filler; γQ1 = 1.35;

γQ2 - partial ratio for the permanent actions from the earth compression; γQ2 = 1.00;

Φ - dynamic ratio for the temporary action of the road traffic (see table 43);

αP, αQ - heavy traffic loading factors; αP = αQ = 1.10.

Table 43. Adopted values of the dynamic ratio Φ.

H Pipe coverage thickness [m]	Dynamic ratio Φ
≤ 0.50	2.00
0.60 ... 0.90	1.80
1.00 ... 1.50	1.50
1.60 ... 3.00	1.20
> 3.00	1.00

Thus the following formulas result for the groups of actions (see table 44):

Table 44. Calculation formulas.

H Pipe coverage thickness [m]	Ed Calculation formula
≤ 0.50	1.35 · Gk + 3.00 · Pk + 1.50 · Qk1 + 1.10 · Qk2
0.60 ... 0.90	1.35 · Gk + 2.65 · Pk + 1.50 · Qk1 + 1.10 · Qk2
1.00 ... 1.50	1.35 · Gk + 2.20 · Pk + 1.50 · Qk1 + 1.10 · Qk2
1.60 ... 3.00	1.35 · Gk + 1.80 · Pk + 1.50 · Qk1 + 1.10 · Qk2
> 3.00	1.35 · Gk + 1.50 · Pk + 1.50 · Qk1 + 1.10 · Qk2

The stresses were assessed for a selection of pipes used for water distribution networks covering a large range of materials and diameters, as follows:

- round steel pipes: ø 48.3 x 2.6 mm; ø 88.9 x 3.2 mm; ø 114.3 x 4 mm; ø 168.3 x 5 mm; ø 244.5 x 6.3 mm; ø 323.9 x 8 mm; ø 406 x 8 mm; ø 508 x 10 mm; ø 610 x 12.5 mm;
- round (grey and ductile) cast iron pipes: ø 222 x 11 mm; ø 428 x 14 mm; ø 634 x 17 mm; ø 841 x 20.5 mm; ø 1,048 x 24 mm;

- high density polyethylene tubes (HDPE): ø 20 x 2 mm; ø 40 x 2.4 mm; ø 75 x 4.5 mm; ø 110 x 6.6 mm; ø 160 x 9.5 mm; ø 200 x 11.9 mm; ø 250 x 14.8 mm; ø 315 x 18.7 mm; ø 400 x 23.7 mm.

The technical details regarding the geometrical and physical-mechanical characteristics of the building materials were taken from the catalogues provided by the manufacturers and authorized distributors of these items.

Stresses have been evaluated based on the laying depth of the constituents.

For the automated calculation of the stresses, a calculation model was chosen consisting of a continuous beam with a length of 10 m, supported on elastic supports arranged every 1 m along the pipe (see figure 51), uniformly distributed by the assessed load calculations, both horizontally and vertically.

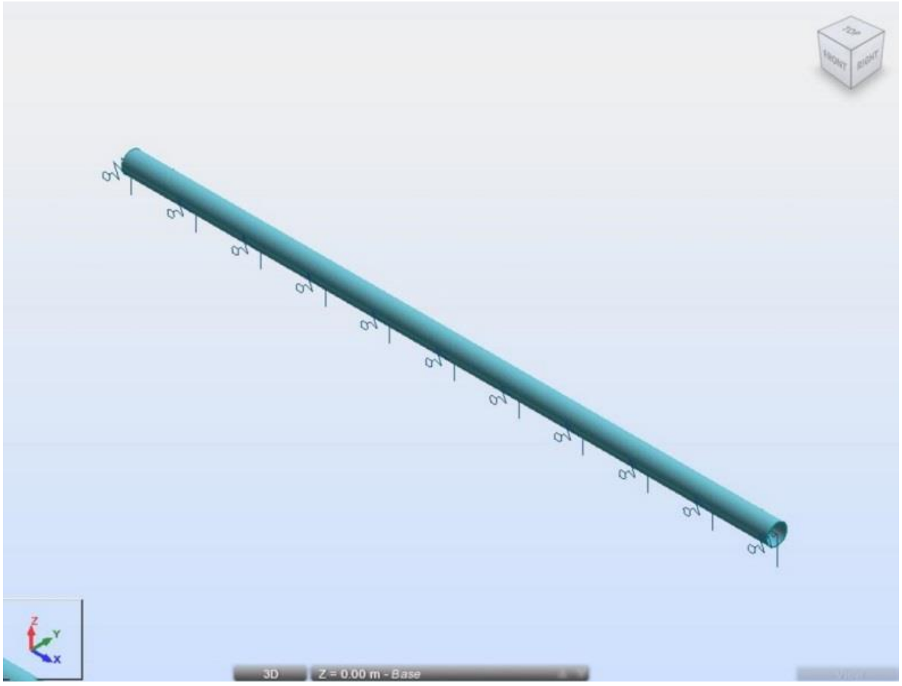


Figure 51. Calculation model for pipes.

3.6.3. Results and Discussions

3.6.3.1. Results

In this study, assessments were made on the loadings occurring in the water distribution pipes subject to heavy road traffic. The case study was conducted for heavy traffic conditions in Romania. The following types of pipes were analysed: steel pipes, grey cast iron pipes, ductile cast iron pipes and high density polyethylene (HDPE) pipes.

a) Steel Pipes

The resistance calculation for the steel pipes was made considering the types of round pipes presented in table 45, having the corresponding geometric and physical-mechanical characteristics. In table 46, its were presented the data used for calculations relating to Ø 48.3x2.6 mm steel pipes, the pipelines being located on a street open to heavy road traffic, the pipe being filled with water, in a ground with underground water.

Table 45. Steel pipes.

No.	Outer diameter [mm]	Wall thickness [mm]	Elastic modulus E [MPa]	Shear modulus G [MPa]	Poisson's ratio μ	Specific weight [kN/m^3]	Yield point [MPa]
1	48.3	2.6	210000	80800	0.30	78.5	235
2	88.9	3.2	210000	80800	0.30	78.5	235
3	114.3	4.0	210000	80800	0.30	78.5	235
4	168.3	5.0	210000	80800	0.30	78.5	235
5	244.5	6.3	210000	80800	0.30	78.5	235
6	323.9	8.0	210000	80800	0.30	78.5	235
7	406	8.0	210000	80800	0.30	78.5	235
8	508	10.0	210000	80800	0.30	78.5	235
9	610	12.5	210000	80800	0.30	78.5	235

Table 46. Action assessment - characteristic values for Ø 48.3 x 2.6 mm steel pipe.

No.	Description	Symbol	Value	M.U.
1	Uniformly distributed pressure - standard semi-axle	p_0	625	kN/m^2
2	Indentation width	l	0.303	m
3	Pipe coverage thickness	H	0.3	m
4	Width of distributed indentation	L	0.903	m
5	Pipe outer diameter	D	0.0483	m
6	Overload volume weight	γ	23	kN/m^3
7	Internal friction angle	Ø	21.7	°
8	Cohesion	c	3.3	kPa
9	Active compression ratio	ka	0.461	
10	Filler volumetric weight	γ_0	19	kN/m^3
11	Internal friction angle	$Ø_0$	25	°
12	Cohesion	c_0	0	kPa
13	Passive compression ratio	kp_0	2.464	
14	Uniformly distributed pressure	pvH	70.37	kN/m^2
15	Uniformly distributed loading - standard semi-axle	pv1	63.5	kN/m
16	Overload	pv2	6.9	kN/m
17	Total vertical loadings	pv	70	kN/m
18	Upper earth compression	pah1	-1.35	kN/m^2
19	Lower earth compression	pah2	18.28	kN/m^2
20	Earth compression	Pah1	0.0	kN/m
21	Earth compression	Pah2	0.4	kN/m
22	Earth compression - overload	Pah	9.2	kN/m
23	Earth compression - total	Pah,total	9.6	kN/m
24	Water volumetric weight	γw	10	kN/m^3
25	Porosity	n	0.33	
26	Volumetric weight of the solid filler framework	γs	26	kN/m^3
27	Volumetric weight of the filler in submersed water conditions	γ'_0	10.72	kN/m^3

In table 46:

- line 6…8 refers to overlay;
- line 10…12 refers to earth around the pipe;
- line 18…23 refers to lateral earth pressure.

The data are entered in a similar way for the other types of pipes.

The results of the calculations for the steel pipes are presented in table 47.

According to the results presented in table 47, in the case of steel pipes mounted under roads subject to heavy traffic, the following conclusions can be drawn:

- 48.3 x 2.6 mm pipes and 88.9 x 3.2 mm pipes have inappropriate behaviour when placed under roads subject to heavy traffic;
- 114.3 x 4 mm pipes behave properly when placed under roads subject to heavy traffic, if they are placed underneath filler earth with heights ranging from 0.9 m to 2 m;
- 168.3 x 5 mm pipes behave properly when placed under roads subject to heavy traffic, if they are placed underneath filler earth with heights ranging from 0.3 m to 6 m;
- 244.5 x 6.3 mm pipes, 323.9 x 8 mm pipes, 406 x 8 mm pipes, 508 x 10 mm pipes and 610 x 12.5 mm pipes behave properly when placed under roads subject to heavy traffic.

Table 47. Results of the calculations for steel pipes.

No.	Coverage thickness [m]	Steel pipes (A = accepted / N = not recommended)								
		Dimensions [mm]								
		48.3 x 2.6	88.9 x 3.2	114.3 x 4	168.3 x 5	244.5 x 6.3	323.9 x 8	406 x 8	508 x 10	610 x 12.5
1	0.30	N	N	N	A	A	A	A	A	A
2	0.40	N	N	N	A	A	A	A	A	A
3	0.50	N	N	N	A	A	A	A	A	A
4	0.60	N	N	N	A	A	A	A	A	A
5	0.70	N	N	N	A	A	A	A	A	A
6	0.80	N	N	N	A	A	A	A	A	A
7	0.90	N	N	A	A	A	A	A	A	A
8	1.00	N	N	A	A	A	A	A	A	A
9	1.10	N	N	A	A	A	A	A	A	A
10	1.20	N	N	A	A	A	A	A	A	A
11	1.30	N	N	A	A	A	A	A	A	A
12	1.40	N	N	A	A	A	A	A	A	A
13	1.50	N	N	A	A	A	A	A	A	A
14	1.60	N	N	A	A	A	A	A	A	A
15	1.70	N	N	A	A	A	A	A	A	A
16	1.80	N	N	A	A	A	A	A	A	A
17	1.90	N	N	A	A	A	A	A	A	A
18	2.00	N	N	A	A	A	A	A	A	A
19	3.00	N	N	N	A	A	A	A	A	A
20	4.00	N	N	N	A	A	A	A	A	A
21	5.00	N	N	N	A	A	A	A	A	A
22	6.00	N	N	N	A	A	A	A	A	A
23	7.00	N	N	N	N	A	A	A	A	A
24	8.00	N	N	N	N	A	A	A	A	A

The meaning of the notations used in table 47 is the following:

- A = accepted; the calculations carried out show that the pipes are resistant to road traffic stresses;
- N = not recommended; the calculations carried out show that the pipes are not resistant to road traffic stresses.

b) Cast Iron Pipes

The resistance calculation for cast iron pipes was made for both grey cast iron pipes and ductile cast iron pipes. The round pipe types presented in table 48 and table 49 with the corresponding geometric and physical-mechanical characteristics were considered. The results of the calculations for the cast iron pipes are presented in table 50.

Table 48. Grey cast iron pipes.

No.	Outer diameter [mm]	Wall thickness [mm]	Elastic modulus E [MPa]	Shear modulus G [MPa]	Poisson's ratio μ	Specific weight [kN/m^3]	Yield point [MPa]
1	222	11.0	110000	44700	0.23	70.5	130
2	428	14.0	110000	44700	0.23	70.5	130
3	634	17.0	110000	44700	0.23	70.5	130
4	841	20.5	110000	44700	0.23	70.5	130
5	1048	24.0	110000	44700	0.23	70.5	130

Table 49. Ductile cast iron pipes.

No.	Outer diameter [mm]	Wall thickness [mm]	Elastic modulus E [MPa]	Shear modulus G [MPa]	Poisson's ratio μ	Specific weight [kN/m^3]	Yield point [MPa]
1	222	11.0	170000	69100	0.23	70.5	200
2	428	14.0	170000	69100	0.23	70.5	200
3	634	17.0	170000	69100	0.23	70.5	200
4	841	20.5	170000	69100	0.23	70.5	200
5	1048	24.0	170000	69100	0.23	70.5	200

Tabel 50. Results of the calculations for the cast iron pipes.

No.	Coverage thickness [m]	Grey / ductile cast iron pipes (A = accepted / N = not recommended)				
		Dimensions [mm]				
		222 x 11	428 x 14	634 x 17	841 x 20.5	1048 x 24
1	0.30	A	A	A	A	A
2	0.40	A	A	A	A	A
3	0.50	A	A	A	A	A
4	0.60	A	A	A	A	A
5	0.70	A	A	A	A	A
6	0.80	A	A	A	A	A
7	0.90	A	A	A	A	A
8	1.00	A	A	A	A	A
9	1.10	A	A	A	A	A
10	1.20	A	A	A	A	A
11	1.30	A	A	A	A	A
12	1.40	A	A	A	A	A
13	1.50	A	A	A	A	A
14	1.60	A	A	A	A	A
15	1.70	A	A	A	A	A
16	1.80	A	A	A	A	A
17	1.90	A	A	A	A	A
18	2.00	A	A	A	A	A
19	3.00	A	A	A	A	A
20	4.00	A	A	A	A	A
21	5.00	A	A	A	A	A
22	6.00	A	A	A	A	A
23	7.00	A	A	A	A	A
24	8.00	A	A	A	A	A

According to the results presented in table 50, the cast iron pipes of 222 x 11 mm, 428 x 14 mm, 634 x 17mm, 841 x 20.5 mm and 1048 x 24 mm mounted under roads subject to heavy traffic behave properly.

c) High Density Polyethylene (HDPE) Pipes

The resistance calculation for high density polyethylene (HDPE) pipes was made considering the pipe types presented in table 51 with the corresponding geometric and physical-mechanical characteristics.

Table 51. HDPE pipes.

No.	Outer diameter [mm]	Wall thickness [mm]	Elastic modulus E [MPa]	Shear modulus G [MPa]	Poisson's ratio μ	Specific weight [kN/m^3]	Yield point [MPa]
1	20	2.0	700	310	0.42	9.5	25
2	40	2.4	700	310	0.42	9.5	25
3	75	4.5	700	310	0.42	9.5	25
4	110	6.6	700	310	0.42	9.5	25
5	160	9.5	700	310	0.42	9.5	25
6	200	11.9	700	310	0.42	9.5	25
7	250	14.8	700	310	0.42	9.5	25
8	315	18.7	700	310	0.42	9.5	25
9	400	23.7	700	310	0.42	9.5	25

The results of the calculations for the HDPE pipes are presented in table 52.

Table 52. Results of the calculations for the HDPE pipes.

No.	Coverage thickness [m]	HDPE Pipes (A = accepted / N = not recommended)								
		Dimensions [mm]								
		20 x 2	40 x 2.4	75 x 4.5	110 x 6.6	160 x 9.5	200 x 11.9	250 x 14.8	315 x 18.7	400 x 23.7
1	0.30	N	N	N	N	N	N	N	A	A
2	0.40	N	N	N	N	N	N	N	A	A
3	0.50	N	N	N	N	N	N	N	A	A
4	0.60	N	N	N	N	N	N	A	A	A
5	0.70	N	N	N	N	N	N	A	A	A
6	0.80	N	N	N	N	N	N	A	A	A
7	0.90	N	N	N	N	N	N	A	A	A
8	1.00	N	N	N	N	N	N	A	A	A
9	1.10	N	N	N	N	N	N	A	A	A
10	1.20	N	N	N	N	N	N	A	A	A
11	1.30	N	N	N	N	N	N	A	A	A
12	1.40	N	N	N	N	N	N	A	A	A
13	1.50	N	N	N	N	N	N	A	A	A
14	1.60	N	N	N	N	N	N	A	A	A
15	1.70	N	N	N	N	N	N	A	A	A
16	1.80	N	N	N	N	N	N	A	A	A
17	1.90	N	N	N	N	N	N	A	A	A
18	2.00	N	N	N	N	N	N	A	A	A
19	3.00	N	N	N	N	N	N	N	A	A
20	4.00	N	N	N	N	N	N	N	A	A
21	5.00	N	N	N	N	N	N	N	A	A
22	6.00	N	N	N	N	N	N	N	N	A
23	7.00	N	N	N	N	N	N	N	N	A
24	8.00	N	N	N	N	N	N	N	N	A

According to the results presented in table 52, in the case of high density polyethylene (HDPE) pipes mounted under roads subject to heavy traffic, the following conclusions can be drawn:

- 20 x 2 mm, 40 x 2.4 mm, 75 x 4.5 mm, 110 x 6.6 mm, 160 x 9.5 mm and 200 x 11.9 mm pipes have inappropriate behaviour when placed under roads subject to heavy traffic;
- 250 x 14.8 mm pipes behave properly when placed under roads subject to heavy traffic, if they are placed underneath filler earth with heights ranging from 0.6 m to 2 m;
- 315 x 18.7 mm pipes behave properly when placed under roads subject to heavy traffic, if they are placed underneath filler earth with heights ranging from 0.3 m to 5 m;
- 400 x 23.7 mm pipes behave properly when placed under roads subject to heavy traffic.

3.6.3.2. Discussions

Analysing the results of the calculations, it is noticed that heavy road traffic primarily affects pipes having a small nominal diameter, namely pipes having a nominal diameter of up to 300 mm.

Also, for the analysed case study, namely the water supply system of the city of Cluj-Napoca in Romania, it was found out that out of the total number of failures, more than 95 % are related to the water connecting pipes and distribution pipes.

As pipes have to satisfy both hydraulic requirements and road traffic resistance requirements simultaneously, we recommend that in the case of pipes with the nominal diameter of less than 300 mm, the resistance to road traffic loading should also be checked. Obviously, if the pipes do not withstand the load of the road traffic, than for the same nominal pipe diameter we can choose a pipe with a thicker wall, so that it can withstand the load of the road traffic.

The selection of pipes with a larger wall thickness leads to a reduction in pipe section and obviously to increased pressure losses. As a result of increased pressure losses, it may be necessary for some pipe sections to be necessary to choose larger diameter pipes.

Analysing the failures occurred in the water supply system of the city of Cluj-Napoca, it should be noted that the failures due to road traffic occur as a rule:

- on streets with intense road traffic;
- on streets where heavy road traffic has been deviated;
- on the roads where road repair works have been carried out;
- on old piping sections.

Failures to the water supply systems of localities due to the unfavourable influence of road traffic lead to higher pipeline repair costs, increased water losses, and water losses can also determine damages to other utility networks.

In this context, we recommend that in the Romanian technical regulations regarding the design, operation and rehabilitation of water supply systems to introduce the obligation to analyze the influence of road traffic on the water supply system pipelines. This obvious analysis can be made on the basis of analytical calculations as presented in this study, either by submitting documents from pipeline manufacturers with regard to the minimum and the maximum mounting depths at which pipelines can be fitted, depending on the type of material and depending on the loads resulting from road traffic.

We recommend that technical regulations in Romania should also comprise the obligation that, besides the technical expertise of the roads, the technical expertise of water networks, sewerage networks, methane gas networks and heating networks be conducted in the following cases:

- on the streets where heavy traffic is to be deviated;
- on the streets where road repair and modernization works will be carried out.

Following the expertise of utility networks, a number of conclusions can be drawn, for example:

- the maximum tonnage of the means of transport that will be able to travel on a certain street;
- the determination of the working technology for road infrastructure rehabilitation, namely the type of construction equipment to be used, the weight of the construction equipment, and the type of means of transport to be used;
- the need to replace utility networks along with the modernization of roads;
- the protection measures that need to be taken to protect utility networks.

Applying these measures will ultimately lead to:

- a reduction in the number of failures of utility networks;
- a reduction in the cost of repairs to utility networks;
- an increase in the safety of the utility networks;
- a reduction in the water losses related to the drinkable water distribution system in the localities.

Although the case study has been conducted for heavy road traffic conditions in Romania, Autodesk Robot Structural Analysis Professional 2011 software allows changing the calculation hypotheses so that calculations can be made for other road traffic loads as well as for different materials used for building the water distribution networks.

3.6.4. Conclusions

Based on this study, it is found that street road traffic exerts a certain influence on the constituents of the water distribution networks, depending on the building materials and the geometric configurations of the constituents, capable of generating defects of the water distribution networks. Therefore, preventive measures are recommended to avoid such situations.

Based on the results obtained from the analytical calculation, we noticed that heavy road traffic primarily affects the pipes with a small nominal diameter, i.e. pipes with a nominal diameter of up to 300 mm. In this context, we recommend that for pipelines with a nominal diameter of up to 300 mm located on roads with heavy road traffic, to carry out a verification of the strength of these pipelines for loads caused by heavy road traffic.

Obviously, if the pipes do not withstand the load of the road traffic, than for the same nominal pipe diameter we can choose a pipe with a thicker wall, so that it can withstand the load of the road traffic. The selection of pipes with a larger wall thickness leads to a reduction in pipe section and obviously to increased pressure losses. As a result of increased pressure losses, it may be necessary for some pipe sections to be necessary to choose larger diameter pipes.

The results of the research are useful in the design phase of water distribution networks, so depending on the type of pipe material, the minimum mounting depth can be indicated, so as to avoid the failure of the pipes due to road traffic.

The proposed method leads to the avoidance of failures in water distribution networks due to the unfavourable action of road traffic, so this method is a proactive method that is preferable to the reactive practice of rehabilitation of water distribution networks, i.e. after a failure.

During the phase of water distribution networks exploitation, the areas where street traffic can lead to water pipeline network failures can be established.

In the perspective, we are considering writing an article on the effect of dynamic loads and vibrations due to heavy road traffic on water distribution networks.

In the future, similar studies could also be conducted, regarding the negative influence of road traffic on sewerage networks, gas networks and thermal networks.

3.7. Establishment of a Method of Protection of Above-Ground Fitted Pipelines Corresponding to the Fluid Storage Tanks

The professional activity carried out mainly as a plant engineer, together with the research activity in the field of Plant Engineering, has led to outstanding results, materializing in the **Invention Patent no.126695/30.12.2013 -** Granted according to the provisions of Law no. 64/1991 in patents for inventions, republished in the Official gazette of Romania, Part I, no. 541, dated August 8th 2007.

Holder: AIB CONSULTING SRL, CLUJ-NAPOCA, CJ, RO

Title of the invention: **ACTIVE SYSTEM FOR THE PROTECTION OF PIPES RELATED TO FLUID STORAGE TANKS**

Inventors: Badea Gheorghe, Cluj-Napoca, **AŞCHILEAN IOAN**, Cluj-Napoca, Romania.

Description of the invention, the claims and drawings at which reference is made in these items are an integral part of the patent for invention hereto.

The invention refers to an active system for the protection of the pipes related to fluid storage tanks, in order to avoid freezing during operation.

In order to protect the pipes related to the fluid storage tanks, a system that comprises electric resistances included in a carpet that is rolled over the pipe and that protects in this manner the occurrence of freezing, irrespective of the minimum exterior temperature is used (US 5714738).

The disadvantages of this solution are those that it is affected by environmental conditions and the energy consumption is not optimum.

The technical problem proposed is that of maintaining the temperature of the pipes related to the tanks for the storage of different fluids above the freezing temperature of the respective fluids, with permanent control of temperature, irrespective of the environment in which the pipes operate and the notification of possible defects in the area in which these pipes are exploited.

The active system for the protection of the pipes related to fluid storage tanks eliminates the above mentioned disadvantages due to the fact that it comprises of a local heating assembly, with a set of individual electric resistances' assemblies, as resistances covered in asbestos layers and mechanic protection layers, assembled by means of lateral sippers in order to cover the entire length of the protected pipe over which the resulted carpet is rolled over and is covered with a mechanical protection layer and a sub-control system comprising of a control unit that develops the directions for controllers that supply each and every electric resistance, in respect of the value of the temperature in the tank, from the exterior of the tank and from the segment of the resistance directed in such a manner so that the freezing shall not occur.

The advantages of the invention are: robust, supple, economic protection that does not affect the resistance of the environment in which the tank us disposed, adaptability of the protection to the actual conditions of the environment in which the pipes operate, simplicity in exploitation, easiness of intervention in case of breakdown.

Below, please find an example of developing the invention and in relation to figures 52, 53, 54, 55 that present:

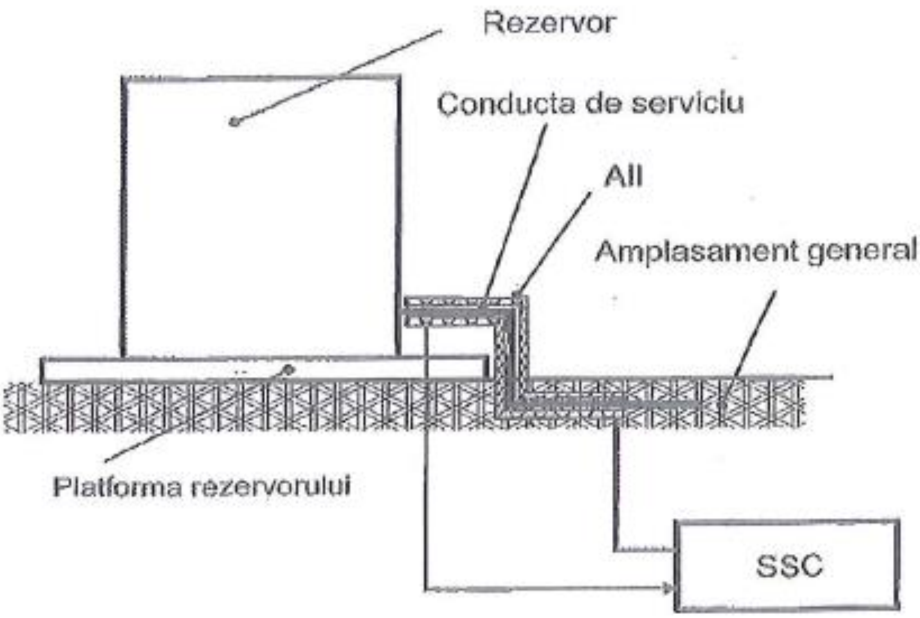


Figure 52. A schematic diagram of positioning the pipe to the served tank

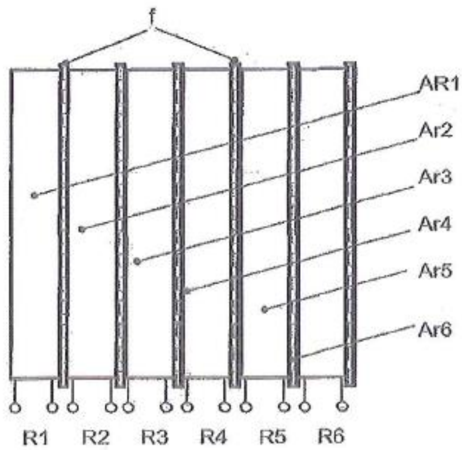


Figure 53. The basic diagram for the assembly of resistances of the local heating layer

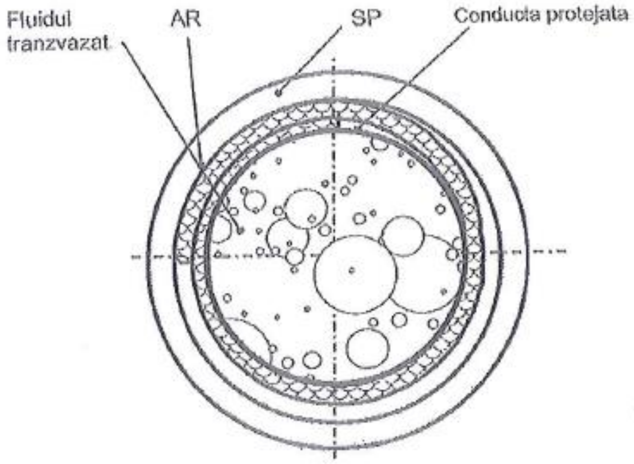


Figure 54. Transversal section in a pipe provided with electric resistances assembly and the mechanical and thermal protection layer of the assembly

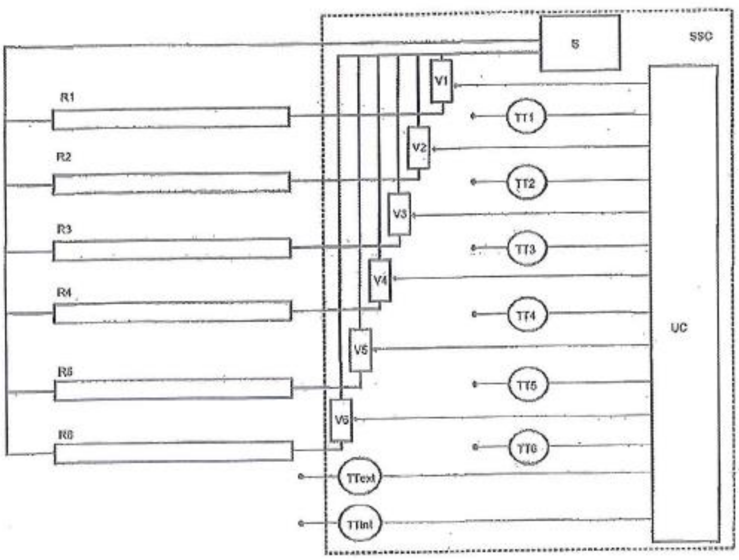


Figure 55. Electric basic scheme of the system for the command of the protection electric resistance assembly

The protection active system, according to the invention, comprises of a local heating assembly AII and the related SSc sub-control system.

The local heating assembly AII comprises of a set of individual electric resistance assemblies (AR1, AR2, AR3, AR4, AR5 respectively AR6) performed by a metallic conductor thread, comprised between two asbestos electric insulation and two mechanical protection layers made of fire-resistant materials. The electric resistance assemblies made up in this manner have at one end the terminals of the related electric resistance (R1, R2, R3, R4, R5 respectively R6), and on the side, certain zipper assemblies type f, with the use of which the individual electric resistance assemblies can be put together in a local heating assembly AII, in order to form a carpet with the width equal to the length of the sector of the pipe that shall be protected. The carpet performed in this manner is rolled over the pipe to be protected so that its circumference shall be fully covered and, at least, another quarter of the circumference. The roller obtained in this manner is connected with circular belts and then covered through rolling with another CP carpet, from a material intended for mechanical protection.

During operation, a SSC command sub-system, comprising of a UC control unit that receives the information upon the value of the temperature that corresponds to each pipe sector covered with each individual electric resistance assembly from certain transducers TT1, TT2, TT3, TT4, TT5 and respectively TT6, upon the value of the temperature of the fluid in the tank with the use of the IIint transducer and upon the value of the exterior temperature of the environment TText. The SSC command system develops, for each local heating assembly, a separate command applied to a controller V1, V2, V3, V4, V5 respectively V6 so that the global temperature of the protected pipe shall prevent the occurrence of freezing.

The command for each controller shall be developed according to the generic rules:

#R1: If the interior temperature is tint, the exterior temperature is text so that text<to and tint~text then the command unit (UC) increases the command for each controller (Vi, I = 1…6) for reaching the temperature t1 ~ t2 ~ t3 ~ t4 ~t5 ~ t6 ~ 0 respectively

#R2: If the interior temperature is tint, the exterior temperature is text so that text ≥ t0 and tint~text then the command unit (UC) stops the command for each and every controller (Vi, I = 1…6)

Claims

1. An active system for the protection of the pipes related to fluid storage tanks, in order to avoid freezing during operation, comprising of a local heating assembly (**AII**), in which the protected pipe is included and that does not penetrate the foundation of the tank, that comprises a set of individual electric resistances (**AR1, AR2, AR3, AR4, AR5** and respectively **AR6**), each of them made of a metallic conductor thread, included between two insulating electric layers made of asbestos and two mechanical protection layers made of fire-resistant material, each of them with an independent electric resistance (**R1, R2, R3, R4, R5** and respectively **R6**), and on the side of the individual assembles zippers are provided (**f**) that could be put together in a carpet with the width equal to the length of the pipe sector that shall be protected, assembly that occurs as a carpet being rolled over the pipe to be protected so that its circumference would be fully covered and at least a quarter of the circumference, and

the roller obtained is connected with circular belts and then covered also by rolling with another protection cover **(CP)** made of a material intended for mechanical protection, the adequate temperature being provided by a control sub-system **(SSC**), **characterized by the fact that** during operation, the command sub-system **(SCC)** comprises of a control unit **(UC)** that received the information with respect to the value of the temperature that corresponds to each sector of the pipe covered with each sub-assembly of individual electric resistance from certain transducers (**TT1, TT2, TT3, TT4, TT5** respectively **TT6**), upon the value of the temperature of the fluid in the tank, with the use of the interior transducer (**TTint**) and upon the value of the exterior temperature of the environment (**TText**) and that develops for each local heating assembly a separate command applied to each controller (**V1, V2, V3, V4, V5** and respectively **V6**) so that the global temperature of the protected pipe shall prevent the occurrence of freezing.

2. An active system for the protection of the pipes, according to claim 1, characterized by the fact that for each controller, the control unit develops a command according to the following rules:

#R1: If the interior temperature is tint, the exterior temperature is t_{ext} so that $t_{ext} < t_0$ and $t_{int} \approx t_{ext}$ then the command unit (UC) increases the command for each controller (**Vi, i = 1…6**) for reaching the temperature $t1 \approx t2 \approx t3 \approx t4 \approx t5 \approx t6 \approx 0$ respectively

#R2: If the interior temperature is tint, the exterior temperature is t_{ext} so that $t_{ext} \geq t_0$ and $t_{int} \approx t_{ext}$ then the command unit (**UC**) stops the command for each and every controller (**Vi, i = 1…6**)

3.8. Establishment of a Method of Functional Isolation of Fluid Storage Tanks

The professional activity carried out mainly as a plant engineer, together with the research activity in the field of Plant Engineering, has led to outstanding results, materializing in the **Invention Patent no. 126490/30.08.2013 -** Granted according to the provisions of Law no. 64/1991 in patents for inventions, republished in the Official gazette of Romania, Part I, no. 541, dated August 8^{th} 2007.

Holder: AIB CONSULTING SRL, CLUJ-NAPOCA, CJ, RO

Title of the invention: **ACTIVE SYSTEM FOR FUNCTIONAL INSULATION OF FLUID STORAGE TANKS**

Inventors: Badea Gheorghe, Cluj-Napoca, **AŞCHILEAN IOAN**,Cluj-Napoca, Romania.

Description of the invention, the claims and drawings at which reference is made in these items are an integral part of the patent for invention hereto.

The invention refers to an active system for the functional insulation of the fluids storage tanks, such as those for liquid or gases, tanks through the walls of which supply or distribution pipes pass.

In order to insulate the working holes of the tanks or of the fluid storage chambers, through the walls of which supply or distribution pipes pass, hereinafter referred to as service pipes, a solution that implies an inflated ring with a chamber in which pressure fluid is introduced is known (patent NL 1010029).

The disadvantages of this solution are related to the fact that the insulation depends in a definite manner on the quality of the chamber and that the modification of the fluid pressure acts on the overall circumference of the insulation area; the potential fluid leaks from the inflatable chamber are fatal to the insulation.

The problem that is solved by the invention is the development of a manner to insulate and separate the two parts of the walls of a fluid storage tank, so that the fluid losses shall be avoided and the defects/abnormal states shall be detectable, for the rapid intervention of technical services.

The active system for the functional insulation of the fluids storage tanks, according to the invention, eliminates the above mentioned disadvantages, due to the fact that is comprises of two parts, an interior pipe that comes from the interior part of the tank and passes through the hole performed in the storage tank wall and that is provided with a flange, and another exterior pipe that continues towards the exterior part of the tank and that is provided with another flange, on the interior pipe, an elastic chamber is provided, that is circular and has only one inflatable chamber, and then a mobile circular ring on the interior pipe, the flange of the interior pipe and the mobile ring being fixed by means of screws in two other rigid rings on the interior side, respectively on the exterior side, of the wall of the tank in which threaded holes are provided and between the flange of the exterior pipes and the wall of the tank, respectively between the mobile ring on the interior pipe and the interior part of the wall of the tank, distance items are introduced that have an interior diameter similar to the diameter of the hole, and that have, each, flanges, the pressing of the elastic piece being performed between the mobile ring on the interior pipe and the distancing part in the interior part of the tank, respectively between the flange of the pipe within the interior part of the tank and the flange from the exterior, of the second distancing part.

The elastic part has certain separate chambers so that it could be independently inflated. The elastic part comprises of elastic chambers, that could be independently inflated, as a carpet formed by means of side zippers or staples and that is afterwards rolled on the pipe to be insulated, prior to the inflating process.

The insulation of the working pipe is made by using the elastic chamber, made up by siding inflatable strips and pressing the pipe by means of two mobile rings on the working pipe and the immobilization of these rings against the rings on the wall of the tank or against the distancing parts.

The automation system is provided with a compressors pump that supplies each chamber of the inflatable elastic chamber by means of a valve with electromagnetic drive, driven by a driving unit, according to the pressure that exists in the chamber.

The automation sub-system takes over the information regarding the evenness of the service pipe, by means of a transducer, and develops the pressure increase command in those chambers that could correct the position of the pipe. The automation sub-system warns the human operator with respect to the occurrence of an evenness abatement of the service pipe, by means of a transducer or to the occurrence of certain pressure values in the chambers exceeding the ranges imposed by the designer.

The advantages of the invention are the efficiency of the insulation, the simple assembly, the robustness during movements or compaction of the insulated pipe, the easiness to perform interventions for the adjustment of the insulation level in respect of the exploitation parameters, such as the pressure of the fluid.

The active insulation system, according to the invention, comprises of an Alz insulation assembly and a related SSc control sub-system. The insulation assembly, according to the invention, comprises of a circular inflatable elastic chamber 1, that is introduced over a pipe 2, finalized, at one end, with a flange 3, that comes from the interior of the tank on which it is assembled, by means of a pipe 4, provided with a flange 5, towards the exterior of the tank. On the wall of the chamber, in the interior part, respectively the exterior part, rings are provided 6, respectively 7, provided with threaded assembly holes. The inflatable elastic chamber 1 bend son the flange 3 of the interior pipe, passes below the wall of the chambers and is circularly supported on a mobile ring 8, on the exterior of the interior pipe 2. Both the mobile ring 8, as well as flange 3 of the pipe 2are assembled, by means of the assembling elements 9, that are either screws in the threaded holes in the rings 6, respectively 7.

Some examples are provided below with respect to the development of the investment and in respect of the figure 56 … 63, that stand for the following:

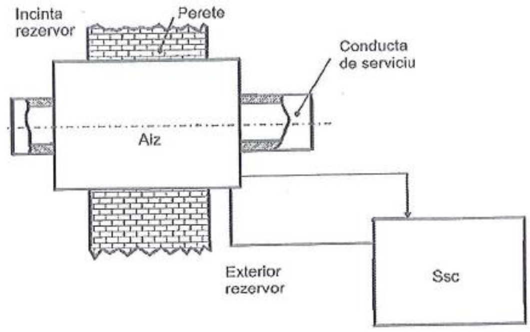


Figure 56. The schematic diagram of the insulation system as a connection in an insulation assembly and of a control sub-system

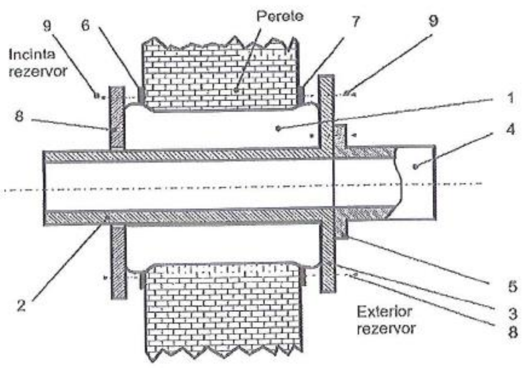


Figure 57. The schematic diagram of the insulation assembly with an inflatable elastic chamber and with support on the wall of the storage tank

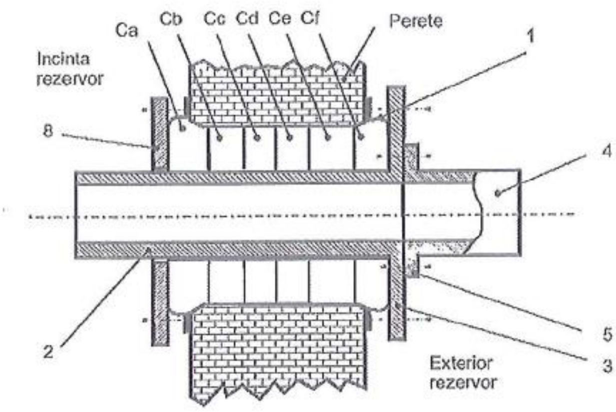


Figure 58. The schematic diagram of the insulation assembly with an inflatable elastic chamber separated in independent sub-chambers and with support on the wall of the storage tank

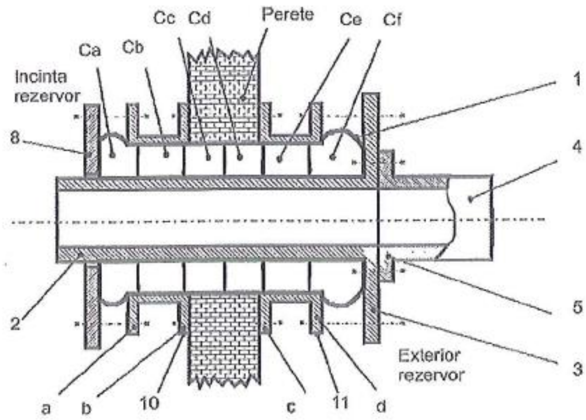


Figure 59. The schematic diagram of the insulation assembly with an inflatable elastic chamber separated in independent sub-chambers and with additional distancing parts

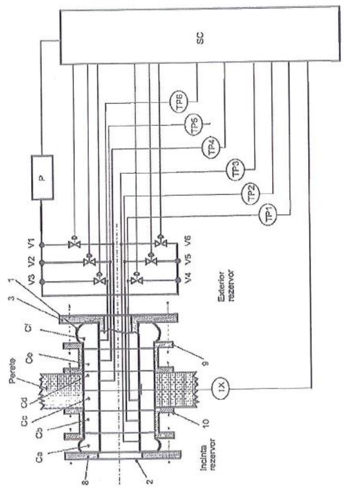


Figure 60. Active insulating system with the insulation assembly with an inflatable elastic chamber separated in independent sub-chambers and with additional distancing parts (with partially distanced pipes)

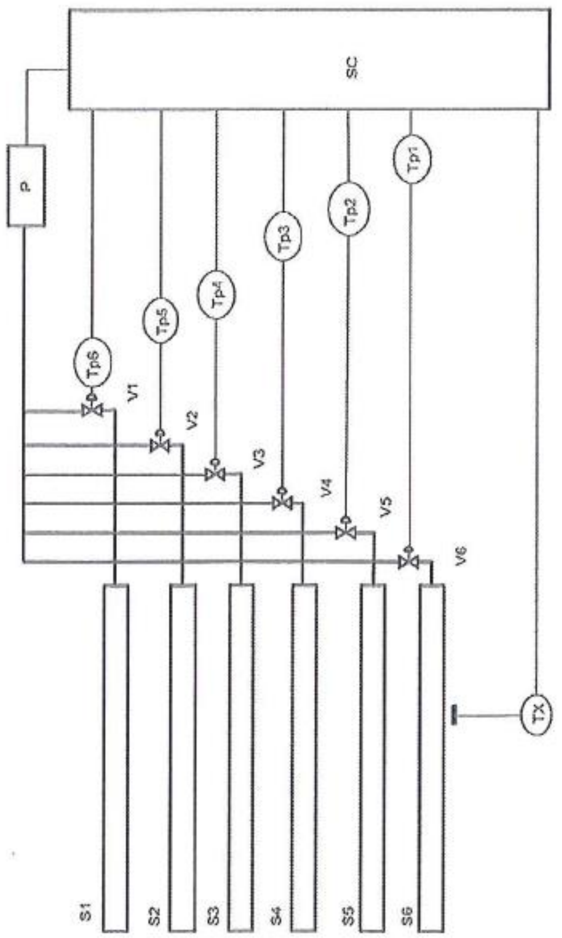


Figure 61. Active insulating system with the insulation assembly comprising of inflatable elastic strips and with additional distancing parts, without the rest of the insulation assembly

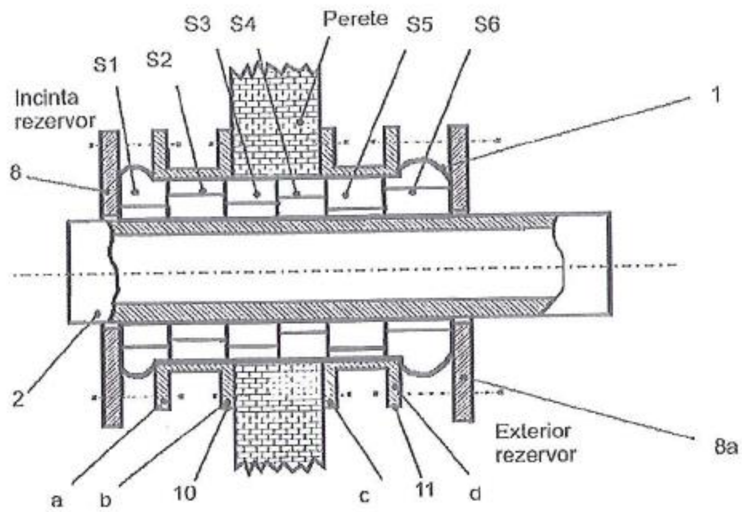


Figure 62. Active insulating system comprising of inflatable elastic strips and with additional distancing parts and with to stiffness rings for the elastic chamber

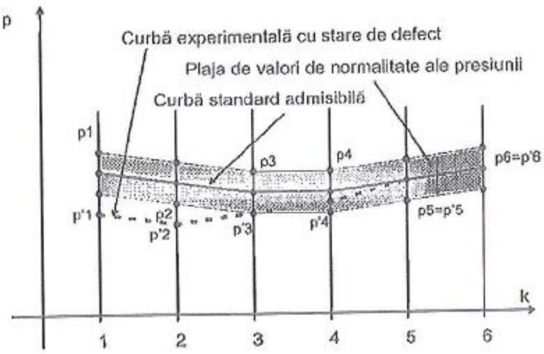


Figure 63. Example of situation in which the active insulating system intervenes for correcting the position of a service pipe

In another example of development, the same assembly has the inflatable chambers 1 separated in independent sub-chambers Ca, Cb, Cc, Cd, Ce and respectively Cf.

In another example of development, between flange 3 of the interior pipe and the ring fixed on the exterior part of the tank's wall 7, and then between the mobile ring 8, and ring 6 fixed on the interior wall of the tank, distancing parts 10 , respectively 11 are introduced; these parts have a diameter large enough so that the pipe 2 passes through them and that there is enough space so that the inflatable chamber 1 shall fit, at a normal diameter, aimed to fill the passing space in the wall. The same distancing parts are provided, at their end, with flanges a and b, respectively c and d, through which assembling elements that fix the intermediary pieces to the stiffened rings on the two faces of the tank's wall, respectively, on the flange 2 and on the mobile ring 8 that is located in the inflatable elastic chamber 1, in inflated state, are passed.

In another example, the insulating inflatable chamber comprises of longitudinal, cylindrical or semi-cylindrical strips (sub-chambers) each of them being inflatable, in their turn S1, S2, S3, S4, S5 respectively S6. The insulating chamber is formed by putting together these sub-chambers, their rolling on the circumference of the pipe that is to be insulated and inflating them.

In order to keep aside the sub-chambers S1, S2, S3, S4, S5 respectively S6, they are connected to one another, two by two, by means of zippers located along the sub-chambers or demountable staples assembled along the sub-chambers also.

In a different development pattern, when inflatable strips are used, the flanges on the service pipes segments can be missed and a new ring 8a can be introduced, located in the exterior part of the tank and stiffened, for example by the distancing part 11.

It should be mentioned that the insulation assembly has the same construction variants when no service pipe is involved, but when a group of pipes is involved, pipes that are reunited in a package, for example, by including a partially insulation material, after which, a s a common body, on the insulation part, the pipes are disposed, under the action of the inflatable body 1, with or without sub-chambers, comprising of ring segments or strips.

The control system of the active insulating system (SSC), according to the invention, comprises of a pneumatic circuit that comprises a compressors' pump P, that provides the inflation of the chamber 1, or of the sub-chambers of chamber 1. The inflation is performed by means of valves with electromagnetic driving system V1, V2, V3, V4, V5 respectively V6, in respect of the value of the pressure measured by means of pressure transducers TP1, TP2, TP3, TP4, TP5 respectively TP6, under the action of a command unit SC. The driving of the value of the pressure in each chamber is performed in respect of the manner in which the hole for the passing of the service pipes closes and of the admissible value of the abatement from evenness with the use of an evenness transducer TX.

In order to develop the action of inflating the sub-chambers, when these chambers exist, the command unit SC shall measure the pressure difference between the real measured value of the pressure that is provided by the designer of the system by means of a range of values in which all pressure measuring points intervene, being either p1, p2, p3, p4, p5 respectively p6.

The occurrence of an inadmissible evenness modification, for example, due to compacting phenomena, shall be corrected by modifying the pressure in the sub-chambers from p'1 to p1, from p'2 to p2 etc until the evenness error is eliminated.

The occurrence of an evenness abatement, that is superior to a prescribed value, shall be notified to the human operator, in order for an intervention to be started, for correcting the position of the service pipe affected.

Claims

1. Active system for the functional insulation of the fluids storage tanks, such as those for liquid or gases, tanks through the walls of which supply or distribution pipes pass, named service pipes, characterized by the fact that it comprises of two parts, an interior part (2) that comes from the interior part of the tank and passes through the hole in the wall of the storage tank and that is provided with a flange (3), and another exterior pipe (4) that is continued towards the exterior part of the tank and that is provided with another flange (5), on the interior pipe (2), an elastic, circular chamber with only one inflatable chamber is disposed (1), and afterwards a mobile circular ring (8) on the interior pipe (2), the flange of the interior pipe (3) and the mobile ring (8) being fixed, by means of screws in two other stiffened rings (6 and 7), to the interior part, respectively, to the exterior part, of the wall of the tank in which threaded holes are provided, and between the flange of the exterior pipe and the wall of the tank, respectively, between the mobile ring (8) on the interior pipe (2) and the interior part or the wall of the tank, distancing parts are introduced (10 and 11) that have an interior diameter similar to the diameter of the hole and that have each certain flanges (a, b, c, and d), the compacting of the elastic pipe (1) being performed between the mobile ring (8) on the interior pipe (3) and the distancing part within the interior part of the tank (10) respectively between the flange (3) of the pipe within the tank and flange (d) from the exterior part of the second distancing part (11).

2. Active system for the functional insulation of the fluids storage tanks as in claim 1, characterized by the fact that the elastic part (1) has separate sub-chambers (Ca, Cb, Cc, Cd, Ce and respectively Cf), so that each of them could be independently inflated.

3. Active system for the functional insulation of the fluids storage tanks as in claim 1, characterized by the fact that the elastic part (1) comprises of elastic chambers, that can be independently inflated (S1, S2, S3, S4, S5 and S6) as a carpet formed by means of lateral

sippers or staples and that is afterwards rolled on the pipe to be insulated (2 and 4) prior to the inflation.

4. Active system for the functional insulation of the fluids storage tanks as in claim 1, characterized by the fact that the insulation of the working pipe (2) is performed by using the elastic chamber (1), comprised by putting together inflatable strips (S1, S2, S3, S4, S5 and S6) and pressing it by means of two mobile rings (8 and 8a) on the working pipe (2) and immobilizing these rings against the rings on the tank's wall (6) or against the distancing parts (10 and 11).

5. Active system for the functional insulation of the fluids storage tanks as in claim 1, 2 and 3 characterized by the fact that the automation sub-system comprises of a compressors' pump (P) that supplies each chamber of the inflatable elastic chamber (1) by means of one valve with electromagnetic driving system (V1, V2, V3, V4, V5 respectively V6) at the command of a command unit (SC) in respect of the pressure that exists in the chamber TP1, TP2, TP3, TP4, TP5 respectively TP6.

6. Active system for the functional insulation of the fluids storage tanks as in claim 1, 2, 3 and 6 characterized by the fact that the automation sub-system takes over the information with respect to the evenness of the service pipe (2 and 4) by means of a transducer TX and develops the command to increase pressure in those chambers (8, Cb, Cc, Cd, Ce, Cf an S1, S2, S3, S4, S5 and S6) that could correct the position of the pipe.

7. Active system for the functional insulation of the fluids storage tanks as in claim 1, 2, 3 and 6 characterized by the fact that the automation sub-system notifies the human operator with respect to the occurrence of an evenness abatement, by taking over the information with respect to the evenness of the service pipe (2 ad 4) by means of a transducer TX or with respect to the occurrence of a value of the pressures within the chambers that exceed the ranges imposed by the designer.

3.9. Final Remarks

As a result of the case studies, it was found that the water supply system of the City of Cluj-Napoca is non-homogeneous both from the point of view of the materials used and their age. New pipelines are currently in operation, along with pipelines having over 100 years.

The rehabilitation of the system can not take into account the 2.4-3.6% ratio of renewal of the pipes resulting from the classification into the normal duration of operation, given that 57.3% of the system, respectively approx. 275 km have already exceeded this duration, and observance of the indicated percentage would lead to an annual rehabilitation of only 15 km, much lower than the one requiring rehabilitation.

When initiating the rehabilitation program, it will be necessary to take into account the increase in the number of faults in the system and the regression coefficients to be determined according to the length of the sections planned to be rehabilitated.

For an estimate of the number of kilometres to be rehabilitated per year in order for the system to meet its normal duration of operation, pipeline rehabilitation should be done in such a way that the number of faults per km and losses in the system do not exceed the cost level that can to be borne by the supplier company, while observing the requirements of continuous water supply for consumers.

An excess of water loss has been found, which leads to high production costs and, implicitly, to the economic inefficiency of the company. Better tracking of losses and implementation of programs for the priority rehabilitation of high loss sectors, in the asbestos pipeline area, is recommended.

Multi-criteria analyses have been successfully applied for the choice of pipelines to be rehabilitated and subsequently for the establishment of the rehabilitation technology.

The study has shown that the first measure to be adopted by the company is the rehabilitation of asbestos pipes. According to this study, it can be done with the Slipline method, by introducing a polyethylene pipe into the old pipeline, without having to be removed or destroyed.

By adopting rehabilitation technologies without excavation, such as the Slipline method, environmental interventions are minimal, thus reducing the social implications and damage to the road traffic in the area.

During the rehabilitation and modernization, the economic, ecological and social factors should be taken into account equally.

In the case of conflicts between social, economic or environmental interests, the environment aspect remains at the forefront because ecological resources can not be restored through material benefits. Damage to the ecosystem can cause social and economic catastrophes that can be very difficult to recognize in the initial phase of decision-making.

Due to the findings of the case studies on the major influence on the pipeline the repairs carried out in the road system and traffic in the area, it is necessary to develop standards regulating the following:

- the intensification of traffic or its change from easy traffic to heavy traffic can be achieved only after the area has been assessed by experts in terms of the stresses transmitted by the newly proposed traffic on the pipelines existing in the area;
- the design and execution of road rehabilitation or modernization works and the selection of specific execution technologies will be based on an expertise in pipeline statics.

In general, the water supply systems in Romania are obsolete, so each water supply company will have to analyse the need to increase the rehabilitation or modernization percentage in the existing pipeline fund from 3% as specified by specific technical standards to a higher percentage, so that systems can be made more technically and economically efficient and more environmentally friendly.

C. PROFESSIONAL, SCIENTIFIC AND ACADEMIC CAREER EVOLUTION AND DEVELOPMENT PLAN

The profession we practice - Construction and Plant Engineer, requires the implementation and maintenance of high quality professional standards. It also implies continuous information on research and discoveries in the field, concerning new methods, techniques and technologies of engineering design and execution, respectively on the new research directions identified. Our experience as a university teaching staff offered us instead the chance to pass on the knowledge gained. Every field - professional, didactic and research, taken separately, offers uncontested professional satisfaction. Taken together, they can equally represent a challenge, but also the chance of generating exceptional results.

C1. Scientific

The academic career development from a scientific point of view will follow the research and expertise directions acquired so far in the fields of:

- Water supply systems;
- Energy-efficient buildings;
- Alternative energies;
- Hybrid power generation systems;
- Sustainable development in the field of construction.

The **priority direction of development** of the academic career from a scientific point of view is to create an interdisciplinary and multidisciplinary research team for participation in research, development and innovation programmes financed by the governmental and European institutions, the activity being directed towards applying for and winning projects/grants for calls to be opened in the future.

I am currently responsible for the project from the part of ZEOLITES PRODUCTION S.A. company, a project under implementation, with the title "Achieving the Transfer of Acquired Knowledge and Technologies Developed by INCDO-INOE 2000, ICIA Subsidiary in the Field of Materials for their Implementation in Romanian Enterprises, TREND" SMIS Code: 105654; Financing agreement no.: 7/01.09.2016, financed by the 2014-2020 Competitiveness Operational Programme. Axis 1 - Research, Technological Development and Innovation (RDI) in Support of economic competitiveness and business development, Action 1.2.3 Knowledge Transfer Partnerships, POC-A1-A1.2.3.-G-2015 Competition. Project partners: National Institute for Research and Development for Optoelectronics INOE 2000, ICIA Cluj-Napoca Branch and Zeolites Production S.A. Within the partnership, research activities have been proposed for the achievement of some products and technologies, as follows:

- Absorbent material obtained from zeolite material for the containment of ammonium and hydrogen sulfide from contaminated environments (wastewater).
- Absorbent material obtained from zeolite material for the absorption of hydrocarbons from contaminated environments.
- Complex fertilizer obtained by absorption of nutrients and pesticides in the zeolite volcanic tuft.

- Zeolite filters for the containment of specific contaminants (Fe, Mn) for drinking-water treatment at treatment and sewage purification plants.

- Filtering material based on zeolite material for heavy metals and radioactive substances.

Continuation of **research directions** in the field of sustainability of water supply to localities, including: sustainable exploitation of fresh water resources, preservation of unpolluted groundwater, avoidance of all situations of deterioration of the already polluted underground water quality, maintenance of polluted underground water quality at a level enabling it to be treated for obtaining drinking water qualities, increase in the knowledge on water resources and development of an appropriate database, integrated water management and protection, substantiation and operationalization of economic and tax instruments for water resource management and distribution networks, reduction or elimination of polluting practices.

Continuation of the **research directions** on sustainable development in the field of construction, which will focus on the following themes: quality management in buildings, tools and techniques for the realization/implementation of energy-efficient buildings, efficient use of natural resources in buildings and permanent dissipation of the negative impacts on the quality of the environment, the use of alternative sources of energy generation in stationary applications.

Opening of new research directions based on our experience in Romania and adapted to the current technological, ecological, economic and social context, being closely related to the European and international trends. In this regard, we propose to approach the concept of a polygenerative energy system, which implies the possibility of obtaining multiple forms of useful energy from the renewable resources: electricity, thermal energy (heat), mechanical energy from steam, chemical energy under the form of hydrogen (fuel), energy for cooling and light flow emission. Another theme we want to develop in our research activity is the use of hydrogen for energetic support (electricity and thermal energy) of buildings. In this respect, we propose the following objectives:

- expanding research on the implementation of hybrid power generation solutions for energetic support of standard residential consumers, but also for energy-efficient commercial and industrial applications;

- carrying out a study outlining the socio-economic perception, the viability and public acceptance by Romania on the use of hydrogen as an energetic alternative and the regional transition to hydrogen-based sustainable and green energy generation systems;

- the development of a database to create the necessary premises for the elaboration of procedures, norms and standards regarding the design, execution and safe operation of alternative energy systems, having as a domain the stationary applications, as well as the elements regarding the production, storage, transmission and distribution - the infrastructure needed to develop an economy based on alternative energies.

Other **career development objectives** from the scientific point of view are:

- Disseminating the results achieved so far in the research activity, in publications indexed in relevant international databases.

- Obtaining and disseminating new research results, publishing papers in scientific journals, and participating in prestigious scientific events in the field, indexed in ISI Web of Knowledge and Scopus.
- Continuing the publishing of specialized books at international publishing houses.
- Developing collaboration relations with prestigious universities / research centres in Romania and abroad for the application of project proposals in order to access structural funds and governmental, European and international financing.
- Developing cooperation relations with entities from the private economic environment in order to access the structural funds and governmental, European and international financing.
- The annual organization of the *"Modern Science and Energy"* scientific conference, a conference with a significant tradition for the Romanian Association of Plant Engineers - Transylvania Branch, which has been organized since 1981 in order to be established as a multidisciplinary platform for the exchange of ideas between academics, researchers and engineers in energy companies across the chain of production, storage, transmission and use. The interest raised among the specialists by the theme "Energy as a Global Issue of Humanity, in Harmony with the Environmental Protection" led to the decision to organize this conference every year, without interruption, from 1981 until 2019, when it reached at its 38th edition. The importance of both the theme of the conference and obviously of the research led to the organisation of the 10^{th} Edition of the "International Conference on Hydrogen Production" and the 3^{rd} Edition of the "International Conference on Research, Innovation and Commercialisation" under the dome of this edition of the "Modern Science and Energy" International Conference.
- Increasing the personal scientific reputation, but also the scientific reputation of the research teams, the department, the faculty and the university.

C2. Academic

The development of the academic career will be carried out especially for the subjects in the staff organizational chart of the Department of Civil Constructions and Management - Faculty of Civil Engineering within the Technical University of Cluj-Napoca, namely: Water Supply I and Quality Management in Construction.

Throughout the academic career, there was a concern to provide teaching materials: courses, books and teaching support materials for the subjects taught. In the future, the following objectives are envisaged: the continuation of the publication of new teaching materials, the permanent updating and the revision of the previous published courses.

In order to improve the teaching activity, the courses and the application part will be uploaded on electronic media, so that students can have access before the course to the teaching material or applications, in order to change the traditional classes into interactive ones by replacing the monologue with the dialogue. In this case, students will be able to focus on understanding the phenomena within the studied field, promoting the development of students' constructive and innovative critical spirit, teamwork skills and competitive spirit. We will also encourage the development of a professional attitude in the students' work, as well as the respect for the historical, cultural and heritage values, especially to the national heritage represented by buildings.

As far as the tutorial classes, the laboratory classes and the Bachelor and Master's degree theses are concerned, we will pursue that the themes proposed for the students to be topical, favouring the work on site in specialized economic units (design and execution of construction works and plants/installations) for the collection of basic data and the practical acquisition of techniques, tools, and methods of achieving the proposed themes.

Given the activities carried out in the personal professional activity in the field of civil engineering (design, project verification, expertise and technical assistance, energy audit of buildings), they can create opportunities for practical training of students through study tours and student practical training in private companies and public institutions activating in the field, so that the link between theory and practice is primordial, but also for the involvement of students in the organization of extracurricular educational activities.

Together with the specialty teaching staff within the Department of Civil Engineering and Management of the Faculty of Civil Engineering, as well as with specialists from other departments of the Technical University of Cluj-Napoca, we propose the organization of postgraduate courses for the professional training of specialists in the field of energy efficiency of buildings, and the organisation of a summer school on the use of alternative hybrid energies in stationary applications.

C3. Professional

Our professional experience is the foundation of the career development plan and also gives it a high probability of achievement. The proposed scientific and academic objectives originate from our own education and professional experience. So, as an engineer, we have created the necessary technical skills and we have developed planning, organization, management, communication, analysis, control and evaluation skills in the field of construction.

The education and professional experience gained throughout the career have resulted in a series of certifications and authorizations, of which the most relevant are the following:

Prevention Expert - Technological Risk Reduction - Ministry of Labour, Family, Social Protection and Elderly and Ministry of National Education and Scientific Research;

Project Inspector for industrial technological fitting works: 26, 2651, 27, 3511, 353, 3320, 36, 37, 38, 39, 49, 70, 712, 72 - Ministry of Economy, Commerce and Business Environment;

Technical Expert on Surface Technology / Upstream Power Supply Systems Related to EGp Natural Gas Production, EGt Natural Gas Transmission Systems and Surface Technology Related to EGs Natural Gas Storage - Romanian Energy Regulatory Authority;

I D Degree Authorization - design, technical approval of projects, as well as coordination of execution, exploitation, reception and commissioning of works - distribution systems, natural gas use installations - Romanian Energy Regulatory Authority;

IT Degree Authorization – design, technical approval of projects for execution, coordination of works execution, operation, reception and commissioning - production, storage, natural gas transmission and use installations - Romanian Energy Regulatory Authority;

EGIU Authorization for the installation and operation of natural gas / biogas / biomethane installations - Romanian Energy Regulatory Authority;

PGIU Authorization for the installation and operation of natural gas / biogas / biomethane - Romanian Energy Regulatory Authority;

EGD Authorization for the execution and operation of biogas / biomethane distribution systems, production/storage installations - Romanian Energy Regulatory Authority;

PGD Authorization for the execution and operation of biogas / biomethane distribution systems, production/storage installations - Romanian Energy Regulatory Authority;

Grade IIIA, IIIB Electrical Engineer - Design/execution of electrical installations with any technically feasible installed power and at a maximum non-nominal voltage of 20kV - Romanian Energy Regulatory Authority;

Quality and extrajudicial technical expert authorized to expertise electrical installations projects and their execution limited to the competencies of licensed electrician - Romanian Energy Regulatory Authority;

Inspector of electrical installations projects or electrical parts within complex projects limited to the competencies of licensed electrician - Romanian Energy Regulatory Authority;

Energy auditor for the construction of building and AE.I. c.i. installations - Ministry of Regional Development and Tourism;

Execution Technical Officer - Edilitary and township management constructions - area IX, Ministry of Transport, Constructions and Tourism;

Site manager for the fields: technical-edilitary works - water supply and sewerage and networks; electrical installations; plumbing, thermo-ventilation; gas installations; electrical networks; thermal networks - Authorization no. 17499/2010 - State Inspectorate for Constructions;

Site manager for the field: telecommunication networks; gas networks; networks for the transport of petroleum products - Authorization no. 17500/2010- State Inspectorate for Constructions;

Professional objectives can be synthesized as follows:

- Obtaining the technical-professional attestation for construction specialists with the competence of technical expert / project inspector in accordance with the Order of the Minister of Regional Development and Public Administration no. 2264 of 28.02.2018 for the following fields: indoor building installations, building electrical installations, gas installations, outdoor sewage systems, water supply and fire extinguishing systems, thermal networks.
- Continuous documentation on new methods, materials, tools, techniques and technologies in the field of construction.
- Expanding personal experience in related fields and gaining new professional competencies and skills, especially in the field of renewable energies and hydrogen for their integration into stationary applications.

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