Transilvania
University
of Brasov

HABILITATION THESIS

Title: MUTIDISCIPLINARY RESEARCH IN MECHANICAL ENGINEERING

Domain: Mechanical Engineering

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University *Transilvania* of Brașov

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Contents

Acknowledgements

The habilitation thesis must prove the ability of doing research and conducting research. In most cases the work of research takes a long time and is made by a group of people not just by the author of this thesis. I want to aqnowledge here the help provided by the coleagues who accepted to follow my research ideas over the years.

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Brașov, Lecturer. eng. Gabriel NĂSTASE PhD

List of notations

R_{cw}	thermal resistance of double skin façade curtain wall;
$U_{cw,1}$	overall heat transfer coefficient of inner envelope;
$U_{cw,2}$	overall heat transfer coefficient of outer envelope;
R_{si}, R_{se}	superficial heat transfer resistance from inside and outside;
R_s	heat transfer resistance of ventilated or unventilated air layer between inner and outer envelope;
Q_i	heat transfer rate to inner surface on inner envelope;
Q_{gi}	heat transfer rate through inner glass pane of inner envelope;
Q_b	heat transfer rate of argon layer between inner envelope glass panes;
Q_{ge}	heat transfer rate through outer glass pane of inner envelope;
Q_{cav}	heat transfer rate of air layer inside cavity between inner and outer envelope;
Q_{ss}	heat transfer rate through secure glass pane of outer envelope;
Q_e	heat transfer rate to outer surface on inner envelope;
A	frontal area of box double skin façade;
h_{ri}	radiation heat-transfer coefficient for inner surface of inner envelope;
h_{re}	radiation heat-transfer coefficient for outer surface of outer envelope;
h_{rb}	radiation heat-transfer coefficient for flow between interior window panes;
h_{cav}	radiation heat-transfer coefficient for flow between interior and exterior envelope;
h_{ci}	convection heat-transfer coefficient for inner surface of inner envelope;
h_{ce}	convective heat-transfer coefficient for outer surface of outer envelope;
h_{cb}	convective heat-transfer coefficient for flow between interior window panes;
h_{ccav}	convective heat-transfer coefficient for flow between interior and exterior envelope;
T_i	air temperature inside experimental room;
T_e	air temperature outside box double skin façade;
T_1	temperature of inner surface of inner window pane;
T_2	temperature of outer surface of inner window pane;
T_3	temperature of inner surface of outer window pane;
T_4	temperature of outer surface of outer window pane;
T_5	temperature of inner surface of secure glass pane;

T_6	temperature of outer surface of secure glass pane;
R_a	Rayleigh number for argon layer inside double pane interior window;
R_{acav}	Rayleigh number for air layer inside box double skin façade cavity;
σ	Stefan-Boltzmann constant;
ε	glass emissivity;
β	bulk expansion coefficient;
g	gravitational acceleration;
H	height of box double skin façade;
L	distance between the two panes of interior window, in mm;
L'	distance between the two envelopes, in mm;
$\nu_{argon/air}$	kinematic viscosity of between-panes gas (argon/air);
$a_{argon/air}$	thermal diffusivity of between-panes gas (argon/air);
$k_{b/cav}$	thermal conductivity of between-panes gas (argon/air);
AR	aspect ratio, H/L;
Nu_b	Nusselt number value for argon layer inside double pane window;
Nu_{cav}	Nusselt number value for air layer inside box double skin façade cavity;
Pr	Prandtl number;
U	overall heat transfer coefficient for box double skin façade;
R_i	interior heat transfer resistance;
R_b	heat transfer resistance for argon layer;
R_{cav}	heat transfer resistance for air layer;
R_e	exterior heat transfer resistance;
$\delta_{gi/ge/ss}$	interior/exterior/secure glass thickness;

List of abbreviations

ISI	International Scientific Indexing;
UNITBV	Universitatea Transilvania din Brașov (Transilvania University of Brasov);
HVAC	Heating, Ventialtion and Air Conditioning;
EU	European Union;
RES	Renewable Energy Sources;
DMSO	Dimethyl Sulfoxide;
MRI	Magnetic Resonance Imaging;
MAGLEV	Magnetic Levitation;
ANRE	Romanian Regulatory Authority for Energy;
INCERC	National Institute of Research and Development in Construction and Economics of Constructions (Institutul Național de Cercetare - Dezvoltare în Construcții și Economia Construcțiilor)
BMS	Building Management System
EN	European Norm
ISO	International Standard Organisation
EN ISO	European Norm adopted after a ISO Standard
GMT	Greenwich Mean Time
B-DSF	Box Double-Skin Façade
EC	European Comission
HP	Horse Power
RPM	Rotations Per Minute
RES-E	Renewable Electricity Standard for Europe
UK	United Kingdom
LHC	Large Hidron Colider
TBO	Toluine Blue
3D	Three dimensional
IAQ	Indoor Air Quality
PVC	PolyVinyl Chloride
TBL	Team Based Learning

ICT	Information and Communication Teaching
CAE	Computer Aided Engineering

1. Rezumat (4000-6000 caractere)

Teza de abilitare intitulată „*Cercetări multidisciplinare in Inginerie Mecanică*” prezintă principalele preocupări ştiinţifice, profesionale şi de cercetare pe care le-am desfăşurat de la finalizarea tezei de doctorat, în domeniul *Inginerie Mecanică*, din anul 2014 (diploma seria J, nr. Minister 0000837, în baza Ordinului Ministrului Educației și Cercetării nr. 3181 din 06.02.2015), până în prezent, evidenţiind, totodată şi activitatea desfăşurată de la obţinerea titului de Șef Lucrări universitar (2015) şi până în prezent, dar mai ales preocuparile mele actuale.

De la inceputul carierei universitare și până în present mi-am desfăşurat activităţile precizate în cadrul Universității Transilvania din Brasov, la Facultatea de Construcții, Departamentul de Instalații pentru Construcții, ocupând initial funcția de Preparator Universitar.

Prezenta lucrare este structurată pe 5 capitole şi o bibliografie în care sunt prezentate realizările ştiinţifice.

Primul capitol este dedicat rezumatului în limba română, cel de-al doilea capitol fiind rezumatul tezei de abilitare în limba engleză. În capitolul al treilea sunt prezentate succint realizările științifice și profesionale și planurile de dezvoltare a carierei. Următoarele două capitole reprezintă o continuare a capitolului precedent, în capitolul patru fiind detaliate realizările științifice și profesionale, iar în capitolul cinci fiind prezentate planurile de evoluție și dezvoltare a carierei. Ultima parte a acestei lucrări este dedicată referințelor bibliografice.

Activitatea mea didactică și de cercetare s-a centrat de-a lungul timpului, în sfera domeniului în care am susținut și teza de doctorat, cu precădere în domeniul promovării energiilor regenerabile și al eficienței energetice în mediul construit. Mai recent, după obținerea titlului de Șef Lucrări, activitatea didactică și de cercetare a fost extinsă. Activitatea didactică a fost îmbogățită cu un curs predat la ciclul de Master, *Materiale și Tehnologii Moderne Utilizate in Mediul Construit*. Activitatea de cercetare a fost extinsă și către domeniul energiilor regenerabile, în care am publicat deja două articole ISI, în jurnalul *Renewable and Sustainable Energy Reviews*, cu factor de impact 8,050, unul în care este prezentată situația energiei eoliene din România iar un al doilea despre energia hidroelectrică în țara noastră, de la începuturile ei până în prezent. Activitatea de cercetare a fost direcționată și în sfera aplicării instalațiilor frigorifice în climatizarea de confort pentru clădiri, al instalațiilor de răcire folosind sisteme de transmitere a energiei prin radiație, al analizei performanței energetice a elementelor de construcție și al promovării și aplicării unor metode noi de predare. Desigur, și la această activitate am pregătit o serie de articole ISI, care sunt în recenzie iar altele au fost deja publicate în cadrul unor conferințe indexate ISI. Cea mai nouă activitate de cercetare, care mă preocupă este legată de aplicarea cunoștințelor de frig și criogenie în domeniul Bioingineriei. În acest sens am participat la un postdoctorat la renumita universitate California, Berkeley, S.U.A., unde am fost implicat în cercetarea și dezvoltarea unui sistem de conservarea a materiei biologice la temperaturi sub zero grade, la volum constant și în cercetarea și dezvoltarea unei imprimante 3D pentru printarea de țesuturi, în mediu de azot lichid și în lichid la +4°C. O parte din cercetarile mele referitoare la sistemul de crioconservare la volum constant au fost deja publicate în cadrul unor articole ISI, la diverse jurnale de renume (*International Communications in Heat and Mass Transfer, Biochemical Biophysical Research Communication, Peer J, PLoS One*), iar o parte sunt prezentate și în cadrul acestei teze de abilitare.

De-a lungul timpului am publicat în calitate de prim autor, coautor și autor corespendent, mai mult de 50 de articole și 6 cărți, dintre care 3 ca prim autor și 3 în calitate de coautor.

Relevanța activității științifice și recunoașterea activității naționale și internaționale în domeniul Ingineriei Mecanice este subliniată de publicațiile mele, multe dintre ele în colaborare cu cercetători recunoscuți din țară, din Europa sau Statele Unite. Valoarea reală a studiilor efectuate și a proiectelor de cercetare iese în evidență prin faptul că toate problemele au fost investigate atât printr-o abordare teoretică cu simulări numerice, precum și cu parte experimentală, care să confirme rezultatele teoretice.

Sunt membru în organizații, asociații profesionale de prestigiu, naționale și internaționale, ce au apartenență la organizații din domeniul educației și cercetării.

Creșterea standardelor de excelența academică, vor trebui permanent urmărite și promovate în marea familie din Universitate formată din: studenți, cadre didactice, cercetători și personal auxiliar, implicându-mă activ în toate inițiativele menite să crească importanța și vizibilitatea colectivului Universității.

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2. Summary (4000-6000 characters)

Habilitation Thesis "Multidisciplinary research in Mechanical Engineering" presents the main scientific, professional and research activities that I have carried out since the completion of the PhD thesis in the field of Mechanical Engineering, in 2014 (series J, Ministry No 0000837, based on the Order of the Minister of Education and Research No. 3181 of 06.02.2015), and to this day, highlighting also the work carried out since the obtaining of the title of Lecturer (2015) until now. From the beginning of my university career to the present I have carried out the mentioned activities on Transilvania University of Brasov, at the Faculty of Civil Engineering, the Department of Building Services, initially occupying the position of Assistant.

This paper is structured in 5 chapters and a bibliography in which the scientific achievements are presented.

The first chapter is dedicated to the summary in Romanian, the second chapter being the summary in English. In the third chapter are presented briefly the scientific and professional achievements and the career development plans. The next two chapters represent a continuation of the previous chapter, in chapter four are detailed scientific and professional achievements, and in chapter five are presented the plans for evolution and development of the career. The last part of this paper is dedicated to bibliographic references.

My teaching and research activity has centered over time in the field of my doctoral dissertation, especially in the field of promoting renewable energies and energy efficiency in the built environment. More recently, after obtaining the title of Lecturer, didactic and research activity was extended. The didactic activity was enriched with a Master's course, *Modern Materials and Technologies Used in the Built Environment*. Research has also been extended to renewable energy, where I have already published two ISI articles in the *Renewable and Sustainable Energy Reviews* journal, with an impact factor of 8,050, one showing the wind energy situation in Romania, and one about the Hydroelectric power in our country, from its beginnings to the present.

The research activity has also been directed towards the application of refrigeration facilities in comfort air conditioning for buildings, cooling installations using radiation energy transmission systems, analysis of energy performance of building elements and promotion and application of new teaching methods. Of course, I also prepared many ISI articles that are in review and others have already been published in ISI indexed conferences. The most recent research activity that I

do is related to the application of knowledge of cold and cryogenics in Bioengineering. In respect to this matter, I had a postdoctoral appoinment at California University, Berkeley, USA, where I was involved in researching and developing a system for the conservation of biological matter at temperatures below zero degrees at constant volume, and researching and developing a 3D printer for printing tissues in liquid nitrogen and in cold liquid at +4°C. Some of my research on the constant volume cryoconservation system has already been published in some ISI articles, in various renowned journals (*International Communications in Heat and Mass Transfer, Biochemical Biophysical Research Communication, Peer J, PLoS One*), and some are also presented in this habilitation thesis.

Over the years I have published as the first author, co-author and co-author, more than 50 articles and 6 books, of which 3 as first author and 3 as co-author.

The relevance of scientific work and the recognition of national and international activity in the field of Mechanical Engineering are underlined by my publications, many of them in collaboration with recognized researchers from the country, Europe or the United States. The real value of studies and research projects is highlighted by the fact that all problems have been investigated both through a theoretical approach with numerical simulations and experimental, that confirms the theoretical results.

Motivated by an interest in developing more efficient and economical building services, innovative 3D printing methods and long-term organ and tissue preservation systems I want explore deeper all these research fileds from my PhD Supervisor.

I am a member in various organizations, prestigious professional associations, national and international, belonging to organizations in the field of education and research.

Raising standards of academic excellence will be constantly pursued and promoted in the great family of our university: students, teachers, researchers and support staff, actively involved me all initiatives to increase the importance and visibility of the University staff.

Brașov, Lecturer. eng. Gabriel NĂSTASE PhD

3. Scientific and professional achievements and the evolution and development plans for career development

The current habilitation thesis makes a synthesis of the research activity done by the candidate and the obtained results. Habilitation Thesis on "**Multidisciplinary research in Mechanical Engineering**" presents the main concerns of scientific, professional and research that I conducted after completion of the Doctoral Thesis in the field of Mechanical Engineering, 2014 (diploma Series J, no. Minister 0000837, based on Minister of Education and Research Order no. 3181 of 06.02.2015), up to now, highlighting in the same time, the work done after obtaining the title of Lecturer (2015) and so far, especially my current concerns.

Refrigeration systems have a prominent role in our everyday life. Most of the systems are used in food preservation, air conditioning and ventilation for ambiental comfort, medical applications (treatments, preservation etc.), special construction works, ice rinks etc. In recent years, environmental aspects have been a prominent issue in designing and development of refrigeration systems. Another important aspect is related to reducing the size of the devices, to lower the power consumption for a specific cooling capacity.

Cryogenics, the science of temperatures lower than -50ºC, play a key role in medical purposes, especially in cryosurgery and cryobiology, space technology and in cooling electronics, that are mainly part of supercomputers.

4. Scientific and professional achievements (min. 150000 characters)

My research is multidisciplinary, but mainly focused on the following seven areas:

1. The study of heat transfer in buildings with double-skin facade;
2. Renewable-energy sources potential in Romania;
3. The study of processes, systems and materials used in Cryogenics;
4. Study of isochoric systems;
5. 3D printing. Applications in bioengineering and food industry.
6. CO_2 accumulation in residential spaces;
7. New teaching and learing methods for students;

4.1.The study of heat transfer in buildings with double-skin facade

Occupants and investors in office buildings ask increasingly these days building designer professionals, be they architects, structural engineers or building services engineers about confortable, healthy, energy efficient buildings that use at maximum free resources, renewable energy sources, performant materials or systems. The multitude of office buildings built with double-skin façade across Europe is a good example in respect with these goals, even if is still too little experience of their behavior globally and more so in Romania.

Double-skin façades have been developed as a response to provision of fully glazed curtain walls and as an effective way to control light, heat, cold and noise through the building envelope and to contribute on reducing energy consumption.

In Europe, this system has been installed on several corporate office buildings, innovative, as an appropriate method to save energy and to receive as much sunlight during the day. Installation of these façades is a complex process which requires combining several fields of engineering area and therefore according to the goal of the system is required very close cooperation between those involved in the project, architects, builders, building services engineers, energy auditors etc.

4.1.1. Double-skin façade in Europe

Spain

I visited in November 2011 two buildings in the city of Barcelona, *Torre Agbar* (Figure 1) and *Interface building* (Figure 2) both located in the Glories part of town.

Torre Agbar building was designed by French architect Jean Nouvel in association with the firm B720 Arquitectos, headed by Fermin Vásquez, is the headquarter of **Ag**ua de **Bar**ceona, has 35 floors and an overall height of 142 meters. The building is in Barcelona, next to Plaça de les Glòries, between Avingua Diagonal and Carrer Badajos. This building's double skin façade consists of an inner concrete façade, upon were mounted boards painted in red, blue, green and grey, with integrated windows in the wall's structure and an exterior façade made of laminated glass modules, anchored by a steel structure on the interior concrete façade.

Figure 1. Exterior facade, the inner cavity and overview of Torre Agbar, Barcelona, Spain

The tower has 4500 windows to maximize natural ventilation and reduce energy costs by optimizing the use of sunlight. Energy consumption for air conditioning is reduced by using external temperature sensors, which controls the opening and closing tabs on the outer façade, adjusting the flow of fresh air in cavity, which enters then in the building, thus making natural ventilation.

Interface Building was designed by the design studio Battle i Roig Arquitectes, led by architects Enriq Battle and Joan Roig, and is the headquarter of several companies in the field of Information Technology and Telecommunications, has 14 floors and an overall height of 52 meters. At this building, the double-skin façade is more like a curtain wall with a fixed glass exterior façade opened on all sides.

Figure 2. Side view, front view and under the cavity, Interface Building, Barcelona, Spain

The outside glasses on this façade are disposed upward, as can be seen in Figure 2, to create a beautiful architectural effect, and at every level in the cavity is a metallic platform to pass by.

Belgium

In Belgium I visited in March 2012 four buildings in the city of Brussels, *Berlaymont* (Building of European Commission), *Brussimo* building, *DVV office building* on the street Joseph II no. 96 and *North Galaxy* building.

Berlaymont (Figure 3) hosted since its construction (1963-1969) European Commission and has become a symbol for the Commission and for the Europeans by its presence in Brussels. The Commission itself is divided into about 60 "strange" buildings but Berlaymont is the headquarter of the institution, the seat of the European Commission President and its Board of Commissioners. The building has a cruciform design, with four wings and varied sizes that start from a central core, and this design is intended to convey a sense of light and transparency. The design includes and other decorative design details such as carvings and frescoes, to prevent it from becoming monotonous.

The building now has 240,000 m^2 of floor, 18 floors, connected by 42 lifts and 12 escalators. Offices for the 3000 officials and meeting rooms are in the tower. And restaurant services, cafeteria with 900 seats, TV studio, conference rooms, storage rooms, sauna, parking for over 1,100 cars occupy the basement and other numerous services.

The architects Pierre Lallemand, Steven Beckers and Wilfried Van Campenhout conducted renovation during 1991-2004.

Figure 3. Front view, side view and overall view, Berlaymont Building, Brussels, Belgium

The façade was replaced with a double-skin façade with movable screens that adapt to weather conditions and reduces glare, while still allowing light to penetrate inside. It also acts as a sound barrier, reducing noise came from the Rue de la Loi. Windows cancels air conditioning, when open, to prevent energy waste. Offices, which are currently bigger, have a heating system that can adjust automatically or manually, and automatically turns off when they are unoccupied.

The exterior façade on *Berlaymont* building is a blinds type, as in *Torre Agbar* building, in Barcelona, Spain. Inner envelope is composed of double glazed windows. The outer envelope is made of a series of suspended frames, which are glass plates (200 cm by 50 cm), not all with the same thickness (8 mm at the bottom and 12 mm at the top of the facade) because of their sizing against the wind.

Glass slides that form outer envelope are composed of two layers of glass separated by a perforated multilayer film showing a white face to the outside for better light reflection. On the inside blinds have a dark side, to allow visibility through them. The lighting contrast being positive, visibility is possible from the inside out, but it is impossible to reverse.

Brussimmo (Figure 4) office building, the headquarter of the European Commission for Freedom of Movement. The site reveals a notable building, placed in the heart of Leopold district, the centre of business activities in Brussels and close to the main European institutions. Because of its location, the site is exposed to noise, dust and other pollution. The building had to be suitable for any kind of organization offices, from individual offices to a fully open plan arrangement, including concepts such as the Scandinavian "combi offices," which proved so effective and easy to use. Attention was paid to the architectural quality of underground parking area, as it is often the first contact of visitors with the building.

The concept was so designed to:

- Easy installation electrical of mechanical equipment, independent of partitioning;
- Simple change partitions without damaging the ceiling and soundproofing enough in enclosed spaces;
- Installation of equipment compatible with the current needs of large international companies;
- A quiet and pleasant working environment;
- Competitive performance of the project from a financial standpoint.

The building comprises a ground floor with reception area, a first floor with meeting offices and waiting areas, five floors with standard offices and level seven, which is half semi-cylindrical shape, which serves as a technical space.

Figure 4. Double-skin façade on Brussimo building, Brussels, Belgium

The building is equipped with double glass façade, with the following advantages:

- ✓ Sound insulation is very good;
- ✓ A glass exterior facade, easy to maintain;
- ✓ Using transparent windows, which practically do not affect the comfort or the temperature inside the building;
- ✓ A large influx of natural light, through facades that are completely build with glass, from bottom to top;
- ✓ Easy distribution of mechanical and electrical parts.

Ex-*DVV* (Figure 6) office building, placed on Joseph II building on the street, at no. 96 is a double-skin façade building, type "box" with mechanical ventilation and inside curtain airflow.

The building was started in 1993 and was completed in 1995, in april, and is a five-storey extension office of DVV insurance company, which since 1990 has increased the number of operations and thus the necessity of an extension appeared due to overcrowding the headquarter. Choosing "box" type windows was motivated by considerations of energy conservation, and good thermal and acoustic insulation. Windows are an integral part of the HVAC system with forced air circulation. In this building air conditioning is discharged into the room at floor level through discharge holes with variable flow control, which incorporate also an electric resistance for heating shortfall. In Figure 5 can be seen the box type double façade system box coupled with the building's HVAC system.

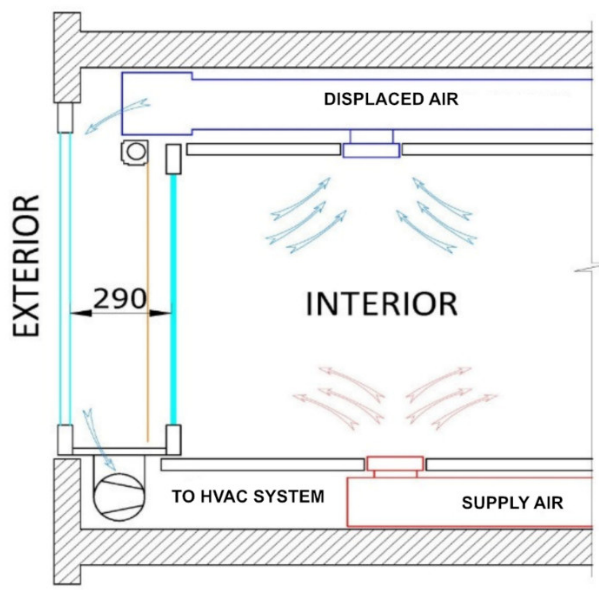

Figure 5. Air flow through DVV building’s façade, Brussels, Belgium. Drawing not at scale.

Warm air is taken from the top, through a system of pipes and sent to the window cavity, which runs through and returns to the bottom of the HVAC system. Air can be recirculated or can be exhausted.

Figure 6. Double-skin façade, "box" type (southwest cardinal direction), DVV extension building, Brussels, Belgium

Design airflow to be circulated through the cavity varies between 100 and 140 m^3/h m window width.

Exterior glass is a double glass type window with thermal break aluminium joinery and the interior glass is a single safety glass panel simple. In the cavity, the shading device like roll is placed about 8 cm from the inside window.

North Galaxy (Figure 7) complex was designed by the architectural offices group M. & JM Jaspers - Eyers & Partners, Art & Build and Montois & Partners, the buildings were built mostly of prefabricated and currently, Galaxy North offices complex is one of the largest real estate projects in Brussels.

North Galaxy Towers, located on the Boulevard Roi Albert II, Brussels, Belgium have 28 levels each with two technical levels on top of each. The building is accessible through a majestic entrance, which is elliptical, with a double glass façade as a key feature. The windows are 13 m in height and hangs by tensioned cables using a steel structure from the roof to below ground floor.

Figure 7. Detail and overall double-skin façade from North Galaxy Towers entrance, Brussels, Belgium

The Nederlands

In the Netherlands, at Amsterdam have been viewed *ABN-AMRO Bank Headquarters* (Figure 8) building located in the south of the city.

The building is one of the top 10 tallest buildings in Amsterdam, with a height of 105 m and 24 floors.

Figure 8. Views of double-skin façade, headquarters of ABN AMRO Bank, Amsterdam, Netherlands

The façade of this building includes cavity ventilation, automatic blinds, heat recovery system in the building and lighting adjusts automatically depending on the occupancy and the level of brightness, thereby reducing energy consumption.

Austria

In Austria, Vienna have been viewed *IBM building* (Figure 9), located at Obere Donnaustraße 95, near the Danube Canal, which was built in 1969 and restored by architect Rudolf Prohazka in 1999-2001. Renovation of existing front consisted of mounting of a double glass façade, covering an area of 1000 m^2, to reduce energy consumption for cooling and heating. Outer envelope is slightly curved outward, as can be seen in the picture below.

Figure 9. Front view of IBM building's double skin façade, Vienna, Austria

In the same area, just near IBM is building a *Raiffeisen Bank* (Figure 10) with double glass façade that allows good natural ventilation of the building. Construction is almost complete and is intended to be a reference building in resource conservation, energy efficiency and environmental protection. Flagship office building was designed by architects Dieter Hayde, Ernst Maurer and Radovan Tajder and is modeled after the concept of "Raiffeisen Klimaschutz-Initiative" (Raiffeisen climate protection initiative).

Figure 10. Double-skin façade of Raiffeisen Bank in Viena, Austria

Also, has been viewed the *UNIQA Tower* (Figure 11), headquarters of insurance company UNIQA Group Austria, completed in 2004 and designed by the Austrian architect Heinz Neumann.

Figure 11. UNIQA tower's double skin façade, Vienna, Austria

This building is the first building in Austria, which has been awarded with a "Green Building" certificate. UNIQA tower's double-skin façade allows the natural ventilation inside through windows. At the same time provide sound and thermal insulation, provide natural light inside the building throughout the year, and use the sun's heat during the winter, through the greenhouse effect achieved within the cavity. In order to maximize natural light without too much heat building, building management system adjusts the blinds, light according to need.

2.5. Germany

In Germany, at Nuremberg have been visited two double glass façade buildings: Business Tower and NCC Nuremberg building (Nürnberg Convention Center - Figure 12) from Nürnberg Messe.

Nuremberg Convention Center (NCC) is one of the most modern facilities for conducting conferences and one of the 20 largest sites in the world, to support international exhibitions. This building is complemented by 160,000 m^2 of exhibition space adjacent and offers seating capacity for 11,000 participants.

NCC building from Nürnberg Messe is built with double-skin façade that allows natural light into a very high proportion, thus providing an open and communicative atmosphere, thus achieving optimal conditions for events for which it was made construction, but is also energy saving.

Figure 12. Photo from inside the double glass facade of NCC building from Nürnberg Messe complex and view of floor heating unit.

In the picture above, you can see some details of the double façade, such as inside the cavity, air intake valves from the bottom of the cavity, indoor unit for heating, embedded in the floor, right next to the inner glass of double facade.

To monitor double glass facade NCC has its own weather station, so regardless of the weather outside, inside the climate is pleasant and comfortable one.

The building was designed by S + P Gesellschaft von Architekten mbH, led by architect Heinz Seipel and was completed in 2005.

The next building viewed from Nuremberg, Germany, was the tower of 135 meters and 34 floors *Nürnberg Business Tower* (Figure 13), designed by architects Friedrich Biefang, Dürschinger and Jörg Peter Spengler and was built in June 1996 - October 2000.

The tower is equipped with double glass façade, allowing its natural ventilation, at every level, despite its height and it was no longer necessary to install an air-conditioning system, thereby achieving maximum economic and environmental efficiency.

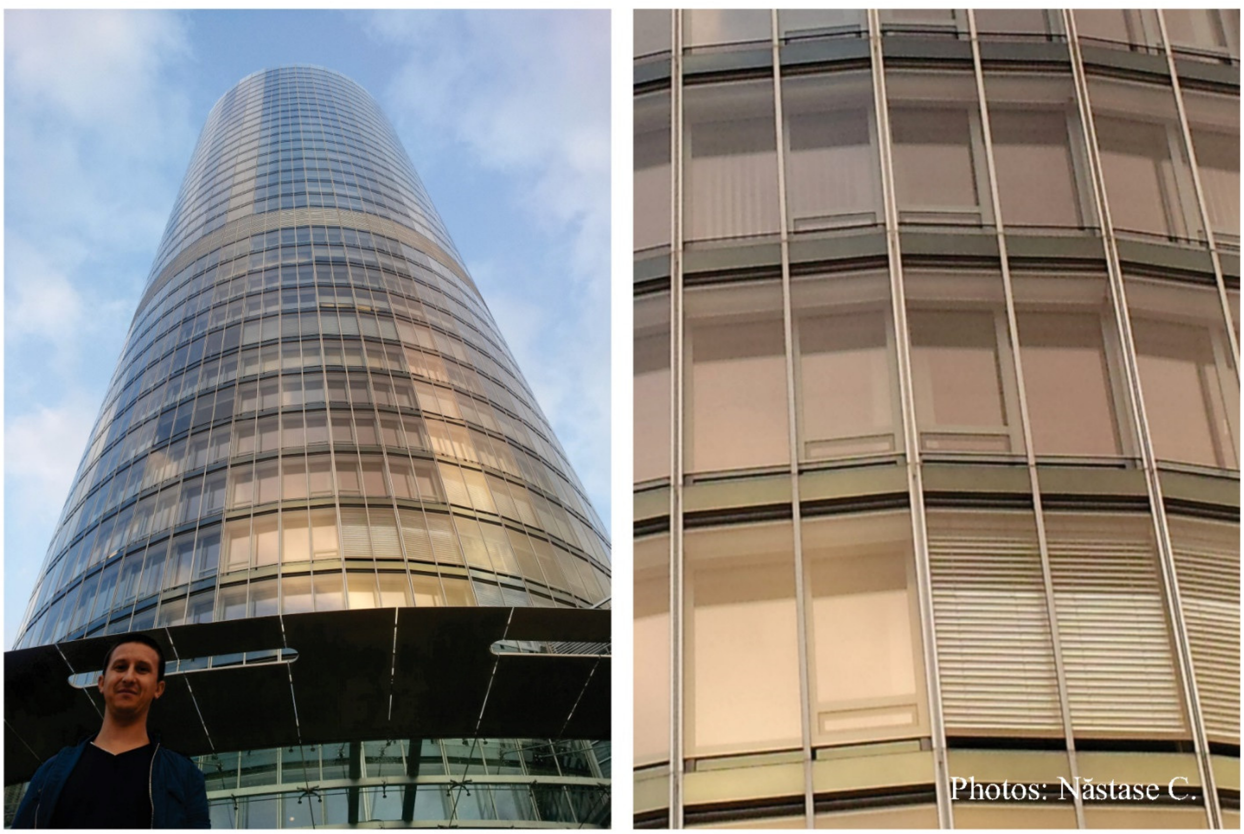

Figure 13. Overview of Business Tower Nuremberg, Germany (left) and double-skin facade detail (right).

The building has one of the largest and most powerful type network LON (Local Operating Network) in Europe, whereby Building Management System (BMS) process the data coming from the 120,000 points of the network hardware and software. This system allows individual control, each room lighting levels, heating system, air exchange, etc [1].

In Romania

In our country until now have been realised 2 experiments with double skin façade, both in Iasi city, one conducted by Mr. Nelu-Cristian Chereches at Building Services Faculty from Gh. Asachi University of Iași (Figure 14A) and the other conducted by Mrs. Chereches Monica at INCERC Iași (Figure 14C).

In 2012 was buit the third experiment for my PhD thesis in Brașov, at Building Services Faculty from Transilvania University of Brașov (Figure 14D). Besides these experimental facades, in Bucharest, in 2011 was finished the first buildings with a double-skin façade, Crystal Tower (Figure 14B). Also in Sfantu Gheorghe, Covasna county, Public Finance Directorate building is equipped with a double-skin façade (Figure 14E).

Figure 14. Examples of double-skin façade in Romania

4.1.2. Heat transfer through a box-double skin façade

Energy audits for buildings are an essential tool to achieve energy savings. They are necessary to assess the existing energy consumption, identify the range of opportunities to save energy and propose solutions. For this purpose, energy auditors need a simple calculation method to be able to propose double skin façade as an appropriate solution, considering all important factors.

Many people contribute to general framework of developing a numerical heat transfer model for double skin façade but much of the literature deals mostly with specific topics in heat transfer modeling.

Most of the numerical solutions for heat transfer in double skin façade have been developed after 2000. Saelens D. (2002) [2], in his Ph.D. is presenting a two-dimensional development of a numerical model for multiple-skin façades for mechanical and natural ventilation, based on a cell centered control volume method (CVM). In his conclusions, it states that obtaining a reliable expression for the heat transfer coefficient is difficult, due to system complexity, and numerical results depend on the accuracy of the input parameters, on the value of the convective heat transfer coefficient and on the numerical error. During night time and during situations with low solar radiation, uniform wall temperature expressions were used in his study, because measurements show small vertical temperature gradients and temperature profiles coincide very well with the measurements [2].

A two-dimensional steady state numerical study has been carried out by J. Xamán et al. (2004) [3] to examine the fluid flow and heat transfer by natural convection in a tall cavity using laminar and turbulent k–ε models. It is found that the turbulent convective Nusselt number increases if the aspect ratio increases, meanwhile the convective Nusselt number for the laminar case decreases as the aspect ratio increases [3].

A zonal approach for modeling airflow and temperature in a ventilated double skin façade was carried out by T.E. Jiru et. al (2008) [4]. The zonal energy equation was used to evaluate the temperature distribution in the DSF system. The results had revealed that the zonal approach can be employed to provide information on the performance of DSF faster and at very low computational resource [4]. Another numerical modelling of a double skin façade (DSF) using zonal approach was carried out by F. Kuznik (2011) [5]. This model includes convective, radiative and aeraulic heat transfers [5].

A dynamical study of the flow in a double skin façade was carried out numerically for modified Rayleigh numbers in a range corresponding to the boundary layer-type flow in the laminar regime, by Popa C. (2012) [6]. The façade is modeled by an asymmetrically heated vertical plane channel. 2D numerical simulations have been carried out with the finite volume approach. They concluded that for a fixed aspect ratio, both the axial velocity magnitude and the recirculation length increase with the modified Rayleigh number [6].

Another numerical model in two-dimensional and based on a cell centered volume method (CVM) has been developed also by M. Ghadimian (2013) [7]. The parameters study distinguishes between system properties and system settings in Tehran's climatic conditions and the overall thermal performance of multiple-skin façades strongly depends on both of mentioned parameters. This indicates the multiple-skin façades may fail by not enough considering the influence of certain design choices [7].

A review of numerical modelling of ventilated façades has been conducted and very nice presented by Alvaro De Gracia et al. (2013) [8]. The authors states that analytical and lumped models can generally provide specific useful information regarding thermal performance of the double skin façade system without consuming high computational resources [8].

Obtaining an accurate simplified model for designers to guide them taking the right decision without extensive scientific background to use is the main purpose of the study conducted by Hagar Elarga et al. (2015) [9]. The study included description of the thermal resistance models with and without blinds. The validation of the simplified model was carried out by comparing its results with a more detailed dynamic simulation model "DIGITHON". The comparison showed a good agreement to use the simplified model on an extensive range [9].

Numerical models presented in most papers are too elaborated for energy auditors.

The mathematical model proposed in this paper is simple and comes from practical reasons. The model can provide energy auditor, beneficiary or designer first impressions about heat transfer amplitude on a double skin façade system.

Double skin façade (DSF) are complex systems and designing them requires detailed analysis of several variables. To evaluate a building, from the energy consumption point of view, nowadays the designers are using more and more modeling and simulation software. They offer the possibility to consider weather conditions over a period of one year or more or less and give precious information, in order to make decisions about the configuration of optimal double glass façade and also on the operation and control strategies for this. The DSF concept, with proper design and control strategies, could positively affect the overall energy consumption of the building [10], [11], [12], [13], [14], [15]. The biggest disadvantage of modeling and simulation software is their initial cost which is in terms of a few thousand euros and not every designing company afford them. There are many double skin façades in Europe and across the world already built. The solution of double skin façade is considered from different considerations, from case to case. Some architect designers include them only for their aspect, while some others because the building is positioned in a crowded place with a lot of traffic and is added for noise protection. Other architects design those consulting building services engineers, to make a low energy consumption building. The low energy consumption may come from using natural ventilation in transitional periods, from night cooling and from the thermal contributions during the cold season due to the greenhouse effect in the presence of solar radiation, in the cavity.

Energy audit of a building aims to identify the main thermal characteristics of the building and its related facilities and the establishment of technical and economic solutions for rehabilitation and/or upgrading thermal and energy building and its related facilities based on the results of thermal analysis and the activity of the energy of the building [16].

An energetic auditor is not a researcher and if the building is not equipped with a BMS or the energetic audit methodology does not specify guidelines for evaluating also buildings with double skin façade it might be difficult to evaluate the building correctly.

In 2008 in [17] at section 8.3 the authors say, “a façade energy certification method has been proposed” but since then no systematically organized standards or unique methodologies have been realized, at European and local level.

The main objective of the energy certification of buildings, which was introduced in the European Union by EPBD – Energy Performance Buildings Directive [18], is to provide clear guidelines for energy performance of buildings to improve the energetic quality of new buildings and existing building stocks [19]. The rules for the implementation of EPBD in Romania were defined by [16] and by the national guidelines for energy certification [20], which were published in 2007.

The envelope (façade) is the part of the building which forms the primary thermal barrier with its environment. It represents the most key factor in determining the level of thermal comfort, natural light and ventilation ability, and finally how much energy is needed for heating and air-conditioning [21].

The complexity in evaluating the heat transfer indicators on a double skin façade comes from the "high complexity of evaluating the heat transfer processes which occur within the ventilated air gap" [22].

In March 2012 has been adopted in our country the Romanian version [23] of the European standard EN ISO 12631:2012 [24]. This calculation is not double skin glass façades dedicated, but in Annex D "Ventilated and unventilated air spaces" is presented a model for calculating the overall thermal resistance R, using the relation:

$$R_{cw} = \frac{1}{U_{cw,1}} - R_{si} + R_s - R_{se} + \frac{1}{U_{cw,2}} \tag{1}$$

Air spaces (ventilated and unventilated) in a curtain wall, e.g. double skin façade, can be considered using the data for air layers given in ISO 6946:2007 [25].

The method of calculation is not wrong, but has a limited application in case of double skin glass façades since it can be calculated only if the air layer in the cavity does not exceed a thickness of 300 mm. This is because Romanian [23] and European [24] standard ISO 12631 refer to ISO 6946:2007 [25] for ventilated and unventilated air spaces. In EN 13947:2006 [26], which is the standard replaced by EN ISO 12631:2012 [24] air layer thickness has two more values 500 mm and 1000 mm, respectively.

In this paper heat transfer for box window double skin façade is investigated and the results are displayed in the form of the global coefficient heat transfer U, thermal resistance R, heat flux density Q/A and bounding surface temperatures T.

Heat transfer calculation method

It is considered a box window double skin façade placed in Brasov, Romania (latitude 45°39′N, longitude 25°36′E, +2 h GMT). The double skin façade consists of a double pane window as internal façade and a secure glass as external façade. The cavity between them is 1 m width. The gas inside double pane is argon and atmospheric air is circulated through the cavity.

The numerical modelling of heat transfer presented in this paper is done for the two extreme climatic cases that characterize the Brasov region. For the warm season was considered an outside temperature of 30 °C and for the winter season was considered an outside temperature of -21 ºC.

Heat transfer is considered nighttime, when solar radiation effect can be ignored, steady state in one direction and the effect of sashes is ignored. The sheets of double pane glass are 4 mm thick, the secure glass is 10 mm thick and is considered for them a thermal conductivity of 1.3 W/m^2K. The double pane glasses are placed from one another at a spacing of 16 mm. The air temperature inside the room is considered 20°C, during the winter season and 24°C during the summer season.

Based on the available results and according to ISO 6946:2007 [25], the convective heat transfer coefficients for interior and exterior can be considered with the values 7,7 and 25 W/m^2K and the emissivity of glass is considered 0.84.

The situation considered in this paper is shown in Figure 15.

Since solar radiation effects are ignored and the glass is essentially opaque to infrared radiation in the case considered, the three sheets of glass is assumed that behave as two conventional opaque grey bodies.

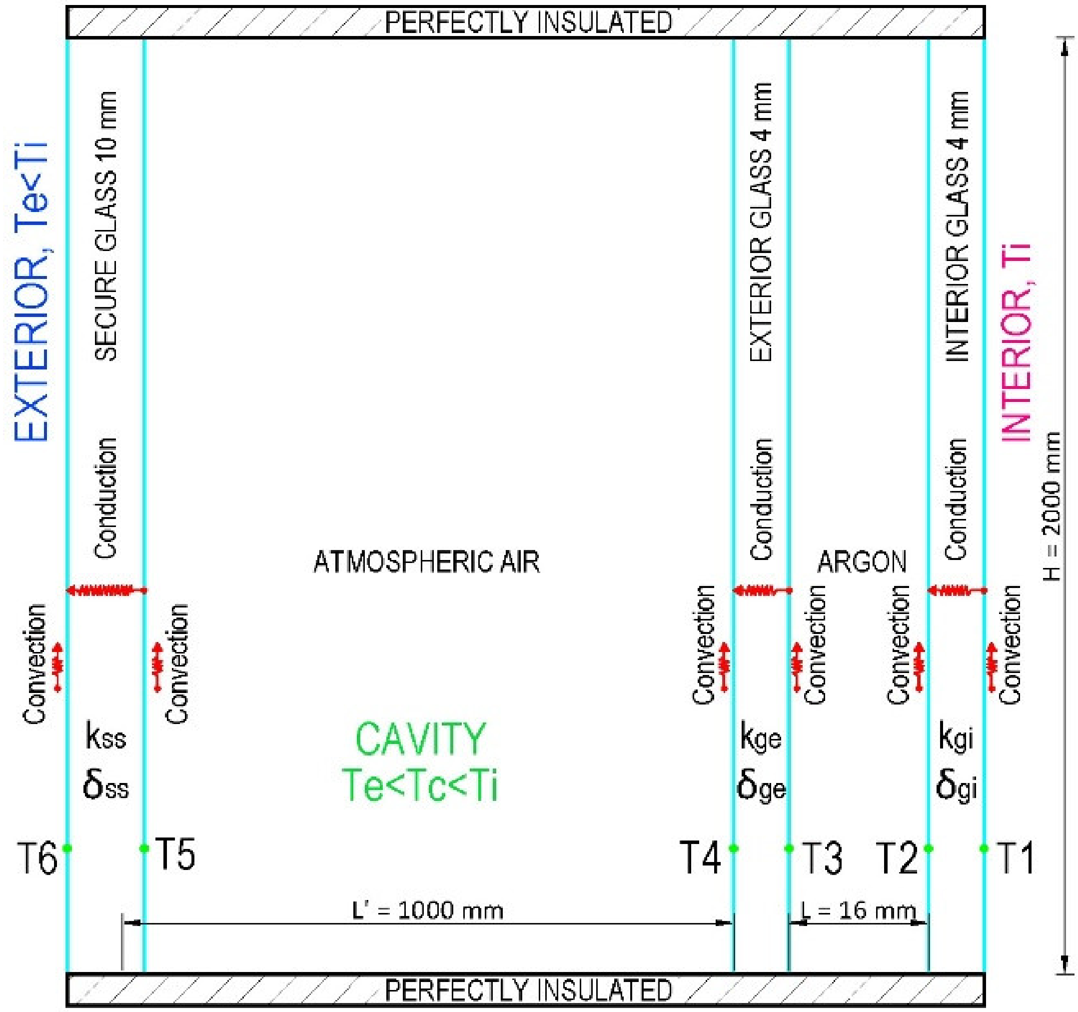

Figure 15. Considered heat transfer and temperature distribution, winter

Also, considering steady state heat transfer means heat fluxes between all layers are equal, which can be expressed as:

$$\frac{Q_i}{A} = \frac{Q_{gi}}{A} = \frac{Q_b}{A} = \frac{Q_{ge}}{A} = \frac{Q_{cav}}{A} = \frac{Q_{ss}}{A} = \frac{Q_e}{A} \tag{2}$$

Radiant heat transfer will be treated by the introduction of radiative heat transfer coefficient h_r. Radiative heat transfer coefficients to the inner surface of the inner glass and outer surface of the outer glass are:

$$h_{ri} = \sigma\varepsilon\left(T_i^2 + T_1^2\right)\left(T_i + T_1\right) \tag{3}$$

$$h_{re} = \sigma\varepsilon\left(T_6^2 + T_e^2\right)\left(T_6 + T_e\right) \tag{4}$$

Radiative heat transfer coefficient between the two panes of glass that forms the interior façade, considering same emissivity is:

$$h_{rb} = \frac{\sigma\left(T_2^2 + T_3^2\right)\left(T_2 + T_3\right)}{\frac{2}{\varepsilon} - 1} \tag{5}$$

Radiative heat transfer coefficient between the two panes of glass that forms the double skin façade cavity, considering same emissivity is:

$$h_{rcav} = \frac{\sigma\left(T_4^2 + T_5^2\right)\left(T_4 + T_5\right)}{\frac{2}{\varepsilon} - 1} \tag{6}$$

Aspect ratio is defined as the ratio between height *H* and distance *L*, between two panes of interior window (inner envelope) or *L'*, between inner and outer envelope in case of double-skin façade.

$$AR = \frac{H}{L} \text{ and } AR_{cav} = \frac{H}{L'} \tag{7}$$

The space between the two panes of interior glass façade forms a vertical high-aspect ratio rectangular enclosure (H>>L) while the cavity space between interior and exterior façade forms a vertical low-aspect ratio rectangular enclosure.

Convective heat-transfer coefficients and the heat-transfer rate across these enclosures is expressed in terms of aspect ratio AR and Rayleigh number Ra, which are defined by the relations:

$$Ra = \frac{\beta g L^2 \left(T_2 - T_3\right)}{\nu \cdot a_{argon}} \tag{8}$$

$$Ra_{cav} = \frac{\beta g L'^2 \left(T_4 - T_5\right)}{\nu \cdot a_{air}} \tag{9}$$

The convective heat transfer coefficient between the two panes of interior glass façade is:

$$h_{cb} = \frac{Nu_b k_b}{L} \tag{10}$$

$$h_{ccav} = \frac{Nu_{cav} k_{cav}}{L'} \tag{11}$$

The thermal conductivity k_b, the kinematic viscosity v and thermal diffusivity a, in the Rayleigh number are evaluated at the mean temperature in the gaps, at

$$T_b = \frac{T_2 + T_3}{2} \tag{12}$$

$$T_{cav} = \frac{T_4 + T_5}{2} \tag{13}$$

In equation (10) Nu_b represents the Nusselt number for the inner envelope and according to ElSherbiny et al. [27] can be expressed as the maximum of the following three Nusselt numbers:

$$Nu_a = 0{,}0605 \cdot Ra^{1/3} \tag{14}$$

$$Nu_b = \left[1 + \left\{\frac{0{,}104 \cdot Ra^{0{,}293}}{1 + (6310/Ra)^{1{,}36}}\right\}^3\right]^{1/3} \tag{15}$$

$$Nu_c = 0{,}242 \cdot \left(\frac{Ra}{AR}\right)^{0{,}273} \tag{16}$$

Thereby

$$Nu = \max(Nu_a, Nu_b, Nu_c) \tag{17}$$

Nu_a applies to turbulent boundary layer regime, Nu_b to conduction and the turbulent transition regime and Nu_c to the laminar boundary regime [27].

In equation (11) Nu_{cav} represents the Nusselt number for the cavity and according to [27], [28] this can be calculated for the proposed case by using Berkovsky și Polevikov equation:

$$\overline{Nu}_H = 0{,}22 \cdot \left(\frac{\Pr}{0{,}2 + \Pr}\right)^{0{,}28} \cdot AR_{cav}^{0{,}09} \tag{18}$$

This equation is valid for natural convection in vertical rectangular spaces, in laminar regime and simultaneous fulfillment of following conditions:

$$2 < \frac{H}{L} < 10;\ Pr < 10^5;\ Ra_H < 10^{13} \tag{19}$$

Overall heat transfer is typically expressed using thermal transmittance U [W/m^{2}K], which is defined as follows:

$$\frac{Q}{A} = U\left(T_i - T_e\right) \tag{20}$$

Using all information above the total heat transmittance, U [W/m^2 K] can be expressed:

$$U = \frac{1}{R_i + \frac{\delta_{gi}}{k_{gi}} + R_b + \frac{\delta_{ge}}{k_{ge}} + R_{cav} + \frac{\delta_{ss}}{k_{ss}} + R_e} \tag{21}$$

where

$$R_i = \frac{1}{\left(h_{ci} + h_{ri}\right)} \tag{22}$$

$$R_b = \frac{1}{\left(h_{cb} + h_{rb}\right)} \tag{23}$$

$$R_{cav} = \frac{1}{\left(h_{ccav} + h_{rcav}\right)} \tag{24}$$

$$R_e = \frac{1}{\left(h_{ce} + h_{re}\right)} \tag{25}$$

To complete the calculations, it is required an iterative procedure, which involves the following the steps:

1. Guess the initial values of temperatures T_1, T_2, T_3, T_4, T_5 and T_6; ^{o}
2. Using initial values, calculate the heat transfer coefficients h_{ri}, h_{rb}, h_{cb}, h_{rcav}, h_{ccav} and h_{re};
3. Calculate Q/A, U and R;
4. With calculated values of Q/A, calculate T_1, T_2, T_3, T_4, T_5 and T_6 using

$$T_1 = T_i - \frac{Q}{A}\frac{1}{\left(h_{ci} + h_{ri}\right)} \tag{26}$$

$$T_2 = T_1 - \frac{Q}{A}\frac{k_{gi}}{\delta_{gi}} \tag{27}$$

$$T_3 = T_2 - \frac{Q}{A}\frac{1}{\left(h_{cb} + h_{rb}\right)} \tag{28}$$

$$T_4 = T_3 - \frac{Q}{A}\frac{k_{ge}}{\delta_{ge}} \tag{29}$$

$$T_5 = T_4 - \frac{Q}{A}\frac{1}{\left(h_{ccav} + h_{rcav}\right)} \tag{30}$$

$$T_6 = T_5 - \frac{Q}{A}\frac{k_{ss}}{\delta_{ss}} \tag{31}$$

The most frequently used gases in double skin façade systems are air and argon. The values of kinematic viscosity *v,* thermal conductivity *k* and thermal diffusivity *a,* for air and argon have to be known over the temperature range covered in the situation considered. Their values used in this paper were taken from Figure 16, Figure 17 and Figure 18, created using tabular data, generated by Refprop Software. Over the curves thus generated trendlines were added, as 2nd degree polynomial functions, to obtain different equations for the properties of interest. Equations thus obtained are temperature dependent and can replace charts, which save calculation time.

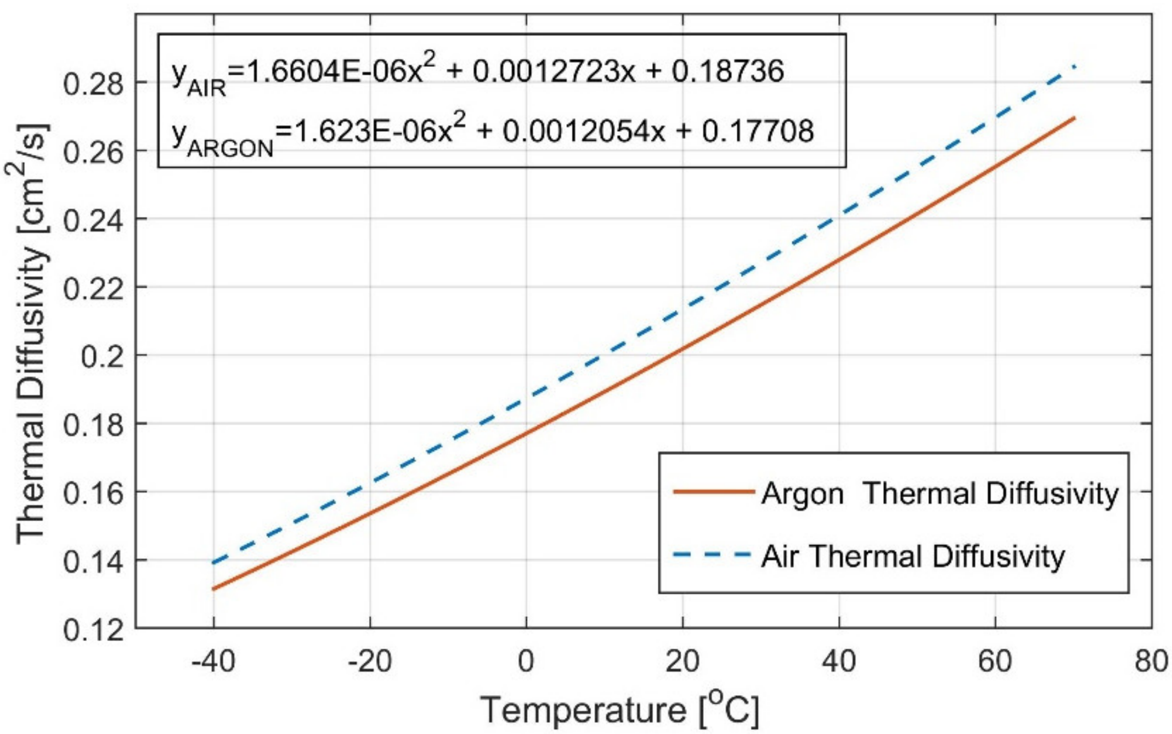

Figure 16. Variation of kinematic viscosity ν of air and argon with temperature

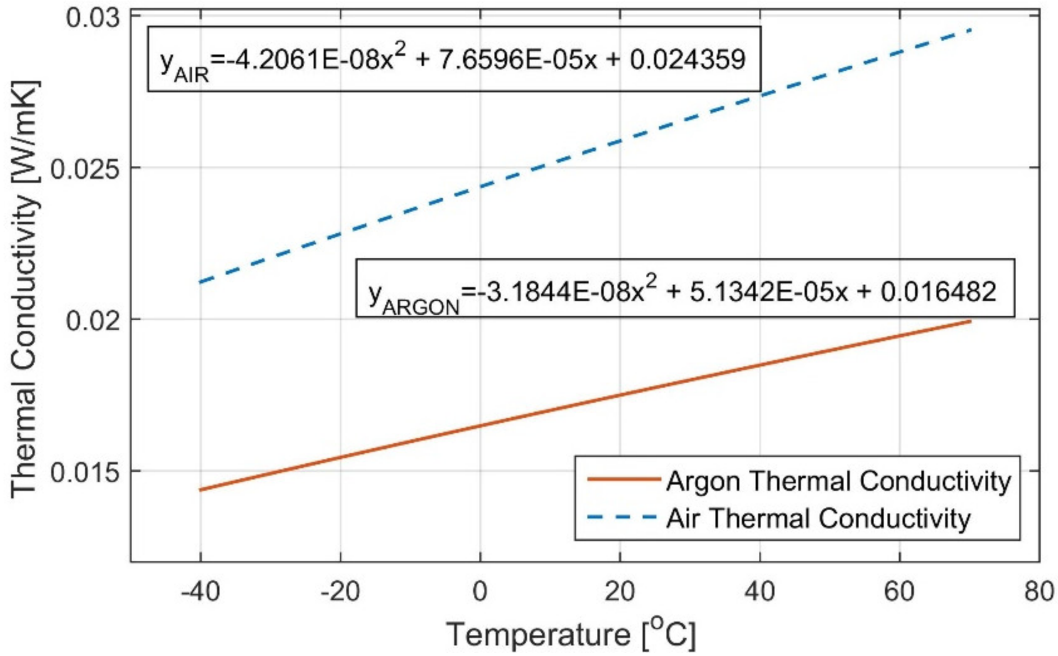

Figure 17. Variation of thermal conductivity k of air and argon with temperature

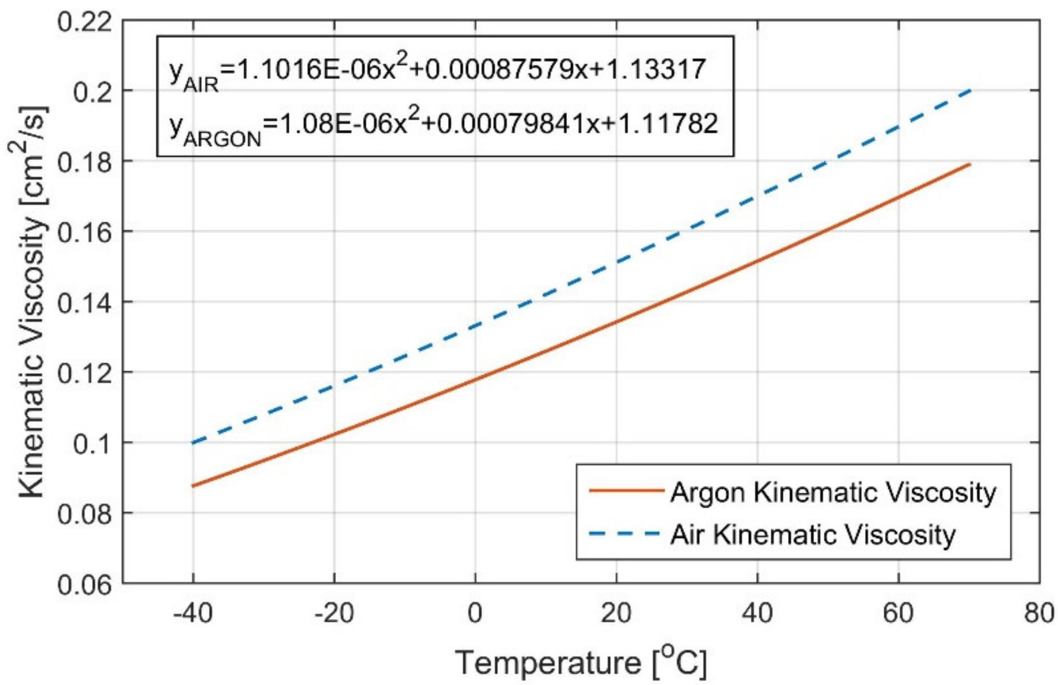

Figure 18. Variation of thermal diffusivity a of air and argon with temperature

Numerical method application

All calculation were made using Microsoft Excel and the results for surface temperatures and heat transfer indicators are presented in Table 1. Surface temperature and heat transfer indicatiors results for summer and winter for the winter season and in Table 2. Yearly parameters comparison between double-pane window and double-skin façade for the summer season, in Brasov.

Table 1. Surface temperature and heat transfer indicatiors results for summer and winter

Winter season				**Summer season**		
Results	Iter. 1	Iter. 2	Iter. 3	Iter. 1	Iter. 2	Iter. 3
T1 [ºC]	13,62	13,72	13,70	24,96	24,94	24,94
T2 [ºC]	13,38	13,48	13,46	25,00	24,97	24,97
T3 [ºC]	-3,13	-2,40	-2,47	27,52	27,31	27,31
T4 [ºC]	-3,38	-2,64	-2,71	27,56	27,34	27,35
T5 [ºC]	-17,58	-17,64	-17,63	29,51	29,47	29,47
T6 [ºC]	-18,19	-18,24	-18,23	29,60	29,57	29,57
R [m^2 K /W]	0,515	0,528	0,527	0,497	0,491	0,491
U [W/m^2K]	1,940	1,892	1,898	2,00	2,03	2,03
Q/A [W/m^2]	79,57	77,59	77,82	12,05	12,20	12,21

Using this calculation methodology, an evaluation of face temperatures, total thermal resistances, transmittances and heat fluxes have been carried out. The comparison of these parameters is presented in Table 2 for double pane window – inner envelope and for double-skin façade respectively. As input parameters for this evaluation were used statistical monthly exterior air temperatures over one year, taken from the climatological data recorded at Ghimbav weather station as a three-year average. Ghimbav weather station is placed 10 km from Brasov.

The differences are highlighted also in Figure 19, shown below, for each month of the year.

Table 2. Yearly parameters comparison between double-pane window and double-skin façade

Month	T_{ml}	DOUBLE PANE WINDOW 4-16-4 (Argon 100%)				DOUBLE SKIN FAÇADE			
		R	**U**	**Q/A**	**Q**	**R**	**U**	**Q/A**	**Q**
	[°C]	[m^2K/W]	[W/m^2K]	[W/m^2]	[W]	[m^2K/W]	[W/m^2K]	[W/m^2]	[W]
January	-2,6	0,334	2,998	67,74	230	0,521	1,917	43,33	147
February	-2,7	0,334	2,997	68,04	231	0,521	1,917	43,52	148
March	2,5	0,332	3,013	52,73	179	0,521	1,919	33,59	114
April	8,8	0,330	3,034	33,97	115	0,521	1,916	21,47	73
May	14,6	0,328	3,046	16,45	56	0,526	1,900	10,26	35
June	17,1	0,329	3,042	8,82	30	0,532	1,879	5,45	19
July	19,4	0,332	3,011	1,81	6	0,548	1,822	1,09	4
August	18,2	0,329	3,036	6,01	20	0,537	1,861	3,35	11
September	13,4	0,328	3,045	20,09	68	0,524	1,905	12,58	43
October	8,3	0,330	3,032	35,47	121	0,521	1,917	22,43	76
November	2,0	0,332	3,012	54,21	184	0,521	1,919	34,54	117
December	-2,1	0,333	2,999	66,28	225	0,521	1,917	42,38	144
Annual averages	**8,08**	**0,331**	**3,022**	**35,97**	**122**	**0,526**	**1,899**	**22,83**	**78**

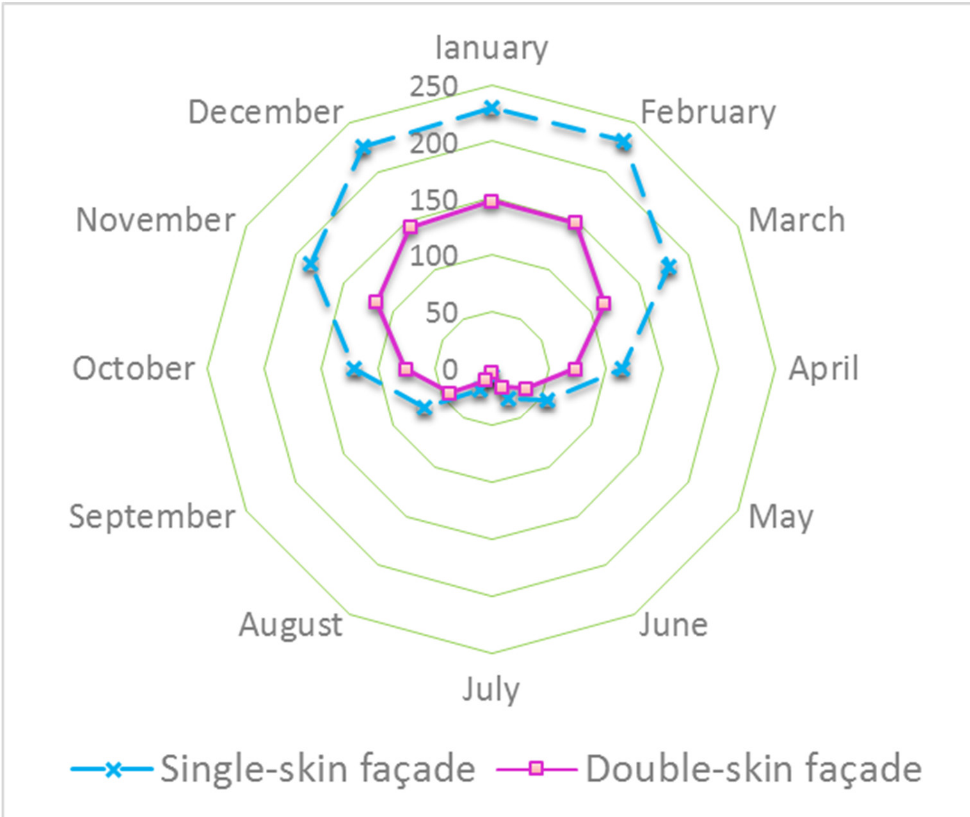

Figure 19. Comparison of heat flow [W] through a single-skin façade and a double skin façade for a period of one year, based on average monthly temperature in the town of Brasov.

Experiment setup

Box double skin façade presented below is developed in situ, on the ground floor of the Civil Engineering Faculty in Brasov, part of Transylvania University from Brasov, on the south façade of the building. The experimental model was part of my PhD thesis [28].

The experiment results refer to temperature measurements of TI, T1, T4, T5 and TE during hot and cold season. Due to the difficulty of installation, the temperatures inside inner envelope and outside outer envelope could not be measured.

Figure 20 shows a description of experiment setup with incorporated temperature sensors.

Figure 20. Experiment setup made for heat transfer analysis

As in the case of theoretical model, the experimental setup was completely closed, during measurements, in both analyzed cases. Completely closed means that convection occurs naturally inside the cavity due to the temperature difference between inside and outside.

For this study, the relevant temperature trends are in the middle section. There are three sensors for measuring T5, two for measuring T1 and T4 and one for TE, respectively TI. All temperature sensors are type K thermocouples, having 2x0,32 section, Teflon insulation and 3 m length. To acquire temperatures in all areas of the model we used two digital multi-channel recorders ISU-MMC-24C, as in Figure 21, with 24 channels each. These data acquisition systems have serial communication, Ethernet and offline recording.

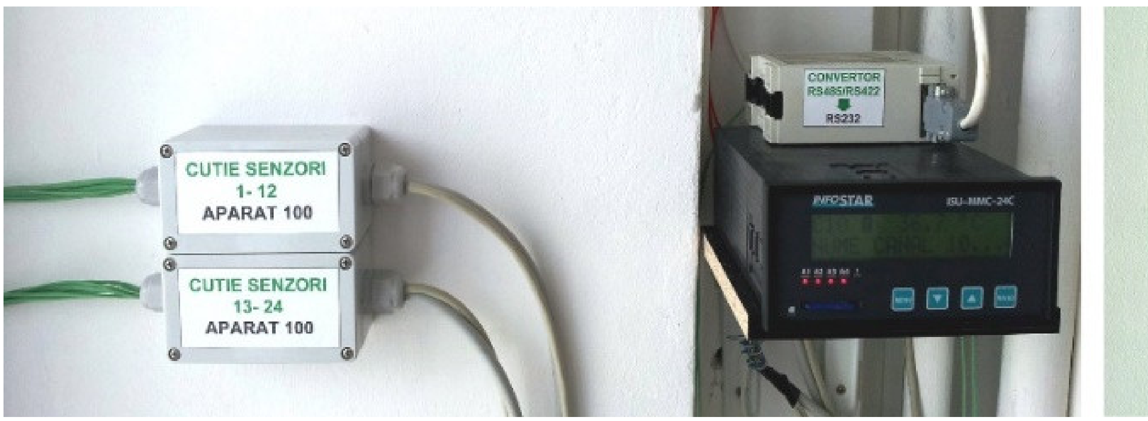

Figure 21. ISU-MMC-24C, the converter RS485/RS422-RS232 and cases related to the 24 temperature sensors

All sensors and measuring instruments were checked and calibrated by standard procedures in laboratory conditions.

The experimental model is equipped also with Venetian blinds shading system but their effect is negligible because the measurements were made in the absence of solar radiation.

During experimental measurement campaign shading system blades position was at 0^o, the fan and all flow dampers were off.

Otherwise, the experiment setup respects the geometrical characteristics and input data as in the theoretical model.

Experiment results

This section presents selected typical temperature measurements results from box double skin façade setup compared by predicted temperatures using described methodology.

For this comparison, for both seasons considered, the measurements in the charts below are presented for lowest and highest outside temperatures.

In winter period, the coldest day during 2013-2014 measurement campaign was 31 of January, when outside temperature was -8,14 ºC, recorded at 5:00 AM.

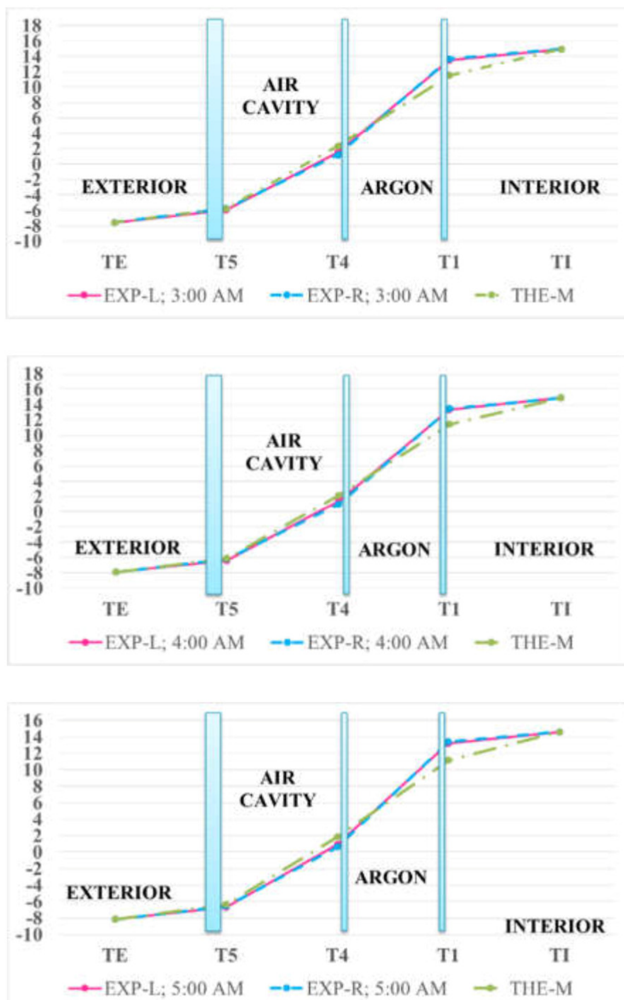

Figure 22. Experimental horizontal trends of temperatures (EXP-L and EXP-R) compared with those obtained using described methodology (THE-M), in winter season

In summer period, the hottest day during 2013-2014 measurement campaign was 29 of July, when outside temperature was +34,74 ºC, recorded at 5:00 PM.

In this study, the vertical temperature gradients are not as relevant as this study was made on a box double skin façade system, where height cannot be much greater than width; they present interest, for the study of "corridor", "trunk" or "curtain" double skin façade.

In the hot season, all measurements reveal that in the climatic conditions of Brasov, the parameter for indoor thermal comfort, indoor air temperature varies between standard values without the need of additional cooling systems. If the indoor air temperature increase can adopt various strategies to reduce it, using ventilation systems and screening the double façade. According to the measurements, it was found that the first step in this situation is to achieve a natural movement inside the cavity, to remove the air overheated, next step is to control sunlight entering the room through shading system, but not to fall light levels below standardized limit, and in the last stage mechanical ventilation system for façade cavity should be started.

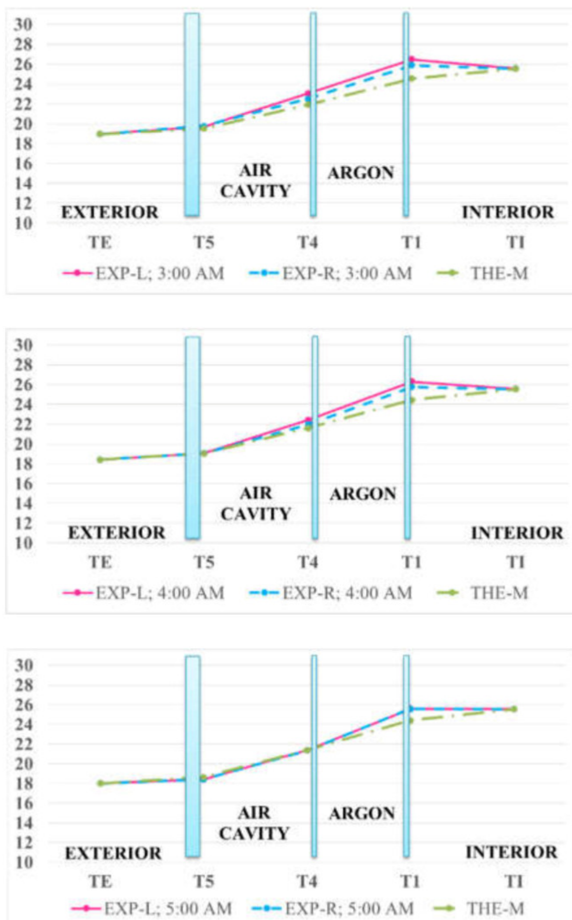

Figure 23. Experimental horizontal trends of temperatures (EXP-L and EXP-R) compared with those obtained using described methodology (THE-M), in summer season

Based on the presented results, the following conclusions are reached for both regimes:

- in absence of solar radiation measurements in left part of B-DSF (EXP-L) and those in right part of B-DSF (EXP-R) show no significant deviations;
- the major differences in measured temperature and those obtained from the methodology are on the inside face of inner façade; they are about 2 ºC in winter and lower than 1,5 ºC in summer;
- in winter season, the nearest values obtained from calculations compared with those from the measurements were recorded at 4:00 AM;
- in summer season, the nearest values obtained from calculations compared with those from the measurements were recorded at 5:00 AM;

The experimental analysis indicates that the proposed methodology can be used in determining with good accuracy the heat transfer indicators Q/A, R, U and surface temperatures T required in energetic audit evaluations of buildings equipped with B-DSF.

Discussions

Analyzing the results, it can be observed that thermal double skin façade thermal resistances are 37% higher than those in case of a single façade consisting of a 24-mm double pane window, thereby reducing the heat losses through the façade.

In the Figure 5 it can be concluded that the greatest benefits of a double skin façade installed in our climatic zone, in terms of heat losses occurs during the cold season.

It was found that the main contributors to the overall thermal resistance R are the two gases between glass panels. The biggest value is given by argon as part of the first façade followed by air inside cavity.

In case of heat transfer by convection inside first (interior) façade Nu number is 1 meaning that heat transfer is actually by conduction and can be treated as such. This is because the distance between glass panels is very small.

The results were obtained fast in MS Excel and the procedure required only three iterations for a good result, but for informative purpose can be made only two iterations.

This thermal analysis is made in the steady state and is used to determine the temperature distribution and the quantities involved, by introducing the boundary conditions which characterize the system in balance. By introducing boundary conditions when the system is in balance ignores practically the temporal effects of thermal accumulation. Materials have thermal properties that vary with temperature thus this steady state analysis is non-linear.

Conclusions and future work

The main goal of this study was to create a simple engineering method to find heat transfer indicators in box type double skin façades.

This façade system is becoming increasingly requested by the beneficiaries, recommended by architects, because considerable positive influence on interior comfort, vision and energy consumption for the entire building.

In Europe, this system has been installed on several corporate office buildings, innovative, as an appropriate method for noise insulation, save energy and to get as much sunlight during the day. Installing such a façade is complex and requires a combination of several fields of engineering. Depending on the aim a very close cooperation is needed between those involved in the project, namely architects, builders, installers, energy auditors etc.

The presented methodology is useful for finding heat transfer indicators involved in energetic audits and not for energetic performance. It can be used universally but for different geometric configurations convection inside cavity should be treated accordingly.

Future work will be done, for extending the methodology to other types of double skin façades. This imply defining for every type of double skin façade convection heat transfer coefficients inside cavity. For this purpose, modeling and simulation software will be used [29].

4.2. Renewable-energy sources potential in Romania

4.2.1. Hydropower development in Romania

Water is a prime element both for sustaining life on Earth and for complex human activity. In 2015 in Romania the average electricity production was of 7,343 MWh and the average consumption was of 6,590 MWh. The average hydropower generated was of 1,894 MWh, which is equal to 26% of the total production.

In this study, together with some coleagues we analyzed the hydropower system in Romania from its beginnings, in 1884, to its present development. The first hydropower plant in Romania was in Sinaia and had an installed capacity of 4x250 kW. Now, Romania has more than 200 HPPs, with a total installed capacity of 6.443 MW. In Romania, hydropower is the first main source of energy among RES, followed by wind energy.

Between 1950 and 1990 were built 115 hydropower stations. This period is characterized by the construction of most of the hydroelectric power plants in Romania, including the largest. The development of the hydro potential has begun in Bistrița basin. After 1990, in the transition period, after the fall of communism, the number of installed hydropower plants decreased, by 2010 totaling an installed capacity of only 838 MW, which means less than 14% of what was done before 1990. About 54% of Romania's hydropower potential is now arranged, and there are plans to reach 63.5% by 2025.

The largest artificial lake of Romania is Lake Iron Gates I (Porțile de Fier I), constructed between 1964-1972 behind a 60 meters' dam. Iron Gate I rank position 52 out of 66, in the list of largest hydroelectric power stations in the world. Iron Gates I system is one of the largest hydro constructions in Europe and the largest on the Danube.

Population and economic growth in developing countries, is demanding high levels of energy in order to meet increasing modern life conveniences [30]. Electricity production is rising significantly in order to provide higher economic welfare, using hydropower as an advantageous alternative for clean energy at a stable price [31]. Hydropower is the energy created from the force of falling or flowing water (rivers, dams and waterfalls). This kind of energy has many advantages: it can be stored (unlike the sun or wind), there isn't any fuel purchase costs, it is a multiple-use resource, it is less expensive than mining fossil fuels and does not contribute to the greenhouse effect. The large hydro power plants require the construction of dams, disrupting the river flow and fish migration and generating various environmental damage. In small hydro projects the river flow is diverted through a large pipe to a downstream turbine that generates electricity, so the environmental effects are lower [32]. The power of falling water has been used since ancient times for different purposes, but to produce electricity is used just for 138 years.

Sustainable development has been defined by political and corporate leaders as the combination of environmental protection and economic growth. As a result, the concept of eco-efficiency has been promoted as the primary tool for achieving industrial sustainability [33].

In 2015, hydropower development continued its rapid growth trend. Globally, the drivers for this include a general increase in demand not just for electricity, but also for qualities such as reliable, clean and affordable power. In 2015, the new installed capacity of hydropower was 33.7 GW (including 2.5 GW pumped storage, with significant capacity under construction or in the planning stages), bringing the World total hydropower capacity to 1212 GW. The share of hydropower contribution, by region, in 2015, in the World is presented in Figure 24. The year 2016 also witnessed the global community adopting a new sustainable development agenda and global agreement on climate change, which will catalyze further actions and investment towards a low-carbon, resilient and sustainable future. This brings a focus on clean and renewable energy. Hydropower will play a significant role in supporting energy and water systems in their transition towards a more sustainable future. In September 2015, the UN Sustainable Development Goals were officially adopted. Superseding the Millennium Development Goals, the SDGs include a specific goal related to energy: “ensure access to affordable, reliable, sustainable, and modern energy for all,” which calls for a substantial increase in the share of renewables by 2030. In December 2015, the parties to the UNFCCC agreed to reduce anthropogenic greenhouse-gas emissions to limit global warming to “well below 2°C”. Both agreements will drive further growth in the hydropower sector, especially in emerging and developing economies [34]. A top five on total hydropower capacity in the World, by countries, include China on the first place, Brazil on the second, United States on third, Canada on forth and Russian Federation on five [35].

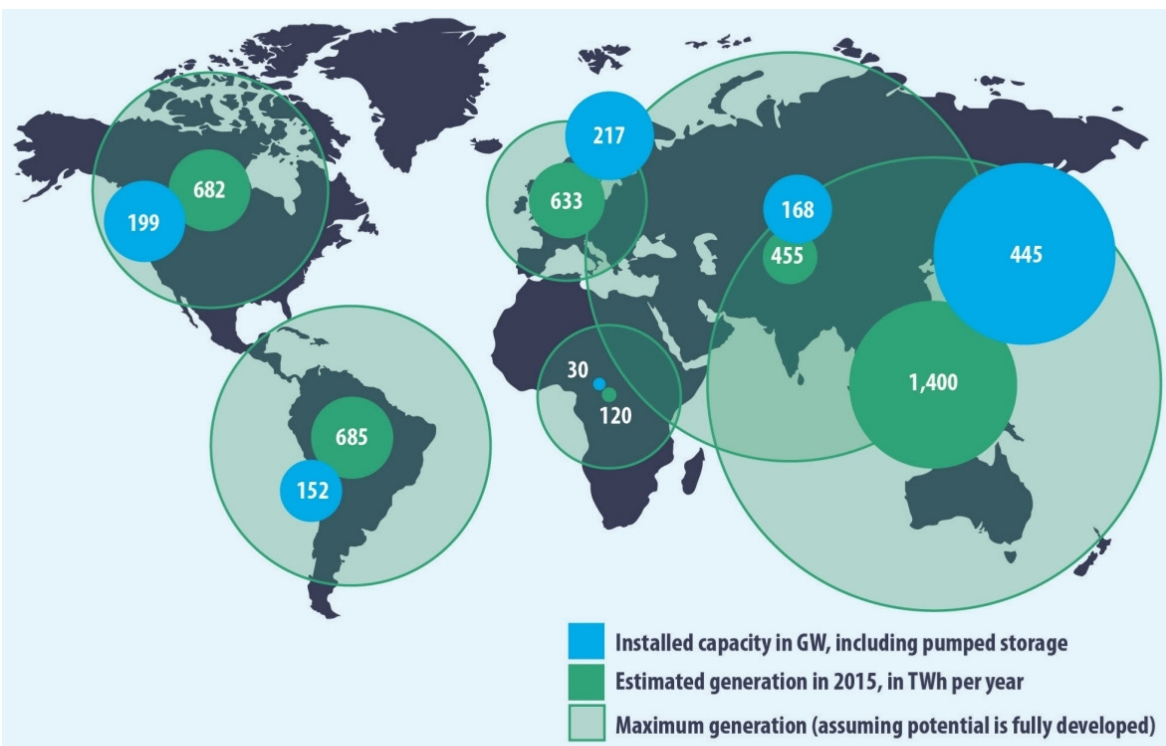

Figure 24. Hydropower’s contribution in 2015, in the World [36]

In many parts of the world, large and medium reservoir based hydropower projects have been in the line of fire for their multiple, large scale socio-economic and environmental impacts such as submergence due to formation of reservoir, displacement of native people and emission of greenhouse gases [37][38][39][40]. Hence, the focus is now on construction and development of small hydropower projects (SHPs) [41].

The breadth and complexity of energy-related issues are increasing in a globalized world with economic and environmental constraints. The EU is called to face an increasing dependence on fossil fuels, growing energy imports and rising energy costs—although recent drastic changes due to unconventional worldwide discoveries of oil and gas reserves may change the latter. These challenges are making European societies and economies vulnerable and in order to deal with them, progress towards a sustainable energy development seems the only way. The European Commission has risen by proposing a range of policies that aim to address these challenges and trans- form them into opportunities for global economic and technological leadership [42]. In November 1997, the European Commission (EC) adopted a White Paper on "*Energy for the Future: Renewable Sources of Energy*" [43]. Its scope was to contribute, by promoting RES, to the achievement of the overall energy policy objectives: security of supply, environment and competitiveness, and protection of environment. To reach this aim, the White Paper proposed to double the contribution of RES to the EU's gross inland energy consumption, establishing an indicative Community objective of 12% by 2010. Shortly after, June 1998, the Council adopted a Resolution on RES [44], embracing the White Paper aims as a basis for actions at Community and national levels, considering the indicative objective of 12% by 2010 as a useful guide. The same welcome was expressed by the European Parliament that, inter alia, asked for: a Task Force on RES and the incorporation of an energy chapter in the Treaty for any future review. An equal approval came from the Committee of Regions, that asked for the creation of a "European Agency for Renewable Energy", and from the Economic and Social Committee that, in turn, give attention to the economic effects on the manufacturing, building and agricultural industry [45][46][47][48]. In Europe, the Hydropower potential, the gross hypothetical capability in TWh/year is presented in Figure 25. Romania has joined the European Union (EU) in 2007 [49]. The EU target for 2020 regarding the share of electricity produced from RES in the national gross final energy consumption is 20%, while the target of Romania is 24%, which means Romania will probably face no difficulties in fulfilling this target [50].

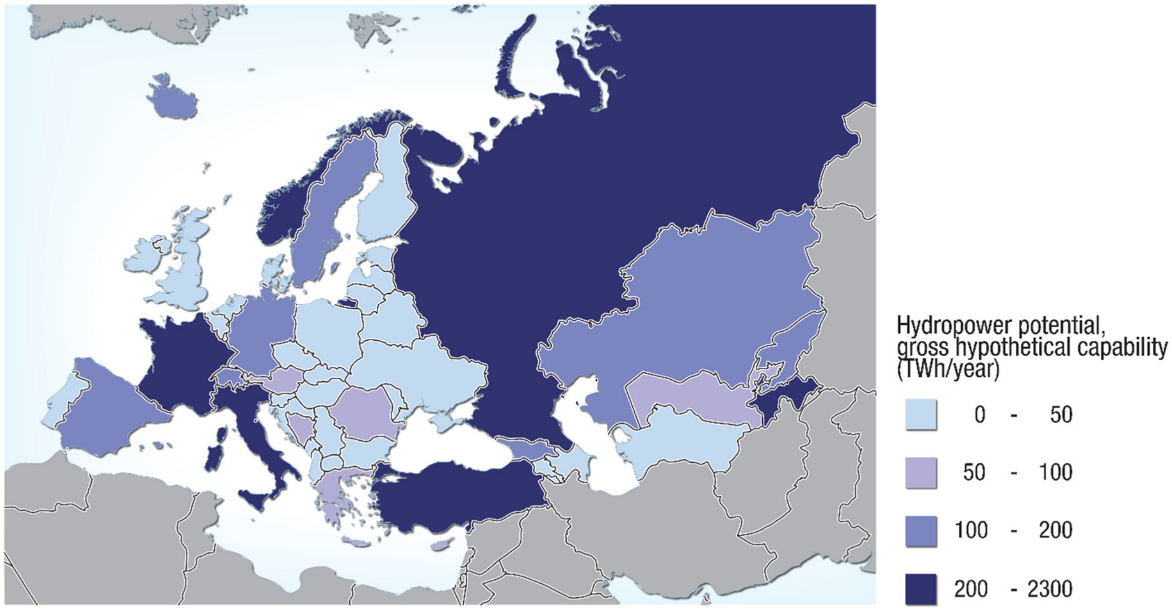

Figure 25. The Hydropower potential, the gross hypothetical capability in TWh/year in Europe [51]

Renewable sources of energy play an important part in the sustainable supply of energy and in the sustainable [52]. economic and social development, mostly by climate change mitigation. Romania is a country with a great potential of renewable energy sources [53]. Most of the energy projects in Romania (very similar with megaprojects defined by [54] as multi-billion dollar infrastructure projects, and characterized by [55] as being commissioned by governments and delivered by private enterprises) were financed, during 2007–2013 period, through Operational Sectoral Program Increase of Economic Competitiveness, Priority Axis 4 Increasing Energy Efficiency and Security of Supply, in the Context of Combating Climate Change, which is part of the European Regional Development Fund (ERDF). Since 2007, the started projects are totalizing more than 1.000 million Euros, more than half of these funds being provided through this Program, which is governed by [50].

Romania's energy potential derived from renewable-energy sources consists of: hydro, wind energy, solar energy, biomass and geothermal energy. The largest contributor in this case is represented by hydro energy, followed by wind energy. Hydroelectric power can be stored, and electricity can be produced at a constant rate. As can be observed in Figure 2, the hydropower potential of Romania is between 50 and 100 TWh/year.

Romania's hydropower potential is influenced by two major factors: the multiannual average flow rate of rivers, which is relatively low (maximum 225 m^3/s), and the altitude at the source, which is about 1,400 m. Due to these factors, we can say that the hydropower potential of Romania is relatively modest. The hydropower potential is expressed in terms of: theoretical flow potential, linear theoretical potential, technical conversion potential and economic conversion potential. In the last decade, it has been reviewed several times, being estimated to have the following values: for the theoretical flow potential 90 TWh/year, for the linear theoretical potential 70 TWh/year, the technically harnessed hydroelectric potential 32-36 TWh/year, and the economic conversion potential 23-30 TWh/year. The biggest technical hydropower potential is harnessed on the Danube, Siret, Olt and Mures, as can be observed in Figure 26.

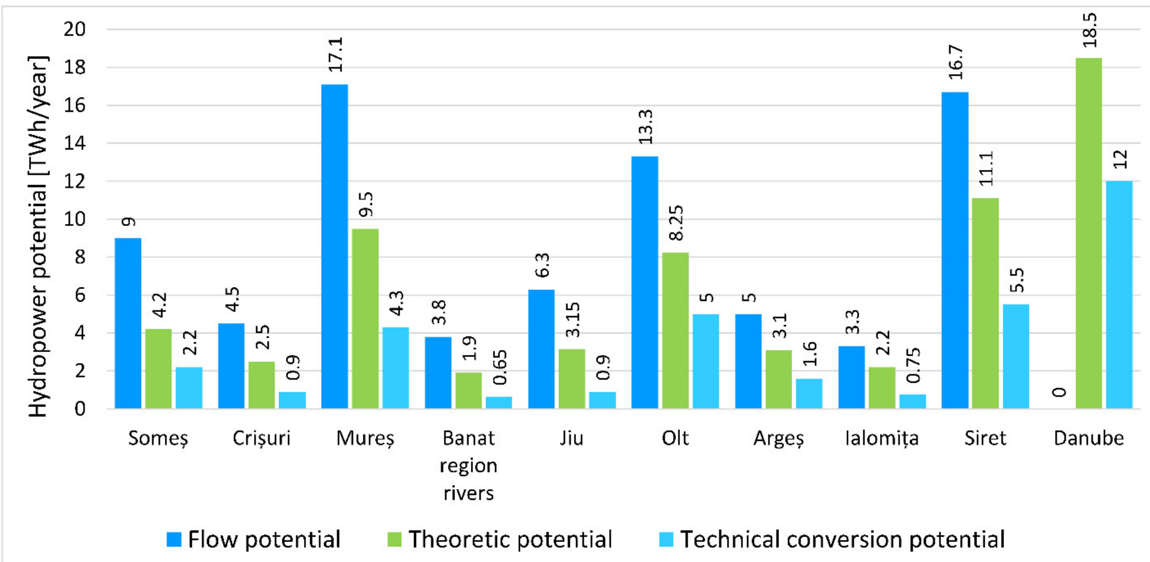

Figure 26. Distribution of hydropower flow potential, theoretical and technical, harnessed on river basin districts.

Lately, in Romania and in the entire European Union, a great emphasis has been put on harnessing micro-hydropower potential. Romania's micro-hydropower linear theoretical potential is estimated at 1,895 MW, and approximately 416 MW of its technical conversion potential is located on streams that have a specific potential greater than 150 kW/km, which is considered an economic harnessed potential. The average annual energy potential to be produced is estimated at 2,750 GWh/year, with savings of only 1,200 GWh/year [56]. Estimates of micro hydropower potential made in Romania revealed the values presented in Table 3, for the main river basins.

Table 3. Micro-hydropower potential of Romania

River basin	Length of river basin [km]	Micro hydropower potential [MW]
Somes-Tisa	2689	177
Crisuri-Barcau	1073	53.7
Mures	3050	301
Nera-Timis-Barzava	1913	256
Cerna-Jiu 1	1830	257
Olt	5029	458
Arges-Dambovita	1328	43
Ialomita	321	305
Siret-Prut	6400	306
Danube	11330	22.3

The first Hydropower in Romania was built near the Peleș Castle, in Sinaia, the summer residence of the Romanian Royal Family and it was built between 1873-1884 on the initiative of King Carol I of Romania (1866 - 1914). From all sovereigns, Carol I was the first Romanian monarch to break with the tradition of having compulsory candle-lightings in the royal palace and adopt electric bulb lighting at his new residence. The hydropower plant with a drop of 125 m and an installed flow of 150 l/sec was equipped with two Girard turbines with an output of 200 HP, 500 RPM, which drove five generators, three of which for indoor lighting and two for architectural lighting. A third Girard turbine with only 4 HP provided for daytime lighting [57].

Hydropower development before 1989

This period is characterized by the construction of the largest and most hydroelectric power plants in Romania. Between 1950 and 1990, a number of 115 hydropower stations were built. The development of the hydro potential began in the Bistrița basin, in the Easthern Carpathians, with Stejaru hydropower station in Bicaz, initiated in 1951 and completed in 1960. The diagrams for watercourse developments started to be drawn up in the 1950s based on some ample multidisciplinary studies regarding:

- the natural geomorphological, hydrological and climate conditions of the river basin as well as its economic development stage;

- its present and future usage in agriculture, power production, industry, human settlements, fish farming, navigation and recreation as well as for preserving the environment;
- the necessity to reduce the effects of heavy floods, with 5-year recurrence intervals in the last century;
- water resource availability in the basin ~~s~~ or in the neighboring basins, together with the possibility to make important storages;
- long-term development of economic branches, and evolution of water needs.

The main target of hydraulic developments between 1950-1975 was hydropower potential usage. Later, the water demands in Romania's economy required changing this approach to the point of focusing on industrial necessities, agricultural and domestic use.

The installed power increased at the time from 60 MW to 5,560 MW (4,240 MW on inland rivers and 1,320 MW on the Danube), and the yearly average power also increased from 169 GWh/year to 16,470 GWh/year (9,910 GWh/year on inland rivers and 6,560 GWh/year on the Danube). Almost 48% of the total power for the whole period was produced by the largest hydropower station on the Danube River, Iron Gates I. In the Five-Year Plan (1986-1990), hydropower stations with an installed power of 1,518 MW and an average power of 3,273 GWh/year were commissioned. Besides these hydraulic developments, the network of the inland rivers allowed building micro-hydropower stations (i.e. under 3.6 MW), totalizing 1,535 MW, with an output of 3,509 GWh/year.

Romania and Serbia (Yugoslavia at that time) achieved in cooperation the hydropower navigation developments Iron Gate I (1970-1971) and Iron Gate II (1985-1986), on the Danube (Figure 27). To exploit the hydropower potential of the river Danube, both countries built on Iron Gates I two hydropower dam-type plants, placed on the retention front between the spillway and the locks. Iron Gates II were placed on the main branch of the Danube, being adjoined but separated by the state frontier Romania-Serbia, thus making on the territory of the country the limits of the power plant, of the lock and of a spillway dam. At the Iron Gates I, each of the two riverside countries has one power plant with an installed power of 1,068 MW and an average power production of 5,250 GWh/year. Both power plants consist of three sections. Each section is 60-64 m long and is equipped with 2 turbines, with an installed power of 178 MW each, and a rotor diameter of 9.5 m. At the Iron Gates II, each power plant contains 8 bulb-type turbines, with a horizontal axle, an installed power of 27 MW each, and a rotor diameter of 7.5 m. The total installed power at the Iron Gates II is 216 MW, and the average electric power output is of 1,236 GWh/year [58].

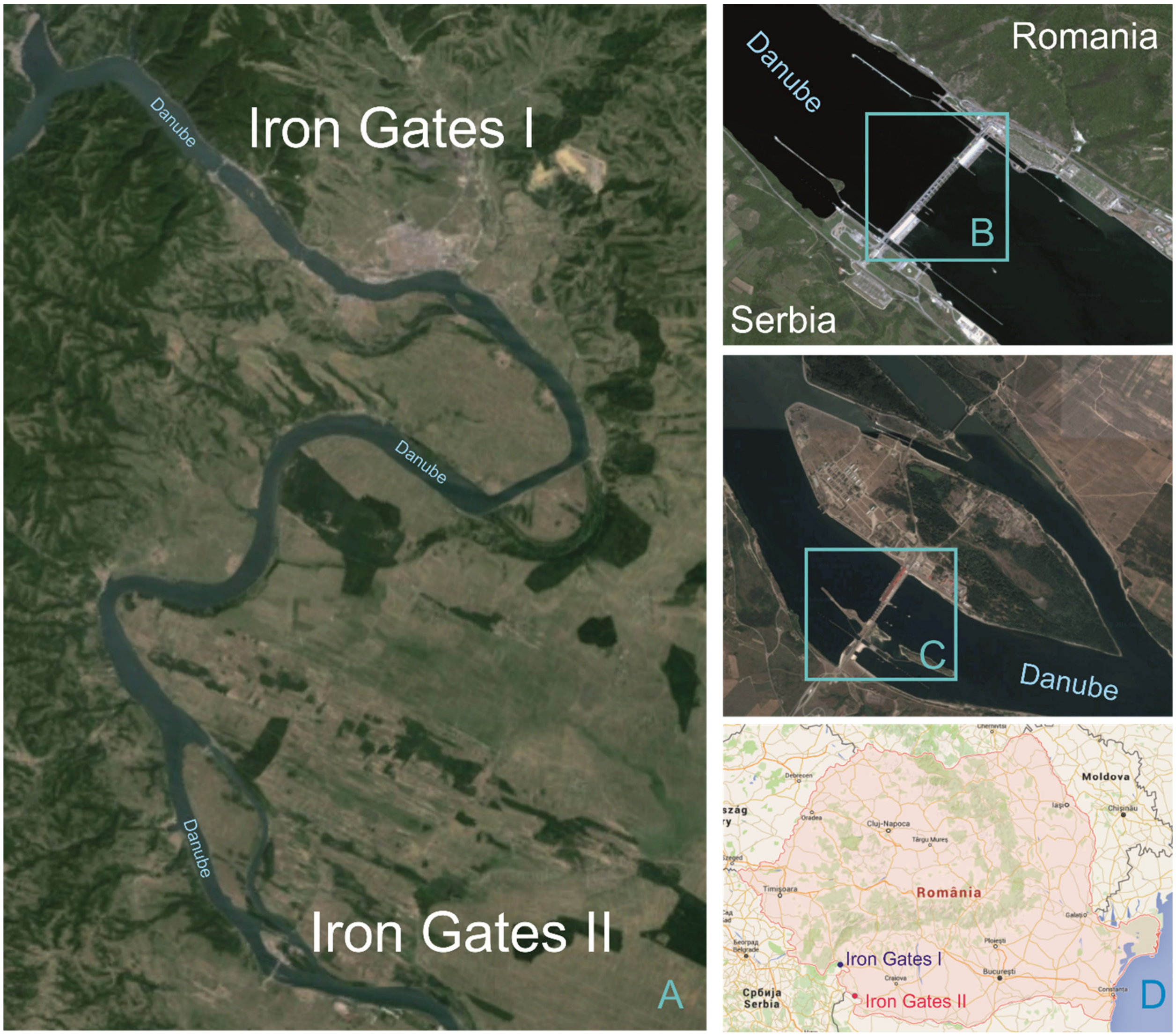

Figure 27. The main Hydropower Plants on the Danube River, Iron Gates I and Iron Gates II, at the Romania-Republic of Serbia border

(A – Satellite view of Iron Gate I and II Hydroelectric Power Stations; B - Satellite view of Iron Gate I, in detail; C - Satellite view of Iron Gate II, in detail; D – Hydroelectric Power Stations' position relative to the country's borders)

Hydropower development after 1989

The average annual installed capacity and the energy production in hydropower plants, in Romania, every five years, between 1950-2015, are presented in Figure 28.

Hydropower plants were also built after 1989, after the collapse of communism during the so-called "transition period". By 2010, the installed hydropower plants had totaled up an installed capacity of 838 MW. This is more than five times less (14.32%) than what Romania had before the Revolution (1989). About 54% of Romania's hydropower potential is now arranged, and there are plans to reach 63.5% by 2025.

As can be observed, by 2015 the hydropower plants by 2015 has totaled up an installed capacity of 6.443 MW, which is correlated to an energy production in hydropower plants of 17,196 GWh/year. Over 85% of the energy produced in 2015 was generated in hydropower plants with an installed capacity exceeding 25 MW.

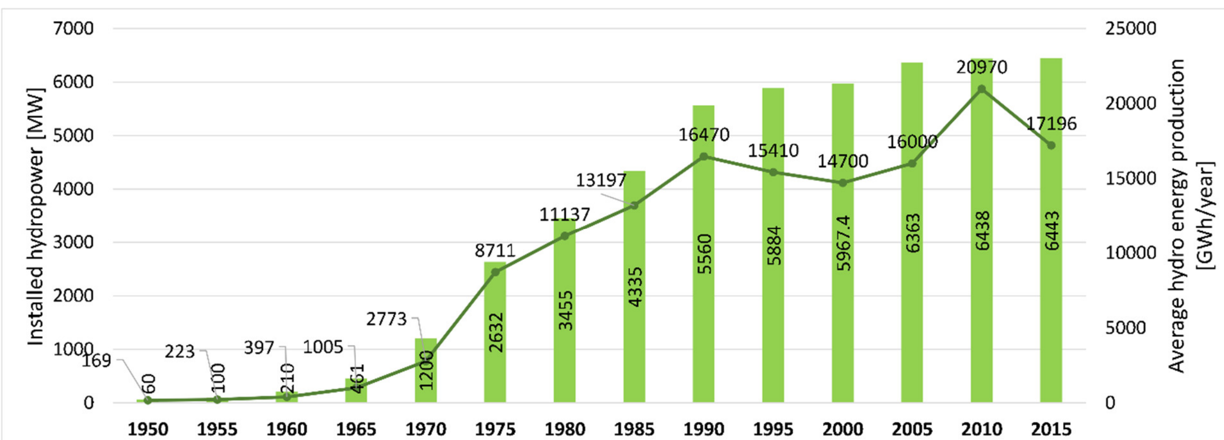

Figure 28. Average annual installed capacity and energy production of hydropower plants, in Romania, between 1950-2015. [58], [59], [60]

In 2015, 393,023 GW of electricity were produced by the Romanian Energy System, 101,059 GW of which from hydropower sources, and the energy consumption was of 351,397 GW (Figure 29). In 2015 the Romanian Energy System produced an average of 7,370 MWh of electricity, of which 1,895 MWh from hydropower sources, and the energy consumption was of 6,590 MWh (Figure 29).

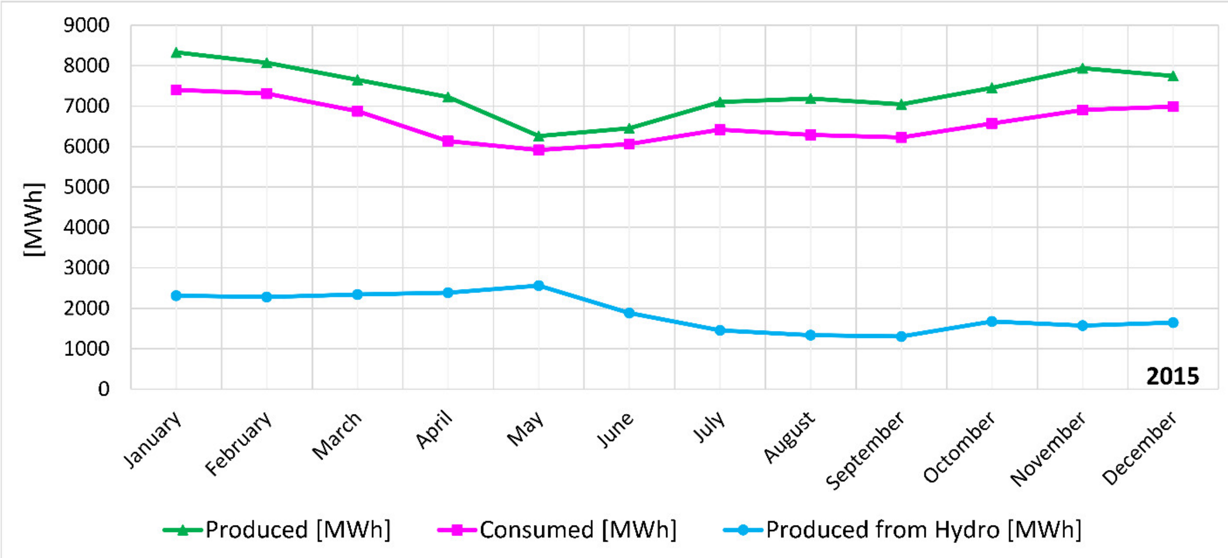

Figure 29. The monthly variation of electricity overall produced and consumed, and of the electricity produced from hydro, in Romania in 2015 [61]

The largest Hydropower Plant commissioned after 1989 (Ruieni) has an installed capacity of 140 MW and is placed on river Bistrița Mărului. The five largest hydropower plants built after 1989 are listed in Table 4.

Table 4. Top five largest hydropower plants built after 1989

Rank	Hydropower Plant	On river	Installed capacity [MW]
1	Ruieni	Bistra Mărului	140
2	Drăgănești	Olt	53
3	Rusănești	Olt	53
4	Frunzaru	Olt	53
5	Izbiceni	Olt	53

The variation of the electricity produced from hydro sources, every month, in the last five years is presented in Figure 30 and, as one can notice, the maximum values are in May, so at the end of spring, and the minimum values are reached in the autumn and winter seasons (most of the times in September).

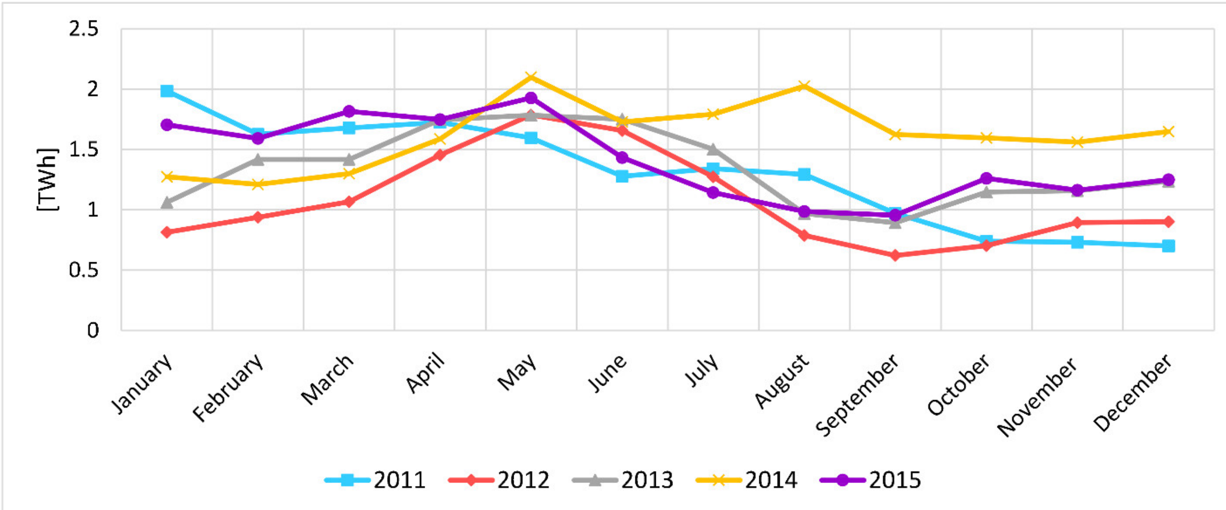

Figure 30. The monthly variation of electricity produced from hydro sources between 2011 and 2015 [61]

A turning point in the development of the hydro electricity production and also of the Romanian society was the Revolution of 1989. After this event Romania faced an economic crisis that led to closing large high energy consumption enterprises and lowering the gross domestic product, resulting in a decrease in the amount of electricity produced or consumed. Another important aspect in the development of Romanian society after 1989 is the fluctuation in the number of inhabitants. The highest rate was recorded in the census of 7 January 1992, about 22,8 million people, whereas in the census of 20th of October 2011, the population was of about 19 million people. Because of this, although after 1990 Romania has attracted small investments in hydro electric energy, the country has had a constant increase of installed power and of the quantity of electricity produced per person. The total electric power and the hydropower installed per person, in Romania, between 1950-2015 are shown in Figure 31.

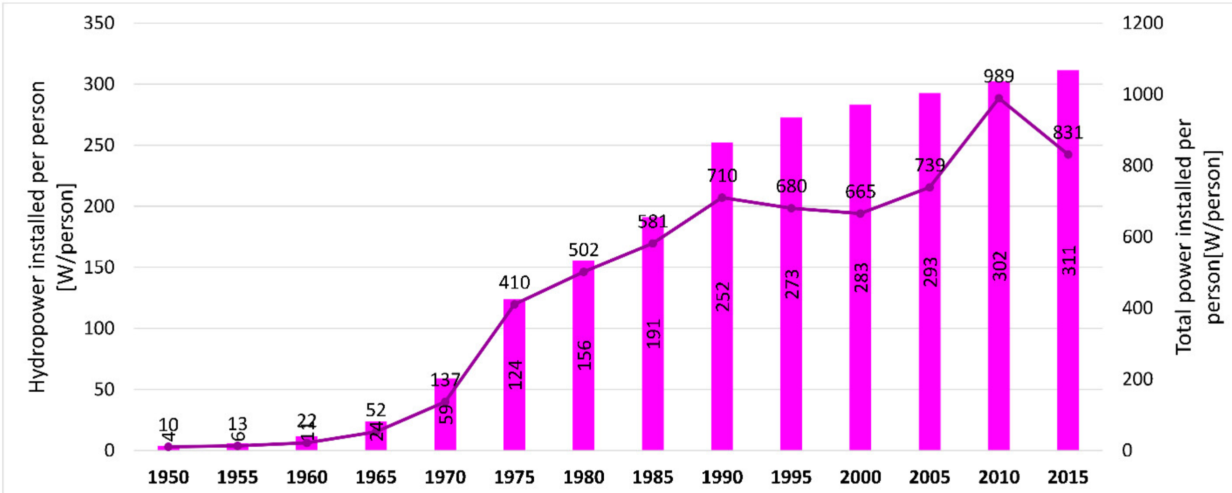

Figure 31. Total electric power and hydropower installed in Romania per person, between 1950-2015. [58], [59], [60]

The total energy and the hydro energy per person per year, in Romania, between 1950-2015 are represented in Figure 32.

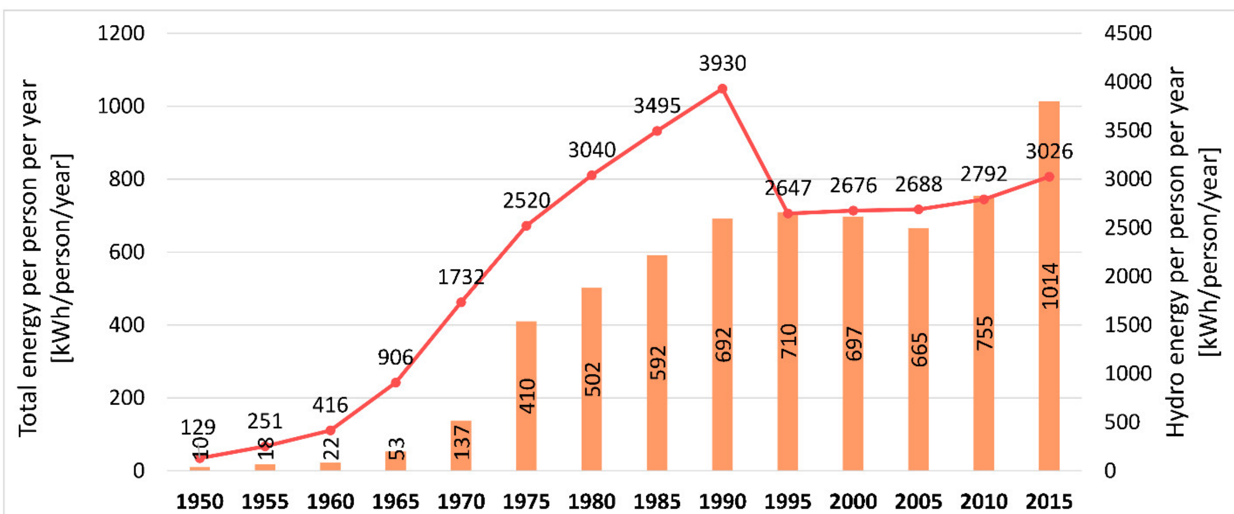

Figure 32. Total energy and hydro energy in Romania, per person per year, between 1950-2015 [58], [59], [60]

Future project developments for hydropower in Romania include both large and small hydropower plants, especially micro hydropower plants.

In terms of large hydropower plants, fall 2016 is the deadline for the negotiation and signing of the final documents with the successful tenderer for the execution of Tarniţa-Lăpuşteşti pumped-storage hydropower plant, which is to begin in 2017 and take between 5 and 7 years. The unit is to be built 30 kilometers away from the city of Cluj-Napoca, on Warm Someș (Someșul Cald) river valley. The hydropower station is expected to have four units of 250 MW each. The project for the Tarniţa-Lăpuşteşti Hydroelectric Power Station is not very recent, dating back 40 years. In the explanatory note of the project it is shown that Romania is the only EU country that, despite its favorable natural conditions for the construction and operation of a pumped hydroelectric energy storage (PHES) system, does not have such a station yet [62].

In terms of micro hydropower plants (less than 10 MW [63]), by December 31, 2014 a capacity of 586 MW had been installed. By 2020 it is expected for this capacity to be extended to 729 MW, by means of the National Renewable Energy Action Plan. The total micro-hydraulic potential of Romania is of about 1,600 MW and it is estimated that the annual energy produced is of 4,000 GWh/year [64], [65]. Small hydropower plants can be a pragmatic solution for isolated power consumers only where other solutions for producing energy from renewable sources are not feasible.

As a conclusion to this section, Figure 33 shows the distribution of HPPs in Romania, by capacity, in September 2015.

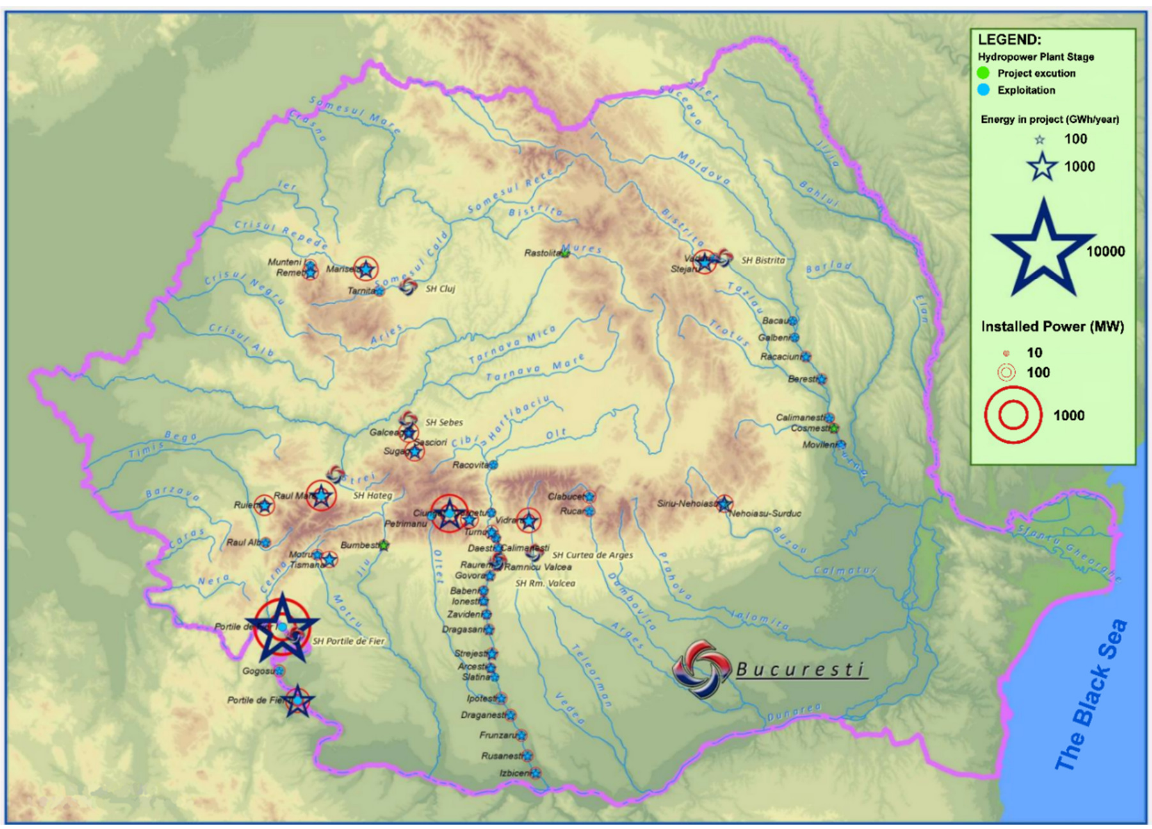

Figure 33. Distribution of HPPs in Romania, by capacity, in September 2015 [66]

4.2.2. A review of wind energy in Romania

Amending legislation in 2013 by diminishing the support for the RES producers led to a significant reduction in investment in this area and eventually will cause an end. Romania met the planned capacity for 2014 with 2967 MW installed above 2880 MW planned. However, reducing the number of GC can affect the deployment of future projects to meet the 4000 MW expected by 2020.

The European Union has set a unique path in terms of developing renewable energies by 2020, but each country has different potentials depending on geographical location, landscape, climatic influences and local policies. Romania's wind potential is considered the highest in Southeast Europe with Dobrogea region being the second highest wind potential area on the continent.

RES Romanian producers benefited Green Certificates (GC) scheme upon accreditation by the National Regulatory Authority for Energy (ANRE). Green Certificates can be redeemed only in Romania within the national agreed quota. Owing to the 2010 legislative measures, installed capacity of wind power increased from 7 MW in 2009 to 976 MW peak in 2012, by 2015 reaching a total installed power of 2,990 MW.

Promotion of electricity from renewable sources over 2010-2013, through the national subsidy policy has led to a significant drop in greenhouse-gas emissions from the production of electricity from 438 g/kWh in 2011 to 326 g/kWh in 2015.

The European Union plays a key role on the international energy market, being the greatest importer and the second largest consumer. Romania’s accession to the European Union on 1 January 2007 has determined significant changes in the energy sector. The changes involved reviewing energy policy, alignment with the EU energy legislation and promotion of renewable and sustainable energy.

There is a widespread interest in reducing energy consumption. Nevertheless, we are undoubtedly witnessing demographic growth (more people have access to energy) and economic development, leading to an increase in energy demand. In 2008, about 81% of the electricity generated on Earth was produced from burning fuels as follows: fossil oil (33.5%), coal (26.8%) and gas (20.9%) [67]. Burning these fuels contributes significantly to emissions of greenhouse gas, the main contributor to the current global warming. Besides the negative environmental effect of excessive use, energy from fossil fuels can put at risk the future global energy security due to the significant drop in remaining resources on Terra. Burning fossil fuels for energy requirements contributes to the increase in greenhouse-gas concentrations in the atmosphere [68]–[83], thus enhancing the security of power supply chain and diminishing the greenhouse-gas emissions, which require heedful care and serious consideration now more than ever [84], [85]. This is the main reason why both local and global measures need to be taken.

Increasingly countries have taken steps to favor the use of renewable energies aimed at alleviating environmental problems and reduce dependence on fossil fuels. Following these measures, wind power has had a rapid growth after 2000 [86]–[90]. Romania's energy potential derived from renewable-energy sources consists of: solar energy, wind energy, biomass, hydro and geothermal energy. The largest contributor in this case is represented by hydro energy, followed by wind energy. Hydroelectric power can be stored, and electricity can be produced at a constant rate. These two are the greatest advantages of hydro energy, but they present many disadvantages too. Among hydroelectric power drawbacks we could mention:

- Dams and all hydroelectric power plants are very expensive to build;
- Payback period is significantly long;
- Natural environment may be destroyed [91]–[95];
- Effects on agriculture;
- Dependence on annual rainfall levels;

Hydropower is a sustainable and long-lasting source of energy but building a hydroelectric power plant raises many environmental concerns.

Among the ways in which electricity can be generated from renewable-energy sources (RES), the one based on wind turbines is believed to be the least harmful to the environment [96]–[98]. It has also been the most cost effective of the RES, until now [99]. Due to the combination of these two factors, wind energy is the most extensively utilized of all renewable-energy sources for electricity generation if large hydropower is excluded from consideration (as it usually is) [100], [101]. Wind energy is sustainable and long-lasting too, pollution free and eco-friendly [101]–[127]. Wind energy is a clean renewable-energy source [32], [102], [103], [128]–[130] and is strategically important to national and socioeconomic development [131], [132].

The paper's main objective is to emphasize wind power energy potential in Romania and to analyze and present this sector at its current state. As a European Union member, the first step of our research was to evaluate this type of energy at European level. Having assessed this, based on energy dependency across EU countries - energy from renewable sources across EU countries, we subsequently put emphasis on the wind energy sector. For each criterion we identified and highlighted our country's position inside the European Community.

We chose to present Romania's wind energy sector in detail, because it is the second largest segment of renewable energy, in Romania, after hydropower energy. The greatest hydropower plants in Romania were built long before the country's accession to the European Union. In the last 27 years only maintenance of existing facilities and resumption of older projects have been made in this sector. In contrast, in short periods of time substantial amounts of money have been invested, in wind power plants. This strategy seems to result from climatic changes (global warming) and longer periods of recorded drought, which hinders investments in large hydropower plants but supports other types of renewable-energy sources.

Romania is in the northern hemisphere and is positioned midway between the North Pole and Equator (over the south-central region passes the 45° parallel north). This causes a transitional temperate continental climate, specific to Central Europe, with four distinct seasons, spring, summer, autumn and winter. Local climatic differences are more due to altitude and latitude and a few are the result of the oceanic influences from the west, of the Mediterranean from the southwest, and from eastern mainland.

Throughout the country, the prevailing air circulation is from the west (West Winds), with lower intensity in the eastern part. Frequently, in the eastern part of the country and the Romanian Plain (Câmpia Română), , a frosty winter wind, dry in the summer (*Crivăţ),* blows from the northeastern part of the continent, causing low temperatures in winter (between -6 °C and 0 °C) and summer droughts (over 23 °C). In some foothill depressions and at the base of mountains there are local Föehn winds. Other local winds in Romania are the Austru (specific to southeastern Romania), the Băltăreț (wet winds from puddles) and the sea breeze, which blows inland in the daytime and in the opposite direction during the night.

Extreme temperatures were reached as follows: an absolute maximum temperature of 44.5 °C (recorded near Brăila) and an absolute minimum of -38.5 °C (recorded near Brașov).

Climate levels, local climate phenomena and local winds, together with the sectors of climatic influence are presented in Figure 34.

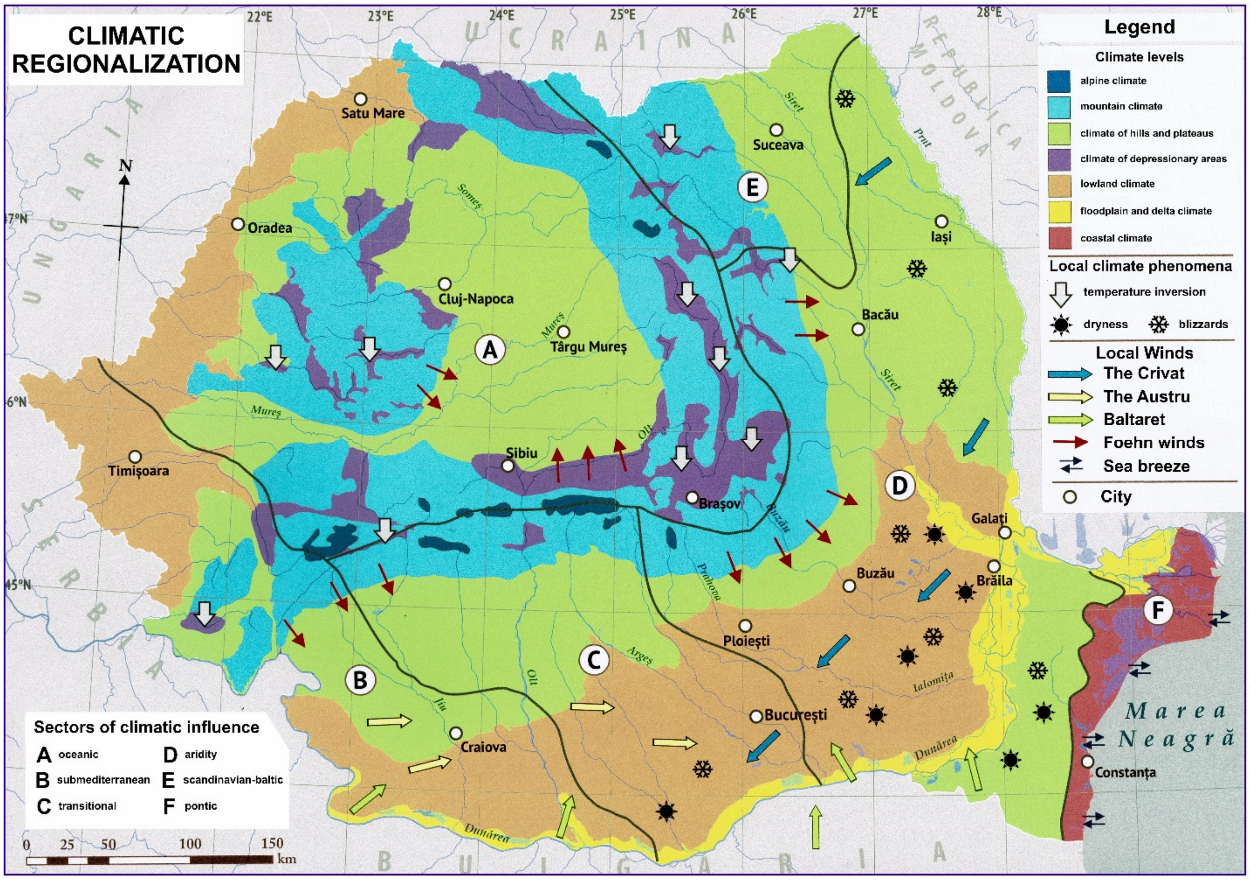

Figure 34. The map of climatic regionalization for Romania [133]

The Earth's atmosphere is dynamic. The air is moving continuously from one region to another. The air's horizontal or almost horizontal movement towards the Earth's surface is called wind. Wind is characterized by two elements: direction and speed. The wind direction near the surface is usually assessed in relation to the cardinal points and on the direction of the air flow (cardinal point windward). The wind speed consists of the distance traveled by air in unit time. Wind speed is expressed in m/s or km/h. We can establish a relationship between these measuring units, i.e 1m/s = 3.6 km/h. In Figure 35 the wind is represented by lines of frequency and average annual wind speed on directions. The direction of the lines represents the direction the wind blows, and their sizes are proportional to the wind average speed and frequency.

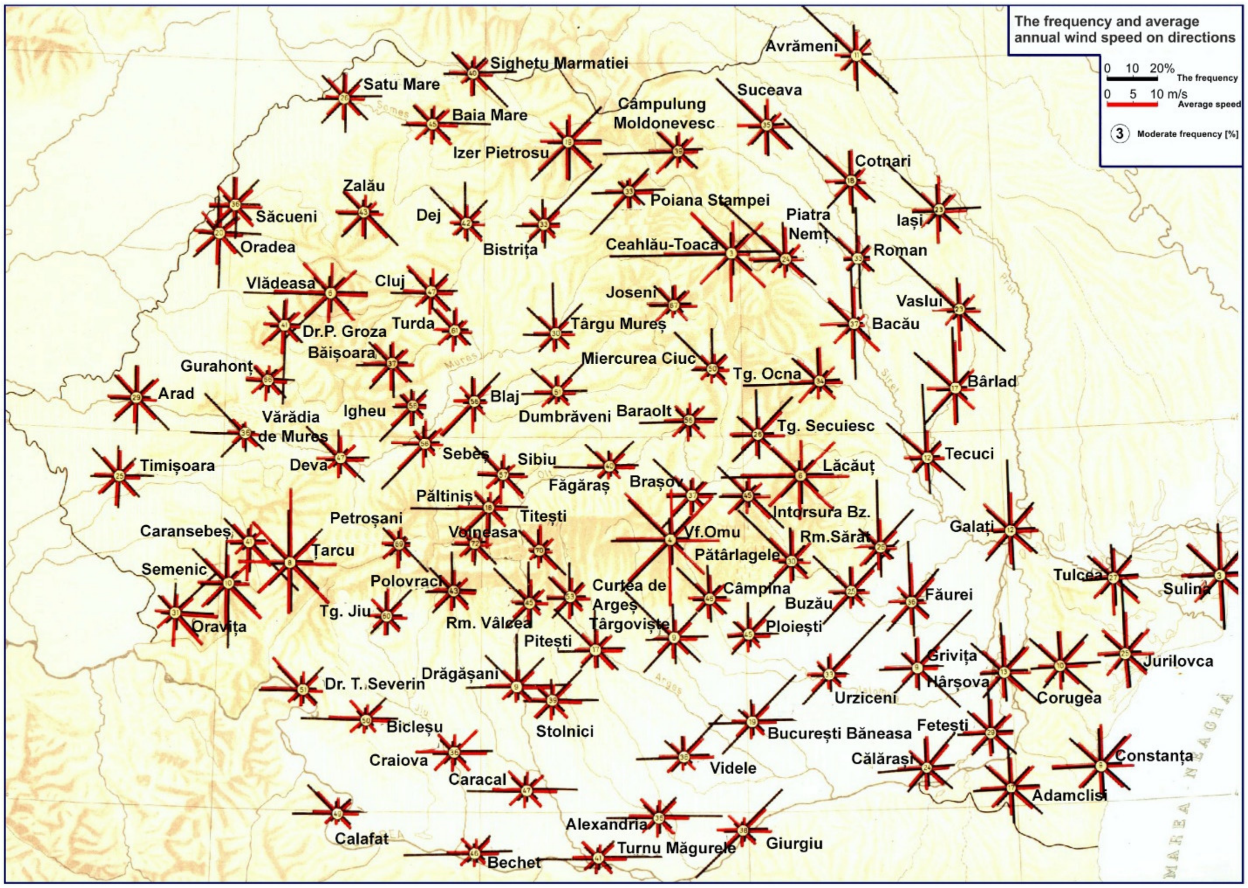

Figure 35. The frequency and annual wind speed on wind directions in Romania [134]

A more detailed overview on local winds and their frequency in warm and cold season is presented in Figure 36. The same figure contains information about dominant winds by sector and the two main regions, with the highest annual average wind speeds and with the greatest wind potential for Romania. Hills and mountains have a major influence on the wind flow. In Romania, because of the shape and position of the Carpathian Mountains, in the center of the country, it is the spatial distribution of eolian parameters that is influenced.

The two main sources of the renewable energy which contributed to this value were hydro (16.13 TWh) and wind (6.50 TWh). Although, lately, the sector for photovoltaic and biomass has been significantly increased, it could only deliver 1.72 TWh.

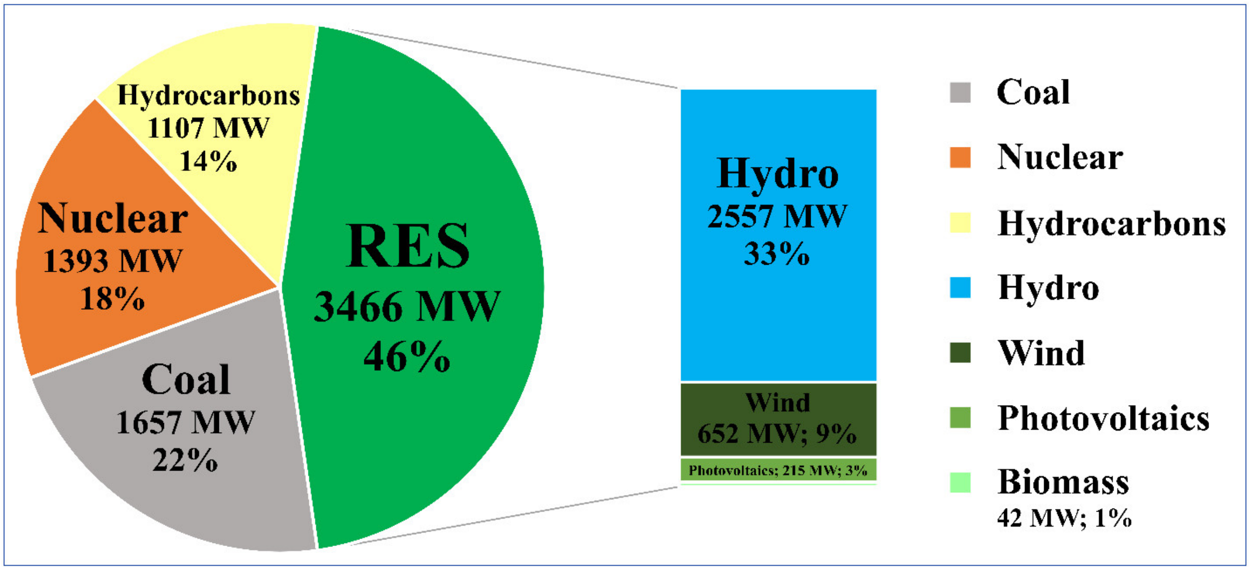

Figure 36. The mix of electric energy in Romania, on February 22, 2016 [61]

Worldwide, the leading sources of renewable energy used for electricity production are hydro, wind, photovoltaic and biomass.

The RES sector has suffered significant changes because of the associated legislation. The system dynamics concerning the production of electricity between 2000 and 2015 changed mainly due to new producers entering the wind, photovoltaics and biomass sector. They become important players on the Romanian energy production market, can generate significant amounts of electricity, as shown in Figure 37.

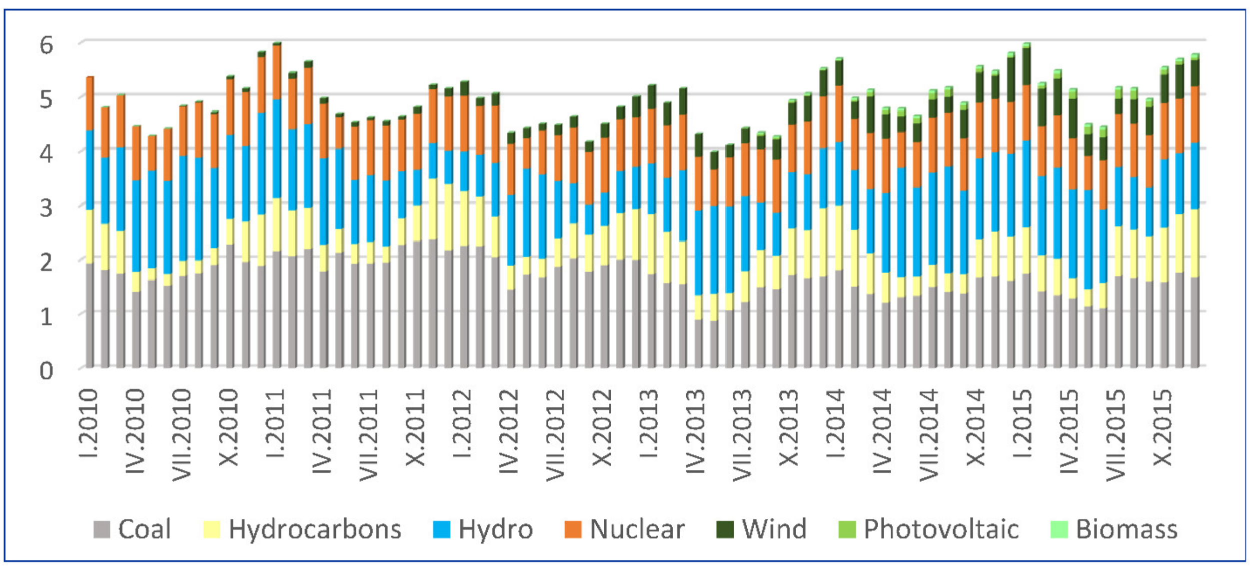

Figure 37. The growth of RES sector in Romania, between January 2010 and December 2015 [135]

Electricity production from wind sources experienced the most rapid development, due to the high wind potential and supporting policies for renewable-energy production. Wind energy in Romania has developed in a short period of time. In less than five years 75 wind farms with a power range from 0.008 to 600 MW and an average of 40 MW were built. In this period 1,200 wind turbines have been installed on the entire surface of Romania. This development of wind farms was achieved primarily in two regions: the core in Dobrogea Plateau, with near 78% of the total power installed, and a secondary one in Bârlad Plateau. The largest onshore wind farm in Europe is located in Dobrogea, in Fântânele and Cogealac, having an installed power of 600 MW. The wind farms locations throughout Romania are displayed in Figure 38.

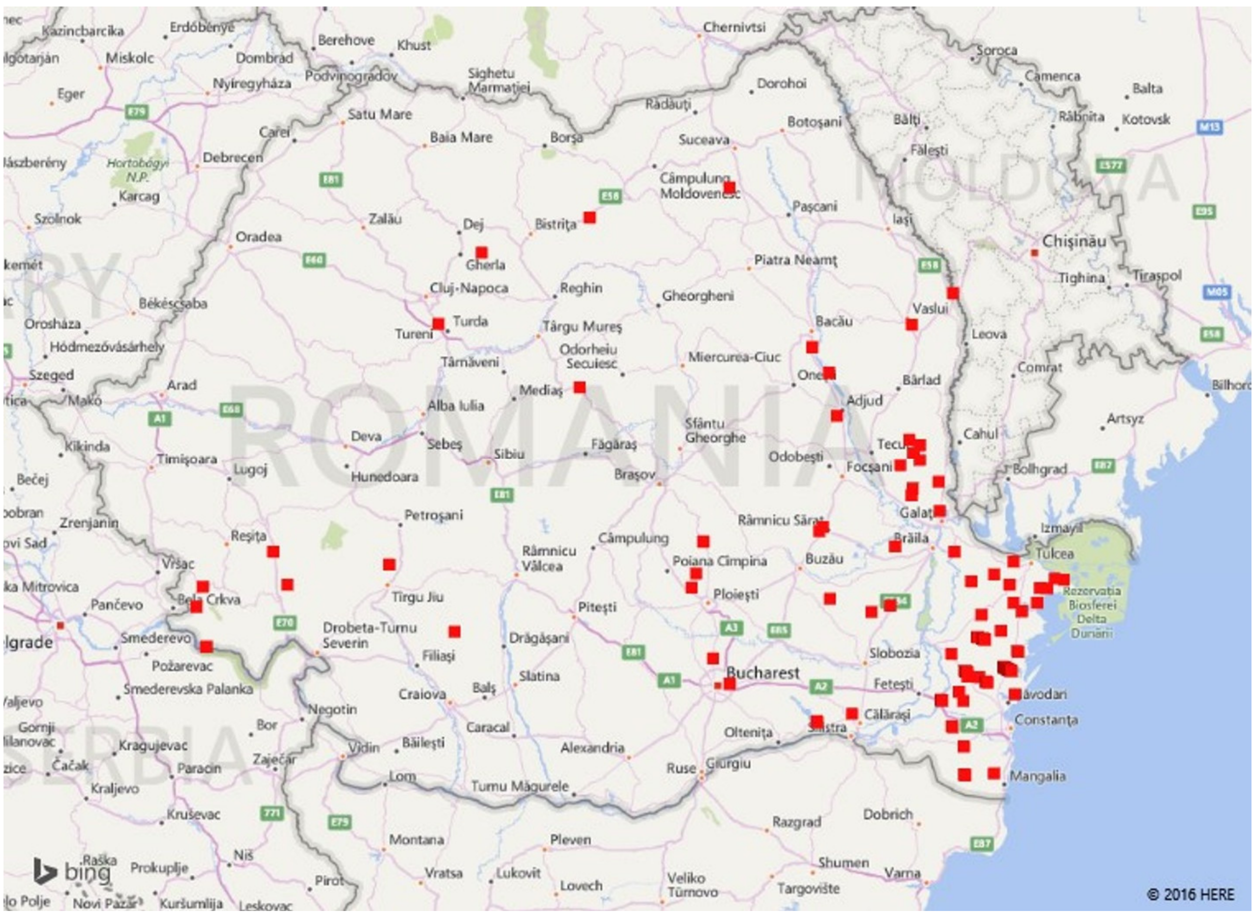

Figure 38. Wind farms locations throughout Romania at the end of 2015

At the end of 2015 wind farms with an installed power of 2,838 MW were already connected to the national electricity network, with another 100 MW approved for connection [61]. While in 2009 the set-up capacity was only 14 MW, in 2010 investments in wind energy intensified, reaching at the end of 2014 an installed power of 2,594 MW. This rapid development of the sector was blocked in 2013 by the change in the Green Certificates granting scheme. After this year, investments in new wind farms have gradually decreased, as shown in Figure 39.

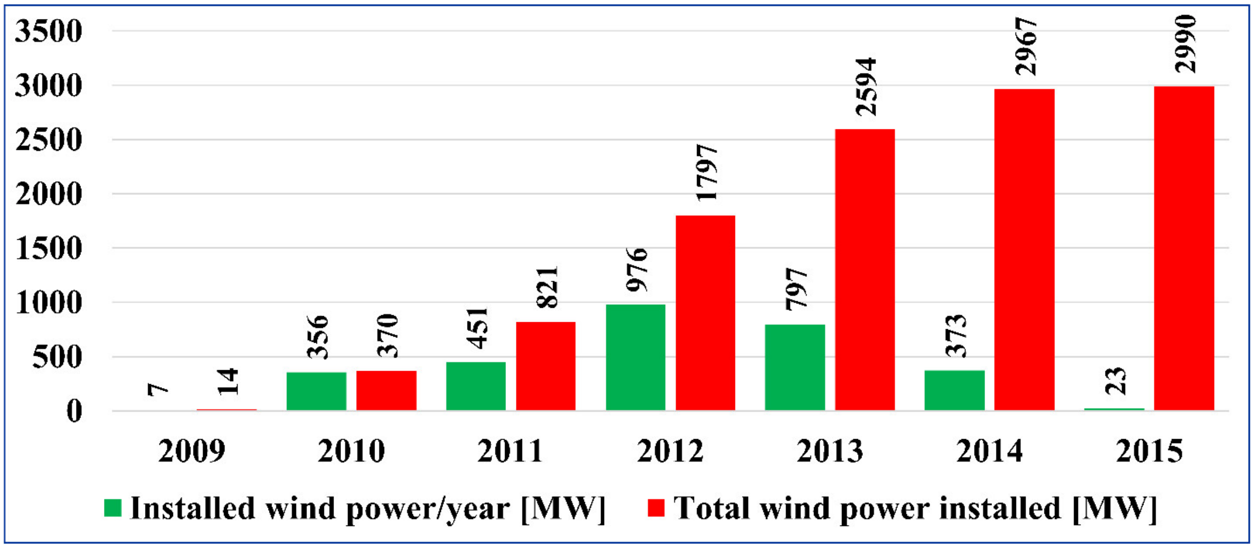

Figure 39. Installed wind power and total wind power between 2009 and 2015, in Romania [61]

Harnessing renewable-energy sources is a global trend because they offer a sustainable alternative to greenhouse gas generating systems. Europe is part of the global trend and its energetic system is under constant change because of the Renewable Energy Directive (Directive 2009/28/EC). As part of this system, wind energy is an important contributor now and a significant growth of this type of energy is expected in the future. The potential of renewable-energy sources in Romania is high, but due to geographical, technological and environmental limitations coupled with the high cost of investments for this, it is not totally exploited. Although the cost of producing electricity from renewable sources, especially wind, is low, compared to the high initial investment, their spread is reduced. The share of RES in the mix of electric energy produced in Romania is higher than in other European Union countries.

4.2.3. Photovoltaic, biomass and biogas in Romania

In Romania the annual solar energy flow ranges between 1000-1300 kWh/m^2/year in more than half of the country [136]. This climate allows the operation of solar panels from March until October, with a conversion efficiency between 40% and 90% [137]. Thus, an important solar potential exists. The most important regions of Romania with high solar potential are the Black Sea coast, Dobrogea and a great part of the Romanian plain, with an average of 1600 kWh/m^2/year [137]. Many photovoltaic parks were developed in various locations of Romania and others are in the planning phase [32].

The EU has assumed objectives for energy sustainability and the fight against climate change. In this regard, the generation of biogas allows contributions to the 2020 established targets. The EU is leader in the production of biogas, representing 60% of total global production in 2011. The estimates of the contribution of biogas to electricity generation for 2020 in the EU-28 represent 1.5% within the total energy mix. Recently, RES-E from biogas has increased more than initially expected in the EU-28. In the period 2010–2013, electricity generated from biogas grew by 20467.20 GWh, representing a growth rate of 64%. This notable growth has meant that EU-28 targets for 2015 were fulfilled in 2013. Five countries are highlighted for their high 2013 production (Germany, Italy, the U.K., the Czech Republic and France), generating nearly 90% of the total. This important growth in the EU-28 has also seen the first RES-E from biogas production. It is also worth noting, that in 2016, the U.K. decided to exit from the EU. This fact will affect the EU global production in future, as the U.K. is one of the largest producers of biogas in Europe [138].

Biomass energy is generated using a variety of sources: forest wastes, energy crops, agricultural waste and household waste, being the most easily accessed and affordable of all renewable energies. Romania has forests that cover more than a quarter of the country and large agriculture lands (43.4% of country's surface). As the biomass potential depends to a great extent on forest and land availability, Romania has a good biomass energy potential, estimated at about 7594 ktoe per year [32].

4.3. The study of processes, systems and materials used in Cryogenics

4.3.1. Austenitic stainless steel

Stainless steel is the most widely used cryogenic material due to its good mechanical properties due to its low thermal conductivity (the smallest of the metals used in cryogenics) and due to its good welding properties. The most used stainless steels used in the cryogenic field are 304, 304L, 304LN, 316, 316L and 321. All of these steels are also called austenitic steels because they contain large amounts of chromium and nickel, which gives them high corrosion resistance, they are ductile and can easily be welded. The austenitic name comes From austenite, which is a mixture of carbon and iron, crystalline, cubic, paramagnetic faceted cubes. The name was given by British metallurgist William Chandler Roberts-Austen,

Steel 304 has the following advantages:

- ✓ good corrosion resistance;
- ✓ good thermal resistance;
- ✓ good mechanical strength and properties at cryogenic temperatures;
- ✓ is a non-magnetic material;
- ✓ is malleable and does not strengthen during the welding process;

But it can lose its non-magnetic properties during welding or during thermal treatments or in contact with very cold fluids,

Steel 304L is a low-carbon austenitic stainless steel, which gives it better inter-granular strength after welding and straining,

Steel 304LN has increased intergranular resistance through the nitrogen content of the material (Nitrogen), which also improves its non-magnetic properties,

Steel 316 has good pitting corrosion resistance (local corrosion leading to holes in the material) due to the addition of molybdenum (Mo)

Steel 316L has the same properties as 316, but also has very good intergranular corrosion resistance,

For steel 321, titanium (Ti) is added to prevent intra-granular corrosion.

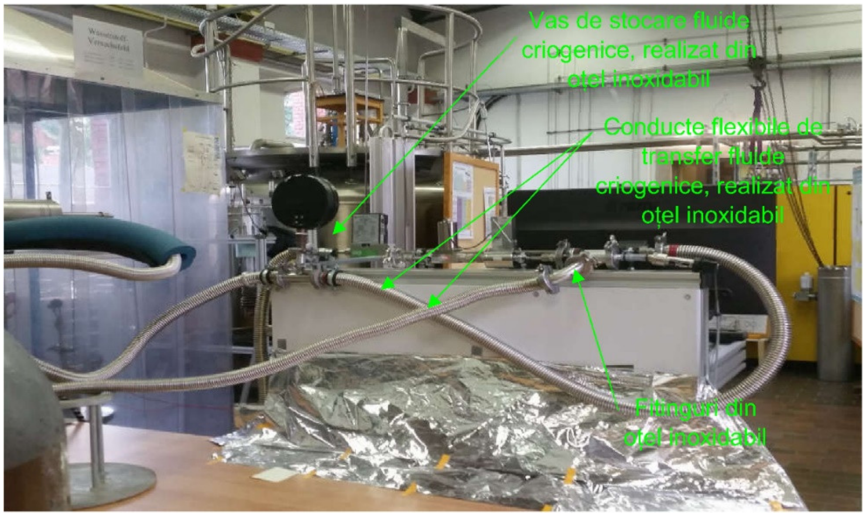

Figure 40. Cryogenic plant with stainless steel components (TU Dresden laboratory)

4.3.2. Vacuum insulation

A great American cryogenic engineer, Russell B. Scott, once remarked that many cryogenic applications require a thermal insulation perfection unmatched in any other field.

Choosing insulation for a particular cryogenic application is a compromise between the economic side, ease of installation and use, weight, robustness, volume and insulation efficiency.

James Dewar was the first man to liquefy hydrogen, but at the same time he was the first man to use vacuum insulation, his invention, the double-walled glass vase, the vacuum separator is an object of daily use in the laboratories Research in the area of cryogenic, nowadays. That is why the inventor is honored by the names of these vessels, being called "Dewar vessels" or simply "Dewar".

The importance of vacuum insulation is obvious, since vacuum is minimized by transferring heat through gaseous conduction and convection. If measures are also taken to reduce heat transfer through radiation and through conduction through the material from which the vessels are made, Says that a very effective insulation is achieved.

The vast majority of Dewar vessels for the storage of cryogenic fluids are nowadays made of one of the austenitic stainless steels presented earlier,

An example of a vacuum isolated cryogenic fluid transfer pipeline is shown below in Figure 41, and the Dewar vessels will be presented in a following section.

Figure 41. Vacuum insulated pipe element for cryogenic fluid transport

4.3.3. Multilayer insulation

Multilayer insulation is a method of vacuum isolation of cryogenic fluid transport lines, or storage vessels, where radiation heat transfer is reduced by repeatedly adding radiation reflecting screens. Radiation-reflecting screens are separated by another insulating material placed between them and the entire insulating package is placed in the vacuum space perpendicular to the flow direction. When properly executed, such insulation may have an apparent thermal conductivity of between 300 and 30 K, up to 0.3-0.6 μW / cmK. This method of isolation was first used in 1958 and over time it was developed by many researchers. The lowest thermal conductivity values for this insulation system were obtained by using aluminum foils as reflective layers separated by an insulating layer of glass fiber paper.

For cryogenic applications, the reflective shield is made of 6 μm aluminum foil and the insulating material of the aluminum foil is made of a glass fiber called Dexiglass (71 μm nominal thickness) or Tissuglass (15 μm nominal thickness).

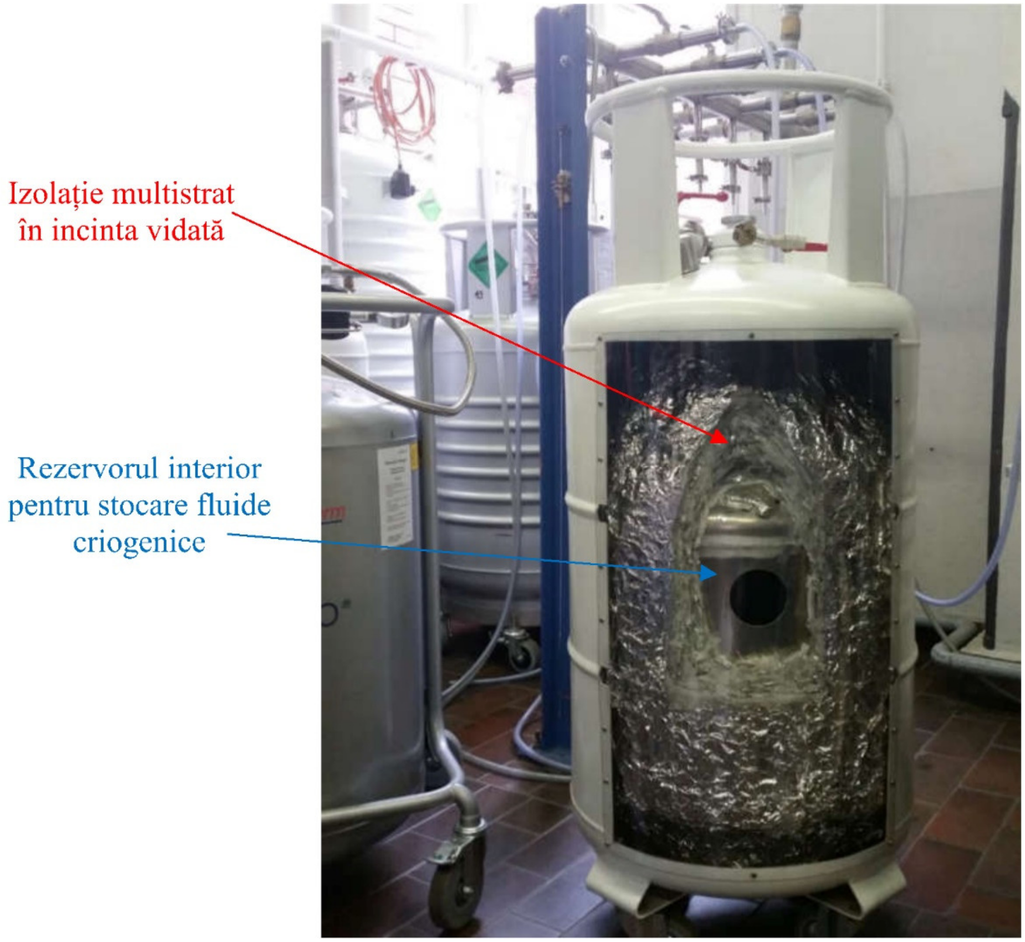

Figure 42. Dewar section, where can be seen the multilayer insulation

4.3.4. Dewars for storage and transportation of cryogenic fluids

The need for storage and transport of cryogenic fluids is evident. The discovery made by James Dewar in 1982 has not yet been replaced by other storage systems, but over time various improvements have been made to the concept by using various materials in The multilayer insulation framework of their components.

Another significant improvement on storage systems is implemented in Dewar vessels for the storage and transport of hydrogen or helium. In particular, these being liquid at very low temperatures (-252.87 °C or 20.28 K for hydrogen and -268.928 ° C or 4.222 K for helium), heat losses due to outside radiation can be significant for Longer periods of time. Thus, in the case of these private vessels, another insulating layer is inserted into which liquid nitrogen (77K) is introduced, which takes over the ambient radiation, leading to its vaporization. The external radiation reduction factor by this method is around 250, which is very much considering the vessel to be in a room with a radiation temperature of 20 ° C (room temperature).

Figure 43. Small capacity Dewar (Wessington Cryogenics UK)

Figure 44. Medium Dewars, for LN (left) and for Helium (right)

4.3.5. Superconductibility

Superconductivity is a phenomenon where the electrical resistance of a conductive material becomes zero if its temperature is less than a certain material-specific value, called critical temperature.

The phenomenon was first observed by Heike Kamerlingh Onnes in 1911. Studying mercury temperature dependence, he noticed that under a certain temperature close to the liquid helium temperature (4.2 K) the resistivity dropped abruptly to zero, A critical temperature could be determined for different simple and compound chemical elements.

It has also been observed that if a superconductor is applied to a magnetic field, the superconductivity phenomenon disappears at a certain field intensity, called critical field intensity. It also depends on the superconductor material and the temperature.

If the current density through the superconductor exceeds a certain critical value, the superconductivity disappears.

Another phenomenon observed was the expulsion of the magnetic field from a body in the state of superconductivity, This phenomenon is called the Effect of Meissner [139].

Table 5. Parameters of the main superconductors (critical temperature Tc in Kelvin and critical magnetic field in Tesla) [140]

Formula chimică	TC (K)	HC (T)	Tip	Formula chimică	TC (K)	HC (T)	Tip
Elementul				Compus			
Al	1,20	0,01	I	Ba_8Si_{46}	8,07	0,008	II
Cd	0,52	0,0028	I	C_6Ca	11,5	0,95	II
Diamant:B	11,4	4	II	$C_6Li_3Ca_2$	11,15		II
Ga	1,083	0,0058	I	C_8K	0,14		II
Hf	0,165		I	C_8KHg	1,4		II
α-Hg	4,15	0,04	I	C_6K	1,5		II
β-Hg	3,95	0,04	I	C_3K	3,0		II
Ga	1,1	0,005	I	C_3Li	<0,35		II
In	3,4	0,03	I	C_2Li	1,9		II

Ir	0,14	0,0016	I	C_3Na	2,3–3,8		II
α-La	4,9		I	C_2Na	5,0		II
β-La	6,3		I	C_8Rb	0,025		II
Mo	0,92	0,0096	I	C_6Sr	1,65		II
Nb	9,26	0,82	II	C_6Yb	6,5		II
Os	0,65	0,007	I	$C_{60}Cs_2Rb$	33		II
Pa	1,4		I	$C_{60}K_3$	19,8	0,013	II
Pb	7,19	0,08	I	$C_{60}RbX$	28		II
Re	2,4	0,03	I	FeB_4	2,9		I
Ru	0,49	0,005	I	InN	3		II
Si:B	0,4	0,4	II	In_2O_3	3,3	~3	II
Sn	3,72	0,03	I	LaB6	0,45		
Ta	4,48	0,09	I	MgB_2	39	74	II
Tc	7,46–11,2	0,04	II	Nb_3Al	18		II
α-Th	1,37	0,013	I	Nb_3Ge	23,2	37	II
Ti	0,39	0,01	I	NbO	1,38		II
Tl	2,39	0,02	I	NbN	16		II
α-U	0,68		I	Nb_3Sn	18,3	30	II
β-U	1,8		I	NbTi	10	15	II
V	5,03	1	II	SiC:B	1,4	0,008	I
α-W	0,015	0,00012	I	SiC:Al	1,5	0,04	II
β-W	1–4			TiN	5,6		
Zn	0,855	0,005	I	YB6	8,4		II
Zr	0,55	0,014	I	ZrN	10		
				ZrB_{12}	6,0		I

Applications of superconductivity

Magnets. Suppose we need a magnet to generate a magnetic field of 2.8 Tesla in a diameter of 0.7m. If we use a standard copper winding, then the required electrical power would be about 7200 kW. If we made the same magnet using a superconducting coil, then the required electrical power would be less than 1 kW, but we would also need cooling at cryogenic temperatures.

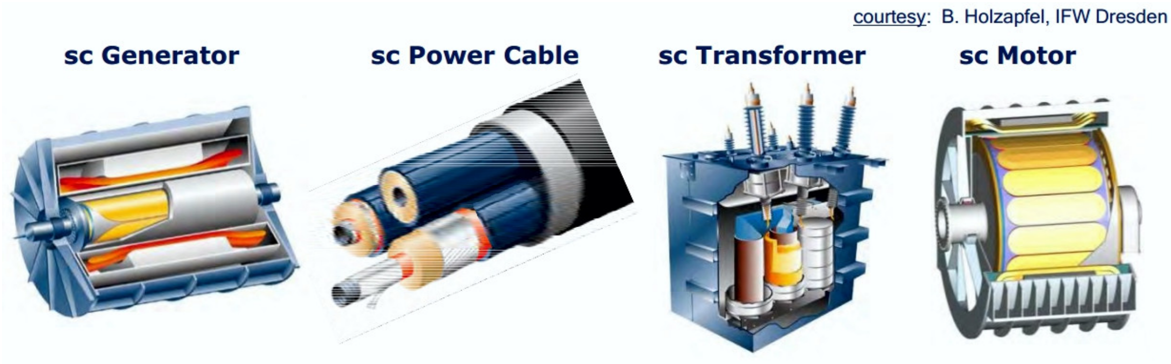

Figure 45. Application examples of superconductibility [141]

Magnetic resonance imaging. It should be noted that at present about 50% of the production of superconducting materials is used for the manufacture of nuclear magnetic resonance imaging equipment (NMR).

Such a system costs about 0.75 MEUR, consumes 0.07 l / h of liquid He, requires filling He liquid every 700 days, and image production takes about 1 minute.

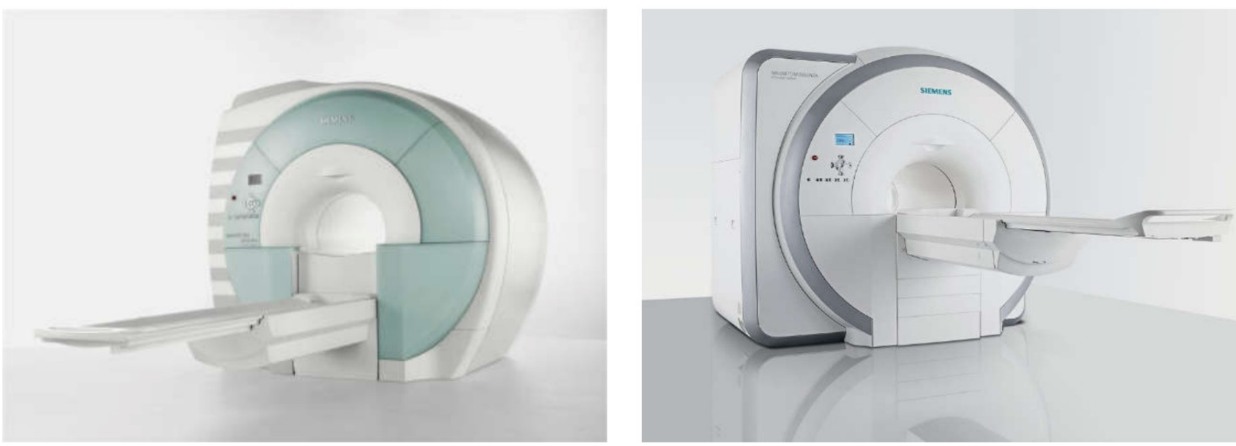

Figure 46. NMR devices used for medical purposes [142], [143]

Japanese trains MAGLEV

A magnetic levitation train, or Maglev, is a train that uses powerful magnetic fields to ensure its sustainability and advancement. Unlike conventional trains, there is no rail contact, which reduces friction forces and allows very high speeds (some systems reach 550 km/h). Because they can not be used with existing infrastructure, Maglev trains must be designed from 0. The term maglev does not only refer to vehicles but also to the interaction between them and the running track. This interaction is very important, each component being designed according to the other to create and control magnetic levitation.

The various maglev technologies are more or less similar, depending on the manufacturer. The world leaders in the field are German companies Siemens and ThyssenKrupp with the Transrapid system [144] (Figure 47).

Figure 47. Maglev Transrapid trains and track detail [145]

Particle accelerators

A particle accelerator is a complex installation used in the field of high energy physics to accelerate elementary particles. Generally, only electrical-charged particles are accelerating. Accelerating takes place under the action of electric and magnetic fields. It is used in the study of elemental particles. There is a wide variety of particle accelerators, which can be classified according to the shape of the accelerated particle beam trajectory, the nature of the accelerator fields, the range of energy impressed by the particles and the nature of the accelerated particles. In accelerators, it is necessary to ensure trajectory stability, that is to say, permanent maintenance of particles in the acceleration process on the trajectories that do not allow for large deviations from the equilibrium trajectory (or reference) [146].

The largest particle accelerator is in the laboratory of the European Center for Nuclear Research (CERN), between France and Switzerland, most of which is in France. This accelerator can accelerate atoms up to 99.999999% of the speed of light. The tunnels where particles are placed meet at 4 points. In some areas of these tunnels the absolute zero temperature can be reached (-271.3ºC = 1.9K). The minimum temperature generated within this accelerator with cryogenic installations is 0.8 K lower than the cosmic space temperature, which is 2.7 K (-270.5 °C). Scientists want that the union of the two particles will generate the so-called "particle of God". The particle accelerator in the CERN lab is located a few dozen meters below ground stretched out over a distance of 26.7 km, and has worked on it over 7,000 scholars and physicists.

Figure 48. The Large Hadron Collider (LHC) accelerator built at the European Center for Nuclear Research (CERN). Air view (left) and detail Magnets superconductors high field included accelerator (right) [147]

Magnets in the LHC produce a 8.33 tesla magnetic field to keep particle beams in the course around the 27-kilometer ring. It requires a current of 11,850 amperes in magnet coils to reach magnetic fields of this amplitude. The use of superconducting materials - those that lead power without any resistance - has proven to be the best way to avoid overheating in windings and keep it as small as possible.

Superconductivity can not happen without the use of cryogenic systems. Niobium-titanium (NbTi) wires must be kept at low temperatures to reach a superconducting state. The superconducting magnets in the LHC are therefore maintained at 1.9 K (-271.3 °C) through a closed helium circuit. The layout of the LHC magnet cooling system is based on five "cryogenic islands" that distribute the cooling fluid and transmit kilowatts of cooling power over several kilometers.

The entire cooling process takes weeks to complete. It consists of three different stages. In the first step, the helium is cooled to 80 K and then to 4.5 K. It is injected into the cold masses of the magnets in a second step before being cooled to a temperature of 1.9 K in the third and last stage. In the first stage, about 10,000 tons of liquid nitrogen are used in heat exchangers in the refrigeration equipment to bring the helium temperature up to 80 K.

The helium is then cooled to 4.5 K (-268.7 °C) by means of turbines. Once filled magnets, 1.8 K cooling units lower the temperature even further to 1.9 K (-271.3ºC).

Overall, the LHC's cryogenic system cools 36,000 tons of magnets [148].

4.4. Study of ischoric systems

Feeding the world population is made possible by advances in food preservation technology. Cooling has been used in food preservation, for food storage and to avoid food spoilage, for centuries. Low temperatures reduce deleterious chemical reactions in food and inhibit growth of microorganisms and other pathogens. In theory, lowering the temperatures has a beneficial effect on food preservation. A temperature of – 18°C, or less, is recommended for long-term storage of foods [149]. However, biological matter is mostly water, and lowering the temperature to below the freezing temperature of water produces a marked change in the physical state of the food. The ice crystals that form intracellularly and extracellularly affect the texture of the thawed food and the quality of the preserved food.

Freezing of a food product is a process in which heat is extracted from the outer surface of the product by a cooling medium. In a conventional freezing process, ice nucleation starts at the outer surface of the product, in contact with the cooling medium, and the ice propagates towards the interior of the product from the exterior as a function of the outer surface, thermal boundary conditions and the properties and dimensions of the frozen material. In general, freezing with high freezing velocities results in smaller ice crystals [150]. The smaller the ice crystals the better is the biologically matter morphologically preserved, and the higher is the quality of the preserved food product [151]. The American inventor Clarence Birdseye who developed the quick-freezing process of food preservation in 1929 first recognized the value of rapid freezing for food preservation [152]. Rapid freezing is commercially referred to as “Flash freezing” or “cryogenic." It is a process in which food is very quickly frozen at extremely cold, cryogenic temperatures. The freezing speed directly influences the ice nucleation process and ice crystal size. Therefore, in flash freezing, the food is usually rapidly immersed in a cryogen such as liquid nitrogen at −196°C, or a mixture of dry ice (solid CO_2) and ethanol [153]. Once flash frozen, the foods are moved to a conventional mechanical freezer with a temperature closer to the freezing point (-20°C for long-term storage).

While flash freezing provides the highest quality frozen foods, it has limitations. Regardless of the cooling medium, the freezing interface must propagate from the exterior in contact with the coolant, to the interior. The freezing interface velocity slows towards the interior. Therefore, small ice crystals cannot form uniformly throughout the frozen food. In flash freezing, they will be small near the outer surface of the freezing object, but increase towards the interior. While flash freezing is the most rapid method of freezing, currently known, the process of freezing in many commercial products takes several hours. During this period the temperature in the interior, unfrozen volume, can be above freezing [154] and conducive to microorganisms proliferation. Flash freezing is also energetically wasteful because the frozen food is first frozen to cryogenic temperatures, but stored at high subzero temperatures. The difference in temperatures between the processing temperature and storage temperature is wasted energy. Furthermore, while the quality of food frozen with flash freezing is high, the device technology is expensive, as it requires systems designed around cryogenic temperatures. There are also other freezing systems referred to as “mechanical freezing”. They are much less expensive. Mechanical freezers were, in fact, the first to be used in the food industry and are used in the vast majority of freezing / refrigerating lines. They function through a conventional refrigeration cycle and operate at temperatures of about – 20°C. While less expensive, mechanical freezers cannot freeze to achieve the small ice crystals that characterize foods frozen with flash freezing [155].

4.4.1. Isochoric and isobaric freezing of fish muscle

Long term *ex-vivo* preservation of biological materials, is of importance to numerous aspects of medicine, biotechnology, the emerging field of tissue engineering and the food industry. In fact, many applications, from the preservation of embryos to organ transplant, to preservation and transport of cell lines, to the world food economy depend on means for the preservation of biological matter, *ex-vivo*.

Life is comprised of a set of bio-electrochemical reactions known as metabolism. The rate of these metabolic chemical reactions is temperature dependent. Lower temperature slows metabolism in such a way that one decade of temperature reduction, in units of Kelvin, decreases the metabolism by a factor of between two and three [156]. This is the principle underlying the majority of biological matter preservation methods, currently used in medicine, biotechnology and food technology. When biological preservation of complex tissue requires functional survival, the preservation is hypothermic, i.e. above freezing temperatures. But, hypothermic temperature preservation is severely limited. Currently, hearts for transplantation can be stored at + 4°C for only 4-5 hours and livers about 6-8 hours. These periods of preservation are not sufficient, and attempts are made to extend the preservation periods [157].

In theory, reducing the temperature to absolute zero will stop all chemical reactions and facilitate unlimited preservation. However, under atmospheric pressure, physiological solutions freeze at – 0.56 °C. This limits the temperature to which a biological system can be cooled without freezing. Freezing, the presence of ice and the associated changes in biological matter solution composition cause cell damage through additional mechanisms to those brought about by above freezing temperature, hypothermic, preservation [158], [159]. Therefore, preservation by cooling is in a conundrum; preservation above freezing temperatures is limited in time while preservation below freezing temperatures induces additional severe damage, which makes storage of more complex organisms and tissues in a frozen state, yet, impossible.

Until now, most of the research on cold preservation of biological matter was done in isobaric, constant atmospheric pressure, for obvious reasons. Everyday life occurs under these conditions. However, recently, our group has taken an innovative approach to low temperature preservation and developed the fundamental thermodynamics of phase transformation of aqueous solutions in an isochoric, constant volume system [160],[161],[162]. The insert in Figure 49 illustrates the difference in the thermodynamic path during an isobaric freezing process and an isochoric freezing process. The constant pressure, isobaric process is the vertical line in the insert. It is evident that when the temperature is reduced at constant pressure, the entire system freezes at the point the process line intersects with the liquidus line; for pure water at 1 Atm. pressure, this is 0°C.

In isochoric freezing, the volume is constant, while the temperature is decreased. In a two-phase system, temperature and pressure are dependent properties, prescribed by the liquidus curve in the insert in Figure 49. For pure water, the pressure and temperature at the triple point between ice I, ice III and liquid water are -21.985°C and 209.9MPa, respectively. Our thermodynamic analysis has verified experimentally and theoretically, that, the process path during the cooling of an isochoric system in the presence of an ice nucleating agent, is along the liquidus curve [160]. The thermodynamic analysis led to an interesting observation with relevance to biological matter preservation at subfreezing temperatures. The observation depicted in Figure 49 shows the percentage of ice in the system as a function of temperature. It is of interest to notice that in an isochoric system, about 45% of the initial volume remains unfrozen, at the triple point. This has suggested a new concept for biological matter preservation. The concept is illustrated by the schematics in panel 2B. When a system is designed in such a way that the matter to be preserved occupies less than 45% of the total volume and nucleation is initiated outside the preserved volume, substantial amounts of biological matter can be preserved to the triple point temperature, without the biological matter freezing.

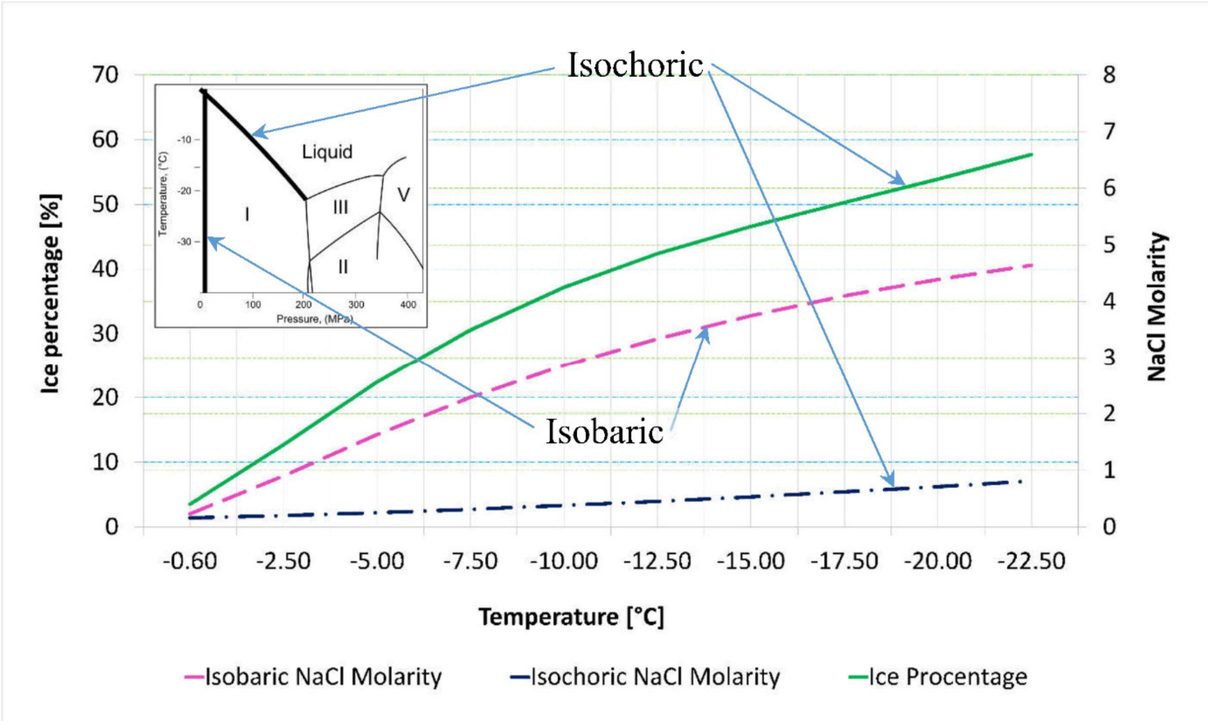

Figure 49. The percentage of ice as a function of temperature in an isochoric freezing system, left y axis. The concentration in the unfrozen volume as a function of temperature in an isochoric system and in an isobaric system, right y axis. Insert: the phase diagram for water and the outline of an isochoric process and an isobaric process.

The first proof of the ability of an organism to survive under isochoric freezing was published in [163]. The study shows that a living invertebrate organism *C. elegans* survives exposure to isochoric freezing at – 4°C, but succumbs to atmospheric isobaric freezing to the same temperature [163]. The next step in our research is to study isochoric preservation in vertebrates. To this end, we use in this study fresh fish muscle tissue from Tilapia (Blue Tilapia: *Oreochromis aureus*). The study compares the histology of dorsal white muscle after, isochoric and isobaric freezing to – 5°C.

Oreochromis aureus

In an effort to satisfy the 3R principles for animal care (Replacement, Reduction, Refinement) of Russell and Burch [164] our research group employs an experimental research model named "*vivens ex vivo*" [165]. Animal research is needed, because currently available methods for cell work and mathematical modeling cannot capture all the complexity of organized tissue. However, at an early stage of examining a hypothesis, it should be possible to gain insight into the value of a hypothesis without using a live animal for the experiment. Therefore, the "vivens ex vivo" concept is to use in a first examination of a hypothesis, fresh animal tissue whose provenance is animals which died from reasons not related to the study, such as other experiments or for food. In this study, we used fresh filets of fish (Blue Tilapia: *Oreochromis aureus*) prepared by a local fishmonger. The filets were white caudal muscle and the tissue was brought on ice, to our lab, in less than half an hour from preparation.

Isochoric system

The isochoric freezing system is a simple constant volume chamber, capable of withstanding the pressures that develop in the system, with minimal deformation. The chamber is instrumented with a pressure transducer. A photograph of the system is shown in Figure 2C. The isochoric chamber is based on a modified stainless-steel OC-1 pressure vessel, (O-ring 316 SS, inner volume 125 ml, working pressure 13,800 psi, test pressure 20,000 psi) custom designed by High Pressure Equipment Company (Erie, PA, USA). We used the standard O-ring made of BUNA-N, for sealing. The constant volume chamber is sealed with a screw and metal seal and is connected to an Ashcroft 4–20 mA Loop-Powered 20,000 psi Pressure gauge, connected through an NI myDAQ Connector (National Instruments, Austin TX) to a laptop and the data recorded and displayed with LabVIEW. For safety, a rupture disk limited the pressure to 60 MPa. The isochoric chamber was immersed in a water-ethylene glycol bath (50/50), cooled by means of a Nestlab RT-140 cooling system (Thermo Scientific, Waltham, MA).

Sample preparation

Fresh Tilapia fish (*Oreochromis aureus*), weight 500 to 700 g, purchased as fresh filets at a local fishmonger (Ranch 99, Berkeley), was used in this study. Cuboid dorsal muscle samples were cut from the filet and enclosed into cryogenic vials (standard 12 mm inner diameter, 1.8 ml, Fisher Scientific cryogenic vial, capped and self-standing) filled with a 0.9% saline solution, [165], in such a way to ensure there was no air in the vials. We made a small hole (0.5 mm) in the vial's wall to ensure thermodynamic and osmolality equilibrium between the interior of the vial and the interior of the isochoric chamber.

Experimental protocol

The samples were exposed to – 5°C, for 3 hours, under isobaric and isochoric conditions. The same chamber was used in the isobaric and isochoric experiments. Controls were cut from the fresh filets at the fishmonger site and immediately immersed in 10% neutral buffered formalin. The isochoric treatment was performed as follows. A metal ice nucleating surface was dropped to the bottom of the isochoric chamber to ensure that ice formation starts at the bottom of the chamber at a distance from the vials, which were on the top of the chamber. The isochoric chamber was filled with the 0.9% saline solution and sealed, with care to avoid the entrapment of air bubbles. Then, the chamber was completely immersed in the cooling bath and cooled to - 5°C. The pressure was monitored and recorded in real time, using LabVIEW. The isochoric chamber was warmed at room temperature until the pressure reached atmospheric. Then the chamber was opened to analysis the samples. The isobaric treatment followed the same procedure as the isochoric treatment except that the chamber was open to atmospheric pressure during the freezing. The samples were kept in the cooling bath at -5 °C for 3h.

Histomorphology

After the treatments, all the samples were fixed with 10% neutral buffered formalin for 24 hours and were later dehydrated in a series of ethyl alcohols of increasing concentrations (70, 85, 95, and 100%), cleared with xylene, and embedded in paraffin embedded wax (Shandon Excelsior Tissue Processor; Thermo Fisher Scientific, Cheshire, UK). They were cut into 5 µm by a microtome (Leica RM2235 rotary microtome, Leica Biosystems Company, Buffalo Grove, USA), placed on glass slides, and stained with Mason Trichrome and with Hematoxylin and Eosin (American Master Tech., Lodi, USA). The microstructure of the various treated samples was observed by an Olympus IX71 Inverted microscopy (Olympus, Tokyo, Japan). Images were captured using an Olympus DP71 camera and the DP Controller software.

Study Results and Discussion

Three repeats were performed for each experimental condition and the results presented in this section are typical to all the experiments. Figure 51, and Figure 52 depict the histology of white muscle preserved for three hours at – 5°C in isobaric, and isochoric conditions, respectively, at various magnifications, in comparison with the histology of the fresh tissue. The fresh fish micrographs are the top raw in each figure. They show a typical axial cross section of the white muscle fibers. The fibers are gathered in a bundle in a typical polygonal shape of about 100 μm in dimension. The fibers are surrounded by thin connective tissue layers, with a light appearance. It is important to notice, the homogeneous appearance of the muscle fibers and the width of the connective tissue.

In Figure 51, the bottom row shows tissue frozen in an isobaric system. The appearance of the tissue has changed completely after three hours of freezing at – 5°C, under atmospheric pressure. The muscle fibers (myotomes) have shrunk and split and the area of the connective tissue (myocommata) has expanded (white dashed arrow). There are regions devoid of muscle fibers within the muscle fiber bundle (solid arrow). The muscle fiber bundle has lost the polygonal shape. The observations are typical to the freezing of tissue with low cooling rates. The mechanism can be explained by the concentration curve as a function of temperature for isobaric freezing, in Figure 49. The figure shows that the composition of a 0.9% saline solution frozen to – 5°C, has changed from about 0.3 M to 2.5 M. This is because ice has a tight crystallographic structure and rejects the solutes into the unfrozen milieu [150]. During a typical process of freezing in a biological organ, ice forms first in the extracellular space, by random nucleation [166]. Freezing propagates preferentially through the extracellular space, because it is not impeded by the cell membrane. The consequent difference in osmolality between the extracellular and intracellular solution, causes a flow of water, from the interior of the cell to the exterior, dehydrating the cell. Ice continues to freeze in the extracellular domain, further enhancing the dehydration of the cell and promoting the formation of additional extracellular ice, until thermodynamic equilibrium is reached. The light areas in the isobaric frozen tissue are the imprint of ice, and serve as a proof to this mechanism of freezing of tissue. It is an accepted fact in the field of cryobiology that the cell dehydration and tissue distortion are responsible for cell damage at high subzero temperatures isobaric freezing [158], [159], [166].

Figure 50 A displays the pressure as a function of time during isochoric freezing, as measured during our experiments.

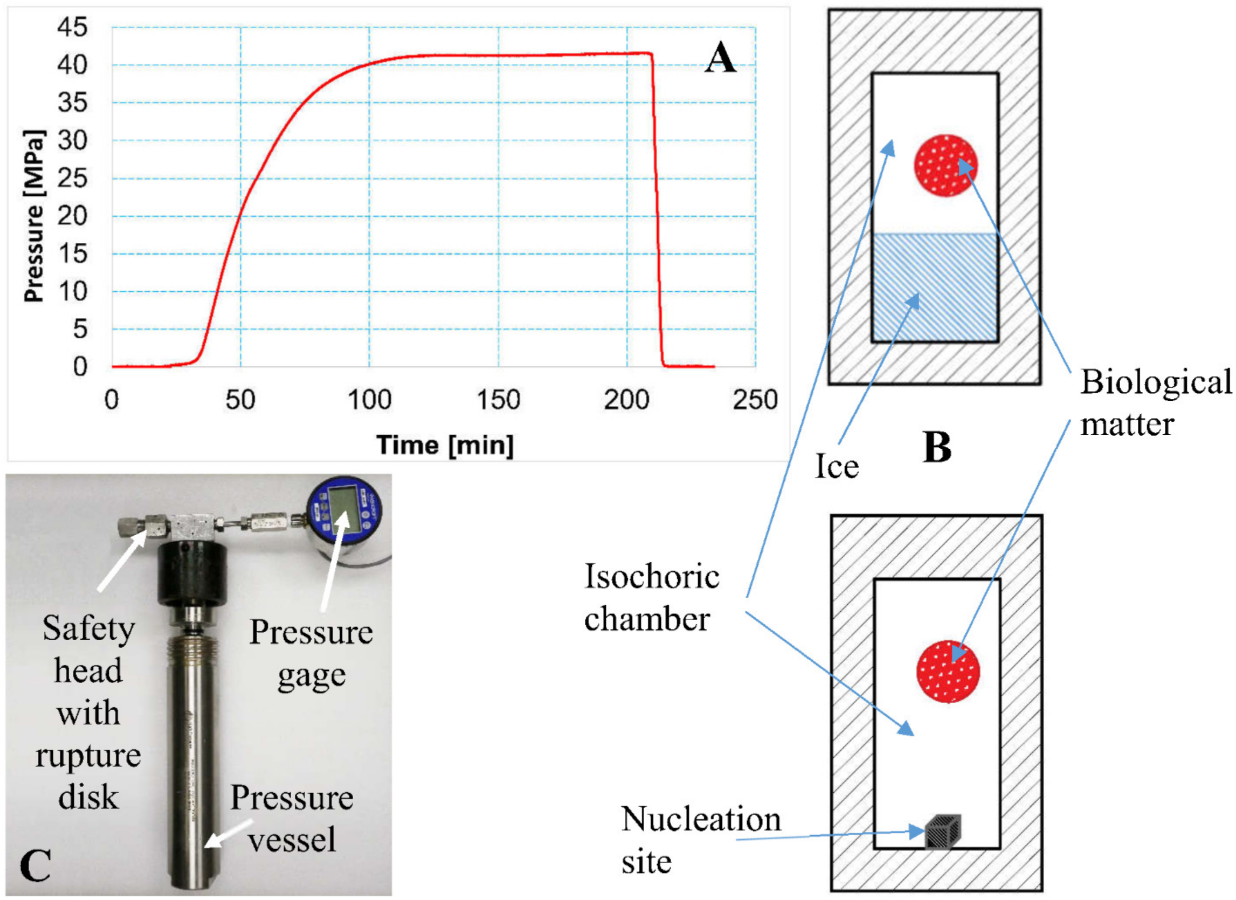

Figure 50. Panel A: Pressure as a function of time during the isochoric freezing experiment. Panel B: Schematic of freezing of a biological material in an isochoric chamber. Bottom at the initiation of freezing, top at the end of freezing. Panel C: a photograph of the isochoric device used in this study.

Figure 52 shows a comparison between the histology of fresh tissue and tissue frozen for three hours at – 5°C in an isochoric chamber. No difference can be seen at this magnification between the fresh tissue and the isochoric frozen tissue. On the other hand, the difference between the isochoric (Figure 52) and isobaric (Figure 51) frozen tissue is striking. The isobaric frozen tissue is completely distorted, while the isochoric frozen tissue appears morphologically intact. An explanation for the mechanism emerges from Figure 49. The curve depicting the concentrations in the isochoric frozen solution, shows that at – 5°C, the increase in concentration is imperceptible. It is lower by orders of magnitude from the concentration during isobaric freezing. Therefore, the mechanism for cell dehydration and solute damage during freezing does not exist in isochoric freezing. Comparing Figure 51 and Figure 52 demonstrates the fact that the structural integrity is preserved during isochoric freezing and lost during isobaric freezing. This is the first study on the morphology of complex animal tissue frozen under isochoric conditions. To the best of our knowledge, this is also the first experimental evidence in support of the hypothesis that in isochoric freezing there is no cellular dehydration and therefore the morphology of the frozen tissue remains intact. The results explain why the C. Elegans survived freezing in an isochoric system and succumbed to freezing in an isobaric system [167]. While much more research remains to be done, it is obvious that isochoric freezing holds promise for biological matter preservation at subfreezing temperatures. The preservation of muscle tissue morphology findings in this study, suggest the possibility that whole organs, such as the heart, could be preserved in an isochoric freezing system, for organ transplantation.

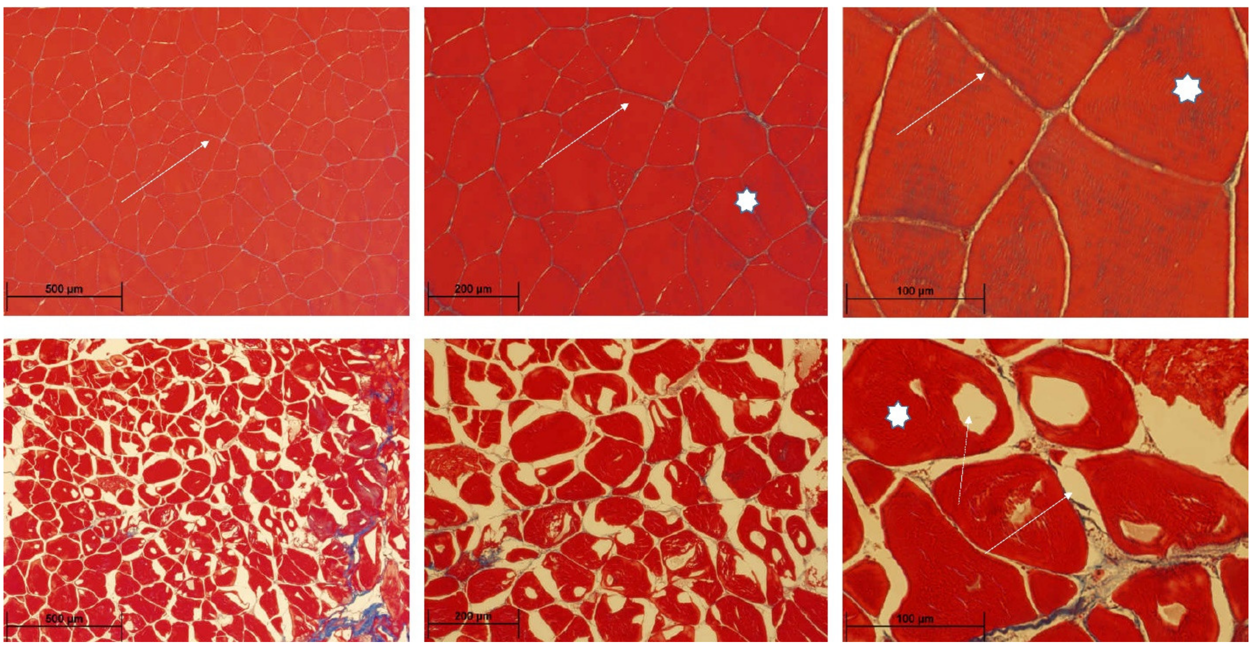

Figure 51. Comparison between fresh muscle tissue (top row) and tissue after three hours isobaric preservation at -5 °C (bottom row). A muscle fiber bundle is marked by a star. The fiber bundle is surrounded by connective tissue, pointed to by a white dashed arrow. The bottom row shows that the muscle fibers have shrunk and that the area of the connective tissue has expanded (white dashed arrow) and regions devoid of muscle fibers within the muscle fiber bundle (solid arrow). The muscle fiber bundle has lost the polygonal shape. Dimensions are given by the scale bar.

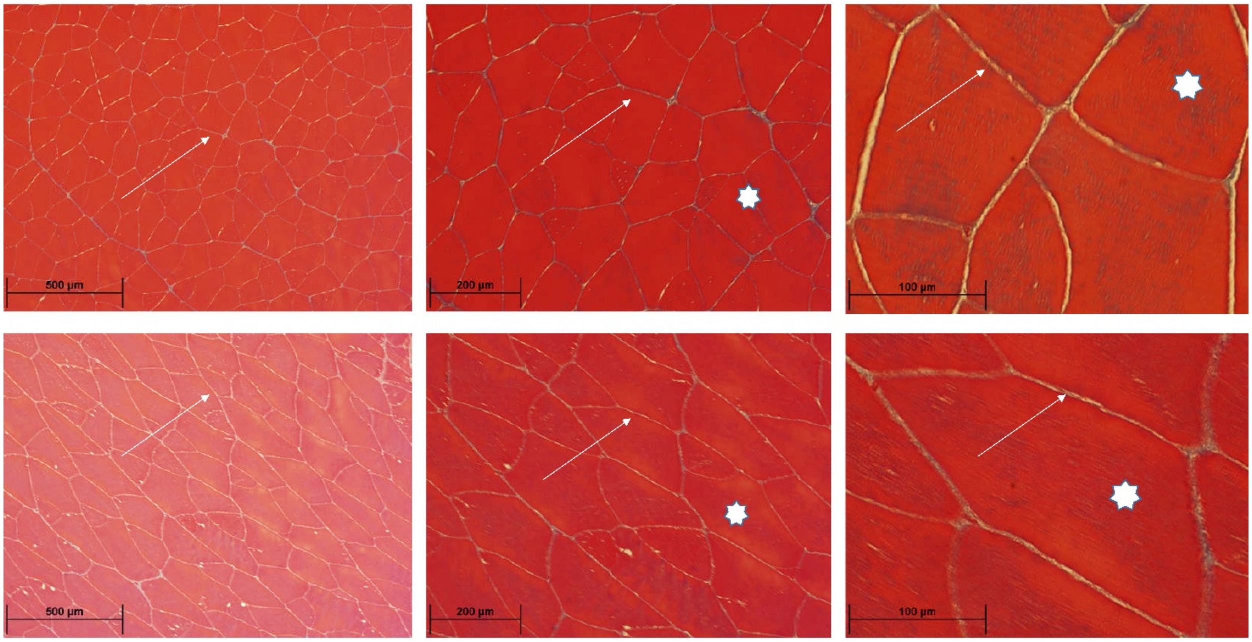

Figure 52. Comparison between fresh muscle tissue (top row) and tissue after three hours isochoric preservation at -5 °C (bottom row). A muscle fiber bundle is marked by a star. The fiber bundle is surrounded by connective tissue, pointed to by a white dashed arrow. The micrographs appearance of the fresh tissue is indistinguishable from that of the isochoric frozen tissue. Dimensions are given by the scale bar.

4.4.2. A comparison of freezing-damage during isochoric and isobaric freezing of the potato

This study was designed to compare the damage to a food item, the potato, due to freezing in an isobaric (constant pressure) atmospheric system with the damage due to freezing in an isochoric (constant volume) system. Refrigeration and freezing are one of the most popular methods of food preservation [168], [169]. Metabolism is temperature dependent and low temperatures aid preservation by reducing deleterious chemical reactions in food and inhibiting the growth of microorganisms and other pathogens. The lower the temperature, the further chemical reactions rates are reduced, and preservation improved. Below the freezing temperature of water, most foods, many of which consist of water, freeze. Freezing, while reducing metabolism and even sometimes killing pathogens has a number of detrimental effects on food [170]. The process of freezing itself will induce several mechanisms of damage. A major mechanism is the "solute-concentration damage". Freezing removes water from the solutions in form of ice. Since ice has a tight crystallographic structure and cannot contain any solutes [171], [150], the concentration of the solutes in the unfrozen portion increases with freezing to lower temperatures. The detrimental effects of the increased concentration of solutes can be lumped together under the heading “solute-concentration damage” [170]. A mechanism related to solute-concentration damage is "dehydration damage"[170]. Biological matter made of cells, freezes preferentially extracellularly [172], [173]. As a result of the increase in concentration in the extracellular medium, there is an osmotically driven transport of water across the cell membrane, from the interior of the cell to the extracellular medium [173]. This causes cell dehydration and cell membrane deformation and the so-called “dehydration damage” [170]. There are also two mechanisms of mechanical damage. One is mechanical damage from ice crystals, associated with local stress when rigid ice crystals compress or deform organic structure entrapped between the ice crystals [170]. The compression is due to the freezing of water in pockets of high concentration solution entrapped between ice crystals [174]. A second is the “ratchet mechanism of damage”, caused by ice growing in the deformed region of tissue in such a way that it prevents the return of the structure to its original shape [170]. Damage also occurs during storage of frozen biological matter. However, in this study, we will address only the mechanisms of damage associated with the process of freezing and explore the hypothesis that isochoric freezing can reduce freezing damage to food, relative to isobaric freezing.

We have published two fundamental thermodynamic studies on the process of freezing in an isochoric system [160] and on the process of nucleation, supercooling and vitrification in an isochoric system [161]. Figure 1 shows the insight gained from the thermodynamic analysis in [160]. The insert in Figure 1 panel A, shows the thermodynamic path of a freezing process in an isochoric (constant volume) system, in comparison to the thermodynamic path in an atmospheric isobaric system and in a hyperbaric system. The process of freezing in an atmospheric isobaric system occurs along the vertical line on the phase diagram. In contrast, the process of freezing in a constant volume system occurs along the liquidus line, to the triple point between ice I, ice III and water. For pure water, the pressure and temperature at the triple point are -21.985 °C and 209.9 MPa, respectively. Under isobaric conditions, the entire amount of water in the system will be frozen at the triple point temperature. The extent of freezing in an isochoric system is different. Figure 1 Panel A, was obtained from the theoretical analysis [160]. It shows the amount of ice in an isochoric system as a function of a homogenized temperature. The temperature is homogenized with respect to the temperature at the onset of freezing under atmospheric pressure, for the composition of the solution that is frozen. Thermodynamic analysis predicts that in isochoric freezing 45% of the water in the system will remain unfrozen at the triple point (Figure 1 Panel A) [160]. This suggests that "mechanical damage from freezing" [170] can be eliminated during freezing to temperatures at (or above) the triple point, by designing an isochoric freezing device in which the stored food product occupies the 45% unfrozen volume. Panel B shows another interesting observation gained from the thermodynamic analysis of the processes of freezing in an isochoric system and in an isobaric system [160]. The figure shows the osmolality of the freezing solution as a function of temperature. The initial osmolality of the solution used in this study was about 0.3086 Osm. Panel B shows that in a solution frozen in an isobaric system (atmospheric or hyperbaric), the osmolality at the triple point is more than twenty times as high as the initial osmolality. Obviously, this leads to the "solute-concentration damage" and "dehydration damage" in conventional isobaric freezing [170]. In contrast, Panel B shows that in isochoric freezing, the osmolality at the triple point is lower by a factor of five from that during isobaric freezing. This result is to be expected, from the data displayed in Panel A. In isochoric freezing, 45% of the solution remains unfrozen at the triple point. Our results suggest that in addition to eliminating mechanical damage, isochoric freezing will also reduce solute-concentration damage and dehydration damage.

There are additional aspects of isochoric freezing that deserve attention. Nucleation theory predicts that "homogeneous nucleation" (i.e. nucleation without a preferential nucleation site) in pure water is about -42°C. In pure water without nucleation sites, the water can supercool to – 42°C and freeze at that temperature, rather than at the thermodynamic equilibrium value of 0°C. In contrast, we have shown from a thermodynamic analysis of the probability of homogeneous nucleation in an isochoric system, that the temperature for "homogeneous nucleation" in water is depressed from about – 42°C in an isobaric atmospheric system to about – 100°C in an isochoric system [161]. This predicts that isochoric cooling will promote vitrification, as the temperature of – 100 ℃, is lower than the glass formation temperature for water. The predicted effect of isochoric freezing on nucleation was examined experimentally in [175] and [176]. This effect of isochoric freezing was utilized for cryofixation for electron microscopy in [177]. The predicted effect of isochoric cooling on vitrification [161] was shown experimentally in [178].

Isochoric freezing, while maintaining a constant volume, causes an increase in pressure, to the triple point. Freezing of biological matter under elevated pressure was studied in the past, [179], [180], [181], [182]. Hyperbaric freezing (see insert in Panel A Figure 53) is used for rapid freezing;

by first increasing the pressure, followed by cooling to the intersection of the hyperbaric line with the liquidus curve and then decreasing the pressure to atmospheric [182]. Treatment of food at hyperbaric pressures (without freezing) is also used for sterilization. Pressure influences microorganisms' sterilization and complete E. Coli death was reported at 210 MPa. In contrast, the same study found that red blood cells survive this pressure and are more resilient to hyperbaric pressures than E. Coli [183]. The increase of pressure during isochoric freezing was employed as a means to increase pressure in a non-mechanical way to sterilize E. Coli in [184].

As mentioned earlier, our previous studies [160] suggest that isochoric freezing has the potential to reduce the damage due to freezing in food products, relative to isobaric freezing. The goal of this study is to assess the damages to a food product, a potato, induced by freezing in an isochoric system in comparison to the freezing damages in an isobaric system. We have chosen to study isochoric freezing in a potato because we have extensive experience with its mechanisms of damage [185], [186], [187]. This study is preliminary and the focus is on freezing-damage in a narrow range of parameters. Our primary goal is a first order exploration of the concept. Obviously, much more work remains to be done to evaluate the effect of isochoric freezing on various food products and to explore the value of isochoric preservation to the food industry.

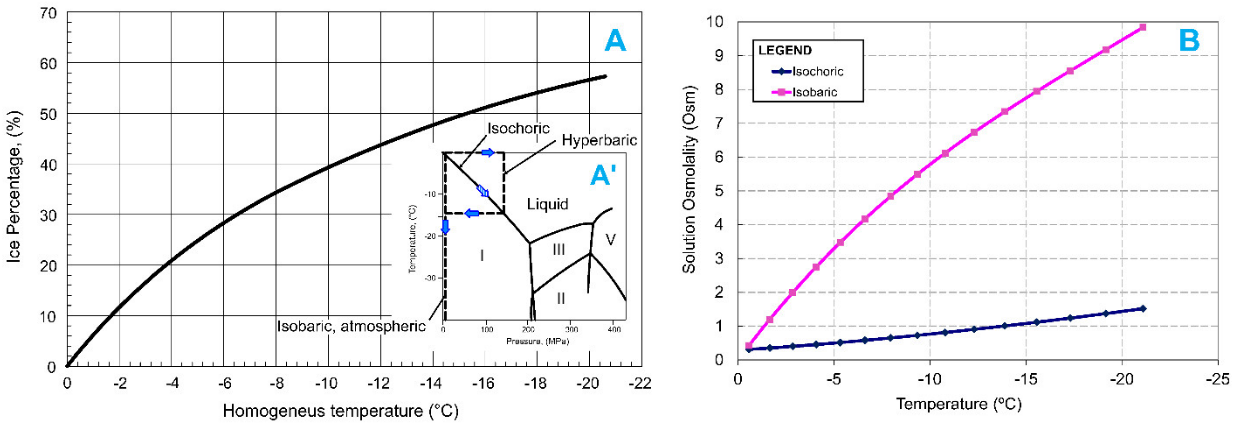

Figure 53. Panel A: Ice percentage-homogenized temperature diagram during freezing in an isochoric system. The temperature is homogenized with the temperature at which the tested solution freezes at atmospheric pressure. Insert in Panel A' Pressure-Temperature diagram for water and process lines for isobaric atmospheric, hyperbaric and isochoric freezing processes. Panel B: Comparison of osmolality as a function of temperature during isochoric and isobaric (at 1 Atm) freezing of the same solution.

Isochoric system

Isochoric freezing systems are simple. They require only a constant volume chamber, capable of withstanding the pressures that develop in the system, with minimal deformation. For control, they require a pressure transducer. A photograph of the system is shown in Figure 54, the right-hand side panel. The isochoric chamber is based on a modified stainless-steel OC-1 pressure vessel, (O-ring 316 SS, inner cylindrical volume of 125 ml, 1" inner diameter, working pressure 13,800 psi, test pressure 20,000 psi) custom designed by High Pressure Equipment Company (Erie, PA, USA). We used a standard O-ring made of BUNA-N, for sealing. The constant volume chamber is sealed with a screw and metal seal and is connected to an Ashcroft 4–20 mA Loop-Powered 20,000 psi Pressure gauge, connected through an NI myDAQ Connector (National Instruments, Austin TX) to a laptop and the data recorded and displayed with LabVIEW. For safety, a rupture disk limited the pressure to 60 MPa. The isochoric chamber was immersed in a water-ethylene glycol bath (50/50), cooled by means of a NesLab RT-140 cooling system (Thermo Scientific, Waltham, MA).

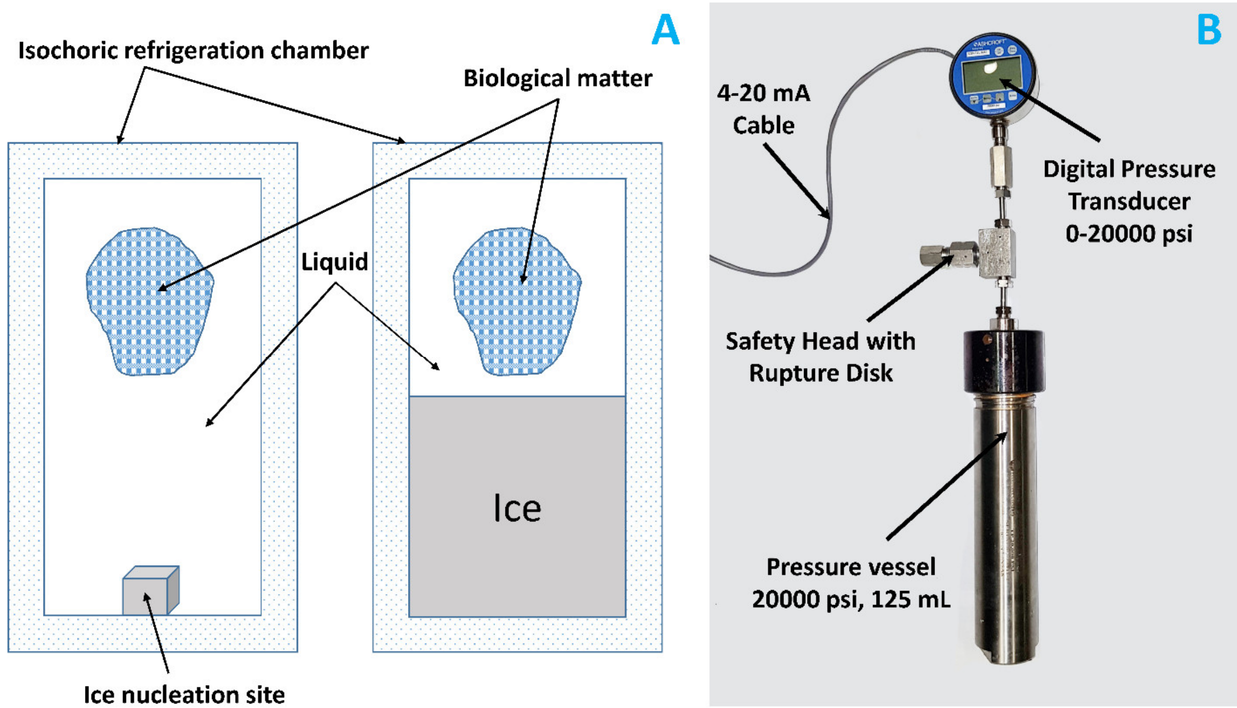

Figure 54. Panel A: Schematic of an isochoric system; ice nucleation site is the place where we placed a small metal whose role is to initiate ice formation. Panel B: Photograph of the isochoric system; the height of the reactor without the fittings and the measurements instruments is 10" and with them is 19". The inner chamber diameter is 1".

Sample preparation

Russian Banana Fingerling potatoes (*Solanum tuberosum* L.) weighing between 12 and 20 g, purchased at a local store, were used in this study. The osmolality of the potatoes was determined in preliminary experiments by measuring the samples' weight loss in different sucrose solution. We found that a solution of 9.09% w/w (0.3086 Osm) sucrose was isotonic with the potatoes. In preparation for the experiments the samples were peeled, cut into cuboid, weighed and enclosed into cryogenic vials (standard 12 mm inner diameter, 1.2 ml, Corning Incorporated cryogenic vial, capped and self-standing) filled with the isotonic sucrose solution (9.09% w/w) in such a way to ensure there was no air in the vials. We made a small hole (0.5 mm) in the vial's wall to ensure thermodynamic and osmolality equilibrium between the interior of the vial and the interior of the isochoric chamber.

Experimental protocol

The potato samples were divided into three groups: room temperature preservation, isochoric freezing, and isobaric freezing. The room temperature preservation samples were preserved in an isotonic sucrose solution at room temperature (22°C) for 120 min. The isochoric samples were processed using the isochoric experimental system. A steel nut (the ice nucleating surface) was dropped to the bottom of the isochoric chamber to ensure that ice formation started at the bottom of the chamber at a distance from the vials, which were on the top of the chamber. The isochoric chamber was filled with isotonic sucrose solution and sealed, with care to avoid the entrapment of air bubbles. It is important to emphasize that care must be exercised to eliminate air from the system. The presence of undissolved air can affect the results [188]. The chamber was then completely immersed in the cooling bath and cooled to -5 °C. We performed the experiments at this temperature because in a previous study we found that organisms can survive isochoric freezing at these conditions [189]. Obviously, in the future, studies need to be performed in the entire range of temperatures to the triple point. The pressure was monitored and recorded in real time, using LabVIEW. It took about 60 min to reach the desired pressure and the experiment was terminated after another 60 min. The isochoric chamber was warmed at room temperature until the pressure reached atmospheric. Then the chamber was opened for sample analysis. The isobaric samples followed the same procedure as the isochoric samples except that the chamber was open to atmospheric pressure. The samples were kept in the cooling bath at -5 °C for 120 min. We limited the period of exposure to subfreezing temperatures to two hours because our focus is on freezing damage, not on the damage due to storage.

Sample analysis

Three methods were used to evaluate and compare the samples preserved at room temperature with samples after isobaric freezing and isochoric freezing: weight loss, color change and microscopic appearance. The samples were analyzed immediately after removal from the chambers.

The weight loss of the sample was obtained by comparing the weight of the sample before and after the treatment with an electronic balance (ER-182A, A&D Company, Tokyo Japan). The surface water on the sample was absorbed by filter papers before weighing. The weight was measured before the treatment and immediately after the treatment. This experiment was done in five repeats.

Colorimetric measurements were taken with a color meter (TES-135A, TES Electric electronic CORP. Taiwan) in Hunter L* a* b* color space values after 120 min when the treatments were terminated. The L*, a*, b* represent the lightness of the color (L* = 0 yields black and L* = 100 indicates diffuse white; specular white may be higher), the redness of the color (a*, negative values indicate green while positive values indicate magenta) and the yellowness of the color (b*, negative values indicate blue and positive values indicate yellow).

The total color difference (ΔE) between the differently treated samples was calculated as follows [190]:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

ΔL is the difference of sample's L* value before and after treatment; Δa is the difference of sample's a* value before and after treatment; Δb is the difference of sample's b* value before and after treatment. The colorimetric experiments were done in three repeats.

The microstructure of the potato samples was observed under a stereomicroscope (Lumar, V12 Stereo Zeiss) at a magnification of 45x and 80x in 10 min after the treatment. The samples were stained with 0.1% Toluidine Blue O (TBO) to observe the cell walls [191]. We sectioned the potato cube and placed the sliced sections on a clean microscope slide. Then, we flooded the sections with an aqueous solution of 0.1% TBO for one minute. The stain was removed gently from the potato surface by using a piece of filter paper and the samples were washed with water until there was no excess stain around the sample. Nine (3x3, 3 samples for each treatment and 3 different sections in each sample) sections were examined in each treatment.

Means and standard deviations were calculated using SPSS 24.0 software (IBM, USA). T ANOVA was used to detect significant differences between means. Significance was set at $p < 0.05$ for the ANOVA matrix F value.

Results and Discussion

The technology of an isochoric system is very simple relative to that of a comparable, high-pressure freezing (hyperbaric) system. Unlike a hyperbaric freezing system, an isochoric system contains no moving parts and requires no power for continuous operation and there is no concern of sealing the chamber around moving parts or deterioration of moving parts [189]. Figure 54 left panel shows a schematic of the device. It is a rigid closed container designed to withstand the pressure. Figure 54, right panel, shows a photograph of the isochoric device used in this study. It is a capped cylinder, made from a standard, commercial, stainless steel pressure vessel.

Control over the isochoric refrigeration process is also very simple. Figure 54 shows that we have used a pressure transducer connected to the vessel, for control. In an isochoric refrigeration system, either only temperature or pressure need to be controlled. A two-phase system in a closed fixed volume is always at thermodynamic equilibrium. Therefore, either pressure or temperature completely specifies the system. In contrast, in a hyperbaric system, there is the need to control both temperature and pressure [192].

Figure 55, was obtained from measurements made with the pressure transducer in Figure 54 during an isochoric freezing experiment. It shows a typical curve depicting the change in pressure with time during the isochoric refrigeration process in our experiments. The interesting aspect is that the pressure reaches steady state and stays at that value for over an hour, to the termination of the experiment. This demonstrates that the isochoric system has reached thermodynamic equilibrium. The time to reach steady state obviously depends on the thermal mass of the device and the heat transfer coefficient to the cooling bath. In all our experiments, the samples reached isochoric thermodynamic equilibrium, and our results represent the state of the treated material after it has reached thermodynamic equilibrium.

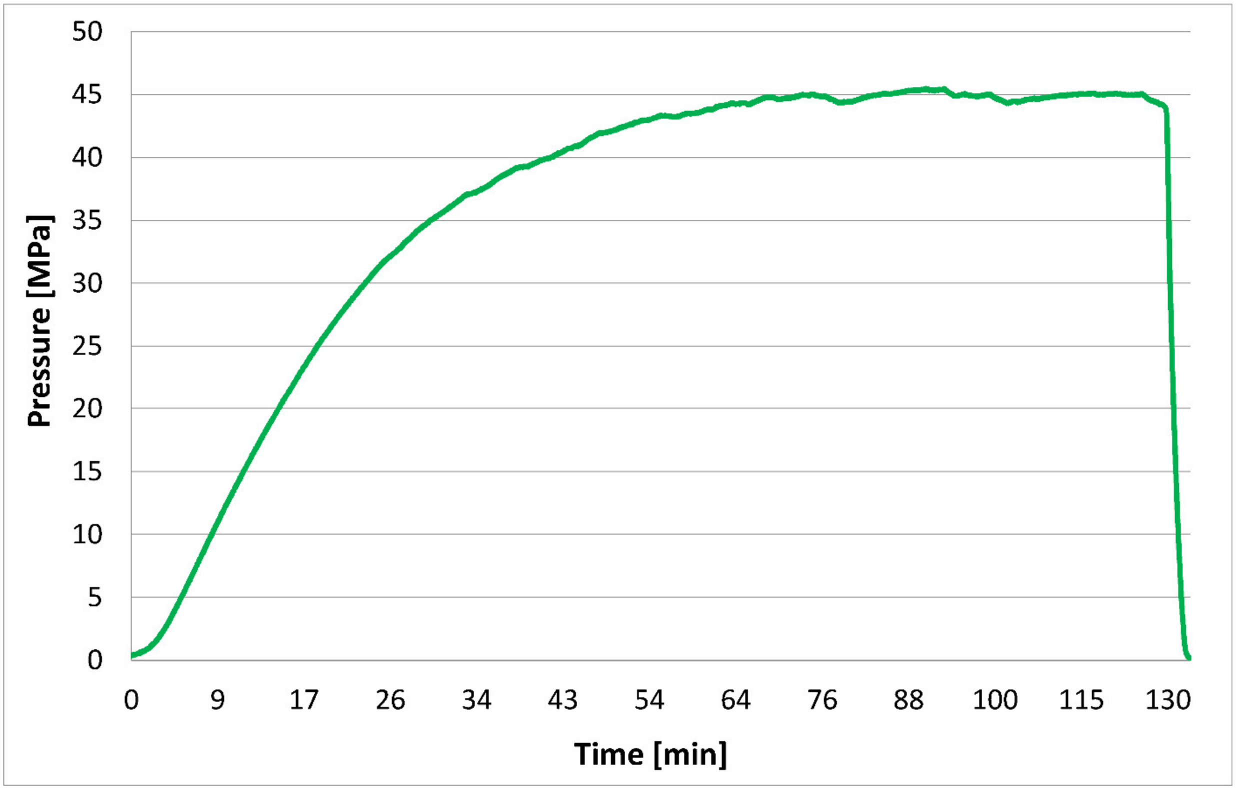

Figure 55. The pressure in the isochoric chamber was measured throughout the experiment with the pressure transducer in Figure 2. This figure shows a typical measurement of change in pressure with time in the isochoric system while performing the potato freezing experiment.

Figure 56 and Figure 57 compares, respectively, the weight loss and color change after two hours of: a) freezing to -5 °C in an isochoric system, b) freezing to -5 °C in an isobaric condition, and c) storage in an isotonic sucrose solution at room temperature. Figure 58 are microscope micrographs that provide an explanation for the mechanisms involved.

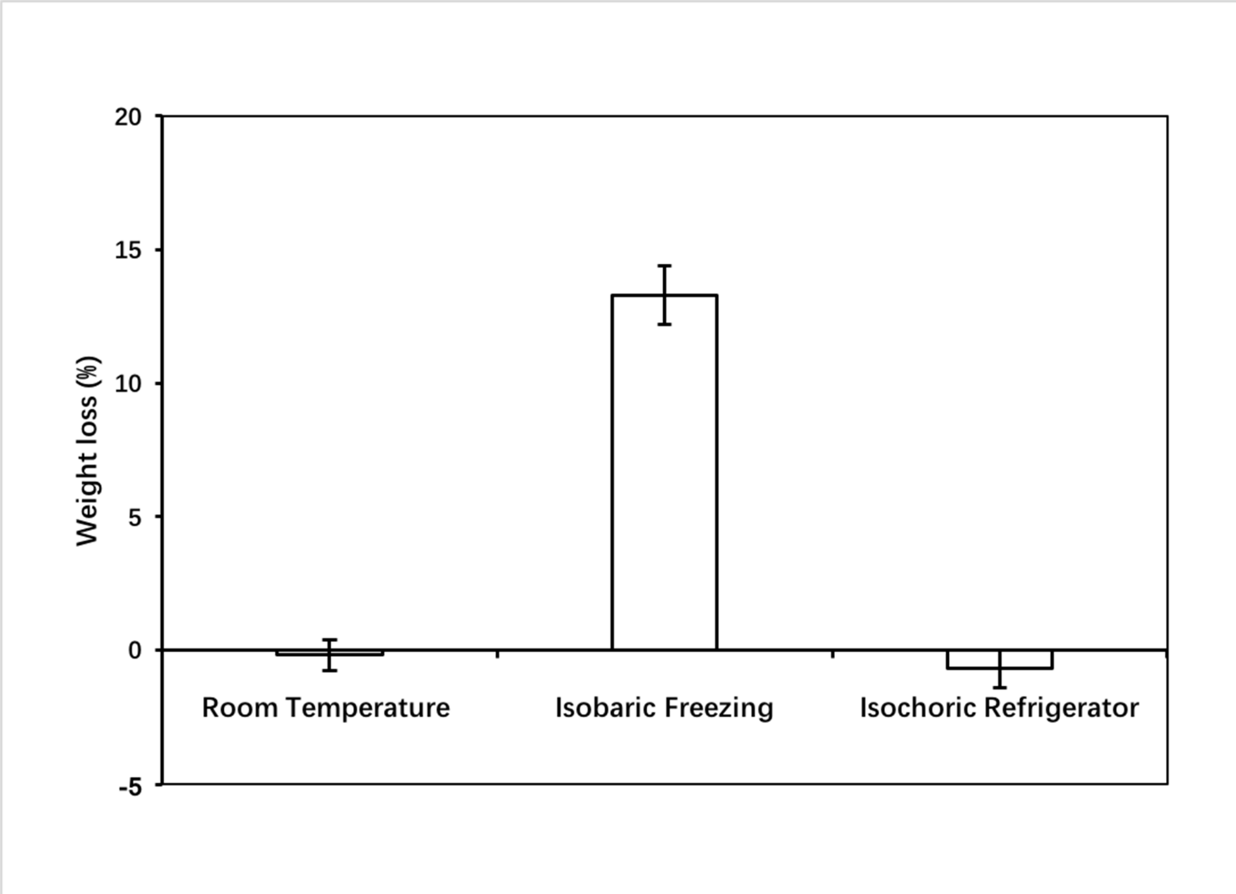

Figure 56. Weight loss of potato after room temperature preservation, isobaric freezing and isochoric refrigeration. The weight loss of the sample was obtained by comparing the weight of the sample before and after the treatment. The surface water on the sample was absorbed by filter papers before weighing. This experiment was done in five repeats. The error bars represent the standard deviation of five replicates.

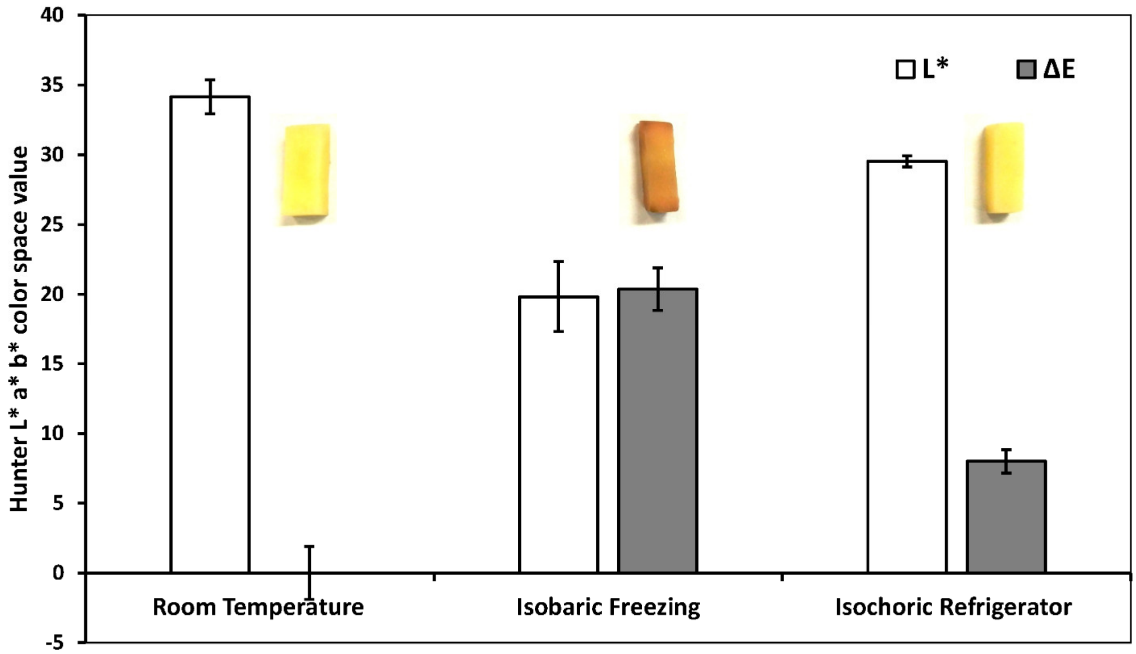

Figure 57. Colorimetric measurements – after room temperature preservation, isobaric freezing and isochoric freezing. ΔE (dark) and L* light data columns. L* represents the lightness of the color (L* = 0 yields black and L* = 100 indicates diffuse white), a* represents the redness and b* represents its yellowness in the color. ΔE is the total color difference which was calculated by $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$, where ΔL, Δa, Δb were the difference of sample's L*, a*, b* value before and after treatment, respectively. The colorimetric experiments were done in three repeats. The values on left are for both, ΔE and L*. Inserts, macroscopic photographs of the potato samples. The error bars represent the standard deviation of three replicates.

Weight loss during storage is of concern to the food industry. It occurs during preservation of all foods, including potatoes [193]. Frozen storage is particularly detrimental as it leads to substantial weight loss [194]. Figure 56 shows a comparison between the change in weight of the potato samples after two hours in a 9.09% w/w sucrose solution at: room temperature, -5 °C in isobaric condition, and -5 °C in isochoric condition. The figure shows that there is no statistically meaningful change in weight either after two hours at room temperature or during freezing at -5 °C in isochoric conditions ($p > 0.05$). In contrast, freezing at -5 °C in isobaric conditions resulted in a weight loss of 13.1 +/- 1.1 percent. The weight loss with isobaric freezing observed here is consistent with findings of many other studies [192]. To the best of our knowledge, the fact that there was no weight loss after isochoric freezing at temperatures lower than 0 °C, is unique to isochoric refrigeration.

Browning in raw fruits, vegetables and their processed products is a major problem in the food industry and is believed to be one of the main causes of quality loss during post-harvest handling and processing. The browning reaction in the potato is a key area of research in the food industry and was studied for well over half a century (e.g. Makower & Schwimmer 1954). It results from the oxidation of phenolic compounds under the action of an enzyme called polyphenol oxidase (PPO, phenolase). In the presence of oxygen from air, the enzyme catalyzes the first steps in the biochemical conversion of iron-containing phenolics, found in the potato, to produce quinones which undergo further polymerization to yield dark insoluble polymers referred to as "melanins". Browning and the formation of melanins occur in the potato when the PPO enzyme is released through damaged cell membranes. Figure 57 shows the color difference between the samples kept at room temperature, those frozen to -5 °C in isobaric conditions and those frozen to -5 °C in isochoric conditions. For each case, the figure shows a typical photograph of the sample, the total color change $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$, and the changed in lightness, L*. Obviously, browning is substantially reduced in isochoric refrigeration relative to isobaric freezing to the same temperature; which is another potentially important attribute of isochoric refrigeration.

Figure 58, shows microscopic images of the treated samples and the effects of isochoric refrigeration. The micrographs show the appearance of the samples after staining with the Toluidine Blue stain, at two magnifications, x45 (top row) and x80 (bottom row). In analyzing the micrographs, it is important to realize that Toluidine stains the cell walls in plants as well as the starch [191]. The arrow points to the cell wall. It is obvious that the cell walls in the room temperature sample and the isochoric -5 °C samples are intact and encircle the cells. Furthermore, the tissue is translucent. In contrast, the arrow in Figure 6 shows that in the isobaric frozen sample the cell walls are impaired. Also important is the observation that the Toluidine has stained the entire volume of the potato. This suggests that the cell membrane was breached and the intracellular starch has become accessible to the stain throughout the sample. In contrast, there is no staining of starch either in the room temperature stored sample or in the isochoric preserved sample. The fact that the intracellular content was released after isobaric freezing explains both the changes in weight and the browning of the isobaric preserved samples, in relation to the room temperature preserved samples and the isochoric preserved samples in Figure 56 and Figure 57.

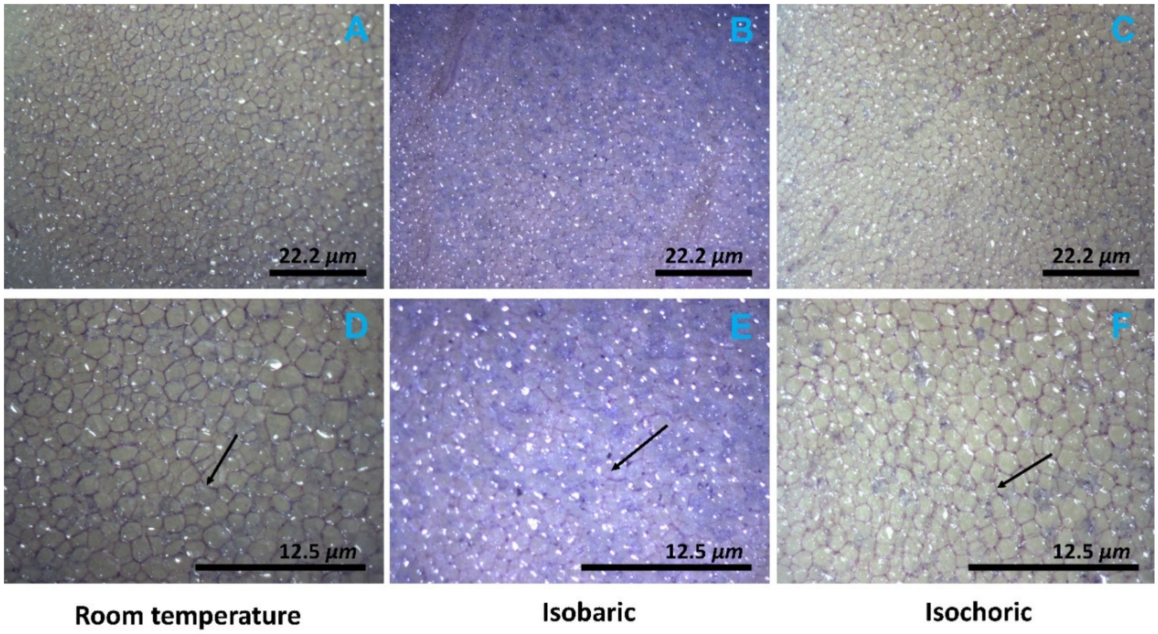

Figure 58. Microscopic photographs of the potato after isochoric refrigeration and isobaric freezing. The arrow points to a typical cell wall. Note the color in the micrographs. The microstructure of potatoes was observed by stereomicroscope (Lumar, V12 Stereo Zeiss) within 10 minutes after the treatment. The samples were stained by 0.11% Toluidine Blue O for one minute to observe the cell walls of potato. Nine (3x3, 3 samples of each treatment and 3 different sections in each sample) sections were examined in each treatment. Top row (A-B-C), x 45 scale bar 22.2 μm; bottom row (D-E-F) x 80, scale bar 12.5 μm.

The mechanisms of damage during isobaric freezing were discussed in the introduction [170]. According to Figure 53 Panel A, only 25% of the water is frozen in an isochoric system at - 5°C. Obviously, in isochoric freezing, there is no ice in the preserved biological material and, therefore, the mechanism of cell damage by freezing is eliminated. In contrast, from conservation of mass and Panel B in Figure 1, it is possible to estimate that in an isobaric system at – 5°C, 85% of the volume is frozen, and the freezing engulfs the potato. With respect to solute concentration, our analysis and experiments (Figure 53 Panel A) show that when a solution is frozen under isobaric atmospheric conditions to -5 °C, the osmolality increases to 3.5 Osm.[160]. In contrast, when the solution is frozen to -5°C under isochoric conditions, the osmolality of the unfrozen milieu composition is lower by a factor of seven from that in an isobaric system [160]. The increase in extracellular osmolality during isobaric freezing may be another factor contributing to the detected weight loss, because of the dehydration effect.

It should be noticed, though, that in isochoric refrigeration the pressure increases, while in an isobaric system the pressure remains constant. Obviously, this is a potential mechanism of cell damage during isochoric freezing, that does not exist in isobaric freezing. However, the increase in pressure in this experiment is hydrostatic and mild. Experiments have shown that even whole livers can survive the pressures in our isochoric experiments conditions [195]. This should explain why the cell membrane is intact and the intracellular content is maintained in isochoric refrigeration. The integrity of the cell membrane and the isosmotic composition of the intracellular milieu and the extracellular milieu during isochoric refrigeration is the reason why there is no weight loss or substantial browning during isochoric refrigeration to -5°C; as shown in Figure 56 and Figure 57. In contrast, the breaching of the cell membrane and the hyperosmotic extracellular concentration in isobaric freezing to -5°C, results in weight loss to the extracellular milieu and browning of the intracellular and membrane enzymes. It is possible to draw a practical conclusion from these experiments. Metabolic analysis predicts that lowering the storage temperature of a meat product from 4°C to – 5°C will reduce metabolism by a factor of between two and three. This suggests that a minor change in storage conditions, from 4°C isobaric to – 5°C isochoric could double the storage time of a product with minimal effect on the quality. Obviously, this is an extrapolation that needs to be examined.

In summary, this is a first experimental study on the feasibility of isochoric refrigeration of a food product at subfreezing temperatures. While obviously, much more research must be done on this technology, it is evident that a food product, the potato, can be preserved at -5°C in isochoric conditions without the deleterious effects of isobaric atmospheric freezing to -5°C, i.e. weight loss and browning. It should be emphasized that we have focused here on the damage due to freezing and not storage damage. A further study on storage damage is also needed. In addition, our laboratory is equipped for mechanical engineering work and does not have the devices necessary for chemical and nutritional studies on food quality deterioration, such as changes in vitamin C. There is no doubt that much more research is needed on the effects of storage, on chemical changes and of course a more extensive study over the entire range of temperatures to the triple point. Nevertheless, the main value of this study is that it introduces a possible new method of food storage, with some apparent potential.

4.4.3. Vitrification of the solutions used in preservation;

Vitrification solutions are aqueous cryoprotectant solutions which do not freeze when cooled at moderate rates to very low temperatures. Vitrification solutions have been used with great success for the cryopreservation of some biological systems but have been less successful or unsuccessful with other systems, and more fundamental knowledge about vitrification solutions is required [196]. Recent developments have opened the possibilty that the problems of freezing and thawing organs might eventually be over- come by an alternative approach to organ cryopreservation, namely, vitrification [197].

While in Berkeley, together with my coleages from there we tryied to make vitrification experiments using water and dimethylsulfoxide (DMSO) in different concentrations. We immersed the solutions in LN (-196°C). DMSO has the chemical formula $(CH_3)_2SO$ and is a wood industry product used in medicine as a solvent, in organ preservation. All experiments we did were performed at 1 atm pressure, and the minimum concentration of the DMSO in water, needed for vitrification is 49% (%w/v) according to Fahy et. all [196].

In the following figures, it can be observed some of our results in vitrification of water and DMSO.

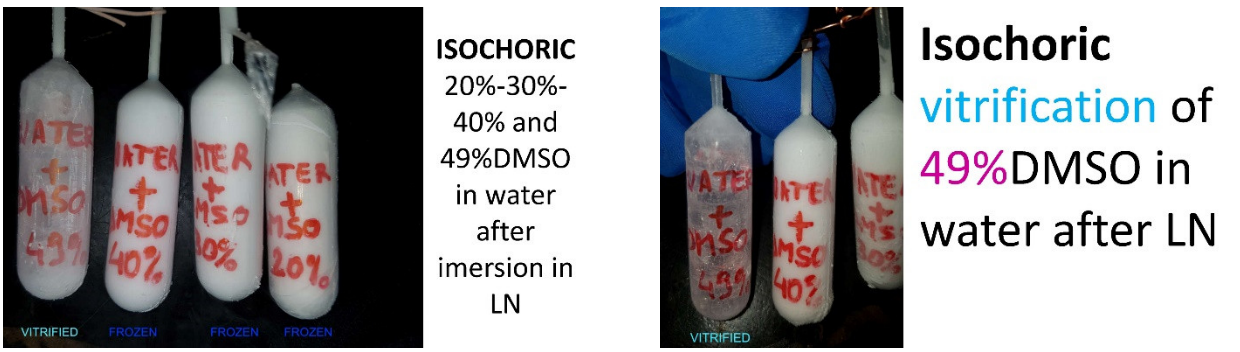

Figure 59. Water and DMSO samples, with different concentrations, after imerison in LN. It can be observed that only the 49%w/v of DMSO in water has vitrified.

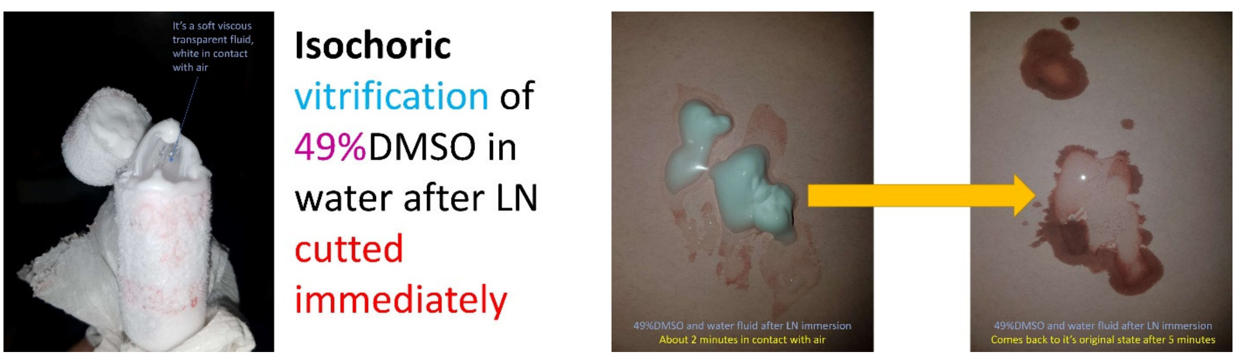

Figure 60. The 49%w/v of DMSO in water sample, cut, to observe the properties of the result. At room temperature, after vitrification, we see a soft visous, transparent fluid, white in contact with air.

The study of vitrification of cryoprotective agents (CPA) in isochoric systems will be one of my new research activities. What is interesting is that, in isochoric system the phase transition from liquid to glass show no increase in pressure, this being the indicatior of vitrification. This observation makes pressure measeurements in isochoric systems very valuable.

4.5. 3D Printing. Aplications in Bioengineering and Food Industry

4.5.1. 3D Printing in Bioengineering

Recent advances in tissue engineering have adapted the additive manufacturing technology, also known as three-dimensional printing, which is used in several industrial applications, for the fabrication of bioscaffolds and viable tissue and/or organs to overcome the limitations of other in vitro conventional methods. 3D bioprinting technology has gained enormous attention as it enabled 3D printing of a multitude of biocompatible ma- terials, several types of cells and other supporting growth factors into complex functional living tissues in a 3D for- mat. A major advantage of this technology is its ability for simultaneously 3D printing various cell types in defined spatial locations, which makes this technology applicable to regenerative medicine to meet the need for suitable for transplantation suitable organs and tissues. 3D bioprinting is yet to successfully overcome the many challenges related to building 3D structures that closely resemble native or- gans and tissues, which are complex structures with defined microarchitecture and a variety of cell types in a confined area. An integrated approach with a combination of tech- nologies from the fields of engineering, biomaterials science, cell biology, physics, and medicine is required to address these complexities. Meeting this challenge is being made possible by directing the 3D bioprinting to manufacture biomimetic-shaped 3D structures, using or- gan/tissue images, obtained from magnetic resonance imaging and computerized tomography, and employing computer-aided design and manufacturing technologies. Applications of 3D bioprinting include the generation of multilayered skin, bone, vascular grafts, heart valves, etc. The current 3D bioprinting technologies need to be improved with respect to the mechanical strength and in- tegrity in the manufactured constructs as the presently used biomaterials are not of optimal viscosity. A better under- standing of the tissue/organ microenvironment, which consists of multiple types of cells, is imperative for suc- cessful 3D bioprinting [198].

3D printing is emerging as an enabling technology for a wide range of new applications. From fundamentals point of view, the available materials, fabrication speed, and resolution of 3D printing processes must be considered for each specific application. It should be noted that the versatility of 3D printing materials comes from the variety of 3D printing systems, and all the new prin- ters or processes for novel materials have not gone beyond the seven categories defined in ISO/ASTM standard. However, 3D printing should never be seen as a standalone process, it is becoming an integral part of a multi-process system or an integrated process of multiple systems to match the development of novel materials and new requirements of products [199].

Three dimensional (3D) bioprinting has been a powerful tool in patterning and precisely placing biologics, including living cells, nucleic acids, drug particles, proteins and growth factors, to recapitulate tissue anatomy, biology and physiology. Since the first time of cytoscribing cells demonstrated in 1986, bioprinting has made a substantial leap forward, particularly in the past 10 years, and it has been widely used in fabrication of living tissues for various application areas. The technology has been recently commercialized by several emerging businesses, and bioprinters and bioprinted tissues have gained significant interest in medicine and pharmaceutics [200].

3D printing is a modern technology which creates a three-dimensional object layer by layer. This method can be applied in many fields and in tandem with many other techniques. To demonstrate that the technology can be used in bioengineering, while doing my postdoc in Berkeley I modified two traditional 3D printers to print fluids, instead of plastic materials. The central elements of the modified printers were the printing heads and the injection systems. In both cases the standard printing head was replaced by a syringe of various sizes ranging from 5 mL to 60 mL. For bioengineering purposes, I used two printing methods:

- 3D printing in liquid nitrogen;
- 3D printing in +4°C cooled fluid (water and ethylene glycol or saline solution).

In Figure 61 can be observed some preliminary results of the 3D priniting process using the two methods described above.

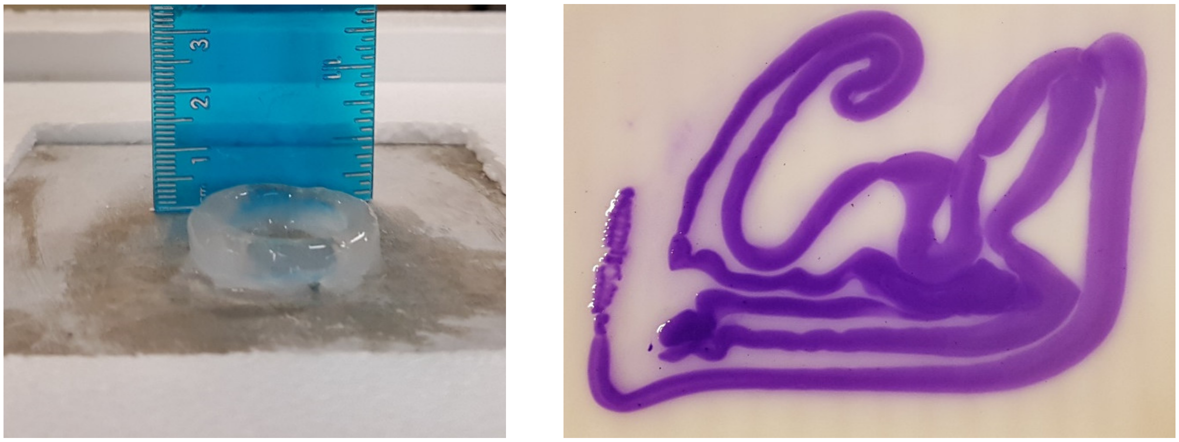

Figure 61. 3D printed Agar gel in Liquid Nitrogen (left) and 3D printed Agar gel in +4°C water and ethylene glycol

Despite its potential benefits in biofabrication of anatomically correct tissue scaffolds, 3D printing of inert materials in tissue engineering faces several limitations in the generation of complex tissues and organs for transplantation or other uses [201]. First of all, manually driven cell placement on the scaffold micro-architecture lacks the necessary precision. It is highly challenging to manually seed, place and pattern cells to recapitulate the complex configura- tions of various cell types in natural tissues and organs. In addition, seeding cells in high cell density is not trivial because cells can only attach to the scaffold surface and cannot penetrate into the matrix. Scaffold biomaterial also occupies a significant volume of space, which does not allow cells to expand to sufficient numbers [202].

4.5.2. 3D Printing in Food Industry

Cooking is one of the most important activities in our life, and a robotic chef capable of following recipes would have many applications in both household and industrial environments. Many articles and papers pertaining to food printing have been published over the past few years. Most of them focused on fabricated novel food items. Recently, some researchers started investigating fundamental-level issues in food printing, such as converting ingredients into tasty products for healthy and environmental reasons. [203].

Differentiated from food extrusion cooking, extrusion-based food printing is a digitally-controlled extrusion process to build up complex 3D food products layer by layer. It is the most popular method in food printing, which provides an engineering solution for digitalized food design and nutrition control [204].

In digital gastronomy, ingredients can be determined according to on-line information on nutritional content, personal and social preference [203].

Using the same principle described in 4.1.13 I tried to print ice cream and yogurt to prove the possibility of using the technology in food industry. Of course, there are lots of prblems that have to be taken care of, to create a stable and pricise method that can be applied on a large scale, but already the first stepps have been taken.

In Figure 62 can be observed my attmpts to print yogurt and ice cream using the 3D printing technology.

Figure 62. 3D printed yogurt (left) and 3D printed Ice Cream (right)

4.6. CO_2 accumulation in residential spaces

The relationship between economic growth, environmental sustainability and energy are of great interest among researchers and policy makers [205]. The progressive technological development of world countries contributed to global warming effect due to the quantities of greenhouse gases emitted [206]. Global warming is happening due to increasing level of carbon dioxide and other greenhouse gases into the atmosphere. To reduce the rising level of CO_2 emitted by human activities, carbon capture and storage technologies are being developed [207]. CO_2 and thermal comfort together with a control logic that, using measured data, provide the optimal rules to actuate the control devices (ventilation, heating/cooling, windows opening, shutters operation and so on)

[208]. The building environmental concerns have motivated industry professionals to pursue minimal impact building designs and strategies. Globally the construction industry has an immense contribution to socio-economic development but is also responsible for the consumption of energy and natural resources. Ideally, a multi-disciplinary approach covering issues like emissions reductions, improved use of materials, reuse and recycling is needed to achieve the goals of building sustainability [209]. Buildings use a significant amount of primary energy and largely contribute to greenhouse gases emission [210]. Most of the research has focused on reducing the operational impact of buildings, however in recent years many studies have indicated the significance of embodied energy in different building types [211]. In residential building sector, the primary indoor pollutant is the CO_2, from occupant respiration. The increase in indoor CO_2 concentration above the outdoor concentration is considered as a good surrogate for the indoor concentrations of bio-effluents. The outdoor concentration of carbon dioxide can vary from 350 to 400 ppm [212] or higher in areas with high traffic or industrial activity [213]. Ventilation is ambiguously related to the energy saving rationale originating from the mitigation of global warming, the reaching of peak oil or health concerns related to fossil fuel burning. Since it makes up for about half of the energy consumption in well-insulated buildings, it is an attractive target for energy saving measures. However, simply reducing ventilation rates has unwanted repercussions on the indoor air quality [214]. The detection of occupants in indoors can be fundamental for a correct operation of the installed engineering systems (e.g. lighting, ventilation, heating and cooling) [215]. When a building is used only for intermittent occupancy, continuous operation of ventilation system is not necessary for achieving good indoor air quality during the occupation periods. Such buildings have a great energy saving potential which is not harnessed enough yet. Indeed, energy loss can be avoided by promoting natural means and managing mechanical ones. Therefore, control strategies based on time and/or occupancy scheduled ventilation associated to pre-purge ventilation constitute a key for an energy efficient ventilation system [216]. Carbon dioxide is most of the time significantly and positively correlated with indoor air pollutants. However, the strength of the correlation is weak [217]. W. Wey et al. reviewed fifty-five building schemes in 31 certifications worldwide. IAQ is included in all the certifications as a section that evaluates the health risk of indoor occupants [218]. In recent years, indoor air quality (IAQ) has become an internationally recognized issue that has attracted the attention of researchers and occupants towards improving the quality of air inside buildings [219]. IAQ is defined as the

desire of humans to perceive the air as fresh and pleasant, with no negative impacts on their health and productivity; this is important in schools to enhance the children's learning and performance [220]. In the last decade, indoor air pollution has been unanimously recognized as a public health hazard world- wide, both in developed and developing countries. Accumulation of indoor air pollutants appears to significantly contribute to ''sick building syndrome'' (SBS) and other reported diseases in affected spaces. Botanical biofiltration has received a great deal of attention in the past decade, likely due its economic, environmental and social benefits, including its potential soon to be incorporated in both traditional and the new trend of sustainable zero-emission green buildings [221]. Urban people spend about 85–90% of their time indoors (residential and public spaces), which can explain the direct relation- ship between indoor air quality and public health risk [222], [223]. Indoor air quality (IAQ) was ranked by the US Environmental Protection Agency in the top five public health concerns [224].

There are many studies about IAQ, but there is no common standard index for the indoor air quality. The IAQ is usually expressed in required level of ventilation or in CO_2 concentration. To maintain a good indoor air quality (IAQ) in residential buildings and decrease the risk of health problems a ventilation system is needed, natural, mechanical or hybrid. In Romania, as in many places, most residential buildings are not designed with a ventilation system, and people resume to opening windows for natural ventilation, during the day. This is not wrong but when outside is cold, during the winter season or during the night, when we sleep, opening windows is not an option. Without a monitoring and data-acquisition system, people cannot quantify their indoor air quality parameters, and they end by having health problems. We studied different scenarios in a bedroom, to evaluate IAQ, by measuring indoor temperature, relative humidity and CO_2 concentration. Measurements were carried out in a three-week period plus one day in the week four, both during the day and at night.

The large scale "energy efficient" solutions for energetic audits in Romania include better insulation for the exterior construction elements and replacement of double glass with wood joinery with high-energy efficiency glass in PVC casement. All these measures minimize the number of air exchange rates between interior and exterior.

Because people spend usually 50% of their lives at home and mainly 30% of their lives in bedrooms arises in the need of generic control indoor air quality in these spaces, with a question of compliance with permissible CO_2 concentrations and in what conditions.

Normally, the level of CO_2 in a given region tends to remain constant if we refer to a prolonged period of time, one year, for example. This is because the CO_2 molecules, as well as other gas molecules tend to diffuse and to equalize in the atmosphere.

For one-week period, we measured the CO_2 concentration in the outside air at the location of the experiment. The measurements were taken at five-minute intervals, for 24 hours each day, from 9 AM on 15 December until 10 AM on December 22, and the results are shown in Figure 63.

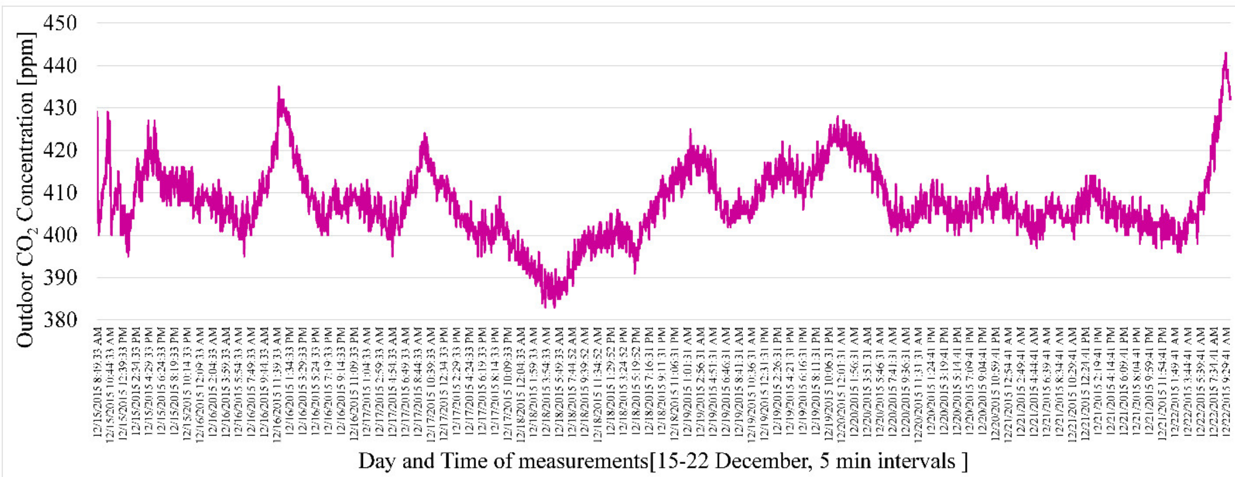

Figure 63. Outside air CO2 concentration [ppm]

The CO_2 concentration in the outside air fluctuated from 383 up to 443 ppm. The average value from the measurements was 408 ppm and the largest variation of CO_2 in the atmospheric air was 60 ppm. Daily week average measured value coincides with all week averages and with weekday average, 408 ppm, while the nocturnal week average was 407 ppm. The weekend average of CO_2 concentration in the outside air was 405 ppm and fluctuations were smaller than during the week. Buildings with natural ventilation systems must be designed according to location, region, specific statistical data of solar radiation and wind, in the days and years, to maximize occupant comfort and minimize energy costs. As buildings with natural ventilation systems must respond to the location and microclimate conditions, it is no set of specific criteria applicable to each naturally ventilated building. However, by choosing natural ventilation for a building, a variation of carbon dioxide in the outside air up to 100 ppm have no considerable influence.

For this study, we considered four cases, each with a different scenario, summarized in Table 6. Easily to observe the differences arising from measurements, after the presentation of four cases results, we did a comparison of them. The comparison is presented in charts with average values for the whole period or for certain times.

Table 6. Proposed cases with related scenarios

Proposed cases	Scenarios			
	Bedroom door	Flowers inside Bedroom	Measurement period	
Case I	Closed	NO	1 week	7-14 December, 2015
Case II	Open	NO	1 week	14-21 December, 2015
Case III	Open	YES	1 week	21-28 December, 2015
Case IV	Closed	YES	1 day	28th of December, 2015

The comparison will include also other related results obtained in this study, such as values of the CO_2 concentration in the outside air, at the location of the experiment.

We chose for the measurements an 11,4 m^2 bedroom inside a three-room apartment with 65 m^2 total living area (see Fig. 1), built in 1978, located in Brașov, which is in the central part of Romania (latitude 45°67′N, longitude 25°60′E, +2 h GMT). During measurements, two adults were living at the apartment, mostly from 6 PM to 8 AM in the week days and all day during weekends.

The apartment has three exterior walls (north, east and south) composed of 20 cm reinforced concrete and 5 cm of polystyrene insulation with a heat transfer coefficient U=0,7 W/m^{2}K. The windows are double glass window panes separated by argon, with a heat transfer coefficient U=2,6 W/m^{2}K. In accordance with the energetic certificate for the apartment, made on 20th of May 2013 the corresponding energetic class is C, with specific annual heat consumption between 201 and 291 kWh/m^2/year.

In this study, we analysed the effect of Spathiphyllum "Sweet Silvio" flowers over IAQ parameters, mostly the CO_2 and relative humidity, inside a bedroom. The study was divided into four cases, each with a specific scenario. The results indicate a beneficial effect brought by the flowers' presence inside the bedroom, but only if the door is open both day and night. The measurements indicate nearly 4% reduction on CO_2 concentration inside the bedroom over one week. In the same cases (II and III) the indoor air relative humidity was almost 5% higher during the nights and closely 4% higher during the days with the flowers inside.

The CO_2 concentration inside the bedroom with the door closed (case I and IV), while two people asleep reaches values near and over 6000 ppm, without the flowers inside and values close to 7000 ppm with the flowers inside. This means four 14 cm pots of Spathiphyllum "Sweet Silvio" placed in a 11,4 m^2 bedroom added almost 1000 ppm in CO_2 concentration by plant respiration in the night time. In this case the indoor air relative humidity is higher than in, we considered the bedroom door open. The measurements indicate that the four flowers inside the bedroom reduced the indoor air relative humidity, both during the days and nights, in last case if compared with the first.

Many people sleep with the bedroom door closed, without realizing how much CO_2 accumulates in 8-hour time. Some of them have also flowers in their bedroom, for their nice aspect but their presence does nothing but worsened the situation. These two situations can lead to adverse health effects, which include headache, general drowsiness, stiffness, odors and the sensation of reduced oxygen level. All these symptoms were felt by the two people who slept in the bedroom during the case I measurements.

It is good to have flowers inside the house, but their place is in living room or in kitchen, and no one should sleep with the bedroom door closed because of the CO_2 accumulation inside.

Energy reduction obtained by adding flowers in a living space it is directly proportional to the CO_2 captured from that space by flowers. In the case of the present study, the reduction was of almost 4%.

4.7. New teaching and learning methods for students

Experiential learning

Experiential learning is helpful for undergraduate students as it helps improve their theoretical knowledge and develop research skills. This article seeks to presents the benefits of experiential learning in the context of the higher-education environment. Through this method we wanted to investigate to what extent such a theme could highlight and develop students' research skills. The method suggests a positive constructive feedback from both, teachers (colleagues) and students.

Based on this feedback we consider the method information-specific, because is transferring the theoretical aspects or ideas into real products. This study establishes a platform for future implementation possibilities at a different scale for the method, for undergraduate students.

In academic environment the tendency to state and to maintain high standards is correlated with academic achievement and seen as a factor that can motivate the student to strive for excellence [225]. Since the establishment of the human capital investment theory in the early 1960s, higher education is generally recognized as a critical investment for a country, especially for a developing country's long-term social and economic development [226]. As the presence of online and hybrid coursework at institutions of higher education has increased, so too has interest among educators and scholars in understanding personal and contextual factors that predict success in different types of learning environments [227]. Teaching is a complex process, demanding special human qualities [228]. More recently, the education aid policy debate has gradually shifted from access to schooling to improving learning quality. The transition is likely to dominate the post-2015 global development framework for education development, and can be explained by two important factors: firstly, growing evidence emphasizes that quality of education is what matters for economic development [229]. Acceptance of innovations - the reception accorded to new ideas of changes in practice - is of great significance in the study of development. This is so if we think of development in the restricted quantitative sense of economic growth, for many projects and schemes depend upon the take-up of some change in practice which will (it is hoped) lead to increases of wealth or productivity. It is also very much the case if we think of development in the broader sense of improvement in the quality of life, since many innovations are aimed at qualitative amelioration of the conditions of life [230]. Negovan and Osiceanu suggest that if the progress in learning is assessed by the knowledge development, the students must to be involved more in activities focused on knowledge, based on an analytical strategy and aiming Bloom' learning objective "application" [231]. Students working in small groups, usually consisting of five to seven students, that communicate and learn from each other and are actively engaged with the course materials is defined by literature as Team-based learning. Team-based learning (TBL) is an active learning-centered teaching strategy that employs small groups to offer an alternative to traditional lecture classes [232]. Students of today are digital natives. They acquire their digital literacy autonomously and are adept at using various Information and Communication Technology (ICT) tools to enrich their daily leisure life [233]. Higher education has been impacted significantly by the proliferation of online instruction [234]. E-learning has been used very widely to offer solutions in higher education in accordance with the demands of the knowledge-based society [235]. The worldwide trend toward lifelong learning assumes that learners need to be more independent and well self-controlled and self- regulated to achieve desired learning goals. Tertiary students are expected to be self-regulated learners, as most of the learning tasks were completed with less supervision from lecturers or tutors compared with primary and secondary teaching modes [236]. Students must acquire knowledge, but the learning process must be diversified and updated. Based on the project results we might say that student living in a digital world need a new set of skills: digital literacy, team-working, online and offline communication, entrepreneurship, leadership and problem solving, as shown in Figure 64.

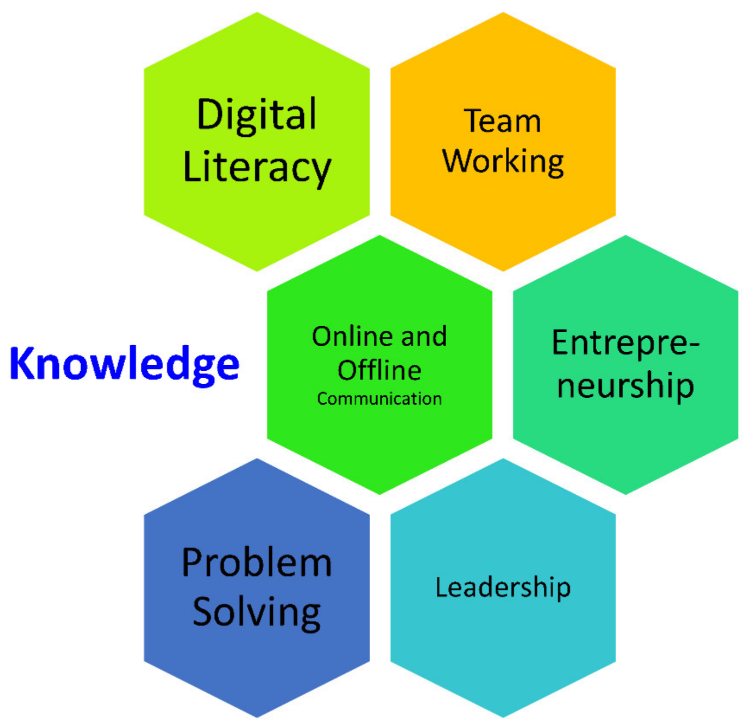

Figure 64. Skills student living in a digital world need

The evaluation of the impact of using the Internet in the learning process, done by their colleagues.

Information and communication technologies (ICTs) have got still very impact on the teaching-learning process, their effect was also in the past at the beginning of the century, when Richards, (2005) wrote, that many teachers find that interesting and well-planned tasks, projects, and resources provide a key to harnessing the educational potential of digital resources, Internet communications and interactive multimedia to engage the interest, interaction, and knowledge construction of young learners.

To evaluate the impact of using the Internet in the learning process in case of our project, we conducted a survey that embodied 15 questions (Figure 65). The description of their positive or negative experiences has been done in this case on a six-point scale (ranging from 1 "Strongly disagree" to 6 "Strongly agree"). In this survey participated 23 students. As can be observed in Figure 4, the results in the survey indicate that the Internet is not a difficult technology and most students agree the Internet can be an efficient tool for learning and useful for their professional development. In the same time, most of the students consider practical training important for their career and agree (43.5%) and strongly agree (47.8%) they learn faster if they do a practical experiment.

Figure 65. Survey results for the impact of using the Internet in the learning process

Digital competences gained in specific courses are now part of any student's development. What we do not know yet is on what level teachers accept and integrate ICT in other courses. There are a few factors that influence ICT integration such as teacher's experience and skills with ICT, his attitude on ICT, his perception on the help brought by ICT for the student's academic development.

Method Conclusions

Young people spend much time on the Internet, and many studies say that in today's world spend too much time in front of computer and time consumed outdoors or for recreational purposes decreases. What we need is to find ways to harness the time spent by students in front of the computer, on the Internet, for their academic development. To succeed learning from online environments, students need motivation, self-regulation and remote assistance.

In this paper, we present an experiential learning method applied in case of two students enrolled in the first year in Building Services specialty, Faculty of Civil Engineering, from Transilvania University of Brasov. The students built a prototype of an air temperature-humidity portable datalogger, using electronic components ordered from the Internet and tutorials to create it, from online environments. Students experienced an active and authentic way of learning, by moving from idea to something practical, from the real world.

We used surveys to evaluate the feedback of our method. As a general impression, the student satisfaction with the quality of their entire educational experience has remained consistently high, across all survey categories. The students embraced the opportunity to participate in a competition, to develop new learning skills and to strengthen their knowledge [238].

Learning using interactive methods

Cryogenics is the branches of physics and engineering that involve the study of very low temperatures, how to produce them, and how materials behave at those temperatures. As subject within Building Services specialization, it is harder to be understood by students because it requires knowledge from many fields, such as chemistry, physics, refrigeration, heat transfer, thermodynamics, mechanics, strength of materials, etc. Studies points out that interactive teaching methods create a deeper learning, students develop better thinking skills by presenting concrete examples, and students demonstrate better memory and are more appreciated. To ensure the next generations have a well-trained workforce that can tackle complex challenges that face these days improving access to information is a key component to effectively compete in the global labor market. All research proves that learning is the result of the exercise, or seeing what was learned. This leads students to process information and give it meaning. Over time, it was found that teaching on a blackboard with chalk and implement a written course is a minimum mandatory but not sufficient, as proven by many of today's courses are made using digital presentations. This paper presents a new method of teaching and learning Cryogenics, for students enrolled in Building Services specialization, in the Faculty of Civil Engineering, part of Transylvania University from Brasov.

Information is a vital resource in development activities of any business [239]. The utilization of the interactive whiteboard is a challenge for Romanian teachers. The education methods involving this device can vary because they depend on the components involved in this process: the teacher, the students, the computer, as basic tool, and software, including applications developed for education in different programming languages [240]. According to the framework for 21stcentury learning, information, media and technology skills are essentially required for 21st century scholars due to the environment of technology and media [241]. Interactive whiteboards (IWB) are being increasingly used as educational resources in higher education all over the world, and in recent years they were also introduced in Romanian universities [242]. There are implied two domains in an integrate vision that offers a new perspective upon the components of education sciences: technology and education [243]. Digital instructional tools develop rapidly, and they can create novel learning experiences. Still, adoption of new formats is often expensive, and their efficacy is untested [244]. With the rapid development of computer information technology, the ways of education and teaching have had a constant change. The use of interactive whiteboard in multimedia network classroom makes up a whole interactive instruction system, which raises the interactivity and interest of teaching and also makes teaching more efficient [245]. The information invigorates and develops through action. It has been accepted that learning occurs more permanently by acting and implementing. In this sense, the students use their minds and experiences when they are active; they become within the act of learning and try to implement what they have learnt. The fundamental purpose is to actualize the permanent learning and make students the leading actor of the act of learning [246].

Together with Prof. Şerban Alexandru, we started this project by creating a website for students where they can access educational resources for Refrigeration. Now we have two websites, one for learning Refrigeration (www.dralexandruserban.ro) and one for learning Technical Cryogenics (www.criomecsa.ro/criogenie). By doing this, we created the premises of an always learning possibility, because students these days use more and more technology: computer, tablets, smart phones etc. To attract them more to school and to make sure they have a deeper learning, we installed an interactive system in the classroom. The interactive system consists of a laptop connected to the internet, a projector, a whiteboard and the interactive whiteboard teaching module. The interactive teaching module comes with a wireless receiver, the interactive teach bar with a rechargeable stylus, a USB micro-B cable, 5V 1,2A power supply and a software licence. All components of the interactive system are presented in Figure 66.

Figure 66. Interactive whiteboard teaching and online learning Cryogenics materials

(A – interactive system; B – laptop; C – projector; D - whiteboard)

To expose all this information, we created a special course room with 20 seats (Figure 67 - right), where we installed two whiteboards and the interactive teaching module (Figure 67 - left).

Figure 67. Presenting a course at the interactive whiteboard (left) and course room (right)

Method Discussion

Due to the positive feedback from students, on the course, future development of several courses this way is desired and diversification of interactivity on the site for even more attractiveness.

We implemented this system in 2012 and since then we noticed that students manifest a faster understanding of the complex concepts in the field of Cryogenics. Also, students' participation on course increased and students' attitude and knowledge were at a very good level [247].

Method Conclusions

In our current society, there is a dynamic process which requires all walks of life to keep up with the evolution of society and therefore education. The application of new learning methods require time, diversity of ideas, commitment to action, discovery of new values, teaching responsibility, confidence in personal ability to apply them creatively to streamline the educational process. Virtual teaching and learning Cryogenics consist of presenting courses online in the classroom and offers students the possibility to learn not only at school but also when they are on the move, using online environment on modern portable devices. This mode the Technical Cryogenics course is more easily assimilated by the students and motivate them for choosing this area in future engineering profession [247].

Using the Interactive Whiteboard System as an instructional tool has proven to be an effective way to teach students, to attract them more to science and to school. Inspiration for this project came because of the lately massive development of innovative portable devices that users interact with, such as smartphones, tablets, laptops, to name just a few.

Over time, it was found that teaching on blackboard with chalk and implement a written course are a minimum mandatory but not sufficient, as proven by many of today's courses are made using digital presentations. This paper proposes a new method of learning by using simulations software based applications. The software that has the capabilities to create simulations based applications is Comsol Mutiphysics version 5. The idea is simple. You create a simulation model and based on it you can create an application with a much simpler and intuitive GUI (Graphical User Interface) for students. Using the new interface, the students from undergraduate years can understand different physics or phenomena without knowing how to use a complex simulation software [248].

Learning by using CAE software

The real-life situation considered in this method is shown in Figure 68.

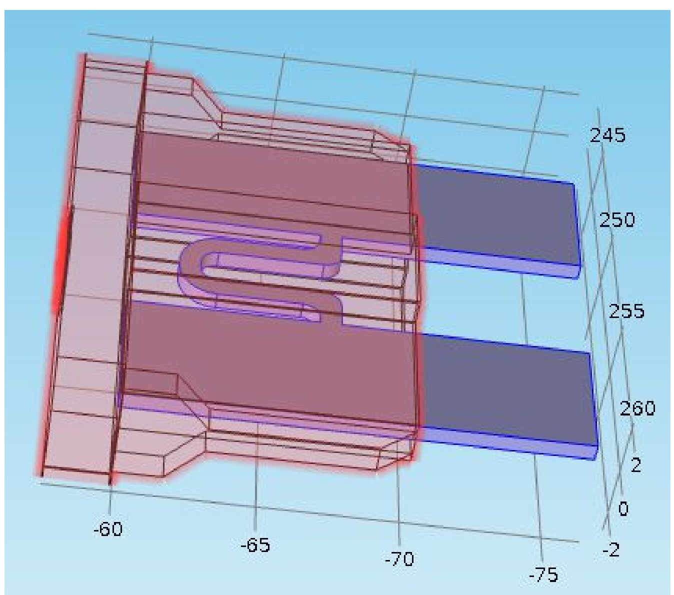

Figure 68. Automotive fuse 60 A, made from copper

The application proposed in this method was created after a simulation of a Joule-Lenz effect on a 60 Amps fuse used in automotive applications. The simulation is created in steady state, which means the field variables do not change over time.

For the initial study, the voltage for the simulation was considered 32 V, the current intensity was considered 40 A, in terms of electric currents and in terms of heat transfer in solids was considered a convective heat flux of 5 W/m^2K and an ambient temperature of 20 ºC, as can be seen in Figure 69.

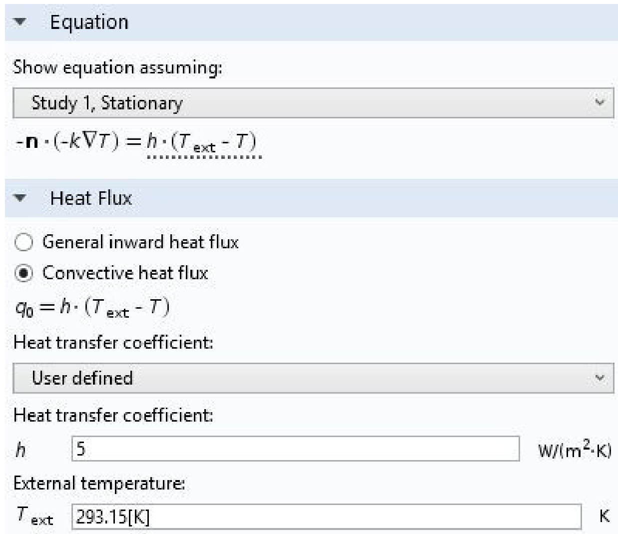

Figure 69. Boundary conditions for the convective heat flux

For the mesh, it was used a fine element size, and the result can be seen in Figure 70.

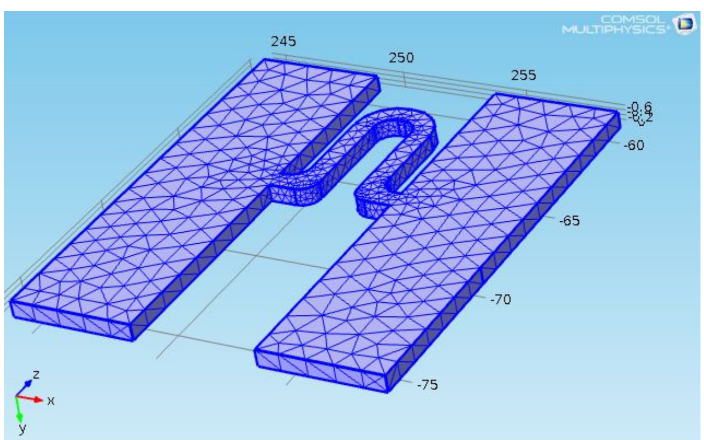

Figure 70. The fine mesh for the copper fuse, used in the simulation

Using these input data, the computer simulation software Comsol Multiphysics 5 solves the problem and the user can choose what result are important to be shown and can plot under different forms. For example, in this simulation it is considered important to show the electric potential and the surface temperature over the fuse. These results can be observed in Figure 71 and Figure 72.

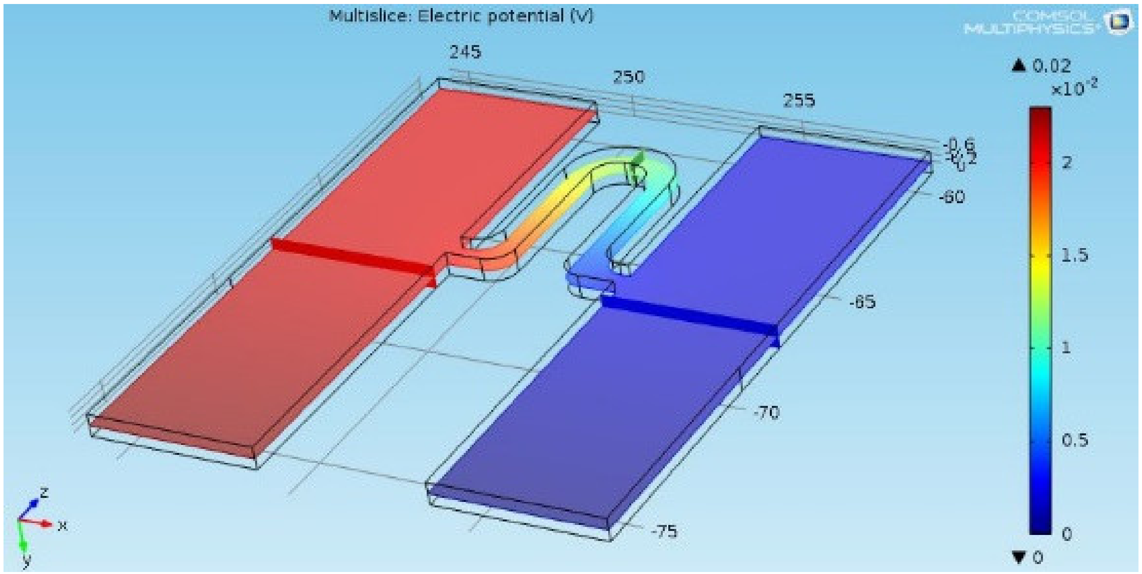

Figure 71. Multislice electric potential results

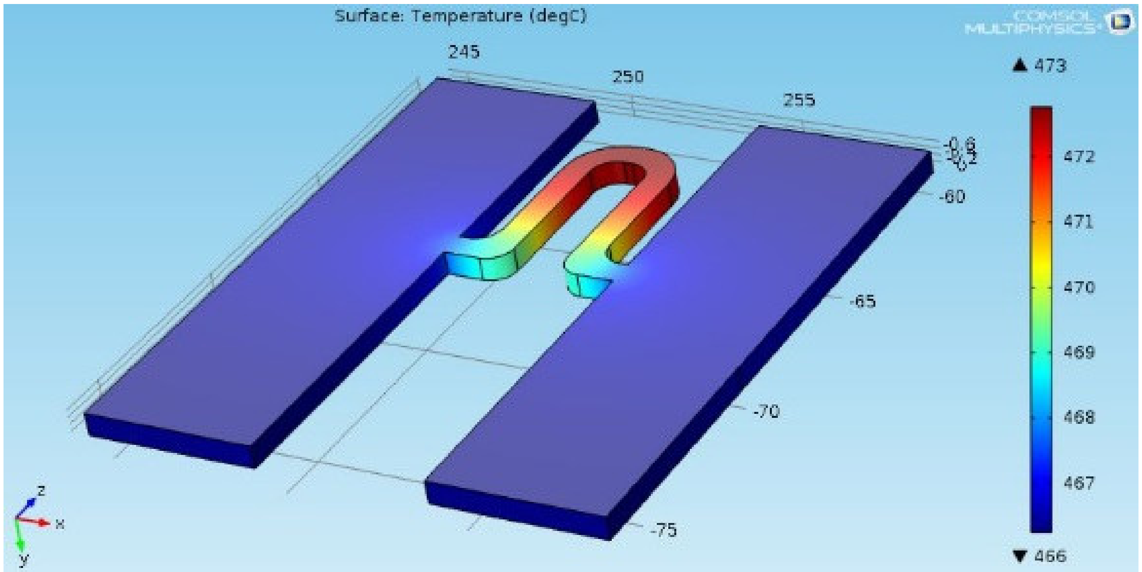

Figure 72. Surface temperature over the fuse

To conclude, creating this simulation the user has to follow five basic steps:

1. To create a geometry 2D or 3D;
2. To mesh it;

3. To setup the boundary conditions of the study;
4. Wait for software to compute the study;
5. Finally, to plot the results.

Following those five steps require CAD knowledge, in order to create more complex 3D models, requires that the phenomenon being studied already to be known and understood in order to setup the correct boundary conditions, require knowing how to use a complex simulation software, require a workstation PC depending on the complexity of the geometry or phenomena studied and in the end if the penultimate condition is fulfilled only partially a lot of waiting time is needed.

The Application Builder from Comsol Multiphysics

To eliminate all these inconvenient wouldn't be easier for the users to have access to a database of ready-made applications, where they can change key parameters to see the system or the component behaviour? With the version 5 of Comsol Multiphysics this is possible, by using the Application Builder.

A COMSOL application is a COMSOL Multiphysics® model with a user interface.

With a license of COMSOL Multiphysics, applications can be run from the COMSOL Desktop in Windows® in this new launched version 5, but in future versions the Application Builder will be available also for OS X and Linux.

With a COMSOL Server license, a web implementation of an application can be run in many popular web browsers on platforms such as Windows®, OS X, iOS, Linux®, and Android™. In Windows®, you can also run COMSOL applications by connecting to a COMSOL Server with an easy-to-install COMSOL client, available for download from www.comsol.com, as for example Amazon.com.

Files extension for Comsol Application Builder is *.mphapp.

The Application Builder includes a comprehensive set of tools for creating and deploying applications based on COMSOL models. The main tools and desktops that you use to create applications are shown in Figure 73 and are the following:

- The Application Wizard: A wizard that guides you through the steps to set up an application from an existing COMSOL Model.

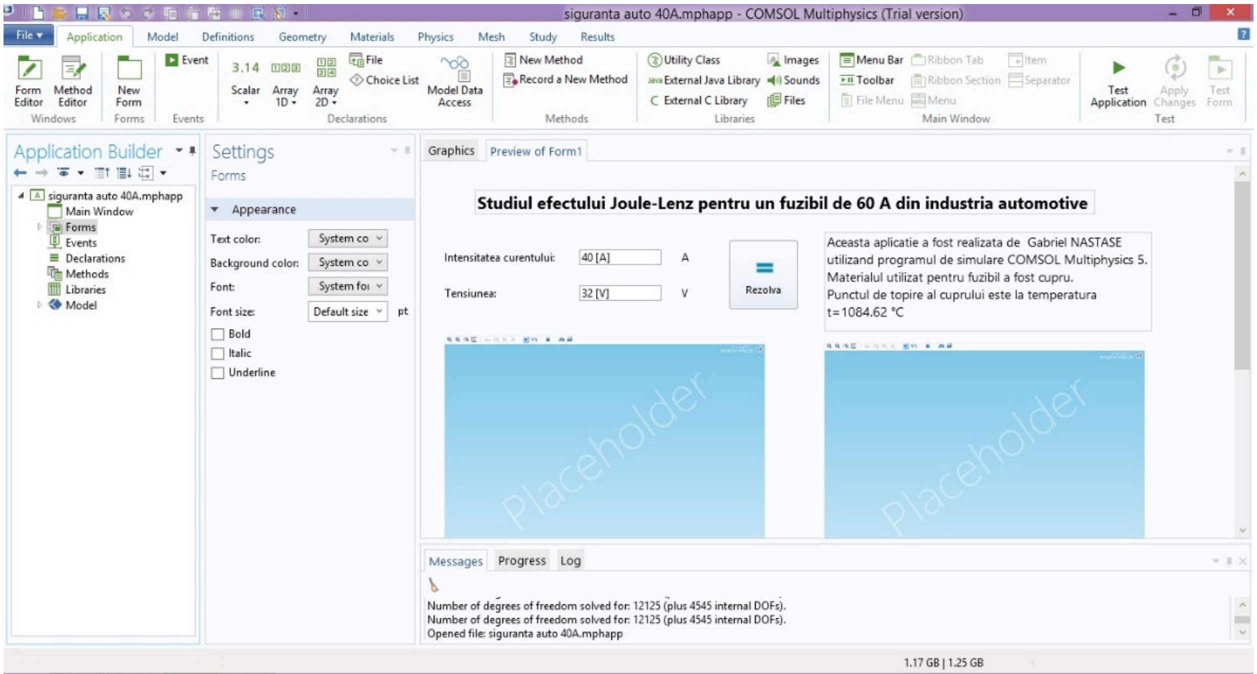

Figure 73. The Main Window Branch in Comsol Multiphysics 5 Application Builder

The main COMSOL Desktop with the Application Builder window, which contains a tree with the model nodes and the nodes that define the application, and an Application ribbon toolbar with tools for creating applications.

- ✓ The Form Editor for creating and designing forms (user interfaces) with various form components (user interface controls) that are adapted for the application in mind.
- ✓ The Method Editor for creating and editing methods and classed for including custom code that can be connected to user interface events, for example.

Based on the simulation proposed and using Comsol Multiphycs 5 Application Builder interface we created a simple user-friendly application example.

A simple application example

In this simple example students can change the electrical current intensity and the voltage and see quickly the effects in terms of thermal heating. This way it becomes easier for them to understand the theoretical aspects of the problem and used also with some aspects of simulations, but without creating one. The application created for the simulation described in this paper is shown in Figure 74, bellow.

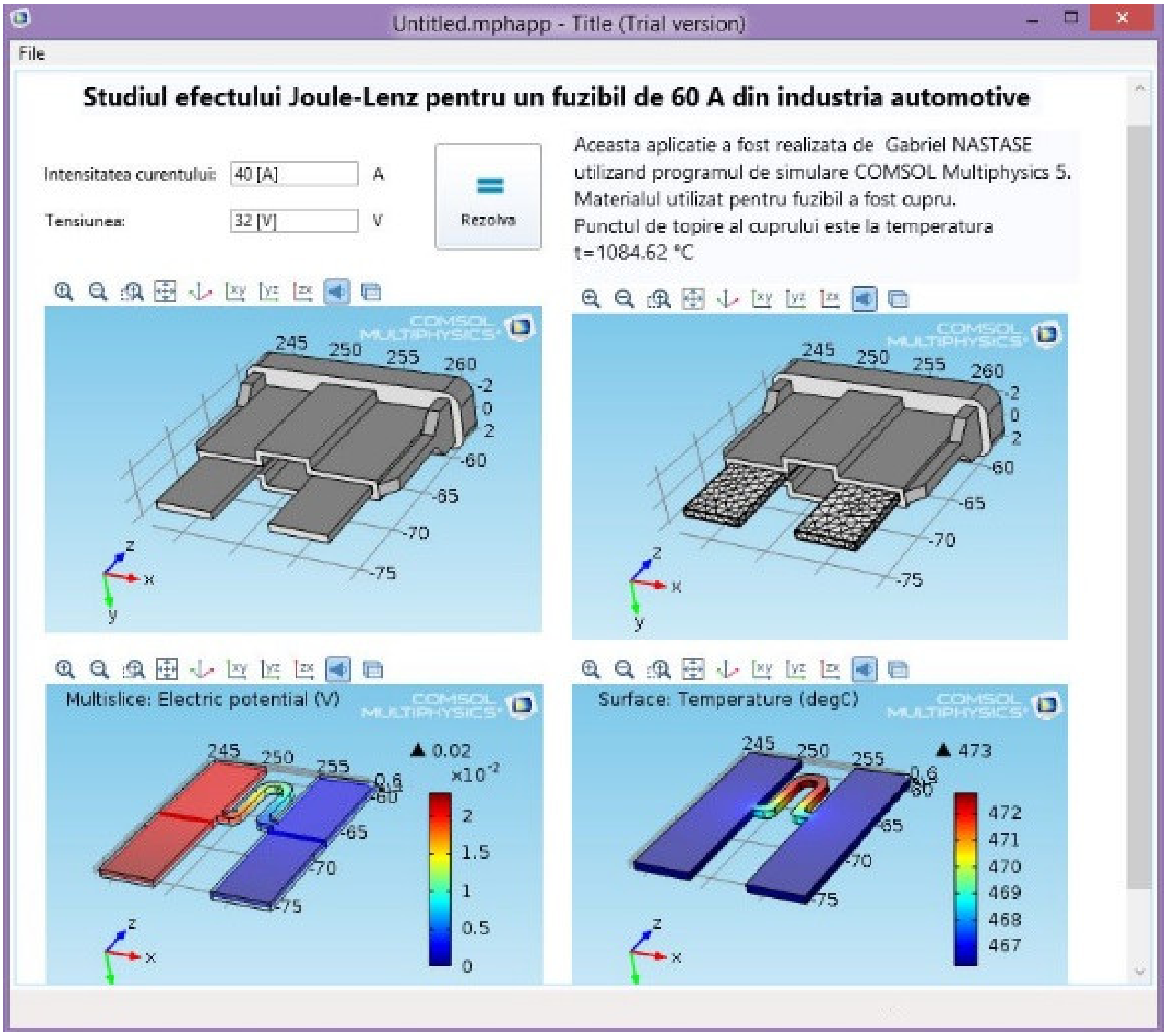

Figure 74. The Joule-Lenz application created using the simulation described

After the application is created it can be run by students from the COMSOL client for Windows® or through a web browser.

To get the most out of the Application Builder, consider these six logical steps:

- Consider what the application should include: parameters are of interest, outputs that a user would like to see, plots are useful, specific numerical results are important;
- Make a sketch of the user interface and its controls and objects, outlining what type of inputs, menus, buttons, plots, and so on that the application should include and making a layout of the form or forms in the application;
- Create a COMSOL model of the application, including the parameters that you want to use

as inputs in the applications and the derived values and plots that you want to use as the outputs and results when running the application;

- Use descriptions for all the parameters that you want to include in the application.
- Solve the COMSOL model, and consider what studies you want to include that the application should then run to produce the output that is of interest to the users;
- Save the COMSOL model as a Model MPH-file that you will then use as a starting point for the application.

Method Conclusions

In our current society, there is a dynamic process which requires all walks of life to keep up with the evolution of society and therefore education. The application of new learning methods require time, diversity of ideas, commitment to action, discovery of new values, teaching responsibility, confidence in personal ability to apply them creatively to streamline the educational process [248].

5. The evolution and development plans for career development (max. 25000 characters)

My professional activity takes place in the Department of Building Services, on the Faculty of Civil Engineering, at Transilvania University of Brasov.

The development of my future career in terms of research and academic activities covers the following subjects:

- Refrigeration;
- Cryogenics;
- Modern materials used in building services;
- Technical drawing and CAD design;
- Computer Programming;
- 3D printing;
- Study of vitrification;
- Isochoric systems;

In this academic career development proposal, I will present the stages I will go through, based on results so far.

The presentation contains the following parts:

1. Previous professional activity results;
2. Development of my academic career in terms of teaching and scientific research.

4.8. Previous professional activity results

Studies:

2002 – 2007 Licensed engineer – Transilvania University of Brașov – Specialty Building Services;

2007-2009 Master in Energy Modernization in Built Environment, Transilvania University of Brașov

2001 – 2004 PhD in Mechanical Engineering, Building Services Faculty, Technical University of Civil Engineering, Bucharest, Romania. PhD Thesis: “Contributions to the reductions of energy consumptions through the superior valorization of solar contributions”.

2016-2017 Postdoc Mechanical Engineering Department, University of California Berkeley, USA Specialization in the filed of isochoric preservation and 3D printing.

2016 European Course of Cryogenics. Germany, Poland and Norway, 3 weeks summer school

4.9. Professional and academic activity:

After graduating from the faculty, as a Building Sevices engineer, I worked in an execution firm for a year and a half, where I participated in cost estimation activities.

Since 2009, I also have the status of Authorized Physical Person for Building Services Design. As the PFA, the main activity is the design of sanitary, thermal, ventilation / air conditioning and fire-fighting installations for several types of buildings, ranging from dwelling houses to industrial halls. This aspect of the professional activity makes possible the continuous connection between the didactic / theoretical part and the practical part of the real life.

Representative works which I have been coordinated within the company, are presented in the table below:

Year	Objective	Client	Loction
2017	Extension of the 2016 product store and production hall for the automotive industry with over 6000 square meters. Design of outdoor networks, rainwater drainage on the roofs, fire extinguishers with interior hydrants, thermal installations and plumbings.	QUIN România	Brașov, România
2016	Product store and production hall for the automotive industry with over 6000 square meters. Design of outdoor networks, rainwater drainage on the roofs, fire extinguishers with interior	QUIN România	Brașov, România

	hydrants, external hydrants, thermal installations and plumbings.		
2015	Storage hall for automotive industry products 5000 square meters. Design of external networks, rainwater drainage on the roofs, fire extinguishers with interior hydrants, external hydrants and sprinkler systems, thermal installations.	QUIN România	Brașov, România
2014	Warehouse and production halls for the wood industry. Design of outdoor networks, rainwater drainage on the roofs, fire extinguishers with interior hydrants, external hydrants.	JF FURNIR România	Brașov, România
2013	Air conditioning systems in 2 industrial premises of SC QUIN Romania SRL. Water-cooled wall-mounted systems with chilled water.	QUIN România	Brașov, România
2012	Product store and production hall for the automotive industry with over 5000 square meters. Design of outdoor networks, rainwater drainage on the roofs, fire extinguishers with interior hydrants, external hydrants, thermal installations.	QUIN România	Brașov, România

By actively participating in these projects, I have accumulated extensive experience in the field of assembly technology, materials, equipment specific to each type of plant, which generated an impressive amount of information that could later be shared with students.

Since 2009 I have been employed by Transilvania University in Brasov as an Assistant at the Faculty of Civil Engineering, the Department of Building Services. Also since 2009, I have been enrolled in the Doctoral School, where I have completed a doctoral thesis in Mechanical

Engineering entitled " Contributions to the reductions of energy consumptions through the superior valorization of solar contributions". Within this doctoral thesis I developed on the faculty a double glass facade laboratory, equipped with various data acquisition systems.

In the Department of Building Services, over time I have taught seminars, laboratories, projects on the following subjects: Computer Programming, Computer Assisted Design, Technical and Infographic Design, Ventilation and Air Conditioning, Refrigeration, Technical Cryogenics, Thermal Networks, Modern Materials used in Building Services.

In my activity, I was preoccupied with the modernization of the content of the disciplines, the teaching methods and their implementation in practice.

The accumulated teaching experience led to the writing of three books:

- Alexandru ȘERBAN, Chiriac F., **Năstase G.** – Instalații Frigorifice – Aplicații și probleme rezolvate, Editura Agir, București, 2011, ISBN: 978-973-720-425-7, 217 pages [249];
- **Năstase G.**, ȘERBAN Alexandru - „Proiectarea 2D cu AutoCAD”, Editura Universității Transilvania din Brașov, 2012, ISBN: 978-606-19-0106-7, 177 pages [250];
- **Năstase G.**, ȘERBAN Alexandru - „Fațade duble de sticlă pentru clădiri de birouri. Studiu de caz Brasov”, Editura Napoca Star Cluj-Napoca, 2014, ISBN: 978-606-690-151-2, 203 pages [249];

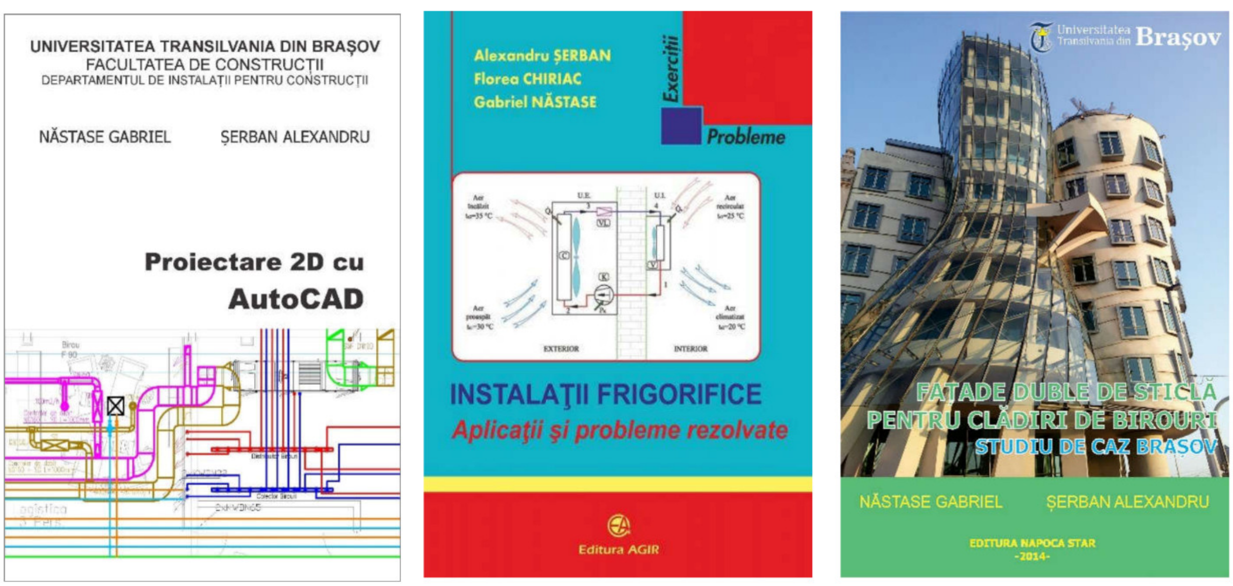

Figure 75. Teaching books

In parallel with the teaching activity presented briefly above, I participated in the design, acquisition of equipment, installation and commissioning of teaching stands and research facilities for students, master students and doctoral students. Thus, these contributions led to the realization of a didactic and research laboratory for Refrigeration Installations and Cryogenics, a Heat Pump Laboratory, a 3D Printing laboratory and a Double Skin Façade Laboratory, all representative for the Department of Building Services from the Transylvania University of Brasov.

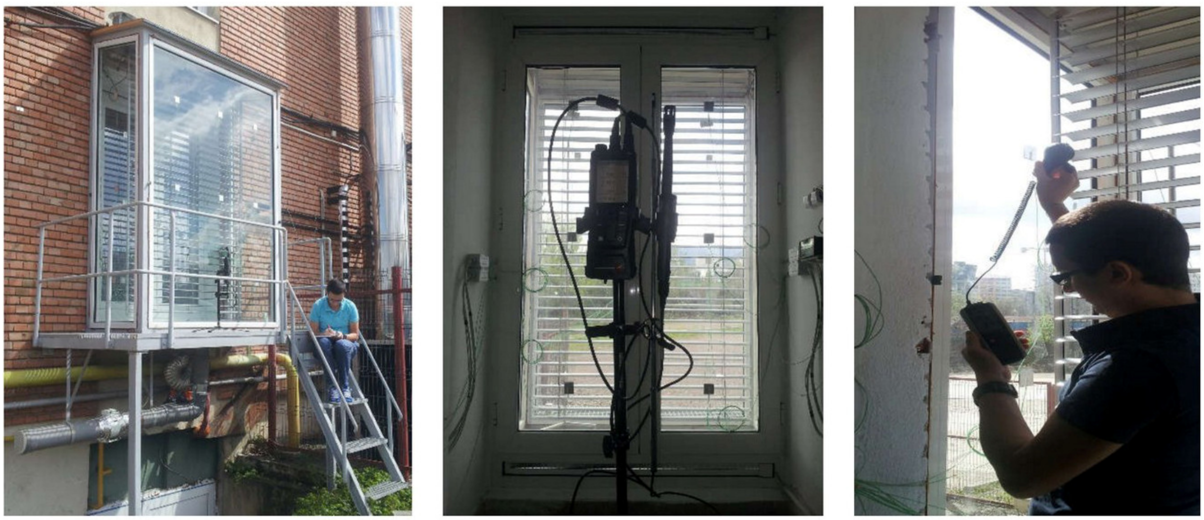

Figure 76. Box window double-skin façade laboratory

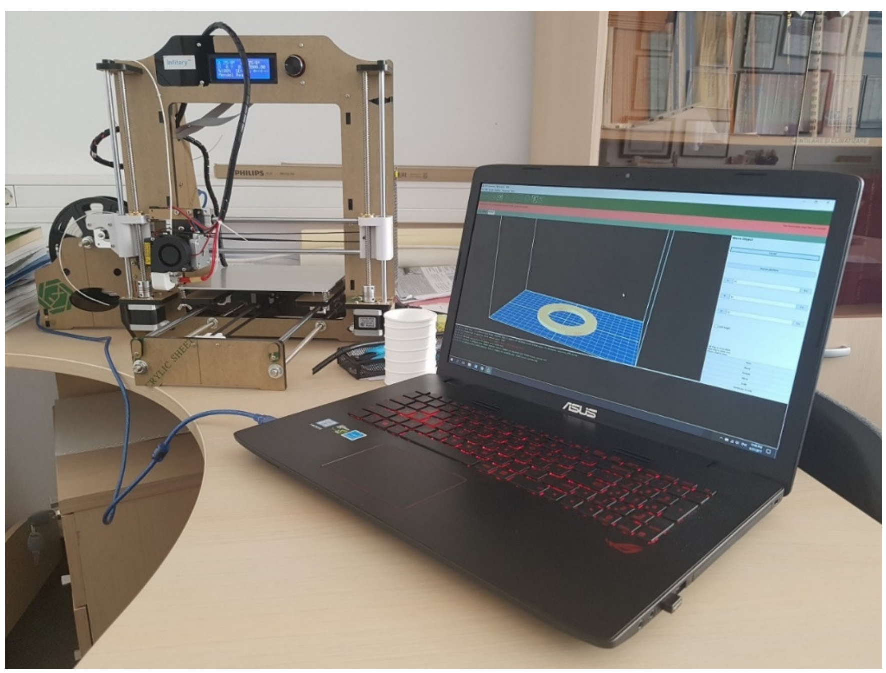

Figure 77. 3D Printing Laboratory at Building Services Department, Faculty of Civil Engineering, Brașov, Romania

Following the experience in writing articles published in journals with impact factor I have contributed to a practical guide for master and doctoral students, through which they can discover writing techniques and can also learn writing articles in LaTeX. Publication of an article in a journal with impact factor is a great satisfaction, especially as a student.

Using my engineer expertise in tabular calculations I wrote together with my friend and colleague, Prof. Maximilian Ionescu a practical book for students to be used as a support for the Computer Programing laboratory. The book has two main chapters, the first written by me, is about Excel as a calculations instrument and the second chapter written by the Prof. Ionescu Maximilian is about MathCAD.

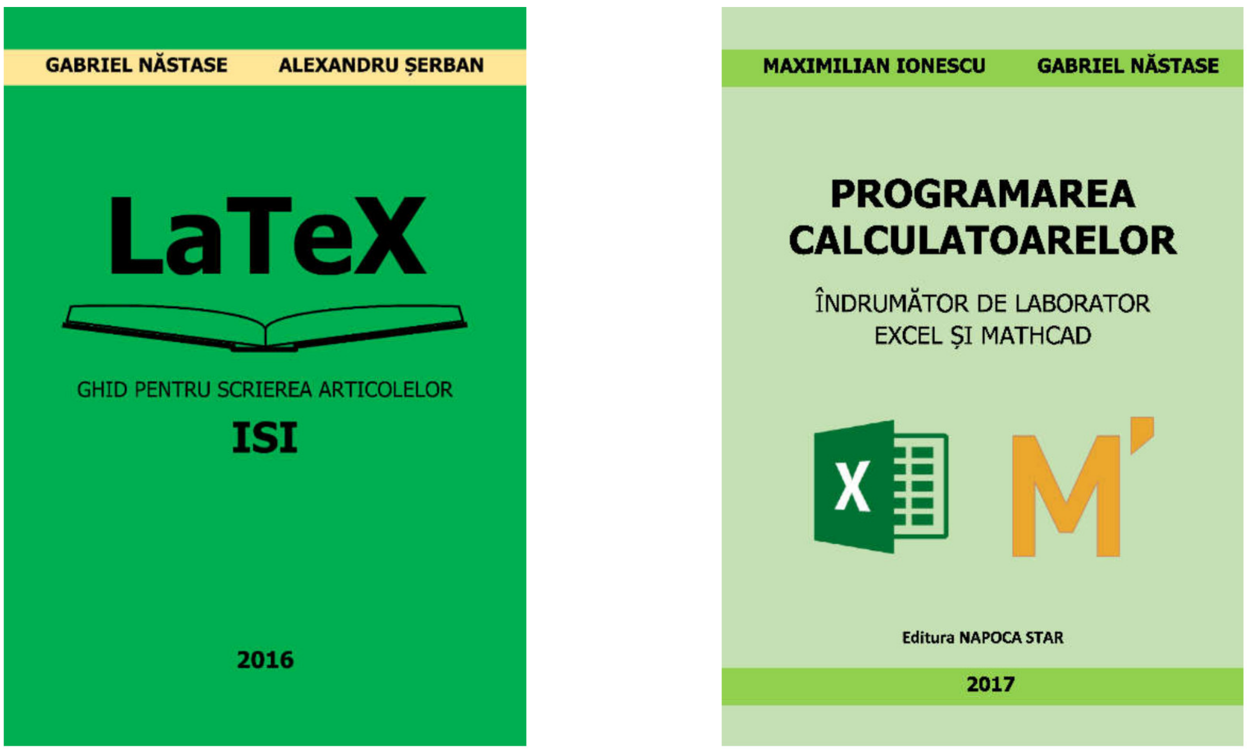

Figure 78. Latex guide, for writing impact factor article [251] (left) and the Computer Programming book [252] (right)

In 2016, together with other three coleagues we developed a Design Guide for Heating Plants [253] (Figure 79), which can be used by students, coleagues or any other Building Serivces Designer, interested in heating plants.

Figure 79. Heating Plants Design Guide

4.10. Research activity

My past research activity was related mostly to my interest in renewable energy, use of alternative system for energy efficiency in buildings, refrigeration and cryogenics. This research activities have been made in Building Services Department, at Transilvania Iniversity of Brasov, between 2009 to present.

Between September 1, 2016 and 1st of June 2017 I had a postdoctoral scholar appointment in University of California, Berkeley, USA.

In my postdoc appointment at UC Berkeley, USA, I expanded my research activity with subjects related to bioengineering and mechanical engineering. Of course, while in USA, my refrigeration and cryogenics knowledge were very useful in the new research activities I discovered.

Bioengineering is a filed which can be defined as the application of engineering principles on biological systems. This filed more precisely is developing new and performant medical instruments, systems or tools by using engineering knowledge from various fields, like mechanical, electrical or chemical.

Mechanical engineering is a domain that uses design, manufacture, materials, engineering, phisycs and some other disciplines to build mechanical systems. In many universities Building Services is part of the Mechanical Engineering Faculty but in some universities, like in ours this specialization is part of the Civil Engineering Faculty.

Figure 80. My Postdoc ID in UC Berkeley and some pictures with me in Prof. Rubinsky's Lab at Mechanical Engineering Department

4.10.1. Works in the field of Refrigeration and Cryogenics

Together with other coleagues I published more than 15 papers in the field of Refrigeration and Cryogenics. The subjects treated in the papers, range form mini-channels heat exchangers, absoption and adsorption systems, to modern Air Separation Plant components. Most of the papers in this chategory were published in national and international conference books.

My next approach in this field will be concentrated on:

- Research of different wood materials compatible with cold environments;
- Use of natural refrigerants in small capacity mechanical compression refrigeration systems;
- Design of new small capacity compressors;
- Use of renewable energy to drive refrigeration systems;
- Optimeze geothermal heat pump systems;
- Role of cooling in superconductivity;

- Use of cryogenic fluids in 3D printing and bioengineering.

4.10.2. Works in the filed of 3D Printing

I worked on this subject for more than 5 months in my postdoc appointment in Berkley, which was too little time to conclude my results in a paper.

Now I already have bought a 3D printer in my lab at Transilvania University of Brasov and the next step is to continue my research activity from here, based on the knowledge I already have from USA.

My next approach in this field will be concentrated on:

- Desiging a surface 3D printer for large tissues;
- 3D printing of food;
- 3D printing of materials used in buildings;
- Optimization of 3D printer heads and injection systems.

4.10.3. Work in the field of Bioengineering and Isochoric Systems

Bioengineering and Isochoric System is another field that can be explored in the future, because of my interest in developing techniques and systems for medical purposes. For this, I will consider collaboration with various Bioengineering Faculties in Romania and outside Romania, and together maybe we can make a Department of Bioengineering in Brasov.

Meanwhile, I will continue working on thermodynamic profiling of various CPA in ischoric systems and the behavior of food and microorganisms in isochoric systems.

4.10.4. Works in field of Renewable Energy and Energy Efficiency in Buildings

In this field, I finished my PhD and I already published a few relevant papers, in journals that have impact factors ranging from 3 to almost 7. I can mention here:

- G. Dragomir, A. Șerban, **G. Năstase**, and A. I. Brezeanu, "Wind energy in Romania: A review from 2009 to 2016," Renew. Sustain. Energy Rev., vol. 64, pp. 129–143, 2016, ISSN: 1364-0321.
- **G. Năstase**, A. Şerban, G. Dragomir, S. Bolocan, and A. I. Brezeanu, "Box window double skin façade. Steady state heat transfer model proposal for energetic audits," Energy Build., vol. 112, pp. 12–20, Jan. 2016, ISSN: 0378-7788

- **G. Năstase**, A. Șerban, A. F. Năstase, G. Dragomir, A. I. Brezeanu and N. Ioardan, “Hydropower development in Romania. A review from its beginning to the present”, Renew. Sustain. Energy Rev., vol

My future interest is related to energy efficiency optimization, intense renewable energy use and large-scale use of recycled materials.

4.11. My future academic career development, in terms of teaching and scientific research

4.11.1. Diversification of curricula and methods of transmitting knowledge

I propose that disciplines "Refrigeration" and "Cryogenics" include knowledge and numerous applications, topical, related to the profession of building services engineer, such as:

- Air conditioning plant provided with efficient refrigeration systems powered by renewable energy sources (solar, geothermal), with environmentally sound refrigerants;
- Refrigerators for cooling the massive concrete construction;
- Refrigerators for freezing soil for underground construction;
- Installation of heat pumps for efficient and environmentally friendly heating systems for greenhouses;
- Presentation of small and medium refrigeration systems for residential and commercial consumers, efficient and environmentally friendly;

4.11.2. Refrigeration

This course aims at general knowledge, understanding concepts, theories and basic methods of refrigeration; development of professional projects using established principles and methods in the field of refrigeration. Ensure discipline to prepare students to design, build and operation of refrigeration systems used in the built environment. The specific objectives of the course refrigeration are: the understanding of issues related to heat transfer in refrigeration; knowledge of general aspects related to cycles of operation of various types of refrigeration systems (mechanical vapor compression, absorption, etc.); knowledge of the operating principle of refrigeration; understanding the phenomena that occur in various types of refrigerators, as applicable; understanding the phenomena that occur in displacement compressors, rotary.

During refrigeration applications of artificial cold treats and climate in the areas of air, heat pumps, artificial ice rinks, cooling concrete for massive structures and methods of freezing ground. In this way the course is also a starting point for other courses taught in the department, such as "Ventilation and air conditioning", "Heat pumps".

4.11.3. Technical Cryogenics

This course was born from the desire to raise the level of knowledge, to present innovative technologies and materials in the industrial installations.

The course of Cryogenics Engineering is to train students and provide them with knowledge of technical, on the theoretical basis for obtaining very low temperatures, up to about 4K, information related to components and the main types of equipment used cooling, liquefying and gas separation. By rich material presented in this course, the numerous descriptions of various equipment allow students to become familiar with the operation, selection, calculation and dimensioning of the various components or auxiliary equipment cryogenic installations.

All these issues make a positive contribution to students' awareness of proper training, research opens new horizons side, placing the current trends in technological developments.

4.11.4. Teaching career and educational development

For this scope I propose:

- ✓ To diversify the way of presentation and transfer of scientific information based on interactive systems. In this regard, I will continue to expand interactive teaching platform for the discipline "Refrigeration" and "Cryogenics".
- ✓ Continuous upgrade and completion of specialized laboratories and modernization, while ensuring appropriate softwares; in the laboratory works will be presented actual cases encountered in gas separation technique used in high-vacuum thermal insulation, ways to assess the status of building energy and possibilities of reducing primary energy consumption;
- ✓ Making internships at prestigious universities abroad, in order to exchange experience for the benefit of staff, students and the entire staff specialists;

- ✓ Publication of courses, to facilitate access to specialized information to students. In this regard, I propose that the courses provide both the basics of discipline, connection with other specialties and a range of new data from my research and collective, in journals, lecturing and congresses;
- ✓ To encourage students to participate in scientific research, opening them new opportunities to take part in conferences, agreements and collaborations, to specialize doctoral, all designed to broaden their technical and specialized information;
- ✓ To participate alongside colleagues from the Department to realization of projects of national and European importance, supporting teamwork and collectively forming a stable and self-assertive;
- ✓ Students from Bachelor, Master - will be offered follow graduation complex themes, which are contained in refrigeration, heat pumps, cryogenic. Since the Refrigeration and Cryogenics disciplines present a higher degree of difficulty, we follow braiding applications theoretical and practical lessons with visits to the sites.

4.11.5. Research development

Developing research will be oriented in the following directions:

- ✓ Energy preservation in buildings and buildings services;
- ✓ Increase of Environment Protection and Safety for People;
- ✓ Low installation costs and efficient use of space for installation.

To this end will take place the following research:

- Further research within the field of absorption and adsorption refrigeration type using Renewable-Energy, Solar Cooling, Refrigeration systems operated bivalent energy systems (solar and conventional energy);
- Further research in the field of small and medium cold systems with compact (changing microchannel, minicanale, plates, efficient compressors), driven by non-conventional energy.
- Cold Laboratory will develop, allowing research both heat exchangers in the refrigeration and heat pump equipment and systems mentioned above.

- For research in the field of cryogenics, we achieve a testing laboratory materials and equipment construction and installation schemes to extremely low temperatures and variable.
- Participation in National Research Projects through thorough knowledge of the methodology and their requirements.
- Promotional activity and attract a greater number of students in research teams, following both their material stimulation and exploitation of knowledge gained by them in drafting graduation.

The development of scientific research will involve more active in the following areas:

- ✓ attending University and Department effort to modernize and upgrade the material with systems and equipment allowing high finesse research and experimentation;
- ✓ forming a united team with a high readiness, able to achieve high-level scientific results;
- ✓ publishing scientific articles in journals with international recognition in the field;
- ✓ presentation of research findings at conferences and scientific meetings in the country and abroad to raise awareness of refrigeration and cryogenic school in Romania;
- ✓ and to enable participation in national and international research networks;
- ✓ publication of books / chapters specialized in printed works belonging to internationally recognized publishers;

I am certain that these ideas and objectives regarding the development of my academic career will contribute to strengthen the position of Transilvania University of Brasov, in the hierarchy of prestigious national universities, and increasing reputation among students, on providing a solid education.

Raising standards of academic excellence will be constantly pursued and promoted in the great family of our university: students, teachers, researchers and support staff, actively involved me all initiatives to increase the importance and visibility of the University staff.

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7. List of Figures

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