Kielce University
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Instytut Maszyn
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Vilnius Gediminas
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VII International
Scientific-Technical Conference

Book of abstracts

ACTUAL PROBLEMS OF RENEWABLE ENERGY, CONSTRUCTION AND ENVIRONMENTAL ENGINEERING

14-16 December 2023, Kielce
(Poland, Ukraine, Lithuania)

The time and place of the meeting: 14-16 December 2023
Faculty of Environmental Engineering, Geomatics
and Renewable Energy
Kielce University of Technology, Poland
al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce

Beginning of conference: 14 December 2023 in 10:00
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Conference languages: Polish, English, Ukrainian

Conference Chairs

Hanna Koshlak
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Anatoliy Pavlenko
Department of Building Physics and Renewable Energy
Kielce University of Technology

KIELCE 2023

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Partners Conference:
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Vilnius Gediminas Technical University (Lithuania)
Institute of fluid-flow machinery of the Polish Academy of Sciences (Poland)

Scientific and organizing committee of the conference:
Co-organizers (Scientific committee):

Prof. doctor of science ANATOLIY PAVLENKO – Head of Department of Building Physics and Renewable Energy, Kielce University of Technology (Poland)

Prof. doctor of science VIOLETA MOTUZIENĖ – Vilnius Gediminas Technical University (Lithuania)

Prof. doctor of science HANNA KOSHLAK – Department of Sanitary Engineering, Kielce University of Technology (Poland)

Prof. doctor of science, Corresponding Member of NAS of Ukraine BORYS BASOK – Head of Department "Thermophysical Basics of Energy-Saving Technologies" Institute of Engineering Thermophysics National Academy of Sciences of Ukraine (Ukraine)

Prof. doctor of science ROBERT MATYSKO – Head of the Laboratory of the Heat Processes Control Systems Institute of Fluid-Flow Machinery of the Polish Academy of Sciences (Poland)

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FRAMEWORK PROGRAM

FIRST DAY – 14 December 2023

Registration of participants

SECOND DAY – 15 December 2023

11^{00}–11^{40}

GREETING INTRODUCTION AT THE CONFERENCE

Kielce University of Technology
Prof. **Hanna Koshlak** – Development of renewable energy source in Poland
Chairman of the Scientific Committee of the Conference

Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine
Prof. **Borys Basok** – Hydrogen energy: “pro” and “contra”

Vilnius Gediminas Technical University, Lithuania
Prof. **Violeta Motuzienė** – EU taxonomy – implementation of the requirements for building

12^{00}–14^{00}

Session I: ADVANCES IN ENERGY EFFICIENT BUILDINGS

Moderator *Borys Davydenko*

12^{00}–12^{20} **Ihor Bozhko** – Analysis of the energy parameters of the heat pump heat supply system of energy efficient building

12^{25}–12^{45} **Natalia Siwczuk** – Investigation of thermal comfort, productivity and lighting at polish university buildings (video presentations)

12^{45}–13^{00} Questions to the speakers and their answers

13^{00}–14^{15}

Session II: LATEST RESEARCH OF BUILDING HEAT AND MASS TRANSFER

Moderator *Borys Davydenko*

13^{00}–13^{20} **Borys Davydenko** – Application of a combination of two double-chamber windows to increase the heat transfer resistance of window structures

13^{20}–13^{40} **Maryna Moroz** – Experimental research of heat transfer through heat-insulated wall enclosure structures

13^{40}–14^{00} **Sylwia Wciślik** – Influence of the heating surface geometry on the droplets evaporation under leidenfrost conditions

14^{00}–14^{15} Questions to the speakers and their answers

12^{00}–14^{00}

Session III: BUILDING PERFORMANCE SIMULATION, ENERGY EFFICIENCY AND RENEWABLE ENERGY RESOURCES FOR BUILDINGS

Moderator *Violeta Motuzienė*

12^{00}–12^{20} **Łukasz J. Orman** – Comparative analysis of thermal insulation properties of polish single family homes

12^{25}–12^{45} **Luiza Dębska** – Performance of the heat pump and photovoltaic systems installed in the polish house (video presentations)

12^{50}–13^{10} **Dalia Mohammed Talat Ebrahim Ali** – AI applications in buildings: a review of energy management advancements

13^{15}–13^{35} **Katarzyna Stokowiec** – The effect of the temperature increase on heat demand calculation for building in the polish climatology

13^{40}–13^{55} Questions to the speakers and their answers

12^{00}–14^{00}

Session IV: GREEN TECHNOLOGIES IN ENVIRONMENT AND ENERGY

Moderator *Hanna Koshlak*

12^{00}–12^{20} **Marta Zegarek** – Renewable energy sources: support mechanisms, benefits, and barriers for prosumers and private investors

12^{25}–12^{45} **Paweł Lesiak** – Review of methods for conversion of biomass to biofuels

12^{50}–13^{10} **Robert Matysko** – Computational analysis of electric field effects on electrodialysis for enhanced desalination processes

13^{10}–13^{30} **Violeta Misevičiūtė** – Multi-criteria evaluation of technological solutions to improve gas distribution station efficiency

13^{35}–13^{50} Questions to the speakers and their answers

14^{20}–14^{40}

SUMMARY OF THE SECOND DAY CONFERENCE

THIRD DAY – 16 December 2023

10^{00}–10^{30}

SUMMARY AND CLOSING OF THE VII INTERNATIONAL SCIENTIFIC-TECHNICAL CONFERENCE *ACTUAL PROBLEMS OF RENEWABLE ENERGY, CONSTRUCTION AND ENVIRONMENTAL ENGINEERING*

Anatoliy Pavlenko – Head of Department of Building Physics and Renewable Energy, Kielce University of Technology, Poland.
Scientific direction of work – thermophysics of dispersed media.
Scientific interest – mathematical modeling of thermophysical processes occurring in liquids in the metastable state.

Dear Colleagues,

I cordially greet all participants of our 6th international conference.

For seven years now our Conference traditionally consolidates all those best scientific ideas, that authors present in their speeches.

All these years we examines the questions and problems of modern power engineering, energy technology of power-consuming industry branches, alternative sources of energy, resource conservation, questions of modeling the process of industrial equipment, processes and equipment of various branches of industry, questions of automated control systems and information processing, heat-and mass-exchanging processes and equipment of special technique, questions and problems of electricity and power control.

I see these directions also in the submitted works this year.

Unfortunately, the restrictions associated with the coronavirus did not allow us to traditionally meet for discussion. I think that next year we will be able to do this at our university.

I wish everyone good health and new creative achievements.

Conference Chair
Anatoliy Pavlenko

Violeta Motuzienė – professor at Vilnius Gediminas Technical University, Department of Building Energetics, Lithuania.

Scientific interests – buildings energy efficiency and sustainability, life cycle analysis, indoor environment, ventilation, occupants' behaviour.

Dear participants of the Conference,

It is my pleasure to join this conference as a member of scientific and organizing committee for the first time and welcome you at the conference. In the context of the growing climate change and global energy crisis many countries are facing with great challenges. A transition to clean energy requires moving faster than what we are capable of doing now. Here research can decisively support the energy transition through appropriate transformations and suggest effective pathways to turn polluting global energy systems into zero-emission systems by developing RES solutions. I believe the researches presented at the conference and discussions will have added value into solving above mentioned problems both at regional or global level.

I hope that you will enjoy the conference and wish you all the fruitful discussions at separate sections.

Borys Basok – professor, doctor of science, Corresponding Member of NAS of Ukraine.

Head of Department "Thermophysical Basics of Energy-Saving Technologies" Institute of Engineering Thermophysics National Academy of Sciences of Ukraine.

Dear colleagues!

Dear conference participants!

We are very grateful for the invitation and the opportunity to participate in your conference.

It is a great honor for us and the opportunity to share with you our scientific and engineering achievements.

On my behalf, I wish the participants of the conference fruitful work, the exchange of interesting scientific achievements, the establishment of new creative contacts, as well as power and inspiration to realize them.

Separately, heartfelt and sincere gratitude to the Polish people and the leadership of the Republic of Poland for the great help to Ukraine.

Hanna Koshlak – professor at Kielce University of Technology. Scientific interests: engineering and environmental protection, environmental engineering, energy.

Ladies and Gentleman,

Welcome you all to the VIIth International scientific-technical conference "Actual problems of renewable energy, construction and environmental engineering".

This is the third year we have held our annual event in a hybrid format, without the physical presence of participants. But this year I speak to you in a much more positive context, both in terms of the renewable energy situation and the economic outlook for the near future.

A glance through the list of presentations planned for the next few days reveals the amazing diversity of these applications.

These range from the latest research in the field of heat and mass transfer in buildings to the developing of new technologies for membrane wastewater treatment, improving the efficiency of gas distribution stations and research on thermal comfort in public buildings.

Conferences such as this provide a valuable opportunity for research scientists to share experiences. I am sure you will have fruitful and rewarding exchanges iviews over the next few hours. I wish you every success with this important conference and I look forward to learning about the outcome.

Table of Contents

ANALYSIS OF THE ENERGY PARAMETERS OF THE HEAT PUMP HEAT SUPPLY SYSTEM OF ENERGY EFFICIENT BUILDING

***Borys Basok*[1]*, Oleksandr Nedbailo*[1]*, Ihor Bozhko*[1]*, Volodymyr Marteniuk*[2]**

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In order to further increase the energy efficiency of the experimental building, field experiments were conducted to maintain the proper thermal regime of its premises when using a heat pump heating system. The paper presents the results of experimental studies of the operating parameters of the heat pump heat supply system of an energy-efficient building of the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine. The given analysis of the energy efficiency of the operation of the “soil-water” type heat pump in the nominal mode with the maximum load showed a high value of the energy conversion coefficient.

The main aim of the article is to demonstrate the possibility of integration of the energy-efficient heat pump heat supply system into new construction sites and during thermal modernization of existing buildings of various types and purposes.

The energy-efficient building is a three-story building with a basement located on the territory of the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine in Kyiv with a heating area of 306 m^2 and an estimated specific energy consumption for heating and hot water supply of approximately 14.8 kWh/(m^2·year). At the same time, the heat pump has a capacity of 6.1 kW.

The soil circuit consists of a horizontal soil heat exchanger – a group of multi-pass and coil heat exchangers connected in parallel, made of polyethylene pipes 40 × 3.2 mm and 32 × 2 mm, located next to the house at a depth of 2.2 m. The site of their location has a surface area of about 180 m^2. The heat carrier in the soil circuit is a 30% aqueous solution of propylene glycol.

The intermediate circuit is made of a polypropylene pipe 40 × 6.7 mm filled with treated water. The tank-accumulator is designed for hydraulic decoupling of circuits of heat sources and consumers. It is a heat-insulated cylindrical container with a volume of 300 liters with coil heat exchangers inside.

The heating circuit consists of a set of heating devices connected in parallel, which includes water-heated floors of various configurations (including the so-called capillary floor heating device), coils in the walls of the house, as well as water-air heating devices (fan coils). The heat carrier used is prepared water.

The circulation of heat carrier in each of the above-described circuits is made by pumps with the possibility of adjusting their pressure-flow characteristics. Hourly measurements during the day in each of the circuits of the amount of heat, the volume of the heat carrier, as well as its temperature values in the supply and return pipelines were carried out by Sharky 773 heat meters (optionally every 10 minutes). For further analysis, recalculation of thermal power and volume flow was carried out, taking into account the dependence of the thermophysical properties of the heat carrier on changes in its temperature.

The values of the heat carrier parameters in each of the circuits in one of the operating modes (nominal heat load) are shown below.

The calculation of the coefficient of heat transformation of the heat pump (COP – Coefficient of Performance) in the mode of its constant full load based on the balance of the amount of transferred heat:

$$\text{COP} = Q_1/(Q_1 - Q_2) = 5.90 / (5.90 - 4.42) = 3.98$$

where: Q_1 – the average daily value of the thermal power of the heat pump-tank circuit, kW; Q_2 – the average daily value of thermal power of the geothermal circuit, kW.

At the same time, by definition, based on the law of energy preservation:

$$\mathrm{COP} = Q_1/N = 5.90 / 1.66 = 3.55$$

where: N – the total average daily electric power consumption by the heat pump, kW.

The amount of electricity consumed by the heat pump and circulation pumps was measured using an electric power inverter with its own meter.

A short analysis of the operation of the heat pump in the nominal mode showed its high energy efficiency due to its use as a source of low-potential heat of the soil massif, and as consumers – low-temperature heating systems.

Conclusion

A short analysis of the operation of the heat pump in the nominal mode showed its high energy efficiency due to its use as a source of low-potential heat of the soil massif, and as consumers – low-temperature heating systems.

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APPLICATION OF A COMBINATION OF TWO DOUBLE-CHAMBER WINDOWS TO INCREASE THE HEAT TRANSFER RESISTANCE OF WINDOW STRUCTURES

***Borys Basok*[1]*, Borys Davydenko*[1]*, Volodymyr Novikov*[1]**
***Svitlana Goncharuk*[1]*, Anatoliy Pavlenko*[2]**

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Typically, window structures have lower heat transfer resistance than walls, for which heat-insulating coatings are used to increase this resistance. Well-known methods of increasing the heat transfer resistance of windows are the use of low-emission coatings on the internal surfaces of glass, replacing the air medium in the area between glass surfaces with inert gases that have lower thermal conductivity than air, increasing the number of chambers in windows, etc. When using a double-chamber window with a width of 32 mm instead of a single-chamber window with the same width, the heat transfer resistance of the window structure increases by 1.7 times [1], even without the use of low-emission coating and without replacing the air in the chambers of the window with inert gases.

Replacing a double-chamber window with a three-chamber one can significantly increase heat transfer resistance, that is, increasing the number of chambers in windows unit increases its heat transfer resistance. But the manufacture and installation of windows with a large number of chambers is associated with certain difficulties. Therefore, in practice, three-chamber windows are used less frequently than double-chamber windows, and windows with more than 3 chambers are almost never produced. It is also possible to solve the problem of increasing the heat transfer resistance of windows by combining two double-chamber glass units, which are sequentially installed in the window frame. Numerical studies of this process are carried out in order to determine the characteristics of heat transfer through two double-chamber glass units and heat transfer resistance through such a structure.

Numerical studies of heat transfer through two double-chamber windows, the distance between which is equal to Δ, are carried out by finite-difference solving of a system of equations for the dynamics of the air medium in the chambers of a double-chamber window and in the space between the double-chamber windows, as well as heat transfer equations in a gaseous medium and glass. Air flow due to natural convection is considered laminar. Temperature values are set on the outer surface of the outer glass unit and the inner surface of the inner glass unit (conditions of the first kind). On all other vertical glass surfaces, boundary conditions of the fourth kind are specified, taking into account radiation-convection heat transfer on these surfaces. At the top and bottom surfaces of windows thermal insulation conditions are set. As a result of the numerical solution of the system of equations with these boundary conditions, the air velocity fields in the chambers of the windows and in the space between the windows, as well as the temperature fields in the gaseous medium and glass, are determined. The influence of the distance between double-chamber windows on the heat transfer characteristics of this system is investigated.

Heat transfer through a double window system is considered using the example of two double-chamber windows without low-emissivity coating. Each double-chamber window has dimensions: height H = 0.72 m; width L = 0.94 m and thickness 0.032 m. A double-chamber window consists of three glasses with a thickness of δ_g = 4 mm and two air layers δ_a = 10 mm. Emissivity of all surfaces is ε = 0.89. Thermal conductivity of glass is λ_g = 0.74 W/(m·K). Numerical studies are carried out under boundary conditions of the first kind. The temperature on the outer surface of the outer glass unit is $t_{out} = -5.0°C$, and the temperature of the inner surface of the inner glass unit is $t_{in} = +15.0°C$. The heat transfer problem is solved for three different distances between double-chamber windows: $\Delta = 32$ mm; $\Delta = 56$ mm and $\Delta = 80$ mm. The problem is solved in a two-dimensional formulation in a vertical section of the window structure, perpendicular to the glass surfaces and passing through the middle of the glass unit.

The distributions of velocity of free-convection flow and temperature in the middle part of a system of two double-chamber windows at $\Delta = 80$ mm are presented in Figure 1.

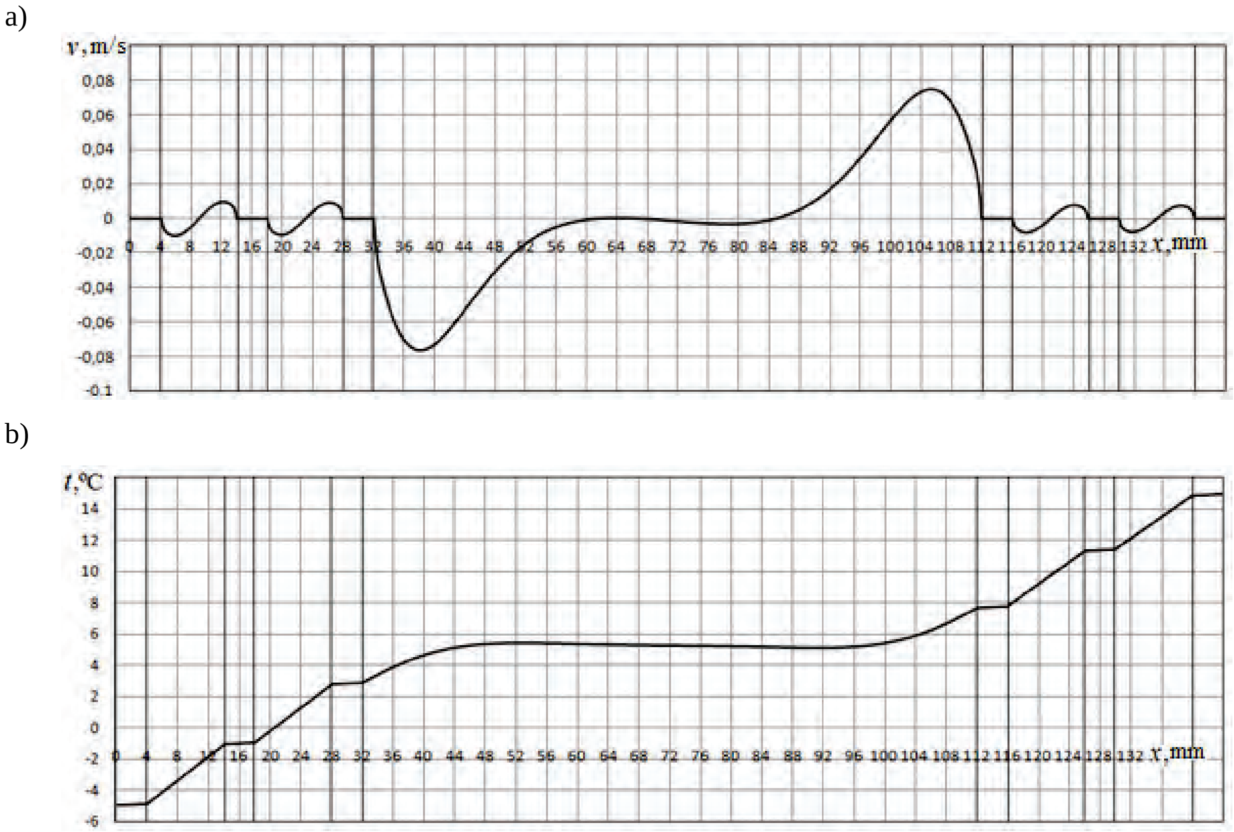

Figure 1. *Distribution of vertical air velocity (a) and temperature (b) along the thickness of a system of two double-chamber windows at Δ = 80 mm*

Based on the results of numerical modeling, the heat transfer resistance of individual double-chamber windows and the entire system as a whole were determined. The dependence of the heat transfer resistance of the gap between the windows R_g on the distances between the double-chamber windows and the heat transfer resistance of system as a whole is shown in Figure 2.

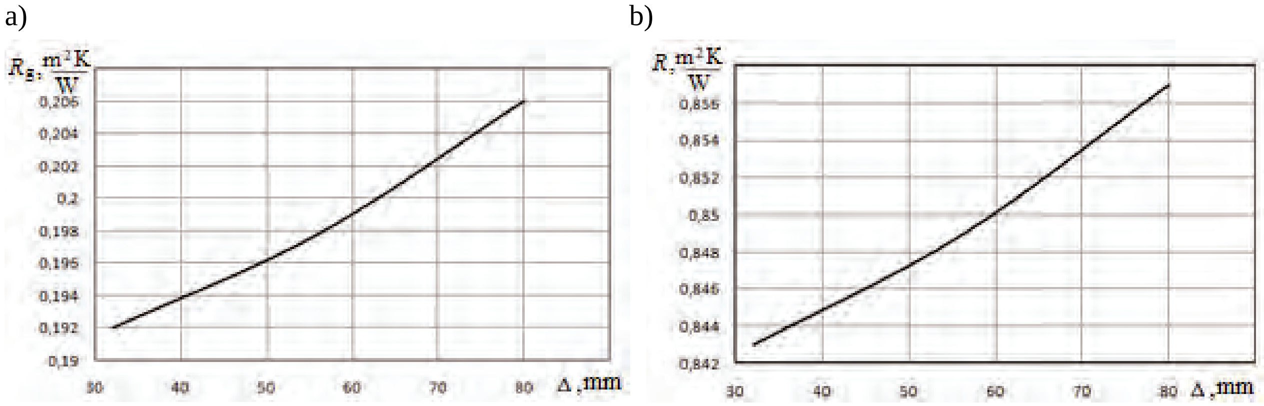

Figure 2. *Dependence of the heat transfer resistance of the air gap between the windows (a) and the entire system as a whole (b) on the distances Δ between the windows*

Conclusion

A system of two double-chamber windows located at a distance Δ from each other makes it possible to increase the heat transfer resistance relative to one double-chamber window without coatings from 0.31, ..., 0.33 m^2K/W to 0.843, ..., 0.857 m^2K/W, i.e. 2.6, ..., 2.75 times. The heat transfer resistance of a system of two double-chamber windows increases with increasing distance Δ between them. But this increase is insignificant. With an increase in Δ from 32 mm to 80 mm, the total heat flux decreases by 1.65%, and the heat transfer resistance coefficient accordingly increases by 1.66%.

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EXPERIMENTAL RESEARCH OF HEAT TRANSFER THROUGH HEAT-INSULATED WALL ENCLOSURE STRUCTURES

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Introduction

The introduction of energy efficiency requirements into the legislative framework is one of the instruments of influence on the reduction of energy dependence for the state. The modern direction of Ukraine's development leads to the need to adapt the current legislative and regulatory framework to the European one, as well as to the need to develop new standards in the field of energy efficiency of the building stock, including the quality of the microclimate in buildings. The main way to bring the thermal insulation envelope of buildings up to standards are measures of complete or partial thermal modernization [1], namely thermal renovation of enclosing structures, the main measures of which are the replacement of window structures and the installation of an additional layer of thermal insulation on the external walls.

The literature review shows that heat transfer through enclosing structures is a hot topic in the construction industry, and research in this direction continues to ensure a sustainable and efficient operation of the construction sector. The use of experimental and theoretical research makes it possible to obtain comprehensive information about the thermal properties of enclosing structures and their influence on the energy efficiency of buildings. An important, little-studied factor in the choice of thermal insulation and the design of the building's thermal envelope is the change in the thermophysical characteristics of thermal insulation materials during long-term operation during the life of the building itself [2].

The purpose of the study is to analyze the results of experimental studies of heat transfer through heat-insulating wall-enclosing constructions of the building of building No. 1 of the Institute of Technical Thermophysics of the NAS of Ukraine in real climatic conditions of long-term operation in real climatic conditions of long-term operation.

Results

The defining thermophysical characteristic of thermal insulation materials is its coefficient of thermal conductivity, which actually determines the reduced resistance of heat transfer through the enclosing structure. To determine the thermal technical characteristics of each of the options for thermal renovation measures, a system of measuring the temperature and density of the heat flow is used on different areas of the surfaces of the enclosing structures by installing heat flow converters with built-in platinum and copper resistance thermometers [3]. To prevent exposure to solar radiation, experimental data obtained at night are used for calculations.

The obtained array of experimental data makes it possible to carry out a comparative analysis of the air temperature in the middle of the premises and to monitor the time dependence of the temperature characteristics of the premises and the wall structure with different insulation. Also, a comparative analysis of the actual thermal conductivity coefficients, which were calculated based on the data of the last 6 years, was carried out.

Conclusions

From the results of experimental studies, it follows that an additional layer of insulation on the outer surface of the supporting wall structure contributes both to an increase in the temperature of this surface and to a decrease in the range of its fluctuations with a significant change in the ambient temperature. During long-term operation, heat-insulating materials are constantly exposed to seasonal temperature cyclical effects, and are in a somewhat moistened state, which leads to deterioration of the thermophysical characteristics of the materials.

Also, the given results show that the thermal conductivity coefficient increases during operation and should be taken into account during engineering calculations in the future.

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MULTI-CRITERIA EVALUATION OF TECHNOLOGICAL SOLUTIONS TO IMPROVE GAS DISTRIBUTION STATION EFFICIENCY

Violeta Misevičiūtė, Rapolas Tučkus, Artur Rogoža

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Introduction

Due to the global energy crisis, rising energy demand, and climate change, there must be a way to recover energy that is not used for beneficial purposes, reduce primary and secondary energy consumption, and reduce emissions. The natural gas sector and its transmission networks, including gas distribution stations (GDSs), are an important component of Lithuania's energy sector. Because the gas pressure is reduced by the use of gas pressure regulators, the energy potential in high pressure gas is not used effectively, the need to heat natural gas is conducted with the use of natural gas boilers, and additional environmental pollution is caused by the use of GDS. The purpose of the study is to analyse GDSs, identify areas where the energy potential is not being exploited and the environment is polluted, and propose reasonable solutions.

Object

The Lithuanian gas transmission system consists of 64 GDSs. The main purpose of the pressure of the GDS is to measure the gas and reduce it to required by the system user [1]. Many of the GDSs in the Lithuanian transport network are new or have been rebuilt and have similar or identical structures. Therefore, the study collected data on new construction GDS, which were used for further calculations (Table 1).

Table 1. *Data applied for the analysis of GDS*

Parameter (unit of measurement)	Designed	Actual
Average gas flow (n.m^3/h)	10÷5000	107÷918
Gas temperature at the inlet to the GDS (°C)	+2÷+10°C	+5°C÷+11°C
Gas pressure at the inlet to the GDS (bar)	20÷55	39÷41
Gas temperature at the outlet of the GDS (°C)	+3°C÷+7°C	+3°C
Gas pressure at the outlet of the GDS (bar)	3÷16	3
Area of a roof (m^2)	50	

The literature review has shown [2–4] that the impact of gas filtration, metering, and odorisation systems on the mass-energy balance of the GDS is negligible, and therefore, for the purposes of the study, the boundaries of the subject are shifted, and only gas preheating and pressure control systems are considered as potential elements for improving GDS energy efficiency and reducing emissions. A simplified GDS scheme investigated in the study, together with the key indicators and alternatives shown in Figure 1.

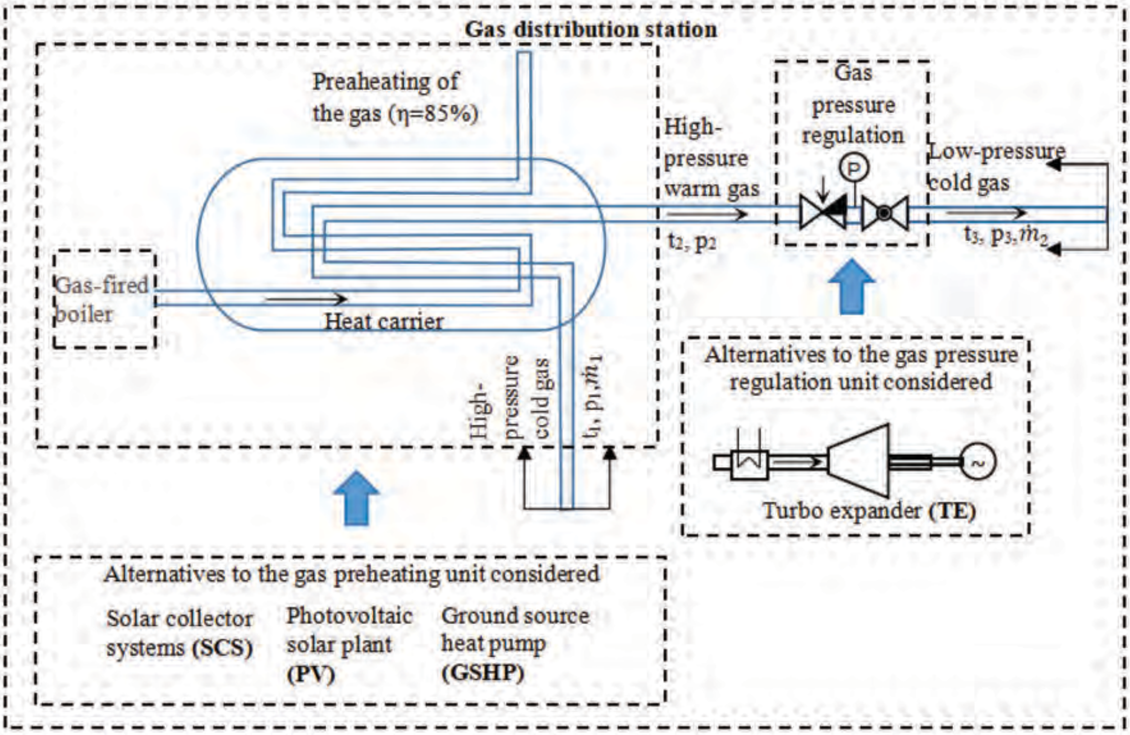

Figure 1. *A simplified scheme of the GDS, its main performance indicators, and alternatives based on master thesis [6]*

Three alternative sources of gas heating are considered: solar collector systems (SCS), photovoltaic solar plants with electricity (PV), ground-source heat pumps (GSHP), and alternative gas pressure control devices – turbine expanders (TE). The following alternative combinations were calculated: TE+GSHP; TE+PV; GSHP+PV; TE+GSHP+PV; TE+GSHP+PV; TE+SCS; TE+GSHP+SCS.

Research methodology

Calculation of the heat demand for gas preheating according to the collected data (gas flow rate, upstream and downstream gas pressures) is performed (1):

$$G = \frac{B \cdot \left(\left(p_1 - p_2\right) \cdot \mu + \left(t_{out} - t_{min}\right)\right) \cdot c_p \cdot \rho \cdot k}{3.6}, \mathrm{W} \tag{1}$$

where: B – the gas flow rate, n.m^3/h; p_1 – the upstream gas pressure, bar; p_2 – the downstream gas pressure, bar; $\mu = 0.6$°C/bar – the Giauli Thomson coefficient; t_{out} – the gas temperature at the outlet of the GDS, °C; t_{min} – the minimum gas temperature at the inlet of the GDS, °C; $c_p = 2.25$ kJ/kg·K – the specific heat of the gas; $\rho = 0.73$ kg/m^3 – the density of the gas; $k = 1.05$ – the coefficient of assessment of the heater's fouling.

To evaluate GDS alternatives, a multicriteria analysis taking into account energy, environmental, and economic indicators is applied. The energy criterion evaluates the energy consumption and/or production of the object under consideration, the environmental criterion covers the impact of the life cycle assessment (LCA) on the environment, and the economic criterion covers cost indicators (capital investment, operating costs, potential revenues in terms of net present value (NPV).

Once all of the above criteria are identified and evaluated for individual solutions, the feasibility and sustainability of the different GDS alternatives can be assessed, and the options best suited to the objectives can be selected. It is assumed that all three criteria are equal, i.e. they have the same weight of 0.3. The fact that two of the criteria (energy and environment) are best at the lowest level and the third (NPV) at the highest level, so the weighting of several criteria is calculated by formula (2):

$$\mathbf{3\textit{E}} = \mathbf{0.3} \cdot (\mathrm{EUR(NPV)/(m^3\ of\ gas)}) - \mathbf{0.3} \cdot (\mathrm{MWh/(m^3\ of\ gas)}) - \mathbf{0.3} \cdot (E/(\mathrm{m^3\ of\ gas})) \tag{2}$$

where: EUR(NPV)/(m^3 of gas) – the relative magnitude of the economic evaluation criterion; MWh/(m^3 of gas) – the relative magnitude of the energy evaluation criterion; E/(m^3 of gas) – the relative magnitude of the ecological evaluation criterion.

According to the calculation methodology, the solution with the highest 3E value is the best solution for all three evaluation criteria.

The modelling of the gas preheating alternatives (GSHP, PV and SCS) is carried out using energyPro software [5], where baseline ambient data (annual solar radiation intensity, outdoor air temperature, ground temperature) are entered, and on the basis of the available technical data, the system scheme is drawn up, and the amount of heat to be produced and the electricity to be used are calculated.

Results

As a whole, the alternatives of GSHP, PV, GSHP+PV, and SCS are not appropriate for the intended use and purposes of the study, as they have negative effects on multi-criteria analysis (3E). This is due to excessive electricity demand from the grid, insufficient energy generation during the operational phase, and high costs during the operation of alternatives. However, the installation of an additional generation unit – turbine expander (TE) changes the alternative evaluation: a value of 0.001 is generated only by TE, a value of 0.017 is generated by TE+PV, a value of 0.008 is generated by TE+SCS. The results show that the best alternatives are TE+GSHP (0.057), TE+GSHP+PV (0.061) and TE+GSHP+SCS (0.064).

Conclusions

The calculations show that the GDS has an unexploited energy generation potential in the pressure relief unit. This energy can be used for electricity generation using TE, but it would increase the demand for heat for gas heating by a factor of three. In Lithuanian GDS, solar photovoltaic and SCS will save only a minor amount of GDS energy, and these measures are not advantageous in a cumulative multi-criteria way if deployed separately. The PV and SCS alternatives have negative economics, whereas the other have positive economics. TE+GSHP+PV and TE+GSHP+SCS produce the majority of electricity, releasing 1 n.m^3 of gas and emitting less CO_2, SO_2, PO_4 P-lim and CFC-11.4. The alternatives TE + GSHP, TE + GSHP + SCS and TE + GSHP + PV are the most economical, with 0.016 to 0.017 EUR (NPV)/n.m^3. When individually evaluated in all parameters and in several parameters, the combinations of alternatives with GSHP and TE were the best: TE+GSHP, TE+GSHP+PV, TE+GSHP+SCS.

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RENEWABLE ENERGY SOURCES: SUPPORT MECHANISMS, BENEFITS, AND BARRIERS FOR PROSUMERS AND PRIVATE INVESTORS

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Introduction

As a result of population growth and economic development, the demand for energy is constantly growing; the International Energy Agency predicts that the demand for electricity will increase by 30% in 2040, compared to the base year 2016 [1]. An analysis of statistics [2] on energy use in buildings shows that, worldwide, space heating and water supply account for almost 50% of energy, and cooking energy accounts for about 25%. Recently, there has been a downward trend in energy demand in buildings as space heating and cooking appliances become more efficient and fuel efficiency and energy savings increase. However, with the transition to environmentally friendly energy sources, an increase in the share of electricity in the energy balance is predicted (Figure 1a). This is due to the replacement of traditional fossil fuel boilers with heat pumps, as well as the widespread use of air conditioning systems.

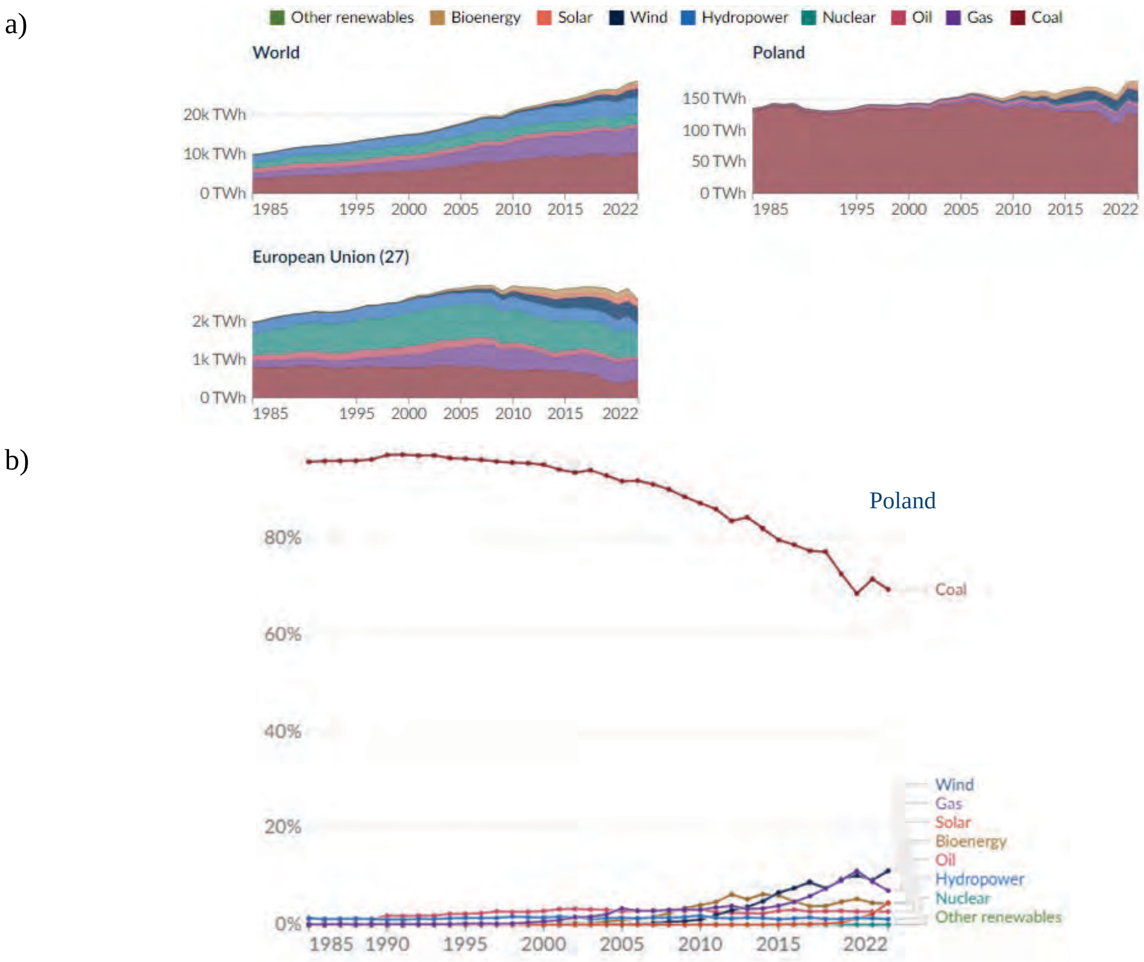

Figure 1. *Production of electricity by source [2]: a) world electricity production by source, b) share of electricity production by source in Poland*

The tone for accelerated clean energy development in this decade in advanced economies is set by new policy packages and government plans and goals, particularly those set out in the Inflation Reduction Act (United States); RePowerEU plan, the Renewable Energy Directive III and the Fit for 55 package (European Union); Climate Change Bill (Australia); and GX Green Transformation (Japan). Efforts to address climate change are projected to lead to increased use of energy from renewable sources and the rapid electrification of numerous end users, from transport to industry, leading to a massive increase in demand for electricity, as well as the need to generate as much of it as possible from renewable sources. The result is a dramatic transformation of energy systems around the world, although fossil fuels still account for more than 60% of global electricity production [3].

Implementing the assumptions contained in Renewable Energy Directive III will be particularly difficult for Poland, since it has been lagging behind European countries in terms of the share of renewable energy in the energy market for many years, and electricity generation in percentage terms is still mainly based on coal, accounting for almost 70% electricity generation market in the country (Figure 1b).

In the current situation, the role of prosumer installations in increasing the share of renewable energy in the energy market and achieving the goal of distributed energy is emphasized. The concept of prosumer refers to producers of electricity that consume it; therefore, they have installations that generate energy for their own needs [4]. One of the main factors blocking entry into the consumer market are the initial installation costs, which, depending on the type and size of the installation, range from several to several hundred thousand zlotys. Due to high initial costs, financial forms of support for prosumers are very popular, including various subsidies, reliefs, and loans, of which subsidies are among the most effective in terms of effectiveness. Reducing the continuously rising electricity bills is also related to saving for the average electricity consumer.

Financing programs for prosumers and private investors and their impact on the development of renewable energy in Poland

One of the largest financial support programs for renewable energy producers is the “My Electricity” program, which was implemented in 2019–2020 in Poland [5]. Initially, it included photovoltaic installations with a capacity of 2 kW to 10 kW, with an established budget of PLN 131.9 million. The installed capacity of the photovoltaic modules registered in the program was 152 MW. The first edition turned out to be a success, so it was continued for the next 4 editions. Currently, there is recruitment for the “My Electricity 5.0” program, the budget of which has been increased from PLN 100 million allocated for co-financing to PLN 950 million. The current edition covers not only photovoltaic installations but also heat pumps and energy storage [6, 7].

Another large initiative aimed at encouraging investments in renewable energy sources as well as improving the energy efficiency of buildings is the “Clean Air” program [8]. The programme is based on receiving financial assistance to partially cover the costs of replacing the heat source. The programme will operate for 10 years until the end of 2029. The anticipated final effect is a reduction in residential emissions of PM10 and PM2.5, and other pollutants compared to 2017. The main goal of the programme is to replace ineffective heat sources in single-family buildings and to co-finance the thermal modernization of the building. Additionally, the program can also settle a photovoltaic installation, and the subsidy amount may be higher than in “My Electricity”. This program is particularly profitable for the lower income households because it is divided into funding thresholds depending on the applicant’s income. The new edition of the clean air 3.0 programme was launched on 3 January 2023 [9]. Introduces additional measures to be used in the case of carrying out a comprehensive thermal upgrading project, which is intended to ensure a reduction in the consumption of usable energy for heating to not more than 80 kWh/m^2 per year, or by at least 40%. Despite its advantages, “Clean Air” imposes restrictive requirements on the future beneficiary, which may be the reason for the inflow of much fewer applications than expected at the beginning of the program in 2018 [5].

Rising energy prices motivate investment in renewable energy sources

According to data from the Energy Regulatory Office and the Energy Market Agency, electricity prices for household consumers increased by almost 29% in 2023 compared to 2022 [4, 6]. This means that the average individual energy consumer certainly has felt the changes that have occurred, despite the actions taken by the government to cushion the effects of the increase in electricity prices. In a situation of rising prices of electricity and conventional fuels, households, wanting to ensure greater stability, decide on a photovoltaic installation for the production of electricity and a heat pump to meet the building's heat demand.

Energy infrastructure in Poland

Technical challenges include adapting existing infrastructure to new solutions related to the connection of renewable energy installations, both in the field of large-scale renewable energy sources (wind and photovoltaic power plants) and at the consumer level. It is necessary to expand and modernize medium and low voltage power grids, as well as build power plants. However, achieving these goals requires significant financial costs, which will mainly fall on the shoulders of distribution companies. Although they can rely on support from EU funds in this area, these costs will place a significant burden on the operating budgets of the companies involved and this may result in future costs being passed on to consumers, i.e. recipients of energy. Distribution and transmission network operators note that the very limited control capabilities of renewable energy sources pose challenges in managing their systems [10].

Photovoltaic installations

An undoubted obstacle to the development of solar energy is the price of installing a photovoltaic installation. EU and government support programs aimed at encouraging prosumers to install this type of installation have addressed this problem. The programs have fulfilled their purpose, but over the years their profitability and availability have been decreasing. An additional problem is the location of the roof slope or the lack of available, unshaded area for PV installations.

Energy storage

When installing PV, it is also energy-efficient to use energy storage. However, the currently available technology does not allow for the profitable and effective use of energy storage for the needs of individual prosumers [11].

Profitability analysis of heat pumps

Heat pumps are less popular than photovoltaic installations, mainly due to their price. Air heat pumps are the most advantageous in this respect, however, they are associated with the lowest efficiency and higher operating costs. Ground heat pumps, despite their greater efficiency, are characterized by a higher price due to the need to use a vertical or horizontal ground heat exchanger. Although ground pumps generate lower operating costs, in comparison to investment and operating costs over a period of 20 years, it turns out to be more economical to install an air heat pump [12]. Another factor limiting the development and popularity of PCs is their use of electricity – in order to reduce operating costs, it is necessary to use a PV installation.

Conclusion

Poland, as a country with an electricity generation sector based on coal and imported gas, must make significant efforts to decarbonize its economy. Active implementation of renewable energy sources is impossible without additional funding due to the still high cost of this type of investment. In this context, legal mechanisms and government support programs for renewable energy sources are key tools for the development and active implementation of renewable energy sources in Poland.

Such support should also include power producer groups (system producers, commercial producers and prosumers), because appropriate use of Poland potential in the field of renewable energy sources requires investment of hundreds of billions of zlotys. However, the costs incurred will be offset by lower electrical and heat energy prices, increased energy independence, and security. Therefore, it is necessary to properly stimulate and support their actions in this direction.

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COMPARATIVE ANALYSIS OF THERMAL INSULATION PROPERTIES OF POLISH SINGLE FAMILY HOMES

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Infrared measurements have been know for decades. Their first applications were related to the military purposes and the development of thermovision technology has been significantly influenced by the military applications. However, these days they are very common in the civilian sector due to the considerable reduction in the price of these devices. They can be used in the building sector and other areas such as health diagnostics, electrical circuit failure analysis, search for missing people and etc. The infrared measurements are based on the detection of infrared radiation, which is emitted from every body of temperature above the absolute zero. Thus, everything around us emits radiation (in the form of electromagnetic waves) and thermovision cameras can detect this radiation and turn it into the temperature readings with the use of appropriate software. Thermal energy emitted from a body is significantly dependent on temperature (to the forth order) as well as emissivity, which takes the values of 0 to 1. Due to the fact that emissivity is a feature of an object, this values needs to be input into the infrared camera, so that proper temperature reading could be obtained. Equally vital is the care with which the measurements have to be performed. Any reflection of thermal radiation from sources that are located in the area where the measurements are taken can influence the temperature readings. In the building applications, the thermovision technique is typically applied to determine the areas of intense heat losses, the malfunction of the thermal insulation or some defects in the heating system (for example the leakage of water in the underfloor heating). The present paper discusses the peculiarities of infrared measurements with the use of a thermovision camera and focuses on the impact of measurement errors on the surface temperature determination. The experiments have been performed on two single family buildings located in the Swietokrzyskie region near Kielce under the autumn weather conditions (for comparison two buildings were selected: new and old ones) and the discussion on the thermal resistance of the walls has been presented.

Literature on the application of infrared measurements is quite broad and it covers many areas of engineering such as environmental applications (for example [1–4]). Antczak et al. [5] analysed thermal losses of buildings in Leszczyny near Kielce. Church and a single family home were considered by the authors. The measurements were performed during the winter month and conclusions regarding the investigations were given. Stokowiec et al. [6] carried out an experimental study of a heat and power plant chimney in Kielce. Thermal losses were analysed from the ground measurements, which seems to be a limitation of the study (the usage of drones could help obtain more accurate results). A cement plant chimney was investigated by Orzechowski and Orman [7], however in this paper the detection of thermal losses on the surface of the chimney was used as a tool to calculated the cooling of exhaust gases' emissions released from the chimney. It turned out that the reduction of the temperature of these gases leads to the fact that the contaminants in the smoke can travel shorter distances and can accumulate closer to the chimney. Thus, causing possible health problems. Additionally, thermal imaging plays a vital role in medical diagnostics as well, as presented in [8–10], where the areas of inflammation can be easily detected with the help of an infrared camera.

The infrared measurements are quite easily made, however the interpretation of the results can be quite difficult. However, in terms of the buildings, the infrared technique enables to determine the location of areas of increased heat losses. Figure 1 presents a thermograph of a building with visible increased heat losses below the window and on the right. The possible explanation could be poor thermal insulation of the outside wall. Consequently, heat generated by the radiator located below the window is conducted through the wall quite easily and increased thermal losses are seen below the window.

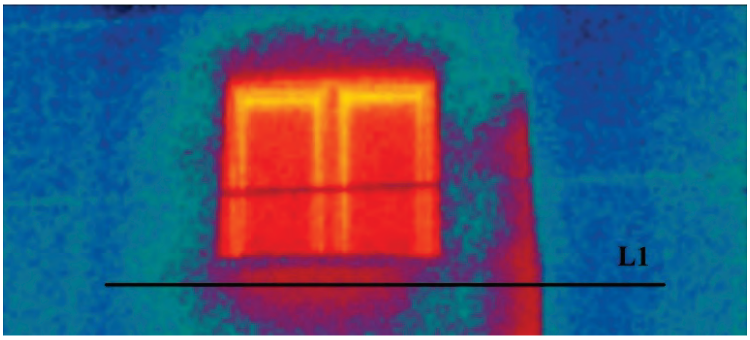

***Figure 1.** Thermal image of the single family home*

On the other hand the area of increased heat losses on the right to the window can also be caused by the presence of a heating element – a vertical pipe transporting hot water to individual radiators from the boiler located in the basement. The fact that these locations are characterised by higher surface temperature can mean that the thermal insulation is not thick enough to ensure proper thermal resistance. Figure 2 presents the temperature distribution along line L1, which is the line where these two interesting areas of increased heat losses occur (below the window and next to the window, covering also the areas of "normal" surface temperatures on the right and on the left).

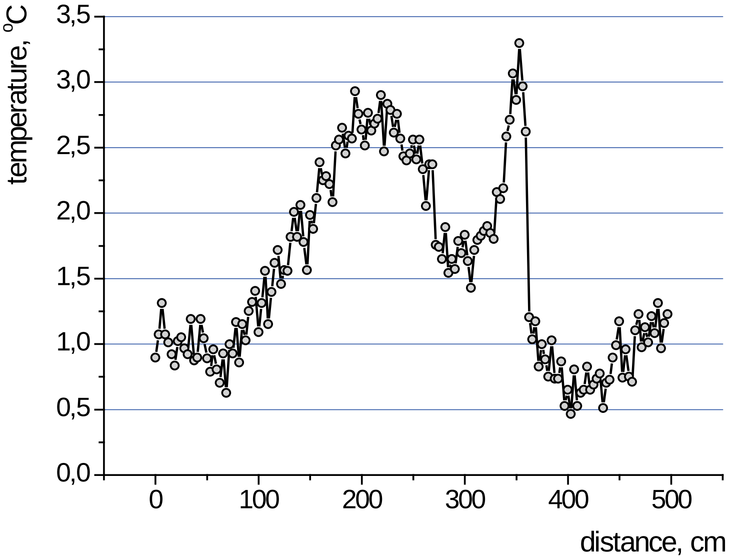

***Figure 2.** Temperature distribution along L1*

As can be seen, the differences in the temperature values can reach a few degrees Celsius. In the determination of the thermal performance of building insulation, it might be not so important to properly determine the temperature values (which is quite difficult if high precision is required), but rather the differences in these values are of much higher importance.

Naturally, the infrared investigations can help determine if the repair works might be necessary for the buildings. It can also be applied for the calculation of energy efficiency of buildings as indicated by Orman and Sułek [11]. However, thermovision measurements need to be performed highly precisely, avoiding possible sources of errors and measurement uncertainties (such as the incorrect emissivity values of the surface elements and etc.).

Conclusions

Infrared technology has been used for decades and has now become much cheaper and affordable both for companies but also for individual users for domestic applications. It can be successfully used for the determination of the thermal fields on building elements. This enables the assessment of insulation properties of the partitions, detection of thermal bridges and etc. This knowledge is essential to properly design thermomodernisation works. However, it is very important to pay close attention to the errors and uncertainties of infrared measurements because they can significantly influence the obtained results.

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PERFORMANCE OF THE HEAT PUMP AND PHOTOVOLTAIC SYSTEMS INSTALLED IN THE POLISH HOUSE

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Introduction

Producing energy and heat for your own use using renewable energy sources (in particular photovoltaic panels and heat pumps) now means independence from energy and heat suppliers. The definitely advantages of photovoltaic installations and heat pumps are ecological aspects and financial benefits.

Many authors try to check whether it is actually profitable to install renewable energy sources in homes. One such example is the work of Schlemminger et al. [1] who analyzed 38 single-family buildings in northern Germany from May 2018 to the end of 2020. Their analysis showed that for approximately 2.38 people there is approximately 2.829 kWh of energy consumption, taking into account the heat pump's demand for nearly 4.993 kWh. Rej-Witt and Dębska [2] examined a single-family house in the village of Rzymsko BG, where 17 photovoltaic panels with a unit power of 300 Wp were installed, of which the entire tested installation had 5.1 kW. It turned out that summer conditions are not always conducive to higher energy production – as in the examined example, where 850.9 kWh of energy was produced in April, while in July 100 kWh less. In economic terms, the tested installation will start paying off after four years, and in year five the first financial profits will be visible. The authors of the work [3] mainly focused on the barriers faced by private investors (households) and entrepreneurs in various European countries. In Latvia and Belgium, the problem was economic and legal issues, for Spain it was legal and organizational, and in Germany it was only financial issues. The analysis conducted provided information that society does not have sufficient knowledge on this subject and perceives such an investment as a long payback period.

Another example of research proposed by Nordgard-Hansen et al. [4] was related to a ground heat pump, where it was found that its use has a positive impact on ecological aspects and economic aspects for single-family houses where the demand for heat is low or medium. Kijo-Kleczkowska et al. [5] selected a photovoltaic installation in Poland and then analyzed the return on investment costs, ensuring its profitability. The authors of works [6, 7] also analyzed the use of heat pumps for single-family and residential houses. In Latin America and the Caribbean, Miravet-Sanchez et al. [8] analyzed rural communities for the use of photovoltaic panels. They singled out the countries of Peru, Brazil, Argentina, Chile and Nicaragua, where there is noticeable interest and an increase in the installed photovoltaic systems. The authors emphasized that these are positive changes due to the improvement of the health of these communities and the reduction of CO_2 emissions. Staying in Latin America, authors Ramirez-Sagner et al. [9] analyzed the photovoltaic systems used in residential and commercial buildings in Chile. 314 districts in 13 regions were surveyed. The research provided information that the greatest potential for energy production is located in the central northern part.

In one New Zealand school, Emanuel et al. [10] conducted research on 40 panels, where during the holidays the surplus energy generated was fed back to the power grid. On the economic side, the school's energy expenditure decreased by almost 45%, and the energy consumption from the network itself decreased by 32%, which saved approximately 4.000–5.000 New Zealand currency. However, in Queensland, Australia, in Cape York, Boarin et al. [11] performed a technical and economic analysis of the installation. It turned out that the energy production was much lower than the energy produced using conventional methods. In Jordan [12], the University of Science and Technology analyzed energy production from the installed PV system (inclination angle 15°) from 2017 to 2018. A number of factors influencing the operation of this system were selected for analysis, such as wind speed, ambient temperature or final efficiency, efficiency factor, sunlight, etc. It was also noted that this investment was profitable because the annual return was about 30% and the period was between 4–5 years.

The main aim of the work will be to analyze the production of electricity and heat using a heat pump and photovoltaic panels, as well as to present the economic costs of the system's interoperability.

Methodology

The research was conducted in a small village near Kielce in the Świętokrzyskie Voivodeship. A photovoltaic system and a heat pump were installed in the selected single-family house for a family of four. In order to find out the amount of energy and heat produced, a special application was used that allows monitoring such data on a monthly or hourly basis as well as the financial documentation of the investment project.

Conclusion

The use of renewable energy sources, in particular PV systems and heat pumps in cooperation, constitute a stable source of energy and heat for a single-family house. Such use of more than one installation ensures financial and energy stability but also has a positive impact on the environment by reducing CO_2 production.

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AI APPLICATIONS IN BUILDINGS: A REVIEW OF ENERGY MANAGEMENT ADVANCEMENTS

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Introduction

In response to the multitude of climatic challenges, which require robust action to mitigate climate change and reduce emissions, the European Union (EU) has initiated the European Green Deal, which aims to reduce gas emissions by 55% by 2030 and make Europe a climate neutral continent by 2050 [1]. Buildings in Europe are responsible for roughly 40% of the total energy consumption. The energy consumed solely for heating, ventilation, and air- conditioning (HVAC) ranges from 35% to 65% of the total energy consumption, depending on the building's characteristics [2].

Buildings are evolving to become more intelligent. They present many possibilities to enhance efficiency and lower energy consumption. However, there are issues like discrepancies between energy predictions and actual performance, referred to as the "performance gap" [3].

Several factors contribute to the performance gap in buildings, including assumptions in building energy models that are used at design stage, inaccurate modelling tools, poor building management and control, occupancy behaviour [3] and others. While traditional HVAC controllers do enhance equipment performance, they have limited impact on overall energy saving. These controllers cannot adapt to sudden changes in occupancy and environmental factors, displaying low accuracy and poor quality which undermines energy-saving efforts [2].

We live in an era signified by extensive data and witnessing the rapid evolution of Artificial Intelligence (AI) capabilities. This presents opportunities to integrate these technological advancements into building energy management systems (BEMS) to reduce performance gaps. The capability of AI to mimic human intelligence through environmental learning makes it a potentially valuable tool for reducing HVAC energy consumption.

This paper provides a review of the application of AI within BEMS in diverse settings of buildings, demonstrating the potential for substantial energy savings and the reliability of the applied AI models, as well as the challenges and future directions of AI-driven approaches, paving the way for more sustainable and intelligent building management practices.

Findings

Table 1 summarizes the findings of diverse studies demonstrating the potential for energy and cost savings in various buildings where AI models are applied to HVAC systems control. It was found that residential buildings exhibit a range of energy and cost savings from 5.05% to 31% [4, 5]. It was also found that HVAC AI-based control in different public buildings can reduce energy consumption from 10% to 36.5% and highest savings are found in offices and educational buildings [6–10]. These percentages highlight the significant opportunities for enhancing energy efficiency in various building types, offering both environmental benefits and cost savings.

Table 1. *Energy and cost savings in buildings with AI-model applied to various HVAC systems*

Reference	System	Building Type	Savings, %
[4]	Control	Residential	Energy and cost savings range 5.05%–31%
[5]	Control	Residential	Energy saving up to 18%
[6]	Optimization	Educational	Energy saving potential of 36.5%
[7]	Cooling	Shopping Mall	Minimum energy consumption saved is 10%
[8]	Control	Commercial	Energy savings of over 12%
[9]	Heating	Office	Energy saving potential of 25%
[10]	Cooling	Office	Energy consumption reduced to 58.5%

Table 2 summarizes the reliability of different AI techniques applied to improve HVAC systems performance. Reliability is the model's ability to predict parameters controlling the HVAC system. Different indicators could be used to measure the reliability, such as the Root Mean Square Error (RMSE), R2, and Mean Square Error (MSE) [6, 11, 12]. RSME predicted various factors, including thermal comfort prediction, PMV, CO2, PM10, and PM2.5 concentrations [11, 14]. R2 measured the accuracy of internal heat gain and prediction of cooling power, with excellent results exhibiting the effectiveness of AI techniques and their potential for accurate predictions and modeling in HVAC systems [10, 12].

Table 2. *Accuracy of different AI techniques applied to various HVAC systems*

Reference	AI Technique Employed	Accuracy-R2, MSE, RMSE, %
[6]	Single layered feedforward artificial neural network	R2 > 99% MSE = 0.000044
[7]	Artificial neural network	Prediction accuracy = 87%
[11]	Reinforcement learning	Highest accuracy with RMSE = 0.07
[12]	Shallow neural network	R2 > 0.95
[10]	Model predictive control, recurrent neural network	R – values of training = 0.993, validation = 0.991 testing = 0.992
[13]	Machine learning	R2 = 0.925
[14]	Integrated neural network	For PMV RSME = 0.2243, for CO2 RSME = 0.8816, for PM10 RSME = 0.4645, and for PM2.5 RSME = 0.6646

Conclusions

Integrating various AI techniques with BEMS in different HVAC control, such as heating/air conditioning energy optimization and indoor thermal comfort, has led to significant improvements in energy efficiency, with some studies reporting energy savings of up to 36.5% compared to traditional control methods. The reliability of the AI models applied is defined by different parameters, including R2-values and the RMSE, where in some studies, R2 values were higher than 0.95, and in other studies, RMSE = 0.07. Despite the promising results and benefits of AI application in BEMS, there are several challenges, such as the lack of high-quality data, the difficulty and high cost of obtaining data, and the complexity of some AI models that may require significant computational resources, which can be challenging to implement in real-world applications. In terms of future research avenues, there is a need to develop better-integrating AI-models with other optimization techniques, to achieve better building energy efficiency.

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HEAT DEMAND COMPARISON FOR ACTUAL TEMPERATURE VALUES

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Heat demand calculations procedures for buildings are currently being conducted on the basis of Polish Standard that was grounded on European Standard for heat losses methodology. Poland was divided into several climatic zones with given calculation and annual average external air temperatures values. In each zone, the temperature that is required to be considered is given by the technical committee. The data included in the Polish Standard preparation concern several years backward. However, throughout the previous years we have observed the tendency of the temperature increase during the whole year long not only in Poland. The phenomenon provides the scientists with the conclusions that each year the temperatures will continue to increase. The low temperatures in winter season will no longer occur. Therefore, it becomes necessary to analyze the possibility for lowering the calculation heat demand including the actual prevailing temperature values. The study was conducted with the regard of possible economic benefits for the building users due to the lower temperature difference between the internal and external temperature.

The history of design temperature standards for heating in Polish region was extensively described by Narowski [1] in his work. As stated, the first articles regarding heating were published in 1817 but in 1836 Koncewicz [2] wrote a paper that took into account the impact of climate on the materials used to construct the new building to overcome the coldness and humidity. The first works regarding the heat losses calculations were published in the beginning of XIX century. Orębowicz in 1913 [3] assumed the outside design temperature at –30°C, then in 1929 a released book by Wójcicki [4] shows –25°C as a design temperature, since then the external design temperatures described in the studies have varied. In 1929 Dawidowski [1] presented, in table format, corrections to the average outside air temperature for 86 Polish cities, which took into account the appearance of occasional frosts. The first published map dividing Poland into climatic zones was published in 1934 as polish standard (PN/B-102) [1]. Polish region was divided into several zones with the lowest design temperature –25°C as zone IV for the foothill and mountain areas with an altitude above 600 m above sea level and the highest temperature –15°C located at the Baltic Sea shore as zone I. Rodowicz's studies [5], which were the basis for creating the first temperature divisions, included a formula for determining the design temperature. In the equation, the mean between the lowest average daily temperature and the absolute minimum temperature was increased by 10°C. In a number of articles Mielnicki [6–8] has justified the increasement due to, among others, the cessation of winds during severe frosts or the phenomenon of thermal inertia of buildings. The adoption of too low external temperatures was discussed in 1936 by Nierojewski [9] during the first heating congress. At that time, it was questioned whether the design external temperatures were too low and whether they would not provide too large reserves, considering the frequency of their occurrence.

The aim of the work was to compare the external temperatures in Poland that are applied in the building heat demand procedure with the actual appearing temperature values and investigate the necessity of meteorological data involvement with regard of increasing the energy savings in residential buildings. The analyzes involved the calculated building heat demand for a single family residential two-storey building with the heated area of 106 m^2.

The calculations were conducted in each of the climatic zones for winter in Poland. Firstly, the considered calculation and annual average external air temperatures values were assumed as it was assigned in the Polish Standard [10]. The comparison included the actual temperature values that have occurred for previous five years in Poland in each climatic zone read from data presented in meteorological annual. The calculation external air temperatures were identified as the lowest values in each year. The results are presented in the diagram below.

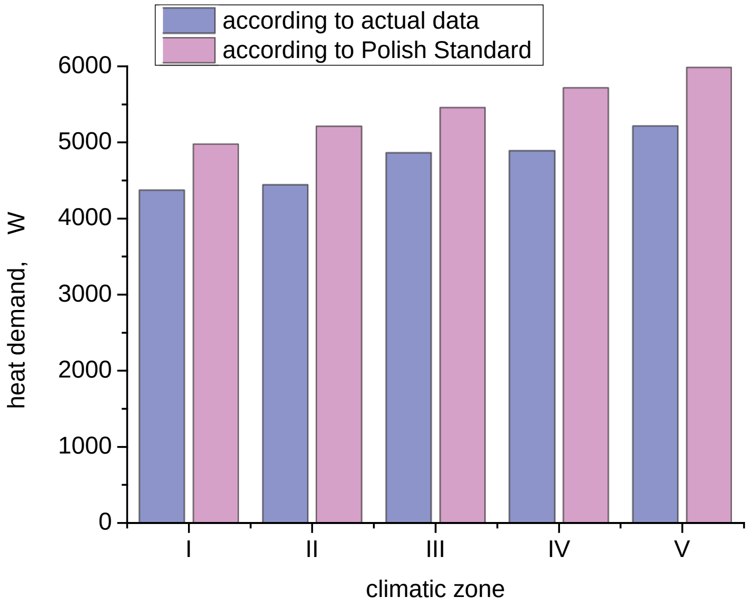

Figure 1. *Heat demand comparison for calculation and annual average external air temperatures values according to Polish Standard and actual values from meteorological annual*

The average share of the heat demand calculated including the data recorded from the meteorological statistics in comparison with the Polish Standard is 87%.

The energy savings contribute to the financial benefits for the heating system user. The conducted study involved three heating sources with different heating systems: air to water heat pump, pellet or gas condensing boiler with heaters. The initial costs due to the different temperatures calculations are not significant, since the value comparing to the Polish Standard is only 3% lower. However, the annual costs savings for each of the methodology are notable, as presented in the figure below. The calculations were conducted for the assumed air to water heat pump with coefficient of performance 4.7. The calorific value of pellet is 18.300 kJ/kg, and for natural gas: 9.44 kWh/m^3.

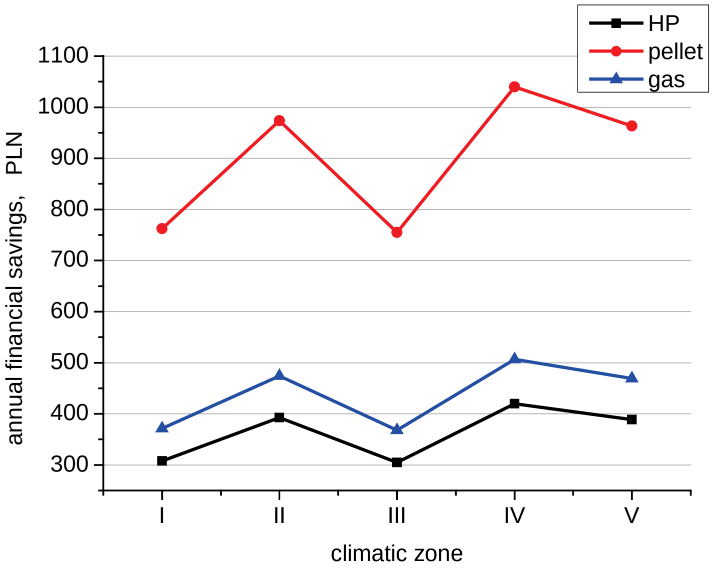

Figure 2. *Annual operational costs savings*

As presented in the diagram, the decrease in annual expenses strongly depends on the climatic zone, due to the differences in heat demand and therefore in the energy savings during the heating period. The most significant financial benefits are gained for heating the building with pellet boiler, exceeding even 1.000 PLN/year.

Conclusions

The lower heat demand in a building results in reduction of operation costs of heating system as well as the decrease of investment costs. On one hand the necessary heating device cost decrease with its lower thermal output, on the other hand the heating pipes require smaller diameters. Moreover, the power consumption in case of heat pump or fuel consumption when considering the conventional heating source, will decrease the system users expenses. The analyzes involved three types of heating system: air to water heat pump with COP = 4.7 / pellet boiler / gas condensing boiler. In the first case the average annual costs reduction reaches 363 PLN, whereas in the third one 438 PLN. The highest expenses decrease is observed in case of pellet as a heating fuel with average value of 899 PLN/year. Therefore it is necessary to include the differences in climate changes to calculation procedures.

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INVESTIGATION OF THERMAL COMFORT, PRODUCTIVITY AND LIGHTING AT POLISH UNIVERSITY BUILDINGS

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Thermal comfort and lighting conditions are important aspects of the indoor environmental quality. They are considered to influence productivity of room users. Thermal comfort conditions are related to the feeling of well – being, namely of experiencing neither cold nor warmth. Such favourable conditions can be obtained mostly with a correct setting of indoor temperature, however other factors such as relative humidity, air flow velocity and others, can also play a role. Moreover, thermal comfort is highly subjective and we can only aim to create comfortable conditions for the overwhelming majority of room users (typically 95%). Lighting conditions are less subjective, however the previous studies of the authors also imply the influence of individual needs and preferences in this aspect of the indoor environment. On the other hand, productivity can be assessed objectively (when the volunteers perform tests or exams, which are checked for knowledge absorption) or subjectively (by the individual assessment of the respondents regarding their current state of productivity, thus it is called “self-reported productivity”). The paper presents the experimental test results of research conducted in university educational building of Kielce University of Technology (Central Poland) using anonymous questionnaires and physical measurements of indoor air parameters with a high precision microclimate meter with adequate probes. It covers the analysis of the subjective assessment of thermal sensations, acceptability and preference as well as productivity, lighting and air quality in twelve rooms (both lecture rooms and classrooms). The study analyses the impact of the indoor environment (mostly air temperature, carbon dioxide concentration and illuminance) on the subjective sensations of the respondents expressed by them in the questionnaires. The experiments have enabled to provide valuable insights into the development of the proper indoor environmental conditions that would maximize the comfort and productivity of room users.

The literature on thermal comfort is quite broad. Becker and Paciuk [1] analysed thermal sensations in residential buildings both in winter and in summer. Some authors focus on primary education buildings. In [2] air quality in Slovak classrooms was tested. Jindal [3] analysed students’ thermal comfort. Singh et al. [4] performed studies on the students’ thermal feelings and their preferences. Similarly, Aghniaey et al. [5] performed a study on a university campus. Fang et al. [6] stated that there might be a significant relation between the results of thermal sensations and the operating temperature. The studies are conducted in single family homes. Krawczyk and Surmańska [7] analysed thermal environment in the single – family home using the traditional temperature measuring system. On the other hand, Dębska et al. [8] focused their paper on the technical description of the thermal measurements. Dębska [9] presented data on thermal comfort tests performed in the intelligent building. While Białek et al. [10] focused on equally important area of indoor environment, namely light intensity and productivity in the same higher education building of Kielce University of Technology called “Energis”. The present study uses the microclimate meter testing method as well as the questionnaire survey with a set of questions regarding individual sensations of the respondents located in the classrooms and lecture rooms. Figure 1 presents the microclimate meter on a tripod situated in a large lecture room at the height of half of the total height of the room.

Figure 1. *Microclimate meter in the lecture room*

The results of the measurements are analysed in such a way that from all the questionnaires a set of graphs is presented. Figure 2 presents an example graph related to the answers to the first question in the questionnaire, namely about thermal sensations of the people. The answers range from "–2" ("too cold") to "+2" (too hot).

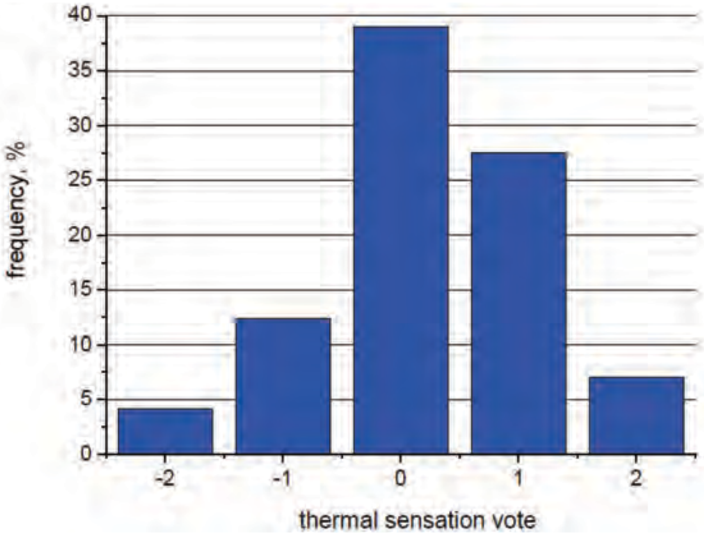

Figure 2. *Results of the thermal sensation vote in one room*

In the room, whose data are visible in Figure 2, the majority of people were satisfied with thermal environment (answers "+1", "0", "–1"), but there were some students who complained that it was too hot (7% of this population) and too cold (almost 5% of the group).

Conclusions

Thermal comfort can be successfully analysed with the questionnaires, which provide data on the current sensations experienced by the respondents. At the same time, microclimate meter collects indoor environment data (for example air temperature). Both of these data sets enable to correctly conclude about the thermal conditions of the rooms in the analysed building and can help with providing room users with as comfortable conditions as possible due to proper indoor air temperature setting.

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REVIEW OF METHODS FOR CONVERSION OF BIOMASS TO BIOFUELS

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Introduction

As civilization develops and technological progress progresses, people's living standards improve and the demand for primary energy increases. However, the extent of this increase is offset by energy saving and energy efficiency measures. It is estimated that over the next 25 years the demand for energy will increase only by about 30% and the dominant energy carrier will be electricity, using about 70% of primary energy sources. At the same time, the analysis of changes in the structure of energy consumption indicates that renewable energy sources, which are characterized by the greatest development dynamics today, will use approximately 45% of primary energy in the future [1]. Figure 1 shows the structure of electricity production for Poland in period 2019-2021.

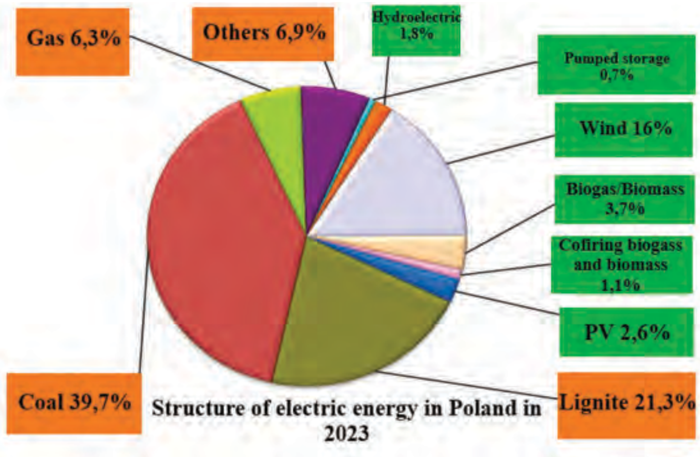

Figure 1. *Structure of production of energy in Poland in year 2023 [2]*

The use of biofuels and biomass for electricity production increased from 0.5% in 2019 to 2.9% in 2021 [2] and the consumption of bioethanol and biodiesel increased from 631 thousand tons in 2014 to 794 thousand tons in 2018. The global biofuel market, is expected to increase in value from nearly USD 121 billion in 2020 to nearly USD 202 billion in 2030, and global biomass production is expected to increase in value from over USD 127 billion in 2021 to over USD 210 billion USD in 2030 [3, 4].

One of the pillars of sustainable economic development is the use of biomass as a raw material for the production of fuels and biofuels. The use of renewable raw materials in a sustainable manner should apply to all technological processes, including one of the most important ones, which is the production of energy and its carriers. [5] When using biomass for energy purposes, three energy carriers are important – electricity, heat and transport fuel (liquid and gaseous). Biomass can be converted using various technologies. In order to demarcate the sectoral use of biofuels, it is assumed that liquid biofuels are fuels used in transport, and bioliquids and solid and gaseous biofuels are fuels used to generate electricity and heat.

Main methods of biomass conversion

Biomass is processed to produce high quality heat or fuel. Considering the type of final product produced (solid, liquid or gaseous fuel), there are different ways to process biomass: thermal, chemical, thermochemical, biochemical [6]. The main methods of biomass conversion are presented in Figure 2.

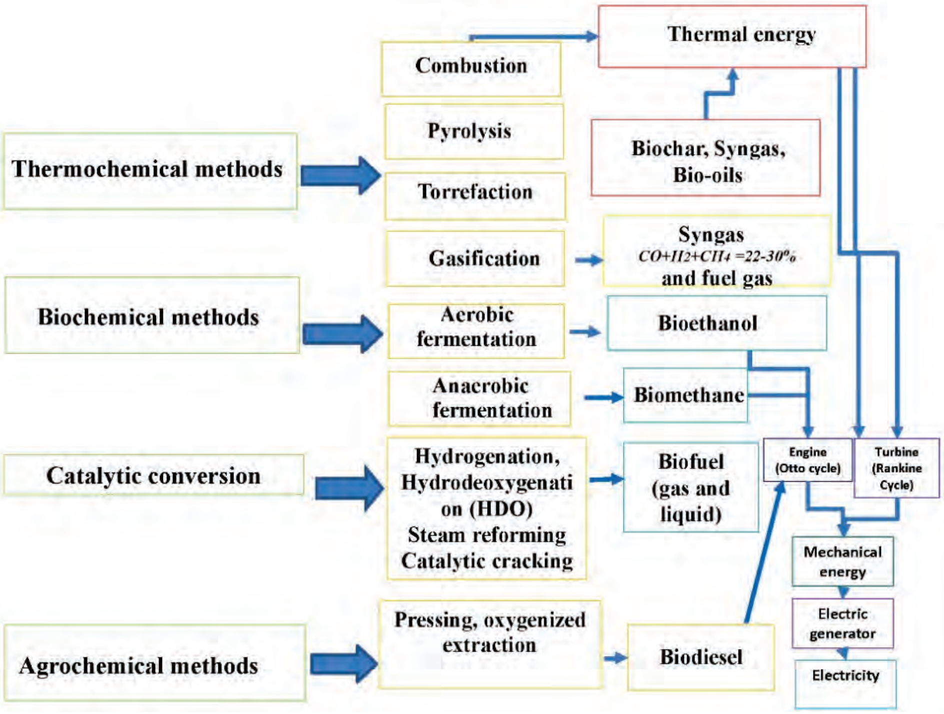

Figure 2. *Basic energy processes for biomass-to-energy conversion processes*

The use of biomass to produce heat in the processes of direct combustion or co-combustion with coal, consisting in the conversion of the chemical energy of carbon compounds, hydrogen and oxygen contained in it into thermal energy in boilers, is at the same time the cheapest, but – according to many experts – the least effective and economically the least profitable solution. In the case of combined production of heat and electricity in biomass-fired power plants (wood, straw, raw materials from energy plantations, RDF, etc.), the investment outlays are slightly higher, but thanks to fluidized bed combustion, cogeneration systems, trigeneration, ORC systems, etc., the efficiency conversion increases, and the economic and ecological effect improves. However, the most advantageous methods of biomass processing, both from the economic and technical point of view, are its partial oxidation, gasification and pyrolysis for the production of liquid fuels, with the possible use of Fischer-Tropsch synthesis, hydrogenation and hydrocracking in relation to the products of thermal decomposition of biomass [7].

Another method is the pyrolysis of solid fuels such as coal or biomass, which is a process of thermochemical decomposition without the presence of oxygen, resulting in solid, liquid and gaseous products, organic matter, leads to the formation of solid residue, tar, decomposition water and gas. This process is used to transform waste that is particularly harmful to humans or the environment into neutral or less hazardous compounds. There are two main stages of pyrolysis:

1. Degassing of the material and thermal decomposition of the main components, during which transformations such as dehydrogenation, dehydration and decarboxylation occur.
2. Secondary reactions occur between the solid and gas phase components, such as polymerization or condensation [8]. Fuel conversion is a physicochemical transformation involving the transformation of fuel energy into another type of energy, which is called direct transformation, which may include combustion, or the transformation of fuel into another form, which is called indirect transformation.

Depending on the speed of the process, a distinction can be made between slow pyrolysis and fast pyrolysis. Most often, pyrolysis is carried out at temperatures from 400°C to 1000°C, and the residence time of the raw material in the reactor ranges from several minutes in the case of slow pyrolysis and up to 0.5 seconds in the case of very fast pyrolysis. Low process temperatures and slow heating of the raw material favor the formation of solid products, while high temperatures allow for obtaining larger amounts of liquid products. If very fast pyrolysis is used at a temperature of 900°C, gaseous products can be obtained. Fast pyrolysis is a high-temperature process in which biomass is heated at high speed without air. The products of this process include gaseous products, aerosols and carbonized residue. After cooling and condensing the gas phase and aerosols, a brown liquid is obtained, the calorific value of which is half that of traditionally obtained diesel oil. In the fast pyrolysis process, 60–75% by weight of liquid bio-oil, 15–25% by weight of solid carbon products and 10–20% by weight of gaseous products that have not been condensed are obtained, and their amount depends on the type of raw material used. The advantage of the process is that it does not generate waste because bio-oil and carbonized products are used as fuel and the gases can be returned to the process. In this process, the rate of heat transfer is important, which is facilitated by the use of finely ground material in the process. Another feature of fast pyrolysis is careful control of the process temperature, which ranges from 450°C to 900°C. The differences between fast and slow pyrolysis are presented in detail in Table 1.

Table 1. *Types of biofuels produced from different types of biomass [5]*

Fuel	Typical raw materials	Technological Readiness Level/Fuel Readiness Level	Major technology providers
Methanol	wood, black lye (waste from papermaking processes), solid organic waste (wood, municipal solid organic waste, straw), alternatively biogas or glycerol	4–6/5	USA, PRC, EU
Ethanol from lignocellulose	several types of lignocellulose (mainly straw, corn straw, bagasse (pomace) from sugar cane, wood, grasses); distributed (municipal) waste, industrial waste streams	7–8/7 for fermentation	USA, PRC, UE, Brazil
Biomethane	agricultural and forestry waste (straw, sawdust) municipal solid waste (landfill gas)	7–9/7	Netherlands, France, Norway, USA (landfill gas)

Biomass gasification is a technology based on the conversion of carbon compounds contained in biomass into a gaseous fuel called syngas or bio-syngas. The biomass gasification process is carried out in various types of reactors, e.g. fixed bed or fluidized bed. Depending on the structure and type of reactor, biomass gasification takes place at temperatures of 700–1500°C, in an atmosphere of air, water vapor or pure gases such as oxygen, nitrogen, carbon dioxide [6]. Gasification is a process of oxidation of biomass, as a result of which the chemical energy of the bonds of carbon structures is released and then stored in the bonds of gaseous products. Syngas contains mainly CO, CO_2, H_2, N_2. By-products of the gasification process are small amounts of biochar, ash, tar and oil [6]. The typical share of products is – biochar 5%, oil 10% and syngas 85%. The efficiency of syngas production is influenced by the low O/C ratio in the biomass, therefore, before the gasification process, the raw material is often conditioned in the torrefaction process. In addition to reducing the O/C ratio, torrefaction increases the energy concentration and hydrophobicity of substrates, which contributes to improving the efficiency of the technology, but also the quality of the obtained syngas [10].

Biofuels from biomass

Liquid biofuels, produced from solid biomass (biomass-to-liquid), are an alternative to traditional petrochemical fuels. Currently, the main raw material for liquid biofuels, ethanol and biodiesel, are food crops, such as cereals, sugar beet, rapeseed or potatoes. For example, in Poland, the production of rapeseed and cereals for biofuels, respectively, increased from 1.69 and 0.52 million tons in 2014 to 2.20 and 0.65 million tons, respectively, in 2018 [6], and biomass and biogas together in the first half of 2022. They accounted for 20% of energy production from renewable energy sources [11]. However, straw from the production of cereal and oil plants, as well as residues from sugar and starch production, are still an attractive lignocellulosic material with future potential for the production of 2G (Second Generation) biofuels. The heating value (HHV) for pure methane is 37.78 MJ/m^3. In biogas, the methane concentration depends on the amount of fats, proteins and carbohydrates present in the fermented biomass and ranges from 50% to 70%. Moreover, there is an additional high concentration of CO_2 in the raw biogas. For the above reasons, the real energy value of raw biogas is estimated in the range of 19–26 MJ/m^3 or 6–6.5 kWh/m^3, which is equivalent in energy to approximately 0.65 dm^3 of crude oil [12]. However, raw gas energy values reported in the literature vary significantly depending on the lignocellulosic material used. This is mainly due to the different C/H and C/O ratios. Raw biogas has a very limited scope of use due to the presence of trace compounds that may negatively affect installation components and the process. Therefore, in order to avoid problems with biomass utilization, H_2S, NH_3, high concentrations of H_2O and siloxanes should be avoided [21]. The effects of using unpurified gas may include corrosion, a decrease in the specific calorific value or the formation of undesirable products after the combustion process [6].

Zeolites as catalysts in biomass conversion into biofuel

Another possibility of converting biomass into biofuels is the use of zeolites as chemical reaction catalysts. This is particularly profitable because it allows easy use and recycling of fly ash. Biogas, although it is a renewable form of energy, usually contains 40–45% CO_2, which significantly reduces its calorific value [14]. Various porous materials have been adapted to adsorb CO_2 gas from the biogas stream to obtain 95–97% biomethane. Zeolites are one of the promising porous materials that can significantly contribute to the upgrading process through selective adsorption of CO_2 gas from biogas [14]. The use of natural material as a catalyst or substrate for the production of a catalyst not only reduces the costs associated with the production of catalysts, but also makes the process used environmentally friendly. Moreover, the use of waste materials reduces the problem of waste disposal.

Biodiesel is typically produced from vegetable oils and methanol, which also produces glycerol as a byproduct. To improve the overall economic performance of the process, selective formation of methanol from glycerol is important in biodiesel production. The incorporation of HZSM-5 as an acid catalyst and CaO as a basic catalyst in a synergistic catalytic system led to higher glycerol conversion and methanol selectivity [15].

Biochemical processes

An alternative method of producing biofuels is the biochemical process using microorganisms such as Clostridium butyricum, Enterobacter aerogenes or Enterobacter cloacae [6], in which hydrogen is one of the products of their metabolism. Biotechnological methods include those involving light, such as direct and indirect biophotolysis and photofermentation. The second group of processes are those occurring without access to light, such as dark fermentation, bioelectrolysis or bioconversion of carbon monoxide. A significant advantage of biochemical processes for hydrogen production is the ability to perform them without the need to use increased pressure and temperature –

they can take place in ambient conditions, which is of great economic importance. Lignocellulosic biomass consists of carbohydrate polymers and lignins. Agricultural waste and all processing residues contain approximately 32–47% cellulose, 19–27% hemicellulose and 5–24% lignin, and these proportions depend on the origin of the biomass [6].

Photofermentation is a process during which organic acids are converted to hydrogen and carbon dioxide by photosynthesis under the influence of specific strains of anaerobic bacteria. Hydrogen is produced thanks to the enzyme nitrogenase. Oxygen, as a nitrogenase inhibitor, is not produced as a result of such a transformation. Hydrogen yields are similar to those from biophotolysis. Additionally, such a process requires specialized types of microorganisms, an appropriate type of medium designed for the appropriate type of photofermentation, as well as appropriate light intensity.

Bioelectrolysis is a method of converting biodegradable materials into hydrogen using modified microbial fuel cells (MFCs – microbial fuel cells), also called MEC (microbial electrolysis cells), whose efficiency is between 60% and 80%. MEC reactors consist of two chambers (anode and cathode), which can be separated by a diaphragm. The process occurs under the influence of an external source of electrical energy [6]. In the anode chamber, organic medium with a high glucose content (such as sugar beet or corn) [6] is oxidized as a result of the metabolism of bacteria such as Gammaproteobacteria, Deltaproteobacteria or Shewanella [3], as a result of which protons and electrons are produced at the anode.

Conclusions

The use of organic raw materials for the production of biofuels using zeolite-based catalysts is one of the prospective options for increasing market resources and developing distributed renewable energy, in which biomass is locally obtained and used for own needs. The reasons for the development of the market for many types of biofuels include the lack of competition with food production for arable land, and the possibility of using inedible plant parts and waste from agricultural production and agri-food processing, additionally making lignocellulosic biomass a key renewable energy resource, which is becoming an important element of sustainable development, including the development of a circular bioeconomy (reducing greenhouse gas emissions, mitigating climate change, using waste for energy purposes). Technologies for converting biomass into solid, liquid and gaseous biofuels are systematically improved. An opportunity for further development of liquid and gaseous biofuels are biorefinery processes that involve cascade processing of biomass, including treating the energy use of biomass as one of the final stage options in the value chains of bio-based products. In addition to the use of biomass from dedicated woody plant crops, there is a wide range of agro-forestry post-production and post-consumer residues that require intensive research and development work integrating not only the technological sphere but also the economic and social sphere.

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INFLUENCE OF THE HEATING SURFACE GEOMETRY ON THE DROPLETS EVAPORATION UNDER LEIDENFROST CONDITIONS

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Physical and geometric factors are generally considered to be the main cause of the evaporation characteristics of Leidenfrost droplets that levitate above the hot surface. It is well known and generally accepted that similar research is conducted under different conditions and on individual measurement set-up. This is one of the potential reasons for the differences in the results of thermal fluxes and computational models in scientific papers. This paper discusses the influence of the heating surface geometry on the heat transfer coefficient h during water drops evaporation under the film boiling regime. The variable geometry parameters are the radius of curvature of $R = 64$ and 254 mm. An individually compiled test stand allowed one to measure the instantaneous drop mass for each R radius and determine the coefficient h. The methodology was validated by calculating the relative error. This parameter changes with the radius of curvature and does not exceed ±10% for the size of the droplet and its mass. The heat transfer coefficient h is about 15% higher for a drop located on a surface with a larger radius of curvature. Moreover, the devised method allows us to estimate the h-value for asymmetric droplet shapes.

The levitating of droplets above a hot surface has been known since 1756, and like the minimum temperature above which it floats, is called the Leidenfrost phenomenon and temperature, respectively [1]. On the other hand, its wide interest is related to the development of cooling technology, fuel evaporation, metal technology processes, and evaporative cooling, as well as in medicine and others [2]. Depending on the needs, the aim is to maximize the heat flux removed [3], especially during emergency operation of, e.g. a nuclear reactor or a highly loaded electronic system, and sometimes only to the desired reduction of the surface temperature, e.g. of the skin during medical treatments. In many technical applications, it is desirable to control the temperature of the material and the discharged heat flux in such a way as not to damage its structure or mechanical properties [4]. It is very difficult in systems with a surface temperature higher than the Leidefrost point. This is due to the highly complex physical nature of the phenomenon. Among others, it is difficult to accurately and unambiguously give the minimum surface temperature at which the beginning of a stable membrane boiling is observed. Various values of this point are quoted in the literature [5]. According to [6], it is a function of surface parameters such as roughness and thermal diffusivity, as well as environmental parameters.

The evaporation process of droplets levitating above the hot surface is a function of physical and geometric parameters. The research is carried out in various conditions and on individually designed measuring stands. This is one reason for the discrepancy in the results of heat flux and computational models available in the literature. One of the variable parameters is the geometry of the heating surface. The subject of the presented research is the geometry of the heating surface influence on the amount of heat dissipated during cooling, as an example of a levitating droplet of water in the Leidenfrost regime. The paper also discusses instabilities during evaporation of the water droplet from the heating base.

The basic research module is a copper cylinder on which a band heater. Its power must be sufficient to stabilize the surface temperature, i.e. up to 500°C. As shown in Figure 1, a K-type thermocouple is centrally located in a hollow cylinder, the indications of which, are used to control the temperature of the heating surface. Detailed descriptions of the measurement procedure and the stand are provided in [7] and [8].

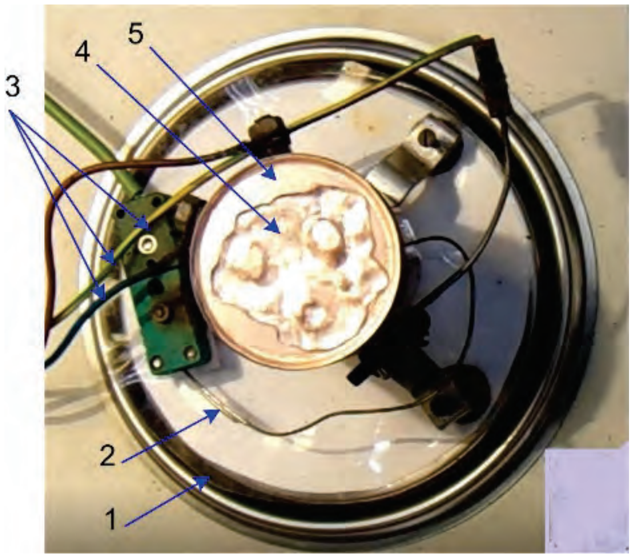

Figure 1. *Photograph of the experimental set-up (top view): 1 – scale, 2 – thermocouple, 3 – electrical power supply, 4 – droplet, 5 – copper cover*

The main result of the measurements is the drop mass change in time, *dm/dt* recorded with a given frequency for a constant wall temperature $T_w \approx 390°C$ and varying curvature radius, $R = 64$ mm, $R = 254$ mm.

Such a determined coefficient can be here referred to the drop perpendicular projection onto the heating base and can be used to the following heat and mass transfer balance that describes the drop mass change over time *dt*:

$$\frac{dm}{dt} = -\frac{1}{K} h\left(T_w - T_d\right) A \tag{1}$$

Next, the total heat transfer coefficient can be obtained as:

$$h = \frac{\sqrt{\pi} K b_D}{b_A \sqrt{A}} \tag{2}$$

where: T_w, T_d – surface and droplet temperatures, respectively; A – the droplet orthogonal projection onto the heating surface; K, b_A – supplementary obtained parameters.

The local value of the heat transfer coefficient, *h* for both surfaces are shown in Figure 2. It is about 15% higher for a drop located on a surface with a larger radius of curvature.

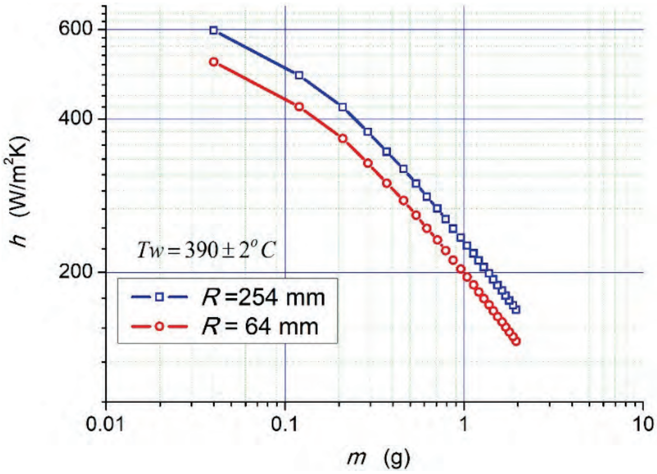

Figure 2. *Heat transfer coefficient as a function of the droplet mass for surfaces with different radii of curvature*

Conclusions

Designing the course of the technological process, in which maintaining the proper cooling rate of the hot surface is one of the parameters, requires possibly precise specification of the dependencies determining the amount of heat flux removed. This is especially difficult in the phase change processes, for which the relationships reported in the literature often differ significantly. This also applies to the evaporation of liquid droplets from the hot surface, including its film boiling.

The method proposed here is based on direct measurement of the drop mass during its evaporation. On this basis, the total heat transfer coefficient h is calculated with good precision. This improves engineering heat transfer calculations when cooling is accompanied by the Leidefrost effect.

One of the parameters, which is not described in the literature, is the shape of the heating surface. Therefore, the influence of the shape of the heating base on the amount of dissipated heat flux is investigated here. For this purpose, two radii of curvature of the heating surface are analysed, amounting to 64 mm and 254 mm, respectively. It was found that in the range of linear dependencies of the perpendicular projection on the heating surface as a function of mass and the equivalent drop diameter as a function of time, the calculated heat transfer coefficient is about 15% higher for a drop of water located on the surface with a larger radius of curvature. The influence of the shape of the heating surface on the amount of heat flux carried away by the large drops floating above the surface with a temperature above the Leidenfrost point is significant. For droplets with a mass greater than 3 g, the relative error was always less than 10%. On the other hand, for $m < 3$ g, this error grows sharply, which in the presented research made it impossible to analyze this range of heat transfer.

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EU TAXONOMY – IMPLEMENTATION OF THE REQUIREMENTS FOR BUILDING SECTOR

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Introduction

Regulation (EU) 2020/852 of the European Parliament and of the Council (the "Taxonomy Regulation") [1] aims to help channel capital towards activities that substantially contribute to reaching the objectives of the European Green Deal, such as climate neutrality and resilience, zero pollution, etc. The Taxonomy Regulation is expected to help direct investments in economic sectors where they are most needed for a fair green transition [2]. For this reason, the financial sector needs methodologies and guidelines that reflect the national situation of energy efficiency in the building stock.

The objective of the performed study was to develop a methodology to identify the 15% and 30% of the most energy efficient residential and non-residential buildings in Lithuania, based on the requirements of European regulations [1] and [2]. The criteria established for the study:

- the methodology for identifying the 15% and 30% of the most energy efficient national building stock in Lithuania with the best functional primary energy demand performance is based on sound evidence;
- the methodology uses data from available and reliable data sources to determine the functional primary energy demand (FDE) performance of the Lithuanian 15% and 30% most energy efficient buildings;
- the energy performance of the assets concerned must be comparable to the energy performance of the national stock of buildings built by 31 December 2020.

Methodology

The most efficient buildings in Lithuania can only be identified on the basis of the data contained in the energy performance certificate, i.e., the design energy needs, which are made publicly available in the register of the Construction Sector Development Agency [3]. 358,000 energy performance certificates were registered by 2023, of which almost 176,000 were TCAs. TCA is a typical apartment certificate issued formally without calculations assuming the lowest energy efficiency label, therefore it is assumed that it has no value as a data source.

In Lithuania, all certified buildings have energy demand (design) data, but not all the indicators in the certificate are made public in the register. Primary energy demand, although calculated and included in the certificate since 2012, is not published in the register. Also, due to a change in methodologies in 2012 and 2016, the certificates had different assessments of the total energy consumption of the building and the only indicator on which the assessment methodology can be reliably based is the heating energy consumption (kWh/m^2/year) and primary energy is in this study is further calculated based on assumptions.

The functional primary energy demand indicators for the identification of the 15% and 30% most efficient building thresholds in the study are determined by the following steps presented in the Figure 1.

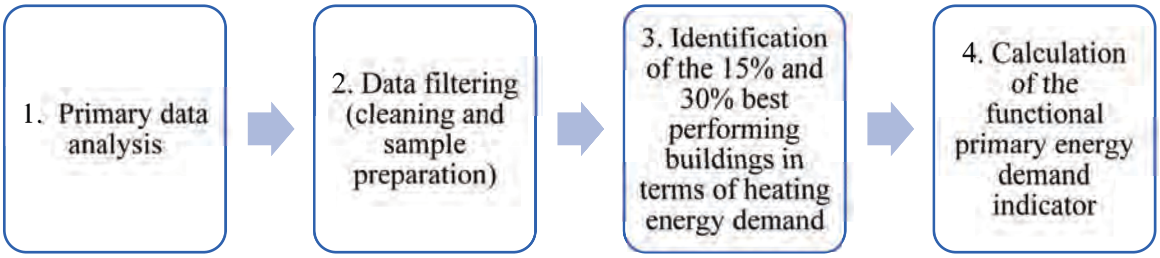

Figure 1. *Steps of the methodology*

The functional primary energy demand indicator is calculated by summing up threshold values for heating (see Table 1 and Table 2) with domestic hot water, ventilation, cooling energy demand and building's electricity demand for lighting and other purposes. Before summing up, the demand is converted to primary energy using national conversion factors.

Results

The analysis of the heating energy demand distribution between the buildings assumed to be most energy efficient is presented in Table 1 and Table 2. As it can be noticed that based on heating energy even buildings with a very low energy label (A+ is a low energy building and G is the lowest energy efficiency label) can be considered as energy efficient, as label does not always reflect the real energy efficiency, because in Lithuania energy performance assessment methodology [4] is multicriteria based and buildings must correspond to all the listed criteria for a certain efficiency label, not just energy demand.

In Tables bellow: T1 – warehouses; T2 – commercial buildings, etc.; T3 – office buildings; T4 – industrial buildings, etc.; T5 – apartment buildings; T6 – 1 or 2 family houses.

Table 1. *Heating energy demand (kWh/m^2/year) of the 15% most efficient buildings – breakdown by efficiency label*

Label	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
A	25	131	90	27	295	2918
A+	47	351	93	64	403	9108
B	59	582	395	282	1244	7103
C	8	73	135	40	567	586
D	0	41	163	7	64	262
E	1	6	26	12	3	10
F	0	15	24	7	3	51
G	0	1	5	1	1	0
Total number	**140**	**1200**	**932**	**440**	**2580**	**20038**

Table 2. *Heating energy demand (kWh/m²/year) of the 30% most efficient buildings – breakdown by efficiency label*

Label	T1	T2	T3	T4	T5	T6
A	30	164	90	33	308	4730
A+	60	433	93	74	418	11997
B	168	1244	596	544	2485	20533
C	13	223	337	121	1755	1893
D	5	200	484	41	163	691
E	3	52	115	34	14	42
F	1	81	137	30	14	181
G	0	3	11	4	2	3
Total number	**280**	**2400**	**1863**	**881**	**5159**	**40075**

Table 3. *Threshold values for functional primary energy indicators for most efficient buildings*

Building type	For 15%	For 30%
	Functional primary energy indicator, kWh/m²/year	
T1	77	100
T2	133	155
T3	121	153
T4	135	185
T5	142	161
T6	146	198

Recommendations

Based on the analysis of EU and national legislation and examples from other countries, it is recommended that the 15% and 30% most efficient buildings should be evaluated on the basis of the Functional Primary Energy Index (FPEI), which corresponds to the calculated non-renewable primary energy consumption in the Lithuanian national certification system. The detailed methodology is published in [5].

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DEVELOPMENT OF RENEWABLE ENERGY SOURCE IN POLAND

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Introduction

As a result of constant population growth and increasing levels of economic development, the demand for energy is constantly growing. However, the production and provision of energy to various industries by increasing the combustion of fossil fuels will entail irreversible processes and consequences for our planet, including a contribution to the formation of the ozone hole, biological imbalance of life, soil and air pollution, and degradation of natural resources. Tasks related to environmental protection and the use of renewable energy sources, established by various countries around the world, as well as the European Union (EU), are becoming a priority. Eliminating high-emitting fuels, especially coal, increasing energy efficiency and reducing the intensity of the energy of the economy are the most important goals of the new climate and energy policies of various countries around the world and the European Union [1, 2].

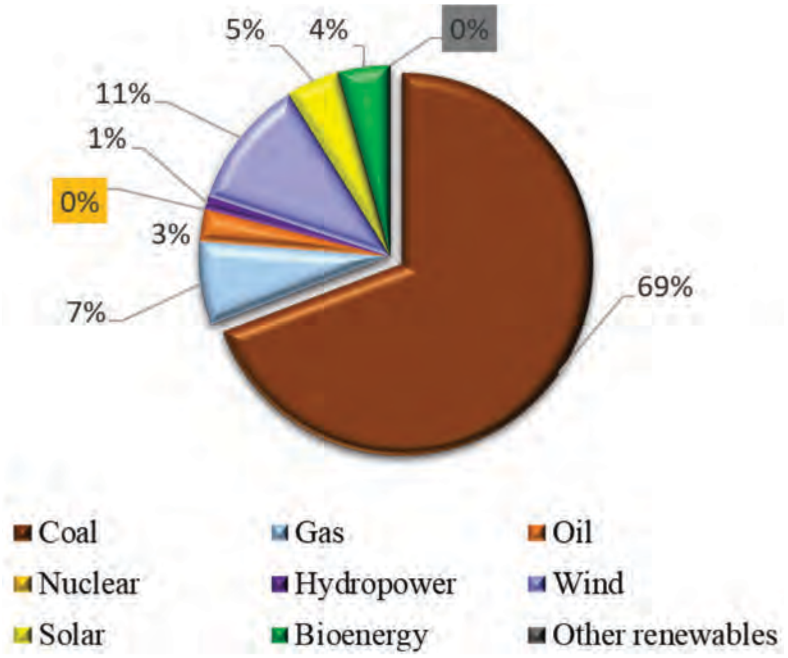
To reduce CO_2 emissions and local air pollution, the world needs to quickly transition to low-carbon energy sources – nuclear and renewable technologies. Countries around the world are united in the transition to a future based on sustainable energy. The globally adopted 2030 Agenda for Sustainable Development and the Paris Agreement on Climate Change have provided an ambitious framework for keeping global warming within safe limits. Following these goals and the principles of sustainable development in the future, our world will be dominated by low-carbon, highly efficient energy systems based on renewable energy sources with universal access for all consumers.

Poland is a significant source of carbon dioxide emissions, the main sources of which are coal power and industry. These industries are estimated to emit about 150 million tons of carbon dioxide per year. The share of coal in the country's electricity production exceeds 70% [3]. Although Poland had the highest share of coal in electricity production among IEA member countries in 2020, as well as the second highest share in heat production, in 2023, thanks to government programmes to financially support the development of renewable energy sources, Poland has made significant progress in advancing the energy transition. Government support for solar photovoltaics (PV) has made Poland one of the fastest growing PV markets in the EU. The purpose of this study was to identify the prospects for the development of renewable energy sources in Poland. Data on electricity production from fossil and renewable energy sources over the last 20 years are analyzed, forecasts, prospects, and factors that will stimulate the growth of renewable energy sources in the Polish energy mix are presented.

Production of electricity by source

Renewable energy and energy efficiency technologies are reliable and cost-effective and make sense today. The cost curve for technologies like wind, solar, and energy storage continues to drop. Both governments and the private sector will play a pivotal role in financing and deploying new clean energy projects. The main sources for the generation of electrical energy in Poland were coal (69.21%), wind (11.02%) and natural gas (7.79%) (Fig. 1a). In December 2023, total electricity production from all generation sources in Poland amounted to 179.30 TWh. The production from renewable energy sources amounted to 36.7 TWh (Fig. 1b), which already accounts for 20.4% of the total energy balance.

a) Electricity production by source in Poland 2022



b) Renewable electricity generation Poland 2023, TWh

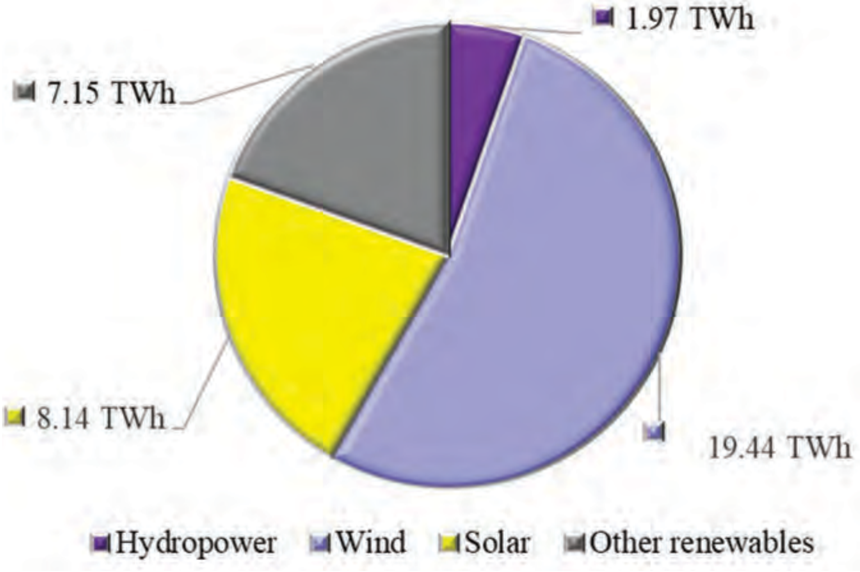


Figure 1. *Electricity production data by source [4, 5]*

Coal plays a central role in the energy system and economy. Among IEA member countries in 2020, Poland had the highest shares of coal in energy production, TES, TFC and electricity generation, and the second-highest share in heat production.

Rapid growth in solar

Despite the continued dominance of coal, Poland has had notable success in pushing for an energy transition. Government support for solar photovoltaics (PV) has made Poland one of the fastest growing PV markets in the EU. From 2016 to 2021, Poland's PV capacity increased from just 0.2 GW to 7.7 GW, mainly driven by residential deployment of 5.9 G small-scale distributed PV systems.

Wind power

The amount of energy produced from wind sources and introduced into the Polish power system is systematically increasing. Renewable energy sources In Poland, renewable energy sources also develop quite rapidly. The leading position is held by wind energy. According to data of the Energy Regulatory Office (URE), as of the end of September 2021, total installed capacity was 6347 MW (these are only onshore farms). There are more than 1339 installations in Poland that use wind as a renewable energy source with a capacity of more than 6 GW (Fig. 2a). Most wind farms are located in north-western Poland. The leader is the Zachodniopomorskie Province (716.8 MW), followed by the Pomorskie Province (246.9 MW) and the Wielkopolskie Province (245.3 MW). The current share of wind energy in all sources of renewable electricity is 57.6%. It ranked first among renewable energy sources in 2009.

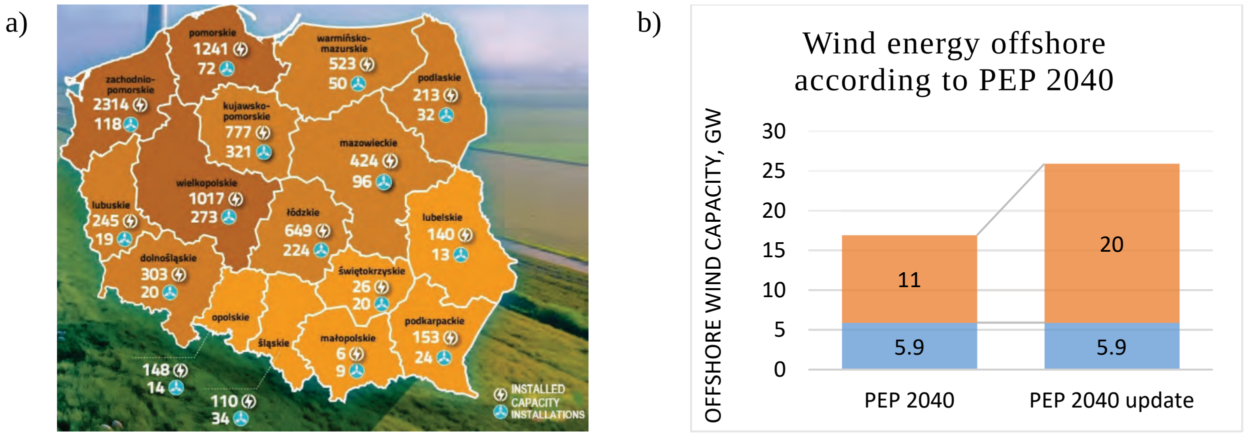


Figure 2. *Installed wind energy capacity [5]*

Poland also has a comprehensive and well-designed offshore wind strategy that has resulted in deals for 5.9 GW of capacity to come online by 2027 and plans for at least 11 GW by 2040 (Fig. 2b).

Biofuels

Traditional biomass – burning of charcoal, organic waste and crop residues – was an important energy source for a long period of human history.

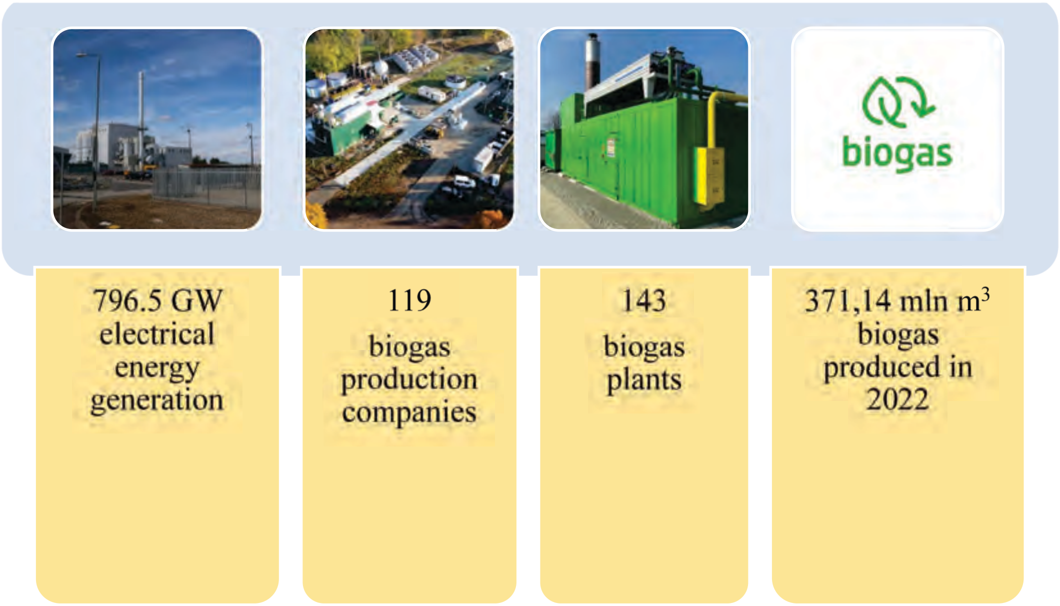


Figure 3. *Biofuel energy production [6]*

Agricultural biogas plants are supported by a new energy auction and are expected to drive biogas growth in Poland. Figure 3 presents data on the production of biogas and electricity from biofuels in Poland in 2023.

The largest production of biogas electricity, amounting to 371,14 mln m^3, was recorded in 2023, and the lowest of 24,7 mln m^3 was determined in 2004. Therefore, an almost 15-fold increase in the maximum relative change in production. In 2013 and 2015–2017, there was a significant decrease, and the rest of the period saw stabilization or a slight increase in biofuel production.

Conclusions

In 2023, the main sources for the generation of electrical energy in Poland were coal (69.21%), wind (11.02%) and natural gas (7.79%).

Currently, wind power dominates the electricity production from renewable sources at 11%. In second place is photovoltaics with 4.55%, in third place are biomass power plants (4.33%), followed by hydroelectric power plants with 1.15%.

Currently, wind energy and photovoltaics are two segments of renewable energy sources that record the fastest development dynamics. In the long term, biogas plants and biofuels, whose potential remains unexplored, may gain a considerable portion of the mix.

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COMPUTATIONAL ANALYSIS OF ELECTRIC FIELD EFFECTS ON ELECTRODIALYSIS FOR ENHANCED DESALINATION PROCESSES

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Introduction

Desalination constitutes the technologically-mediated extraction of saline and mineral constituents from marine or brackish water sources, rendering the resultant fluid suitable for potable or industrial applications. A myriad of desalination technologies are extant [1]:

1. Reverse Osmosis (RO): Predominantly, this modality stands as the epitome of energy-efficient desalination, particularly when meticulously optimised and deployed in locales with constrained freshwater availability.
2. Electrodialysis (ED): This technique excels in the treatment of low-salinity aqueous solutions and may surpass distillation in energy efficiency, albeit falling short in efficacy compared to RO for high-salinity matrices.
3. Heat Pump-Assisted Vacuum Distillation: The incorporation of a heat pump substantially augments the thermodynamic efficiency of the distillation process.
4. Multi-Stage Flash Distillation (MSF).
5. Cryogenic Desalination.
6. More…

Cutting-edge membrane technologies, distinguished for their energy efficiency, are increasingly prevalent in the domains of fluid filtration and purification [1, 2]. These technologies employ a gamut of physical mechanisms to facilitate the membrane transport of particulates. Inherent and passive transport modalities are governed by osmotic pressure interactions (osmosis) and solute concentration gradients (dialysis). Moreover, externally applied active forces, such as mechanical pressure and electrostatic fields, can also instigate membrane particulate transport.

Osmosis, Reverse Osmosis (RO), Electrodialysis, and Dialysis are distinct membrane-mediated processes, each with unique operational principles and applications, despite their apparent similarities [1]:

- osmosis is a spontaneous phenomenon where a solvent, predominantly water, traverses a semi-permeable membrane towards a region of higher solute concentration, aiming to achieve osmotic pressure equilibrium. This process is fundamental in various biological systems, including plant water uptake and cellular activities;
- dialysis facilitates the selective permeation of dissolved substances through a membrane based on molecular size and electrostatic charge. This technique is pivotal in medical applications, notably in renal dialysis, where it substitutes for impaired kidney functions;
- electrodialysis employs ion-exchange membranes to segregate ions and dissolved substances, leveraging their intrinsic electric charges. An applied electric current facilitates ion migration across the membrane, making it instrumental in various industrial applications, including water desalination and chemical separation;
- reverse osmosis (RO) is an engineered process that employs external pressure to propel a solvent through a semi-permeable membrane, counter to the direction dictated by natural osmotic pressure. RO is extensively utilized in desalination technologies and potable water recovery from lower-salinity sources.

Mathematical Model of Membrane Processes in a Thermodynamic Framework

Membrane processes are described by mass, momentum, and energy balance equations. Additional relationships, such as Maxwell's equations or chemical reactions, may serve as supplements to the fundamental equations used in describing issues related to transport through membranes. Below are the general equations describing transport through a membrane, which can then be further specified depending on the transport process being modeled. In the dialysis process, the governing equations are those of mass, momentum, and energy balance, as presented below.

Mass balance equation [3–5]:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

where: ρ – density; $\mathbf{v}$ – velocity; t – time.

Momentum balance equation [3–5]

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla)\mathbf{v}\right) = -\nabla P + \rho g + \nabla \cdot \mathbf{T} + \rho \boldsymbol{F_{elmag}}$$

where: P – pressure; g – gravity vector; $\mathbf{T}$ – shear stress tensor; $\boldsymbol{F_{elmag}}$ – electromagnetic force.

Energy balance equation [3–5]:

$$\rho c\left(\frac{\partial T}{\partial t} + (\mathbf{v} \cdot \nabla)\mathbf{T}\right) = -\boldsymbol{P}\nabla \cdot \mathbf{v} + \nabla \cdot (k \nabla T) + Q_{heat} + Q_{elmag}$$

where: T – fluid temperature; c – heat capacity of the fluid; k – thermal conductivity of the fluid; Q_{heat} – heat flux originating from chemical reactions or other processes; Q_{elmag} – heat flux introduced due to electromagnetic field interactions.

To model membrane processes in an electromagnetic field environment, Maxwell's equations are introduced [3]:

Gauss's Law for Electric Field:

$$\nabla \cdot E = \frac{\rho_e}{\varepsilon_o}$$

Gauss's Law for Magnetic Field:

$$\nabla \cdot B = 0$$

Faraday's Law of Electromagnetic Induction:

$$\nabla \times E = -\frac{\partial E}{dt}$$

Ampère's Law with Conductance:

$$\nabla \times B = \mu_0 J + \mu_0 \varepsilon_o \frac{\partial E}{dt}$$

where: E – electric field; B – magnetic field; ρ_e – electric charge density; J – electric current density; ε_o – electric permittivity in vacuum; μ_0 – magnetic permeability in vacuum; t – time; $\nabla \cdot$ – divergence; $\nabla \times$ – curl.

For the above equations, the general Onsager relations (Fourth Law of Thermodynamics) can be written in matrix form, describing non-equilibrium phenomena occurring in membrane systems interacting with an electromagnetic field [7, 8, 4, 5]:

$$\begin{bmatrix} J_v \\ J_m \\ J_C \\ J_q \\ J_e \\ J_b \end{bmatrix} = \begin{bmatrix} L_{11} & L_{12} & L_{13} & L_{14} & L_{15} & L_{16} \\ L_{21} & L_{22} & L_{23} & L_{24} & L_{25} & L_{26} \\ L_{31} & L_{32} & L_{33} & L_{34} & L_{35} & L_{36} \\ L_{41} & L_{42} & L_{43} & L_{44} & L_{45} & L_{46} \\ L_{51} & L_{52} & L_{53} & L_{54} & L_{55} & L_{56} \\ L_{61} & L_{62} & L_{63} & L_{64} & L_{65} & L_{66} \end{bmatrix} \begin{bmatrix} -\nabla P_m \\ -\nabla P_o \\ -\nabla C \\ -\nabla T \\ -\nabla E \\ -\nabla B \end{bmatrix}$$

where: J_v – volumetric flux induced by the mechanical pressure gradient $-\nabla P_m$; J_m – volumetric flux induced by the osmotic pressure gradient $-\nabla P_o$; J_C – volumetric flux induced by the concentration gradient $-\nabla C$; J_q – heat flux induced by the temperature gradient $-\nabla T$; J_e – electric charge flux induced by the electric field gradient $-\nabla E$; J_b – magnetic flux induced by the magnetic field gradient $-\nabla B$.

In the electrodialysis process, it is assumed that only the concentration gradient and the electric field are present, serving as stimuli for ion flow through the membrane system. The general Onsager matrix simplifies to a two-dimensional matrix due to these two stimuli:

$$\begin{bmatrix} J_C \\ J_e \end{bmatrix} = \begin{bmatrix} L_{11} & L_{12} \\ L_{21} & L_{22} \end{bmatrix} \begin{bmatrix} -\nabla C \\ -\nabla E \end{bmatrix}$$

The individual flux equations are represented as:

$$J_C = \frac{dC}{dt}, \quad J_C = \frac{dq}{dt}$$

$$\begin{cases} \dfrac{dC}{dt} = -L_{11}\nabla C - L_{12}\nabla E \\ \dfrac{dq}{dt} = -L_{21}\nabla C - L_{22}\nabla E \end{cases}$$

For each *i*-th component of the fluid, the equations can be written as:

$$\frac{dC_i}{dt} = D_i \nabla C_i + F C_i z_i u_{m,i} \nabla E$$

$$\frac{dq}{dt} = I = F \sum_i \left(-F C_i z_i^2 u_{m,i} \right) \nabla E$$

$$I = -k \nabla E$$

The Onsager matrix coefficients are (assuming that the cross-effect of concentration on electric current $L_{21} = 0$, is neglected).

$$L_{11} = D_i$$

$$L_{12} = F C_i z_i u_{m,i}$$

$$L_{22} = k = F \sum_i \left(-F C_i z_i^2 u_{m,i} \right)$$

The above equations were used in modeling the electrodialysis process, which is presented in the next chapter.

Computational Fluid Dynamics (CFD) Calculations of the Electrodialysis Process for Saline Water

Computational Fluid Dynamics (CFD) calculations were performed assuming three computational domains, with the fluids bordering a membrane on which electrodes were placed to induce salt ion transport. The assumptions are as follows:

- for the dialysate and permeate in the steady state, the equation includes convective, diffusive, and migration terms influenced by the electric field [1]:

$$\nabla \cdot \left(-D_i \nabla C_i - F C_i z_i^2 u_{m,i} \nabla E\right) + \mathbf{u} \cdot \nabla C_i = 0$$

- for the membrane in the steady state, the equation includes diffusive and migration terms influenced by the electric field [1]:

$$\nabla \cdot \left(-D_i \nabla C_i - F C_i z_i^2 u_{m,i} \nabla E\right) = 0$$

The electric field interacts only within the membrane area due to the placement of electrodes at the membrane boundaries. The equation describing the electric field in the steady state is [1]:

$$\nabla \cdot \left(\varepsilon_0 \varepsilon_r \nabla E\right) = 0$$

On both boundary conditions for the electric field, it is assumed that $E = V$ consistent with the notations in Figure 1. The following assumptions were made $D_i = 10^{-9}\ \frac{\mathrm{m}^2}{\mathrm{s}}$ for both the fluid and membrane regions, relative electrical permittivity for water $\varepsilon_r = 80$, moblility $u_{m,i} = 0.000001\ \frac{\mathrm{s \cdot mol}}{\mathrm{kg}}$, charge numer $z_i = 10$ l, and F is Faraday's constant.

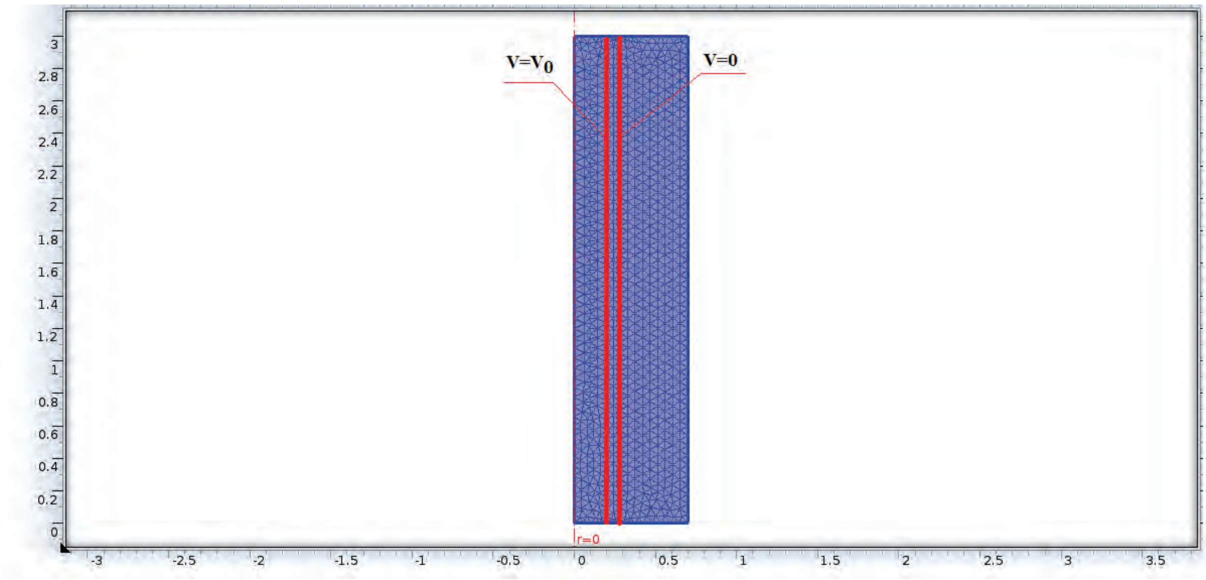

Figure 1. *Geometry of the Membrane System and Boundary Conditions for the Electric Field*

Discontinuities at the phase boundary between the membrane and the fluid are described by the following relations [1]:

- between the dialysate and the membrane:

$$\left(-D_d \nabla C_1 - F C_1 z_i^2 u_{m,i} \nabla E + C_1 \mathbf{u}\right) \cdot \mathbf{n} = M\left(c_2 - K c_1\right)$$

$$\left(-D_m \nabla C_2 - F C_2 z_i^2 u_{m,i} \nabla E\right) \cdot \mathbf{n} = M\left(K c_1 - c_2\right)$$

– between the membrane and the permeate:

$$\left(-D_m \nabla C_2 - F C_2 z_i{}^2 u_{m,i} \nabla E\right) \cdot \mathbf{n} = M\left(K c_3 - c_2\right)$$

$$\left(-D_p \nabla C_3 - F C_3 z_i{}^2 u_{m,i} \nabla E + C_3 \boldsymbol{u}\right) \cdot \mathbf{n} = M\left(c_2 - K c_3\right)$$

where: $K = 0.7$ and $M = 1e4\ \frac{\text{m}}{\text{s}}$.

Below are the calculations for concentration distribution obtained from the presented model. The calculations were performed assuming that the dialysate at the inlet has a concentration of $C_{d,in} = 1\ \frac{\text{mol}}{\text{l}}$. The figure illustrates the concentration equilibration along the dialysis path, resulting from convective movements and ion transport due to concentration differences. The electrodialysis modeling results for a system where the electric field is turned off are presented below (Figure 2).

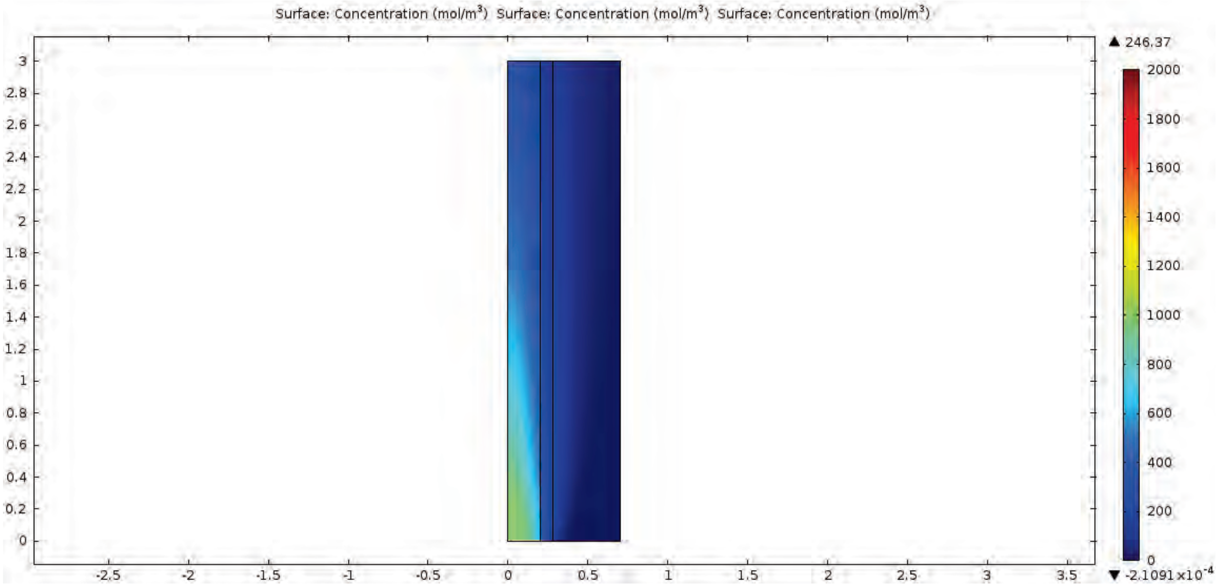

Figure 2. *Calculation Results for Concentrations in the Dialysis Process*

Figures 3 and 4 below present the modeling results of the electrodialysis process when the electric field is activated (Figure 4). Electrodes generating the electric field are placed at the membrane boundaries, intensifying the salt ion transport into the permeate space (Figure 3).

The results shown in Figures 3 and 4 illustrate the impact of the electric field on the salt ion transport process through the membrane. The influence of the electric field operating in the membrane area intensifies mass exchange. At the dialysate-membrane phase boundary, a reduced salt solution concentration in water is observable. Also, at the membrane-permeate boundary, an increase in concentration is evident in the solid-liquid phase boundary area. Comparing Figures 2 and 3, it is evident that the effluent (purified) liquid has significantly lower salt concentrations in the presence of an electric field.

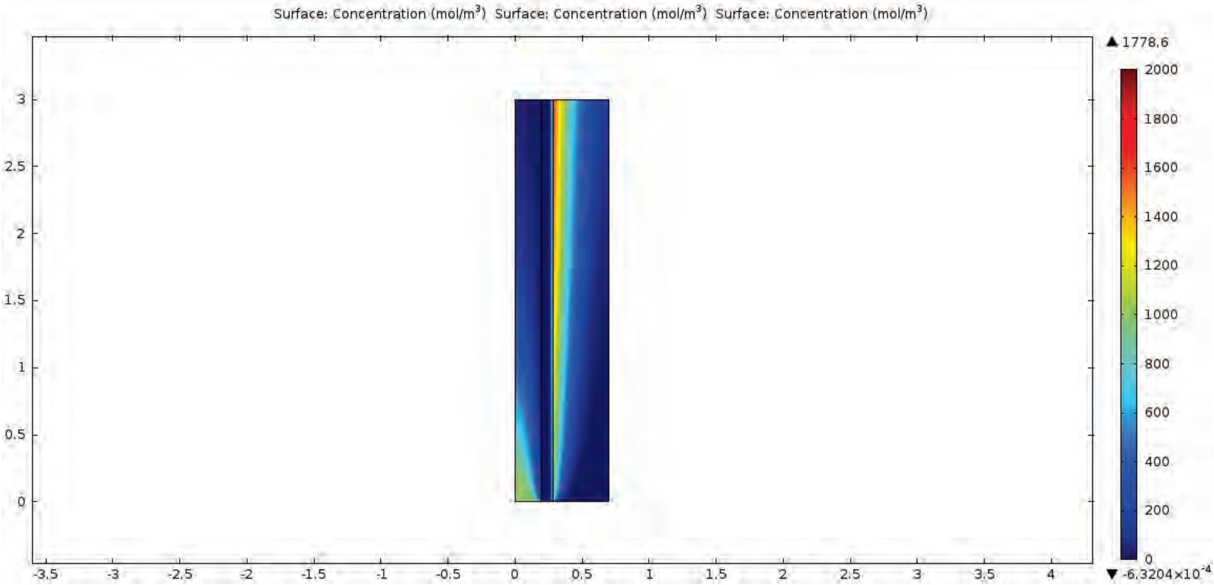

Figure 3. *Calculations of Transport Intensification Through the Membrane Due to the Applied Electric Field*

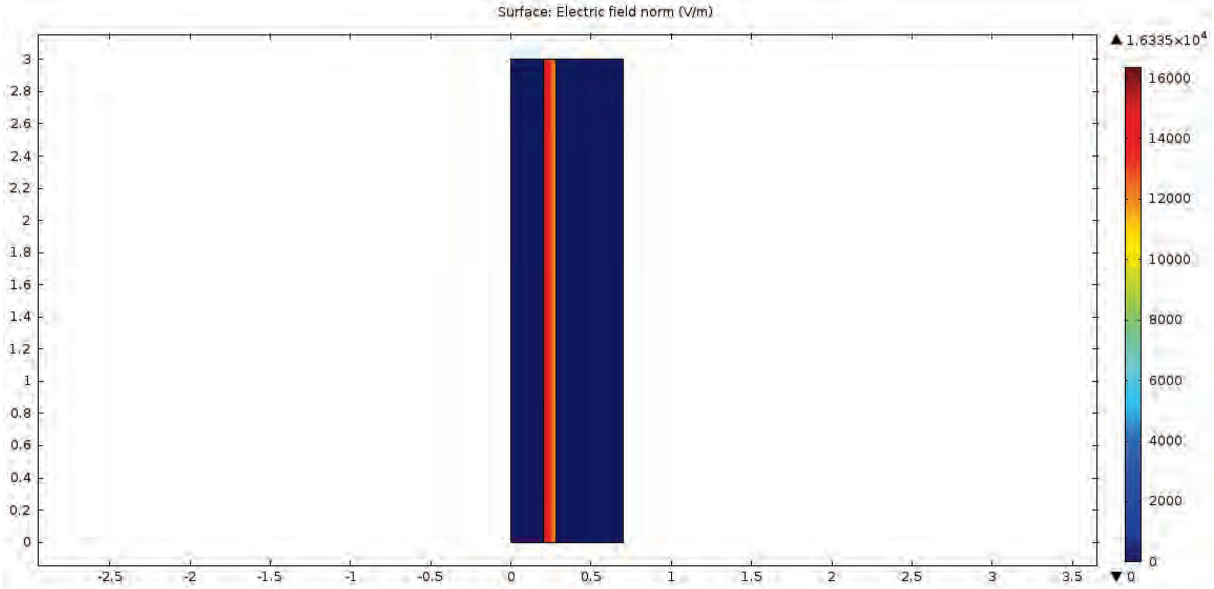

Figure 4. *Electric Field Resulting from the Interaction of Electrodes Placed at the Membrane Boundaries*

Conclusions

This study focuses on modeling the impact of an electric field in the electrodialysis process, aiming to intensify desalination procedures. The paper presents:

1. **Description of Membrane Technologies**: Various desalination technologies such as reverse osmosis, electrodialysis, vacuum distillation with heat pump, multi-stage distillation, and cryogenic desalination are discussed. It is pointed out that membrane technologies are currently the most energy-efficient in the field of fluid filtration and purification.
2. **Theoretical Foundations of Membrane Operations**: Differences between osmosis, dialysis, electrodialysis, and reverse osmosis are presented. Attention is drawn to particle transport mechanisms through the membrane, such as osmotic pressure, concentration differences, and active interactions.
3. **Mathematical Model of Membrane Processes**: Membrane processes are described in the context of mass, momentum, and energy balance equations. Maxwell's equations, which describe electromagnetic interactions in membrane systems, are introduced. Onsager's

relations, describing non-equilibrium issues in membrane systems under the influence of an electromagnetic field, are also presented.

4. **CFD Calculations of Electrodialysis in Saline Water**: Modeling results of electrodialysis in the absence and presence of an electric field are presented. The results show that the electric field intensifies the transport of salt ions through the membrane, leading to more efficient desalination.

The study proves that the electric field can significantly impact the efficiency of the electrodialysis process, which is crucial for the industry of water purification and seawater desalination.

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Faculty of Environmental Engineering, Geomatics and Renewable Energy
Kielce University of Technology, Poland