МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра авіаційних комп'ютерно-інтегрованих комплексів

ДОПУСТИТИ ДО ЗАХИСТУ

Завідувач випускової кафедри

_______Віктор СИНЄГЛАЗОВ

"_____"_____________2023 р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ

"МАГІСТР"

Спеціальність 151 "Автоматизація та комп'ютерно-інтегровані технології " Освітньо-професійна програма " Інформаційне забезпечення та інженерія авіаційних комп'ютерних систем"

Тема: «Автоматизована система опалення житлових приміщень підвищенної енергоефективності»

Виконавець: студент групи ІЗ-225Ма Мізерний Руслан Олексійович

Керівник: кандидат технічних наук, доцент Сергеєв Ігор Юрійович

Консультант розділу «Охорона навколишнього середовища»____Радомська М.М.

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Нормоконтролер:__________Філяшкін М.К

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Київ – 2023

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

Faculty of Aeronautics, Electronics and Telecommunications

Department of aviation computer-integrated complexes

ADMIT TO DEFENSE

Head of the graduation department

_______Viktor SINEGLAZOV

"____"_____________2023

QUALIFICATION WORK

(EXPLANATORY NOTE)

GRADUATE DEGREE OF EDUCATION

"MASTER"

Specialty 151 "Automation and computer-integrated technologies"

Educational and professional program " Information support and engineering of aviation computer systems "

Topic: "Automated residential heating system with increased energy efficiency"

Performer: student of group IZ-225Ma Mizernyi Ruslan Olexiyovich

Supervisor: candidate of technical sciences, associate professor Sergeyev Igor Yuriyovych

Consultant of the "Environmental Protection" section _______Radomska M.M.

Consultant of the "Labor Protection" section ______ Kazhan.K.I.

Normocontroller:_______ Filyashkin M.K

Kyiv – 2023

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра авіаційних комп’ютерно-інтегрованих комплексів

Освітній ступінь: магістр

Спеціальність 151 «Автоматизація та комп'ютерно-інтегровані технології» Освітньо-професійна програма «Інформаційне забезпечення та інженерія авіаційних комп’ютерних систем»

ЗАТВЕРДЖУЮ

Завідувач кафедри

______Віктор СИНЄГЛАЗОВ

“_____”_____________2023 р.

ЗАВДАННЯ

на виконання кваліфікаційної роботи студента

Мізерного Руслана Олексійовича

1. **Тема роботи:** “Автоматизована система опалення житлових приміщень підвищенної енергоефективності”.
2. **Термін виконання роботи:** з 02.10.2023р. до 18.12.2023р.
3. **Вихідні дані до роботи:** Розробка схеми підключення енергоефективних датчиків. Написання коду. Вибір автоматизованної системи опаленення. Розрахунки енергоефективності. Аналіз результатів.
4. **Зміст пояснювальної записки (перелік питань, що підлягають розробці):**

1. Аналіз архітектурно-будівельних енергоефективних методів.
2. Ознайомлення з автоматизованими системами опалення житлових будинків.
3. Вибір системи, датчиків, їх встановка, та розрахунок енергоефективності.
4. Розробка та написання коду для плати Arduino.

5. Перелік обов’язкового графічного матеріалу: 1.Схеми датчиків та розрахунки енергоефективності. 2. Автоматизована система обігріву. 4. Написання коду 5. Висновки.

6. Календарний план-графік

№	Завдання	Термін виконання	Відмітка про виконання
1	Отримання завдання	02.10.2023	
2	Формування мети та завдання	04.10.2023	
3	Аналіз актуальності проблеми	05.10.2023-11.10.2023	
4	Аналіз існуючих методів	13.10.2023-25.10.2023	
5	Опис об'єкта дослідження та його характеристика	25.10.2023-05.11.2023	
6	Підбір обладнання	08.11.2023-18.11.2023	
7	Ознайомлення з датчиками та системами автоматиз. обігріву	20.11.2023-27.11.2023	
8	Розробка підключень датчиків, написання коду, вибір системи	03.12.2023-12.12.2023	
9	Написання висновків	13.12.2023-17.12.2023	
10	Оформлення пояснювальної записки	17.12.2023	
11	Підготовка презентації	17.12.2023	

7. Консультанти з окремих розділів

Розділ	Консультант (посада, П. І. Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці	Катерина КАЖАН		
Охорона навколишнього середовища	Маргарита РАДОМСЬКА		

8. Дата видачі завдання 02.10.2023

Керівник: _____________Ігор СЕРГЕЄВ

Завдання прийняв до виконання ______________Руслан МІЗЕРНИЙ

NATIONAL AVIATION UNIVERSITY

Faculty of aeronavigation, electronics and telecommunications

Department of Aviation Computer Integrated Complexes

Educational level: Master

Specialty: 151 “Automation and computer-integrated technologies”

APPROVED

Head of Department

Viktor SINEGLAZOV

“____” __________2023

TASK

For the student's qualification work

Mizernyi Ruslan Oxexiyovich

1. **The thesis title:** "Automated residential heating system with increased energy efficiency"

2. **The term of the project:** from 02.10.2023р. until 18.12.2023р.

3. **Output data to the project:** Development of the connection scheme for energy-efficient sensors. Code writing. Selection of an automated heating system. Energy efficiency calculations. Results analysis.

4. **Contents of the explanatory note:**

1. Analysis of architectural and construction energy-efficient methods.
2. Familiarization with automated heating systems for residential buildings.
3. Selection of a system, sensors, their installation, and energy efficiency calculations.
4. Development and writing of code for an Arduino board.

5. **List of required illustrative material:** 1. Sensor schematics and energy efficiency calculations. 2. Automated heating system. 3. Code writing. 4. Conclusions.

№	Завдання	Термін виконання	Відмітка про виконання
1	Receiving the task	02.10.2023	
2	Formation of the goal and task	04.10.2023	
3	Analysis of the relevance of the problem	05.10.2023-11.10.2023	
4	Analysis of existing methods	13.10.2023-25.10.2023	
5	Description of the research object and its characteristics	25.10.2023-05.11.2023	
6	Selection of equipment	08.11.2023-18.11.2023	
7	Familiarization with sensors and automated heating systems	20.11.2023-27.11.2023	
8	Development of sensor connections, code writing, system selection	03.12.2023-12.12.2023	
9	Drawing conclusions	13.12.2023-17.12.2023	
10	Issuance of an explanatory note	17.12.2023	
11	Presentation preparation	17.12.2023	

6. Planned schedule.

7. Consultants from individual departments

Section	Consultant	Date, signature	
		Issued the task	I accepted the task
Labor protection	Katerina KAZHAN		
Environmental protection	Marharyta RADOMSKA		

8. Issue date of the task 02.10.2023

Supervisor: __________Igor SERGEYEV

The task was accepted by: __________Ruslan MIZERNYI

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи: «Автоматизована система опалення житлових приміщень підвищенної енергоефективності»: 98с., 38рис., 21 лієратурних джерел.

АВТОМАТИЗАЦІЯ, СИСТЕМИ ОПАЛЕННЯ, ЕНЕРГОЕФЕКТИВНІСТЬ, РОЗРОБКА СИСТЕМИ, ЕНЕРГОЕФЕКТИВНІ ДАТЧИКИ, НАПИСАННЯ КОДУ.

Предмет дослідження: Підвищення ергоефективності шляхом розробки автоматизованої системи опалення для житлових приміщень

Мета кваліфікаційної роботи: Розробка енергоефективної автоматизованої системи опалення для житлових приміщень

Метод дослідження: Аналіз літературних джерел, практичне впровадження технічних рішень, дослідження.

Об'єкт дослідження: Автоматизовані системи обігріву, Системи обігріву на основі ШІ

Основні результати дослідження: Ознайомлення з системами обігріву, датчиками, програмуванням мікроконтролера. Використання автоматизованної системи обігріву дозволить заощаджувати і зберегти екологію

Рекомендації та подальші напрями досліджень: Результати роботи можуть бути використані в практичній діяльності різних підприємств, країн для більш енергоефективної розробки систем опалення та зберігання навколишнього середовища.

ABSTRACT

Explanatory note of the qualification work: "Automated residential heating system with increased energy efficiency": 98p., 38 figures, 21 references.

AUTOMATION, HEATING SYSTEMS, ENERGY EFFICIENCY, SYSTEM DEVELOPMENT, ENERGY-EFFICIENT SENSORS, CODE WRITING.

Research Subject: Increasing energy efficiency through the development of an automated heating system for residential premises

Objective of the Qualification Work: Development of an energy-efficient automated heating system for residential premises

Research Method: Analysis of literature sources, practical implementation of technical solutions, experimentation.

Research Object: Automated heating systems, IoT-based heating systems

Key Research Findings: Familiarization with heating systems, sensors, microcontroller programming. The use of an automated heating system will enable energy savings and environmental preservation.

Recommendations and Future Research Directions: The results of the work can be applied in the practical activities of various enterprises and countries for more energy-efficient development of heating systems and environmental conservation.

CONTENT

INTRODUCTION

1 Relevance of the issue

In the context of undeniable human impact on the planet's ecosystem, the question of energy sustainability and efficient resource utilization becomes more acute. The methods employed for residential heating today not only demand thriftiness but also necessitate long-term sustainability in the face of climate change and the need for environmentally responsible solutions.

2 Brief overview of the importance of residential heating systems

Residential heating systems play a pivotal role in maintaining comfortable living environments, especially in regions with cold climates. As the winter season approaches, the significance of reliable and efficient heating becomes paramount for the well-being of individuals and families. Beyond mere comfort, adequate heating is essential for preventing health issues associated with cold temperatures, such as hypothermia and respiratory problems. Additionally, it contributes to the preservation of property by preventing damage caused by freezing temperatures, such as burst pipes.

3 Research objective

The primary goal of our research is the development and thorough analysis of innovative, automated heating systems aimed at energy efficiency and minimizing environmental impact. This represents not just a technological challenge but a strategic step in redefining our contribution to planetary well-being.

4 The need for increased energy efficiency in home heating

The traditional methods of heating homes often involve the use of fossil fuels, such as natural gas or heating oil, which not only contribute to environmental pollution but also lead to escalating energy costs for homeowners. In the face of global concerns about climate change and the depletion of natural resources, there is a growing imperative to shift towards more sustainable and energy-efficient heating solutions. This need is further underscored by the rising costs of energy and the desire for homeowners to reduce their carbon footprint.

5 Introduction to automated systems as a solution

Recognizing the need for energy-efficient heating solutions, automated systems emerge as a promising avenue to address these challenges. Automated residential heating systems leverage advanced technologies, such as smart sensors, machine learning algorithms, and Internet of Things (IoT) connectivity, to optimize the heating process. These systems can intelligently adapt to the occupants' preferences, weather conditions, and the thermal characteristics of the building, resulting in more precise and efficient heating. By automating various aspects of the heating process, these systems not only enhance user comfort but also contribute significantly to reducing energy consumption and, consequently, lowering utility bills.

In this qualification work, we will delve into the key features and benefits of automated residential heating systems, exploring how they enhance energy efficiency, provide cost savings, and contribute to a more sustainable and environmentally friendly approach to home heating. Additionally, we will examine the current landscape of such technologies, discussing their potential impact on residential energy consumption and the broader implications for a greener and more efficient future.

6 Role of Artificial Intelligence

The introduction of artificial intelligence into heating systems opens new horizons for optimization. Considering the colossal volume of real-time data available, AI can transform heating management into a flexible and responsive system capable of predicting and adapting to user needs and changes in climatic conditions.

7 Significance of the research

In the face of global challenges confronting humanity, this research represents not only a technological development but an act of responsibility. Proposed solutions should not only enhance living comfort but also become a reliable element in the collective pursuit of sustainability and resource conservation for future generations.

8 Research methodology

Throughout the research, we will conduct an analysis of various technologies, including cutting-edge developments in materials, energy-saving technologies, and aspects of using renewable energy sources. The combination of engineering and ecological methods will help achieve a balance between efficiency and responsibility.

9 Expected outcomes

It is anticipated that the results of my thesis will shed light on several financial and environmental challenges in residential heating, along with effective ways to address them. This thesis will explore various automated heating systems, including those utilizing artificial intelligence. The objective of the work is to identify optimal solutions for addressing energy efficiency issues and to develop a customized automated heating system for residential spaces.

Problem statement

1 Traditional residential heating systems and overview of traditional heating methods

Traditional residential heating systems have long relied on conventional methods such as furnaces and boilers to generate and distribute heat throughout homes. Furnaces typically burn fuel, like natural gas or oil, to produce hot air, which is then circulated through ducts to various rooms. On the other hand, boilers heat water, and the resulting steam or hot water is circulated through pipes to provide warmth.

These systems have been the backbone of residential heating for decades, offering a relatively straightforward means of maintaining indoor temperatures. However, advancements in technology and a growing awareness of environmental issues have highlighted the limitations and drawbacks of these traditional approaches.

2 Common issues and inefficiencies in traditional systems

Traditional heating systems often face several common issues and inefficiencies that can compromise their effectiveness and contribute to higher energy consumption. Inadequate insulation, for example, can lead to heat loss, forcing the heating system to work harder to maintain a desired temperature. Ductwork in forced-air systems may develop leaks, resulting in uneven heating and energy wastage.

Moreover, traditional systems lack the adaptability to respond dynamically to changing conditions. They typically operate on fixed schedules or manual adjustments, leading to unnecessary heating when occupants are away or excessive energy consumption during milder weather. The lack of precise control can also result in certain areas of a home being overheated while others remain too cold.

3 Environmental impact of conventional heating methods

The environmental impact of conventional heating methods is a significant concern in an era where sustainability is a top priority. The burning of fossil fuels in furnaces and boilers releases carbon dioxide (CO_2) and other pollutants into the atmosphere, contributing to air pollution and climate change. The extraction and transportation of these fuels also have environmental consequences, including habitat disruption, water pollution, and landscape degradation.

In addition to greenhouse gas emissions, traditional heating systems may involve the use of non-renewable resources, further depleting finite reservoirs of fossil fuels. As society becomes increasingly conscious of the need to reduce its carbon footprint and transition to cleaner energy sources, there is a growing demand for alternative heating solutions that are both efficient and environmentally friendly.

In the following sections, we will explore how automated residential heating systems address these issues and provide a more sustainable and energy-efficient alternative to traditional methods.

CHAPTER 1

TECHNOLOGIES AND METHODS TO IMPROVE ENERGY EFFICIENCY IN CONSTRUCTION AND EXISTING RESIDENTIAL SPACES

1.1 Technologies for Improving Energy Efficiency in Modern Construction

There are numerous automated and energy-efficient heating systems available today. There are individual measures to prevent heat loss using energy-saving technologies in building construction, as well as energy-efficient heating systems. Each system has its own properties, advantages, and disadvantages, serving different purposes and functionalities.

Moreover, certain standards have become mandatory in the construction of new housing. Energy efficiency in construction isn't just a trend but a necessity due to the increasing cost of natural resources in modern conditions. Energy-saving technologies in heating supply are a pressing issue, given the gradual rise in communal tariffs. Everything indicates that in the future, a crucial factor in choosing housing will be its energy efficiency.

Energy-saving technologies in the construction of residential buildings are widely used in modern construction. Measures aim to increase the energy efficiency of buildings.

The use of modern energy-efficient materials and structures-such as mineral-based materials, high-quality thermal insulation, facade systems with cladding or plastering, and the construction of efficient boilers-plays a significant role.

To a large extent, the final result depends on the qualifications and expertise of the project authors, as well as the quality of construction work.

Often, energy consumption in apartments occurs inefficiently. While creating comfort and coziness, energy is consumed highly uneconomically. Effective energy-saving methods are relatively simple yet enable significant savings in natural resources and financial expenses.

Energy-saving technologies for residents include installing heat recovery ventilation systems, using energy-efficient windows and modern door systems.

Additionally, incorporating energy-saving light bulbs, installing water heaters, and heat meters are part of the list.

The possibility of installing Smart Home technology is also highlighted. An intelligent system that integrates and controls all essential utilities in an apartment, providing easy management through a mobile application.

All these measures are aimed at reducing consumption and maximizing the rational use of natural resources.

Energy-saving technologies in Ukraine aim to align with European standards, which include the installation of solar panels, harnessing wind energy, installing heat pumps, and greening roofs for heat preservation.

As mentioned earlier, there are not only energy-efficient heating systems but also standards for the construction of new buildings, as well as measures for retaining heat in long-established spaces. When considering standards for new constructions, they include: proper orientation of buildings with consideration for terrain relief, cardinal directions, wind directions, and the choice of building shapes. In addition to architectural and construction characteristics, the thermal insulation properties of enclosing structures play a crucial role.

The use of modern materials for external enclosing structures, advanced insulation materials for external walls, coverings, and floor structures, as well as the utilization of mineral-based materials with thermal insulation, allows for a significant reduction in heat losses from buildings during the cold periods of the year. Besides the materials of solid enclosing structures, glazing plays a significant role in preventing heat losses, as a substantial portion of heat loss occurs through external enclosing structures.

The application of double-glazed windows with varying numbers of chambers and filling chambers with different gases (air, argon, krypton) allows for a substantial reduction in thermal resistance to heat transfer and minimizes heat losses during the cold periods of the year, virtually eliminating the infiltration of outside air.

In addition to windows, it is crucial to use thermal insulation materials for insulating both basement and attic structures, improve ventilation systems, install thermal insulation doors, and incorporate heat-reflecting screens and heating regulators, infrared sensors, and screen systems.

The use of LED lighting, motion sensors in common areas and in more expensive options, automated systems based on artificial intelligence, or the utilization of non-traditional renewable sources such as solar panels or wind generators, are all crucial. All these measures are vital since heat losses occur through walls, roofs, windows, ventilation systems, and exterior doors.

Figure 1 Volumetric-planning and constructional measures for energy conservation in the systems of creating artificial climate in buildings

Figure 2 Percentage ratio of heat losses in a building

1.2 Solutions to energy efficiency issues in old houses

As for already constructed buildings, there are also some methods for effective energy saving. These methods can be categorized as long-term measures requiring significant capital investment, with payback periods of more than 5 years, medium-term measures with payback periods of 2 to 5 years, and priority measures with payback periods of up to 2 years.

Each of these methods has its own disadvantages and advantages, and its own price category. So, for example, in medium-term measures some methods can be cheaper than the primary or, on the contrary, more expensive than long-term, but they all make sense only if they are not carried out separately, but simultaneously extracting all the advantages and removing the disadvantages.

The mere replacement of windows with new airtight ones can create problems with natural air ventilation, which can lead to unfavorable consequences in the form of high humidity and poor air quality, this will entail the likelihood of fungal infections on the structures. Or, for example, uncomfortable indoor air temperatures are often attributed to poor thermal insulation of the exterior fences or facade of the building.

However, insulation of the building (without proper modernization of the heating system), removing complaints, only aggravates the problem of low efficiency of the heating system, due to overconsumption of heat energy.

Excessive heat supply, the so-called "overheating" of premises is eliminated, at best, with the help of thermostats (or other regulating valves), at worst - with the inflow of cold air through open windows.

To encourage the population to reduce heat consumption, recommendations and programs have been developed to introduce individual and communal heat metering devices.

It should be noted that replacement of piping material, type and number of sections of heating devices is also not the best option for reconstruction, as it leads to disruption of the heating system as a whole, i.e. thermal and hydraulic imbalance.

Figure 3 Comparison of the battery tube before and after flushing

Even some off-the-shelf systems that support the Danfoss-type energy-saving concept, which includes:

- automatic maintenance of the temperature schedule at the building inlet;

- qualitative-quantitative regulation of the system heat output, including thermostatic regulation on heating devices and risers;
- automatic maintenance of the required/calculated distribution of the heat carrier flow over all sections of the system;
- individual heat metering, motivated by payment based on actual consumption,

are not without disadvantages, namely: expensive automation (automated heating control units, balancing valves, thermostats, thermostats, thermostats) far from always achieve the expected result, which is explained by the lack of proper water treatment, quality maintenance and theoretical justification.

Also, when improving the energy efficiency of the heating system, it is necessary to take into account the operation of the ventilation system: the introduction of thermostats should be conditioned by the presence of a constant air exchange in the normative volume.

The most hydraulic and thermal stability have horizontal heating systems of buildings. The above requirements are met by a heating system containing network water mains, local heating point, supply and return pipelines, combined with vertical supply and return risers, to which are connected floor branches with heating devices. The system is provided with apartment heat points, each of which is limited to one apartment and connected respectively to vertical supply and return risers placed in that apartment. Further, each of these pipelines is connected to individual supply and return risers of the building.

The disadvantage of this technical solution is low sanitary and hygienic indicators of the premises, associated with uneven heating of the supply air. Therefore, the known solutions do not allow to fully provide the required parameters of the heat and air regime of buildings.

As heating devices are installed radiators connected to the floor horizontal branches, which are connected to the risers of the heating system. One of these risers is the supply riser and the other is the return riser. These two risers limit the length of the floor branches to one apartment. In order to reduce material costs, the existing risers are not replaced by new risers, they have the original arrangement. The supply unit is installed in the kitchen and is connected to (the remaining two supply and return risers), which are connected to the supply and return pipes of the heating system, as well as to the supply and return risers for the supply and return of the heating medium from the radiators.

Due to the fact that the proposed scheme additionally contains a supply unit, in a room or a group of rooms there is a constant supply and heating of fresh air, which corresponds to an increase in sanitary and hygienic conditions of individual rooms and the building as a whole. In addition, this solution will provide a reduction in the required heat output of radiators, which will lead to an increase in the efficiency of individual regulation of heat energy consumption.

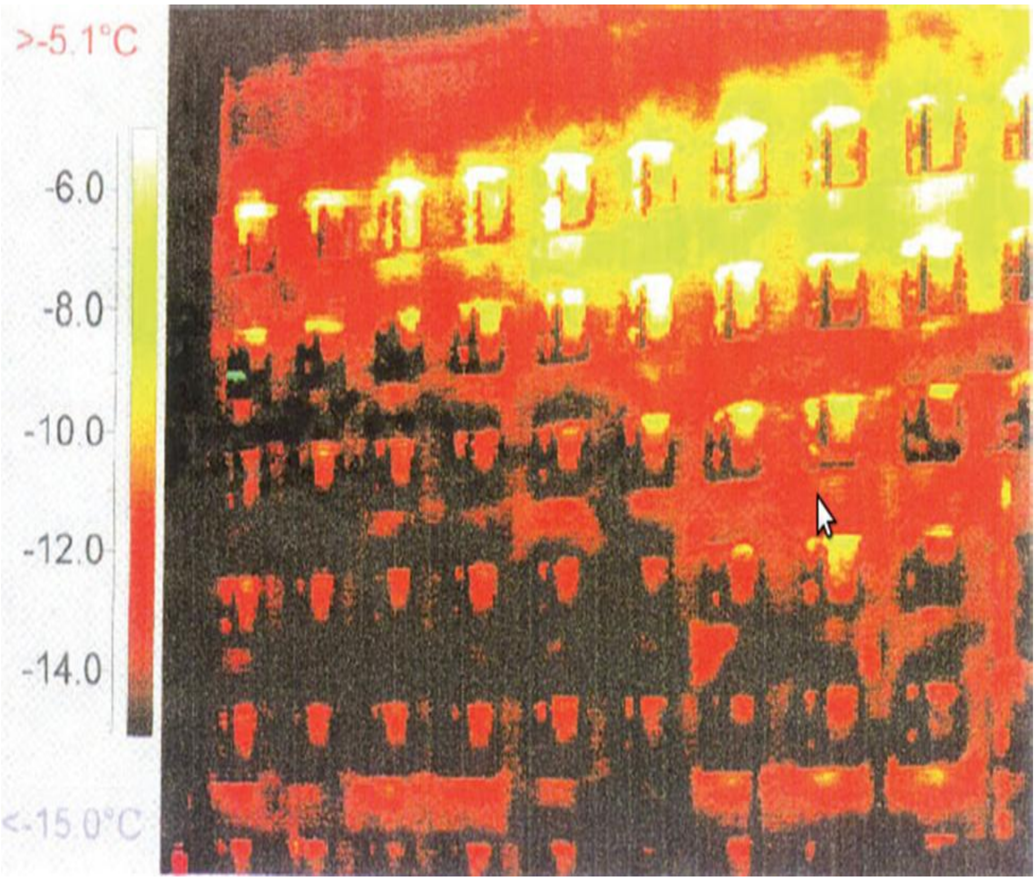

Figure 4 Uneven heat distribution in a building

As we can see, individual solutions to combat heat loss not only can not benefit, but also harm, so to solve this issue in already built buildings should be analyzed and comprehensive, because each case, building, requires its own approach to solving this issue. Therefore, to begin with, before the work should be carried out organizational measures to save energy. Namely:

- conducting an energy audit,

- analyzing the quality of electricity, heat and water supply,
- analysis and revision of contracts for electricity, heat, gas and water supply of residential apartment buildings,
- assessment of accidents and losses in heat, electricity and water supply networks.

After organizational measures it is worth to proceed to low-cost measures:

- flushing of the heating system inside the house,
- balancing of the heating system and risers,
- insulation of doorways in entrances,
- installation of door closers,
- infrared imaging of building facades,
- inspection of the heating system,
- installation of heat-reflecting screens behind heating devices,
- installation of heating regulators (regulation of the heating medium temperature based on the room temperature).

After performing low-cost to medium-cost:

- insulation of black floors in wooden houses,
- equipping buildings with communal metering devices for heat, water and electricity,
- installation of automatic heating control units,
- sealing and insulation of inter-panel joints,
- insulation of attics and basements,
- restoration of DHW circulation systems,
- restoration of heat supply to stairwells,
- replacement of street lighting fixtures with energy efficient ones,
- installation of LED lamps,
- installation of motion sensors in public areas.

And lastly, to the technically major and high-cost measures:

- replacement of old windows with modern ones with increased thermal resistance,
- modernization of heating systems and installation of new radiators,
- modernization of the ITP,
- installation of energy-efficient heating boilers,
- insulation of building envelopes and common areas,
- modernization of boiler houses using energy efficient equipment,
- introduction of automation systems for boiler operation and utilization,
- automation of heat energy supply to consumers,
- replacement of heating networks using energy efficient equipment,
- replacement of obsolete thermal insulation on pipelines,
- installation of a variable speed drive in water supply and wastewater disposal systems,
- installation of variable frequency drive on pumping equipment,
- replacement of electrical networks.

If we look at some of the items in more detail, we can also distinguish between priority and secondary activities. For example, the heating and HTW systems include in the priority activities such items as:

- Installation of balancing valves,
- Balancing of the heating system,
- Flushing of pipelines and risers of the heating system,
- Installation of a communal heat and hot water meter,
- Installation of apartment heat and hot water meters.

The second stage includes:

- Installation of individual heating unit,
- Installation of heating exchanger,
- Installation of automatic control system for heating and DHW,
- Replacement of pipelines,
- Replacement of fittings,

- Thermal insulation of pipelines in basements, attics and common areas,
- Installation of thermostatic regulating valves on heating devices,
- Installation of shut-off valves,
- Installation and modernization of pumps for water recirculation in DHW systems.

In the power supply and lighting systems, the priority measures include:

- Installation of communal and individual electricity meters,
- Installation of energy-saving lamps in public areas.

Second priority measures include:

- Installation of automatic lighting regulation,
- Replacement of electric motors,
- Installation of frequency regulation drives.

Priority measures for doors, roofs and walls include:

- Caulking, sealing and insulating entryway doors,
- Installation of doors and shutters in basements,
- Installing doors and shutters in attics,
- Caulking and sealing of windows in public areas.

Second phase of measures:

- Installation of heat-reflective films on windows,
- Installation of low-emission glass on windows in entrances,
- Replacement of window and door units with energy efficient ones,
- Basement floor and wall insulation,
- Insulation of the attic floor,
- Roof insulation,
- Caulking of inter-panel joints,
- Wall insulation,
- Glazing of balconies and loggias,
- Installation of air dampers in the ventilation system.

There are also non-traditional methods of improving the energy efficiency of a building. These measures aimed at improving the energy efficiency of buildings should be done after you have completed all previous measures. These include:

- Installing heat pumps for heating, hot water and air conditioning systems,
- Installing heat recuperators to recover heat from ventilation emissions,
- Installing solar water heating collectors.

In improving the energy efficiency of the heat supply system, both simple and complex measures are possible. The simplest measures to start with are:

- Installation of balancing valves,
- Periodic balancing of the heating system,
- Installing doors in basement openings,
- Installing doors in attic openings,
- Caulking and sealing of window blocks,
- Installation of heat energy metering devices,
- Installation of local heating regulation systems,
- Optimization of hydraulic modes of heating networks,
- Reduction of losses due to illegal drains of heat carrier.

Complex measures that require higher capital expenditures:

- Modernization of boiler houses and central heating substations,
- Reconstruction and construction of new heat networks,
- Construction of new boiler houses,
- Modernization of heating systems in houses and apartments,
- Installation of modern quality thermal insulation.

In addition, not only resource producers, transmission companies, management companies, owners' associations, but also the residents themselves should invest in improving the energy efficiency of buildings.

Improving the energy efficiency of buildings by apartment owners includes:

- Insulating doors and window openings. The apartment loses up to 15% of heat through windows and doors,

• Installing plastic or wooden windows with multi-chamber double-glazed windows. Increase the temperature in the apartment by 2-3 degrees.

New, airtight windows will also help to reduce street noise. If it is not possible to install new windows, it is worth installing polyurethane gaskets around the perimeter of windows and shutters. After sealing with polyurethane, the air permeability (draught level) of the apartment is reduced by 30-40%. Sealing old wooden windows is very effective. This measure will pay for itself in less than a year.

After sealing the windows, it is recommended to tightly fit the entrance and balcony doors. If the corridors inside the apartments are cold, you should install a second entrance door (create a small vestibule). The vestibule will help to increase the temperature in the apartment by 2-3 degrees.

You should also install heat-reflecting screens behind the radiators. This is a very simple and cheap measure that can increase the temperature in the apartment by 1-1.5 degrees. In comparison, the installation of multi-chamber plastic windows will cost dozens of times more expensive, but will increase the temperature in the room by only 2-3 degrees.

Figure 5 Heat-reflective shield behind the radiator

If radiators are covered with decorative or wooden covers, they should be removed. Covering radiators with decorative grids was a favorite in Soviet times, when heat cost nothing. Also, you need to make sure that the curtains do not cover the radiators. Curtains in this case play the role of an insulator, which does not allow heat to enter the apartment.

If necessary, replace old radiators (especially cast iron batteries), with new bimetallic or aluminum devices. Replacing old radiators will not be cheap, but will increase heat transfer by 30-40%. It should be noted that the replacement of radiators is equal to redevelopment and affects the heat loads in the whole building, so the replacement of radiators should be coordinated with the management organization.

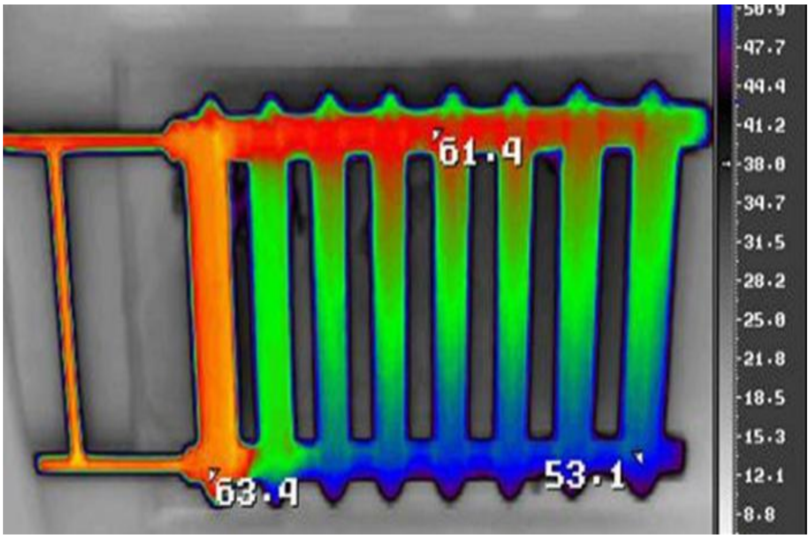

Figure 6 Uneven heat distribution in an old radiator

It is also necessary to glaze the balcony or loggia, which is equivalent to installing a vestibule or an additional window. The effect of glazing and insulation of balcony and loggia is similar to replacing old wooden windows and can increase the temperature in the apartment by 2-3 degrees. Glazing leads to a significant reduction in heat loss and is often more effective than installing plastic windows.

Saving electricity in the apartment is also one of the most important points to focus on, it allows you not only to save your own money, but also natural resources. Saving electricity can be started from the most elementary:

- Turn off the lights. If you're not used to turning off lights, install motion or occupancy sensors. When appropriate, use table lamps and light fixtures in lieu of general lighting,

- Unplug cell phones, chargers, televisions, and microwaves. When a charger is plugged in all the time, about 90% of electricity is wasted,
- Do not install your refrigerator very tightly against a wall, stove or near a heating radiator. This can increase electricity consumption by 30%,
- Use a kettle rather than an electric stove to heat water,
- Clean windows, lamps and fixtures, light-colored walls and curtains help save 12-15% of lighting energy,
- Avoid overloading or underloading your washing machine. This will help reduce electricity consumption by 10-15%,
- Turn on the air conditioner only after all windows and doors are tightly closed,
- Replace incandescent light bulbs with energy-saving bulbs. This will help reduce electricity consumption for lighting by 4-5 times.

Water conservation is not to be overlooked. Saving water is also quite simple:

- Don't rinse laundry under running water,
- Take showers. Taking a shower uses 10 to 20 times less water than taking a bath,
- Fix or replace any leaking faucets and pipes. A faulty faucet can drip 30-50 liters of water in a day,
- Install spray nozzles on your faucets. Better yet, install modern faucets. This will save 10-15% of water,
- Regularly check for water leaks in the cistern. Through a thin trickle of leaks, you can lose 30-50 liters of water a day,
- Install two-button cistern drains,
- Only use your dishwasher and washing machine with a full load,
- Do not defrost food under running tap water.

In general, it is possible to reduce heat, water and energy costs by 30-40% in an apartment without much expense or reduction in quality of life.

If we consider typical energy saving measures in heating systems, we get a table:

No.	**Contents of the event**	**Energy saving potential assessment**

1	Availability or creation of a system for metering thermal energy consumption. Installation of individual heat meters for subscribers	Up to 10 ÷ 40% of thermal energy when installing individual heat meters in apartments and industrial consumers. Up to 10% of DHW in housing and communal services
2	Availability of systems for automatic control of coolant temperature depending on the outside temperature	An increase in indoor air temperature above normal increases heat consumption by 4 ÷ 6%
3	Eliminating water droplets from shut-off valves	Leaks per year are 10 ÷ 35 m3/year
4	Transferring the heating system of some industrial buildings to standby mode during non-working hours, holidays and weekends	Allows you to save 10 ÷ 15% from the building's heat consumption
5	Reducing the temperature in residential buildings at night	Allows you to save 2 ÷ 3% of the building's heat consumption
6	Triple glazed windows	Gives savings of 3 ÷ 4%
7	The presence of vestibules and their sectioning at the entrances to the room and springs on the doors	Gives savings of 3 ÷ 4%
8	Choosing the right color for heating appliances	Painting a heating device with zinc white increases heat transfer by 15%; - painting with oil paint reduces heat transfer by 8.5% (for a cast iron radiator it reduces even more, up to 13%); - covering the heating device with decorative plates and curtains reduces heat transfer by 10 ÷ 12%
9	Installation of radiator thermostats	Provides heat savings of 6 ÷ 7%
10	Installation of coolant temperature regulators for heating	Estimated savings will be approximately 15%
11	Availability of a block individual automated heating point	Reduces heat consumption by 35 ÷ 37% in industrial and administrative

		buildings and by 12% in residential buildings
12	Adjustment of heating systems and sealing of elevators and regulators in the position of the adjustment cards, respectively	The economic effect is 15 ÷ 35%, and the payback period is 1 ÷ 2 years
13	Installation of convectors with a mechanical heat removal stimulator	Provides savings of up to 7%
14	Installation of air heating systems	Provides savings of up to 10 ÷ 15%
15	The use of glazed loggias	Gives savings of 7 ÷ 40%
16	Elimination of cold bridges in places where window sashes meet the wall	Gives savings of 2%
17	Sealing cracks and leaks in window and door openings	Heat consumption after sealing cracks and leaks is reduced by 10 ÷ 20%. 1 linear meter of unsealed window sash equals a loss of 50 kWh in 228 days
18	Installation of windows with increased heat-insulating characteristics. Best: 1) triple glazing; 2) double-glazed window; 3) combination of glass + single-chamber double-glazed window	Heat savings 35 ÷ 45% compared to conventional double glazing
19	Installation of a thermal mirror or “comfort screen” in windows (low-emissivity heat-reflecting translucent film stretched over a profile frame installed between the panes)	The use of a heat shield allows you to reduce heat losses through windows from 40 ÷ 45%
20	Additional thermal insulation of external walls, upper floor ceilings	The implementation of measures will ensure a reduction in overall heat losses

	and first floor floors. Losses of industrial andpublic buildingsthrough fences: - external walls – 30 ÷50%; - overlap of the upper floor – 15 ÷ 40%; - first floor floor – 3 ÷ 10%	by 5 ÷ 15%
21	Replacing tubular heat exchangers with plate heat exchangers and using energy-efficient radiators	Allows you to save 5 ÷ 10% of heat
22	Installation of a heat reflector - a gasket with a reflective layer between the heating device and the wall	Allows you to save 2 ÷ 3% of total energy consumption
23	Restoration of thermal insulation on pipelines of heating and hot water systems	Allows you to reduce heat losses by 7 ÷ 9% of total consumption
24	Conversion of the heating system from the coolant “steam” to the coolant “hot water”	Saving 20 ÷ 30% heat
25	Presence of cold air infiltration in heated rooms	Additional consumption 10 ÷ 15 kcal for each cubic meter of cold air
26	Introduction of an energy-saving mode of heat supply for heating from boiler houses or central heating stations	Annual heat savings are 4 ÷ 17%
27	Introduction of façade-by-facade regulation of heat supply, taking into account meteorological factors (wind speed and solar radiation)	The excess consumption of thermal energy per year without taking into account meteorological factors (without facade regulation) in the range of wind speed changes from 0 to design is 6 ÷ 12%. When taking into account the combined influence of wind speed and solar radiation during façade regulation,

		annual savings can amount to 9 ÷ 18%
28	Introduction of an economical coolant supply schedule, taking into account the type of heating system and type of heating appliances	Savings range from 5% (depending on the type of heating and heating devices) of the heat load when regulating heat supply in accordance with current schedules
29	Insulation of uninsulated pipelines of heat consumption systems located in basements and unheated rooms	The annual heat savings when insulating 1 linear meter of a bare pipeline with an average diameter of 25 mm is 0.22 Gcal/p. m

Table 1 Typical energy saving measures with expert estimates of energy saving potential in heating systems

CHAPTER 2

TECHNOLOGIES, METHODS, AND EXISTING SYSTEMS FOR IMPROVING ENERGY EFFICIENCY IN HEATING

2.1 Technologies and methods for improving energy efficiency in heating

To increase energy efficiency in heating residential homes, various technologies and methods are available. In addition to architectural and construction technologies aimed at insulating the building itself and methods such as replacing doors, windows, radiators, etc., there are other heating technologies for residential spaces. The application of these systems reduces the load on the electrical grid, saves planetary resources without compromising the quality of life for the residents of the house. Each system has its advantages and disadvantages, and in some cases, multiple methods are applied simultaneously for improved results.

1. The first method involves the use of new and efficient heating systems. This includes heat pumps and condensing boilers.

Heat pump: This device, also known as a "thermal boiler," extracts dispersed heat from the surrounding environment (ground, water, or air) and transfers it to the heating circuit of the house.

Figure 7 Heat Pump

Thanks to the continuous influx of solar rays into the atmosphere and onto the Earth's surface, there is a constant release of heat. This ongoing process ensures that the Earth's surface receives thermal energy throughout the year. The air partially absorbs heat from solar radiation, and the remaining solar thermal energy is almost entirely absorbed by the Earth.

Furthermore, geothermal heat from the Earth's depths consistently maintains the ground temperature at +8°C (starting from a depth of 1.5-2 meters and below). Even during cold winters, the temperature in water bodies at depth remains in the range of +4-6°C. It is this low-potential heat from the ground, water, and air that the heat pump transfers from the surrounding environment to the heating system of the house, pre-raising the temperature of the heat carrier to the required +35-80°C.

The operation of the heat pump is based on the reverse thermodynamic cycle (reverse Carnot cycle), consisting of two isotherms and two adiabats. However, unlike the direct thermodynamic cycle (direct Carnot cycle), the process occurs in the reverse direction: counterclockwise.

In the reverse Carnot cycle, the surrounding environment acts as the cold source of heat. During the operation of the heat pump, heat from the external environment, through the performance of work, is transferred to the consumer but with a higher temperature. Transferring heat from a cold body (ground, water, air) is possible only with the expenditure of energy (in the case of a heat pump — the consumption of electrical energy for the operation of the compressor, circulation pumps, etc.) or another compensatory process.

The operation of the heat pump consists of several stages of the cycle, which are repeated in a certain sequence. The first stage is the absorption of heat from the surrounding environment, followed by compression of the refrigerant by the compressor, then the transfer of heat to the heating system, and the final stage is the reduction of the refrigerant pressure.

Figure 8 Operating principle of a heat pump

Benefits of heat pumps include:

1. Energy Efficiency: Heat pumps can provide significant energy savings as they utilize the surrounding environment to extract heat (air, water, ground) rather than generating it directly.

2. Environmental Advantage: Heat pumps are generally considered more environmentally friendly as they do not rely on traditional energy sources such as natural gas or coal.

3. Cooling Operation: Many heat pumps can operate in reverse, providing air conditioning during hot weather.

4. Long Service Life: With proper maintenance, heat pumps can have a long service life, and their components are often reliable.

5. Federal Subsidies and Incentives: In many countries, federal subsidies and incentives are available for the installation of energy-efficient systems, including heat pumps.

Drawbacks of heat pumps include:

1. High Initial Costs: Installing a heat pump can require significant upfront investments. However, over time, energy savings may offset these costs.

2. Temperature Dependence: The efficiency of heat pumps may decrease at low temperatures, especially for air-source heat pumps.

3. Need for Regular Maintenance: Heat pumps require regular maintenance, and their performance may decline with improper care.

4. Limited Market Choices: In some regions, the selection of heat pumps may be limited, especially considering the type of surrounding environment.

5. Dependency on the Power Grid: If the electricity used is generated from non-environmentally friendly sources, the environmental efficiency of the heat pump may be reduced.

6. Limited Cooling Efficiency: In cooling mode, the efficiency of heat pumps may be lower than that of specialized air conditioning systems.

Condensing boilers are gas boilers designed for heating and hot water supply that operate on the principle of condensation. This equipment has high efficiency, low gas consumption, and high durability.

The working principle of all condensing boilers is quite simple. In a conventional gas heating boiler, condensation is an undesirable phenomenon—combustion products along with steam are expelled through the flue system. In contrast, in condensing boilers, condensation of this steam is necessary for efficient operation. In front of the heat exchange circuit, there is a fan with adjustable speed. The steam contained in the flue gases is cooled in the heat exchanger by the heat transfer medium coming from the return line. The exhaust of combustion products is carried out through a coaxial chimney. The ability to adjust the power of the blower fan allows achieving the perfect air-to-gas ratio.

One of the peculiarities of the operation of a condensing boiler is that the efficiency of this type of equipment becomes more noticeable the lower the temperature of the heating circuit. The equipment can operate normally in condensation mode only if the temperature of the heat exchanger is lower than the dew point temperature. If the boiler equipment operates in the 80/60-degree mode, its efficiency will differ little from that of a conventional gas boiler. However, in the 50/30 mode, the efficiency of condensing equipment becomes more pronounced, as condensation of steam occurs in this case.

Figure 9 Condensing Boiler

Condensing gas boilers have the following advantages:

1. Maximum efficiency with minimal fuel consumption. The efficiency of a condensing boiler is the highest among all gas heating equipment. At the same time, the consumption of gas fuel is reduced by almost 15-20% compared to conventional gas water heating equipment.

2. Environmental friendliness. The gas mixture in condensing boilers burns more productively, reducing the amount of harmful emissions and combustion by-products.

3. Wider range of hot water temperature control. Condensing gas boilers allow for smooth regulation within the range of 30-85 degrees.

Disadvantages:

1. High cost. One of the main drawbacks of condensing boilers is their relatively high cost, which is usually 2 times higher than that of conventional gas boilers. However, when the boiler is used in condensing mode, the high equipment cost will be recouped quite quickly, typically within 2-3 years.

2. Lack of clear advantages in case of incorrect mode selection. The optimal operating mode for a condensing boiler, where up to 11% of heat is additionally returned to the system, is 50/30°C (50 – supply and 30 – return). Otherwise, condensate will not form, and the efficiency of the equipment compared to a conventional gas boiler will be reduced to zero.

3. Drainage system installation. It requires the installation of a system to drain the water accumulating inside the unit.

2. The second method is the installation of smart thermostats and heating control systems for more precise temperature control and optimization.

A smart thermostat is a compact device that connects to the home or apartment energy system, allowing users to change and control the temperature. This control can be done through a smartphone and even remotely. The main convenience of a smart thermostat is that users can check and adjust the temperature in the home, even from a distance.

Smart thermostats are most commonly used in heating systems for private houses. However, if a boiler is installed in an apartment, such a device can also be connected to the heating system.

A smartphone-controlled thermostat can be programmed with your schedule, based on which it will automatically lower or raise the temperature. For example, if you frequently turn on the air conditioner, the thermostat can turn it on and off to prevent unnecessary energy consumption.

Smart thermostats operate on the principle of geofencing. In simpler terms, the device, using positioning technologies similar to GPS, establishes a virtual zone. When the smartphone leaves the boundaries of this zone, the thermostat activates, turning off devices.

Programmable smart thermostats allow you to set different temperatures at different times of the day, significantly reducing it when you are not at home, thus reducing energy consumption. Additionally, thermostats divide the space into zones, automatically planning the temperature for each room — this allows for even more efficient energy use.

Advantages of smart thermostats:

1. Energy Savings: Smart thermostats can optimize energy consumption by automatically adjusting the temperature based on your schedule and habits, leading to significant economic and environmental benefits.
2. Remote Control: The ability to control the home temperature from anywhere in the world through a mobile app. This is especially convenient if you forget to turn off the heating when leaving home or want to warm it up before returning.
3. Voice Control: Many smart thermostats are compatible with voice assistants such as Amazon Alexa, Google Assistant, or Apple HomeKit, providing even more convenient heating control.
4. Compatibility with Smart Scenarios: Smart thermostats can be integrated into smart home systems and automation scenarios. For example, they can interact with smart lighting or security systems.
5. Automatic Habit Recognition: Some smart thermostat models learn your habits and adapt to your lifestyle automatically, contributing to more efficient heating.
6. Sensors and Zone Control: Some smart thermostats come with sensors, allowing temperature control in different zones. This is particularly useful for large houses or multi-apartment buildings.
7. Long-Term Money Savings: Investing in a smart thermostat can lead to significant long-term savings due to the optimization of the heating system.

Disadvantages of smart thermostats:

1. High Acquisition Cost: Smart thermostats may have a higher cost compared to traditional thermostats. However, this cost is usually offset by energy savings.

2. Dependency on Internet Connection: For full functionality, smart thermostats require an internet connection. In the absence of the internet, some features may be unavailable.

3. Installation Complexity: Installing a smart thermostat may require skills in working with electricity and heating systems. In the absence of experience, it is better to consult professionals.

4. Compatibility with Existing Systems: Not all smart thermostats are compatible with every heating system. Before purchasing, it is essential to ensure that the selected thermostat is suitable for your system.

5. Service Issues and Updates: From time to time, there may be service issues or the need for software updates, requiring additional efforts.

6. Power Availability Dependency: In the event of a power outage, smart thermostats may stop functioning, while traditional thermostats will continue to work on batteries.

Figure 10 Smart thermostat

The third method is the use of heat accumulators.

A heat accumulator is special equipment that helps maintain a stable temperature in a house where heating is provided by a boiler or air-to-water heat pump (or other type).

It looks like a buffer tank, the principle of operation of which is simple and clear. The tank can be of different sizes, depending on the type of boiler and other circumstances. On average, sizes range from 350 l to 3500 l. These tanks take up a lot of space, so you need to be prepared for this in advance. The tank must be very well insulated. Essentially, a buffer tank is a large thermos that keeps the water temperature at a stable level. The inside is covered with a reflective surface, and the outside is insulated with polyurethane foam. Inside the tank there are coils through which water circulates. Pipes extend from the heat accumulator through which hot and cooled water circulate while the boiler is operating. After it is turned off, the heat accumulator comes into operation. That is, in essence, heat accumulators designed to accumulate and store excess energy in the form of heat, which can then be used for heating during periods of low energy consumption or absence of heat sources.

Advantages of heat accumulators:

1. Energy saving: Thermal accumulators allow energy to be used during periods of low demand, which contributes to the efficient use of energy resources.

2. Time of Day Independence: Excess energy can be stored for use at any time of day, which is useful in the face of seasonal changes and grid variability.

3. Saving Money: During periods when electricity rates are lower (eg at night), thermal storage tanks can be loaded and then provide heating during periods with higher rates.

4. Use of Renewable Sources: Thermal storage devices can work effectively with renewable energy sources such as solar panels and wind turbines, increasing the sustainability of the system.

5. Reliability: Thermal accumulators typically have a long service life and require minimal maintenance, ensuring reliable operation.

6. Peak Load Reduction: The use of thermal storage can mitigate peak loads in the power system, which has a positive effect on stability.

Disadvantages of heat accumulators:

1. Limited Capacity: Thermal storage tanks have limited capacity and larger systems may require multiple units, increasing costs.

2. Heat Loss: During storage, thermal accumulators may lose some heat, which reduces their efficiency. This effect can be minimized by using good insulation.

3. Technical Difficulties: Installing and maintaining thermal storage tanks may require heating and energy knowledge, which may be difficult for some users.

4. Requires Management: Effective use of thermal storage devices requires management and programming to account for changes in energy consumption and tariffs.

5. Insulation Required: The efficiency of thermal storage units may be reduced if not properly insulated.

6. Wear of Batteries: In the case of using thermal accumulators with batteries, the latter may require replacement over time.

Thermal storage devices are an effective tool for optimizing energy consumption and saving money, but their successful use requires careful planning and configuration.

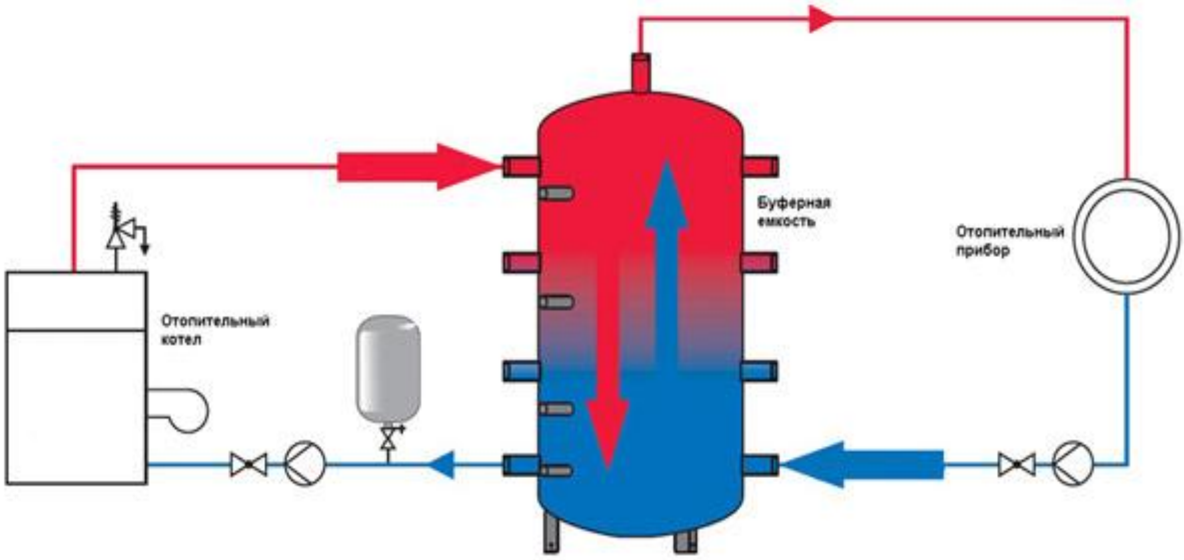

Figure 11 Operating principle of the heat accumulator

1. Use of heat pumps.

Heat pumps are devices designed to transfer thermal energy from a source with a low temperature towards a coolant with a higher temperature. this means that these units are capable of converting low-grade heat from water, air or soil, and then transferring it to the circulating fluid in heating or hot water supply systems. To put it as simply as possible, a heat pump transfers energy from a less heated body to a more heated one, due to which the temperature of the latter increases. and the main value of such machines is that using alternative energy sources, they make it possible to obtain inexpensive and constantly available heat without harming the environment. this quality makes them increasingly in demand all over the world, including in our country.

The operating principle of heat pumps of various modifications is based on the fact that all bodies with a temperature above absolute zero have a reserve of energy. Moreover, it is directly proportional to the mass, as well as the specific heat capacity of the body. It is easy to guess that soils, reservoirs and groundwater, which have a huge mass, can be used to generate almost free heat. but, in order to take away the thermal energy of any body, it needs to be cooled. the approximate amount of heat released in this case can be calculated using a simplified formula: $q = c\ m\ (t2 - t1)$, in which q is the heat received, c is the heat capacity, m is mass, and $t2 - t1$ is the temperature difference of the body before it is cooled and after. This formula allows us to make the important observation that by cooling 1 kg of coolant from 1000 to 0 people, you can get the same amount of heat as cooling 1000 kilograms from 1 to 0 people.

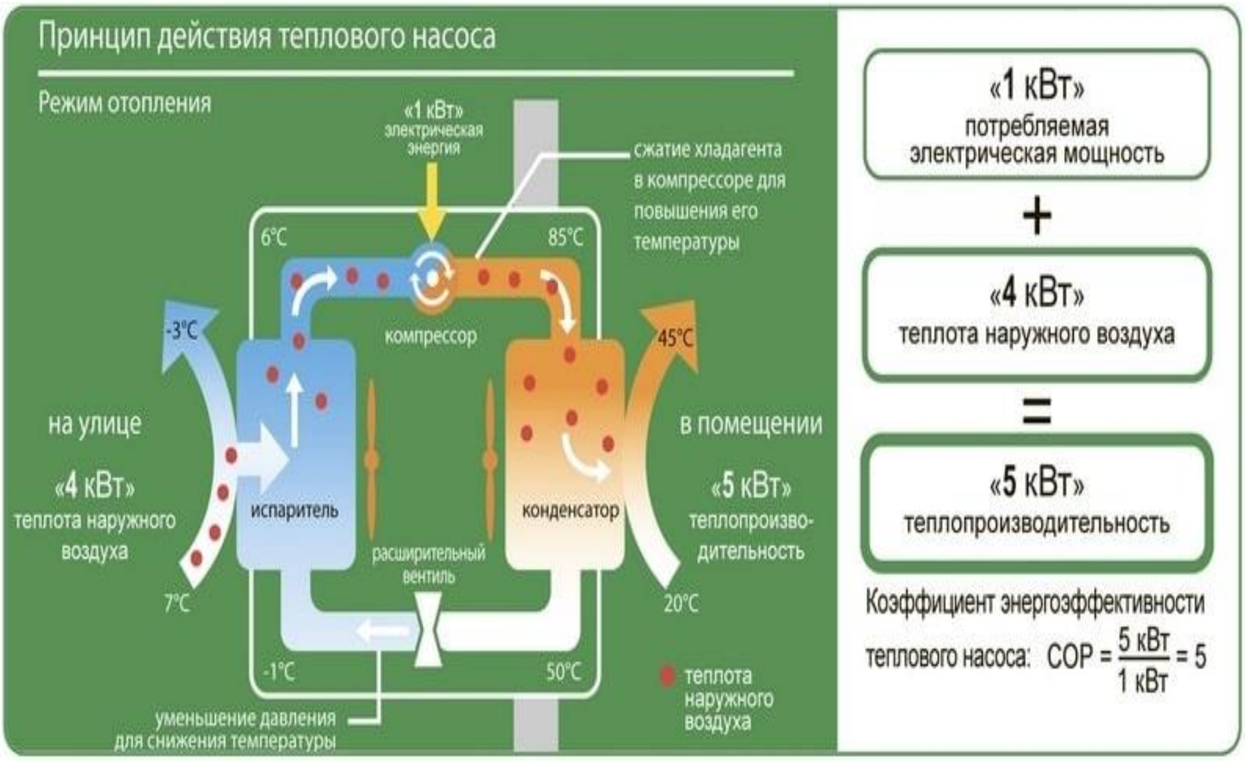

Figure 12 Operating principle of a heat pump

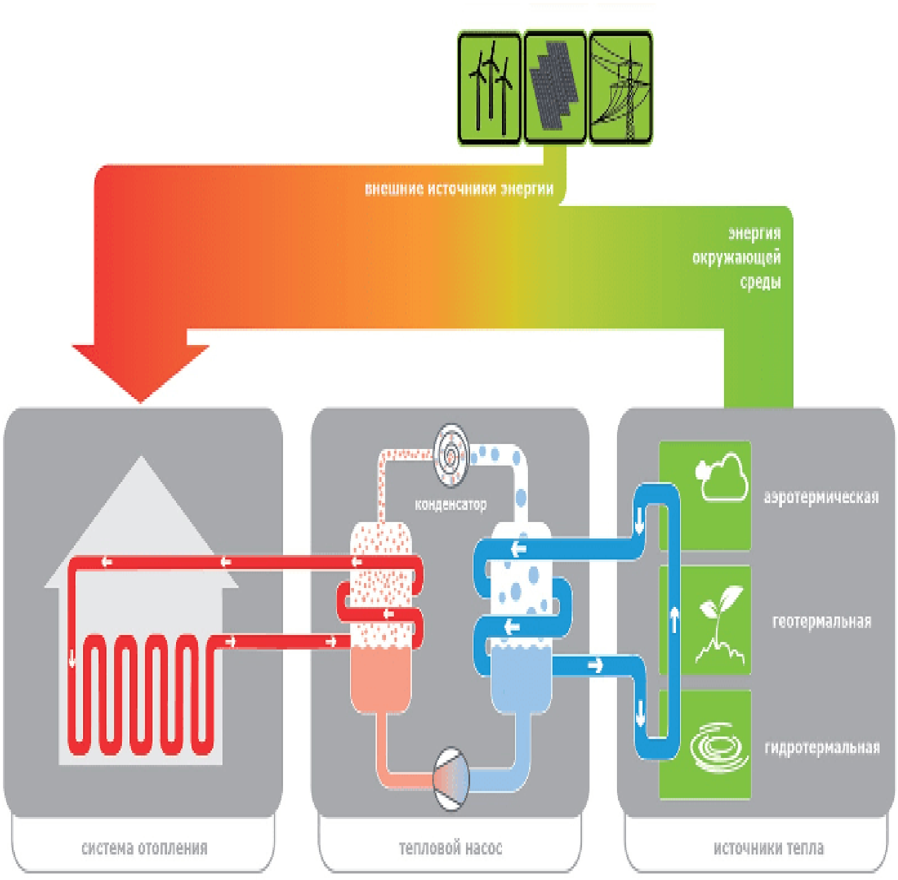

Figure 13 Heat pump operation with alternative energy sources

The classification of heat pumps implies their division into several groups based on different characteristics. Depending on the method of energy transfer, there are the following types of heat pumps:

• Compression heat pumps - use a cycle of compression-expansion of the coolant with parallel release of thermal energy. The main components of such devices are a condenser, compressor, evaporator and expander. compression-type heat pumps are easy to operate and highly efficient, which is why they have earned great popularity,

• Absorption heat pumps use a combination of absorbent and refrigerant. they are new generation devices with high performance. and the very use of the absorbent makes absorption-type heat pumps as efficient as possible.

Depending on the heat source involved, the following types of heat pumps exist:

- Geothermal heat pumps – extract energy from the ground or water,
- Air heat pumps – extract energy from the atmosphere,
- Heat pumps use recycled heat - they extract energy from air, water or even sewage.

In turn, depending on the type of coolant in the input and output circuits, there are the following types of heat pumps:

- Air-to-air heat pumps - take energy from outside air with a lower temperature, and then transfer the resulting heat to heating rooms using heated air,
- Water-to-water heat pumps – they take energy from groundwater and then transfer the resulting heat to water circulating in heating and hot water supply systems,
- Water-to-air heat pumps - extract energy from groundwater using probes or water wells, and then transfer the resulting heat to an air heating system,
- Air-to-water heat pumps - take energy from the atmospheric air, and then transfer the resulting heat to water circulating in heating and hot water supply systems,
- Ground-to-water heat pumps - take energy from the ground using pipes laid underground through which water circulates, and then transfer the resulting heat to water circulating in heating and hot water supply systems,
- Ice-water heat pumps - take energy from the released air when making ice, and then transfer the resulting heat to water circulating in heating and hot water supply systems.

Determining the overall efficiency of a geothermal heat pump is quite simple. To successfully implement its functions, any such unit must produce more thermal energy than it consumes electrical energy. This ratio is called the conversion coefficient, and its value can change based on the temperature difference in the input and output circuits. Moreover, the lower the temperature outside the building, the less effective such a system is. Depending on the modification of the heat pump, its conversion coefficient varies from 1 to 5. And for a more accurate assessment of such a device, an additional annual performance parameter is used.

However, in the case of heat pumps, unfortunately, only their overall efficiency is easily determined. Determining this parameter for a specific heat pump is quite difficult. the fact is that its own effectiveness depends on many factors, so it is almost impossible to calculate it without special training. therefore, there is no universal formula or algorithm for calculating this value. Well, in order to choose the right heat pump, it is advisable to contact specialists who can select its optimal type and the volume of required refrigerant, based on the existing conditions of use.

Advantages of heat pumps:

1. Highly Energy Efficient: Heat pumps are among the most energy efficient heating systems because they transfer heat from the outside environment using only a small amount of electricity to drive the pump and compressor.

2. Save Energy and Money: By using the environment as a heat source, heat pumps can significantly reduce energy costs compared to traditional heating systems.

3. Versatility: Heat pumps can provide not only heating, but also cooling in the summer. Some models support water heating for domestic use.

4. Environmental Acceptability: Heat pumps can be considered a greener option compared to traditional systems as they do not produce significant greenhouse gas emissions.

5. Convenience and Ease of Control: Most modern heat pumps are equipped with automatic control systems, which makes them easier to use and maintain.

6. Long Lifespan: When properly maintained, heat pumps typically have a long lifespan, making them a sound investment.

Disadvantages of heat pumps:

1. High Initial Costs: The initial cost of purchasing and installing a heat pump can be high, especially when compared to traditional heating systems.

2. Dependence on External Conditions: The efficiency of the heat pump depends on external conditions such as ambient temperature. They may be less effective in some climate zones.

3. Need for Additional Heating: During cold periods of the year when temperatures are too low, heat pumps may require additional heating to maintain the desired room temperature.

4. Installation and Maintenance Challenges: Installation and maintenance of heat pumps may require specialized skills, which may incur additional costs.

5. Dependent on Type of Technology Supported: The efficiency of heat pumps can vary depending on the type of technology supported, such as air, ground or water pumps.

6. Impact on the Electrical Grid: Massive deployment of heat pumps may require strengthening the electrical grid, which can become an additional problem for the infrastructure.

7. Noise: Some heat pump models can be noisy, which can cause discomfort, especially if the pump is installed close to living areas.

If we talk about the experience of use, then such an alternative heating source was used in an apartment building in Lviv.

The company "Institute of Heat Without Gas" designed and commissioned a 10-story building with heating by heat pumps.

In Kyiv, not far from the Obolon metro station, there are buildings of the Obolon-1 water pumping station, the area of which is about 1800 m2. This production enterprise is the first of the city's municipal facilities that dared to restructure the heat supply and hot water supply systems using heat pump technologies.

Figure 14 Heat pumping equipment in the hall of the Obolon-1 pumping station

In a small village in the Khmelnitsky region called Myslyatino, in the Izyaslavsky district, where about 600 people live, there is a kindergarten “Kalinka”, which uses heat pumps.

The heating system for an apartment building in Kiev at 52 Shcherbakova Street was designed from scratch, which included work on analyzing the heat loss of the entire building (Fig. 15). Based on this analysis, it was decided to use enclosing structures to increase the energy efficiency of the building, which made it possible to exceed the standards adopted in Ukraine by 27%.

Figure 15 New building with a heating system from a heat pump

Namely, the walls were insulated with polystyrene foam with a thermal conductivity coefficient λ = 0.04 W/m2K: brick walls - with panels 120 mm thick; concrete structures - panels 150 mm thick.

Window profiles and energy-saving double-glazed windows of type 4LowE-12arg-4-12arg-4LowE are installed in the windows and balconies. As a result, when designing, it was decided to proceed from a thermal load of 33 W/m2 and optimize the heating system for low coolant temperatures (60 °C). Thermostatic valves are installed on each heating radiator in order to be able to individually regulate the temperature in the room and realize the energy saving potential.

In general, the system is designed to use four air-to-water heat pumps of the IVT Optima brand (Sweden) with a power of 17 kW each in combination with solar collectors Buderus SKN - 4 (Germany) with a total surface area of 90 m2 (Fig. 16). Ventilation of apartments is carried out by an internal unit M-WRG-Standart (manufacturer Meltem, Germany).

Figure 16 Solar collectors Buderus SKN – 4

Thus, to date, Ukraine has already accumulated sufficient experience in introducing energy-efficient technologies that can be used in the field of housing and communal services. After all, it is the reduction of gas consumption in housing and communal services (as the main consumer of blue fuel) that is the key to the revival and formation of an independent state. And, as practice shows, in domestic conditions systems based on renewable energy sources that use heat pumps have proven themselves well.

2. Use of solar panels.

Typically, the term “solar battery” refers to a panel that generates electric current when exposed to sunlight. A solar battery is also called a photovoltaic converter. There are also terms such as: solar panel, solar module, photomodule, etc.

A solar battery is a device that collects light energy from the sun's rays and converts it into electrical current. It is based on photocells – semiconductor photoelectric converters.

Figure 17 Photovoltaic installation structure

To obtain electricity from a solar battery, it is necessary to carry out the photoelectric effect. This process is associated with the physical phenomenon of pn junction that occurs in a photocell. Structurally, the photocell consists of two plates of semiconductor material. One of the plates used contains boron atoms, and the second contains arsenic atoms. In this case, the upper layer is characterized by an excess of electrons (electron region), and the lower layer is characterized by their shortage (the so-called hole region). In this case, an electron-hole junction, the so-called pn junction, is maintained at the boundary of these plates.

As a result of solar rays (photons) hitting the photocell, the plates are illuminated and both layers interact like the electrodes of an ordinary battery - an electromotive force (EMF) arises. The sunbeam excites electrons, which begin to move from one plate to another. To remove electrical energy, thin layers of conductor are soldered onto both surfaces and connected to the load. The production of this energy is not associated with chemical reactions, so such a solar battery can last quite a long time.

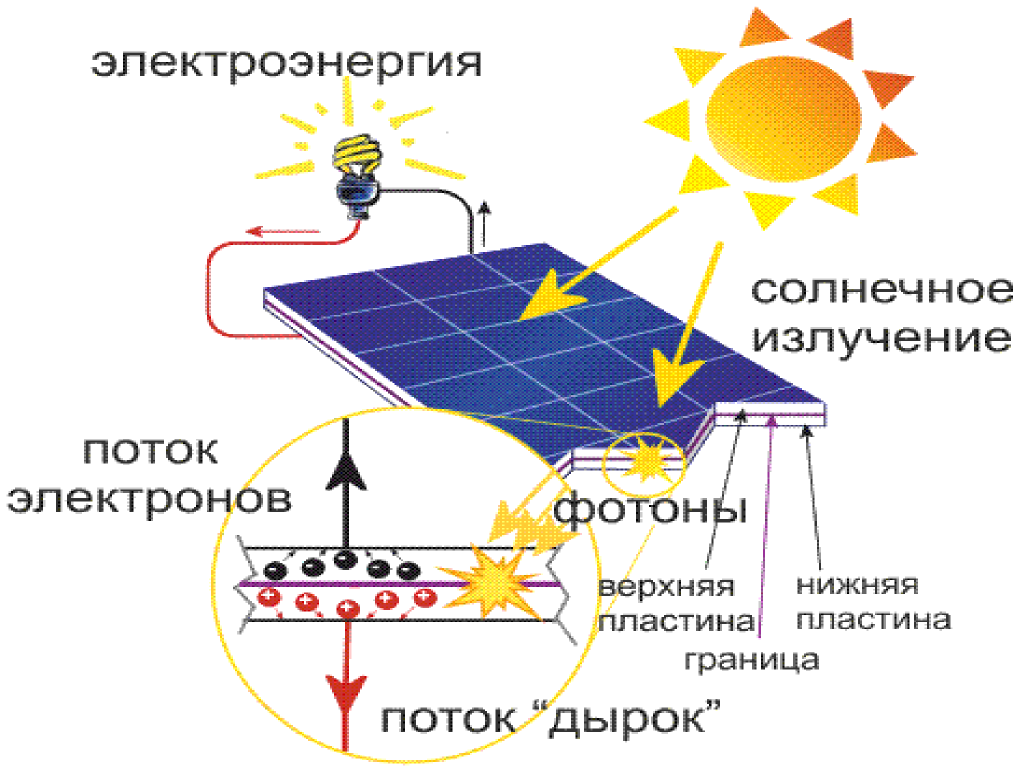

Figure 18 Operating principle of solar panels

Solar panels for heating an apartment building are one of the options for using solar energy in heating systems.

Advantages of solar panels for heating:

• Renewable Energy Source: Solar energy is a renewable source, which means an endless source of energy.

• Energy Savings: Installing solar panels can reduce your dependence on traditional energy sources, which will save you money in the long run.

• Low Operating Costs: Once solar panels are installed, operating energy costs are usually minimal.

• Environmentally Friendly Energy: The use of solar panels is an environmentally friendly way of producing energy, as it does not produce greenhouse gas emissions.

• Long Lifespan: Solar panels have a long lifespan, which can range from 20 to 30 years.

• Grid Independence: In some cases, solar panels can provide independence from centralized energy systems.

Disadvantages of solar panels for heating:

- High Initial Costs: Installing solar panels requires a significant investment at the beginning, which may be unaffordable for many consumers.
- Weather Dependent: Energy production from solar panels depends on weather conditions and time of day. During periods of cloudy weather or at night, efficiency is reduced.
- Space Constraints: Installing a sufficiently efficient solar system may require a large area, which may be limited in the case of an apartment building.
- Necessity of a Battery Power System: Effective use of solar energy may require the installation of a battery power system to store energy during periods of low production.

From an environmental point of view, solar panels are considered very environmentally friendly, since they do not produce noise, do not emit harmful substances and do not require the extraction of natural resources during operation. However, the production of solar cells and their disposal after their useful life may also have some environmental impact, especially if the recycling system is insufficient. However, modern technologies are trying to minimize the negative impact and improve the sustainability of solar panels.

Experience of use in Ukraine is still rare, and their use for heating water for hot water supply (DHW) in apartment buildings is practically not carried out. With the emergence of condominium associations as a directly interested party in order to reduce the “common house” bill, the prospect of introducing economically feasible projects for the use of renewable energy sources in multi-apartment high-rise buildings in urban areas has emerged.

It should be recognized that, in fact, tariffs for thermal energy for heating and for hot water have not yet reached an economically justified market level, as, for example, in the EU countries. Therefore, at the first stage, it is possible to use solar systems with a small fraction of the replacement share of the domestic hot water load, which will reduce the cost of the system itself and its efficiency per unit of investment. For the further development of the home renewable system, part of the costs due to the achieved savings must be borne by the home owners, and the second part - at the expense of the state or sponsors.

As the experience of other countries shows, solar panels have not only shown their benefits from an economic point of view, but also from an environmental one.

There are known options for hot water systems of an apartment building with modular installations for heating water with electricity. The main elements of these installations are capacitive electric boilers, both closed (pressure) and open (non-pressure). The water in these boilers is heated primarily at night using less expensive electricity ("night tariff") and then distributed to consumers. In the daytime, as water heated at night is consumed, it becomes possible to accumulate heat from an additional heat source - from solar collectors. This option assumes that the capacitive electric boiler of a modular installation performs two functions - accumulating heat received from electricity and from the Sun. Solar systems for heating water in apartment buildings are also built on a modular basis, which makes it possible to gradually increase the number of solar collectors in the system, which means to gradually increase the heating capacity of the solar system and the degree of replacement of water heating with solar energy. And, what is important, the gradual investment of funds in the development of such a system.

3. Use of Highly Efficient Coolants.

Graphene (single-walled) nanotubes are a layer of graphene rolled into a tube, one carbon atom thick. These nanotubes, which have increased electrical conductivity and strength (higher than steel), and can withstand high temperatures, are added to other materials to give them new properties. For example, using graphene nanotubes in lithium-ion batteries increases battery life by four times. Adding them to glass, aluminum and a number of plastics increases the strength of products made from them. The use of technology in the production of textiles for workwear gives the materials antistatic properties, silicone with nanotubes exhibits conductivity and retains color, and tires improve grip and wear resistance.

Research highlights the importance of selecting coolants with high thermal conductivity. Innovative materials such as graphene nanotubes can significantly improve heat transfer while reducing energy consumption to ensure optimal temperatures in the heating system.

Their unique properties, such as high thermal conductivity, lightness and strength, make them attractive for use in heating systems and thermal media.

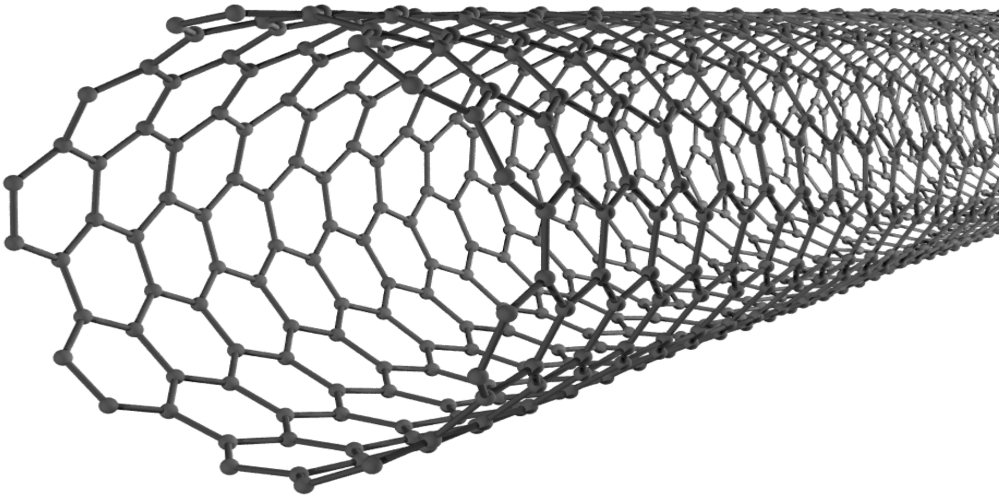

Figure 19 Graphene nanotube

Advantages of graphene nanotubes:

1. High Thermal Conductivity: HNTs have one of the highest thermal conductivities of known materials. This means that they are able to efficiently transfer thermal energy, which is important for optimizing heat transfer processes in heating systems.

2. Heat Sink: HNTs can be used to create heat sink surfaces or coatings that improve the efficiency of heating systems.

3. Strength of composites: Graphene nanotubes can be incorporated into composite materials to create strong, lightweight heating system parts, improving their mechanical properties.

4. Flexible Heating Elements: Integrating HNTs into flexible materials allows for the creation of flexible heating elements that can adapt to different shapes and surfaces.

5. Thermal storage: Graphene nanotubes can be used in thermal storage systems, where they provide high thermal conductivity and can serve to store heat in heat-intensive materials.

6. Supplemental Pipe Heating: Integrating HOT into pipe heating elements can improve uniform heat distribution in heating systems.

7. Electrically Controlled Elements: HNTs can be used in electrically controlled heating elements due to their electrical conductivity, allowing precise temperature control.

8. Environmental Sustainability: Graphene nanotubes as materials can be more environmentally sustainable than some traditional materials, leading to more sustainable heating systems.

9. Energy Saving: Due to their thermophysical properties and strength, HNTs can help create more efficient heating systems, which in turn contributes to energy savings.

It should be noted that the use of graphene nanotubes in heating systems is at the research and development stage. Before these materials are widely adopted, additional research is required to evaluate their effectiveness, safety, and cost-effectiveness in specific application conditions.

Use in Thermal Media. In heating systems, graphene nanotubes can be incorporated into thermal media such as water-glycol solutions. By adding HNT to the thermal fluid, its thermal conductivity improves, which contributes to more efficient heat distribution throughout the heating system.

The use of graphene nanotubes in heating systems and thermal media is a promising direction, where their unique thermophysical properties contribute to more efficient and economical functioning of heating systems.

2.2 Automated heating systems and existing examples

Automation of the heating system in an apartment building has recently become very popular. This is due to the fact that tariffs are constantly rising. Weather-dependent automation allows you to save energy costs and therefore becomes in demand.

Automation of the heating system of an apartment building is a means of regulating the microclimate in the premises during temperature changes outside. As practice shows, these devices for the heating system of an apartment building are really useful in regions where frequent daily temperature changes occur in winter.

Such devices are equipped with programs that allow you to set the necessary parameters in advance. For example, at -10, the heating of the batteries reaches one level, but when the temperature outside drops to -15 degrees, it reaches another, hotter level, and vice versa.

Where the temperature regime in winter is not subject to sudden changes, but remains at approximately the same level, weather-dependent automation is not in demand.

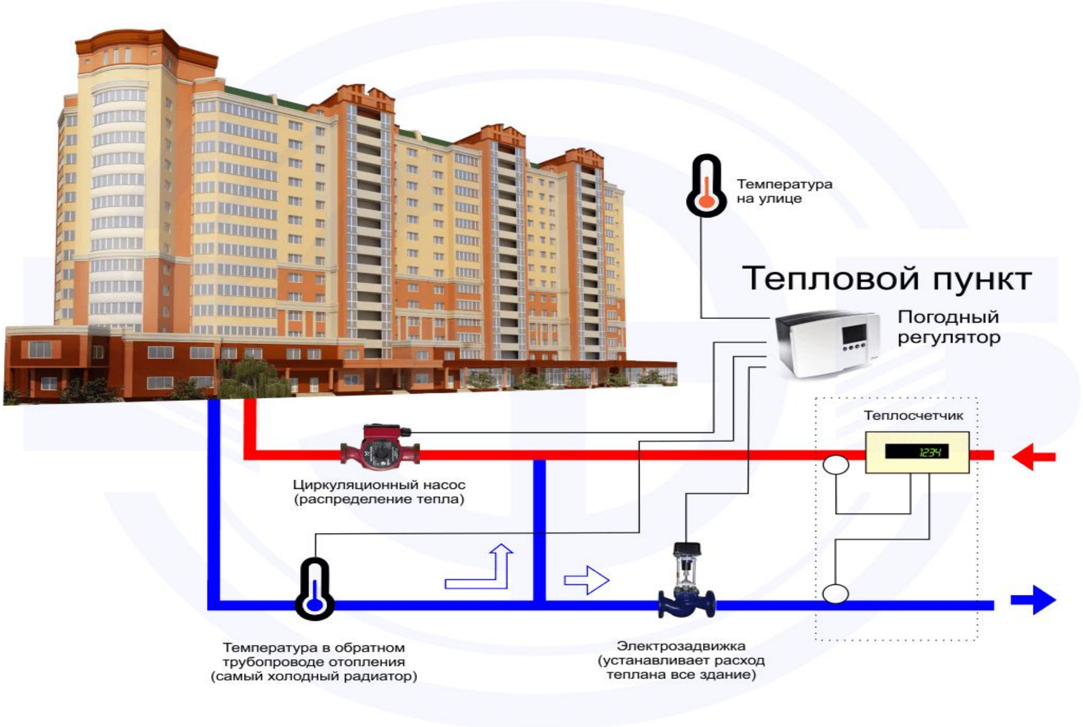

Figure 20 An example of a finished automated heating system for a residential building.

The problem of economical consumption of thermal energy in heating systems of apartment buildings due to rising energy prices and, accordingly, fees for the provision of heat is becoming increasingly important. Automated heating systems are installed in new construction. Automatic regulation of coolant temperature parameters, installation of an automated control unit in an individual heating unit at home.

In old houses, the problem of rational use of heat is practically not solved, firstly, due to the lack of technical and economic justification for the necessary work, and secondly, due to the lack or absence of financial resources.

Although, the largest expense item in payments for utility services is payment for heating and hot water supply, it amounts to about 60%. Produced every month regardless of the heating season.

In this regard, the task of increasing the efficiency of existing heating and water supply systems in apartment buildings is especially urgent. One of the promising solutions to this problem is the installation of metering devices and the introduction of an automated heating and control system, which will eliminate unreasonable excess consumption of thermal energy.

Installing a thermal energy metering unit allows you to proceed to calculations for actual energy consumption, and the automatic heat control system saves thermal energy. The purpose of using a heating automation and control system is to control the process of heat use according to the outside air temperature.

This is done by increasing or decreasing the intensity of the coolant flow in apartment buildings. This process depends on the real needs of the room for thermal energy at a particular moment.

The use of an automated heating system allows us to highlight the following saving factors:

Removal of forced “overtoppings” during transitional and off-season periods. The use of heating temperature control systems at heating points allows achieving 30–40% savings during these heating periods. The relevance of regulating the supply of coolant in the off-season period increases due to the increase in the overall value of positive outdoor air temperatures in the autumn-winter period.

Removing the influence of the inertia of the heating network on heat losses. This means that the temperature in the networks cannot change quickly. In Ukraine, the difference between day and night temperatures can reach 3–8 C. The thermal inertia of a building, as a rule, is not enough to compensate for these changes. As a result, “overflows” are possible during the daytime hours. Consequently, there is heat loss or “underheating” at night, which leads to overconsumption of more expensive electricity due to the inclusion of household heating appliances. This factor can only be estimated approximately, within 3–5% of total heat consumption.

Correction of the temperature schedule based on the actual performance of heating devices. That is, adjusting the design temperature schedule for heating a building, taking into account the elimination of reserves that designers include when determining the required area of heating devices. The saving effect from automation of a heating point in this case can range from 7 to 15%.

Economic effect due to the use of a quality regulation schedule. With high-quality regulation, all rooms are in equal heat conditions. Consequently, deep regulation can be applied with the greatest economic effect (the above applies to hydraulically regulated systems). So, for example, one degree of overheating in the premises (i.e. 21°C instead of 20°C) is equivalent to almost 7% losses.

Thus, we can conclude that the transition to an automated heating system is quite effective from an economic point of view. Low payback periods allow us to classify this method of energy saving as low-cost and quickly payback.

2.2.1 Weather-compensated automatic operating principle

A heating control system based on current weather conditions consists of several main components:

- control controller;
- temperature sensors;
- elevator, or control valve with pump.

The operating principle of the controller is based on the analysis of data from four temperature sensors:

- inside the house;
- outside;
- on a direct pipeline;
- on return.

When the outside temperature increases or decreases, the controller gives a command to the actuators to close or open and, accordingly, increase or decrease the supply of hot water from the heating network. Automation analyzes all data and uses special algorithms to calculate the required temperature.

An algorithm for maintaining temperature depending on the street temperature in apartment buildings is already built into the controller’s automation. It needs to be adjusted depending on what kind of house it is. Let's say a brick house with thick walls or a panel house with cold walls. It is very unprofitable to install heat meters in old panel houses; they have very cold walls and instead of the expected savings, you will pay more. Therefore, if there is a heat meter in a panel house, then in order to save money, it is necessary to install weather-compensating automation.

You can maintain a certain temperature in the house depending on the temperature in one of its apartments, and in an apartment in one of the rooms. This should be an average temperature, and its fluctuations should be minimal. A bedroom or children's room is best suited for these conditions.

During operation, the controller periodically, at a certain time interval, polls temperature sensors that measure the temperature of the coolant, outside air and (or) indoor air, if available.

When the temperature outside increases or decreases, the controller gives a command to the elevator actuator (stepper motor) to close or open and, accordingly, increase or decrease the flow of coolant from the heating network. The stepper motor drives a conical needle, which, by moving, reduces or increases the coolant passage area.

As a result, more cooled (used) coolant from the return pipeline enters the elevator and, accordingly, the apartment heating system if it is necessary to reduce the temperature. Or less if it is necessary to increase the temperature in the home heating system.

If a decision is made not to install an air sensor in the room, the automated heating system maintains the temperature according to the temperature schedule.

An automated heating system is guaranteed to pay for itself in multi-storey buildings and large cottages. In small private homes, cost effectiveness varies greatly depending on local conditions.

2.3 Existing automated heating systems

There are many automated residential heating systems. Most of them are based on the use of combined methods. If we talk about ready-made solutions, we can give a couple of examples:

1. Siemens Desigo CC:

Siemens Desigo CC is a building automation system designed to control heating, ventilation, air conditioning and other systems. It provides centralized control of all aspects of energy in a building.

Advantages: Centralized management, optimization of energy consumption, integration with various technologies.

Desigo CC is designed for objects of any size and complexity: public and commercial buildings, schools and universities, offices, hospitals, stadiums and airports. All building systems can be integrated into it, from HVAC automation systems, lighting control, blinds, to security systems.

List of key features of Desigo CC:

- Centralized control station for all building systems, equipped with various auxiliary tools to solve tasks assigned to the operator
- Optimized for both fast and efficient operation and configuration
- Easy integration of BACnet, SNMP, Modbus-TCP, Web services and OPC protocols both client and server
- Support for remote work from mobile and Web clients
- Support for remote configuration from Web clients

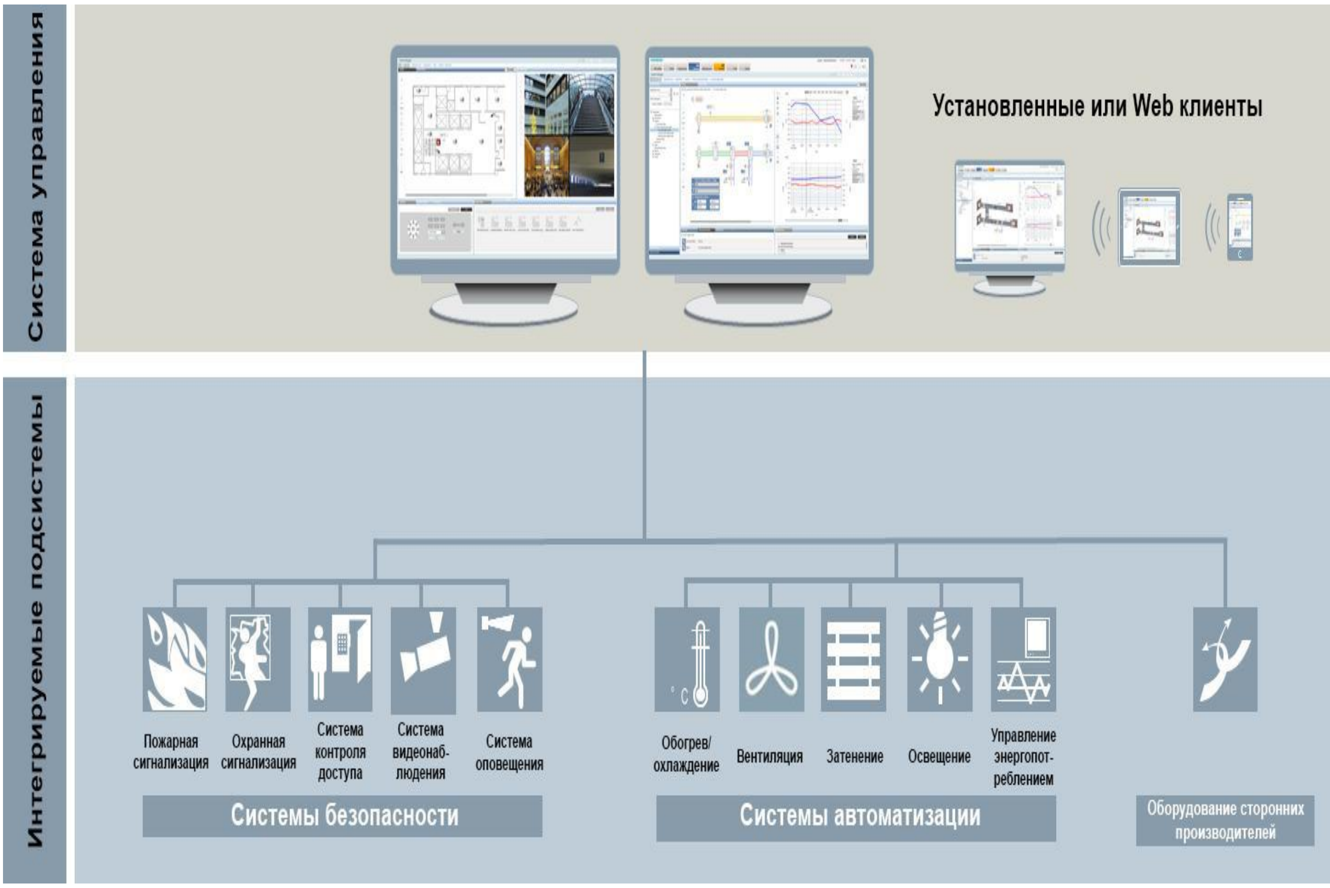

Figure 20 Building automation system: Siemens Desigo CC

2. Schneider Electric EcoStruxure Building Operation:

This system provides control of building systems including heating, ventilation, air conditioning and lighting. It allows you to create flexible control scenarios and provides monitoring of energy consumption.

Advantages: Flexible programming, energy consumption monitoring, ability to integrate with devices from different manufacturers.

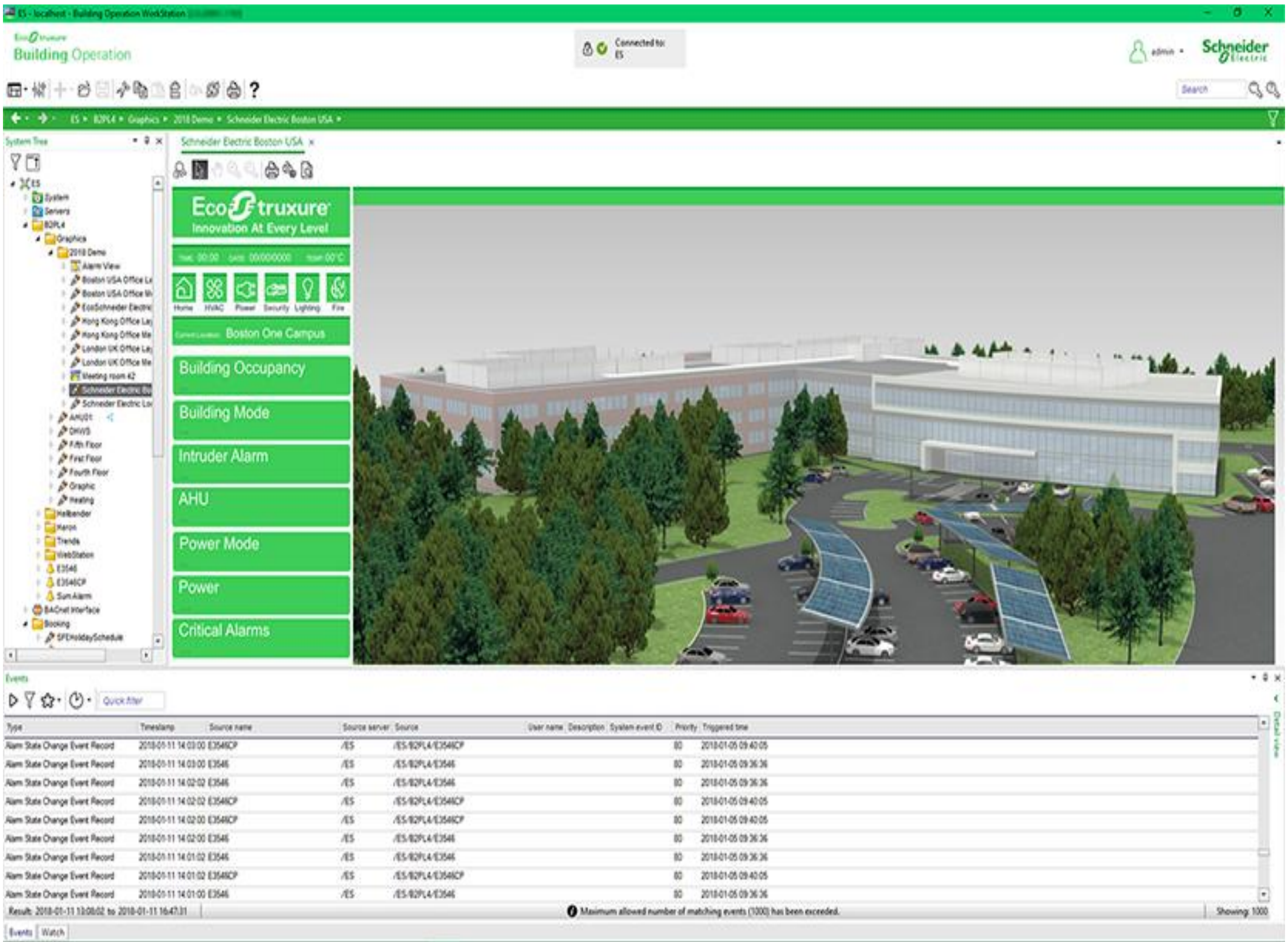

Figure 21 Comprehensive monitoring program EcoStruxure Building Operation 3.1

3. Johnson Controls Metasys:

Metasys is a building automation system designed to integrate and control heating, ventilation, air conditioning and other systems. It provides centralized control and monitoring. This is a software and hardware complex for building automation and dispatching from Johnson Controls. This concept includes field level controllers, network level controllers, as well as dispatch software.

Advantages: Integration of various systems, centralized monitoring, optimization of energy consumption.

Figure 22 Building Control System: Johnson Controls Metasys

4. Danfoss NovoCon S Digital Actuator:

This digital drive is designed to control heating and ventilation systems. It can be used in combination with smart thermostats and zone heating automation systems.

Advantages: Digital control, ability to integrate with smart technologies, precise temperature control.

5. Carrier i-Vu Building Automation System:

Description: Carrier's building management system provides control of heating, ventilation, air conditioning and other systems. It provides a graphical interface for monitoring and control.

Advantages: Graphical interface, centralized management, integration with other systems.

If we talk about a simpler, inexpensive, but no less effective system, we can cite as an example a smart system for heating rooms, houses and heating hot water from Ecosvit. This is a Ukrainian site that offers ready-made solutions, services and technologies for automated residential heating systems.

Figure 23 Smart system for heating rooms, houses and heating hot water

This system consumes 4–7 kWh. electricity for heating rooms up to 100 m2.

Possible uses of the system:

Heating and hot water heating for private houses, industrial and budget premises, a current solution for significant savings in energy costs of newly built communities, as well as for constructed multi-storey buildings. And of course, for condominium houses, which will have constant hot water at prices significantly lower than the central water supply.

Brief characteristics:

- saves up to 40% of heat loss due to the absence of heating mains;
- saves up to 25% of money due to the absence of overheating;

- has an efficiency coefficient greater than 1, which makes it possible to release more thermal energy in relation to consumption;
- when using a night tariff, it has the lowest cost per 1 Gcal of heat;
- provides the opportunity to independently make decisions about the beginning or end of the heating season depending on weather conditions or the financial capabilities of the User;
- has a fully automated system for maintaining a set coolant temperature depending on weather conditions with the ability to control parameters via a Wi-Fi network;
- constant post-warranty support;
- unlimited power range, starting from 0.6 kW;
- The average payback period for projects is up to 2 years.

Technical description of the system:

1. Purpose.

1.1 Electric electrode heaters of the Gulfstream D series are installations assembled on the basis of electrode heating elements and designed for heating coolant in water heating or hot water supply systems with forced circulation in residential and industrial premises with an outlet temperature of up to 75 ° C.

1.1.2. The main advantages of electrode boiler houses:

- high operational reliability (the heating process is based on the ionic conductivity of the coolant and occurs due to the direct flow of electric current through it);
- “soft” starting characteristic (no inrush current surges);
- there is no penetration of return parasitic harmonics into the power supply network, which can lead to malfunction or failure of other energy consumers;
- smooth access to full power, since the electrical conductivity of the coolant is directly dependent on its temperature;
- high accuracy of control and maintenance of specified temperature parameters;
- compact installation and ease of installation;
- the possibility of organizing a local (individual) heating system;

- possibility of use as an auxiliary heat source in an existing heating system;
- quiet operation (noise level does not exceed 37 dB)
- complete fire safety in case of depressurization of the system (if there is a coolant leak, the heating system automatically stops working);
- ease of integration into existing heating systems;
- significant savings in consumed electricity (at least 25% compared to heating elements) due to smooth access to full power and control algorithm (no overheating);
- high energy conversion coefficient (close to 1), since the resistive element is the coolant itself.

2.4 Design and principle of operation

Modern engineering solutions incorporated into the design of electrode heaters are based on the latest scientific and engineering achievements in the fields of materials science, physics and electronics. Electrode heaters are direct-acting units, the operating principle of which is based on the ionic conductivity of the coolant. Heating occurs due to the direct flow of electric current through the coolant, which leads to an increase in the amplitude of oscillations of the coolant ions between the electrodes with a frequency of 50 Hz and causes a rapid increase in the temperature of the coolant as a whole.

The electrode boiler room is simple and reliable in operation, has a long service life with optimal energy consumption.

The casing and fastening elements of the electrode boiler room are made of powder-coated steel, heat-resistant plastics and silicone seals. They are designed for a large number of assembly and disassembly cycles and have high maintainability. The service life of the heaters is at least 15 years.

No.	Name of parameter and size	Norm
1	Heater rated power, kW	from 4 to 7.0
2	Rated supply voltage, V	220
3	Number of phases, pcs.	1
4	Permissible supply voltage deviation, %	± 15
5	Current type	variable

6	Rated frequency of the supply network, Hz	50 (60)
7	Coolant	distillate
8	Temperature at the heater outlet, °C	no more – 75

Table 2. Main parameters and dimensions of heaters.

Complete set of boiler room supply:

• electrode heater with a power of up to 5 kW;

• hydraulic piping on the assembled mounting frame (primary circuit circulation pump, plate heat exchanger, expansion tank);

• Remote Control.

Examples of economic implementation of the system (before system modernization)

1. CP "Kyiv Metro"

The heating area is 4800 m², before the reconstruction we used central heating without a meter.

Consumption before equipment installation:

4800 m² × 0.0548 Gcal/m² per month (standard) = 263.04 Gcal/month

Expenses:

263.04 Gcal × 1315 UAH. = 345,897.6 UAH. / month

Consumption after installation of the system - installed power - 480 kW:

Automatic adjustment, operating time from 4 to 8 hours a day.

Calculation of consumption with generated heat flow:

4800 m²×0.015 kW×24 hours×30 days = 51840 kW/month.

51,840 kW x 0.99 UAH. = 51,321.6 UAH. /month.

Economic effect for the season – 1,767,456 UAH.

The price of a 480 kW system is UAH 1,060,800.

2. School in Kyiv region

The heating room has an area of 1,700 m²; before modernization, a coal boiler room was used.

Costs before modernization:

130 tons of coal per season = 130×3000 UAH. = 390,000 UAH. (minimum costs shown).

Two stokers with a payroll of 2,000/month:

2000×2×12 months × 1.37=65,760 UAH.

Off-season repairs – up to 40,000 UAH.

Total expenses: 495,760 UAH. per season.

Consumption after equipment installation – installed power – 100 kW:

Average consumption is 12,606.8 kW per month or 118,000 UAH. per season.

The economic effect per season is more than UAH 300,000.

The price of a 100 kW system cost the school UAH 221,000.

2.5 Environmental aspects in heating systems

Environmental aspects in heating systems play an important role in the context of sustainable development and reducing the impact of human activities on the environment. Some of the key environmental aspects to consider when choosing and using heating systems are:

1. Use of Renewable Energy Sources such as:

- Solar Energy: Solar collectors and solar panels can be used to generate electricity and heat water. These are environmentally friendly technologies that can significantly reduce dependence on traditional energy sources.

- Wind Power: Wind turbines can be installed to generate electricity. This provides a stable source of renewable energy, reducing the need to use traditional sources.

Benefits: Heating systems powered by renewable energy sources such as solar, wind or biomass significantly reduce emissions of greenhouse gases and other harmful substances, helping to combat climate change.

2. Efficient Heat Technologies:

- Heat Pumps: These extract heat from the environment and can provide efficient heating. Using low carbon heat pumps can significantly reduce your environmental impact.

• High Efficiency Boilers: New technologies in burners and heat exchangers allow for high efficiency boilers, which help reduce fuel consumption and emissions.

Benefits: The use of highly efficient heating technologies, such as heat pumps or high efficiency boilers, can significantly reduce energy consumption, leading to reduced emissions and conservation of natural resources.

3. Geothermal Heating:

Advantages: Geothermal heating systems use heat stored in the ground to provide heating. They are a clean source of energy with no emissions and can be effective for a long time.

4. Thermal Storage Systems:

Advantages: Thermal accumulators allow you to store heat for periods when it is needed in the room, which allows you to optimize the operation of the heating system and reduce energy consumption during periods of peak demand.

5. Energy Saving Technologies:

Benefits: Adopting energy-saving technologies such as smart heating controls, smart thermostats and sensors helps you accurately regulate temperature and avoid excess energy consumption.

6. Eco-friendly Materials and Fuel:

• Using low carbon building materials, such as recycled content or materials derived from renewable sources, helps reduce your overall environmental footprint.

• Switching from traditional fuels to cleaner options such as biomass or biogas can reduce emissions of harmful substances into the atmosphere.

Advantages: The use of environmentally friendly materials in the construction of heating systems and the choice of environmentally friendly fuels (for example, biomass or biogas) also helps to improve the environmental performance of heating systems.

7. Heat Recovery Ventilation Systems:

Benefits: Ventilation systems that recover heat from exhaust air reduce the need for separate heating systems and help save energy.

8. Minimizing the Use of Traditional Fuels:

• Switching to cleaner fuel sources, such as renewable electricity, can be a key step in reducing the environmental impact of heating systems.

• The widespread use of technologies to burn traditional fuels such as coal and oil has the potential to significantly reduce greenhouse gas emissions.

Benefits: Gradually switching to alternative energy sources and minimizing the use of traditional fuels such as coal or oil helps reduce pollution and emissions.

Considering environmental aspects when designing, selecting and operating heating systems is important to reduce environmental impact and create more sustainable homes.

2.6 The role of artificial intelligence in heating systems

Artificial intelligence (AI) is playing an increasingly important role in optimizing and improving the efficiency of heating systems. Options for how artificial intelligence can be applied in heating systems:

Artificial intelligence (AI) is playing an increasingly important role in optimizing and improving the efficiency of heating systems. Here are a few ways artificial intelligence can be applied to heating systems:

1. Smart Thermostats:

• Adaptive Temperature Control: AI-powered smart thermostats can adapt to users' behavior and automatically adjust the temperature according to their preferences and activity schedule.

• Energy Consumption Forecasting: AI algorithms can analyze weather data, historical energy usage patterns and other factors to predict future consumption and optimize heating system performance.

2. Automation of Zone Heating:

• Individual Zone Control: AI-based systems can provide individual heating control in different zones of a room, helping to optimize energy consumption.

• Adaptive Algorithms: AI algorithms can adapt to changing conditions in each zone, allowing you to maintain a comfortable environment with minimal energy consumption.

3. Optimization of Heat Supply Operation:

- Heat Use Forecasting: AI can be used to predict peak heat use times and optimize heating operation to avoid excess consumption.
- Dynamic Regulation: AI systems can dynamically adjust temperature and heat output based on changing conditions such as weather or occupant activity.

4. Monitoring and Maintenance Systems:

- Condition Diagnostics: AI algorithms can analyze sensor data and provide diagnostics on the condition of the heating system, simplifying maintenance and preventing problems.
- Proactive Maintenance: AI can predict possible problems or malfunctions in the heating system and offer recommendations for eliminating them before they lead to serious breakdowns.

5. Integration with Smart Grids:

- Smart Home Systems: AI can integrate with other smart home systems, such as security systems or smart lighting, to provide more comprehensive and efficient energy management.
- Asset Management: AI can manage energy-efficient assets in a home, such as heat pumps or solar panels, to maximize the use of renewable energy.

Artificial intelligence in heating systems can not only improve comfort, but also significantly improve energy efficiency, which is important from the point of view of environmental sustainability and reducing environmental impact.

CHAPTER 3
SELECTION AND TECHNICAL CHARACTERISTICS OF THE BUILDING

Despite the established image of Kyiv - a city that is actively developing, the vast majority of houses in the city - almost half - are low-rise (no more than three floors) houses. Houses with a height of 4 to 16 floors occupy slightly less - 45.1%. High-rise buildings in total occupy 8.7% of all development.

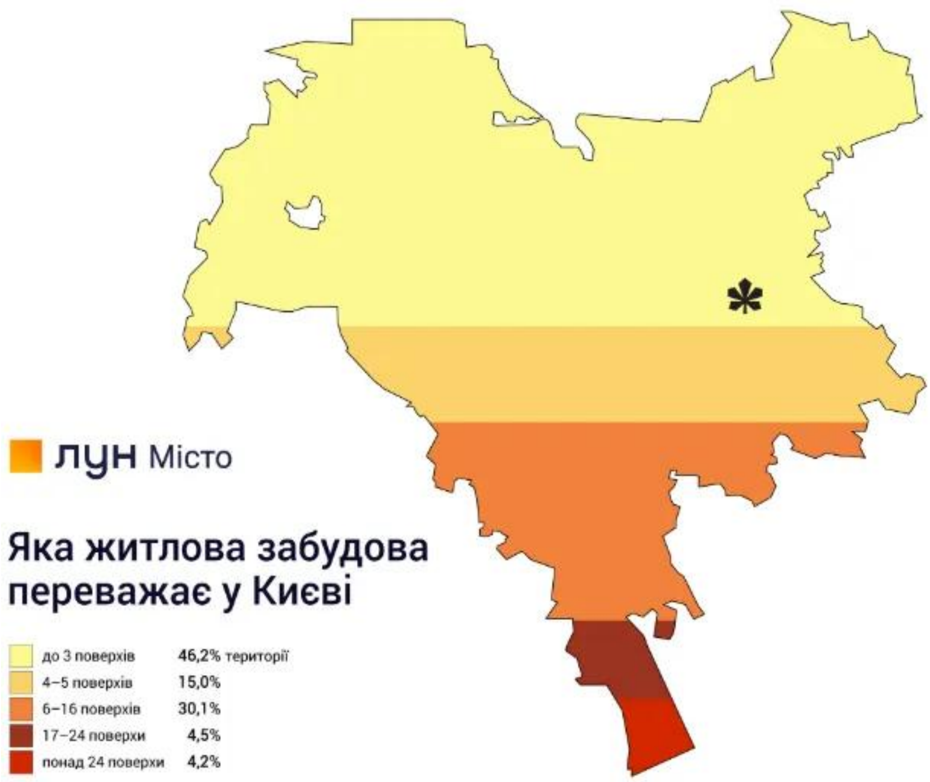

Figure 24. Ratio of floors of residential buildings in Kyiv

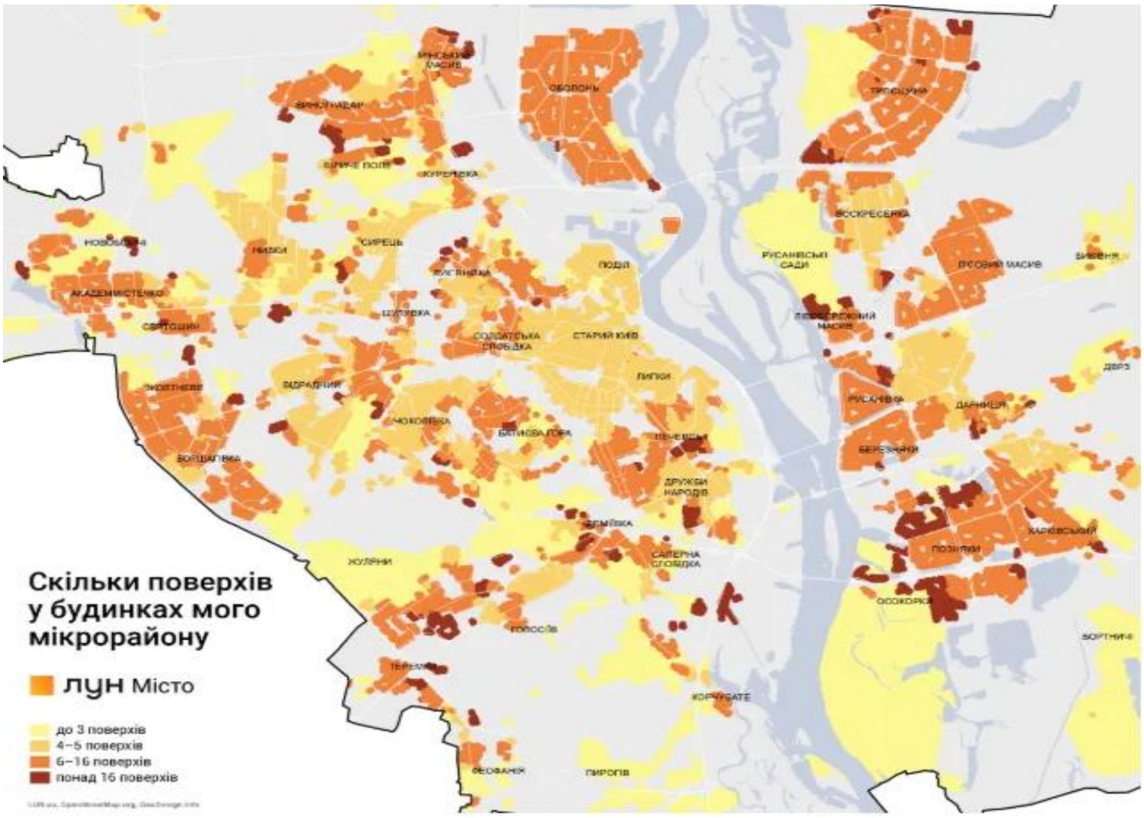

Figure 25. Proportion of buildings by district

If we consider the most densely populated areas of Kyiv, we will see that almost half of the residents of Kyiv live in the Darnitsky, Desnyansky, Dneprovsky, Obolonsky districts of the city.

Goloseevsky	254123
Darnitsky	348383
Desnyansky	368676
Dneprovsky	358152
Obolonsky	318346
Pechersky	163607
Podolsky	209003
Svyatoshinsky	342064
Solomensky	384330
Shevchenkovsky	216465

Table 3. Population by district of Kyiv per 1 breast in 2020.

Based on Figure 25, 6-16 storey buildings are superior in these areas.

This thesis will examine the building at Kharkov Highway 21. This is a 9-story, multi-apartment residential building, built in 1967. The construction material of this building is reinforced concrete panel. Not far from the building there is a heating main and a TP. But in 2019, a quarterly reconstruction was carried out: instead of a central heating unit (CHS), an individual heating unit with weather regulation was installed in a residential building. Thanks to the weather control system, residents can set the appropriate temperature at home from their smartphone and save 25-30% on heating.

Figure 26. Individual heating point with weather control.

3.1 Features of climatic conditions

The most significant part of the territory of Ukraine is located in zones with temperate and cold climates.

Figure 27 Map of temperature zones of Ukraine according to DBN V.2.6-31:2016

As can be seen from Figure 27, Ukraine is divided into 2 zones of the heating period. The first zone is more than 3501 degrees-day. The second zone is less than 3500 degrees-day.

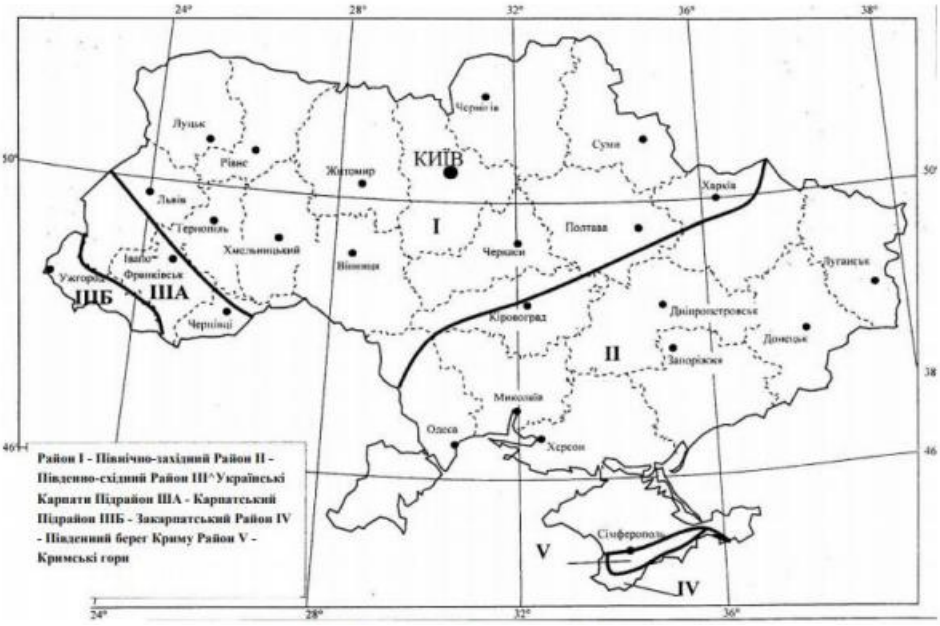

Figure 28 Climatic regions of Ukraine for DSTU-N B V.1.1-27:2010

Characteristic internal air temperatures for the city of Kyiv are given in Table 3.

Київська область																									
Київ	–4,7 / 5,5	–3,6 / 5,7	1,0 / 6,6	9,0 / 8,8	15,2 / 9,8	18,3 / 9,6	19,8 / 9,4	19,0 / 9,6	13,9 / 9,1	8,1 / 7,5	1,9 / 4,7	–2,5 / 4,7	8,0	-29	-26	-25	-22	28	23	176	-0,1	195	0,7	–	–
Область, місто	Середня місячна температура повітря / середня добова амплітуда температури, °C												Середня за рік	Температура повітря, °C						Період із середньою добовою температурою повітря					
														холодного періоду				теплого періоду		≤ 8 °C		≤ 10 °C		≥ 21 °C	
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII		найхолодніша доба забезпеченістю		найхолодніша п'ятиденка забезпеченістю		найжаркіша доба забезпеченістю 0,95	найжаркіша п'ятиденка забезпеченістю 0,99	тривалість, діб	середня температура, °C	тривалість, діб	середня температура, °C	тривалість, діб	середня температура, °C
														0,98	0,92	0,98	0,92								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

Table 3 – Internal air temperatures for the city of Kyiv according to DSTU-N B V.1.1-27:2010

Data on the prevailing wind directions and its speed for the city of Kyiv are presented in Table 4.

Zoning of Ukraine by the number of degrees-days of the heating period as shown in Figure 29.

Область, місто	Переважний напрям вітру, його повторюваність, % / Середня швидкість вітру, м/с по місяцях											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Київська область Київ	З, 24 / 2,8	ПдСх, 18 / 2,9	ПдСх, 17 / 2,7	Пн, 16 / 2,6	Пн, 17 / 2,3	Пн, 19 / 2,2	З, 20 / 2,1	Пн, 21 / 2,0	З, 24 / 2,1	З, 21 / 2,3	З, 21 / 2,6	З, 21 / 2,7

Table 4 – Predominant wind directions and speed in Kyiv according to DSTU-N B V.1.1-27:2010

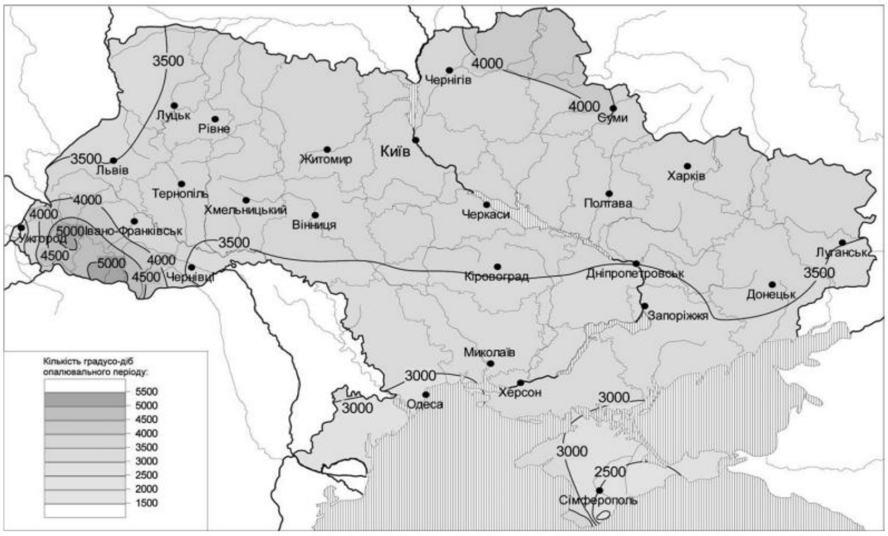

Figure 29 Zoning of Ukraine by the number of degrees-days of the heating period

By interpolation we determine the number of degrees for Kyiv - about 3540.

Let's check the obtained value by calculation:

$$\text{ГДОП} = Z_{\text{ОП}}\left(t_{\text{в}} - t_{\text{ср.оп}}\right) = 176(20 + 0{,}1) = 3537.6$$

($Z_{\text{ОП}}$- duration of the heating period at an average annual air temperature ≤+8°C, is the temperature of the internal air of the building in$t_{\text{в}}$°C, is the average temperature of the heating period in $t_{\text{ср.оп}}$°C).

The main design parameters of the house in the conditions of the city of Kyiv are presented in Table 5.

Name of design parameters	Designation	Units	Quantities
Estimated internal temperature air	$t_{\text{в}}$	°C	20
Estimated outside temperature air	$t_{\text{з}}$	°C	- 5
Duration of the heating season	n_o	days	176
Average outside air temperature in heating	$t_{\text{ср.оп}}$	°C	- 0.1

season			
Estimated number of degrees-days heating season	D_d	°C/About a day·	3537.6

Table 5 Design parameters of the house for the conditions of Kyiv.

3.2 Geographical location of the building

The geographical location of the building also plays an important role in the use of automated heating systems.

After all, as often happens, one part of the building goes into the yard, in which, on the contrary, there is a house, growing trees, it creates not only shade and coolness in summer, but also cold in winter. And the second part opens onto a larger area that is free from draughts.

In the example of a residential house, which is given in the paper, these conditions exist. Also, the spacious part that faces the road is illuminated by the sun, because sunset and sunrise take place from this side. In summer time one side is heated more strongly because of this, in winter time, an uneven temperature distribution is created and the rear part of the building loses more heat than the front part, which is additionally heated by the sun, because of the entrance doors, draughts and windows in the entrance hall.

In this chapter it was described that the building has an individual heat supply system with weather regulation, thanks to which the occupants can save 25-30% on heating. But the disadvantage of this system is that the heat is distributed unevenly throughout the building, so if you set the average temperature of the building at 22°C, one part of the building will have a little more than 22 degrees C, and the second part less, as well as, despite the fact that due to the installation of individual heat point can control the temperature of the building, it does not solve the environmental and economic issue in connection with these shortcomings, because in winter the building will be unevenly heated, and therefore the system does not have the ability to evenly heat the building and the heat.

Figure 30 Building location

CHAPTER 4

SOLVING THE PROBLEM AND DEVELOPING AN ENERGY-EFFICIENT AUTOMATED SYSTEM

4.1 Installation of an automated system "Gulfstream D"

To solve the problem of inefficient distribution of heat in the house, as well as to abandon the individual heating unit, which is less environmentally friendly and more expensive, it is worth installing a ready-made automated system "Gulfstream D" and use the intelligent system of the house.

To calculate the floor area of a building with all floors, let's use an online calculator.

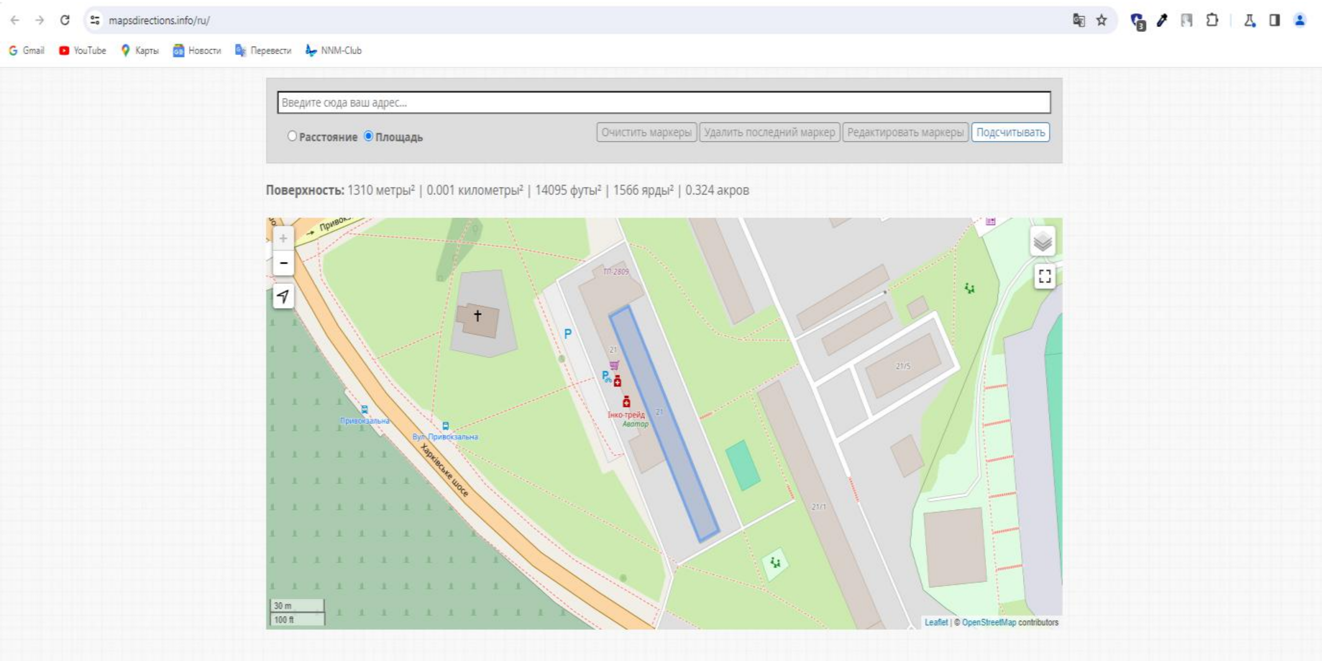

Figure 31 Approximate building footprint

Since the building has 9 floors and its area is 1310m^2, we multiply 1310 • 9 = 11790m2. If we remove the area of walls and balconies, we can reduce this area to 10000m^2.

Heating tariffs in Kiev

Heat supply company	Tariff with metering devices, UAH including VAT per 1 Gcal	Tariff without metering devices, UAH including VAT per 1/m^2
ПАО	1654,41	38,50

Heat supply company	Tariff with metering devices, UAH including VAT per 1 Gcal	Tariff without metering devices, UAH including VAT per 1/m^2
«Київенерго»		
ООО «Євро-Реконструкція»	1341,53	35,63

Table 6 Heating tariff in Kyiv

The house is connected to "Euro-Reconstruction", so multiply 10000m^2 • 35,63 = 356300 UAH. This is the approximate amount that the residents pay per month. Heating season is 5 months, multiply 356300 UAH by the number of months: 356300 • 5 = 1781500 UAH.

Installing two "Gulfstream D" systems with a capacity of 480 kW each, which will operate for 20 hours a day, we will get the following economic effect:

10000m^2 • 0.015 kW • 20 hours • 30 days = 90000 kW/month.

90000 kW • 2,64 UAH. = 237600 UAH/month.

Economic effect for a month – 356300 - 237600 = 118700 UAH.

Economic effect for the season – 118700 • 5 = 593500 UAH. 1781500 - 593500 = 1194300 UAH.

The price of two systems with a capacity of 480 kW - 2121600 UAH.

Payback system two seasons.

4.2 Hardware Solution For Automation Of Heating

To solve the problem of inefficient energy distribution, a hardware solution like a "smart home" system should be used.

The hardware components used to implement IoT can vary from low-power boards or single-board processors such as the Arduino Uno. These elements are included in additional motherboards to increase their functionality by providing specific features such as GPS, light and heat sensors, or interactive displays. Other possible alternative with a low-power and open-source software is the single-board computer BeagleBoard. Recently, the most popular platform for IoT is Raspberry Pi because it is a very affordable tiny computer that can incorporate an entire web server.

In order to make possible to manage the energy efficiency in a smart home is necessary to be able to control the temperature.

This can be achieved by using of sensors for motion, temperature, smart contacts, thermostats and more. A possible solution for energy efficiency management in a smart home using similar sensors is shown in Fig. 32.

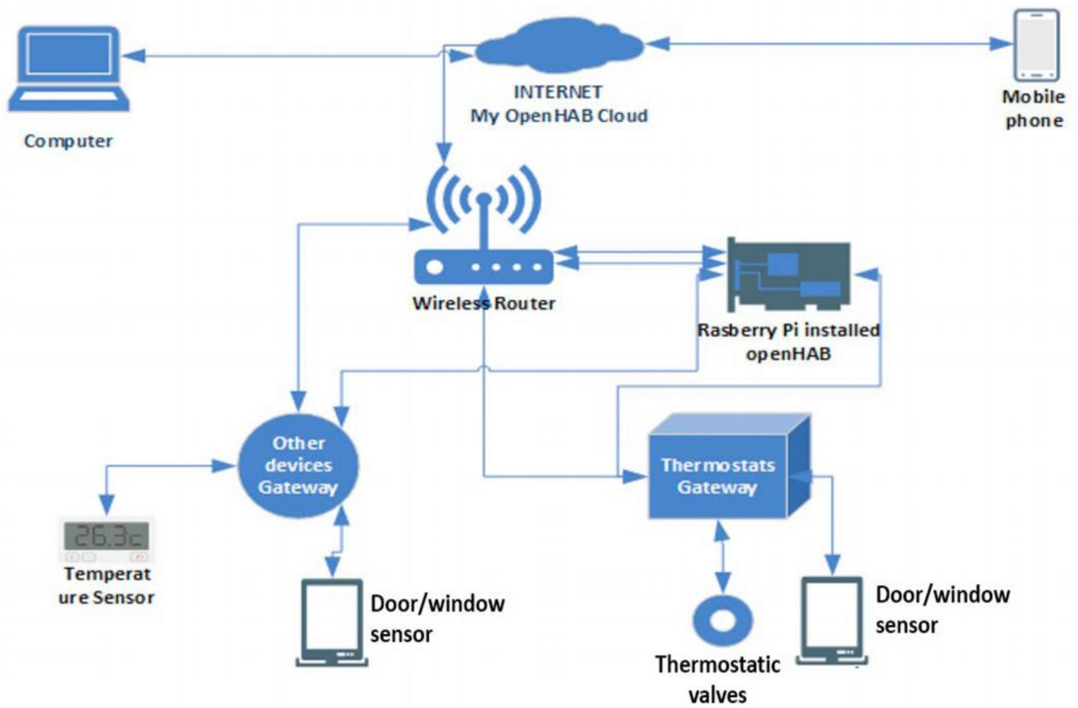

Figure 32 Smart home architecture for automation of heating

To realize the automation of heating in a smart home some smart thermostatic valves for radiators are to be mounted.

These valves could be connected to a proper software platform such as OpenHAB. When commanded to the preferred temperature, these valves remain open until temperature value is reached. This is realizing by valve built-in temperature sensor provides information about the temperature in the room.

Thermostatic valves can also be controlled manually when residents want a temperature other than the automatically set.

One of the advantages is that no matter how the temperature rises (from direct sunlight from the window, electric heater, etc.), the thermostatic valve closes automatically when the set temperature is reached. Heating control is only part of the overall digital transformation of the home, which includes lighting management, security, fire and flood protection and more.

4.3 Software solution for heating Automation

Software platform OpenHAB is based on Java programming language and support representational state transfer (REST). In addition, this software platform can be accessed via web interface, support many plugins and many protocols including MQTT (OpenHAB, 2022). All this makes this open source platform preferable in transforming our home into a smart home.

4.3.1 Software configuration rules

In order to implement the control of thermos-valves, which are used to ensure a certain temperature, it is necessary to define certain rules. The purpose of these rules is to give instructions on what to do at a certain temperature and time, or when opening a window.

First type of rules refers to the time and temperature and allow to set a specific temperature at a specific time of day. Pseudo-code of this rule is as follows:

IF time = <certain time> **THEN** <valves_name_setpoint_temperature> = <preferable temperature>

It is possible to set different time zones for morning, day, evening, night (respectively for: 6:30 – 8:00, 8:00 – 18:00, 18:00 – 21:00; and 21:00 – 6:00). These time zones can be different for each room and a different temperature can be set.

It is also possible to combine the rooms in one rule or to create another rule for one of the rooms to ensure the desired temperature in other time zones. The number of automatically set temperatures at certain hours is practically unlimited.

The second type of rules concerns the opening and closing of window/s. When a window in the room is opened, the thermostatic valve needs to be closed to prevent further heat loss. Pseudo-code of these rules is as follows:

CLOSED_OPEN

IF <sensor_status_open_window> changed from CLOSED to OPEN **THEN** variable = <valves_name_setpoint_temperature> & <valves_name_setpoint_temperature> = MIN ***OPEN_CLOSED***

IF <sensor_status_open_window> changed from OPEN to CLOSED **THEN** <valves_name_setpoint_temperature> = variable

Using the variable ensures that the desired valve temperature returns before the window is opened. The MIN constant can be set to a certain value at which the valve is completely closed. Since radiators are almost always located next to windows, the purpose of these rules is to prevent direct heat from escaping when opened, for example during ventilation.

4.4 Results and discussion

The applicability of the described approach was tested for an apartment with rooms, the distribution and used sensors of which are shown in Fig. 33.

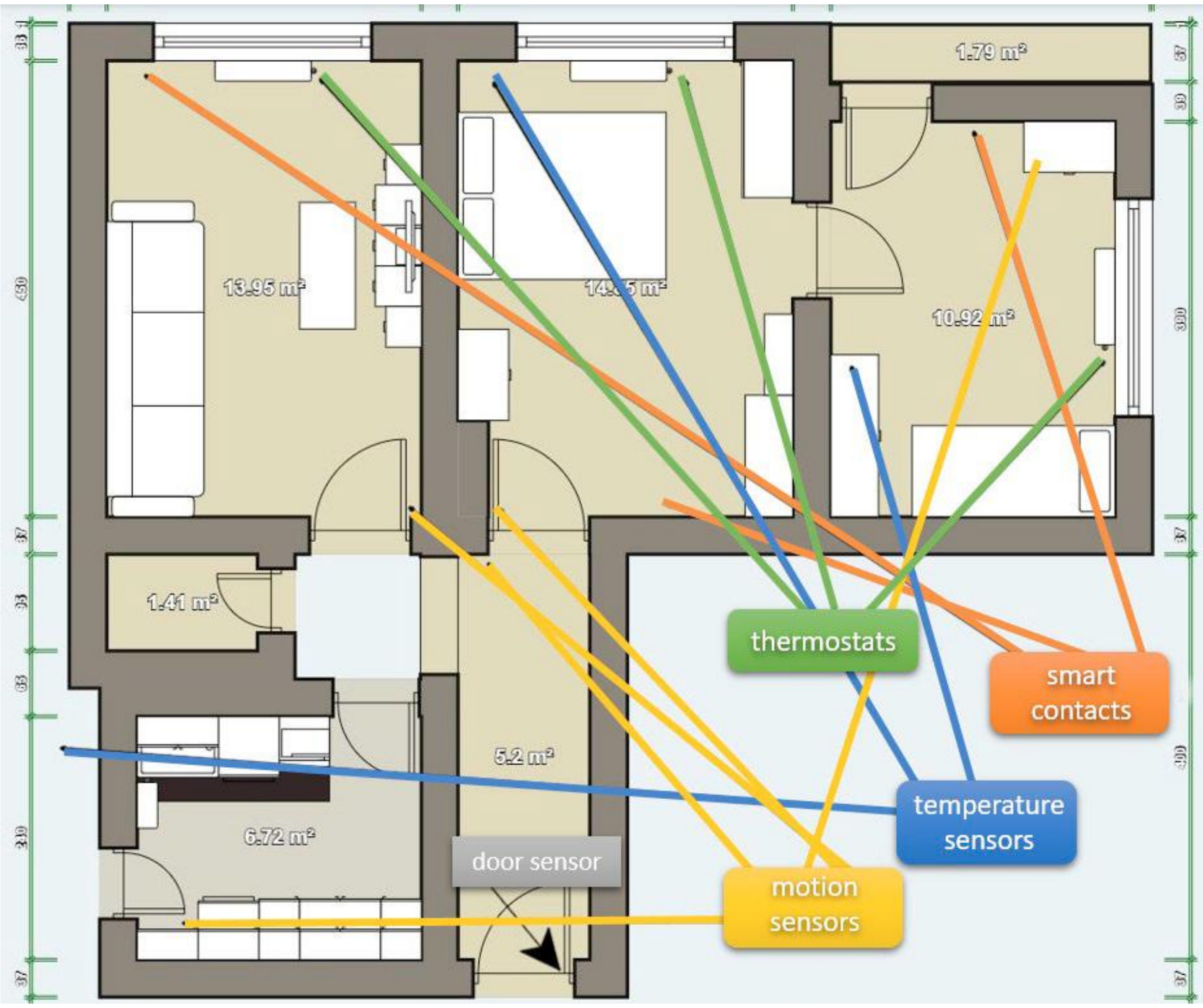

Figure 33 Rooms and sensors distribution

The apartment was digitally transformed more than one year ago, so a full one-year cycle was present to compare the results of the simulation. The apartment studied has no insulation, but it does have PVC frames with double glazing, and is surrounded by occupied neighboring apartments, which maintain higher temperatures. This results in a very high effect of the digital transformation while keeping its temperature low, it extracts heat from the neighbors and multiplies the effect of the digital transformation.

A full 3D model with the adjacent interior spaces is created (Fig. 34) and full interior and exterior model specifications are set, such as:

- Location settings and climate data input,
- Building enclosure input – glazing, exterior walls, pitched/flat roof, exterior floor to air/ground, etc. Local shadowing, if present, etc.,
- Interior data input – natural ventilation, temperature set-points for heating/cooling, internal loads, infiltration [n50, ac/h],
- Setting up manual (scheduled control of the devices) or automated (through setpoints/sensors, three step control, etc.).

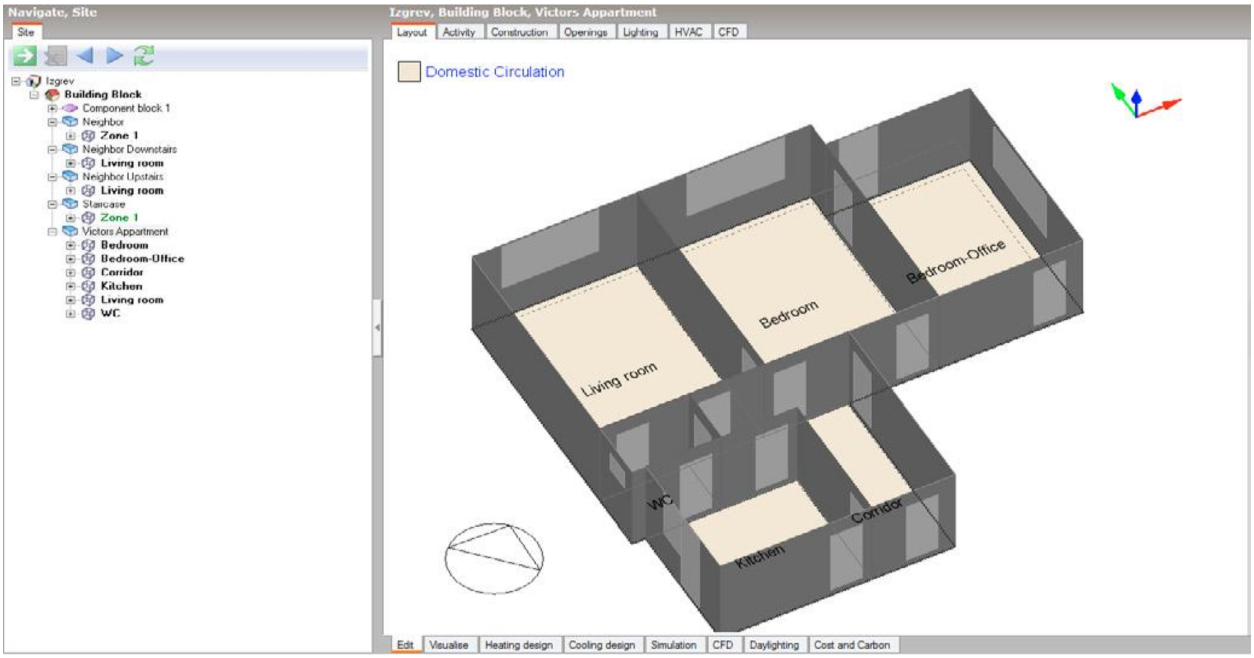

Figure 34 The digital twin model of the single apartment studied

A digital twin of the apartment is used to simulate the effect of the digital infrastructure on the heating loads. The heating load before application of IoT for digital transformation of home into smart home is shown in Fig. 35 while Fig. 36 illustrate the heating load after IoT application.

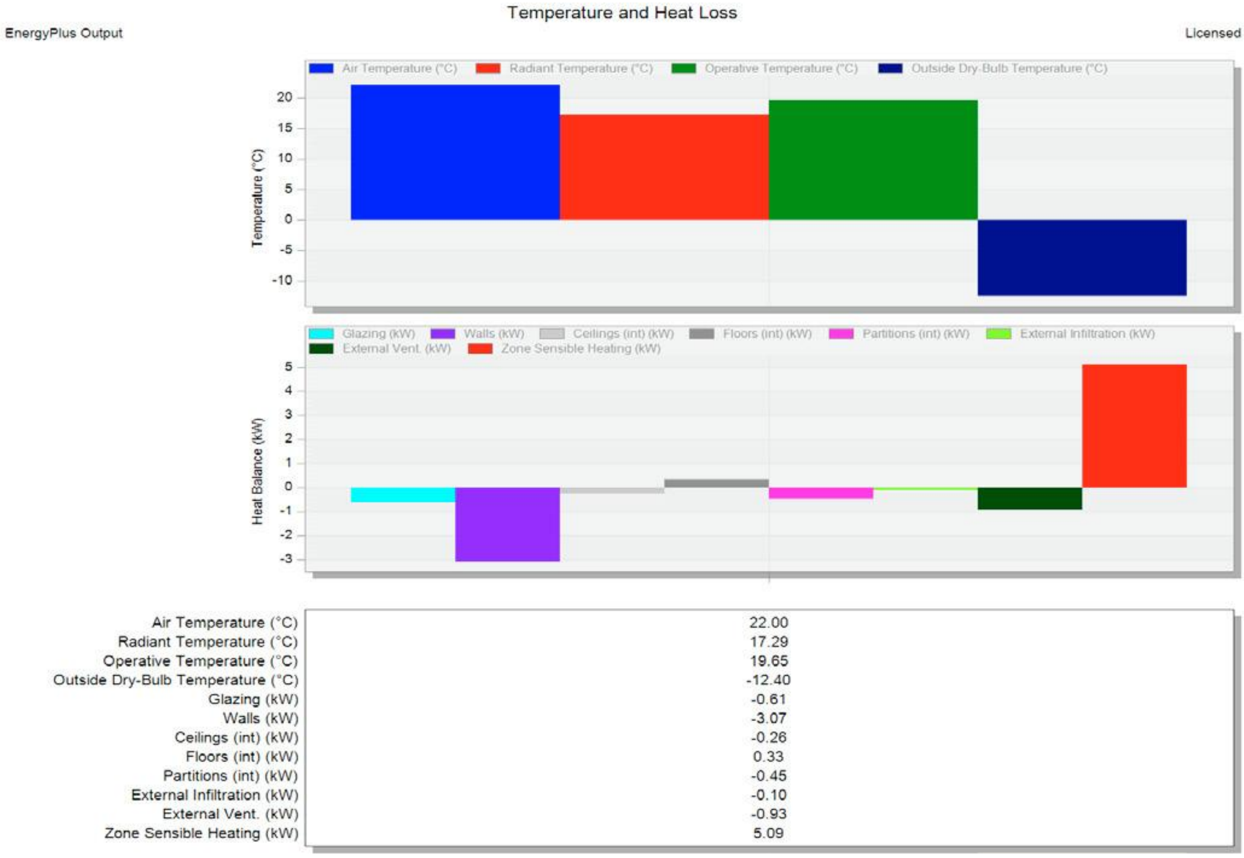

Figure 35 Heating load before application of digital transformation

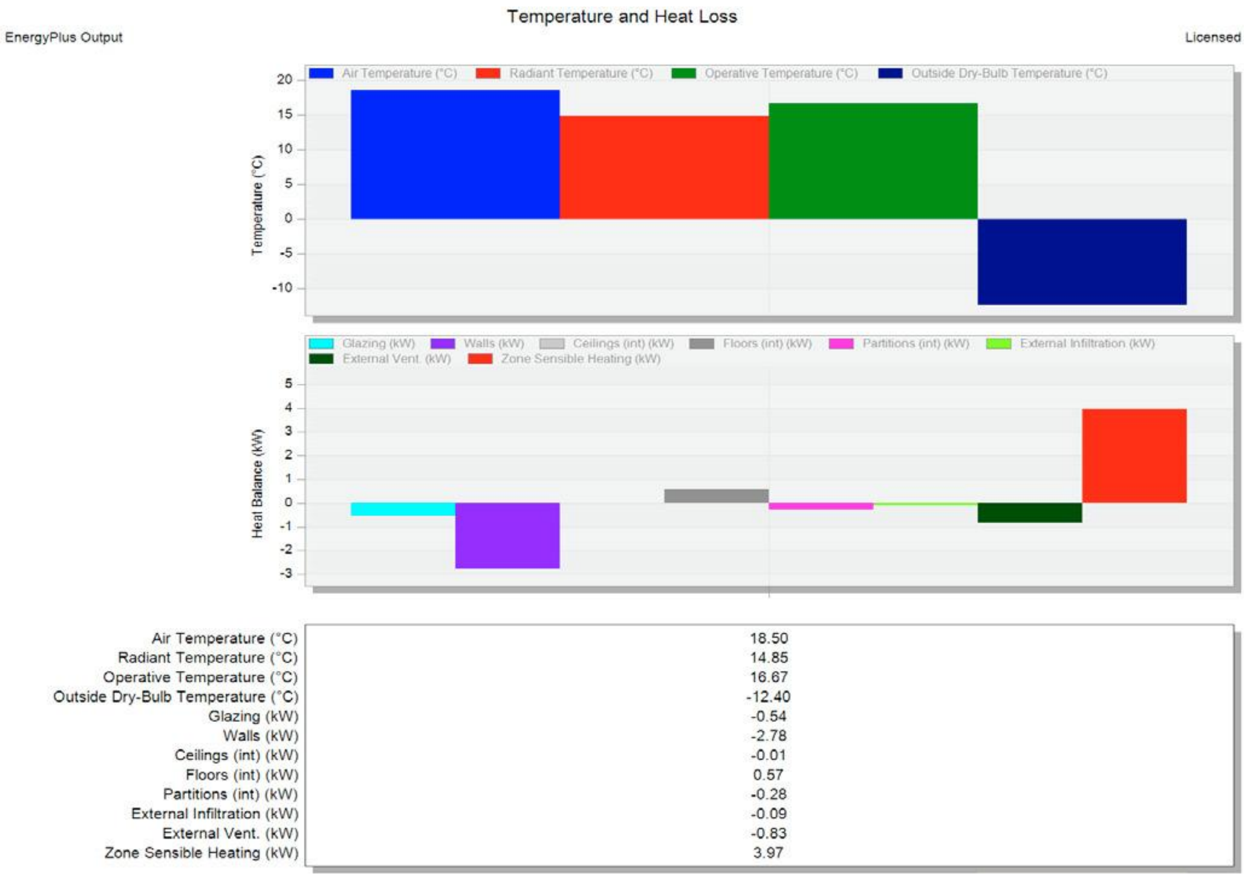

Figure 36 Heating load after application of digital transformation

The energy consumption in both cases in a one-year period is shown in Fig. 37.

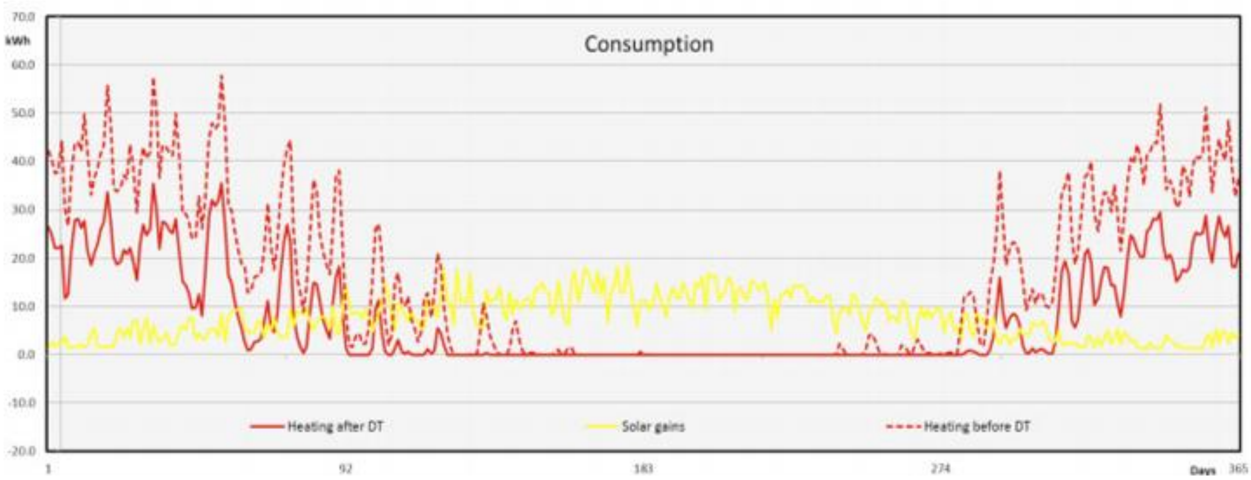

Figure 37 Daily thermal energy consumption for heating before and after application of digital transformation (for 365 days)

As observed on the graph, the peaks and dips preserve similar patterns for a statistically averaged climate year, however the curve for the digitally transformed home shows clearly lower daily consumption rates. Furthermore, the exterior and interior air temperatures, including the surface radiant temperatures are shown in Fig. 38.

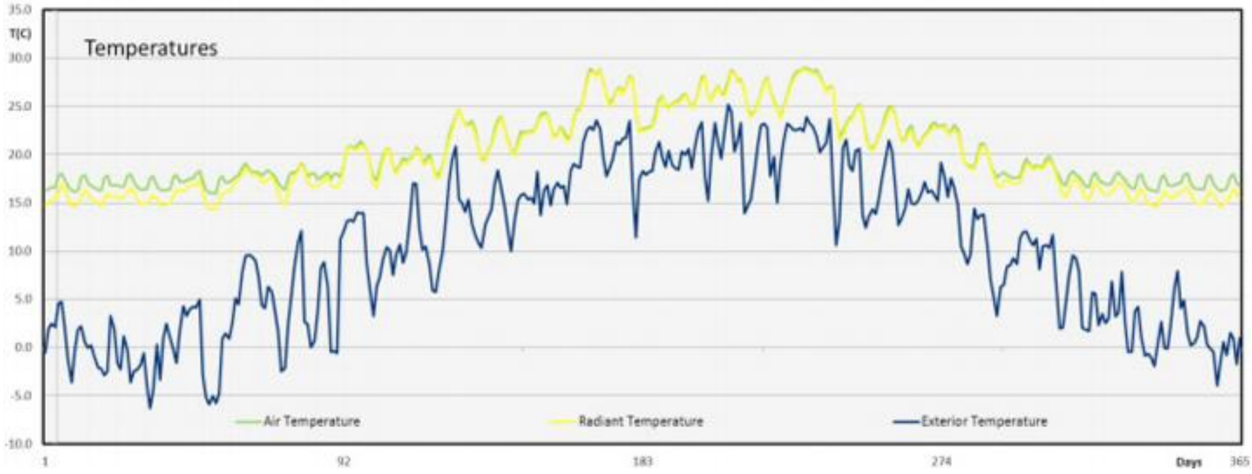

Figure 38 Average daily air, radiant and exterior temperatures

The gap between interior air and interior surface (or radiant) temperatures grows in winter because of the lack of proper thermal insulation on the exterior walls. In summer the surface temperature approaches, but hardly ever exceeds the interior air temperature because of the north orientation of the apartment.

All of the simulations are made by using of EnergyPlus models. The algorithms behind EnergyPlus are developed especially for building energy simulations from the US Department of Energy. It should be noted that EnergyPlus models are based on fundamental heat balance principles and rely on a conduction transfer function. To achieve a zero-energy cell, a new room-sized test cell was observed using a similar modeling approach. A survey of the EnergyPlus constructions solution algorithm and heat balance method in EnergyPlus is presented in. The authors reported differences in the range from 12.41% to 0.71% between the simulation and testing values which means relatively small deviations.

One important consideration of the digital transformation of the apartment is that the reduction of the heating setpoint temperatures leads to an increased incoming heat flow from the neighboring apartments. For digitally transformed apartments such as this one, the results are obvious from the monitoring history and proven by the energy bills of the home owner. If the heating temperature setpoint is lowered and controlled by the home automation, the apartment starts to “extracts” heat from its neighbors and the “savings” are significant (see Table 7) when compared with the former state of the apartment.

	Heating before (tkWh)	Heating after (tkWh)	Difference, %
Total	5925.49	2818.64	47.56
kWh/m^2	95.57	45.46	

Table 7 Comparison between the total and surface heating consumption before and after digitalization using IoT

This site is especially good example, because the temperature setpoint is further reduced in the night time (the coldest period of the day) according to the user set schedule as low as 17 ℃ , and the neighbors are families with young children, maintaining higher than the usual temperature setpoints. This results to some astonishing outcomes with this user having lower energy bills than his neighbors (partly insulated apartments), despite having his apartment not thermally insulated at all. In this sense, one important conclusion is that the first people to digitally transform their buildings with reduced and actively controlled temperature setpoint will benefit more at the expense of their neighbors.

4.5 Conclusions

The major challenge today is related to global warming and the ambition is transitioning to zero carbon emissions. In this regard, energy management solutions based on IoT ecosystem play essential role for can be exploited for energy conservation. The key factor in the context of decreasing of carbon footprint is the home energy efficiency. That is why the main problem of the article is focused on combining the advantages of IoT to achieve the effective management of smart home heating. The described approach implements open-source software platform like OpenHAB with low-cost, and high-performance computing hardware such as Raspberry Pi. The conducted experiments during a year are compared with simulation from digital twin of an apartment to demonstrate the effect of the digital infrastructure on the heating loads. The obtained results show significant reduction of the total and surface heating consumption after digitalization using IoT that amount to 47%.

Future improvements are related to some smart home extensions, including photovoltaics on the roof and their integration into the overall IoT ecosystem scheme.

CHAPTER 5
ENVIRONMENTAL PROTECTION

In the conditions of modern society, efficient heating systems play a pivotal role in ensuring the comfort of residents and workers. In Ukraine, as in many other countries, the issue of improving the energy efficiency of heating systems becomes an integral part of sustainable development strategies. Not only does the level of comfort matter, but the ecological sustainability of these systems also has a significant impact on the environment and the overall health of the nation.

Analyzing the current state of heating systems in Ukraine provides a unique perspective for studying the impact of these systems on energy consumption, emissions of pollutants, and socio-economic aspects. Understanding these factors is crucial in shaping strategies aimed at optimizing energy consumption, reducing the negative impact on the environment, and enhancing energy sustainability.

5.1 Influence on the environment

The consumption of energy is inherent in almost all types of human economic activities, including home heating, food preparation, transportation, industrial processes, agricultural production, and more. The development of various forms of energy on a global scale has led to unprecedented improvements in the standard of living. Today, people are highly dependent on energy. We often do not think about where energy comes from until we experience a power outage or heating failure. When such events occur, our ability to live and work is compromised.

The main sources of energy available to humans can be classified as follows:

- Fossil fuels (coal and shale, oil, natural gas)
- Nuclear and thermonuclear energy
- Renewable energy resources (hydro, wind, solar, geothermal, biomass, etc.)

Energy production significantly impacts the state of the environment. The combustion of fossil fuels releases sulfur dioxide, carbon dioxide, carbon monoxide, nitrogen oxides, particulate matter, and other pollutants.

Open-pit coal mining and peat extraction alter natural landscapes, sometimes leading to their destruction. Oil spills during extraction and transportation can devastate entire ecosystems, especially in aquatic environments.

The creation of infrastructure necessary for coal, oil, and gas extraction negatively affects landscapes, plant life, and wildlife.

The construction and operation of large hydroelectric power plants result in the displacement of people from flooded areas, the destruction of valuable fish species hindered by dams during migration, the loss of forests and fertile land, increased risk of earthquakes in mountainous regions, and a higher risk of catastrophic floods downstream, altering landscapes and causing destruction.

Nuclear energy poses potential hazards due to accidents at power plants that release radioactive materials into the environment. Additionally, issues arise with the processing and disposal of nuclear waste, which is expensive and lacks a reliable engineering solution. Nuclear waste remains hazardous for hundreds and thousands of years, especially pertinent for Ukraine, which suffered from the consequences of the Chernobyl disaster.

Despite their apparent benefits, renewable energy sources can also negatively impact the environment. The operation of stations generating energy from renewable sources involves significant land use and may lead to various environmental consequences, such as changes in landscapes (wind turbines, solar panels), increased noise levels (wind turbines), soil pollution (geothermal and biomass installations), and detrimental effects on other natural resources (tidal power stations).

In recent years, global leaders and the population express concerns about escalating environmental issues, including acid rain, climate change, and the consequences of these processes on the environment.

Given the described situation, a rational solution would be to prioritize energy conservation. It should become a central element in the development strategy of any country, considering that traditional energy sources are finite.

5.2 Climate change due to heating systems

Climate change due to heating systems is primarily associated with the use and combustion of fossil fuels for space heating, leading to the emission of greenhouse gases into the atmosphere. The main aspects of this impact include:

1. Greenhouse Gas Emissions:

- Carbon Dioxide (CO_2): The combustion of fossil fuels, such as coal, oil, and natural gas, results in the release of carbon dioxide, a major greenhouse gas. CO_2 traps heat in the atmosphere, contributing to global temperature rise.
- Methane (CH_4): Incomplete combustion of fossil fuels can produce methane, another potent greenhouse gas with a higher warming potential over a shorter timeframe than carbon dioxide.

2. Air Pollution:

- Particulate Matter and Sulfur Dioxide (SO_2): Coal combustion, in particular, releases particulate matter and sulfur dioxide, contributing to air pollution. These pollutants can have adverse effects on air quality, human health, and ecosystems.

3. Black Carbon:

- Soot or Black Carbon: Heating systems using solid fuels, such as wood or coal, emit black carbon, a component of fine particulate matter. Black carbon can settle on snow and ice, reducing their reflectivity and accelerating the melting of glaciers and polar ice.

4. Deforestation and Biomass Burning:

- Wood and Biomass Burning: In some cases, heating systems rely on the combustion of wood or other biomass. Deforestation for fuel and the burning of biomass release carbon into the atmosphere, contributing to climate change and impacting biodiversity.

5. Energy Inefficiency:

• Wasteful Energy Consumption: Inefficient heating systems can lead to higher energy consumption, exacerbating the demand for fossil fuels and increasing greenhouse gas emissions.

6. Urban Heat Islands:

• Localized Temperature Increases: Concentrations of heating systems in urban areas can contribute to the development of urban heat islands, where temperatures are higher than in surrounding rural areas. This localized warming can have various environmental and health implications.

Addressing climate change associated with heating systems requires a shift toward cleaner and more sustainable alternatives. This includes promoting energy-efficient technologies, transitioning to renewable energy sources, and encouraging the adoption of green building practices. Policy measures, public awareness, and technological advancements are essential components of mitigating the climate impact of heating systems.

5.3 The impact of renewable energy sources on the environment

When using renewable non-traditional energy sources, emissions of various pollutants, including greenhouse gases, are reduced compared to traditional energy sources. RES can also play a role in reducing local air pollution, improving air quality in cities and recreation areas.

Solar radiation collected by solar energy devices replaces energy produced using environmentally polluting technologies. This is the main environmental effect of solar energy.

Ground-mounted solar power plants, in which energy conversion is related to the concentration of solar radiation, require the allocation of large areas. Thus, on average, for a 1 MW tower solar power plant, tracking heliostats require an area of about 0.035 km2. In general, the area required for solar power plants per 1 MW of power is 0.001–0.008 km2 in different countries of the world.

As for solar collectors, they are usually installed on the roofs of houses and do not affect the landscape and atmosphere of the area, and they do not take up additional land space.

The main harmful impact of solar power plants on the environment is indirect and is caused by technological processes associated with the production of new connections for solar power plants. In many cases, this requires rare earth elements, which are found in very low concentrations in earth rocks and require significant quantities of such rocks to be processed to extract them.

Solar power plants do not affect the natural thermal regime of the planet, since they take a very small part of solar energy, but after conversion into electrical energy and its use, it returns to the environment in the form of heat.

Wind power. Wind turbines generate electrical energy with virtually no environmental pollution, but their negative impact is associated with the allocation of large areas for construction and changes in the landscape, noise effects, interference with the propagation of radio signals, vibration, the threat of bird death, and the metal consumption of wind turbines, which causes pollution during metal production.

The main disadvantage of wind power stations is the use of significant land resources for the construction of wind farms. Powerful industrial wind farms require an area of 5 to 15 km 2 /MW, depending on the wind pattern and the local topography of the area. The maximum power that can be obtained from 1 km 2 of area depends on the area where the wind farm is installed, the type of station and the technological features of the design; the average value of the received power is approximately 10 MW. A 1000 MW wind farm would require an area of 70–200 km2, although most of this land could be used. Wind farms themselves occupy only 1% of the entire territory; 99% of the rest can be engaged in agriculture or other activities, which is carried out in such densely populated countries as Denmark, the Netherlands, and Germany.

One of the disadvantages of such wind farms is the unpleasant sounds caused by the rotation of the rotor blades. People complained that often when approaching the power plant they began to experience discomfort and sometimes even attacks of unmotivated fear. Animals and birds preferred to immediately leave the areas built up by wind farms, and migratory birds deviated from the route and made a detour of several kilometers to fly around them.

A particular environmental problem is the noise impact of wind turbines with a power of 250 kW and above. The problem of generating ultrasonic wind turbines was overcome by choosing the blade profile and the rotation speed of the wind wheel, or rather the ends of the wind wheel blades.

Test results in Denmark, as well as an analysis of information on the operation of approximately 50 types of wind turbines available in the European catalog of wind turbines, showed that most modern wind turbines in the immediate vicinity of their installation site generate noise of about 95–103 dB at a wind speed of 10 m/s, which corresponds to the noise level in a typical industrial plant. However, already at a distance of 100 m from the wind turbine, the noise level decreases to 50 dB, and at a distance of 300 m it is less than 40 dB; at a greater distance, the operation of the wind turbine is barely audible against the background noise of the environment. Based on this, in Germany, the Netherlands, Denmark and other countries, laws have been passed that establish that the minimum distance from a wind turbine to housing should be at least 300 m. In Ukraine, it is accepted that the permissible distance from a wind turbine to housing should be 150 m, from the wind power plant to housing – 250 m. The negative impact of wind farms can be eliminated by locating wind turbines in shallow waters at sea.

For Ukraine, first of all, this is the non-freezing shallow water (depth is mainly 0.5 m with a maximum of 3.2 m) of the Sivash Bay, which is about 2700 km 2 and is not used for economic use; In addition, a significant part of the bay area remains without water for a long period of time (2–3 months), especially in summer.

The appearance of an experimental wind turbine in the Orkney Islands (England) in 1986 caused numerous complaints from television viewers from nearby settlements. The interference was created by the steel frame of the blades and the metal strips on them, designed to deflect lightning strikes. They reflected and scattered the ultrashort wave signal. The reflected signal mixed with the direct signal coming from the transmitter and created interference on the screens. As a result, a television repeater was built near the wind farm. The blades of the winged wind turbine were made of fiberglass, which did not reflect or absorb radio waves.

To reduce the influence of wind turbines on radio and television transmissions, their blades, instead of metal (reflect radio and television signals) and wooden (absorb signals), began to be made of fiberglass without metal inclusions, and therefore they are translucent for the passage of radio and television signals. However, if the transmission of radio and television signals is carried out via satellite, the problem automatically disappears.

As the height of the tower increased to 100 m and the size of the blades to 40–60 m, the issue of protecting the blades from lightning became acute. To solve this problem, aluminum conductors of a large cross-section began to be laid in the middle of the blades, through which the current flows into the ground during a lightning strike. Such blades become a kind of mirrors for the passage of radio and television signals, especially for military radar signals. As a result, demands have intensified in the UK to limit the construction of powerful wind farms along the coast. In Norway, according to experts, taking into account these military requirements could lead to a reduction in potential wind energy resources by 50%.

The results of an assessment of the impact of wind turbines on bird mortality, which was carried out in the Netherlands, show that bird mortality from a 1000 MW wind farm is 300 times lower than from moving cars, and 50 times lower than from power lines. This is also facilitated by the transition to more powerful wind turbines and a decrease in their rotation frequency. If the rotor speed of a unit with a power of up to 100 kW reaches 300–450 rpm, then for a wind turbine with a power of 1–2 MW it is from 10 to 30 rpm, and for a power of 3–4.5 MW it is 8–14 rpm. min.

Bioenergy. Direct use of biomass for energy is more environmentally friendly than, for example, coal. When burning biomass, less than 0.2% of sulfur and 3 to 5% of ash are released, compared to 2–3 and 10–15%, respectively, for coal, the rest is predominantly carbon dioxide. In addition, biomass ash can be returned to the soil, which ensures a closed cycle of nutrients. From the point of view of accounting for carbon dioxide, biomass is practically neutral, that is, during the growth period, plants absorb solar energy, water, carbon dioxide, release oxygen and form carbon in the process of photosynthesis; During combustion, the process goes in the opposite direction: oxygen is absorbed, and heat, water and carbon dioxide are released. In this process, the amount of carbon dioxide absorbed and released is exactly the same. During the formation of 1 kg of dry biomass (wood), 1.83 kg of CO_2 is absorbed and the same amount is released during its decomposition (oxidation, combustion). As for oil, coal and gas, the same pattern is observed for CO_2, but the time required to update the CO_2 balance reaches several million years. The average heat of direct combustion of biomass is 7–9 MJ/kg.

It is now recognized that all technologies for the energy use of biomass do not increase CO_2 emissions, but prevent emissions in the volume of generated electrical and thermal energy.

Gasification of biomass is a more efficient way of using it. Air gasification produces a generator gas with a calorific value of about 4–6 MJ/m3; gasification using oxygen produces gas of the highest quality with a calorific value of 10–18 MJ/m3. The gas obtained as a result of gasification of wood using an air oxidizer contains : nitrogen – 50–54%, carbon monoxide – 20–22%, hydrogen – 12–15%, carbon dioxide – 9–12%, methane – 2–3%. An even greater effect is obtained with gasification in a fluidized bed, in a circulating fluidized bed, in a flow, gasification in two fluidized bed reactors, etc.

During the pyrolysis of biomass, non-condensed gases CO, CO_2, H_2, CH_4, C_2H_4 are formed, the content of which depends on the type of biomass and the heat treatment mode. The yield of non-condensed pyrolysis gas can reach 70% of dry biomass, and the calorific value is 12.5–13.3 MJ/m3. The composition of liquid pyrolysis products includes various substances: acids, alcohols, acetone, formaldehyde, water, etc. It depends on the type and quality of biomass and process conditions; the heat of combustion of liquid products reaches 20–25 MJ/kg. The coke residue of pyrolysis has about 95–97% carbon, and its yield can reach 25–30% of dry biomass, the calorific value of the residue is up to 35 MJ/kg.

With methane fermentation, the resulting biogas contains 60–70% methane, 30–40% carbon dioxide, a small amount of hydrogen sulfide, as well as a mixture of hydrogen, ammonia and nitrogen oxide; the heat of combustion of biomass is 22–26 MJ/kg. The residue formed during the methane fermentation process contains a significant amount of life-giving substances (especially nitrogen) and can be used as an excellent fertilizer.

The production and use of liquid fuel from biomass not only helps to increase the energy security of the state, but also improves the environmental situation.

Fuel ethanol obtained from biomass, as an additive to gasoline, allows you to increase the octane number and improve operating mixtures; with an ethanol content in gasoline of up to 15%, no changes in the design of modern internal combustion engines are required. When operating on a mixture of gasoline and ethanol, the CO 2 content in the exhaust gases is reduced by 25%, and hydrocarbons and NO x by 5%, which is especially important for reducing environmental pollution in large cities with significant use of road transport.

Biodiesel fuel (biodiesel) is a product of processing vegetable oils (rapeseed, sunflower, palm). Biodiesel fuel for road transport based on rapeseed oil has the following advantages compared to fuel from oil:

- does not affect the greenhouse effect, since rapeseed, like all biomass, is neutral with respect to CO 2;
- forms a lower concentration of harm
- substances in exhaust gases (the concentration of CO, hydrocarbons and solid particles is reduced by 25–50%, the smoke content of gases is halved);
- does not contain carcinogenic substances (polycyclic aromatic carbohydrates, especially benzopyrene);
- requires less air for combustion;
- has a high degree of biological decomposition (in 21 days its biological decomposition is about 90%).

At the same time, the disadvantages of biodiesel fuel compared to petroleum fuel are lower calorific value, which leads to increased fuel consumption and a decrease in engine power by 16%; high viscosity of rapeseed oil, which impairs atomization, mixture formation and combustion in diesel engines; the need to frequently replace oil filters and carry out routine maintenance on injectors due to severe coking of the nozzle holes.

Increasing biomass production improves the microclimate through the use of water and recycling mechanisms. The production and use of biomass composts improves soil structure and reduces water pollution.

A number of technologies for producing biogas from landfills, from livestock waste, and from food industry waste are essentially environmentally friendly, as they prevent water, soil and air pollution from these wastes.

Geothermal energy. Active industrial use of geothermal sources may have some negative effects in terms of environmental impact. With intensive release of groundwater to the surface, local subsidence of the earth's surface is possible, which leads to disruption of the stability of ground structures and changes in the landscape. Simultaneously with a decrease in reservoir pressure, the seismicity of areas of intensive use of geothermal waters may increase.

Geothermal water contains many impurities, which in small quantities does not pose a threat (salts of various metals, hydrogen sulfide), as well as harmful substances (arsenic, boron), methane, carbon dioxide, ammonia can be released. Although these indicators are significantly less than the corresponding indicators for the operation of traditional energy systems, they must be taken into account. In addition, the release of significant volumes of water to the surface can worsen the condition of groundwater in the operation area (swampiness and salinization).

New effective technologies will help minimize the negative impact of geothermal energy on the environment, as well as obtain additional economic benefits through the extraction of valuable components.

The efficiency of exploitation of thermal waters increases significantly when used in an integrated manner. At the same time, in various technological processes it is possible to achieve the most complete realization of the thermal potential of water, including excess, and also to obtain valuable components of thermal water (iodine, bromine, lithium, cesium, kitchen salt, Glauber’s salt, boric acid and many others) for industrial applications.

The most promising way to extract deep heat is to create underground circulation systems with full or partial return of waste water to productive formations. These systems prevent the depletion of geothermal water reserves, maintain hydraulic balance in underground formations, and eliminate environmental pollution in the areas where geothermal objects are located.

Geothermal power plants, compared to thermal power plants using fossil fuels, produce very little sulfur and no nitrogen oxides. Geothermal installations require very small plots of land, which are much smaller than for other types of energy installations; they can be located on almost any land, in particular on agricultural land. In addition, drilling geothermal wells has much less impact on the environment than the development of any other energy sources. The landscape around the geothermal installation is not spoiled by mines, tunnels, or waste heaps.

At modern geothermal stations, CO 2 emissions per 1 MWh of electrical energy are minimal and amount to an average of only 0.45 kg, while at power plants using natural gas - 460 kg, oil - 720 kg, coal - 820 kg.

Environmental energy use. The use of heat pumps significantly improves the state of the environment due to the absence of the combustion process to obtain thermal energy, as well as through the disposal of thermal waste from production, which, thus, protects the biosphere from thermal pollution.

Small hydropower. Small hydropower plants have an extremely limited impact on the environment, even when a reservoir is created to regulate river flow. The use of a set of environmental and protective measures makes it possible to minimize the negative impact of small hydropower on fish and aquatic ecosystems, eliminate land flooding, and reduce the area of allocated land. Small hydroelectric power stations make it possible to preserve the natural landscape, there is no negative impact on water quality, it completely preserves its natural properties and can be used to supply water to the population.

Tidal power plants. Changes in the water regime of bays and river mouths fenced off from the sea by dams of tidal power plants will have a negative impact on the environment, primarily on flora and fauna, to minimize which a set of environmental protection and compensation measures will be required. The negative impact of the construction of dam-free power plants using high-speed tidal energy is significantly less.

CHAPTER 6
OCCUPATIONAL SAFETY AND HEALTH

6.1 Assessment of risks and negative factors

Issues of ensuring labor safety must be resolved at all stages of the labor process, regardless of the nature of the activity. Ensuring healthy and safe working conditions largely depends on the correct assessment of harmful and dangerous production factors. The human body can undergo major changes for various reasons, such as the work environment, excessive mental and physical stress, neuro-emotional stress, or various combinations of the above factors.

This section deals with the issues of ensuring work safety for programmers at the stage of developing a model of a robotic system for searching and identifying GNPs. Analysis of working conditions showed that a number of physical and psychophysiological factors can negatively affect programmers in laboratories:

1. Organization of a neat and comfortable workplace.
2. Control of the level of noise and dust at the workplace.
3. Reducing the level of electromagnetic radiation.

6.2 Optimization of workplace organization

The programmer's workspace, equipped with three PC workstations, has a total area of 30 m^2 and a ceiling height of 2 m. Each workstation is equipped with a 1.3 m^2 desk, a personal computer or laptop and an upholstered chair.

A personal computer includes a monitor, a system unit, a keyboard and a graphics tablet. The area and volume for one workplace meet the standards - 10 m^2 and 20 m^3, respectively.

Suggestions for improving the organization of the programmer's workplace:

1. It is recommended to choose an adjustable desk to ensure optimal height.

2. Increase the size of the working surface to at least 1500 mm × 1100 mm.

3. Provide a subfloor under the table for comfortable work.

4. The work table must have a footrest located at an angle of 20° to the table surface.

5. The distance from the edge of the table to the keyboard should be more than 30 cm, but not more than 70 cm, to ensure a comfortable body position.

6. The distance to the monitor should be from 50 cm to 70 cm to maintain comfortable eye contact.

7. A work chair must have a soft seat, a height of 46 cm to 56 cm, a back height of at least 30 cm and a width of at least 38 cm.

8. Considering the heaviness and stress on the body, it is recommended to reduce the time of working in front of the monitor and take breaks to rest the eyes every 50 minutes for a total shift of 8 hours.

6.3 Electrical safety. Static electricity

The danger of electric shock in the workplace belongs to the 1st class of increased safety, since the conditions (dryness, absence of dust, normal air temperature, insulated floor, a fairly small number of grounded devices) meet high safety standards.

The programmer's workstation contains only the metal case of the PC system unit, which meets the standards and has working insulation, a grounding element and power wires with a properly grounded core.

The three main causes of electrocution when working indoors include:

1. touching metallic housings or live peripherals due to damaged insulation;

2. improper use of electrical devices;

3. lack of instruction for persons conducting occupational safety classes.

4. During the working day, the computer case accumulates static electricity. At a distance of 6 cm to 11 cm from the screen, the electrostatic field strength can be from 60,500 V/m to 280,500 V/m, which is 10 times higher than the norm of 20,000 V/m.

To ensure safety in the workplace, it is recommended to use technical means and methods of protection: reduce the accumulation of static electricity with the help of moisturizing and neutralizing floor coverings; connect the metal case of the equipment with the grounding wire.

The grounding of the computer case can be ensured by connecting the grounding wire to the sockets, and the grounding resistance should be up to 4 ohms for electrical installations with a voltage of up to 1000 V. You can also take organizational measures, such as constant safety training and the prohibition of the use of electrical equipment not intended for the workplace equipment.

5.4 Safety requirements during emergency situations

In the event of an emergency situation, the programmer must act in accordance with the following safety requirements:

When a dangerous situation is detected, such as fire, earthquake, radiation hazard, electrical problems, etc., the programmer must try to calm others and ensure their safety, including their own lives and the lives of employees.

You should not repair malfunctions in the electrical network and electrical equipment yourself. Instead, turn off the general power supply.

When a fire is detected, the fire department should be immediately called and measures should be taken in accordance with the evacuation plan for the safe evacuation of workers and the preservation of property.

In the event of the appearance of an outsider who poses an illegal threat to the safety of others, law enforcement agencies should be called.

If employees or customers are injured, an ambulance should be called immediately and, if necessary, first aid should be provided. It is also necessary to organize the work of the DPD (state fire protection) for the preservation of property and securities.

When providing first aid, you should:

Assess the general condition of the victim and determine the nature of the damage.

In case of sudden disturbance or absence of breathing or heartbeat, artificial respiration and heart massage should be started immediately and emergency medical assistance should be called.

In case of electric shock:

It is important to disconnect the electrical equipment from the power source, or to pull the victim away from the current-carrying parts with the help of insulating material.

If there is no breathing and pulse, start artificial respiration and heart massage, and then call an ambulance.

These actions should be carried out taking into account the specific emergency situation and the possibilities of providing assistance.

5.5 Evaluation of workplaces and conducting medical examinations

Attestation of workplaces is carried out at the enterprise in cases where parts of the technological process, equipment, raw materials or materials adversely affect the health of employees. Special commissions, the powers of which are determined by the order of the enterprise within the stipulated terms provided for in the agreement, conduct attestation, which in general should be carried out at least once every 4-5 years.

According to Article 169 of the Code of Labor Laws, the employer organizes regular medical examinations of employees at his own expense or at the company's expense. He is also obliged to conduct an annual mandatory medical examination of persons under the age of 21. The results of medical examinations, in the form of expert conclusions regarding the employee's fitness to perform work, are recorded in their personal medical card, which is kept by the employer.

Carrying out an annual medical examination is an important initiative for both the employer and the employee. When hiring a new employee, an objective assessment of his state of health determines the need for a preliminary medical examination. Next, regular periodical medical examinations are necessary for the timely detection of occupational diseases, determination of the impact of negative factors on health and ensuring the general working capacity of the staff.

In this section, a study on occupational health and safety was conducted at the stage of development of the software module. An analysis of harmful and dangerous factors that can affect the work process was carried out. Among the main problems to which attention was drawn, the following were identified:

The issue of workplace organization: the importance of the correct organization of the workspace for optimal efficiency and comfort during the development of a software product is assessed.

Increasing the level of noise in the workplace: the influence of noise factors on the work of a programmer is considered and possible ways of reducing the level of noise to improve working conditions are determined.

Increased level of electromagnetic radiation: the impact of electromagnetic fields on health was investigated and ways to minimize risks for programmers during work were indicated.

In the subsections, the values of the parameters are considered and suggestions are made for improving the working conditions during the development of the software product. This includes recommendations for organizing the workspace, reducing noise and controlling the level of electromagnetic radiation in order to ensure an optimal and safe working environment.

CONCLUSION

During the development of an automated energy-efficient heating system for residential spaces, extensive research was conducted to enhance the efficiency and ecological sustainability of heating systems. The obtained results confirm the importance of integrating modern technologies into the heating sector to optimize energy consumption and reduce environmental impact.

The developed system incorporates innovative automation technologies that effectively regulate temperature levels in various rooms, taking into account individual user needs. The implementation of this system not only significantly saves energy resources but also reduces heating costs for end-users.

An essential aspect is the reduction of emissions of harmful substances into the atmosphere by optimizing fuel combustion processes. This contributes to the creation of environmentally friendly and sustainable heating systems, aligning with contemporary requirements for energy efficiency and the environment.

Overall, the developed automated energy-efficient heating system represents a significant contribution to the field of modern technologies and engineering solutions in the energy sector. Its successful implementation could lead to improved living conditions, reduced energy expenses, and a diminished negative impact on the environment.

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