

THE HYBRID SYSTEM – ENERGY FOR THE FUTURE

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ABSTRACT: One of the most pressing future issues is expected to be the optimisation of energy consumption in the building sector. A massive shift is needed to the use of environmentally friendly heating systems, the use of which will lead to a reduction in greenhouse gas emissions. One of the most promising solutions to the decarbonisation of residential heating and cooling are hybrid systems.

This report examines a technological solution for the production of electrical energy, heating, and cooling through a hybrid system that includes photovoltaic panels, a gas boiler, and a heat pump—not only as a technical solution, but also as a tool for: reducing energy poverty; building sustainable habits; increasing energy literacy; protecting personal data in the smart home; and creating more sustainable communities.

Key words: hybrid system, energy, photovoltaic, gas boiler, heat pump.

ХИБРИДНАТА СИСТЕМА – ЕНЕРГИЯ ЗА БЪДЕЩЕТО

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РЕЗЮМЕ. Един от най-належащите бъдещи въпроси се очаква да е оптимизирането на потреблението на енергия в сградния сектор. Масово трябва да се премине към използването на екологосъобразни отоплителни системи, чиято употреба ще доведе до редуциране на емисиите на парникови газове. Едно от най-обещаващите решения за декарбонизация на жилищното отопление и охлаждане са хибридните системи.

В настоящия доклад е разгледано технологично решение за производство на електрическа енергия, отопление и охлаждане чрез хибридна система, включваща фотоволтаик, газов котел и термопомпа, не само като техническо решение, а като инструмент за: намаляване на енергийната бедност; изграждане на устойчиви навици; повишаване на енергийната култура; защита на личните данни в смарт-дома и създаване на по-устойчиви общности.

Ключови думи: хибридна система, енергия, фотоволтаик, газов котел, термопомпа.

Introduction

One of the most pressing future issues is expected to be the optimisation of energy consumption in the building sector. In order to achieve the goals set in the Kyoto Protocol, a complete transition in terms of energy consumption in households is necessary. A massive shift is needed to the use of environmentally friendly heating systems, the use of which will lead to a reduction in greenhouse gas emissions. One of the most promising solutions for the decarbonisation of residential heating are hybrid systems.

In the face of global climate change and increasing demands for sustainable development, reducing carbon emissions is becoming a top priority for the energy sector. Energy production and consumption, especially when using fossil fuels, are major contributors to greenhouse gas emissions (IPCC, 2021).

This paper examines a technological solution for the production of electricity, heating and cooling through a hybrid system including a photovoltaic, a gas boiler, and a heat pump not only as a technical solution, but as a tool for:

- reducing energy poverty;
- building sustainable habits;
- increasing energy literacy;
- protecting personal data in the smart home;
- creating more sustainable communities.

Objectives of the project

The objectives of this project are to solve the following tasks:

1. Problems in a social context

- *Energy poverty*

In Bulgaria, many households use inefficient heating

appliances, rely on wood and coal, and spend a high percentage of their income on heating.

The smart hybrid system offers lower monthly costs, more stable bills, and reduces dependence on a single source.

– *Air pollution*

Burning solid fuels increases fine particulate matter (PM 2.5), affects people's health, and creates social and health costs.

The hybrid system reduces emissions, uses renewable energy and contributes to a cleaner urban environment. Hybrid energy systems, which combine different energy sources (e.g. electricity and gas), are seen as an effective solution to increase energy efficiency and reduce emissions (IEA, 2022). This report aims to analyse the difference in CO₂ emissions between a conventional gas system and a hybrid system.

– *Digitalisation and personal data*

Smart systems collect information about the presence in the home, temperature habits, and consumption.

2. Influence on the change in habits - the system shows in real time: how much energy is used, which source is active, and what is the price per day. This leads to:

- *more conscious consumption,*
- *reduction of excess consumption,*
- *building an energy literacy.*

3. Educational effect - the project can be used in an educational institution as:

- *a model of a smart home;*
- *a demonstration of energy transition;*
- *an example of sustainable energy.*

This is how one understands how renewable energy sources works; how costs are calculated; and what a carbon footprint is.

4. Energy fairness - intelligent energy management allows

access to cheaper energy, use of night-time tariffs, and optimisation according to household income. The system can operate in the following modes:

- “Minimum costs”;
- “Minimum emissions”;
- “Balance comfort - savings”.

This gives a user a choice.

5. Community effect - if the system is implemented on a large scale, it will lead to reduced load on the electricity grid, reduced peak loads, more sustainable neighbourhoods, and lower public health costs.

Buildings become part of the energy ecosystem.

6. Automation with a social purpose - the developed algorithm compares the price of gas and electricity, takes into account the outside temperature, predicts the load, and selects the most economical solution. But in addition to saving, it reduces emissions, supports the stability of the grid, and creates a sustainable consumption model.

7. Ethical aspect - the project raises questions, like:

- Should energy be a luxury?
- How can technology reduce social inequality?
- How can we combine digitalisation with privacy protection?

The answer is: Intelligent systems must be accessible, transparent, and oriented towards the public interest.

Problem Analysis

Features of the Hybrid Heat Pump System

A hybrid heat pump system is supposed to consist of:

- an electric air-to-water or ground-to-water heat pump combined with a gas boiler;
- a mechanism for supplying heat energy to an existing heat distribution system;
- a special control system to switch between the two sources.

These are shown in fig. 1



Fig. 1. Hybrid heat pump and gas boiler

The main component of the system is the **heat pump**. It uses renewable energy from the environment (air, soil or groundwater), by converting low-potential heat into high-potential heat through electrical energy.

The second key element is the **gas boiler**, which acts as a backup or supplementary heat source. It is switched on in unfavourable operating conditions for the heat pump – for example, at very low outdoor temperatures or during peak heat demand. This ensures reliability and continuity of heat supply.

An essential part of the hybrid system is the **mechanism for supplying and distributing heat energy**, which usually uses an existing heating installation (radiators, underfloor heating, or fan coils).

This allows for relatively easy integration of the hybrid system into existing buildings without the need for significant infrastructure changes.

A key role is also played by the **intelligent control system**, which automatically selects the most efficient energy source in real time.

There are two types of solution:

- a hybrid heat pump package, including a heat pump unit, a gas boiler and an intelligent controller;
- an additional hybrid heat pump with an intelligent controller, which is installed to an existing gas boiler.

Hybrid pumps usually operate in two ways. In balancing mode, the boiler is switched on with additional heating capacity and maintains the heat pump at a certain temperature value. This temperature point is the temperature below which the heat pump cannot meet the heat load. Below this point, two operating modes are possible - the heat pump can continue to operate in parallel with the boiler, or the heat pump can be switched off and the boiler can take the entire load. The balance shifts according to the capacity and size of the heat pump. In addition, users can to a certain extent choose the equilibrium temperature point. fig. 2 shows a hybrid system including a gas boiler and a heat pump separately.



Fig. 2. Hybrid system including gas boiler and heat pump separately

Smart controllers can be set to perform a wide range of functions, including optimising operating costs, increasing energy efficiency, reducing emissions, or controlling the heat pump by a utility company in order to regulate demand based on weather conditions, for example.

Since “hybrid” essentially means two different systems working together, some other technologies are also offered as hybrid products. These include, for example, a combination of a solar system and a boiler, two separate heat pumps, and heat pumps and oil boilers.

Hybrid heat pumps can be monoblock or split. In **monoblock** solutions, the heat pump is a single unit, usually installed outside. The heat energy is transferred to the interior of

the building through water containing glycol, which protects it from freezing. In **split** hybrid systems, the heat pump consists of two parts - an outdoor unit, including a heat exchanger and a compressor, and an indoor unit (indoor heat exchanger). A refrigerant circulates between the two parts. Some of the indoor elements can be installed in a single housing.

It is recommended to add a buffer tank (fig. 3) to the system for storing thermal energy, which allows the separation of the heat supply from the heat pump and the energy required for the heating system. The buffer tank can be used for ensuring a minimum flow through the heat pump, minimising the duration of the cycles or for heat supply in the event of a heat pump failure.



Fig. 3. A hybrid system with a buffer tank for thermal energy storage

The buffer tank can be connected to the heat pump system in parallel or in series. If a series connection is used, the tank is usually added in the direction of movement towards the heat pump to avoid delaying the heat supply when needed.

A hybrid heat pump system can meet the overall heating and hot water needs of any household. The boiler is used to reach higher temperatures for obtaining domestic hot water, while the heat pump can provide low-temperature heating at reduced costs and significantly lower energy consumption.

By switching between the two heat sources, smart hybrid heat pump systems can help optimise operating costs, improve energy efficiency, and reduce carbon dioxide emissions.

Hybrid heat pump control

Smart controllers (fig. 4) in hybrid systems allow switching between the heat pump and the boiler for optimisation based on a number of factors. Ideally, it should be possible to set the fuel price, carbon dioxide conversion factors, and the efficiency of the alternative heat source. There should also be a function for compensation of weather conditions and load. In most cases, it is possible to set a floating (variable) point, characterised by the lowest costs, lowest emissions, and least energy consumption.



Fig. 4. Hybrid heat pump controller

The controller can also offer Wi-Fi connectivity with smart features, including two-way communication, allowing external control of the system. In the future, this feature could be used by utility companies for demand management. Not all controllers on the market offer this level of functionality.

The control system is usually compatible with a simple two-channel controller and can be connected to the customer's existing heating solutions and a hot water controller.

The maximum temperature provided by the heat pump component of a domestic hybrid system is typically in the range of up to 55°C. Although these high temperatures are actually achievable, it is a more common practice for the heat pump component to operate at low temperatures, providing a continuous low-temperature base load while the boiler provides high-temperature heating (when needed) and domestic hot water.

Hybrid systems combining photovoltaics, gas boiler and heat pump

Hybrid systems combining a photovoltaic, a gas boiler and a heat pump are an innovative approach to energy production that offers numerous advantages and opportunities for optimising energy efficiency. This technology is becoming increasingly popular due to its flexibility and ability to reduce energy costs and carbon emissions.

Features of the hybrid system with photovoltaics, a gas boiler and a heat pump

The hybrid system with photovoltaics + heat pump + gas boiler is one of the most efficient solutions for heating and cooling a home in Bulgaria. It combines renewable energy with a backup source for maximum savings and security.

A photovoltaic system produces electricity from the sun.

Features: reduces heat pump electricity costs; option for batteries or net metering (if available); most effective during the day and in sunny seasons; requires sufficient roof area and proper orientation.

With a good configuration, it can cover 30–70% of the annual consumption of the home.

A heat pump (air-to-water or ground-to-water) is the main source of heating, cooling and DHW (domestic hot water).

Features: very high efficiency (COP 3–5); most effective in low-temperature systems (underfloor heating); its consumption depends on the outdoor temperature and runs entirely on electricity → ideally compatible with photovoltaics.

In a temperate climate (like in most regions of Bulgaria) the heat pump can be the main source 80–90% of the time.

A gas boiler (reserve/peak load) provides additional power at very low temperatures.

Features: works regardless of the outside temperature; cheaper as an initial investment; higher operating costs compared to a heat pump; suitable for "boosting" at -10°C and lower temperatures.

Provides security in extreme cold or heat pump failure.

The smart controller selects the most economical source according to: the outside temperature; the price of electricity and gas; the available solar energy and the heating/cooling needs.

Operation:

– In mild winters → the heat pump works (with electricity from the photovoltaics).

– In very cold weather → the gas boiler is turned on. and

– In summer → the photovoltaics cover the cooling.

Advantages:

+ Very low monthly costs - by combining different energy sources, the hybrid system can reduce overall energy costs. Heat pumps are more efficient at lower temperatures, which reduces the need for gas and therefore fuel costs.

+ Flexibility when energy prices change. In addition, the hybrid system can adapt to different weather conditions and seasons. The heat pump is more efficient during colder months, while the gas boiler can handle the higher load during peak consumption times.

+ Energy independence.

+ Easy integration - the hybrid system can be easily integrated into the existing heating systems, facilitating the transition to more sustainable solutions without significant construction modifications.

+ Lower carbon emissions - heat pumps use renewable energy sources, which reduces the dependence on fossil fuels and, therefore, carbon emissions. This makes the hybrid system more environmentally friendly and sustainable.

+ Backup source (security).

Disadvantages:

- Higher initial investment;

- More complex installation and management;

- Need for proper sizing.

The hybrid system is **suitable for**:

– new construction with good insulation;

– houses 120–350 sq. m;

– homes with underfloor heating;

– long-term savings.

Energy producer for the future. Hybrid systems with photovoltaics, a gas boiler, and a heat pump are a promising energy producer for the future for the following reasons:

- Sustainability and environmental friendliness – the estimated share of these systems shows a reduction in the dependence on fossil fuels and use of renewable energy sources, making them more sustainable and environmentally friendly.
- Economic efficiency - by optimising energy costs and reducing carbon emissions, hybrid systems offer economic benefits for consumers and businesses.
- Adaptability to different conditions - the system's ability to adapt to different climatic conditions and seasons makes it suitable for a wide range of applications and geographical areas.
- Technological advancements - the development of new technologies and materials continues to improve the efficiency and reliability of hybrid systems, making them even more attractive for the future.

Practical study and quantitative analysis of the hybrid system

Research methodology. For the purposes of the study, a single-family house with an area of 150 m² in the climatic conditions of Bulgaria is considered.

The parameters adopted are as follows:

- Annual heat demand: 12,000 kWh

- Electricity price: 0.25 €/kWh

- Natural gas price: 0.12 €/kWh

- Heat pump COP: 3.5

- Photovoltaic share: 40% of electricity consumption.

The electricity consumption of heat pump systems is determined by an integral relationship taking into account the instantaneous power and the system efficiency over time. This allows for a more accurate assessment of the actual energy consumption under variable operating conditions.

The simplified formula for heat pump consumption has the form:

$$E_{el} = \frac{Q}{COP} \quad (1)$$

where:

Q – required thermal energy

COP - transformation coefficient

Calculation:

$$E_{el} = \frac{12000}{3.5} = 3429 \text{ , kWh}$$

Consumption in different systems:

– Gas boiler only, € per year only:

$$C_{gas} = 12000 \times 0.12 = 1440 \text{ €/year}$$

– Heat pump only:

$$C_{HP} = 3429 \times 0.25 = 857 \text{ €/year}$$

– Hybrid system (with 40% photovoltaic):

The photovoltaic covers:

$$0.4 \times 3429 = 1371 \text{ kWh}$$

Remaining energy:

$$3429 - 1371 = 2058 \text{ kWh}$$

Cost:

$$C_{hybrid} = 2058 \times 0.25 = 514 \text{ €/year}$$

Table 1. Results table: Annual cost comparison

System	Energy, kWh	Cost, €/year
Gas boiler	12000	1440
Heat pump	3429	857
Hybrid	2058	51

Analysis of the results

The hybrid system reduces costs by: 64% compared to a gas boiler, and 40% compared to a heat pump. The photovoltaic system has the greatest contribution. The savings increase with higher electricity prices and a larger share of renewable energy sources.

Graphical representation of the "system-cost" relationship. This is given in fig. 5. The expected result is clearly visible cost reduction.

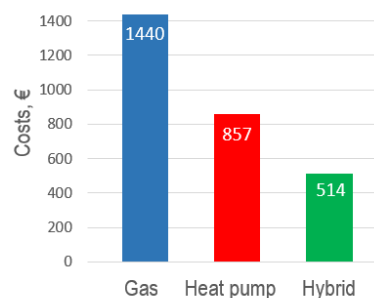


Fig. 5. "System-cost" dependency

Additional indicator. This is graphically presented in fig. 6 – CO₂ emissions.

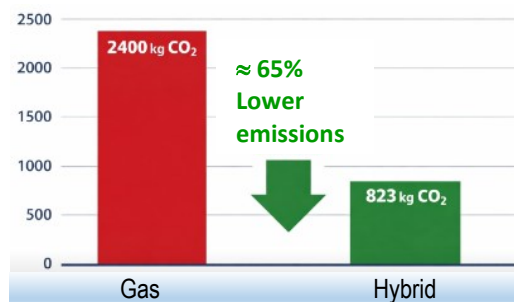


Fig. 6. CO₂ emissions

Approximate factors – gas: 0.2 kg CO₂/kWh, and electricity: 0.4 kg CO₂/kWh (EEA, 2023)

Gas: $12000 \times 0.2 = 2400$ kg CO₂

Hybrid: $2058 \times 0.4 = 823$ kg CO₂

Reduction: $\approx 65\%$

The chart shows a significant reduction in carbon emissions when using a hybrid system. With a gas system, emissions reach approximately 2,400 kg CO₂ per year, while with a hybrid system they are around 823 kg CO₂, which represents a reduction of approximately 65%.

Conclusion regarding the practical part. The conducted research shows that the hybrid system:

- provides significantly lower operating costs;
- reduces carbon emissions by over 60%.

The results obtained show a significant reduction in emissions when using a hybrid system. The reduction amounts to approximately 65%, which is a significant contribution to limiting the carbon footprint.

These results are consistent with other studies which show that integrating more efficient and combined energy solutions leads to significant emission reductions (Smith & Jones, 2019; Petrov et al., 2020). Furthermore, such systems allow for the optimisation of energy consumption and a more flexible resource management (Davis et al., 2018, 2021).

- increases energy independence.

That makes it, not only technically, but also economically and environmentally, an optimal solution for Bulgaria.

Conclusion

The hybrid system is not just a technology. It is a tool for social sustainability, a means to reduce energy poverty, a solution for cleaner air, and an example of responsible digitalisation. The study proves that the future of energy is not

only about efficiency, but also about the connection between technology and society. Thanks to the flexibility, combinations of domestic hybrid heat pumps can be used both in new buildings and in the modernisation of existing ones. The greatest potential of hybrid systems is precisely in retrofit applications. The technology can provide the link between the widespread gas boilers and the requirement for a transition to the use of low-carbon electric heating.

This paper examined a technological solution for electricity production, heating, and cooling through a hybrid system, including photovoltaics, a gas boiler, and a heat pump, not only as a technical solution, but also as a tool for:

- reducing energy poverty;
- building sustainable habits;
- increasing energy literacy;
- protecting personal data in the smart home;
- creating more sustainable communities.

The study has shown how smart energy management impacts people's daily lives and how technologies can work for the benefit of society. The implementation of such technologies is key to achieving sustainable development goals and reducing environmental impacts (IEA, 2022; IPCC, 2021). Their importance is expected to grow in the future, especially in the context of the energy transition to a low-carbon economy.

References

- Angelov, S. & Asenov, T. (2015). Mining Industry. *Mining and Geology*, 2, 24–31.
- Ivanov, A. (2023). Mineral and Raw Materials Industry of Bulgaria, 5, 12-19.
- Davis, L., Brown, T., & Wilson, R. (2018). Hybrid energy systems and efficiency improvements. *Energy Journal*, 45(2), 112–130.
- Davis, L., Brown, T., & Wilson, R. (2021). Advances in hybrid energy technologies. *Renewable Energy*, 67(4), 210–225.
- EEA - European Environment Agency. (2023). Greenhouse gas emission intensity of electricity generation.
- IEA - International Energy Agency. (2022). World Energy Outlook 2022.
- IPCC. (2021). Climate Change 2021: The Physical Science Basis. Cambridge University Press.
- Ivanov, P. (2017). Energy efficiency in modern systems. *Energy and Environment*, 12(3), 55–63.
- Petrov, D., Ivanov, A., & Georgiev, M. (2020). Analysis of hybrid systems in residential buildings. *Energy Systems*, 9(1), 33–41.
- Smith, J., & Jones, M. (2019). Reducing CO₂ emissions through hybrid solutions. *Journal of Cleaner Production*, 145, 200–210.