Research Article

Tomasz Sumera, Tadeusz Olkusi*

Improving the thermal performance of existing buildings in light of the requirements of the EU directive 2010/31/EU in Poland

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Abstract: Nowadays, the issue of energy saving is becoming increasingly important. Both households and large public facilities, such as schools, kindergartens, health centers, shopping, or leisure centers, implement energy saving systems. To start saving, one must first identify where the greatest energy losses occur. For this purpose, energy audits are carried out. The results of the audit make it possible to implement the necessary changes, including the replacement of old heating systems with modern energy-efficient equipment with the same, or even better, heating effect. This article presents research conducted in two public buildings, namely the Elementary School in Powroźnik in the administrative district of Muszyna and the Municipal Sports and Recreation Center in Dębica in Poland. The tests were carried out in accordance with the Directive 2010/31/EU (with later changes: directive 2012/27/EU and (EU)2018/844). The obtained results confirmed the need for comprehensive thermal upgrades in both buildings. The objective of the research was to develop the method aimed to reach the nearly zero-energy building in a public sector. Buildings in this category are usually of the great volume and heating space, but the functions of the buildings may be very diverse. It can be an administrative office, school, swimming pool, ice rink, hospital, etc. The article shows that although the functions of the buildings can be different some common methods of effective thermomodernization can be developed. In general, in large public buildings, complex solutions should be implemented. These include heat recovery using heat pumps in ventilation systems, renewable energy sources, such as photovoltaics, heat

pumps, or combined heat and power for space heating, building management systems that adjust the heat supplied according to the weather conditions, and lighting systems.

Keywords: thermal performance of buildings, energy auditing, heat recovery, building management system, climate protection

1 Introduction

Global environmental awareness is increasing every year. More and more people recognize the need for the rational use of fuels and energy, taking care of the natural environment, saving air, water, and land resources. The growing environmental movement is forcing national governments to pass and implement laws to protect our planet from devastation. To prevent a climate catastrophe, measures are being undertaken by various countries to reduce the use of fossil fuels and switch to renewable energy sources (RES). These include, among others, the commitments made during the Paris Agreement [1–6]. For years, the European Union has been at the forefront of activities aimed at decarbonizing national economies and achieving climate neutrality, through the so-called European Green Deal [7]. Intensive work is also underway on revising the clean energy for all Europeans package [8], European Climate Law [9], and Carbon Border Adjustment Mechanism [10], as well as on strengthening the EU Emissions Trading System (ETS) system for the next decade (EU ETS Revision for phase 4 [2021–2030]) [11], and the Just Transition Mechanism [12].

In Europe, the leading country in renewable energy is Germany. Country, which already in May 2011 adopted the Energiewende package aimed at the transition to renewable energy [13–18]. Among others, in the construction sector, it is planned to reduce CO₂ emissions from 209 million tons in 1990 to 70–72 million tons in 2030, a reduction by 66–67% [19]. The federal government will support the retrofitting of existing buildings and

* **Corresponding author: Tadeusz Olkusi**, Department of Sustainable Energy and Fuels, The Faculty of Energy and Fuels, AGH University of Science and Technology, Kraków, Poland, e-mail: olkusi@agh.edu.pl

Tomasz Sumera: Eco-Doradztwo, Wola Rzędzińska 2c, 33-150, Poland, e-mail: tomasz.sumera@op.pl

implement high energy-efficiency standards. The demand for heating and cooling will be covered by RES.

The need to protect the climate is recognized by politicians and citizens of most countries in the world. It is a sign of the times that the United States has rejoined the Paris Agreement [20] on 21 January 2021.

2 Background

Poland has adopted the Act on RES [21], the Energy Efficiency Act [22], and the National Air Protection Plan [23], aimed at improving the air quality in Poland. This is particularly vital in areas with the highest concentrations of air pollutants and large population centers. One of the most recent documents regulating energy and environmental issues in Poland is the Energy Policy of Poland until 2040, adopted in February this year [24]. Numerous government documents, such as acts and regulations concerning buildings, heating, cooling, ventilation, and air conditioning, have also been adopted in Poland over the years [25–31]. Additionally, at the local level measures are being undertaken to encourage the implementation of the thermal upgrade of public buildings. The Provincial Fund for Environmental Protection and Water Management in Kraków cofinances the thermal upgrade of buildings, with assuming a minimum area of 600 m². Such subsidies are available for the following [32]:

- Hospitals or medical entities (up to 30%).
- Hospices (up to 60%).
- Cultural institutions (state and local government; up to 20%).
- Church legal entities (up to 30%).
- Research institutes and public universities (up to 20%).
- National parks (up to 20%).

Loans, which are granted for up to 100% of eligible net costs, have preferential interest rates. Similar activities are also carried out by other provincial funds, such as the Provincial Fund for Environmental Protection and Water Management in Warsaw [33], Lublin [34], Łódź [35], Wrocław [36], Poznań [37], Gdańsk [38], Katowice [39], and many other provincial cities.

In addition to the fear of an ecological disaster that can result from overexploitation of the planet's resources, there is a growing generation that recognizes the potential negative effects of such management. As pointed out by Fücks [40], there is a trend in wealthy societies to move away from accumulating material possessions to satisfying other needs, such as self-realization or learning about oneself

and the surrounding world. Above a certain threshold of prosperity, it is no longer about “more” but “better.” Such an approach to life gives hope that the environment can be preserved to ensure that future generations can function at a level no worse than today.

In Poland, coal is still the main energy source for household heating. As much as 87% of coal burned in the EU for individual heating purposes is consumed in Poland [41]. However, this situation will change as the decarbonization of the power sector progresses. A similar trend develops by the space heating. According to an analysis carried out by the Forum Energii, around 1.5 million heat pumps could be installed in Poland by 2030, which would make it possible to replace almost half of the coal-burning furnaces and boilers used today. The authors of this report believe that Poland needs a vision for the transformation of the heating sector and a strategy that will achieve its goals of clean air, increased energy efficiency, and minimized climate impact of the energy sector.

Energy management in buildings is also an important issue. There are many systems for energy management in buildings, and the most effective are Building Management Systems (BMS), that is, advanced technical solutions aimed at efficient control of installations in a building, such as electrical, ventilation, heating, and cooling systems, and adjusting their operation to changing conditions [42,43].

Thermal efficiency improvement will be carried out at such a pace to meet the goal of zero-emission buildings by 2050 [44]. This is important as most Poles live and work in insufficiently insulated buildings. It is estimated that this problem affects 72% of detached houses (approximately 3.6 million), 50% of multifamily residences, and approximately 70% of nonresidential buildings [45]. Currently, the “Clean Air” program is being implemented in Poland [46]. It is a program targeted at owners and coowners of detached houses. Under this program, it is possible to obtain a grant to replace old and inefficient solid fuel heat sources with modern heat sources meeting the highest standards and to carry out the necessary thermal upgrade of the building. The maximum grant amount is up to 30,000 PLN for the basic financing level and 37,000 PLN for the increased financing level. The total amount allocated for this purpose is 103 billion PLN. According to the survey conducted by Market and Social Research Institute [47], as many as 70% of Kraków's residents would like electricity in public buildings to come from renewable sources. Every second respondent would expect the municipality to make announcements about air quality, and nearly 43% want the municipality to inform its residents about air protection regulations.

Replacement of old inefficient appliances with new energy-efficient ones and thermal upgrade of buildings are costly but bring long-term benefits. These issues have been addressed by many authors in Poland [48–51], but each case requires individual analysis and calculation. Similar problems also exist in other countries [52,53] and must be analyzed on a case-by-case basis.

The Act on the Energy Performance of Buildings [54] and further regulations [55] connected with the Act require that the energy used for heating space and domestic hot water in a new building owned by the community council after 2020 cannot exceed $E_{PH+W} = 45 \text{ kWh/m}^2$. Similarly, low values are set for lighting ($E_{PL} = 50 \text{ kWh/m}^2$) and cooling ($E_{PC} = 25 \text{ kWh/m}^2$). These limits pose the same problems to project makers because the limits are set for 1 m^2 independent of the height of the building. For example, if the internal height of the story is 2.5 m, then $E_{PH+W} = 45 \text{ kWh/m}^2$ means 18 kWh/m^3 . In the case of the story height of 16 m (like in sports halls), the same factor is 2.81 kWh/m^3 (Figure 1).

To reach such a low factor, it is often not enough to insulate the walls and roof, even by the standard of passive houses, and use low-emission windows. Most of the energy in insulated buildings goes to heating the air during the ventilation process, especially if the volume of the building is significant, for example, in sport halls.

In this case, the primary energy factor EP was exceeded in all aspects (space heating, domestic hot water, air conditioning, and lighting), although the window wall

and ceilings insulations as well as light-emitting diodes (LED) lamps were designed according to passive house standards. In addition, the ventilation system was equipped with a heat exchanger of 68% efficiency.

Figure 2 shows that the key to solving the problem of the use of primary energy over the limit of space heating is to reduce ventilation losses. The solution aimed at and developed in the energy audit is to introduce a ventilation unit equipped not only with a passive heat exchanger but also with an air/air heat pump. This increases the recuperation efficiency over 95% during an average heating season. This solution not only recovers heat but also reduces the energy used for air conditioning. Two problems seemed to be solved by one unit. Unfortunately, heat pumps use electric energy, and the demand for electric energy by the ventilation system increases seasonally. Electric energy in Poland has its primary energy factor equal to three because our power plants are mostly supplied with coal. Electric energy produced this way is equal to one-third of the chemical energy of coal and two-thirds is waste heat. Hence, although the final energy use by heat pumps is very limited due to very good coefficient of performance (COP) of the heat pump, the primary energy use is still high.

To solve the next problem, it is necessary to reduce the consumption of electric energy using photovoltaics (PV) installations, for example. A PV system reduces the demand for the primary energy through utilizing RES directly from the sun.

Figure 1: Primary energy limit depending on the height of the building [56].

Energy losses [kWh]

Figure 2: Space heating-energy losses (source: based on an earlier study [56]).

3 Method

Directive 2010/31/EU [57] at the article 7 (existing buildings) states:

“Member States shall take the necessary measures to ensure that when buildings undergo major renovation, the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements set in accordance with Article 4 in so far as this is technically, functionally and economically feasible.” This means that an existing building does not have to meet the requirement of $E_{PH+W} = 45 \text{ kW h/m}^2$ like in the example above, but it is important to balance the cost and results so as not to do things which are unfeasible economically.

3.1 Case 1: elementary school at Powroźnik community Muszyna

The Elementary School at the Powroźnik Community in Muszyna is a building from the 1970s. The heating space is 3511.41 m^2 (Figure 3).

About 10 years ago, the building was insulated with 5 cm thick polystyrene, so thermal transmittance of the walls was on the level $U = 0.3 \text{ W/Km}^2$. The thermal transmittance for the roof was $U = 0.6 \text{ W/Km}^2$ and $U = 2.6$ for the windows. The boilers were replaced and thermosolar system was already developed. The ventilation system is natural and the heating system is based on gas boilers. The energy used by the school building is shown in Table 1 and the calculation of Ep factor is shown in Table 2.

Based on the results of the energy audit, the following solutions were proposed:

- (1) Isolation of the roof with rock wool of $\lambda = 0.035 \text{ (W/[m K])}$ and 14 cm thickness
- (2) Isolation of the external walls using 8 cm polystyrene of $\lambda = 0.036 \text{ (W/[m K])}$
- (3) Isolation of the floor on the ground floor using 10 cm polystyrene of $\lambda = 0.036 \text{ (W/[m K])}$
- (4) Replacing the windows with new ones of $U < 0.9 \text{ (W/[m}^2 \text{ K])}$
- (5) Implementation of a mechanical ventilation system using ventilation units equipped with rotors as the heat exchangers and integrated heat pump as the second stage of recovering energy.

Figure 3: Elementary school in Powroźnik (source: Tomasz Sumera).

- (6) Cascade of three new condensing gas boilers and two absorption heat pumps powered with natural gas. Total power of the set is 179.8 kW. Heat pumps alone about 70 kW.
- (7) Energy control system based on the weather forecast.

In terms of the electric energy:

- (1) New light sources in LED technology inside and outside the building.
- (2) PV system of 39.73 kWp.

In addition, BMS monitoring the energy for space heating, domestic hot water, lighting, and the rest of electric energy was applied. This means 2 m of the heat and two of electric energy were integrated with controlling program. The results are as follows:

The single increase by auxiliary energy comes from the heat pumps working in the ventilation system, which is only partially compensated by the PV system.

Generally, the reduction of the energy demand of the building reaches 75%.

The values presented in the tables are the results of calculations made within the energy audit based on the monthly method. The real gas consumption for space heating in the year 2018 was 530,896 kW h, which is about 11% less than the calculated value. The calculation was made using temperatures in a standard heating season as defined by the Polish Ministry of Infrastructure. The year 2018 was warmer than the standard values. For example, according to the Institute of Meteorology and Water Management National Research Institute [58], the temperature of January 2018 was of about 3°C higher than the average value in years 1971–2000.

Table 1: Energy demand of the building

Annual primary energy demand in public buildings [kWh/year]							
1	Description	Heating + ventilation	Domestic hot water	Cooling	Lighting	Auxiliary energy	Total
	2	3	4	5	6	7	8
School	Before modernization	590,219	71,500	0	73,323	5,832	740,874

Source: own study.

Table 2: Factors: E_{PH+W} , E_{PL} , and E_{PH+W+L} (kW h/m²)

Description		Total energy for heating and domestic hot water	Heating space (m ²)	E_{PH+W} indicator	E_{PL} indicator	E_{PH+W+L} indicator
1	2	3 + 4	9	10	11	12
School	Before modernization	667,551	3511.41	190.11	20.88	210.99

Source: own study.

The external temperature anomaly explains the difference between calculated values and those measured by the gas counter.

3.2 Case 2: The heat recovery from an artificial ice rink

A sports complex in Dębica consists of an ice rink and swimming pools. Everything is arranged in one great hall divided into two parts (Figure 4).

The existing equipment was separated before the energy audit has started.

The ice rink was cooled with an old cooling machine, which returned the heat from cooling into the atmosphere. However, the swimming pool was supplied with energy from the district heating.

The idea to use heat recovered from the ice rink for heating the swimming pool was considered in the energy audit provided by Tomasz Sumera.

A high power heat pump with a cooling capacity of 403 kW and heating power of 560 kW was considered in

the project. A heat pump using CO₂ refrigerant (R744) is also better for the environment and human health than the old system, which uses ammonia.

4 Results and discussion

Both examples show the increasing role of proper use and preserving the internal heat gains of the building. Increasingly sophisticated methods and equipment should be used to reach the goal, which is the nearly zero or very low amounts of energy required per building. The first case shows that preserving the energy in the building, sometimes, can be the most effective way to reduce than using RES. The ventilation system takes a very important role in reducing the energy demand of the building. High-effective ventilation unit consists of the rotation heat exchanger of maximum efficiency about 80% and also a heat pump air/air, which works with a very high COP level over five and heats the incoming air after the rotation heat exchanger using the energy gained from the exhaust air. Of course, it increases the electric energy demand of the building because the new ventilation units require electric supply and the previous ventilation system was the natural one. The photovoltaic system reduces the demand of the electric energy. To recover 100% of the thermal energy given back by the ventilation units, the internal heat pumps at the ventilation system use electric energy on the level of only about 20% of the thermal energy recovered. This is possible due to COP > 5 of the heat pumps working in ventilation system. In such case, covering the additional demand of the electric energy by a photovoltaic system is a very efficient solution. It reduces the external energy electric demand to a level almost zero. Parallely, the heat recovery at the ventilation system reduces the demand of the thermal energy demand to the level, which would not be possible to reach due to the isolation of the building only (Table 3).

The second case – the energy recovery from the ice rink shows a great potential for saving the energy by the heat recovery form one part of the building to another or even between two separated buildings located nearby.

Figure 4: Municipal sports and recreation center in Dębica (source: Tomasz Sumera).

Table 3: Energy saving after modernization

1	2	Description	3	4	5	6	7	8
			Heating + ventilation	Domestic hot water	Cooling	Lighting	Auxiliary energy	Total
School		Before modernization (kWh/year)	590,219	71,500	0	73,323	5,832	740,874
		After modernization (kWh/year)	82,684	54,017	0	39,381	8,303	184,384
Energy reduction		(kWh/year)	507,536	17,483		33,942	-2,471	556,490
		%	85.99	24.45		46.29	-42.37	75.11

Source: own study.

Table 4: Energy saving due to the heat recovery at the ice rink

Month	Heat pump electricity consumption (MWh)	Heat recovery by heat pump		The heat consumption of the MOSiR ¹ facility in Dębica based on invoices				Saving heat energy from MPEC ² by using a heat pump (GJ)
		MWh	GJ	Space heating of cloakroom at the ice rink + swimming pool (GJ)	Swimming pool (GJ)	Domestic hot water. Ice rink + swimming pool (GJ)	Total MOSiR facilities (GJ)	
1	83.160	248.648	895.132	909.000	516.000	208.000	1633.000	895.132
2	47.600	142.324	512.367	805.000	468.000	201.000	1474.000	512.367
3	62.472	186.790	672.444	789.000	420.000	168.000	1377.000	672.444
8	96.240	287.757	1035.925	13.700	91.500	16.900	122.100	122.100
9	65.008	194.373	699.743	164.300	156.200	109.400	429.900	429.900
10	64.791	193.725	697.411	569.400	337.300	138.000	1044.700	697.411
11	60.000	179.401	645.843	655.300	390.000	156.700	1202.000	645.843
12	62.622	187.241	674.066	743.800	424.600	168.500	1336.900	674.066
Sum	541.893	1620.259	5832.931	4649.500	2803.600	1166.500	8619.600	4649.263

¹MOSiR, Municipal Sports and Recreation Center and ²MPEC, Municipal Heat Supply Company.

Source: own study.

The calculations made at the energy audit showed that the proper use of the internal heat gains, via transfer from the zone where they are useless to the zone where the energy is needed can be more effective than simple isolation of the envelope of the building or using RES. The examples are shown in the table below. The calculations are made based on the Polish price levels.

The heat recovery shown in Table 4 is $4649.263/8,619 = 54\%$.

During the cooling season, the heat pump will use $106.637 \text{ MW h} = 383.9 \text{ GJ}$ of electric energy, so the building's final energy consumption reduction will be $(4649.263 - 383.9)/8,619 = 49.1\%$.

The thermal energy consumption of the sports facility given in Table 4 (ice rink and swimming pool) is counted by proper energy meters. The electric energy consumption and the heat produced by the heat pump were calculated in the energy audit. Selection of the heat pump was based on the cooling capacity of existing equipment because the cooling capacity of the old system was sufficient and proper (as evidenced checked by about 20 years of operation), and only the energy efficiency of the old machines was low.

In both cases (1 and 2), the calculations of the improvements have been made in MS Excel using formulas implemented by the author. The energy demand at each variant separately was calculated by the dedicated polish programs for calculation of an energy performance of buildings. Developing our own formulas has been necessary because the norm [59] gives no solution for calculation of the internal energy gains that can be transferred to another building or a separate section of the building in other way than through the walls, ceilings,

or ventilation system. Our formulas are based on the basic law of conservation of energy and the technical parameters of the heat pumps used in calculation (such as COP, heating capacity, and cooling capacity) The calculations have been confronted with the energy measured by the proper meters and reached the proper accuracy.

The payback time was calculated at the tables according to the formula (Table 5):

$$\text{Simple Pay Back Time (SPBT)} = N_U / \Delta O_{ru},$$

where N_U – cost of implementing the modernization. Annual cost savings $\Delta O_{ru} = (Q_{0U} - Q_{1U})O_z + 12(q_{0U} - q_{1U})O_m$

The best variant of thermoisolation of the walls of the building using Styrofoam shows 73.2 years payback time (Table 6).

The example above shows the payback time of a photovoltaic installation.

The heat recovery by the heat pump installation was calculated in Table 4. The heat recuperation level is 4649.263 GJ (54% of the heat demand of the swimming pool; Table 7).

The examples show that the heat recovery system calculated in the energy audit gives two advantages:

- (1) best payback time from the modernizations considered above and
- (2) highest energy level gained by the system.

The previous technical norms and current one: EN ISO 52016-1:2017 [60].

“Energy performance of buildings – energy needs for heating and cooling, internal temperatures, and sensible and latent heat loads – Part 1: Calculation procedures” describes how to calculate the internal heat gains and

Table 5: Payback time of the isolation of external walls of the building of the ice rink

No.	Overview	Unit	Before thermos-modernization	Variants			
				1	2	3	4
1	Thickness of an additional layer of thermal insulation g	M		0.02	0.05	0.08	0.12
2	Increase of the thermal resistance ΔR	$\text{m}^2 \text{ K/W}$		0.6	1.6	2.5	3.8
3	Thermal resistance R	$\text{m}^2 \text{ K/W}$	3.46	4.1	5.0	6.0	7.2
4	$Q_{0U}, Q_{1U} = 8,64 \times 10^{-5} \text{ Sd A } U_c$	GJ/a	9.1	7.7	6.3	5.3	4.4
5	$q_{0U}, q_{1U} = 10^{-6} \text{ A } (t_{w0} - t_{z0}) U_c$	MW	0.001	0.001	0.001	0.001	0.001
6	Annual cost savings $\Delta O_{ru} = (Q_{0U} - Q_{1U})O_z + 12(q_{0U} - q_{1U})O_m$	PLN/a		72.80	145.60	234.23	244.40
7	Unit price of improvements	PLN/ m^2		143.00	153.00	158.30	175.50
8	Cost of implementing the modernization N_U	PLN		15486.90	16569.90	17143.89	19006.65
9	SPBT = $N_U / \Delta O_{ru}$	Years		212.7	113.8	73.2	77.8
10	U_c	$\text{W/m}^2 \text{ K}$	0.29	0.24	0.20	0.17	0.14

Source: own study.

Table 6: Payback time for the photovoltaics at the ice rink

Assessment and selection of a project to reduce electricity costs				
Description		Electricity cost:	330.35	PLN/MWh
The modernization consists of the installation of 370 photovoltaic panels with an area of 603.4 m ² and a total capacity of 120 kW for electricity production.				
Lp.		Unit.	Current status	After modernization
1.	Annual electricity consumption	kWh/a	547.423	547.423
2.	Annual electricity production	kWh/a	0.000	117.850
2.	Share of RES	%	0.0	21.5
3.	Cost of electricity	PLN/year	180841.32	141909.57
5.	Annual cost savings	PLN/year		38931.75
6.	Cost of modernization	PLN		1048770.96
7.	SPBT	Years		26.9

Source: own study.

Table 7: Payback time for the heat recovery form the ice rink to the swimming pool (source: own study)

Saving heat energy	4,649.263	GJ/year
Financial savings for thermal energy	241,761.70	PLN/year
Increase in electricity consumption	106.637	MWh/year
Cost of electricity	35,227.69	PLN/year
Total financial savings	206,534.01	PLN/year
Investment cost	3,037,691.15	PLN
SPBT	14.7	Years

energy transmitted from other zones through the walls and other building elements. There is no ready procedure how to include the heat gain transferred from one part of the building to another in other ways than natural transition through the building elements in the calculations. In our opinion, it should be taken into consideration by reviewing the norm.

5 Conclusion

Based on the obtained results, it can be stated that an energy audit in public buildings may be complicated, especially if one wants to meet the requirements of the Directive 2010/31/EU (with later changes: directive 2012/27/EU [60] and (EU) 2018/844 [61]).

To solve this problem, a complex solution is necessary, including, but not limited to heat recovery using heat pumps in ventilation systems, RES such as photovoltaics, heat pump or heating and cooling systems for space heating, building management system that automatically controls space heating based on the weather

forecast, and lighting depending on the natural sunlight levels in the building. Heat recovery from other sources can be used where possible; for example, waste heat from industrial production can be used for space heating in factory buildings, and heat recovered from artificial ice rinks can be used to heat swimming pools, etc.

Reaching the goal set by the directive 2010/31/EU (with later changes: directive 2012/27/EU and (EU) 2018/844), therefore, requires that the energy auditor thinks in a more interdisciplinary manner. The ice rink example shows that transmitting the internal heat gains from one part of the building to another or even between two buildings located nearby can improve the energy efficiency and maximize the internal heat gain factor in both buildings. By reviewing the norms regarding energy performance of buildings, this problem and potential updates to the norm should be considered.

Summing up, it should be stated that measures to reduce the consumption of chemical energy contained in fossil fuels are undertaken in many countries, especially in the EU. The effects of these activities are visible in the data showing the final energy consumption. The decline in energy consumption is particularly visible in highly developed countries such as the United Kingdom, Germany, France, and Italy [62].

Due to the work carried out in two public buildings in Poland and presented in this article, the consumption of chemical energy contained in fossil fuels is reduced, which in turn reduces CO₂ emissions and helps to protect the Earth's climate.

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