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Urszula PAWLAK[1], Marcin PAWLAK[2]

[1]Faculty of Civil and Architecture, Kielce University of Technology
[2]Faculty of Electrical Engineering, Automatic Control and Computer, Kielce University of Technology

The thermomodernization of a single family house located in the Świętokrzyskie Mountains – a case study

Key words: thermomodernization, demand indicator for non-renewable primary energy, *EP*, renewable energy, heat transfer coefficient

Introduction

Thermomodernization is currently one of the most frequently mentioned concepts in construction, from small houses to public and industrial facilities. Thermomodernization means eliminating heat losses directly at the construction level by ensuring proper insulation of partitions separating the interior of the building from the outside world in new and already existing facilities, also replacement of devices working for central heating and hot utility water. Today, everyone is saving, i.e. they control expenses spent on maintaining the premises in which they live. In particular, this applies to the care for proper management of energy necessary in everyday life. Due to the fact that the deposits of non-renewable resources end and the pollution of the natural environment increases (Fig. 1), renewable sources are used to obtain energy, which together with modern-intelligent building materials are to ensure hygienic and financial comfort of life.

That is why energy certification of buildings was introduced and legalized at the European level by the Directive 2002/91/EC, in Poland by two regulations of the Minister of Infrastructure of 2008 and 2016 (Journal of Laws 2008 No 201, item 1238; Journal of Laws 2008 No 201, item 1239) and one regulation of the Minister of Infrastructure and Construction of 2016 (Journal of Laws 2017, item 22). At present, each newly built building must meet not only the safety, durability, reliability but also energy efficiency in the area of building materials and the method of energy consumption for everyday operation. Hence the need for thermomodernization of existing facilities to improve the quality of life of their users.

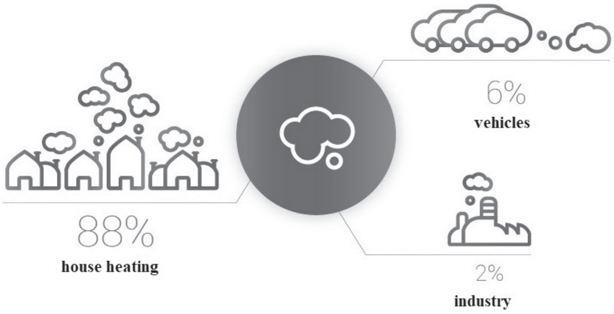

FIGURE 1. Producers of air pollution (based on Cichosz, 2015)

In the paper, the single-family house, located in the Świętokrzyskie Mountains, was analyzed for the impact of the type of thermomodernization on energy performance. To ensure thermal comfort and maintenance-free power consumption devices, and thus reduce maintenance costs, in accordance with the applicable standards, the object has been thermo-modernized twice.

A few words about energy standards in construction

The 21st century in construction is the development of modern technologies in the field of building materials, methods of manufacturing individual elements and entire structures, which are often called intelligent. An intelligent building is an almost self-sufficient facility, i.e. no media needed for "life" from publicly available networks, e.g. energy, gas, water supply. It is not cheap at the level of creating a project, buying the right area and finally building itself. However, using the latest technology and proven materials and installations, it can become a low-energy or even zero-energy building, i.e. a building whose current maintenance, in addition to simple depreciation, will be free. The broadly defined energy classification that nearly all buildings are subject to are currently in force (Directive 2002/91/WE, Journal of Laws 2002 No 75, item 690; Journal of Laws 2008 No 201, item 1238; Journal of Laws 2008 No 201, item 1239; Journal of Laws 2008 No 17, item 104; Journal of Laws 2009 No 161, item 1279; Journal of Laws 2015, item 1422).

By WT 2017 (Journal of Laws 2002 No 75, item 690) energy requirements correspond to the *EP* indicator, i.e. the non-renewable energy demand, necessary to satisfy the needs related to the use of the building or its part (Fig. 2). A low *EP* indicator will obtain an object in which the heat transfer coefficients $U_{c\max}$ of individual partitions (Table 1) separating it from the outside world will be lower than in WT 2021. However, compliance with the current *EP* requirements is possible mainly after installation of central heating and hot water equipment using renewable energy sources, i.e.: solar, wind, water, geothermal, tidal energy. It should be remembered that these devices must be characterized by high efficiency in transforming energy, which scientists and engineers constantly work on.

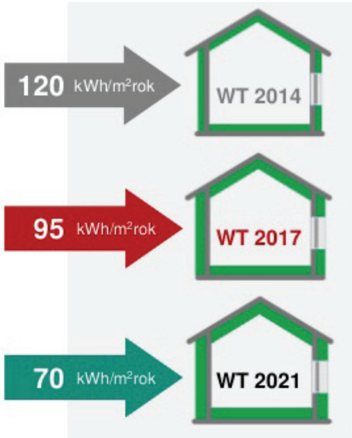

FIGURE 2. Maximum values of the *EP* indicator for heating, ventilation and preparation of hot utility water according to WT 2014, 2017 and 2021 in a single-family building (EKO-BLOG.pl, 2019)

the impact of thermal modernization works carried out in the facility on its energy class, it is necessary to determine the annual demand for non-renewable primary energy *EP*, which should be used for the needs of the building. This indicator is determined by the formula:

$$EP = EP_{H+W} + \Delta EP_C + \Delta EP_L \quad [\mathrm{kWh \cdot m^{-2} \cdot year^{-1}}]$$

where:
EP_{H+W} – partial maximum value of the *EP* index for the needs of central heating, ventilation and hot utility water;
ΔEP_C – partial maximum value of the *EP* index for cooling;
ΔEP_L – partial maximum value of the *EP* index for lighting.

TABLE 1. Heat transfer coefficient (Journal of Laws 2008 No 17, item 104)

Type of partition and temperature in the room	Heat transfer coefficient $U_{C(max)}$ [$\mathrm{W \cdot m^{-2} \cdot K^{-1}}$]		
	from 01.01.2014	from 01.01.2017	from 01.01.2021
External walls at $t_i \geq 16$°C	0.25	0.23	0.20
Roofs, flat roofs and ceilings under unheated attics or over entrances, at $t_i \geq 16$°C	0.20	018	0.15
Floors on the ground, at $t_i \geq 16$°C	0.30	0.30	0.30
Ceilings over unheated rooms and closed underfloor spaces, at $t_i \geq 16$°C	0.25	0.25	0.25
Ceilings over heated underground rooms and inter-story floors, at $t_i \geq 8$°C	1.00	1.00	1.00
Facade windows	1.30	1.1	0.9
Roof windows	1.50	1.30	1.10
Exterior doors, garage doors	1.7	1.5	1.3

Methodology of research

The amount of energy collected from the grid for heating, obtaining hot water, air conditioning, ventilation and room lighting is directly affected by the energy performance of the building. To estimate

The lower the *EP* value, the greater the homeowner's financial savings due to heating, water, electricity, heating comfort in the premises, protection of the building from overheating in the summer and cold in winter, protection of the natural environment resulting from the use of renewable energy sources and higher value of real estate in the case of sales.

Another way of energy classification of buildings, where the indicator is *EU*, i.e. energy used for heating and ventilation in the building, excluding heating of hot water (Table 2), presents the Association for Sustainable Development (Stowarzyszenie na rzecz Zrównoważonego Rozwoju). Usable energy is a part of primary energy.

TABLE 2. Energy classification of buildings (Żurawski, 2013)

Energy class	Type of building	*EP* indicator [kWh·m^{-2}·year^{-1}]
A++	zero energy	to 10
A+	passive	10–15
A	a low energy	15–45
B	energetic	45–80
C	medium energy	80–100
D	minimum legal (meet current WT)	100–150
E	energy consuming	150–200
F	highly energy consuming	over 250

At work, the *EP* indicator was determined using the Certo 2015 program, educational version 1.3.4.0, meeting the requirements of the Regulation of the Minister of Infrastructure on the methodology for calculating the energy performance of a building and WT 2017 (Journal of Laws 2002 No 75, item 690).

Analyzed object, results

In the work, the analysis consisting in the determination of the *EP* indicator was a single-family house, located in Domaszowice, at the foot of the Świętokrzyskie Mountains, and the Kielce poviat (Fig. 3). Object:

– located in the third climate zone;
– to the north-south sides of the world;
– type of land: gravel and sand;
– usable area: 242.41 m^2;
– cubic capacity: 661.32 m^3;
– year of construction completion: 2009;
– year of putting into use: 2010;
– three floors;
– mansard roof;
– gravitational ventilation;
– entrance from the north;
– a large number of windows on the south side.

FIGURE 3. Analyzed building

Basic data on the installations and partitions of the analyzed house

Condition for 2010

– heat source for central heating and ventilation – SAS solid fuel furnace – hard coal;
– heat source for domestic hot water – in the heating period, water heated using a central heating furnace, in the summer period an electric heater;

– joinery: windows and external doors with a heat transfer coefficient $U = 1.1\ W{\cdot}m^{-2}{\cdot}K^{-1}$;
– external partitions:
- exterior wall basement: styrofoam Thermo Organika, façade 12 cm, block of cellular concrete 40 cm, lime plaster 1.5 cm, $U = 0.20\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- floor on the ground: terracotta 1 cm, concrete undercoat under the floor 6 cm, polyethylene 0.2 mm foil, polystyrene foam 5 cm, polyethylene foil 0.2 mm, 2× papa on a glue, petroleum asphalt 0.2 cm, foundation with lean concrete 3 cm, rubble 25 cm, medium sand 15 cm, $U = 0.398\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- basement-ground floor: cement-sand plaster 1.5 cm, ceiling with FERT-20 20 cm, styrofoam Thermo Organika 6 cm, polyethylene film 0,2 mm, concrete undercoat under the floor 4 cm, terracotta / oak board 2 cm, $U = 0.40\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- external wall floor-floor: 1.5 cm silica plaster, MAX block on cement and lime mortar 19 cm, mineral wool Rockwool 12 cm, block brick 9 cm, lime plaster 1.5 cm, $U = 0.26\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- ceiling floor-floor: cement-sand plaster 1.5 cm, ceiling with FERT-20 20 cm, styrofoam Thermo Organika 3 cm, polyethylene film 0.2 mm, concrete undercoat under the floor 4 cm, terracotta / oak board 2 cm, $U = 0.69\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- ceiling floor: cement-sand plaster 1.5 cm, gypsum plasterboard 1.3 cm, polyethylene film 0.2 mm, styrofoam Thermo Organika 9 cm, pine boards 2 cm, mineral wool Rockwool 25 cm, pine board 4 cm, $U = 0.115\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- roof: plasterboard 2 cm, roofing foil 0.2 mm, styrofoam Thermo Organika 9 cm, pine boards 2 cm, mineral wool Rockwool 25 cm, roofing foil 0.2 cm, pine board 4 cm, ceramic tile 0.88 cm, $U = 0.077\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- internal supporting wall: limestone plaster 1.5 cm, full brick wall 25 cm, limestone plaster 1.5 cm, $U = 1.515\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- internal partition wall: plasterboard 1.3 cm, wooden grate + Rockwool 10 cm mineral wool, plasterboard 1.3 cm, $U = 0.530\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- windows: plastic windows and balcony doors by Drutex, $U = 1.10\ W{\cdot}m^{-2}{\cdot}K^{-1}$,
- external doors: wooden exterior doors of the AFB Kraków, $U = 1.20\ W{\cdot}m^{-2}{\cdot}K^{-1}$.

EP index for the building in the year of its commissioning

The indicator of annual demand for non-renewable primary energy necessary to meet the needs related to the use of the building was obtained from the Certo educational program 1.3.4.0 according to the methodology contained in the applicable regulations (Journal of Laws 2002 No 75, item 690). According to WT 2008, the *EP* indicator for a new, normative building was $173.70\ kWh{\cdot}m^{-2}{\cdot}year^{-1}$, and for the analyzed object, in the year of putting it into use in 2010 is presented in Figure 4.

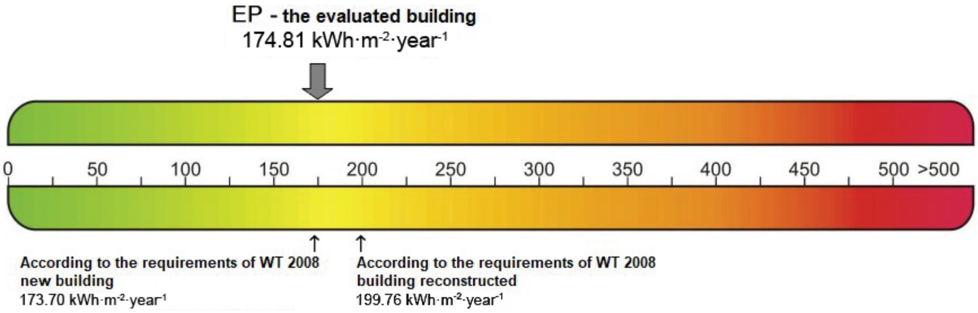

FIGURE 4. *EP* index for the building in the year of putting it into use in 2010

Stages of thermomodernization of the analyzed building

The first thermomodernization

In 2015, the owner of the building benefited from the subsidizing of the Masłów Commune Office and founded the Schüco Premium solar collectors with an area of 5.38 m^2 and a nominal capacity of 4 kW using solar energy for hot utility water (Fig. 5). The cost of investment after co-financing PLN 6,800.00.

FIGURE 5. Analyzed building with solar collectors mounted on hot water needs

According to WT 2014, the *EP* index for the new building is 120 kWh·m^{-2}··year^{-1}, and for the analyzed object is 96.52 kWh·m^{-2}·year^{-1}. In addition, a household sewage treatment plant with a water recovery for watering the garden was installed next to the facility, costing approximately PLN 10,000.00.

The second thermomodernization

In 2018, the owner of the house, bearing in mind the health aspects as well as maintenance-free central heating devices, no pollution of the house and the environment, installed an air-water heat pump Daikin Altherma 3, ERGA08DV + EHBH08D9W with power 8 kW (Fig. 6). The pump also heats domestic

FIGURE 6. Installation of a heat pump cooperating with solar collectors

water in the event of a small amount of solar radiation. The cost of the investment is PLN 33,000.00.

According to WT 2017, the *EP* indicator for the new building is 95 $kWh \cdot m^{-2} \cdot year^{-1}$, and for the analyzed object is 70.50 $kWh \cdot m^{-2} \cdot year^{-1}$

Discussion and conclusions

Thermomodernization is a process that a building is subjected to in order to reduce heat losses (Fig. 7) to the external environment.

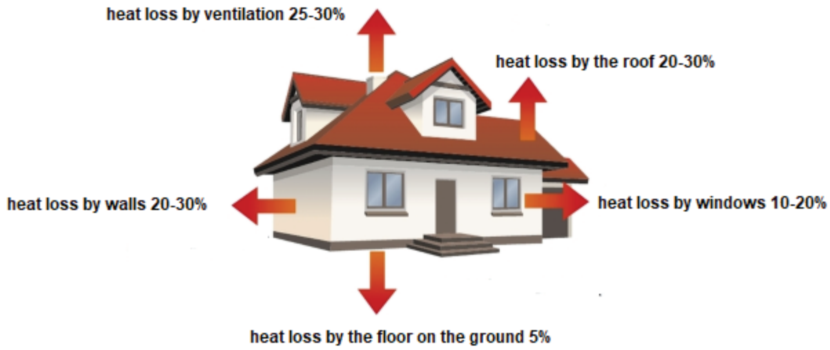

FIGURE 7. Heat loss in the building (Pawlak, Radomski & Kapłon, 2015)

For this purpose, a number of works are carried out in the enclosure and inside the house, for example:

– insulation of external walls, floors on the ground, ceiling above the basement, last storey, roof, flat roof by adding a valuable insulating material with a low heat transfer coefficient;
– replacement of windows, external doors and garage doors with the requirements of Table 1;
– modernization of the central heating and hot utility water installations in whole or only by exchanging the devices necessary for its operation;
– changing the way of supplying fresh air, that is, changing the gravitational ventilation into a mechanical one;
– the use of devices using renewable energy sources.

In this house, the thermomodernization process concerned the modernization of central heating and hot water installations with the use of renewable energy sources. The owner has not decided to insulate the partitions separating the building from the external environment. Mainly because the building is relatively “young” and its technical condition is very good, although some heat transfer coefficients U are greater than those given in the standards (summary in Table 3).

According to WT 2017, the *U* factor for the external ground floor and floor walls is higher than the standard by 0.3, and the floors on the ground by 0.1. For other partitions, including windows and external doors, *U* values are smaller than those currently in force. Despite the fact that ventilation has a large share in heat losses, however, it has not been changed either.

TABLE 3. Analysis results

Parameters analyzed	2010/2014/2018	Standard condition according to WT by year			
		2008	2014	2017	2021
	U [kWh·m^{-2}·year^{-1}]				
External walls: basement /ground floor – first floor	0.2/0.26	0.3	0.25	0.23	0.2
Internal wall supporting	1.515	no requirements			
Internal wall partition	0.53				
Floors on the ground	0.398	by [5]	0.3	0.3	0.3
Ceiling above the basement and ground floor	0.40	by [5]	1.0	1.0	1.0
Ceiling above the floor	0.115	by [5]	1.0	1.0	1.0
Roof	0.077	by [5]	0.2	0.18	0.15
Exterior doors	1.2	2.6	1.7	1.5	1.3
Windows	1.1	1.8	1.3	1.1	0.9

The house in the year of commissioning (2010), due to the obligatory WT 2008, did not meet the requirements of the *EP* index (Table 4). However, the difference is only 0.51 kWh·m^{-2}·year^{-1}, which is why the permission for using the facility has been issued. In 2014, in order to limit the high annual costs of using the facility (heating, electricity, water and sewage) equal PLN 7,300, the owner decided to carry out the first modernization. Due to the very good location of the building on one of the Szydłówkowskie Hills, i.e. in the absence of cover, Schüco Premium solar collectors with an area of 5.38 m^2 and a nominal power of 4 kW for hot water were installed. In addition, a household sewage treatment plant with water recovery for garden irrigation was installed. The cost of modernization (after installation of collectors) amounted to PLN 16,800. The *EP* index decreased to 96.52 kWh·m^{-2}·year^{-1}, and the requirements for 2014 were met. This investment has brought many benefits:

– decrease in home maintenance costs (Table 4);
– reduction of air pollution through the share of renewable energy sources – solar energy;
– limiting the use of water for irrigation through recovery from wastewater treatment plants.

Subsequent years of using the house, and especially the furnace service, forced the owner to the next modernization. The main reason was poor quality, ie decreasing calorific value of hard coal, weekly

TABLE 4. Analysis of the EP index and home maintenance costs

Parameter	2010	2014	2018	2008	2014	2017	2021
Index *EP* [kWh·m^{-2}·year^{-1}]	174.81	96.52	70.50	173.70	120	95	70
Annual house maintenance costs [PLN]	7 300	4 600	3 200	–	–	–	–

cleaning of the boiler, also the chimney during the heating season, frequent painting of boiler rooms and other rooms. Therefore, in 2018, the Daikin Altherma three air-water heat pump with the power of 8 kW was installed. In winter, in the absence of insolation, the pump also heats hot water. Although the costs of improvement were high (PLN 33,000), they gave the owner and residents incommensurable benefits in the form of maintenance-free devices, even better air quality and cleanliness at home. In addition, the cost of living has also decreased, this time by PLN 1,400 in relation to the previous modernization, which placed the object in the class of energy buildings, $EP = 70.50\ \mathrm{kWh \cdot m^{-2} \cdot year^{-1}}$.

The thermomodernization process carried out by the owner locates the analyzed object in the group of energy-efficient buildings. The high costs incurred for the purchase and installation of solar collectors, home sewage treatment plant and heat pump, will pay back after about 13 years, and the building, even in 2021, will meet the applicable standards. A huge, noticeable improvement in the comfort of living fully pleases and satisfies the residents of the house. The devices use renewable energy sources, do not require owner service, do not pollute the environment. Fees for home use are current bills for electricity, water and maintenance of the treatment plant. It is possible to minimize costs by investing about PLN 20,000 in a household power plant using wind power or photovoltaic panels (Fig. 8) with a capacity of 5 kW in the on-grid system. The 5 kW power plant will fully satisfy the needs of the analyzed facility, after installing the heat pump, the demand for electricity increased to 4 MWh per year.

In this case, the investment in thermomodernization will pay back after 11 years, because the cost of maintaining the facility annually will be at PLN 1,000. The building will become a zero-energy house, as evidenced by the indicator $EP = 0\ \mathrm{kWh \cdot m^{-2} \cdot year^{-1}}$ (Fig. 9).

Thermomodernization works are associated with high financial outlays, both due to construction materials, equipment

a b

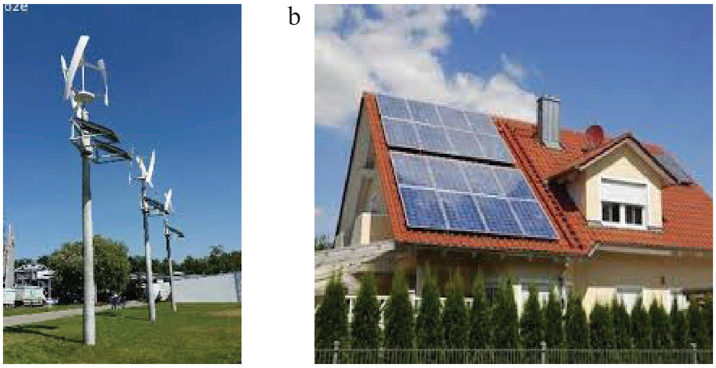

FIGURE 8. A home-made power plant using renewable energy sources: a – wind turbine (http://odnawialnezrodlaenergii.pl/images/com_adsmanager/contents/przydomowa-elektrownia-wiatrowa-vawt-moc-2-5-kw-na-zerdzi-wirowanej-e-12-15_239_3.jpg) or b – photovoltaic panels (https://thumbs.img-sprzedajemy.pl/1000x901c/5d/78/d6/panele-sloneczne-fotowoltaika-suwalki-493904596.jpg)

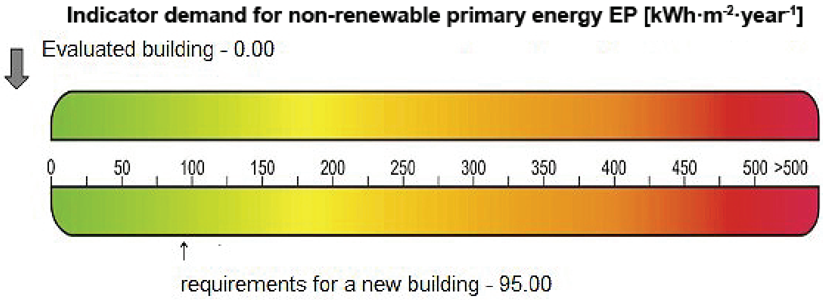

FIGURE 9. EP indicator for the proposed modernization using photovoltaic panels or a wind turbine

and labor. At present, it is possible to obtain preferential co-financing of such investments from various national programs (e.g. Clean Air) or EU programs as well as relief in deductions from revenues.

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Summary

The thermomodernization of a single family house located in the Świętokrzyskie Mountains – a case study. The paper presents the energy performance of a single-family house located in Domaszowice, the Kielce poviat. The analyzed object has been put into use in 2010 year. Due to the devices using non-renewable energy sources, installed in the building for the needs of hot tap water and central heating, for servicing, which human presence is necessary, two thermomodernizations were performed. The purpose of the calculations was to indicate the financial benefits, i.e. to reduce the costs of maintaining the home and to provide its residents with proper comfort of use of the building, bearing in mind also the health aspect. Changes have been proposed to reduce the demand for non-renewable primary energy of *EP* using renewable energy sources. As a result, the energy-efficient building that meets WT 2017 was obtained. The Certo 2015 program was used in the analysis.

Authors' address:
Urszula Pawlak
(https://orcid.org/0000-0002-1454-6181)
Politechnika Świętokrzyska
Wydział Budownictwa i Architektury
Katedra Mechaniki, Konstrukcji Metalowych
i Metod Komputerowych
al. Tysiąclecia Państwa Polskiego 7
25-314 Kielce
Poland
e-mail: u.pawlak@tu.kielce.pl

Marcin Pawlak
(https://orcid.org/0000-0003-4124-1698)
Politechnika Świętokrzyska
Wydział Elektrotechniki, Automatyki
i Informatyki
Katedra Elektrotechniki Przemysłowej
i Automatyki
al. 1000-lecia Państwa Polskiego 7
25-314 Kielce
Poland
e-mail: m.pawlak@tu.kielce.pl