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Evaluation of Energy Efficiency in Thermally Improved Residential Buildings, with a Weather Controlled Central Heating System. A Case Study in Poland

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Abstract: Optimization of energy consumption and related energy efficiency can be realized in various ways, both through measures to reduce heat losses through building partitions and the introduction of modern systems of regulation and management of heat distribution. In order to achieve the best possible results, these actions should be interlinked, especially in older buildings that have undergone thermomodernization. Therefore, the aim of the study was to evaluate actions aimed at improving energy efficiency of buildings made in prefabricated technology. These buildings were thermomodernized and then the weather-controlled central heating system was installed. The study assessed whether the application of the change of the method of central heating regulation from the traditional one, taking into account only the change of external temperature to the weather-controlled one, will contribute to the increase of energy efficiency of buildings. The research was carried out in the existing residential buildings, for which data on the actual energy consumption was collected and elaborated and includes periods before modernization, after thermomodernization and the period after the introduction of the central heating system with weather control. The collected data cover an eighteen-year period of buildings' use. The obtained results indicate that in Polish conditions the introduction of weather-controlled regulation system in buildings made in prefabricated technology (made of large slab) allows to achieve energy savings in the range of 16–23%, it may be related to their high thermal capacity resulting from the use of concrete elements in the building envelope.

Keywords: weather controlled central system; energy saving; energy consumption; thermal improved of buildings; new energy technologies; sustainable buildings

1. Introduction

Heat is one of the main factors influencing the comfort of living or staying in the premises of residential buildings as well as public utility. It affects not only our well-being, efficiency and effectiveness but also the financial aspect related to the need to rationalize the costs of property maintenance in the phase of its exploitation and the impact on environmental protection by reducing carbon dioxide emissions to the atmosphere [1]. Single- and multi-family houses but also public buildings account on average for about 41% of total energy consumption in the European Union. These estimates reinforce the thesis that the need to reduce energy consumption in buildings, especially for heating and air conditioning, is of great importance for rational energy management. According to the report of the European Environment Agency in the European Union, energy used for space heating represents 68% of global energy consumption in buildings [2]. In Poland it is 71% [3]. For the needs of hot water, 13% is used, for lighting and other electrical appliances - 14% and only 5% for preparing meals [2].

Potential savings resulting from thermal upgrading of buildings are estimated at the level [3]:

- 33–60% to reduce energy consumption by improving thermal insulation of walls,
- 16–21% for the modernization of the ventilation system,
- 14–20% to improve the thermal insulation of the window joinery,
- 10–12% for regular inspections and modernization of central heating boilers.

The above-mentioned activities, in order to achieve the assumed effect, must take into account the so-called human factor, namely, additionally the behavior, attitudes and habits of residents- users of buildings- must change. Changing their attitude towards energy-saving measures, such as, for example: room temperature control (by means of thermostatic valves) depending on needs, limiting excessive ventilation of rooms and others, can bring real savings of 5% to 15% [4].

In recent years, a huge progress has been observed in technological solutions used in residential and commercial buildings. Starting from architectural solutions up to heating technology. More and more complicated technical innovations are being applied nowadays, whose task is to improve the living comfort in buildings. Intelligent buildings, with the help of innovative systems, have become not only more comfortable but also safer. The rapidly developing technologies make it possible to apply these modern solutions in buildings where people stay every day. Optimization of energy consumption and related energy efficiency are increasingly often analyzed in depth in practically all aspects of life of modern society. These issues, in a special way, also affect buildings and their infrastructure, because they are one of the most energy-intensive areas of human functioning. Users of residential units but also of public buildings, attach increasing importance to the possibility of offering high comfort in them and also want to make widespread use of the achievements of modern heating, ventilation or multimedia technology. The research conducted on the quality of the internal environment shows that users of various types of buildings—including thermally improved buildings—feel satisfied with their living conditions, which has a positive effect on health and productivity and at the same time translates into ecological attitudes [5–8]. This situation determines the need for a new approach to the very design phase of the planned facilities and in the case of existing buildings, their modernization and adaptation to contemporary trends and requirements [9]. These actions are taken not only in the scope of improving the comfort of use but also energy efficiency and, what is important, safety. Therefore, it has become necessary to conduct research in the scope of already available and search for new, functional building automation systems. All this in order to continuously optimize the consumption of electricity, heat and other media in buildings [10]. The most common form of energy efficiency improvement of existing buildings is their thermal improvement- often called thermomodernization. Thermomodernization is a broad concept, often mistakenly associated only with the thermal insulation of building walls. These activities also include modernization and replacement of heat sources, replacement of windows and modernization of internal heating systems. In Polish conditions, according to the research carried out on a group of 109 multi-family residential buildings, for which energy characteristics were determined, based on actual energy consumption before and after thermal improvement, it was indicated that thanks to comprehensive thermomodernization, savings of 38–40% can be achieved [11], such a level of savings can be described as "average" [12,13]. Therefore, it is advisable to use other instruments to improve energy efficiency, through modernization and improvement of heat management- operational regulation in heating systems of buildings.

The main task of operating control of each heating system is to maintain the indoor air temperature within the assumed tolerance range. A commonly used method of weather regulation of heating centers is the so called "tracking regulation," where regardless of the outside air temperature fluctuations, the regulation system maintains a constant temperature in the rooms of the heated building. There are two concepts to be distinguished here [14]:

- quantitative regulation, consisting in adjusting, depending on the individual thermal needs of the user of the premises, the amount of the flowing heating medium in the system without changing its temperature, e.g., by an appropriate setting on the thermostatic valve head,
- quality regulation, which consist in changing the temperature of the heating medium with its constant flow through the installation.

2. Literature Review and Justification of Topic Selection

In the literature can find several approaches related to the control of heating systems in buildings, which are connected to the municipal heating network.

Detailed approaches can be divided into [14,15]:

- control of night-time temperature reduction in the heating system [9],
- control based on outside temperature [15],
- energy control with indoor temperature sensors [16–18],
- control based on weather forecasts [16,19–25],
- forecast control by using a barometer [15,16],
- energy limitation by installing an accumulator tank [26,27],
- complex object control models- predictive models based on data analysis using methods such as artificial neural networks and others [21,28–32].

Some of the above-mentioned ways of regulating the operation of the heating system have been commonly used in real residential buildings as commercial systems. These are among others: EnReduce, Egain Edge oraz Kabona (these systems are discussed in detail in the paper [16]). Therefore, in this research we want to focus on the evaluation of one of the presented methods, which has been implemented in buildings in Poland.

Previous research carried out mainly in Sweden has shown that depending on the applied method of regulation, measurable savings in energy consumption can be achieved. The level of savings for selected regulation systems [16,17,20] is presented in Table 1.

Table 1. Comparison of energy saving levels for different control systems for central heating in residential buildings.

	Heating Control System in Objects		
Specification	**Egain Edge**	**EnReduce**	**Kabona**
number of buildings tested	19; 2	7	4
range of energy savings achieved %	0–26; 13,7–14	7–20	9–16
average energy saving %	11; 13,85	13	13

The presented research results indicate that the average energy savings regardless of the applied regulation system is about 13%, with the biggest differences in the achieved savings (0–26%) being observed in the case of the Egain Edge method [16]. In addition to temperature indicators (and others), one of the key values for energy storage in buildings is the time constant τ. The time constant describes how quickly a building will react to changes in the weather and additional heat. The constant differs between buildings, the heavier the structure, the greater the time constant (temperature inertia) of the building. It is estimated that a "heavy" type building has a time constant of about 160 h, an "average" building has about 66 h and a "light" building has about 25 h [33]. In the literature [16,17] there is no precise information on what type of buildings were tested, looking at the range of energy savings (0 to 26%) in the case of the method based on the Egain Edge weather forecast, it can be assumed that these buildings may have differed from each other by the type of construction and therefore by the time constant.

In Poland, from the sixties to the eighties of the last century, the technology of large plate (prefabricated elements) dominated in the residential construction. The issue of energy efficiency of large panel buildings is discussed in many scientific works [34,35]. None of the buildings erected at that time in the large panel technology, by assumption, is able to meet the thermal and energy requirements set today. The research carried out on the analyses of thermal insulation of external walls of buildings made in the large panel technology, confirmed the deterioration of their thermal insulation, mainly due to the use of concretes with increased density. The defects and errors resulting from the execution or damage of thermal insulation layers as well as the location of thermal bridges also had an impact. The occurrence of these places was caused by insufficient thickness of thermal insulation or lack of it, which additionally favored the dampness of partitions [36]. An additional factor that contributes to the appearance of moisture in building partitions is the way the apartments are used. This is due to an improper approach to ventilation of rooms, for example, covering up ventilation grilles, which leads to the occurrence of surface condensation of water vapor and, consequently, the appearance of fungus and mold. The thermomodernization carried out by insulating walls and ceilings mostly eliminated the problem of thermal bridges, however, the installation of airtight windows in old type of buildings with the simultaneous lack of sufficient ventilation may result in the occurrence of periods with increased air humidity, which indirectly affects the deterioration of the comfort of use of apartments- especially in the autumn and winter period. Hence the need to improve the regulation of the heating system, which will allow to maintain comfort of use while optimizing energy consumption in thermally improved buildings. One of the heating regulation systems in large panel buildings, which has found application in objects previously covered by thermomodernization works is Egain Edge system. This solution takes into account the prediction of heat demand, using a constantly updated weather forecast. The system consists of weather forecast receivers, which replace the existing outdoor temperature sensors and their task is to optimize heat consumption in buildings. Additionally, the Egain Edge includes climate recorders installed in selected apartments, recording humidity and temperature. According to the distributor's information, in Poland the system operates in about 400 heat distribution centers installed in multi-family residential buildings [23]. Hence the authors' interest in this topic. Preliminary research was conducted for three representative residential buildings, which were made in various prefabricated technologies. The aim of the study was to evaluate the effects of thermomodernization activities aimed at improving thermal protection of buildings made in large plate technology. The main objective was to examine whether the application of the change of the method of central heating regulation from the traditional one, taking into account only the variable external temperature to the weather control, will increase the energy efficiency (energy savings) of the buildings covered by the analysis.

3. Materials and Methods

The research was conducted for three selected prefabricated multi-family residential buildings located in the north-eastern part of Poland in the city of Łomża. The buildings have the following location: 6 Śniadeckiego St. - Building A; 12 Kołłątaja St.- Building B and 1 Niemcewicza St.- Building C. The city is located in the area of the IV Climate Zone [37] for which the calculated outdoor temperature is −22 °C, the average annual outdoor temperature is 6.9 °C and the number of degree days in a standard heating season $HDD(t_b)_0$ = 4095.4 Kd. These buildings were thermally improved in the years 2011–2015 and then the central heating control system with weather control type Egain Egde was installed in them.

The control system is connected to the existing heating system. It can only work with water heating systems, which can be controlled from one point- the central heating node. The system uses forecast control, in which the external temperature sensor controlling traditional systems is replaced by a receiver receiving local weather forecasts (Figure 1).

Figure 1. Weather forecast receiver Egain Hub, building A at 12 Śniadeckiego St. in Łomża.

The control system takes into account such parameters as: solar radiation, sunlight angle, reflection from the ground, wind speed, wind direction, surface of windows and walls of the building, orientation and thermal inertia of the building (Table 2).

Table 2. Compilation and comparison of elements included in heating regulation systems [19].

Parameters Taken into Account by the Heating Control System		Forecasting Regulation Egain Edge	Weather Control
External factors (environmental)	outside temperature	x	x
	insolation	x	-
	wind direction and speed	x	-
	precipitation	x	-
Features of the building	location of the building in relation to the directions of the world and other buildings	x	-
	ventilation system in the building	x	-
	condition of the building's facade (glazing surface)	x	-
	amount of water in the central heating system	x	-
	shape and height of the building	x	-
Internal factors	measurement of temperature and humidity in apartments	x	-

Energy savings are made by adjusting the heating system of the building to its thermal capacity on the basis of the building time constant and weather forecasts. The system uses the equivalent temperature instead of the outside temperature to determine the supply temperature setpoint. The peaks of the heating system operation are shifted and the system can work with less and more even power, because heat energy is taken from the building structure. The system continuously evaluates the quality of the forecast and in case of excessive deviations, the system switches to control according to the outside temperature instead of the forecast.

The analyzed buildings are heated from the municipal heating network. Therefore, has been information on actual heat consumption for heating in the eighteen heating seasons covering the period before and after thermomodernization. On this basis, calculations of final energy demand for heating were made and then the energy characteristics of objects in the state before and after thermal modernization were determined. To exclude seasonal fluctuations, the actual energy consumption values obtained were converted (corrected) to standard season conditions (multi-year average). The data concerning the heating season degree days (from the years 2001–2019 and the multi annual average) based on which the calculations were carried out were taken from the climate database Institute of Meteorology and Water Management-National Research Institute (IMWM-NRI) for the Łomża region. The amount of final energy consumption was calculated using the formula:

$$Q_{K,H} = \sum\nolimits_{i=1}^{n} \frac{HDD(t_b)_i}{HDD(t_b)_0} \cdot Q_{K,H_i} \cdot \frac{1}{n}, \quad (1)$$

where: $Q_{K,H}$—the final energy demand for the heating season, [kWh]; $HDD(t_b)_0$—the number of degree days in a standard heating season, [°Cd]; $HDD(t_b)_i$—the number of degree days for the "i" of this year, [°Cd]; Q_{K,H_i}—final energy consumption for heating in a measurement period for the "i" of this year, [kWh]. n-number of years of the measurement period.

Due to the different periods of thermal improvement of buildings and the introduction of a weather-controlled central heating control system. Table 3 shows the values of measuring years n for energy consumption before and after modernization.

Table 3. Number of years of the measurement period—n.

Building Condition	Building		
	A	**B**	**C**
before modernization, [year]	10	12	9
after thermal improvement, [year]	2	1	2
after the introduction weather controlled central heating system, [year]	6	5	7

The index of final energy demand for heating before and after the implementation of the improvement was calculated according to the formula:

$$FE = \frac{Q_{K,H}}{A_H}, \quad (2)$$

where: FE—index of final energy demand for heating, [kWh·m^{-2}·year^{-1}]; $Q_{K,H}$—the final energy demand for the heating season, [kWh]; A_H—calculated area of temperature-controlled rooms (heated surface), [m^2].

For individual building states the FE indicator has been defined as follows: FE_0—index of final energy demand for heating converted to the conditions of the standard heating season, before modernization, [kWh·m^{-2}·year^{-1}]; FE_1—index of final energy demand for heating converted to the conditions of the standard heating season, after thermal improved, [kWh·m^{-2}·year^{-1}]; FE_2—index of final energy demand for heating converted to the conditions of the standard heating season, after the introduction weather controlled central heating system, [kWh·m^{-2}·year^{-1}].

These buildings had energy audits prepared, on the basis of which the optimum variants of thermal modernization were selected, the partitions that should be modernized were indicated and the appropriate thicknesses of layers of thermal insulation materials were selected. Some of them are measured and others calculated, as pointed out in Table 4. The table contains, among others, such information as: the year of the building's construction, the year in which the thermal improvement was performed and the year in which the modernization of the central heating system was introduced. Moreover, the table includes the following data characterizing the buildings: area and cubic capacity, area of walls through which heat losses occur, time constant of the building, power demand for heating and index of final energy demand for heating before and after the improvement consisting in insulation of external partitions.

Table 4. Characteristics of variables influencing the energy needs of analyzed buildings.

No.	Parameter	Abbreviation	Building		
			A	B	C
1	construction year of a building, [year]	C_A	1984	1992	1994
2	year in which the thermal improvement was performed, [year]	C_{ti}	2012	2014	2011
3	year in which the installing weather controlled central heating system, [year]	C_{hs}	2013	2015	2012
4	calculated from exterior measurements the heated volume of building, [m^3]	V_e	9876	10294	18376
5	calculated from interior measurements total (net internal area), [m^2]	A_{in}	2231	1646	3572
6	calculated surface of heated floors from interior measurements, [m^2]	A_f	1576	1051	2235
7	calculated from exterior measurements surface of roof projection area (net), [m^2]	A_r	602	869	1141
8	calculated from exterior measurements total walls' surface (net) area, [m^2]	A_w	1560,1	1417,3	2762,3
9	calculated surface of floor from interior measurements (floor over basement or floor on the ground), [m^2]	A_{fl}	446	549	714
10	calculated from exterior measurements total windows area, [m^2]	A_{tw}	383,5	272,5	742,2
11	number of storeys, [pc.]	N_{Os}	5	3	5
12	number of residential flats, premises [pc.]	N_{Op}	45	30	75
13	number of living persons per building [N$_b$]	N_{Opb}	145	99	195
14	shape coefficient of buildings (the ratio surface to volume), [m^2·m^{-3}], [m^{-1}]	S/V_e	0,37	0,36	0,38
15	calculated thermal transmittance of walls components before modernization, [W·m^{-2}·K^{-1}]	U_{w0}	0,57	0,44	0,36
16	calculated thermal transmittance of peak walls components before modernization, [W·m^{-2}·K^{-1}]	U_{pw0}	0,56	0,49	0,33
17	calculated thermal transmittance of roof projections components before modernization, [W·m^{-2}·K^{-1}]	U_{r0}	0,49	0,2	0,18
18	calculated thermal transmittance of floor components on the ground before modernization, [W·m^{-2}·K^{-1}]	U_{g0}	3,19	3,03	3,23
19	calculated thermal transmittance of floors components (floor over basement) before modernization, [W·m^{-2}·K^{-1}]	U_{f0}	1,37	0,74	0,39
20	thermal transmittance of windows (commercial data) before modernization, [W·m^{-2}·K^{-1}]	U_{win0}	2,6	2	2
21	calculated thermal transmittance of walls components after thermal improved, [W·m^{-2}·K^{-1}]	U_{w1}	0,24	0,22	0,19
22	calculated thermal transmittance of peak walls components after thermal improved, [W·m^{-2}·K^{-1}]	U_{pw1}	0,26	0,23	0,19
23	calculated thermal transmittance of roof projections components after thermal improved, [W·m^{-2}·K^{-1}]	U_{r1}	0,18	0,2	0,18
24	calculated thermal transmittance of floor components on the ground after thermal improved, [W·m^{-2}·K^{-1}]	U_{g1}	3,19	3,03	3,23
25	calculated thermal transmittance of floors components (floor over basement) after thermal improved, [W·m^{-2}·K^{-1}]	U_{f1}	1,37	0,74	0,39
26	thermal transmittance of windows (commercial data) after thermal improved, [W·m^{-2}·K^{-1}]	U_{win1}	1,4	1,4	1,4
27	calculated time constant, [h]	τ	78	62	84
28	calculated heating consumed power, [kW]	Φ_h	154	125	236
29	calculated temperature of the internal wall surface before modernization, [°C]	T_{iwb}	16	16,91	17,47
30	calculated temperature of the internal wall surface after thermal improved, [°C]	T_{iwa}	18,32	18,46	18,67
31	measured, (average) index of final energy demand for heating converted to the conditions of the standard heating season, before modernization, [kWh·m^{-2}·year^{-1}]	$FE_{0(avg)}$	95,4	104,0	102,9
32	measured, index of final energy demand for heating converted to the conditions of the standard heating season, after thermal improved, [kWh·m^{-2}·year^{-1}]	FE_1	74	77,6	95,3

The buildings subjected to the analysis were characterized by a similar value of the unit energy demand indicator for heating, which ranged from about 95 to 104 [kWh·m^{-2}·year^{-1}]. The demand for heating power after thermal improvement is in the range from 125 kW (building B) to 236 kW (building C).

The calculated building time constants τ (according to EN 13790 [38]) range from 62 h for building B to 78 and 84 h for buildings A and C respectively. They can be classified as "medium" buildings [34], with buildings A and C having a higher thermal inertia compared to building B.

For the analyzed buildings, the amount of energy savings was calculated for two states:

(a) after thermal improvement, where the energy saving in percent is calculated according to equation:

$$FE_{\%,ES,a} = \left(1 - \frac{FE_1}{FE_0}\right) \cdot 100, \tag{3}$$

where: $FE_{\%,ES,a}$—the energy savings achieved through thermal improvement of buildings in percent; FE_0—(average) index of final energy demand for heating converted to the conditions of the standard heating season, before modernization, [kWh·m^{-2}·year^{-1}]; FE_1—index of final energy demand for heating converted to the conditions of the standard heating season, after thermal improved, [kWh·m^{-2}·year^{-1}].

(b) after the introduction weather controlled central heating system.

The energy saving in percent is calculated as:

$$FE_{\%,ES,b,i} = \left(1 - \frac{FE_{2,i}}{FE_{1,r}}\right) \cdot 100, \tag{4}$$

where: $FE_{\%,ES,b,i}$—the annual energy savings achieved through the introduction weather controlled central heating system in percent; $FE_{2,i}$—index of final energy demand for heating for the "i" of this year, converted to the conditions of the standard heating season, after the introduction weather controlled central heating system, [kWh·m^{-2}·year^{-1}]; $FE_{1,r}$—index of final energy demand for heating converted to the conditions of the standard heating season, in the reference year, [kWh·m^{-2}·year^{-1}]. The year preceding the installation of the Egain Edge system was adopted as the reference year, converted to the conditions of the standard heating season.

- Building A. As the system was installed in September 2013, the first period with a full 12-month cycle, from January to December, included in the savings analysis, is 2014.
- Building B. As the system was installed at the beginning of January 2015, the first period with a full 12-month cycle, from January to December, included in the savings analysis, is 2015.
- Building C. As the system was installed in September 2012, the first period with a full 12-month cycle, from January to December, included in the savings analysis, is 2013.

Reducing energy consumption is calculated as:

$$\Delta FE_{,ES,b,i} = FE_{1,r} - FE_{2,i}, \tag{5}$$

where: $\Delta FE_{,ES,b,i}$—the annual reducing energy consumption, [kWh·m^{-2}·year^{-1}]; $FE_{1,r}$—index of final energy demand for heating converted to the conditions of the standard heating season, in the reference year, [kWh·m^{-2}·year^{-1}]; $FE_{2,i}$—index of final energy demand for heating for the "i" of this year, converted to the conditions of the standard heating season, after the introduction weather controlled central heating system, [kWh·m^{-2}·year^{-1}].

Total energy savings as a result of comprehensive thermomodernization (wall insulation plus introduction weather controlled central heating system) for the buildings analyzed is calculated as:

$$FE_{\%,ES,tot} = \left(1 - \frac{FE_{2(avg)}}{FE_{0(avg)}}\right) \cdot 100, \tag{6}$$

where: $FE_{\%,ES,tot}$—the energy savings achieved through thermal improvement of buildings in percent; $FE_{0(avg)}$—(average) index of final energy demand for heating converted to the conditions of the standard heating season, before modernization, [kWh·m^{-2}·year^{-1}]; $FE_{2,i}$—(average) index of final energy demand for heating, converted to the conditions of the standard heating season, after the introduction weather controlled central heating system, [kWh·m^{-2}·year^{-1}].

4. Results and Discussion

The consumption of thermal energy for the analyzed buildings for the needs of central heating in the years 2001–2019 is shown in Figures 2–4. The amount of consumption was expressed using unit indicators of final energy demand, covers the periods before modernization, after thermal improvement (reference year) and the period after the introduction weather controlled central heating system (Egain).

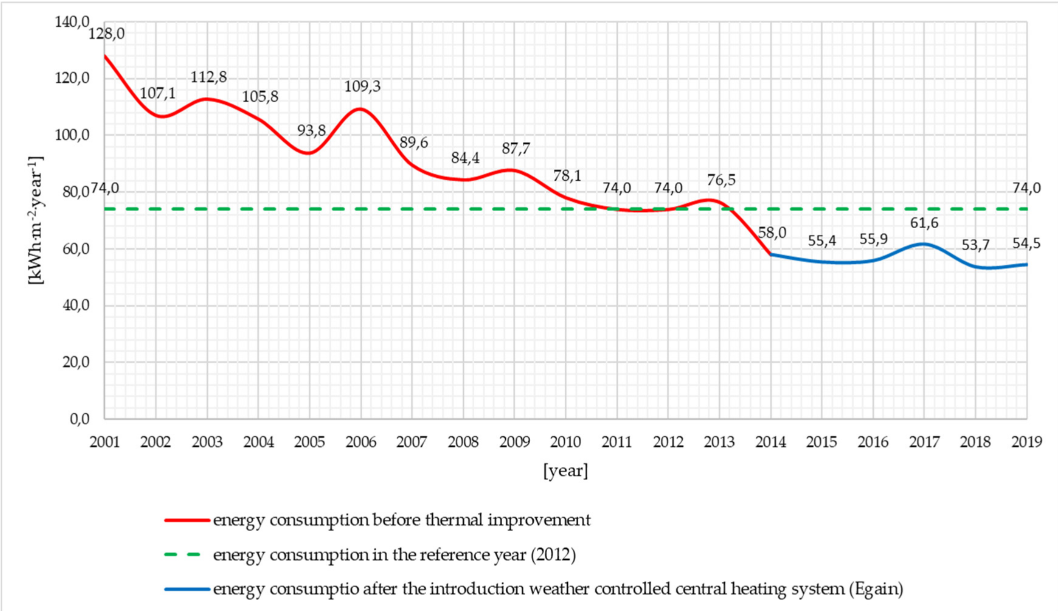

Figure 2. Thermal energy consumption for central heating in the years 2001–2019 in building A.

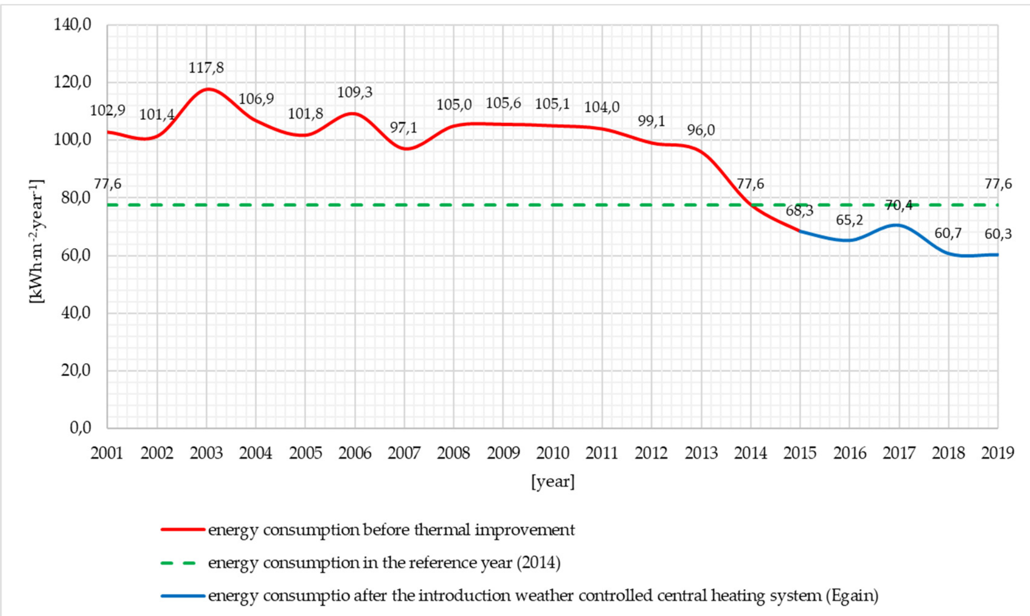

Figure 3. Thermal energy consumption for central heating in the years 2001–2019 in building B.

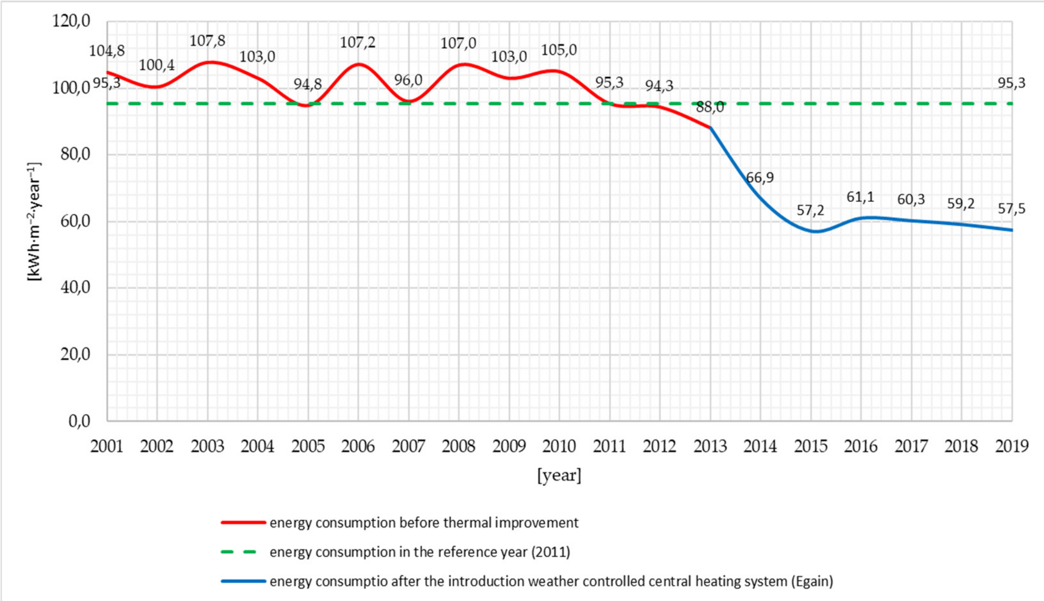

Figure 4. Thermal energy consumption for central heating in the years 2001–2019 in building C.

In the years 2011–2014, the buildings were thermomodernized by insulating the walls. After the thermal improvement (without modernization of the heating system), energy consumption was reduced, which is shown in Table 5.

Table 5. Energy savings achieved through thermal improvement of buildings.

$FE_{\%,ES,a}$	**Building**		
	A	**B**	**C**
savings achieved, %	22,5	25,4	7,4

The thermal improvement of the external partitions has had the best effect in buildings A and B, where energy consumption has been reduced by about 22–25%. In building C, thermal modernization of the walls did not bring much savings, because only about 7%.

The next stage of the research was to check whether the application of the change in the method of central heating regulation from the traditional one, taking into account only the change in the outside temperature to the weather control, will increase the energy efficiency (savings in energy consumption) of the buildings covered by the analysis. For this purpose, the amount of energy consumption reduction $\Delta FE_{,ES,b,i}$ and energy savings $FE_{\%,ES,b,i}$ were calculated. The calculations were made, for each (full) year after installation of the Egain control system according to formulas 4 and 5. Then the average values of the energy savings obtained were calculated. The results of the calculations are summarized in Table 6.

Table 6. The impact of the introduction weather controlled central heating system on the reduction of energy consumption in the building.

Year	Building					
	A		B		C	
	$\Delta FE_{,ES,b,i}$ [kWh·m^{-2}·Year^{-1}]	$FE_{\%,ES,b,i}$ %	$\Delta FE_{,ES,b,i}$ [kWh·m^{-2}·Year^{-1}]	$FE_{\%,ES,b,i}$ %	$\Delta FE_{,ES,b,i}$ [kWh·m^{-2}·Year^{-1}]	$FE_{\%,ES,b,i}$ %
2013					7,3	7,7
2014	16	21,6			28,4	29,9
2015	18,6	25,3	9,3	12	38,1	39,9
2016	18,1	24,5	12,4	15,8	34,2	35,9
2017	12,4	16,7	7,2	9,3	35	36,8
2018	20,3	27,6	16,9	21,8	36,1	37,9
2019	19,5	26,3	17,3	22,3	37,8	39,8
average	17,5	23,6	12,6	16,2	30,9	32,5

Analyzing the results contained in Table 6, it can be concluded that the change of the method of central heating control from the traditional one, taking into account only the external temperature variation to the weather control, has resulted in increased energy efficiency in the analyzed buildings. The energy consumption in comparison with the reference year (after the partitions have been insulated) has decreased on average from 12.6 to 30.9 kWh·m^{-2}·year^{-1}. The energy savings are about 16% to 32%. Comparing the savings associated with the introduction of a new control system for central heating installations for individual buildings in relation to the savings obtained as a result of insulating the walls, it can be concluded that in the case of building C, there is a supposition that only a 7% reduction in energy consumption after insulating the walls (where from the theoretical calculations should be about 20% [9]), could be caused by faulty operation of the central heating control system. After changing the control system to a forecast, there was a significant reduction in energy consumption, which in 2015 and 2019 reached almost 40%.

Taking into account the above observations when estimating energy efficiency, it was decided to refer to buildings A and B, where as a result of thermomodernization the obtained savings levels are similar and amount to 22% to 25%. These buildings, after thermal improvement, were characterized by similar energy consumption rates in the reference year, which amounted to 74–77,6 kWh·m^{-2}·year^{-1}. In these buildings, the change of regulation method resulted in average reduction of energy consumption in the range of 12,6 kWh·m^{-2}·year^{-1} (building B) to 17,5 kWh·m^{-2}·year^{-1} (building A). Energy saving in the range of 16,2% (building B) to 23,6% (building A). It can be assumed that the differences in achieved savings may result from different curtain wall structures, where in building A prefabricated elements based on reinforced concrete were used, while in building B prefabricated elements based on aerated concrete. The values of calculated time constants of buildings 78 h for building A and 62 h for building B also prove it.

Comparing the obtained results with the data presented in the literature, where the obtained savings amount to about 13–14% [16,17,20], it can be stated that the application of weather-controlled central heating system in buildings made in the prefabricated technology (which have been thermally improved) gives better results, which, depending on the applied technology of making curtain walls, can give the average energy savings of about 20%.

The total energy savings achieved as a result of the thermal improvement combined with the modernization of the heating system are presented in Table 7.

Table 7. Total energy savings achieved through thermal improvement of buildings and of the introduction weather controlled central heating system.

$FE_{\%,ES,tot}$	Building		
	A	B	C
total savings achieved, %	40,7	37,5	37,5

Buildings, that have undergone comprehensive thermal upgrading measures can achieve energy savings on heating of about 37% to 41%.

5. Conclusions and Perspectives

The paper presents an evaluation of measures to improve the energy efficiency of buildings made in large plate technology. These buildings were subjected to thermal improvement consisting in insulation of external partitions and then the weather controlled central heating system was installed. The main objective was to examine whether the application of the change of the method of central heating regulation from traditional, taking into account only the variation of outside temperature to weather control, will increase the energy efficiency (energy savings) of buildings. The analysis covered the period between 2001 and 2019. The amount of energy used by buildings for heating was determined on the basis of actual consumption and then converted to the conditions of the standard heating season. Annual energy consumption is presented using unit final energy demand indicators and covers the periods before modernization, after thermal modernization (reference year) and the period after introduction weather controlled central heating system. The thermal improvement of the external partitions has energy consumption has been reduced by about 22–25%. Modernization of heating consisting in the implementation of weather-controlled central heating system, depending on the technology used to make curtain walls in buildings, allows to achieve savings in the range of about 16–23%. The total energy savings in the analyzed buildings is on average about 39%.

The presented results of the research carried out for three representative residential buildings can be treated as a preliminary one, where they wanted to indicate the potential for savings that can be achieved in buildings made in the large panel technology. Further research should be carried out on a set of dozens of buildings, so that it is possible to identify specific groups of buildings, made in prefabricated technology using various materials, for which, after applying the regulation of weather controlled central heating system, it will be possible to indicate a specific level of energy savings—characteristic for a given group.

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