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POTENTIAL FOR ENERGY SAVING IN HEATING AND VENTILATING SYSTEMS IN OFFICE BUILDINGS

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Reduction in energy consumption with regard to building maintenance results from necessary primary energy (mainly from fossil fuels) savings. Increased final energy consumption is typically a consequence of improved standards of building appliances, which is a reason for maintenance problems regarding fuels as well as supply and demand balancing during periods of the highest and lowest temperatures. In the article, results of studies on thermal characteristics of selected office buildings – a conventional, modernized building and an energy-efficient building– in the aspects of meeting requirements of the amended European Union Directive 2010/31/EU are presented.
Key words: energy-efficient building, heating and ventilating system, thermal conditions.

Mogućnosti uštede energije u sustavima za grijanje i ventilaciju nestambenih zgrada. Smanjenje potrošnje energije s obzirom na održavanje zgrada rezultira iz potrebe uštede primarne energije, poglavito one iz fosilnih goriva. Povećana ukupna potrošnja energije je posljedica postroženih normi u zgradarstvu, što je razlog za stalan problem uravnoteženja zahtjeva u vezi s vrstom, mogućnosti dobave i potražnje goriva na tržištu tijekom razdoblja najviše i najniže temperature. U ovom radu prezentirani su rezultati studije o toplinskim karakteristikama odabranih nestambenih zgrada - konvencionalna, modernizirana i energetski učinkovita zgrada - s aspekata zadovoljavanje normi i propisa izmijenjenih i dopunjenih Direktivom Europske unije 2010/31/EU.
Ključne riječi: energetski učinkovite (niskoenergetske) zgrade, sustav za grijanje i ventilaciju, toplinski uvjeti.

INTRODUCTION

In the climate and energy package, approved by the European Parliament and called "3x20", tasks for the ecological policy to be performed by the member states until 2020 have been determined. They include the necessity for CO_2 emission and energy consumption reduction by 20% and increase in the use of renewable energy sources (RES) by 20% [1]. Construction industry is one of the most energy-consuming sectors of the national economy. In the European Union, the industry uses about 40% of energy [2], including Poland where 8% is used for building construction and as much as 32% is utilized for their maintenance [3]. Regarding primary energy, its supplies for construction industry needs is even higher and estimated at about 42% [4]. A building and its indoor environment form a neighbourhood-related part of the ecosystem.

The indoor environment is associated with thermal and acoustic comfort, proper quality of indoor air and proper lighting intensity. Thus, a building is a multi-parameter, controlled facility which can be separated by a balance shield affected by the following parameters:

- input and external parameters – basically the parameters of the balance system (building) and climate (building architecture, construction of partition walls, technical infrastructure, topographic features, energy resources etc.)
- output and internal parameters, i.e. energy loss related to thermal load resulting from the thermal comfort requirements, air pollution, solid and liquid wastes, vibroacoustic emission, electromagnetic radiation.

People-oriented residential comfort is mainly achieved through dynamic development of technically-advanced ventilating and air-conditioning systems. A goal for modern buildings is reduction in their energy consumption through reduction in energy use by heating as well as ventilating and air-conditioning systems with achieving a good level of thermal comfort. Fig. 1 shows a flow chart of energy balance for office and commercial as well as residential buildings [5, 6]. To meet these requirements, the following solutions must be considered at the design stage:

- a compact form of the building (optimal A/V ratio);
- utilization of passive solar energy systems for heating purposes, including more transparent components as well as south- and southwest-sided daily rooms;
- additional thermal protection of the building, e.g. by trees;
- optimal thermal insulation of the building envelope;
- high thermal capacity of the building envelope (walls and roof);
- utilization of mechanical ventilation with heat recovery;
- utilization of renewable energy sources for heating and cooling purposes;
- implementation of active envelope shading systems for reduction in solar energy gain during summer.

While designing low-energy buildings, which are the basis for sustainable development, expected climate changes (i.e. global temperature rise) should be considered with the emphasis on the Design Summer Year parameters. According to these, there are four basic principles of low-energy, sustainable development (see Fig. 2 [7]).

Types and parameters of the assumed solutions primarily depend on the geographical location of buildings. Based on the analysis of the earth temperature rise by 2ºC, this will result in, for example:

- reduction in the number of heating degree days (HDD) from 3988 to 3396, i.e. by 592 HDD;
- increase in the number of cooling degree days (CDD) from 533 to 893, i.e. by 360 CDD.

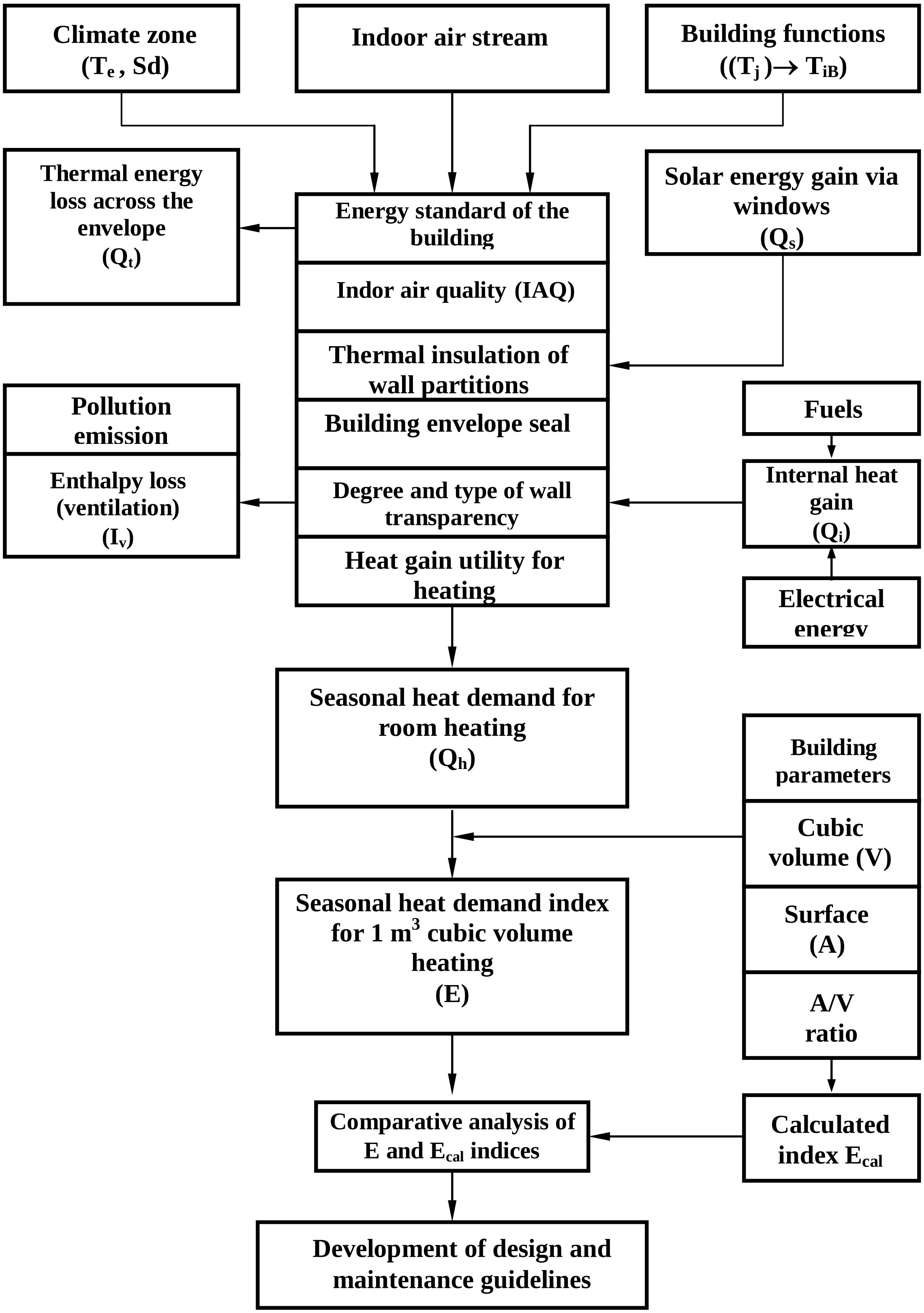

Figure 1. Energy balance for a commercial or residential building – a flow chart [5, 6]
Slika 1. Energetska bilanca za poslovne ili stambene zgrade - dijagram toka [5, 6]

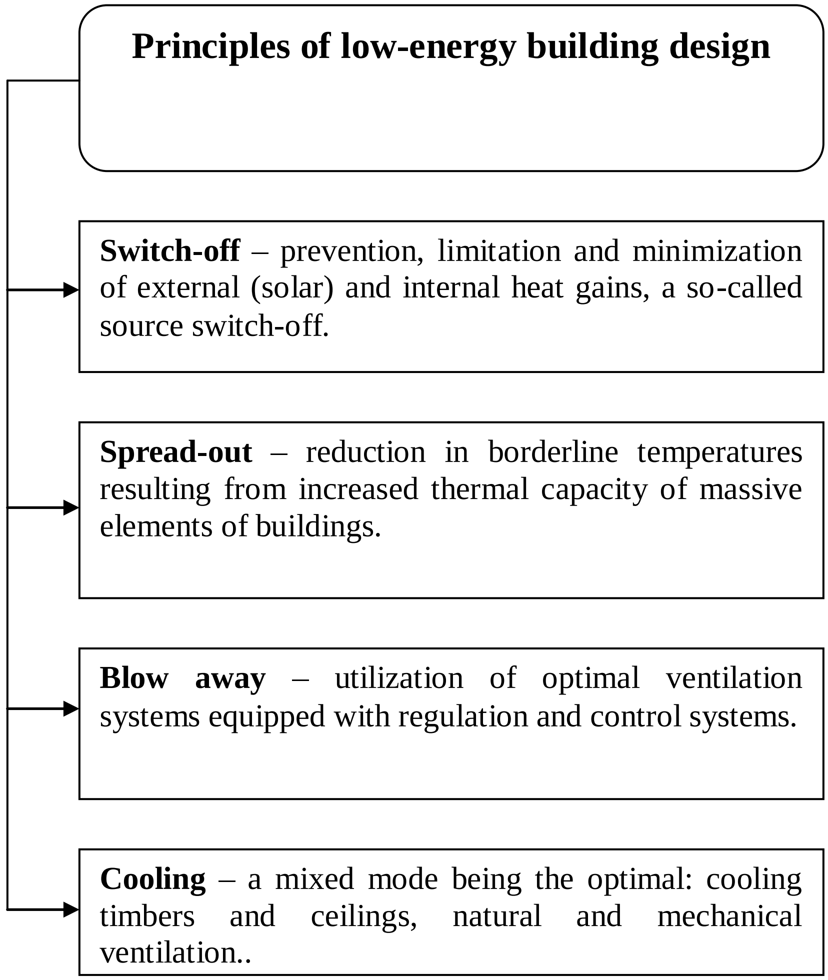

Figure 2. The principles of low-energy building design [7]
Slika 2. Načela gradnje niskoenergetskih zgrada [7]

Thus, although the number of degree days will decrease by Δ(HDD – CDD) = 232 and the demand for heating will decrease by approximately 17%, the demand for cooling will rise by about 40%, which results from the differences in the heat generation efficiency $\eta_o = 0.5 \div 0.85$ (depending on the fuel) and the cold generation efficiency $\eta_o = 0.25 \div 0.30$. Due to reduced demand, heat transport efficiency will decrease and the demand for electrical energy used for cold generation will rise, resulting in investments aimed at increasing the power plant capacity [8]. In Table 1, heating degree day values (HDD temperature index) according to the EUROSTAT method and cooling degree day values (CDD temperature index) according to the ASHRAE method for 30 selected European cities are presented (ECOFYS [9]). In order to compare total energies for individual cities, the sums of degree days, corrected by the Authors with the correction coefficient k = 2.5 that increases the cooling degree day values, were added to Table 1. The values of heating and cooling degree days show that except two cities (Palermo and Athens), the numbers of heating degree days are typically several times higher than the numbers of cooling degree days. Sample values of corrected degree day sums are as follows:

- the lowest for south-eastern Europe (below 2000 degree days for Porto, Santander and Lisbon)
- the highest for northern Europe (from 4318 for Stockholm to 4938 for Helsinki) and borderline for Ivalo (Finland) – 7008 degree days – only heating).

Mean values from 3000 to about 3500 regard such cities as London, Paris, Amsterdam, Split, Seville, Brussels, Zagreb, Vienna and Budapest while high values from about 3500 to approximately 4000 refer to Berlin, Prague, Copenhagen, Munich and Warsaw.

Table 1. Numbers of degree days in the aspect of energy consumption estimates in cities [9]
Tablica 1. Broj stupanj dana s obzirom na procijenjene potrošnje energije u gradovima [9]

No.	City	Country	HDD	CDD	∑ HDD + 2.5 CDD
1	Porto	Portugal	1247	147	1615
2	Santander	Spain	1428	167	1846
3	Lisbon	Portugal	846	410	1871
4	London	Great Britain	2800	58	2945
5	Paris	France	2702	114	2987
6	Amsterdam	The Netherlands	3039	27	3107
7	Split	Croatia	1486	663	3144
8	Seville	Spain	931	908	3201
9	Brussels	Belgium	3067	67	3235
10	Madrid	Spain	1860	596	3350
11	Zagreb	Croatia	2723	257	3366
12	Geneva	Switzerland	3000	156	3390
13	Vienna	Austria	2844	221	3397
14	Athens	Greece	876	1020	3426
15	Budapest	Hungary	2856	260	3506
16	Bratislava	Slovakia	3152	150	3527
17	Berlin	Germany	3296	102	3551
18	Prague	Czech Republic	3431	67	3599
19	Copenhagen	Denmark	3722	20	3772
20	Munich	Germany	3730	47	3848
21	Warsaw	Poland	3747	82	3952
22	Stockholm	Sweden	4210	43	4318
23	Vilnius	Lithuania	4339	50	4464
24	Riga	Latvia	4430	41	4524
25	Oslo	Norway	4714	9	4737
26	Tallinn	Estonia	4760	14	4795
27	Helsinki	Finland	4898	16	4938
28	Trondheim	Norway	5211	0	5211
29	Hammerfest	Norway	5954	0	5954
30	Ivalo	Finland	7008	0	7008

THERMAL CHARACTERISTICS OF BUILDINGS

Table 2 shows the building energy rating system according to the Association for Sustainable Development [10]. A widely accepted assessment criterion is the energy performance indicator which expresses yearly consumption of primary or final energy for one square metre of a building. It should be noted that the definition of an energy-efficient building is a definition that refers to its current technical level. Due to rapid development of new technologies, the current criteria may change several times during a building life cycle.

Therefore, energy-efficient activities should not concern the current standards but they should aim at achieving the lowest possible energy consumption that depends on utilization of the best available techniques (BAT), taking into account the valid indoor comfort standards and the economic efficiency of the enterprise.

Table 2. A building energy rating system [10]
Tablica 2. Ocjena učinkovitosti potrošnje toplinske energije u zgradama [10]

Energy class	**Thermal construction**	**Energy performance indicator** ***kWh m^{-2} $year^{-1}$***
A	Low-energy	20-45
B	Energy-efficient	45-80
C	Moderate energy-efficient	80-100
D	Moderate energy-consuming	100-150
E	Energy-consuming	150-250
F	High energy-consuming	>250

According to the European Environment Agency, the rates of individual energy consumption components with regard to buildings are as follows: heating – 69%, domestic water heating – 15%, lighting and power supply to electrical appliances – 11% and cooking – 5%.

In Poland, these rates slightly differ, i.e. they are estimated as follows: heating – about 71.2%, domestic water heating – about 15.3%, cooking – about 6.9%, lighting and power supply to electrical appliances – about 6.6%. Therefore, cost reduction programs focus primarily on reasonable energy consumption for flat and domestic water heating (thermal efficiency improvement as well as utilization of high-efficiency boilers, solar collectors, heat pumps etc.).

The life cycle of a building, i.e. its life in use, is often longer than 100 years. The costs of building maintenance are approximately 84% and the costs of its construction – about 11% of the total expenses [2].

Out of the heating season, in order to ensure thermal comfort at high external temperatures, rooms should be cooled. Technical and technological solutions used in the heating and ventilating systems of buildings directly and indirectly affect the amounts of pollution emissions, mainly carbon dioxide, into the environment.

The criteria of building selection for the energy efficiency analysis were relatively low energy consumption values, which means that their thermal characteristics should be comparable to a so-called "environmentally friendly house". These requirements are met by the following office and commercial facilities of the Euro-Centrum Science and Technology Park in Katowice: no. 6 – a conventional, modernized building and no. 7 – an energy-efficient building [11, 12]. In Table 3, technical and maintenance data of the energy-efficient building and the conventional, modernized building as well as their heating, ventilating and cooling systems are presented.

Table 3. Technical and maintenance data of the buildings [11, 12]
Tablica 3. Prostorne karakteristike i tehnički podaci za sustave grijanja, ventilacije i hlađenja u zgradama [11,12]

Parameter	**Conventional building**	**1.1.1.1.1.1 Energy-efficient building**
Function	Office and warehouse ground floor - warehouse	Office
Cubic volume V_{net}	4896 m^3	7910 m^3
Area –A	1290 m^2	2404 m^2
$D = A_{build}/V_{net}$	0.50 m^{-1}	0.43 m^{-1}
Thermal energy	Monovalent: externally delivered thermal energy – from Thermal Energy Company	Heat pump and thermal energy from TEC*
Heating system	Fan coils in rooms; heaters in staircases	BKT thermoactive ceilings and underfloor heating (UH)
Ventilation system	Mechanical supply-exhaust ventilation	Mechanical supply-exhaust ventilation
Cooling system	Chiller, fan coils	BKT ceilings
Heat recovery	Gold RX air handling unit: RECOnomic rotary heat exchanger, recirculation section	Gold RX air handling unit
Control system	IQnomic integrated control system	IQnomic Integrated Control System

* Thermal Energy Company

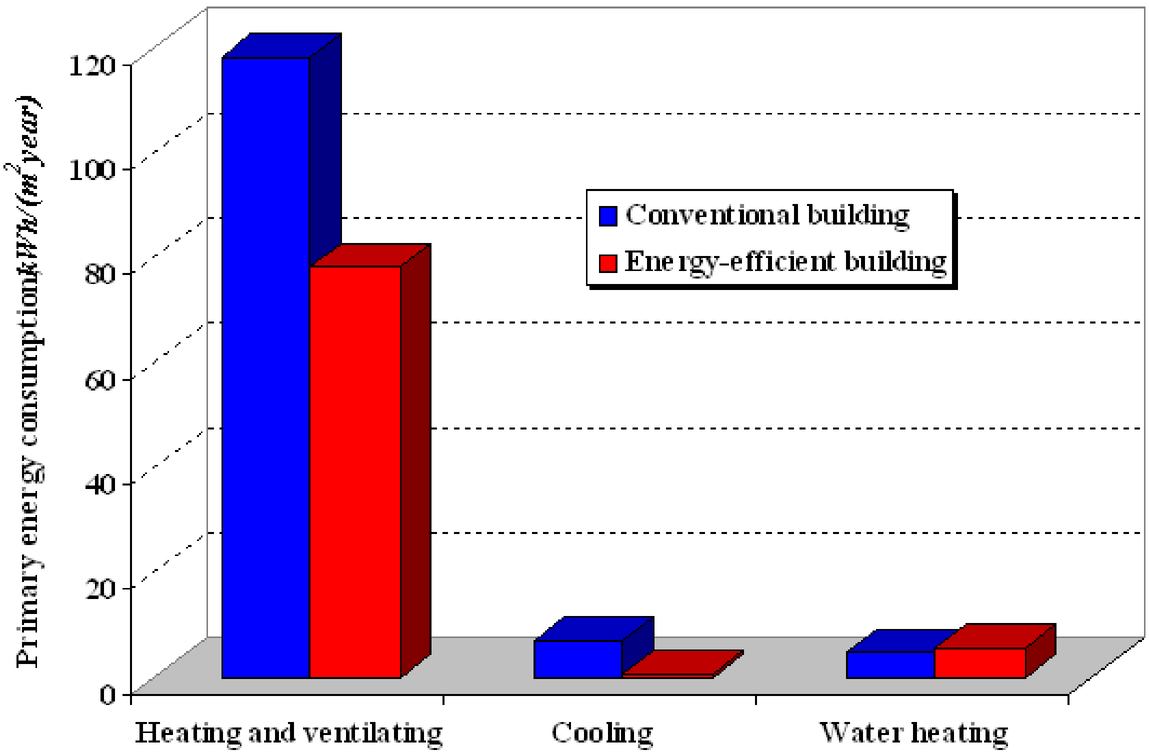

Figure 3. A comparison of primary energy consumptions in the analyzed buildings [6]
Slika 3. Usporedba potrošnje primarne energije u analiziranim zgradama [6]

In Fig. 3, primary energy consumption data for the conventional building and the energy-efficient building of the Euro-Centrum Science and Technology Park in Katowice are compared in terms of heating and ventilating, cooling and water heating [6].

In Table 4, primary energy savings in the systems of indoor environment design of an energy-efficient building compared to the conventional, modernized building are presented. In Table 5, energy demand indices are presented with regard to its intended use: heating and ventilating, cooling, domestic water heating, ancillary appliances and in-built lighting installation. The usable energy demand index (energy directly used for building maintenance) for the energy-efficient building was 36.87 kWh m^{-2} $year^{-1}$ – about 93% of it was the energy used for heating and ventilating, while for the conventional building, it was 62.76 kWh m^{-2} $year^{-1}$ – about 78% of it was designed for heating and ventilating. The final energy demand index (energy delivered to the building) for the energy-efficient building was 65.54 kWh m^{-2} $year^{-1}$ – about 45% of it was the energy designed for heating and ventilating while approximately 47% – for lighting.

Table 4. Primary energy savings in the systems of indoor environment design [6]
Tablica 4. Uštede primarne energije u sustavima grijanja, ventilacije i hlađenja u zgradama [6]

System	*1.1.1.1.2 Building characteristics*		Energy savings
	conventional	energy efficient	
Heating	Fan coils in rooms; heaters in staircases; externally delivered thermal energy (from Thermal Energy Company)	BKT externally delivered thermal energy (from Thermal Energy Company)	33.75 %
Ventilation	Mechanical supply-exhaust ventilation; air stream 3000 m_n^3 during day and 1000 m_n^3 at night	Mechanical supply-exhaust ventilation; air stream 5000 m_n^3 during day and 1000 m_n^3 at night; heat and cold recovery from exhausted air	
Cooling	Chiller, fan coils	BKT thermoactive ceilings with utilization of cold from water below 10°C; chiller as an alternative cold source	89.35 %

Table 5. Thermal characteristics of buildings
Tablica 5. Toplinski karakteristike zgrada

Energy use	1.1.1.1.2.1 Seasonal energy demand index	
	Energy-efficient building	Conventional building
	kWh m^{-2} year^{-1}	
Usable – heating and ventilating	34.51	48.87
Usable – cooling	0.69	12.47
Usable – domestic water heating	1.67	1.43
Usable – TOTAL	36.87	62.76
Final – heating and ventilating	29.98	60.55
Final – cooling	0.25	5.35
Final – domestic water heating	1.82	1.56
Final – ancillary appliances	2.78	2.64
Final – built-in lighting installation	30.71	30.71
Final – TOTAL	65.54	100.80
Primary – heating and ventilation	78.21	118.05
Primary – cooling	0.74	6.95
Primary – domestic water heating	5.45	4.67
Primary – ancillary appliances	8.34	1.85
Primary – built-in lighting installation	92.14	92.14
Primary – TOTAL	184.87	223.65
Primary – TOTAL – a new building according to WT 2008 [13]	242.41	238.61

SUMMARY

A comparison of the final energy demand indices for the energy-efficient and the conventional buildings (without the parameters of cooling, lighting and ancillary appliances) and the standard values is presented in Table 6. The index shows the final energy demand for heating, ventilating and domestic water heating in a building, being the basis for the energy performance assessment of the facility, its appliances and installations. The final energy demand index was compared to the base variant WT 2008, the maximal variant (MV) and the maximal technically possible to perform with mechanical ventilation and heat recovery variant (MTPVR) as well as to the building energy rating system (by the Association for Sustainable Development). The analysed energy-efficient building is classified as the maximal technically possible to perform with mechanical ventilation and heat recovery variant MTPVR and labelled the energy class "A". Its small final energy index confirms low energy demand and highly efficient usage. The conventional building is classified between the maximal (MV) and the WT 2008 variants, but it may be only labelled the energy class “B”.

Table 6. A comparison of the final energy for buildings and the standard values
Tablica 6. Usporedba ukupne energije za zgrade i standardne vrijednosti

Building	**Final energy**	**Energy class**	
	kWh m^{-2} year^{-1} (MJ m^{-2} year^{-1})	**A**	**B**
		kWh m^{-2} year^{-1} (MJ m^{-2} year^{-1})	
Energy-efficient building	31.80 (114.48)	20 – 45 (72 – 162)	45 – 80 (162 – 288)
Conventional building	62.11 (223.6)		
WT 2008 standard	95.09 (342.32)		
MV standard	50.37 (181.33)		
MTPVR standard	34.76 (125.36)		

A review of the EU directives and the modes of their implementation in other member states shows that reduction in the energy performance indicator value together with the environment protection and the principle of sustainable development are the essential goals. These elements are also implemented in Poland, which is seen in large scale thermal renovation programmes and energy certification of buildings. The proceeding changes can be traced in Table 7 through a comparison of the building thermal protection standards by means of the seasonal heat demand indices in selected highly developed EU countries.

Table 7. Building thermal protection standards in highly developed countries
Tablica 7. Norme toplinske zaštite zgrada u visoko razvijenim zemljama

Country	Period	Seasonal heat demand index, *MJ m^{-2} year^{-1}*
1.1.1.2 Austria [4]	Currently constructed buildings Planned	90 - 180 50 - 90
Denmark [5]	Currently constructed buildings	180
Germany [4]	Buildings since 1995 Planned	180 - 360 110 - 250
1.1.1.3 Poland [4, 6]	Buildings by 1967 Buildings of 1967–1985 Buildings of 1985–1992 Buildings after 1993 Buildings since 1998	860 - 1260 580 - 1040 580 - 720 430 - 580 320 - 430
Switzerland [4]	Energy-efficient building Currently constructed buildings	200 200 - 310
Sweden [5]	Currently constructed buildings	110 - 220

Based on the presented building thermal protection standards, the analyzed buildings can be assessed as follows:

- The conventional Euro-Centrum STP building with the final energy value of 223.6 m^{-2} year^{-1} can be compared to the upper limit of planned German buildings (250 m^{-2} year^{-1}) and currently constructed Swedish buildings (220 m^{-2} year^{-1}).
- The energy-efficient building of the Euro-Centrum Science and Technology Park in Katowice meets the most rigorous requirements of the German and Swedish standards, i.e. 114.48 and 110 MJ m^{-2} year^{-1}, respectively.

With regard to design projects of new buildings, highly energy-efficient solutions of heating, ventilating and cooling systems, utilized in the above-mentioned facilities of the Euro-Centrum Science and Technology Park in Katowice, should be considered.

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