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THE PRIMARY ENERGY FACTOR FOR THE URBAN HEATING SYSTEM WITH THE HEAT SOURCE WORKING IN ASSOCIATION

WSPÓŁCZYNNIK NAKŁADU NIEODNAWIALNEJ ENERGII PIERWOTNEJ DLA MIEJSKIEGO SYSTEMU CIEPŁOWNICZEGO ZE ŹRÓDŁEM CIEPŁA PRACUJĄCYM W SKOJARZENIU*

The paper explores the methodology for determining primary energy factor based on EU directives and domestic regulations The estimation of the above mentioned coefficient for a selected urban heating system was performed on the basis of real measurements obtained during the operation of a system and conveyed by the producers as well as heating distributor. The analysis was conducted for the several variants and extended over four years, that is from 2008 to 2011. The results achieved in the operating conditions were compared to the values obligatory to apply in calculations.

***Keywords**: primary energy, primary energy factor, final energy, cogeneraction, heating system, heat source.*

W artykule przedstawiono metodykę określania współczynnika nakładu nieodnawialnej energii pierwotnej w oparciu o dyrektywy UE oraz przepisy krajowe. Na podstawie rzeczywistych pomiarów uzyskanych podczas eksploatacji układu i przekazanych przez producentów i dystrybutora ciepła, przeprowadzono obliczenia w/w współczynnika dla wybranego miejskiego systemu ciepłowniczego. Analizę wykonano dla kilku wariantów i objęto nią okres czterech lat tj. od 2008 r. do 2011 r. Wyniki otrzymane w warunkach eksploatacyjnych zostały porównane z wartościami obowiązującymi do stosowania w obliczeniach.

***Słowa kluczowe**: energia pierwotna, współczynnik nakładu nieodnawialnej energii pierwotnej, energia końcowa, kogeneracja, system ciepłowniczy, źródło ciepła.*

1. Preface

The energy policy of many countries aims at reducing the energy consumption, and thereby, the CO_2 emission into the atmosphere. The generation of energy in cogeneration systems and the proper heating distribution to the final consumer play Dlatego vital part in such a case. Cogeneration is a technological process in which heat and electric energy are simultaneously generated, as opposed to the separate generation of electric energy in a typical condensation power plant and heat in a classic heating station. For this reason, currently, for centralised heating systems, primary energy factor is defined in order to generate and deliver the energy carrier or energy to the building ($\mathbf{w_i}$). The share of electric energy to heat buildings is reduced due to its high values $\mathbf{w_i}$ [1, 2, 3, 5, 6, 9, 10, 12, 13, 15, 17, 18]. The coefficient $\mathbf{w_i}$ is used to determine the annual computational index of the demand for nonrenewable primary energy to heat, ventilate, cool and prepare warm water (marked as EP). According to the domestic regulations, EP is one of the decisive parameters in meeting the requirements in terms of energy economy and maintaining its consumption at the rationally low for a building. The coefficient $\mathbf{w_i}$ determines the final result of calculations of energy characteristics of a building which is featured in the energy certificate. EP is expressed in kWh during the year per unit of room area of adjustable temperature [kWh/m^{2}year]. Its small values indicate low demand of a building for primary energy. The Ep value is defined on the basis of the demand of a buliding for usable and final energy. The quantity of usable energy is calculated at computational parameters as well as the so called standard edge conditions of external and internal environment. However, if final energy is calculated, the total efficiency of installation systems in which the building is equipped is taken into account. According to the EU and domestic directives, the computation of final energy into nonrenewable primary energy is performed by the expenditure coefficient of nonrenewable primary energy. In view of the above mentioned fact, the value of such a coefficient for heating system (w_H) has a decisive impact on EP index of a building, similarly to the expenditure coefficients of nonrenewable primary energy resulting from the use of energy carriers, such as coal, heating oil, natural gas, renewable energy or electric energy.

In accordance with the domestic regulations, the value of coefficient $\mathbf{w_i}$ should be assumed from [14] or calculated on the basis of information on a heating system. In this paper, the method of calculations and the obtained values of coefficient $\mathbf{w_i}$ as w_H (only for heating) for selected urban heating system are presented. The analysis was conducted for several variants on the basis of the real outcomes of measurements over the years 2008-2011 which were obtained in operating conditions from the producers and a heating distributor. The achieved final results were compared to the values contained in the current domestic regulations.

2. The Description of Urban Heating System (UHS)

Heat required by heating demands for the selected urban heating system is produced by the two sources (designated 'big' as A and 'small' as B) which produce electric energy as well as heat in cogeneraction, and in the case of the rise in the demand of heat, additionally, in the conventional way. The urban heating system is the main recipient of heat obtained from the above mentioned sources. It is only the small amount of heat that is sold directly by producents beyond this system. The diagrams of energy production in A source are presented in a fig.1, whereas in B source in a fig. 2. The distribution of heat is through low-parameter as well as high-parameter heat distribution network, individual network, and group network to four categories of

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

Table 1. The data typical of source A [4, 19]

Type of fuel	Parameter	2011 r.	2010 r.	2009 r.	2008 r.
Coal	Quantity [Mg]	21 181	47 391	20 904	20 845
	Calorific value [kJ/kg]	21 531	21 077	21 273	21 330
	Energy in fuel [GJ]	456 048	998 860	444 691	444 624
Natural gas	Quantity [tys. m^3]	272 166	248 451	227 427	230 216
	Calorific value [kJ/m^3]	36 132	36 116	36 099	36 217
	Energy in fuel [GJ]	9 833 902	8 973 056	8 209 887	8 337 733
Fuel oil (only for individual needs of a source)	Quantity [Mg]	152	219	17	32
	Calorific value [kJ/kg]	40 190	40 190	40 190	40 190
	Energy in fuel [GJ]	6 109	8 802	683	1 286
Total amount of energy in fuel [GJ]		10 296 059	9 980 718	8 655 261	8 783 643
Share of energy from fuel	Coal [%]	4,43	10,01	5,14	5,06
	Natural gas [%]	95,51%	89,90	94,85	94,92
	Fuel oil [%]	0,06	0,09	0,01	0,01
Electric energy production					
Sale of energy [GJ]		4 435 866	4 051 645	3 728 981	3 816 270
Individual needs [GJ]		44 557	56 210	23 382	37 246
Total amount of energy [GJ]		4 480 423	4 107 856	3 752 363	3 853 516
Share of sale [%]		99,0	98,6	99,4	99,0
Share of individual needs [%]		1,0	1,4	0,6	1,0

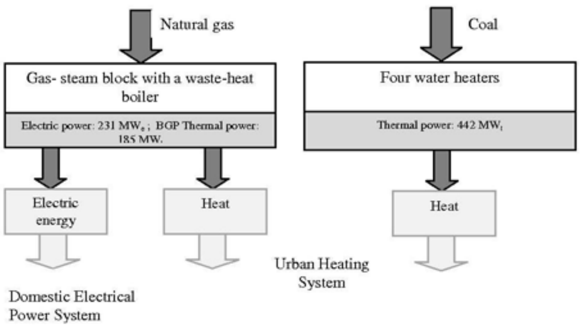

Fig. 1. The diagram of energy generation in source A.

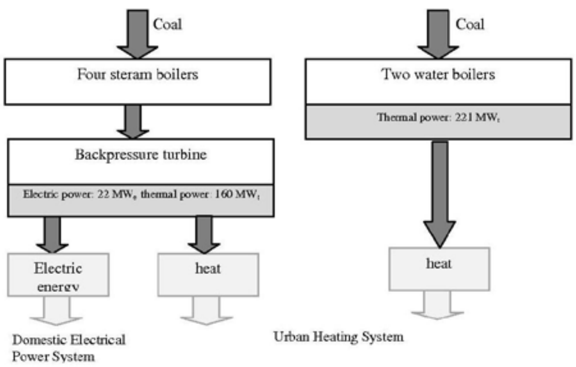

Fig. 2. The diagram of energy generation in source B.

recipients. The area of supply is divided into three spheres, such as supply only through A source, or only through B source, and through the third sphere, common for the both sources. In 2011 the participation of source A in the total sale of heat to the heat system was 68,1%, whereas source B 31,9% [4, 11, 19].The data typical of source A is presented in table 1, data concerning source B is shown in table 2, whereas data referring to heat consumption from both sources over the years 2008–2011 is in table 3.

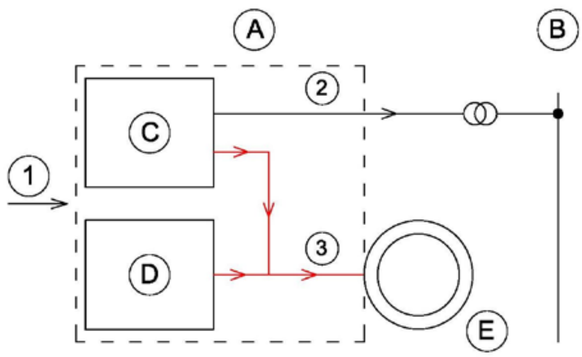

Fig. 3. A diagram illustrating the method of balancing energy in the existing system: A – heat and electric energy source; B – electro-energetic network; C – the production of electric energy and heat in association; D – the production of heat; E- heating consumers; 1 – energy supplied in fuel; 2 – electric energy (sold and the individual needs of source); 3 – heat supplied to the consumer [7]

Table 2. The data typical of source B [4, 19]

Type of fuel	Parameter	2011 r.	2010 r.	2009 r.	2008 r.
Coal	Amount [Mg]	115 030	124 914	121 185	124 543
	Calorific value [kJ/kg]	20 351	20 796	21 364	20 935
	Energy in fuel [GJ]	2 340 967	2 597 718	2 588 991	2 607 300
Natural gas (only for individual needs of a source)	Amount [tys. m^3]	20,6	16,9	17,8	34,3
	Calorific value [kJ/m^3]	36 742	36 585	36 423	36 093
	Energy in fuel [GJ]	756	617	647	1 237
Total amount of energy in fuel [GJ]		2 341 723	2 598 335	2 589 638	2 608 538
The participation of energy from fuel	Coal [%]	99,97	99,98	99,97	99,95
	Natural gas [%]	0,03	0,02	0,03	0,05
The production of electric energy					
Sale of energy [GJ]		250 234	269 447	257 824	264 885
Individual needs [GJ]		49 962	52 098	51 556	58 237
The amount of energy in total[GJ]		300 196	321 545	309 380	323 122
Share of sale [%]		83,4	83,8	83,3	82,0
Individual needs share [%]		16,6	16,2	16,7	18,0

Table 3. Heat collection from sources A and B [4, 19]

Recipient	2011 r.	2010 r.	2009 r.	2008 r.
Urban Heating System (UHS) [GJ]	3 980 836	4 402 986	4 064 271	4 038 320
Source A[GJ] *)	172	196	191	189
Source B [GJ] *)	55 936	84 113	74 858	67 160
The amount of heat in total [GJ]	4 036 944	4 487 295	4 139 320	4 105 669
The participation of UHS [%]	98,610	98,121	98,187	98,360
The participation of source A [%] *)	0,004	0,004	0,005	0,005
The participation of source B [%] *)	1,386	1,874	1,808	1,636
***)recipients of heat outside UHS**				

3. The Methodology for Determining Coefficient w_H

On the basis of [7, 8] as well as domestic assumptions in line with [14], presented in table 4, information obtained from the producents and distributor of heat, the dependence (1) is used in order to determine w_H for the urban heating system, assuming the production of electric and heat energy in association, according to the diagram shown in fig.3.

$$w_H = \frac{\sum_i Q_{P,i} \cdot w_i - \sum_j E_{EC,j} \cdot w_{el}}{\sum_k Q_{OD,k}} \tag{1}$$

where:

w_H – the expenditure coeffcient of nonrenewable primary energy for the selected Urban heating system,

w_i – primary energy factor for i-th fuel assumed in accordance with the domestic principles presented in [14],

w_{el} – expenditure coefficient of nonrenewable primary energy for electric energy,

$Q_{P,i}$ – energy supplied in i-th fuel,

$E_{EC,j}$ – electric energy produced in j-tym energy source, used in a source and added to the domestic electro-energetic system,

$Q_{OD,k}$ – heat supplied by urban heating system to the k-th recipient.

4. The Results of Calculations

Calculations w_H were conducted by three methods and denoted as variants W1, W2 and W3 working on the following assumptions for every computational method:

W1 – according to the principles contained in the domestic regulations [14] when w_{el} = 3,0

W2 – it is assumed that source A is a condensed power station and is characterised by eigenvalue $w_{el\ A\ source}$, whereas for source B it is assumed w_{el} = 3,0 (on account of the lack of full information), average index w^*_{el} is determined as weighted mean in relation to electric energy produced in particular sources.

W3A – according to the principles contained in UE directives, that is assuming w_{el} = 2,5 [7],

W3B – according to the principles contained in UE directives, that is assuming w_{el} = 2,8 [8]

The values of primary energy, defined according to the current domestic regulations, and heat (with the assumptions as for variant W1) are presented in Fig. 4; whereas the relations between primary energy contained in natural gas and the final electric energy for heating source A, whose characteristics determines the value w_H, are shown in Fig. 5. The values of expenditure coefficient of electric energy on the assumptions as for variant W2 are presented in Fig. 6. The results of computations w_H for particular variants are provided in Table 5.

Table 4. Primary energy factor in line with [14]

No	Final energy carrier		Expenditure coefficient w_i
1	Fuel / Energy source	Heating oil	1,1
2		Natural gas	1,1
3		Liquid gas	1,1
4		Hard coal	1,1
5		Brown coal	1,1
6		Biomass	0,2
7		Thermal solar energy collector	0,0
8	Heat from cogeneration [1)]	Hard coal,,Natural gas [3)]	0,8
9		Renewable energy (biogas, biomass)	0,15
10	Local heating systems	Heat from coal heating station	1,3
11		Heat from gas/oil heating station	1,2
12		Heat from biomass Heating station	0,2
13	Electric energy	Mixed production [2)]	3,0
14		PV systems [4)]	0,7

[1)] associated production of electric energy and heat,
[2)] concerns supplying from systemic electro-energetic network,
[3)] in case of lack of information on calorific parameters of network heat from heat and power station (cogeneration), it is assumed that w_H = 1,2,
[4)] photovoltaic cells (the production of electric energy from solar energy)
comment: thermal solar collector – w_H = 0,0

Table 5. Expenditure coefficients of the consumption of nonrenewable primary energy (wH) for particular variants [4, 19]

The coefficient of the consumption of non-renewable primary energy	2011	2010	2009	2008
variant **W1**	-0,1091*	0,1223	0,0445	0,0004
variant **W2**	0,5457	0,6716	0,5793	0,5823
variant **W3A**	0,4830	0,6158	0,5351	0,5090
variant **W3B**	0,1278	0,3197	0,2407	0,2038

****) in line with [2], in the case of negative values wH,, a value amounting to 0 must be assumed***

Table 6. The share of production of electric energy to total energy generated in a source [4, 19]

	2011	2010	2009	2008
The production of heat in a source A - Q_{coA} [GJ]	3 103 499	3 369 995	2 964 692	2 932 408
The production of heat in a source B - Q_{coB} [GJ]	1 455 690	1 671 277	1 700 692	1 679 791
The production of electric energy in a source A - Q_{elA} [GJ]	4 480 423	4 107 856	3 752 363	3 853 516
The production of electric energy in a source B - Q_{elB}[GJ]	300 196	321 545	309 380	323 122
Index φ_{elA}	0,591	0,549	0,559	0,568
Index φ_{elB}	0,166	0,155	0,148	0,156

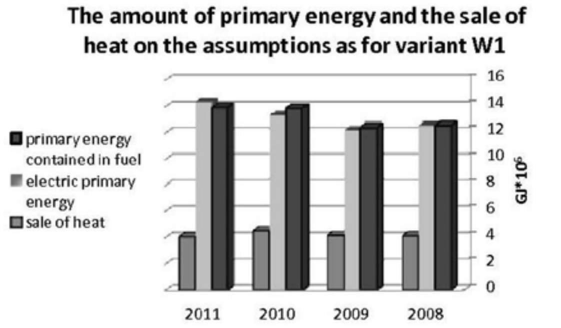

Fig. 4. The amount of primary energy contained in fuel, electric primary energy and the sale of heat on the assumptions as for variant W1

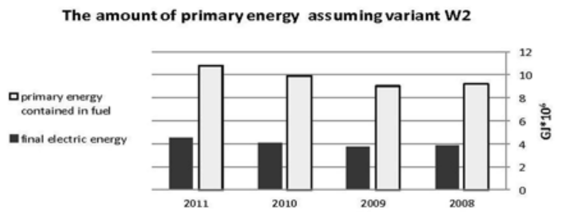

Fig. 5. The amount of primary energy contained in fuel and final electric energy assuming variant W2

In order to provide a full characteristic of heating system for both heat sources, the share of the production of electric energy, in relation to total energy generated in a given heat source according to dependence (2), is assumed. (computational results are shown in table 6).

$$f_{el} = \frac{Q_{el}}{Q_{el} + Q_{co}} \tag{2}$$

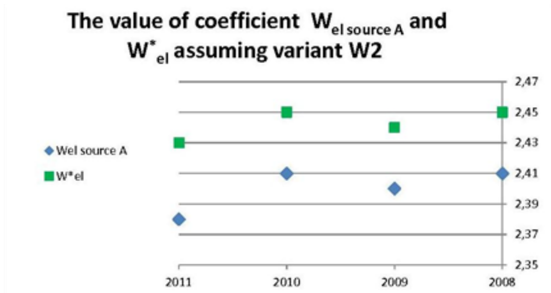

Fig. 6. The value of coefficient W_{el} source A and W^*_{el} assuming variant W2

5. Summary

Values w_H for particular computational variants, provided in tables 5, differ substantially due to the fact that value w_{el} is assumed to computations according to the dependence (1). After the analysis on the data obtained on the basis of the measurements of operating system and the achieved results, the best solution while calculating w_H for a heating system is to assume the expenditure coefficient of nonrenewable primary energy for the energy generation, typical of a given system ($w_{el\ source}$ or w^*_{el}). Such a coefficient is dependent upon the structure of heat and electric energy generation in a source as well as upon the conditions prevailing in a system during its operation. Thus it is justified to determine the actual value of coefficient for the electric energy, in contrast to assuming the value $w_{el} = 3$ (according to domestic regulations) in no respect of specificity of heating source operation. Thus in such a case, w_H assumes a negative value. As calculations show, the analysed urban heating system supplied by associated sources, value w^*_{el} altered insignificantly from 2,43 to 2,45 during the four-year research. Making use of the real value of coefficient w^*_{el} , one obtains a coefficient w_H for the system in 2011 at the level of 0,5457, which means that it is considerably lower than values in tables for the conventional energy carriers as well as value $w_H = 0{,}8$ contained in [14] for heat from cogeneration at natural gas and coal combustion.

According to the widely accessible information, it appears that in different cities in the country in heating systems, supplied by the power and heat stations producing energy from cogeneration, primary energy factor is within $0{,}47 \div 0{,}80$.Therefore, assuming $w_{el} = 3$ which is recommended in the domestic regulations, is unjustified.

The value w_{el} should be lowered after collecting data from the sources producing energy in cogeneration in the whole country. Assuming the values $w_{el} = 2{,}8$ or $w_{el} = 2{,}5$, at the same structure of energy production, w_H is always positive and close to the values obtained in the sample computations in UE directives.

In 2011, heat energy, supplied by the analysed heating system, was at about 85% from the energy produced in cogeneration, which consequently, allowed for obtaining a very low w_H coefficient. For this reason, in accordance with ecological requirements as well as demands on nonrenewable primary energy, such a heating system is rated as the most appropriate source of building supply, located in the area of heat energy supply.

Bibliography

1. Balaras C, Droutsa K, Dascalaki E, Kontoyiannidis S. Heating energy consumption and resulting environmental impact of European apartment buildings. Energy and Buildings 2005; 37: 429–442.
2. Climent F, Pardo A. Decoupling factors on the energy–output linkage: The Spanish case. Energy Policy 2007; 35: 522–528.
3. Cursino dos Santos AH, Werneck Fagá MT, Moutinho dos Santos E. The risks of an energy efficiency policy for buildings based solely on the consumption evaluation of final energy Electrical Power and Energy Systems 2013; 44: 70–77.
4. Data concerning the types, parameters and amounts of fuel consumption, as well as the generation and sale of electric and heat energy obtained by a producer and heating distributor over the years 2008-2011.
5. Georges L, Massart C, Van Moeseke G, De Herde A. Environmental and economic performance of heating systems for energy-efficient dwellings: Case of passive and low-energy single-family houses. Energy Policy 2013; 40: 452–464.
6. Hassine I, Eicker U. Impact of load structure variation and solar thermal energy integration on an existing district heating network. Applied Thermal Engineering 2013; 50: 1437–1446.
7. Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 2.2.5. Space heating generation systems, the performance of quality district heating and large volume system CEN/TC 228 WI 00228 027, 2004–12.
8. Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 4-5 Space heating generation systems, the performance and quality of district heating and large volume system CEN/TC 228 WI 027, 2006-08, prEN 15316-4-5: 2006 (E).
9. Howarda B, Parshallb L, Thompsonc J, Hammerb S, Dickinsond J, Modi V. Spatial distribution of urban building energy consumption by end use. Energy and Buildings 2012;45:141–151.
10. Johansson P, Nylander A, Johnsson F. Primary energy use for heating in the Swedish building sector—Current trends and proposed target. Energy Policy 2007; 35:1386–1404.
11. Cogeneration as a main part in the environment protection- the realisation of improvement policy of energetic efficiency by the producers and distributors of energy in Lublin District, on the basis of Lublin. Lublin Energy Company, Polish Energy Group Górnictwo and Conventional Energy S.A. branch in Lublin Wrotków, Megatem EC – Lublin LLC. conference: ECOFORUM Lublin: 09. 2011.
12. Landweher M, Jochem E. From primary to final energy consumption-Analysing structural and efficiency changes on the energy supply side. Energy Policy 1997; Vol.25: 697–702.
13. Loncar D, I. Ridjan I. Medium term development prospects of cogeneration district heating systems in transition country - Croatian case. Energy 2012; 48: 32–39.
14. The resolution of Ministry of Infrastructure from 6.11.2008 in the case of the methodology for the computations of energy characteristics of a building and flat or the part of a building as the separate technical-usable whole as well as the way of preparing a certificate of energy characteristics. (Dz.U. nr 201/2008 r., poz. 1240).
15. ShimodaY, Nagota T, Isayama N, Mizuno M. Verification of energy efficiency of district heating and cooling system by simulation considering design and operation parameters Building and Environment 2003; 43: 569–577.
16. The expenditure coefficient w_H of nonrenewable primary energy for heat distributed by Energy Company in Siedlce LLC Siedlce: 0.1. 2010.
17. Verda V, Colella F. Primary energy savings through thermal storage in district heating networks. Energy 2011; 36: 4278–4286.
18. Zhi-Ping S. Total energy system analysis of heating. Energy 2000; 25: 807–822.
19. Życzyńska A, Surmacz P, Dyś G. The estimation of the index of primary energy expenditure for Lublin heating system as well as the amount of heat in urban heating system generated in cogeneration. Fundacja Rozwoju Politechniki Lubelskiej; Lublin: 03. 2012.

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