SSP - JOURNAL OF CIVIL ENGINEERING Vol. 7, Issue 1, 2012

DOI: 10.2478/v10299-012-0020-3

Energetic and Ecological Analysis of Energy Saving and Passive Houses

Myroslav Sanytsky, Robert Sekret, Mariusz Wojcikiewicz

Lviv Polytechnic National University, Ukraine
Czestochowa University of Technology, Poland
E-mail: msanytsky@ukr.net, rsekret@is.pcz.czest.pl, tajm@tajm.cze.pl

Abstract

In this paper results of influence of building-installation system parameters on value of energetic coefficients were calculated. Three types of buildings (standard, energy saving and low energy) with heating surface of 100, 150 i 200 m^2 were used. The above types of buildings differ on thermal barrier and heating system efficiency. The influence of the gravity and mechanical ventilation systems on the final heat energy of different kinds of houses was shown. Parameters of the certificate for energy characteristics of building were used. Mathematics models of influence of thermal barrier parameters and heating surface on the value of energy characteristics, namely final energy EF, primary energy EP and useful energy EU were established. Influence of such parameters as heating energy factors, ventilation system and energy sources on the energy efficiency improvement of buildings was analyzed. The building environmental assessment system was proposed on the base of energetic and ecological analysis of houses.

Key words: energetic and ecological characteristics, building-installation system, heating energetic factors, energy sources

1 Introduction

In order to reduce of energy consumption till the year 2020 European Union implements more rigid standards of energy-efficiency in building. The usage of quantified indicators of energetic-ecological view is the base of estimation of conformity for the building with rules of balanced development. Energy saving is required not only as economical need, but also as an important political demand giving energy safety and ecological standards, like limited CO_2 emission. The 2006/32/WE directive concerning the efficiency of the final energy consists balanced development which means creating the conditions to step by step elimination of the natural environment and human harmful processes and promotion of ecological behavior. The new direction of building, analyzing the influence of an object on natural environment during the whole period of usage of the building (harmonized building) has been formed on the base of the newest EU directives and changes in the directive for energy-characterization of buildings. In this case there is a new point of view for buildings, including on this stage of exploitation of the object basing on known methodology of energetic-ecological characteristics of building object in order to obtain optimal project solutions minding their influence on natural environment [1].

2 Test programme

Diminution of energy usage of buildings is strictly connected with thermal insulating of external partitions and usage of modern technologies of building-installation systems what brought to implement energy saving buildings characterized by rather low energy demand (low energy and passive buildings) [2]. The environmental analysis of various buildings gives the advantage of energy demand reduction and unification in one project and further realization of energy-saving architectonical solutions for building installation system [3, 4, 5].

In order to implement the analysis 3 kinds of model buildings have been established: a standard one, energy saving and a low energy building. In all types three possibilities of buildings with heating surface of 100, 150, and 200 m^2 have been considered. The analysed buildings vary in external partition parameters (walls). All of them are bungalows with identical windows, external door surfaces and occupied by 4 persons. All characteristics data are presented in Table 1.

Table 1: Heat transmission rate U for external building's partitions

Building type	External partition, W/ ($m^{2\cdot}$ K)	Windows, W/ ($m^{2\cdot}$ K)	Doors, W/ ($m^{2\cdot}$ K)	Roof, W/ ($m^{2\cdot}$ K)
Standard building, BS	0,3	2,6	2,6	0,25
Energy saving building BE	0,2	1,8	1,8	0,18
Low energy building, BL	0,1	1,0	1,0	0,11

In each of considered buildings, in following categories, a black coal heating boiler system as heating source has been considered. The composition of heating system and hot water efficiency are presented in the Table 2. Two possibilities of ventilation, a gravitation and mechanical with 90% heating recuperation, have been taken into consideration. For mechanical ventilation of the buildings multiplication of air change equal one has been established, what is equal to the following ventilation air streams: 300, 450 and 600 m^3/h. In order to obtain the indicators of energy characteristics used for building installation systems, the methodology of energy certification of buildings established by the Ministry of Infrastructure from 6th November 2008 (Methodology of energy characteristic of building and a flat or a part of a building being a separate unity and the way of preparation energy certification and their energy characteristics) has been used [6].

Non-renewable energy demand for primary energy as well as final and useful energy have been calculated. Useful energy (EU) includes: heat energy losses through partitions, energy needed for hot water heating, ventilation air warming and for mechanical ventilation usage. Final energy (EF), takes into account additionally heating system efficiency and warm water preparation and defines the energy amount required every year for heating (including ventilation), warm water preparation for 1 m² of surface and in buildings with air conditioning - for cooling as well. Primary energy, contrary to final energy, includes losses on energy production and transmission. Non-renewable primary energy demand (EP) shows, most of all, the influence of the building on the environment. It is the amount which expresses how much energy has to be taken from the source of energy in order to cover heating energy needs, warm water preparation, optional mechanical ventilation, cooling (in case of air conditioning) and for the work of generators [6].

Parameters of low energy and passive building partitions are nearly equal but renewable energy is more in use in passive house. The passive building standards consist of the values such as energetic and warm demand factor used for heating not higher than 15 kWh/($m^2\cdot$ year), primary energy demand factor EP for all usage requirements not higher than 120 kWh/($m^2\cdot$ year) [7].

Table 2: Heating system and warm water installation efficiency for buildings

Installation type	Generator's efficiency	Acumulation's efficiency	Distribution's efficiency	Regulation and utilization efficiency	Overall efficiency
Black coal boiler	0,82	1,00	0,94	0,98	0,76

3 Results and discussion

The results of calculation for energetic factors like primary energy EP, final energy EF [kWh/($m^2\cdot$year)], yearly useful and final energy requirement Q_U and Q_F [kWh/year] and pollution emission [kg/year] for natural environment for buildings with gravitation and mechanical ventilation has been presented in Table 3 and 4.

Table 3: Energetic-ecological rates for gravitation ventilation of buildings

Building type		Energetic rates				Ecological rates, kg/year					
		EP, kWh/(m^2year)	EF, kWh/(m^2year)	Q_U, kWh/year	Q_F, kWh/year	CO_2,	CO,	SO_2,	NO_X,	Dust ,	Soot ,
Standard	100 m^2	278	232	16258	23180	6791	136,0	758,9	4,8	32,8	1,1
	150 m^2	218	177	18857	26621	8070	156,4	1118,0	6,1	38,0	1,2
	200 m^2	183	146	20794	29185	9121	171,6	1474,9	7,3	42,1	1,3

Energy saving	100 m^2	239	196	13571	19623	5867	115,2	750,0	4,3	27,9	0,9
	150 m^2	188	150	15766	22529	7007	132,5	1107,8	5,6	32,5	1,0
	200 m^2	159	124	17450	24758	7971	145,8	1463,9	6,8	36,1	1,1
Low energy	100 m^2	202	163	11079	16325	5011	95,9	741,8	3,9	23,4	0,7
	150 m^2	159	124	12745	18530	5969	109,1	1097,8	5,1	27,0	0,8
	200 m^2	136	103	14330	20628	6899	121,6	1453,6	6,2	30,4	0,9

Table 4: Energetic-ecological rates for mechanical ventilation of buildings

Building type		Energetic rates				Ecological rates, kg/year					
		EP, kWh/(m^{2}year)	EF, kWh/(m^{2}year)	Q_U, kWh/year	Q_F, kWh/year	CO_2,	CO,	SO_2,	NO_X,	Dust,	Soot,
Standard	100 m^2	150	116	7486	11567	3774,9	68,1	729,9	3,3	16,9	0,5
	150 m^2	97	67	6369	10090	3776,3	59,8	1076,8	4,0	15,5	0,5
	200 m^2	69	42	5105	8416	3726,9	50,2	1423,1	4,6	13,8	0,4
Energy-saving	100 m^2	119	87	5316	8695	3028,8	51,3	722,7	2,9	13,0	0,4
	150 m^2	77	49	4258	7295	3050,4	43,4	1069,8	3,6	11,7	0,3
	200 m^2	56	30	3293	6018	3103,8	36,2	1417,1	4,3	10,5	0,3
Low-energy	100 m^2	94	64	3603	6428	2440,0	38,1	717,1	2,6	9,9	0,3
	150 m^2	61	35	2689	5218	2510,9	31,3	1064,6	3,3	8,8	0,2
	200 m^2	50	24	2409	4847	1959,6	28,8	649,8	2,2	7,7	0,2

For influence of external partitions analysis of various buildings and their surface for energetic factors experimental-statistics method has been implemented. That gives the possibility to obtain mathematic description of coherence between energetic factors Y with the regression equation:

$$\text{У}=\text{в}_0 + \text{в}_1X_1 + \text{в}_2X_2 + \text{в}_{12}X_1X_2 + \text{в}_{11}X_1^2 + \text{в}_{22}X_2^2 \qquad (1)$$

where: X_1, X_2 - various factor's meaning.

Following the schedule of 2 factors, 3 levels experiment following data has been established: the coefficient of the heat transfer U for external partitions of a standard, energy saving and low energy building (X_1 according to Table 1) and the heating surface (X_2 = 100; 150; 200 m^2).

Basing on the results of these calculations (Table 3, 4) a mathematical models of the influence of external partitions of these types of buildings as well as heating surface on the value of primary energy EP [kWh/(m^2·year)] for gravitation and mechanical ventilation has been obtained (fuel – black coal):

$$EP_{grav} = 187{,}97 + 30{,}28\,X_1 - 40{,}05\,X_2 - 7{,}10\,X_1X_2 + 0{,}85X_1^2 + 11{,}35\,X_2^2, \qquad (2)$$

$$EP_{mech} = 76{,}28 + 18{,}65\,X_1 - 31{,}26\,X_2 - 9{,}22\,X_1X_2 + 3{,}12\,X_1^2 + 11{,}36\,X_2^2. \qquad (3)$$

For the buildings with gravitation ventilation type the value of the primary energy Y_{max} = 277,60 is obtained for the standard building of 100 m^2 and Y_{min} = 136,93, for the low energy building of 200 m^2 the relations between them is 2,02. For the mechanical ventilation building the value of the primary energy Y_{max} is 149,88. It's for a standard building of 100 m^2 and Y_{min}= 50.06 – for the low energy building of 200 m^2, what indicated a relation between them 2,99. The relation between EP_{max} and EP_{min} (Y_{max} = 277,60 and Y_{min} = 50,06) is 5,5. A graphic analysis of the influence of the factors on the value of primary energy EP for gravitation and mechanical ventilation (fuel – black coal) represents the Fig.1.

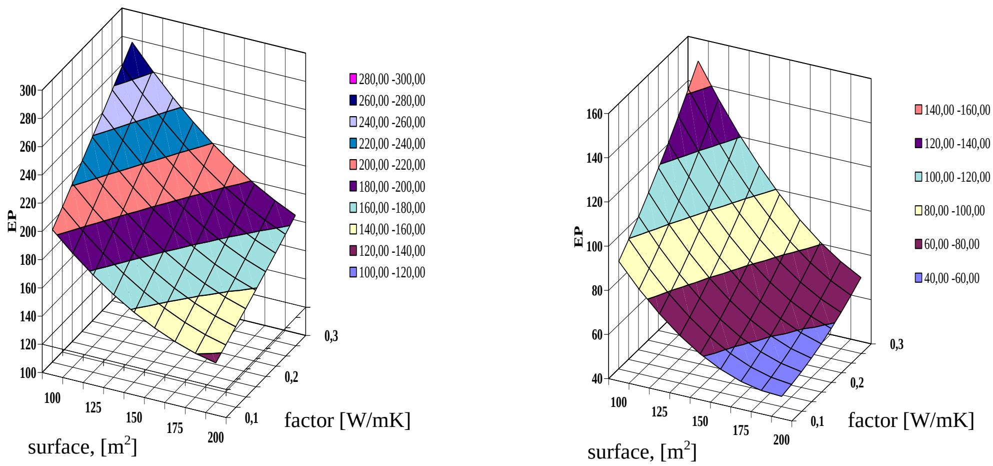


Figure 1: Primary energy factor EP [kWh/m^2·year] depending on external partition parameters and heating surface for gravitation (a) and mechanical (b) ventilation system

An important factor in the energy balance is yearly final energy requirement Q_F [kWh/year]:

$$Q_F = Q_{F,H} + Q_{F,W}\,, \tag{4}$$

where:
$Q_{F,H}$ - annual final energy demand for the heating and ventilation system,
$Q_{F,W}$ - annual final energy demand by hot water installation system.

Basing on data from energetic factors (Table 3, 4) calculations final energy Q_F for gravitation and mechanical ventilation has been obtained:

$$Q_{F\ grav} = 22487{,}85 + 3917{,}19X_1 + 2573{,}90X_2 + 425{,}36\,X_1X_2 + 108{,}09X_1^2 - 276{,}71X_2^2, \tag{5}$$

$$Q_{F\ mech} = 7250{,}69 + 2263{,}53X_1 - 1234{,}96X_2 - 392{,}43X_1X_2 + 425{,}21X_1^2 + 127{,}61X_2^2. \tag{6}$$

Yearly final energy demand from the heating and ventilation system for gravitation ventilation buildings Q_F [kWh/year]: Y_{max}=29235,68; Y_{min}= 16253,50, and for mechanical ventilation Q_F [kWh/year]: Y_{max}=6827,44; Y_{min}= -152,22. Negative Q_F means possibility of excessive energy in low energy building of 200 m^2.

Basing on yearly demand for final energy Q_F depending on heating surface for various types of buildings with gravitation and mechanical ventilation has been defined that linear increase Q_F from heating surface for gravitation ventilation, for low energy building within starting from 16300 kWh/year (A=100 m^2) to 20600 kWh/year (A=200 m^2). Increase Q_F factor from heating suface for gravitation ventilation is +43 kWh/(m^2·year). For mechanical ventilation with the increase of heating surface from 100 to 200 m^2 means decrease the value of Q_F, including low energy house from 6400 kWh/year to 4700 kWh/year. Decrease Q_F factor equals –17 kWh/(m^2·year).

With increasing parameters of external partitions for analysed buildings starting from a standard building to low energy decrease of heating demand for gravitation ventilation will follow: ΔQ_F = 6860-8550 kWh/year and for mechanical ventilation ΔQ_F =3570-5140 kWh/year. Ventilation type has a significant influence: for a standard building of 100 to 200 m^2 ΔQ_F = 11660….20760 kWh/year and for low energy building ΔQ_F =9890…15780 kWh/year respectively.

For a standard building of A=100 m^2 with mechanical ventilation the value of yearly final energy Q_{FH}= 6827,44 kWh/year; Q_{FW} = 4846,53 kWh/year and for yearly primary energy Q_{PH}=8628,95 kWh/year; Q_{PW}= 6382,39 kWh/year. For low energy building of 200 m^2 minimum yearly demand for final energy by heating and ventilation system is Q_{FH} = -152,22 kWh/year. Negative result means energetic self sufficiency of such low energy building. Such low energy building with mechanical ventilation has the parameters of the passive house.

EP value depends enormously on what is the heating source. Energy demand factor EP and EF for a standard building with mechanical ventilation and heating surface of 150 m^2 has been shown on Fig. 2. First of all, it makes evident building natural environment influence. The value of primary energy comes from multiplication of final energy by the unrenewable primary energy factor required to create and supply the energy to the building.

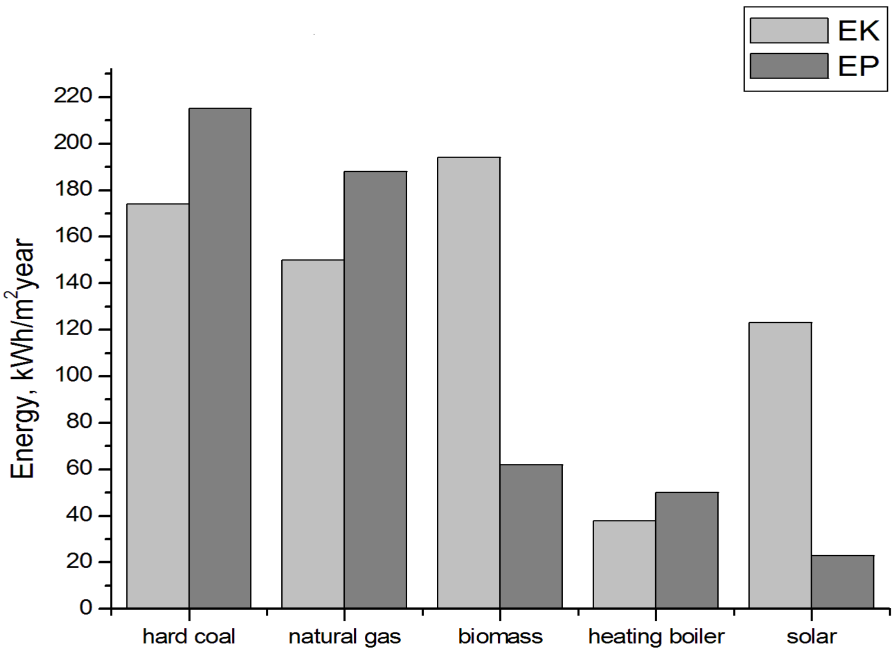
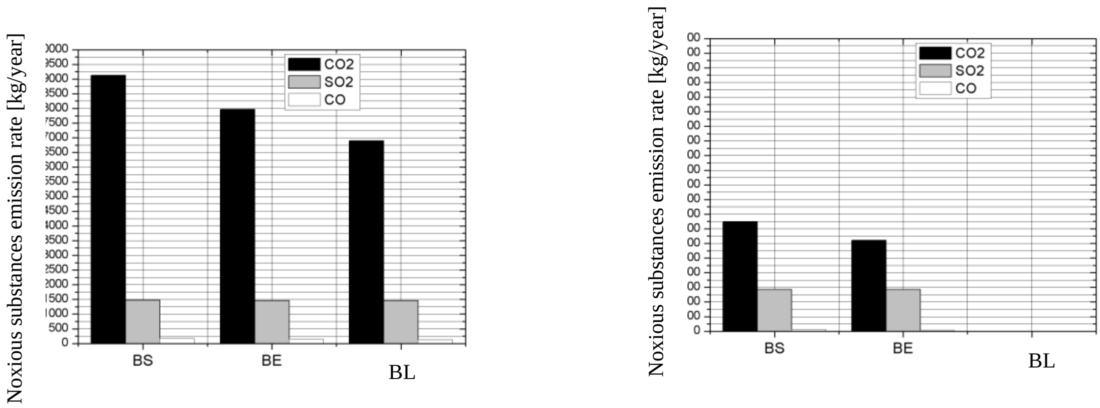


Figure 2: Fuel type influence on the results for primary and final energy calculations for a standard building of A=150 m^2 with mechanical ventilation

Energy characteristics of the building defines the amount of primary energy [kWh/(m^2·year)], necessary to fulfill various needs connected to building exploitation. As shown on the Table 3 and 4, for low energy building of U=0,10 W/(m^2·K) and of 100 and 200 m^2 for gravitation ventilation EP is 202,7 and 136,6 kWh/(m^2·year) respectively and for mechanical ventilation – 93,8 and 49,8 kWh/(m^2·year) respectively. For mechanical ventilation and renewable fuels (biomass and solar collectors) for buildings of 100 and 200 m^2 EP was on the level of 31,1 and 25,4 kWh/(m^2·year) respectively what shows how much nonrenewable primary energy has been really consumed in order to cover the demand for house heating, hot water preparation, eventual mechanical ventilation and for generators work demand. By hot water preparation calculations factor EP for buildings of 100 and 200 m^2, 16,0 and 12,6 kWh/(m^2·year) respectively. For 100 m^2 house EF factor equals 17,1 kWh/(m^2·year) and for 200 m^2 house this factor equals 0, what means it fulfills passive building standards [7].

Fig. 2 presents how big impact on emission of noxious substances like: CO_2, CO and SO_2 have external partitions parameters and ventilation system chosen: gravitation and mechanical with heat recuperation system. The use of mechanical and local installation systems co-working with renewable energy in low energy buildings thank to energy efficiency and natural environment protection increase gives ways to enlarge the energetic effectiveness of buildings, what brings to more balanced development rate.



a b

Figure 3: Noxious substances emission rate comparison for 200 m^2 heating surface buildings with gravitation ventilation (a) and mechanical ventilation with heat recuparation (b)

Primary energy reduction possibilities in low energy demanding houses or passive ones is more or less 200-300 kWh/(m^2·year) what is equal of 20-30 dm^3/(m^2·year) of heating oil, 20-30 m^3 /(m^2·year) of earth gasor 0,72-1,08 GJ/(m^2·year). By CO_2 emission factor equal to 52 kg/GJ the decrease of $C0_2$ emission for low energy and passive buildings is about 37-56 kg CO_2/(m^2·year). 90 % CO_2 reduction means reaching the result “10”. Such a low energy and passive way energy recuperating buildings and maximum limit of conventional energy sources are the way to reach environmentally balanced buildings (pro-ecological buildings), minimalizing their destructive natural environment influence [8, 9, 10].

4 Conclusion

According to the energetic-ecological building analyze (standard, energy saving and low energy building) with heating surfaces of 100..200 m^2 mathematical influence models of external partitions and heating surface on primary, final and useful energy has been obtained. According on the results of energetic factors obtained, regressive annual demand for final energy, heating and ventilation system for gravitation and mechanical ventilation buildings has been obtained. All the analyze show the possibility of excessive amount of energy in energy saving of 200 m^2 surface – this creates new trends in energy saving building of the newest generation – energy sufficient buildings.

Elaborated point of view in energetic-ecological analyze of energy saving houses with the respect of hiring renewable sources of energy in the region implicates possibilities of significant noxious substances reduction (like CO_2, CO, SO_2) to the atmosphere. Projecting buildings for which the environmental influence is keeping on low level during the whole period of building exploitation is promotion to low energy and passive buildings in popular building sectors respecting balanced development and environmental protection issues.

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