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ENERGY AND EXERGY FLOW BALANCES FOR TRADITIONAL AND PASSIVE DETACHED HOUSES

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K e y w o r d s: energy conversion in building, exergy balance, passive house.

A b s t r a c t

The aim of this paper is to give the insight into the energy and exergy analysis and the usefulness of the exergy balance next to the energy balance for the evaluation of the different kind of buildings. In our case we applied this method to the traditional and low-energy (passive) showing the differences in heating systems used for these buildings. In traditional house the condensing boiler and water heating radiator were used while in the passive the heat pump and air heating were used. The exergy analysis showed that the exergy destruction for the low-energy house is much lower than for the conventional one.

BILANS ENERGII I EGZERGII DLA DOMU JEDNORODZINNEGO TRADYCYJNEGO I PASYWNEGO

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S ł o w a k l u c z o w e: przemiana energii w budynku, bilans egzergii, dom pasywny.

A b s t r a k t

Celem artykułu oprócz bilansu energii, jest bilans egzergii oraz wykazanie jej przydatności do oceny różnych rodzajów budynków. Zastosowano tę metodę do budynku tradycyjnego i niskoenergetycznego (pasywnego) i wskazano na różnice w zastosowaniu różnych systemów ogrzewania w budynkach. W budynku tradycyjnym zastosowano kocioł kondensacyjny i grzejniki radiacyjne, w budynku pasywnym pompę ciepła i ogrzewanie powietrzne. Po analizie egzergii wykazano, że w budynku niskoenergetycznym destrukcja egzergii jest znacznie mniejsza niż w budynku konwencjonalnym.

Introduction

Drastically decreasing resources of fossil fuels cause the need to search for the energy efficient technological solutions. In the field of housing technology and construction those trends have resulted in the designs of the so called low-energy and passive houses. Those, however, are not ultimate and fully satisfying solutions (exhausting the potential of scientific and technological development). Further reducing of heat demand for buildings heating will probably require application of new notions and analytical tools allowing the energy efficiency assessment of various heating circuits. This assessment will be done to answer the question where in the entire process of energy flow and conversion the exergy losses are the greatest and occur the most frequently. Energy and additionally exergy analysis with respect to the building could give us such a tool for analysis the heat demand and the choice of proper solution. Actually, this analysis is only partially, because it does not take into account the analysis of exergy in the different processes of production of building materials and components.

The goal of the paper is to show the suitability of exergy analysis – made beside and not instead of the energy analysis – to present the actual processes of energy conversion during its flow (use) in residential buildings in view of computations and to show it on an example of the comparison of two detached houses: the traditional with the passive.

Idea of passive house versus traditional

Exergy loss during the energy conversion (the notion of energy consumption or even worse energy loss is very often used – not only in common language – to describe this process, but it is rather not appropriate designation) for heating the building covers three types of needs: (1) exergy lost through external partitions of the building as the result of the processes of heat conductivity, conversion in wall and radiation, (2) exergy lost as a result of exchange of air in the building for the purpose of ventilation and (3) exergy lost in the energy flow needed to heat the domestic hot water for general use. Continuous progress in technology of building materials, in manufacturing of windows and doors allow decreasing utilization of energy to satisfy the needs of the first type. Application of ground heat exchangers and heat recovers in blow in-blow out ventilation systems decreases the needs of the second type. Solar energy is used to heat water increasingly frequently.

Thanks to the technological development within the last 40 years the demand for energy to heat the buildings decreased by almost a half (from 80%

to 45%) while energy utilization related to ventilation and water heating remained practically unchanged because of the need to secure or enhance the appropriate hygienic conditions. As a consequence, in the energy balance of housing of 1990s the percentage share of energy utilization for ventilation and domestic water heating is relatively high at 30% and 25% respectively.

Shrinking resources of fossil fuels motivate the search for solutions that would allow further limitation of energy utilization during use of residential buildings. Implementation of the notion of low energy house and attempts at practical implementation of that idea are manifestations of those efforts. Low-energy house should consume 30% less energy as compared to a traditional house. Energy consumption per one square meter per year in the low-energy house with the usable area of 150 square meters should not exceed 35 kWh for heating purposes, 35 kWh for ventilation of the space and 15 kWh for water heating. The additional decrease in fossil fuels consumption for satisfying those needs is possible thanks to, among others, application of condensation technology or heat pumps in the building heating installations.

Further attempts at decreasing energy consumption resulted in the idea of the passive house. The notion of the passive house designates an object – roughly speaking – that does not require the active heating system during the house operation. In such a house that significant reduction in heat losses is possible through application of maximally insulated external partitions and tight windows with triple glazing, passive use of solar energy and controlled ventilation with recovery of heat from the air blown out. The so called passive sources in the form of solar energy passing through the windows, heat generated by the residents and heat generated from the use of household equipment especially electric devices is sufficient to cover the exergy losses during the heating. Only during the period of decreased temperatures supplementary (usually ecologically friendly) heating is used, usually based on the heat supplied by the ventilation installation. In the area of Central Europe the passive building have to be equipped with mechanical blow in-blow out ventilation with heat recovery with maximum insulation of the partitions. Appropriate performance of all the above improvements results in obtaining the building offering high heat comfort and very low demand for heat energy not exceeding 15 kWh/ $(m^2 \cdot y)$.

Despite the obtaining of such low heat-demands of the passive house for energy as compared to traditional construction further attempts at minimizing energy outlays are undertaken. It seems that energy balance based on the first principle of thermodynamics is not the sufficient analytical tool in that field. That balance treats in the same way the different forms of energy without considering their different quality and practical value. On those bases it is difficult to asses the energy efficiency of heat circuits and answer the question where in the entire process of the flow the largest losses take place and, as a consequence, in which link further improvements should be searched for. The need appeared to introduce a thermodynamic notion of exergy necessary to characterize the problems considered. The notion of exergy is actually not a new one, but its application for the building and its service systems is rather new.

A few words on exergy

The notion of exergy means the maximum ability to perform work by a given matter determined by considering the participation of environment. Exergy can serve determining the practical use of energy contained in matter. The assessment of that use requires knowledge of total quantity of exergy of the considered thermodynamic medium and the relation of exergy to the volume of the medium. That parameter is called the exergy density.

One of the most important differences between the notion of energy and exergy is that energy is subject to the conservation law while the exergy conservation law does not exist. Additionally, energy has conventional reference levels while in case of exergy the reference levels are imposed by the nature ie. environment. Losses of exergy are inevitable and at the same time unwanted as every loss of exergy cause a decrease of the use effect of a given process (SZARGUT, PETELA 1965, SZARGUT 2005, WALL 1999). The investigations by Gouy – Stodola indicate that loss of exergy is irreversible and cannot be recovered even partly. That characteristic of irreversible loss of exergy differentiates it from the losses of work determined by other methods. In case of investigation on exergy the mutual relation of phenomena occurring in individual links of the compound process should be considered. If, in the process of investigation it is found out that the loss of exergy is particularly substantial in a given link of the compound process than possibilities of decreasing the level of irreversibility of transformations within that link should be investigated and possibilities of changes in the progress of processes at earlier stages should be analyzed.

Losses of exergy can be divided into internal and external. Loss caused by irreversible transformations occurring within a considered device are called the internal loss. The causes of internal losses of exergy can include, among others, heat flow at finite temperature difference, transfer of work coupled with lack of mechanical balance, mixing of substances possessing different chemical compositions or loss of liquid pressure during flow caused by viscosity.

On the other hand, destruction of exergy caused by irreversible equalization of the parameters of waste media with the parameters of environment media is defined as an external loss. In the majority of energetic thermodynamic processes discharge of waste thermodynamic medium into the environment (e.g. discharge of flue gas from the boiler) takes place. Parameters of the components of the discharged medium differ generally from the parameters of the environment. The waste medium still possesses a certain unused exergy. In the environment the destruction of this exergy takes place.

As a consequence of the mentioned exergy losses the exergy does not satisfied a low of conservation. The difference between input and output exergy is equal to the internal exergy loss. As a consequence the exergy balance can be represented by the following formula:

$$B_d = \Delta B_u + B_{wus} + L + \Sigma\Delta B_{sr} + \delta B_w + \delta B_z \tag{1}$$

where:

B_d – exergy of system input substances,
ΔB_u – increase of system exergy,
B_{wus} – useful exergy of useful input products,
L – mechanical or electrical work done by the system,
$\Sigma\Delta B_{sr}$ – increase of exergy of the external heat source operating in the control casing of the system,
δB_w, δB_z– internal and external exergy loss respectively.

According to the simplest representation the exergy balance equation can take a following form:

$$B_i - B_{cons} = B_o \tag{2}$$

$$B_{cons} = T_{ref} \cdot S_{gen} \tag{3}$$

Where B_i and B_o are exergies at the input and output of the system and B_{cons} is the exergy destroyed (consumed) in the system, which in turn is equal to the product of reference temperature T_{ref} and the entropy S_{gen} produced in the system. Usually the environmental temperature is acknowledged as a reference temperature in the building analysis of exergy.

Reference to the notion of entropy in that balance allows explaining what can be used and what can be generated. The notion of exergy is used to express what is used, consumed, while entropy describes what is removed. Exergy means the ability of energy to dissipate during its flow through the system while entropy expresses the state of dissipation. In the context of the purpose of this paper it is important that the theory of exergy can be applicable in assessment of reversibility and efficiency of all energetic processes, in which heat radiation participates that is in case of devices using energy of solar radiation and heating system operating through radiation.

The most important goal of exergy analysis is detecting and quantitative assessment of causes of the thermodynamic imperfection of thermal processes and it can contribute to improvement of those processes. That analysis can be highly useful as a tool in research works aiming at increasing energy efficiency of housing construction as concerns maintaining the conditions of residents thermal comfort with possibly low energy utilization. The aim of such works is to design objects and heating systems with possibly low exergy (i.e. decreasing the input of exergy during heat generation and management). Low exergy of the heating system encompasses: the increased level of use of the chemical energy of fuels (or substitution of fossil fuels with devices using renewable energy sources), low consumption of heat in the building and use of low temperature heat for heating purposes. All that should result in decreasing the consumption of fossil fuels and decrease of the emissions of pollutions, production of waste and environmental losses.

Energy and exergy balance spreadsheet of Annex 49

Development within Annex 37 software of the spreadsheet for exergy balance analysis was one of the effects of works on decreasing the residential buildings heating exergy (Collective work, 2003). It is further complimented and improved in Annex49 (Torio, Schmidt 2011) to the version 7.7.

The spreadsheet is divided into seven modules. In the first of them the basic data concerning the building such as its volume, net area, external and internal temperature is input. The second module covers the heat losses involved in heat transmission. It covers heat losses through partitions (on the basis of the area of partitions and their heat transmission coefficients as well as the difference between the external and internal temperatures) as well as loses for ventilation (computer, among others on the basis of air infiltration, exchanger efficiency and temperature difference). Parts three and four determine the possible heat gains. They include gains from solar radiation (taking into account the surface of windows and their orientation in relation to the sides of the world) and internal gains (in the form of residents; body heat and heat generated by household appliances). In module five the losses and gains are balanced. In part six the types of installations and energy source should be chosen. On the basis of the choice of the heat generating system the spreadsheet describes the efficiency, maximum supply temperature and the degree to which the system uses the renewable energy sources using “macros”. Similarly, in selecting the heat generating system the spreadsheet selects characteristic values for a given type of installation such as the supply and return temperature, output and additional energy. Exergy analysis is done in the last module of the code. It progresses describing one by one the heat flow stages: building envelope (walls, roofing), air in premises, heat discharged, heat distribution, container, generation, basic transformations (Fig. 1). In Figure 1, apart of the mean stream of energy the additional stream of auxiliary energy in the form of electricity is shown.

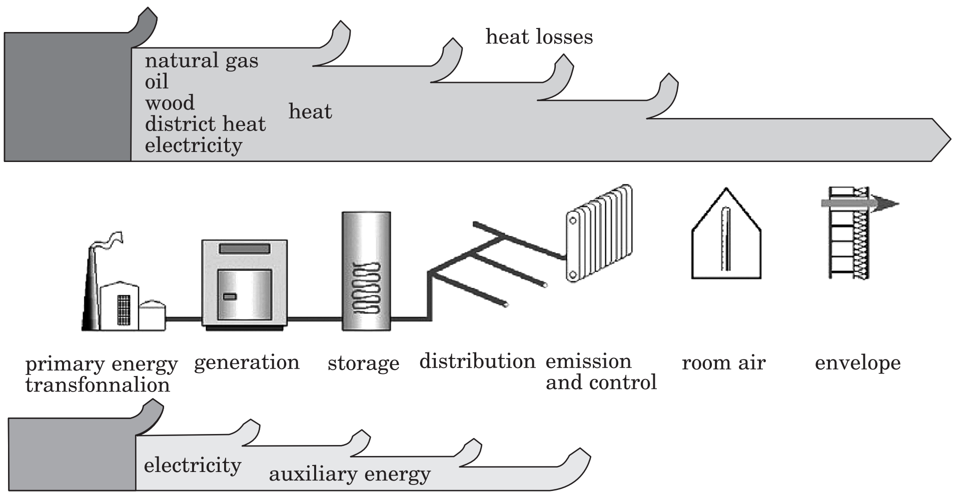

Fig. 1. Energy stream in building services

Source: SCHMIDT (2004).

In the exergy calculation of the room air only the thermal part of the heating exergy is taken into account and the changes of the exergy connected with the change the humidity and pressure of the air both inside and outside of the building are not considered. Sakulpipatsin, (2008), has calculated the exergy changes for three different climates (hot and wet as in Bangkok, rather cold in Holland and finally sea climate in Lissabon) and he came to the conclusion that the error caused by the neglecting of the wet part of exergy for the cold climate can caused not more than 3% error in exergy calculations.

Heat transmission through partitions

We start the computation with determining the thermal load of the building considering transmission coefficients of the window, walls, doors and others according to the formula beneath:

$$\Phi_{tr} = \Sigma(U_i \cdot A_i \cdot F_{xi}) \cdot (\Theta_i - \Theta_e) \tag{4}$$

where:

A_i – area of i-th partition in [m^2] (walls, windows, doors and others),

U_i – heat transmission coefficient for the *i*-th partition in [W/m^2 K],

Θ_i, Θ_e – indoor and exterior air temperatures under the design conditions in [K],

$F_{x,I}$ – temperature correction coefficient.

Heat loss for ventilation

Next the heat flow connected with the ventilation air is considered along the following formula:

$$\Phi_{V,is} = (c_p \cdot \rho \cdot V \cdot n_d \cdot (1 - \eta_V)) \cdot (\Theta_i - \Theta_e) \tag{5}$$

c_p – specific heat of air in [kJ/kg deg],

ρ_a – density of air in [kg/m^3],

V – building volume (capacity) in [m^3],

n_d – air exchanged rate (ach) in [1/h],

η_V – efficiency coefficient of heat exchanger (recuperator) if used.

Solar heat gains Φ_S

The sun radiation gains in the building can be calculated with the formula below:

$$\Phi_{sol,gn} = \Sigma(I_{sol,j} \cdot (1 - F_{fr}) \cdot A_{Wj} \cdot g_j) \tag{6}$$

where:

$I_{sol,j}$ – intensity of solar radiation (dependent on window orientation to world directions and slope angle to direction of radiation) [W/m^2],

F_{fr} – window frame fraction, constant for all windows used in building [–],

A_{wj} – area of *j*-th window [m^2],

g_j – total transmittance of *j*-th window [–].

Internal heat gains Φ_i [W]

These heat gains can be divided into two different parts:
– heat gains from occupants:

$$\Phi_{in,gn,o} = no_o \cdot \Phi''_{in,gn,o} \tag{7}$$

where:
no_o – number of occupants,
$\Phi''_{in,gn,o}$ – heat gains from one person [W]

– Heat gains from internal devices

$$\Phi_{in,gn,equ} = \Phi''_{in,gn,equ} \cdot A_{ni} \tag{8}$$

where:
$\Phi''_{in,gn,equ}$ – specific heat gains from devices [W/m^2],
A_{nt} – netto floor area [m^2].

Another heat gains

Finally two different heat gains are considered especially from lighting and electromotors especially driving the fan:
– lighting [W]

$$P_L = p_L \cdot A_{nt} = \Phi_{in.L} \tag{9}$$

where:
p_L – specific power of lighting [W/m^2],
A_{nt}– netto floor area [m^2].

– gains from the fan motor [W]

$$P_V = p_V \cdot V \cdot n_d \tag{10}$$

where:
p_V – specific fan motor power in [Wh/m^3],
V – volume of building [m^3],
n_d – air infiltration, [ach/h].

Heat demand

At the end of calculation the heat demand and its specific value for the building can be given by following formulae:

$$\Phi_H = (\Phi_{tr} + \Phi_{V,is}) - (\Phi_{sol,gn} + \Phi_{in,gn,o} + \Phi_{in,gn,equ} + \Phi_{in,L}) \tag{11}$$

And also the specific heat demand:

$$\Phi''_H = \frac{\Phi_H}{A_{nt}} \tag{12}$$

Exergy load calculations

In this part of our paper we will show some formulae relating to the exergy calculation used in the code Exergy 7.7.

At the beginning it is necessary to consider the exergy loss understood as the exergy flow through the envelope of the building. So it the exergy needed to sustain the temperature difference between the interior and exterior condition of the building. Thus, the value of exergy for heating the premises results from the formula:

$$B_{heating} = F_{q,room}\Phi_H \tag{13}$$

where

$$F_{q,room} = (1 - \frac{T_e}{T_{in}}) \tag{14}$$

is called a quality factor of room air, and it is in the form of the so called Carnot coefficient, and where T_e and T_{in} are the external environmental and internal temperature of the air. In the case of $T_e = -22^{o}C$ and $T_{in} = 20^{o}$ the coefficient $F_{q,room} = 0.14$.

When the air in the building is heated by the heater (radiator or floor, or any other) then next the exergy load for the heater should be calculated. So next the different temperatures of the heater should be defined as follows: T_{ing} and T_{ret} as the temperature of the inlet and outlet of the heater, and T_{in} is the temperature in the heated room or in whole building.

First, the mean temperature of the radiator T_{heater} can be calculated according to two following formulae:

$$T_{heater} = 0.5 \cdot T_{Ln} + T_{in} \tag{15}$$

Whereas T_{Ln} is the averaged logarithmic temperature of radiator:

$$T_{Ln} = \frac{(T_{ing} - T_{in}) - (T_{ret} - T_{in})}{\ln(T_{ing} - T_{in}) - \ln(T_{ret} - T_{in})} \tag{16}$$

Then the exergy stream from the radiator (heater) will be given by:

$$B_{heater} = \Phi_{heater} \cdot F_{q,heater} \tag{17}$$

Where $F_{q,heater}$ is the quality factor of air at heater (Carnot coefficient) given by below formula:

$$F_{q,heater} = 1 - \frac{T_e}{T_{heater}} \tag{18}$$

Of course, the heater belongs to the so called emission part of the system, Fig. 1. It is necessary to consider the loss in it and to calculate the necessary demand of energy and exergy caused by the loss in this part of the system.

The additional demand for the heating energy should be calculated according to following formula:

$$\Phi_{ls,em} = \Phi_H \cdot \left(\frac{1}{\eta_{em}} - 1\right) \tag{19}$$

Where η_{em} is the efficiency of the emission system.
The exergy demand for the emission system is to be calculated along formula given below:

$$B_{em} = \Delta B_{em} + B_{heat} = \left\{\frac{(\Phi_H + \Phi_{ls,em})}{(T_{in} - T_{ret})}\right\} \cdot \left\{(T_{in} - T_{ret}) - T_{ref} \cdot \ln\left(\frac{T_{in}}{T_{ret}}\right)\right\} \tag{20}$$

Where T_{ref} is usually the environmental temperature of air, as mentioned above.

In very similar way the exergy and energy load in the distribution system and storage can be calculated only using another efficiency factors and temperatures at the inlet and return. The reference temperature remains the same.

It is also possible by means of the Exergy code version 7.7 to calculate the energy and exergy demand according to the number of occupants and amount of DHW for one person per day according to the appropriate standard. And this possibility was used in our calculations of energy and exergy use in the detached family houses.

In each part of the system some additional energy is needed to drive the system usually in the form of electrical power. This auxiliary energy and its exergy should be taken into account.

And finally at the begin of the chain, Figure 1, stands the generation part of the system energy and primary energy transformation usually in the form of chemical energy and exergy of the fuel. To take into account this part of the system the efficiency of the generation (e.g the efficiency of boiler or heat pump) of energy and exergy and its auxiliary energy load is to be included into the balance. If the primary energy transformation is considered and the renewable energy, as the solar gains, Eq. 6, is taken into account the total energy and exergy amount are the results. Actually, all calculation of the energy demand for heating of the building are made according to the European standard EN-13790 Energy performance of buildings. Calculation of energy for space heating and cooling.

Description of houses under consideration

The computations were made for a passive house and traditional technology house according to the design by the Architecture Office Lipinscy Houses. In can be supposed that the first detached passive house designed by the Lipinscy Domy was built in Smolec near Wrocław, see also (Lipińscy Domy).

For the purpose of our calculations the both houses are placed near Olsztyn so in the fourth climatic zone with the standard winter temperature (average) in January -22°C. Both houses have the same heated volume of 415.9 m^3 and heated area of 142.3 m^2.

Passive house

The design was developed in collaboration with the specialists from the Institute of Passive Buildings at the Polish National Energy Conservation Agency in Warsaw. It received the positive opinion of the Passive House-Institute from Darmstadt and at the further stage certification by that

Institute. According to the energetic certificate issued by the above institutions its demand for thermal power is to be 1.9 kW (13.5 W/m^2), year final energy (heat) consumption for heating the building 13.5 kWh/m^2/year and 4.7 kWh/m^3/year. The seasonal demand for heat to heat that building will be 1944 kWh/year. This data are for the passive house located near Wrocław.

As mentioned above, the construction of the passive house is made according to the passive house regulations, and especially the thermal transmittance U of the building elements are appropriately chosen: exterior wall thermal transmittance is equal to 0.1 $W/(m^2K)$, and appropriately the thermal transmittance of window 0. 60 $W/(m^2K)$, door 0.80 $W/(m^2K)$, roof 0.15 $W/(m^2K)$, and finally floors to ground 0.11 $W/(m^2K)$. So the superinsulation was employed to lower significantly the heat conductivity through the house envelope.

The insulation layers are 30–44 cm thick. The house is made of gravelite-concrete prefabricated walls and the thermal bridges are actually minimized as often as possible.

This house is designed fulfilling the passive solar design technique: it is possibly compact in shape to reduce its surface area with the shape coefficient equal to 0.75, the windows are oriented south to maximize the solar gains, but the solar gains are of secondary importance in minimizing the total energy demand requirement. The windows of advanced technology was applied with possible small U = 0.8 $W/(m^2K)$, for the entire window including also the frame. So in the house the door of Clima Design and window woodwork of REHAU Company were used. Of course the airtightness of walls are very important in the passive house, and the special test for tigthness against the air penetration was necessary giving the result 0.3 air change per hour.

The Lipinscy passive house is equipped with the mechanical ventilation including the heat recovery system. According to the passive house standards the ground heat exchanger was provided for and it is Awaduct Thermo of the REHAU Company. The ground heat exchanger heating initially the air supplying the heat pump (air-water) and the building was also installed.

In case of the passive house the temperature of air blown in past the ground heat exchanger was assumed to be 5°C. In this case electric heating installation and hot water preparation was applied using the integrated compact Vitotres 343 device by Viessmann (air-air heat pump, heat recovery device and electrically heated container of water for general use). The heat pump in the heat exchanger heats the air blown into the room after leaving the heat recovery device. To prepare the DHW the vacuum solar heat collectors Vitosol of Viessman were additionally used.

In Figure 2 the scheme of energy streams (with appropriate temperatures) are shown for the passive house heating. The solar collector used for DHW preparation is not shown in this figure.

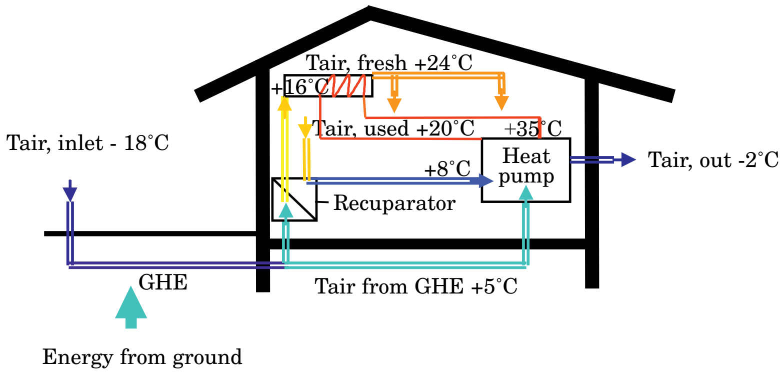

Fig. 2. Scheme of the heating system for the passive house

Traditional house

The traditional house was supposed to be made on the basis of a similar design as the passive house and had the same heated space of volume of 456.1 m^3 and heated area of 153.7 m^2. The difference in construction lies in the thermal transmittance of external partitions made of different materials than the passive house. Thus, especially, the thermal transmittance U of the building elements are appropriately changed: exterior wall thermal transmittance is equal to 0.37 W/(m^2K), and appropriately the thermal transmittance of window 1.0 W/(m^2K), door 1.4 W/(m^2K), roof 0.27 W/(m^2K), and finally floors to ground 0.22 W/(m^2K).

The heating installation in the conventional house consisted of gas condensation boiler and central water heating installation equipped with plate conventional heaters. The boiler also served heating the water. The natural ventilation is only supposed.

Results of calculations

In what follows, the results of computations made using the spreadsheet designed within the frameworks of IEA ECBCS Annex 37 and improved and complemented in the Annex49 are presented. The results are shown in Table 1 and 2. It is easy to see that the heat losses through partition are about 80 percent higher for the traditional house than for the passive one. Furthermore the loss for ventilation is five times higher for the traditional house than passive, what is quite clearly because there is natural ventilation in traditional house versus mechanical in passive house. The mechanical ventilation is also seen in the line for the electrical consumption of electricity for ventilator, where is nil for the traditional house versus 112 W in the passive house. Again the gains from the solar radiation in the case of passive house is 2.5 times higher than in traditional house. Three remaining gains: internal from resident and from electric devices and from lighting solar are the same because of the same number of inhabitants (four persons) and the number of electric devices and the power of lighting.

Table 1

Summary of the demand for thermal power of the traditional and passive house

Components in [W]	Traditional house	Passive house
Heat losses through partitions	5,531	3,045
Heat losses for ventilation	3,511	702
Gains from solar radiation	108	262
Internal heat gains (from residents)	320	320
Internal heat gains (from electric devices)	270	270
Electricity consumption for lighting	284	284
Electricity consumption for ventilators	0	112
Demand for thermal power	8,059	2,610
Demand for thermal power per 1 m^2 of usable area	56.6	18.3

Table 2

Results of exergy calculation

Components in [W]	Traditional house	Passive house
Exergy load room (envelope)	1,154	373
Exergy load at heater (room air)	1,616	408
Exergy load emission	2,134	471
Exergy load distribution	2,371	547
Exergy load storage	2,472	580
Exergy load generation	10,874	752
Exergy load transformation	11,364	2,258
Lighting exergy demand	284	284
Ventilation exergy demand	0	112
Exergy load plant	433	461
DHW prim exergy demand	471	153
Energy/Exergy prim load plant	1,067	1,134
Primary energy renewable	13	629

Finally, the demand for thermal power in traditional house is equal to circa 8.1 kW, when in the passive house is only 2.6 kW. And this huge difference is actually caused by two things: much better isolation and mechanical ventilation in the case of the passive house. Actually, the solar gains in the case of passive house could be a bit higher because it was impossible to calculate it in the spreadsheet Exergy ver. 7.7 according to the rules given for the passive house. The solar gains estimation along the rules for the passive house looks also to some extend optimistic. The specific power for the traditional house is equal to 56.6 W/m^2 and is more than three times higher than for the passive house, which is equal to 18.3 W/m^2.

In Table 2 the results of exergy flow calculations are quoted. These results are more instructive, because the exergy flow points out how much exergy finally disappears.

In Figure 3 and 4 the comparison of energy calculation for the conventional and low-energy house are illustrated. In Figure 3 the energy gains and losses are shown in bar diagram for the conventional, while in Figure 4 the same calculation for the low-energy house (passive) are given. The differences are very striking: the energy losses in passive house are 50% lower than in traditional house. In passive house the renewable energy gains (green) are rather huge, while in traditional house are equal to zero. The total input for the traditional house is equal to 13.525 kW, while for the low energy house is only 5.5 kW. The solar gains in traditional house are small in comparison to passive house, the internal gains are the same the same, because of the same number

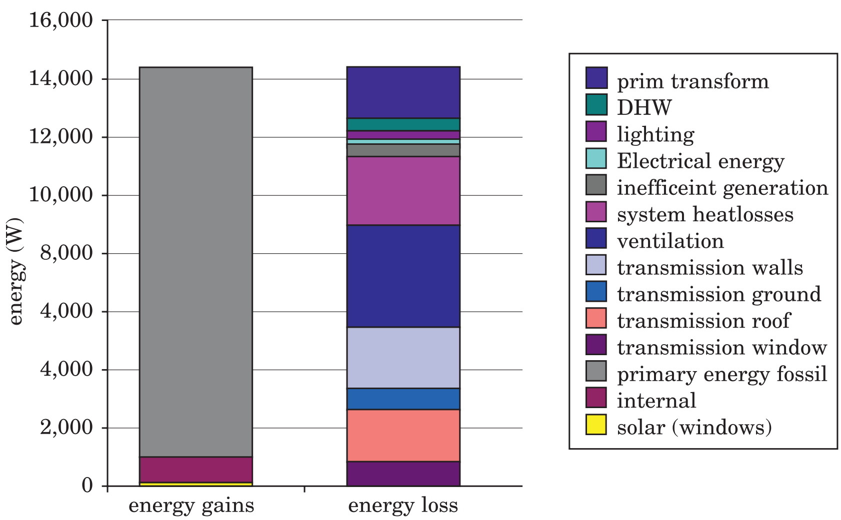

Fig. 3. Energy gains and losses in the traditional house

of occupants and lighting gains. Very instructive is also the comparison of exergy supply and demand for the traditional and low-energy house shown in Figures 5 and 6 respectively. The exergy supply and demand in the case of low-energy house is about two and half times lower than in the traditional house. It is the proper measure what exergy (energy) savings are achieved in the case of the low energy (passive) house.

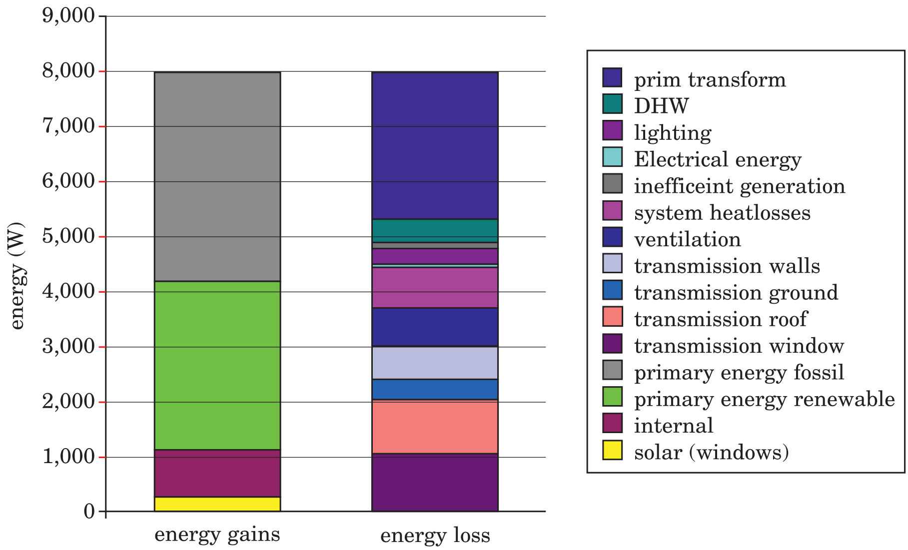

Fig. 4. Energy gains and losses in the low-energy (passive) house

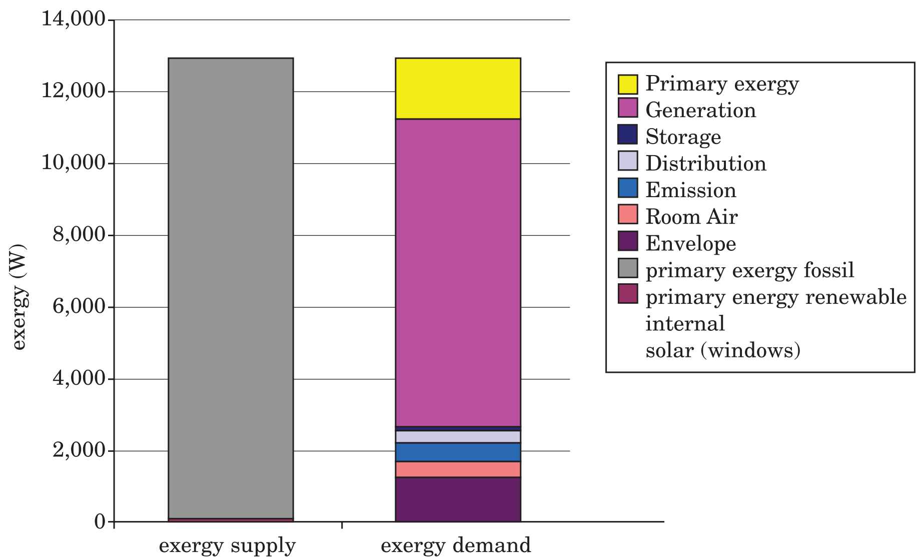

Fig. 5. Exergy supply and demand in traditional house

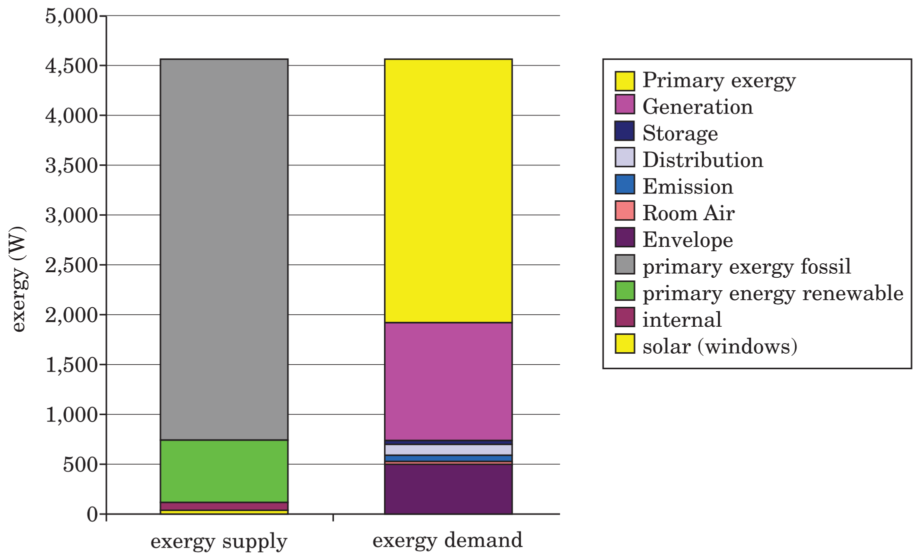

Fig. 6. Exergy supply and demand in low-energy (passive) house

Conclusions

The energy and exergy analysis of buildings are introduced according to the Energy Conservation for Building and Community Systems (ECBCS) Annex 49 and 37 of International Energy Agency. The code Exergy 7.7 was used to accomplish the energy and exergy flow analysis for the traditional and low-energy houses. It was shown that total demand for thermal power (converted to primary energy) of the traditional house was almost two times higher than that of the passive house. On the other hand losses of exergy at heat generation for central heating stage in the first stage were almost eight times higher than the losses of exergy in the passive house. The highest exergy losses occurred in the heat source (particularly the water boiler).

Large exergy losses also occur in heat transmission (distribution) to heaters (or in air channels to blowers in the passive house). In case of the traditional house losses of exergy were five times higher as a consequence of the difference in supply temperatures of water 70°C and air 35°C systems. As a consequence there were also around 3.5 times higher losses of exergy in transmission of heat from heating elements to the air in the premises.

Poorer insulation properties of the traditional building caused only two times increase of losses of exergy through the roofing (as compared to seven times higher losses in the boiler).

The exergy analysis should be a proper tool to compare different innovative solution also in dwelling houses.

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