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RESEARCH OF LOW ENERGY HOUSE DESIGN AND CONSTRUCTION OPPORTUNITIES IN LITHUANIA

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Abstract. Currently, the construction of low energy buildings in Europe is promoted. Existing and newly developed design and construction concepts for such buildings are adapted to their national or regional climatic conditions. The European Parliament has assigned the member countries to get ready for the reduction of the energy consumption in buildings. Therefore, Lithuania, like other EU countries, must be examined for the use of the low energy building design and construction experience, the existing concepts of low energy buildings should be adapted or new concepts of low energy building responding to the region's climate should be created. In this article, the most popular European mid-region passive house concept and the energetic performance of the house, designed and built according to its requirements is analyzed, the main differences of this concept to the normative requirements of Lithuanian building regulations and proposals to improve provisions for the construction of low energy buildings in Lithuania is provided.

Keywords: passive house, low energy building, heat recovery system, internal heating load, outdoor temperature, air tightness, thermal energy consumption, saving of energy.

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1. Introduction

Considering the tendencies of energy production and price, it is becoming urgent to reduce energy consumption in buildings. The European Parliament's Industry Committee (ITRE) on

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31 March 2009 stated that, starting from 2019, all newly constructed buildings must produce the same amount of energy they consume. The committee's recommendation adopted by the European Parliament on 23 April 2009 (European Parliament 2009) oblige the Member States to provide intermediate national targets to reduce energy consumption in buildings, i.e. determine the minimum number of buildings with zero energy consumption in 2015 and 2020.

To implement these intermediate objectives in European Union, a concept of the low energy building was formed. The main idea is that the low energy buildings should consume less energy to compare to buildings built in accordance to the local countries requirements (Jovanovic *et al.* 2009; Madlener and Alcott 2009). EU member states are developing definitions of low energy buildings, but only in 7 of them these definitions are officially published. Several countries are planning to publish them in the coming year (The European Alliance of Companies for Energy Efficiency in Buildings 2008). In most EU countries, a ratio between the energy consumption is determined, comparing low energy buildings and buildings built according to the normative requirements. In other countries, the specific energy consumption values are defined. They must be fulfilled to include energy-efficient buildings in the low energy buildings group. The most comprehensive and widely used concept of a low energy in Europe is offered by the German scientist W. Feist (Passive House Institute 2009a), also called the passive house concept, where the maximum permissible energy consumption for the heating of the building are presented, and at the same time, the total primary energy consumption is limited. The requirements for building elements thermal properties and the air tightness of the building are also presented in this concept.

Lithuania is also foreseeing the design and construction of low energy buildings. So it becomes necessary to explore the possibilities to use one of these existing design and construction concepts or develop own approaches by using the experience of other countries and adaptation to local Lithuanian climate conditions. The first step to achieve this was completed - the first dwelling house corresponding to the passive house approach was designed and built in Lithuania. The issues that arose during the process and their solutions are presented in this article.

2. Substantial attitudes of the passive house concept

The essence of the passive building‘s concept is that the building must be properly oriented, sealed and insulated (Passive House Institute 2008) (Stecher and Klingenberg 2008) in a way that a conventional heating system would not be required and the building could be heated by air supplied into the building, the amount of which must conform to the minimal hygiene requirements. In this heating system supplied air is heated by air extracted from the heated space; additional heat source, if needed, and type of energy depend on the situation. As the temperature of air, supplied to the indoor area cannot be greater than 50 °C, the building heat loss through thermal envelopes must not exceed 10 W/m^2 (Passive House Institute 2009b) (Bertrand and Rybka 2008). This is achieved by using a thicker insulating layer (Ginevičius *et al.* 2008) (Zavadskas *et al.* 2008), choosing windows with low heat transfer characteristics and designing the structural assemblies so that the heat transfer coefficients of thermal bridges do not exceed 0.01 W/m^{2}K. In order to select an energy-efficient heating system, the heat produced by appliances and humans inside the building as well as heat gained through the windows in the form of sun rays must be evaluated (Dombayci 2010). The amount of the solar heat gains depends on the area of translucent envelopes in the building and their cardinal orientation. The best results are achieved when the building is designed so that the rooms which require more light are aimed at the southern part and the corridors, bathrooms, storage or similar areas are aimed at the northern half of the building. The shape of the building must be as close to a cube as possible, in which case it gives the smallest envelope to floor area ratio. The building must be equipped with extra heating device, in order to ensure required temperatures in the rooms during periods of very low external air temperatures or in cases if the ventilation – heating system fails.

Usually low energy building is associated with the passive house concept which was developed in Germany and has the following requirements:

- Extremely good thermal insulation of external building envelope. The heat transfer coefficients of walls, roofs and floors should not exceed 0.15 W/m^{2}K; heat transfer coefficients of windows should not exceed 0.8 W/m^{2}K and the heat transfer coefficients of thermal bridges should not exceed 0.01 W/m^{2}K, whereas the total annual energy requirement to heat the building must be not larger than 15 kWh/m^2.
- The external envelope of a building should be airtight. Measured air exchange ratio in the building, where the external and internal air pressure is 50 Pa must be no greater than 0.6 times per hour. The natural air change in passive house should not exceed 0.04 times per hour.

3. Planning and envelope structural solutions

Building site and positioning of the rooms:

Passive house was designed and built in the township of Gulbinai in Vilnius city near the lake Gulbinas. The technical characteristics of the building are: heated area (according to the PHPP methodology of calculation) – 194.4 m^2, house height – 7.14 m, number of storey's – 2. The building was designed in a newly built area so there was a possibility to orient it according to cardinal points (Fig. 1).

The windows of the open area kitchen and living room on the first floor (Fig. 2) and the windows of bedrooms on the second floor are directed to the south - southwest. Staircases, lavatories and a workroom are designed on the first floor. The window area of the southern facade takes up 47.8% of the southern wall, the window area of the northern wall area – 5.2%. Calculated annual heat losses through the windows of the building are 22.2 kWh/m^2 and annual solar heat gains – 26.3 kWh/m^2. If this building would be designed with the same total amount of windows, but half of them would be oriented to the south and half to the north, the annual heat loss through the windows would remain the same but the annual solar heat gains would drop to 19.4 kWh/m^2, i.e. by 26.2%.

Windows:

The windows with the heat transfer coefficient from 0.73 to 0.84 W/m^{2}K (depending on the size of the windows) are installed in order to fulfil the passive house concept recommen-

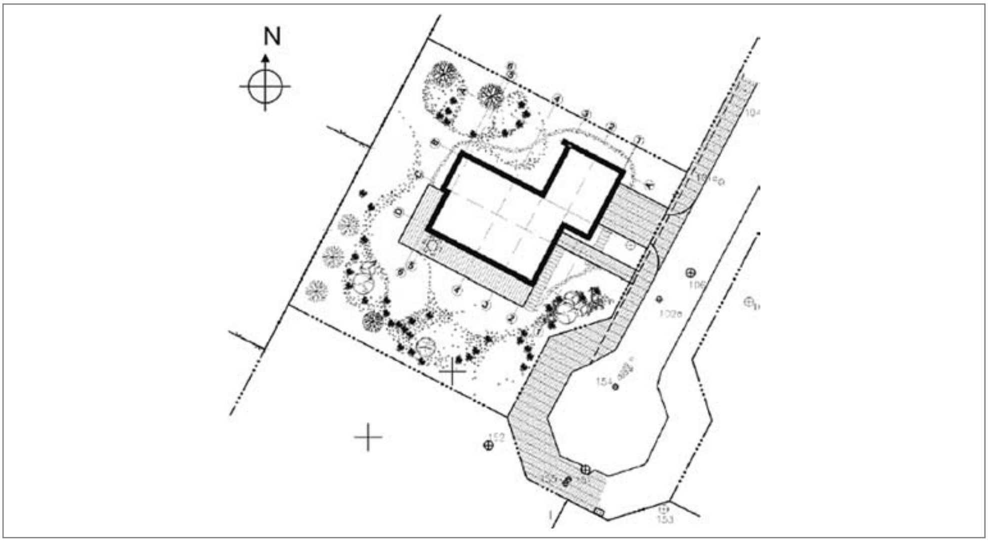


Fig. 1. Passive house orientation according to cardinal points

Fig. 2. The planning solution of the passive house

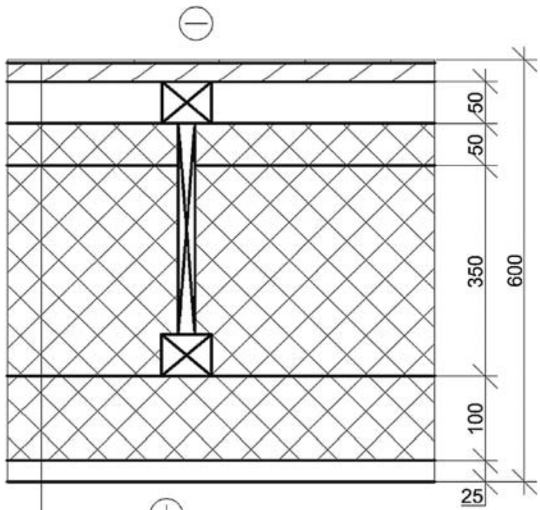
dations. In comparison, if windows conforming to the national regulations STR 2.01.05:2005 were installed, the heat transfer coefficient would be 1.6 W/m^{2}K and annual heat loss through the windows would increase by 100.5% from 22.2 to 44.5 kWh/m^2. The design value of windows solar heat gain coefficient g is 0.57 and the annual solar heat gains through the transparent glazing areas reach 26.3 kWh/m^2. Protection from the overheating in the summer time is provided by mobile shutters and a curtain on the southern side of the building.

Roof construction:

The passive house roof was designed with a one slope (Fig. 3). The roof structure consists of the wooden I-beams and mineral wool insulation. The roof slope oriented to the north, inclination 5%. Between the I-beams 40 cm mineral wool layer is installed. The heat transfer coefficient of this roof is 0.08 W/m^{2}K (regular value – 0.16 W/m^{2}K). The designed annual heat loss through the roof is 4.85 kWh/m^2 and equal to 52.2% of heat loss through a similar roof conforming to the national regulations.

Walls:

Load-bearing walls are made of clay bricks. Mineral wool insulation is used to insulate the walls. Wooden logs or thin-layer plaster are used as external finish, depending on the type of the wall. Two types of external walls constructions are designed: ventilated wall (Fig. 4) and rendered facade (Fig. 5). The thickness of the mineral wool layer is 35 cm. The heat transfer coefficient of walls varies from 0.10 to 0.11 W/m^{2}K (regular value - 0.20 W/m^{2}K). The design value of annual heat loss through the walls is 18.33 kWh/m^2. It is 54.5% of the heat loss of through similar walls conforming to national standards.



Roof covering	
Planking	- 22mm
Wooden I-beam	- 450 mm
Air gap	- 50 mm
Wind insulation PAROC WAS 25t	- 50 mm
Thermal insulation PAROC UNS 37z	- 350 mm
Air and vapor barrier	- 0,2 mm
Thermal insulation PAROC UNS 37z	- 100 mm
Interior finishing - plaster board 12,5+12,5 mm	

Fig. 3. Roof construction

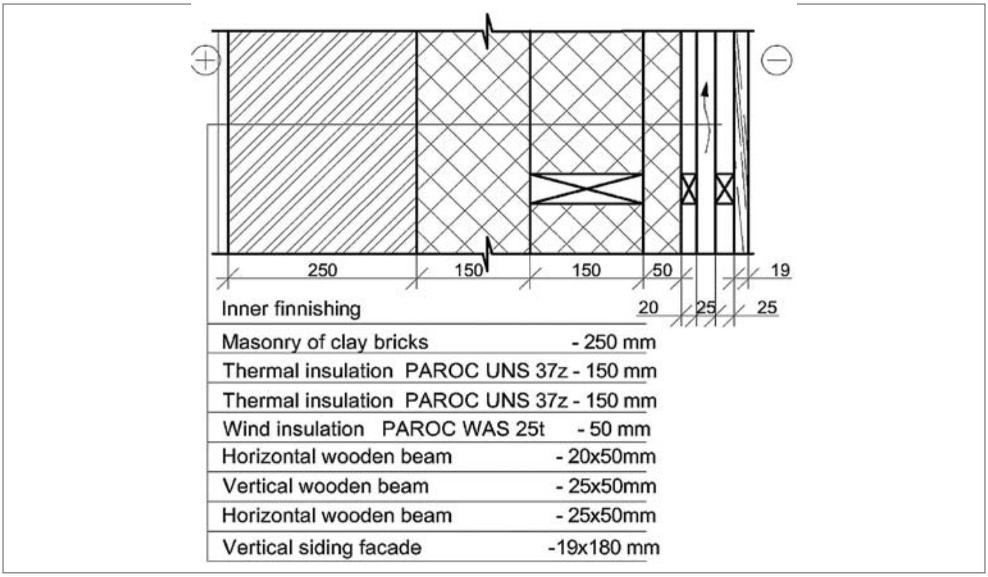


Fig. 4. Ventilated wall

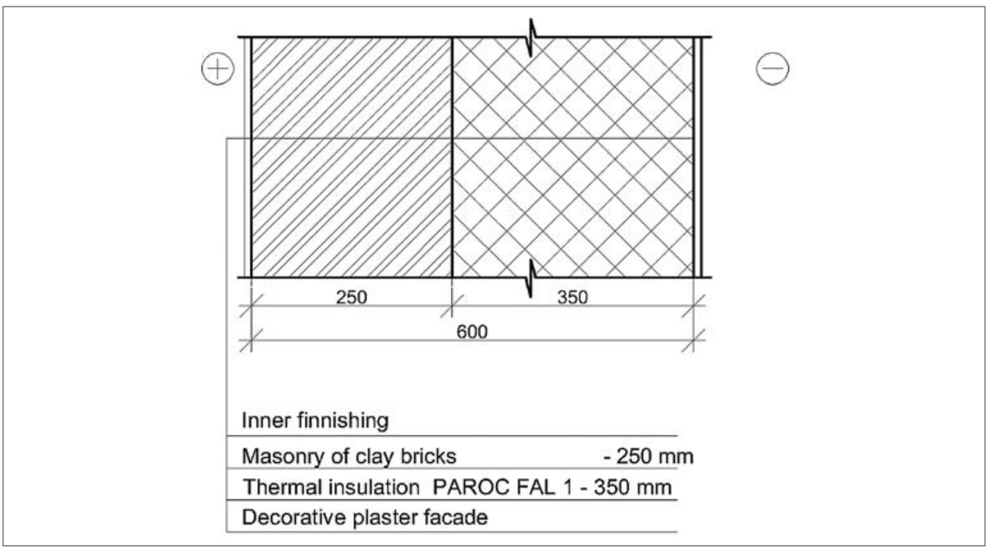


Fig. 5. Rendered wall

Floor:

Floor on the ground is insulated with a 33 cm extruded polystyrene foam layer. The heat transfer coefficient of the floor is 0.12 W/m^{2}K (normative value - 0.25 W/m^{2}K). A design annual heat loss through the floor is 4.1 kWh/m^2 and it comes to 48.7% of the heat loss of the same structure conforming to national standards.

Thermal bridges:

Building elements and their connections should be built in a way that the values of the heat transfer coefficients of the linear thermal bridges do not exceed the guidelines by PHPP – 0.01 W/m^2K .

Building air tightness:

An air-tight inner layer of the wall must be assembled and appropriate combination of insulation and wind protective layers must to be installed to ensure the air tightness of the building. The inner surface of the load-bearing walls, made of clay bricks was plastered to ensure air tightness. Ventilated facade of the building (Fig. 4) is constructed from mineral wool insulation wind protection slabs on top of low density insulation layer in order to decrease the air permeability. The building was inspected for air leakages before installation of internal finishes. Identified leak sites have been sealed. Therefore the final result of the measurement was better than the minimum requirements.

The measured building air changes at 50 Pa difference of external and internal air pressure was 0.4 times per hour (PHPP recommendations ≤ 0.6 times per hour). In real operating conditions, the air exchange does not exceed 0.1 times per hour. If the air tightness of the building meets the requirements of STR 2.05.01:2005 (1.5 times per hour at 50 Pa pressure difference) the annual building heat losses due to infiltration can reach 40 kWh/m^2.

Ventilation:

In order to reduce the consumption of energy required for the heating – ventilation system, a heat recovery device with a heat recovery efficiency of 82 % was selected. Air heating – ventilation system takes outside air and supplies it through the garage to the heat exchanger device. This device heats incoming external air by using the heat extracted from outgoing inside air. Air of the required temperature is supplied to the rooms, and removed from the kitchen and the bathrooms.

Reserve heating source:

The designed heating system provides the required indoor temperature only when the outside air temperature is not below 12°C - 15°C (Pupeikis *et al.* 2010). At low external air temperatures, it is necessary to increase the temperature of supplied air over the 50 °C limit or the air flow rate. The first case disagrees with the hygienic requirements, in the second case the required ventilation air quantity is exceeded, and the velocity of air movement in the rooms is increased. Therefore, the required thermal energy at the coldest period will be supplied by additional floor heating, with the power of 8.9 W/m^2, which consists of one pipe installed in the floor plate in the perimeter.

Building energy performance:

Energy demand and building energy consumption were calculated by passive house planning package (PHPP) and according to national regulations. The result is presented in Table 1.

Table 1. Technical and economical characteristics of the building

Characteristic	Passive house	According to national regulations
U-value (heat transfer coefficients):		
External walls	0.10–0.11	0.20
Roof	0.08	0.16
Floor	0.12	0.25
Windows	0.8	1.6
Transmition heat losses, kWh/m^2 per year	41.9	62.5
Ventilation heat losses, kWh/m^2 per year	7.6	46.0
Annual heat demand kWh/m^2 per year	15	72
Primary energy demand, kWh/m^2 per year	107	166
Heatin load during coldest period, W/m^2	16	57

4. Passive house benefits

The annual heat consumption of the building decreases from 72 kWh/m^2 to 15 kWh/m^2. The inner surface temperature of non-transparent envelopes during the coldest five day period does not fall more than 2 °C below the internal air temperature, therefore comfort conditions are always ensured (Jurelionis and Isevičius 2008). Temperature difference of the glass inner surface and internal air temperature during the coldest day is 4.1 °C, when the windows with a heat transfer coefficient of 0.8 W/m^{2}K are installed.

Proper air tightness of the building ensures that the ventilation heat loss decreases from 46 kWh/m^2 per year (STR 2.05.01:2005, for a building that complies with the requirements of national standards) to 7.6 kWh/m^2 per year (Fig. 6). In addition, up to 80% of the required heat is recovered in the heating – ventilation system using the recuperative device. In an air tight building, air is supplied to the rooms through filters; therefore it is clear of dust.

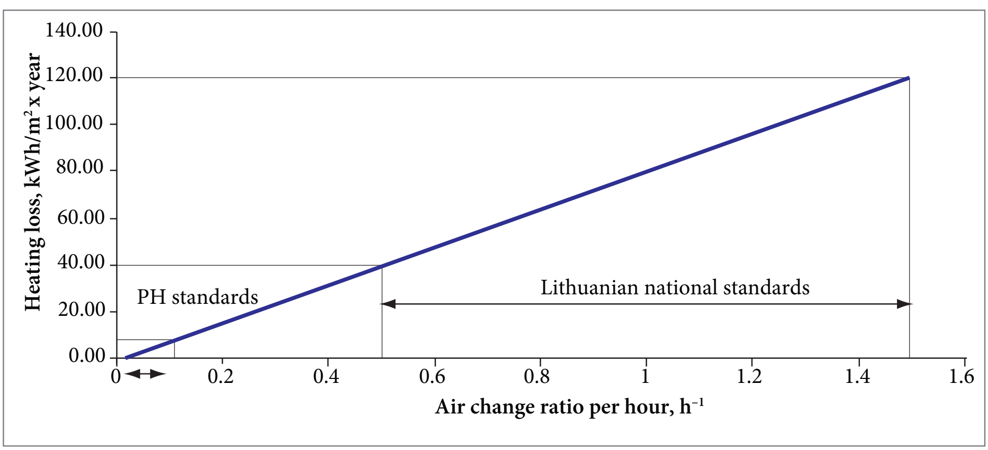


Fig. 6. The dependence of heat loss on the air tightness of the building

According to the national regulations, a heating season of 6 months is required for a new house in Lithuania. The duration of the heating season of the passive house is reduced to five months (Fig. 7). In October and April, the heat losses are covered by the internal heat gains and solar gains through the windows.

The air tightness of the building and a thick layer of thermal insulation in the envelopes, triple glazing in the windows provide protection from external noise.

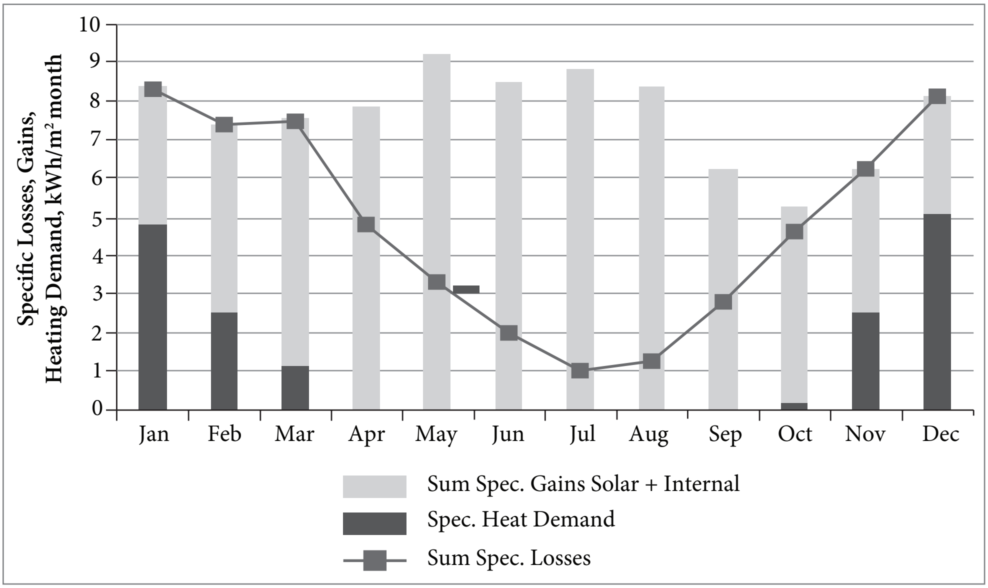


Fig. 7. Annual specific heat demand

5. Differences between the passive house concept and the requirements of Lithuanian building standards

Passive house design program PHPP (Passive House Planning Package) was used for energy consumption calculations for the passive house in Lithuania, whereas design values and normative recommendations adapted for this program.

The main differences were observed while calculating between the PHPP methodology and methodology used in Lithuania, and the differences between the thermal and technical parameters used for calculation in these phases:

- different external climate data is used in calculations;
- different evaluation of internal heat gains during the exploitation period;
- the method of determining the demand of necessary air supply to ensure the internal microclimate parameters varies;
- different performance evaluation of the ventilation equipment.

For the building heat losses calculations, the average external air temperature during the heating season in Lithuania is used. The PHPP program uses average monthly temperatures to evaluate exact heat demand. For the building heating load calculations according to STR 2.09.04:2008, outdoor air temperature is selected from the national building regulations (RSN 156-94 "Climatology of Buildings") depending on the thermal inertia of the building envelope. Potential temperatures for the heating load calculation are: the average of the coldest day, the average of the coldest day and the coldest five days, the temperature of the coldest five days. The temperatures used in the PHPP program for the heating load calculation are: the temperature of the coldest days on a sunny day, the average temperature of a cloudy day of average cold. In the PHPP program, solar radiation data in Lithuania's climate zone from the 1981–2000 period is used, while solar radiation statistics according to Lithuanian climatology RSN 156-94 were prepared using data from the 1955–1980, 1955 to 1991 periods.

The design values of internal heat gains have a significant impact on the calculation of the balance of passive house heat losses and internal gains. In the case of design model, and without knowing the appliances used, the total number of inhabitants and other specific exploitation conditions, PHPP recommends using an internal heat gain that is not greater than 2.1 W/m^2, with regards to the influence of inhabitants and household appliances. According to STR 2.09.04:2008, the heat release of inhabitants in residential apartments of one or two flats is 1.2 W/m^2, and the heat release of electrical lighting and appliances is – 1.6 W/m^2. Due to such differences, a difference up to 2.5 kWh/m^2 of energy consumption for heating per year is achieved.

When calculating the heat losses due to ventilation, it was determined, that the difference between the amount of air extracted (Table 2) from the rooms according to STR 2.09.02:2005 (Annex 1) and PHPP varies from 17 to 63%.

Table 2. Required extracted air flow ratio from the rooms

Name of the room	Air flow ratio according to national regulations	Air flow ratio according to PHPP
Kitchen	72 m^3/h	60 m^3/h
Bathroom	54 m^3/h	40 m^3/h
Shower	54 m^3/h	20 m^3/h
WC	36 m^3/h	20 m^3/h

For the evaluation of the efficiency of the ventilation heat recovery unit using the PHPP program, a further evaluation of the energy consumption for the heat recovery process is needed. This reduces the manufacturer declared efficiency up to 12% (Fahlen *et al.* 2006).

6. Passive House concept integration to Lithuanian climatic conditions

After the passive house was designed, using Lithuanian climatic data (Vilnius city), an evaluation of the building's heat demand was made, using the climate data of various European cities. The calculation results (Table 3) indicate that same house, built in Austria, would use two times less energy for heating than it does in Lithuania, built in Helsinki – 60% more. The heat transfer coefficients of the walls, roof and floor of the Lithuanian passive house are (0.10 to 0.12 W/m^{2}K) 30% – 50% lower than ones presented in the passive house concept. According to PHPP, in a German house it is enough to achieve a threshold value of (0.15 W/m^{2}K). Such improvement of the thermal properties of envelopes in Lithuania is related to the technical capabilities of their installation and their cost.

Table 3. Heating energy consumption depending on climate

State	City	Energy consumption for heating per year, kWh/m^2
Germany	Hanover	11.2
Austria	Salzburg	7.4
Switzerland	Bern (Liebefeld)	8.4
Denmark	Copenhagen	10.4
Ireland	Dublin	3.9
Poland	Warsaw	14.5
Finland	Helsinki	24.3

While designing and building the passive house in Lithuania, all solutions to achieve required insulation level were developed and implemented. Building air tightness level even exceeds recommended value, what means high quality designers and builders attitude. The cost of the passive house price increased by 11% to compare to a same building built on a normative level. At this moment, energy consumption monitoring of the passive house is carried out, the purpose of which is to check the building's energy performance and compare it to calculations.

Analysis of the results have also shown that in colder climate countries such as Finland, Sweden and Norway, it would be difficult to achieve the requirements provided in the passive house concept, or it would require specific solutions, which would significantly increase the cost of the building. Therefore, in these countries, the design and construction of passive houses generally comply with the passive house concept, but the requirements for energy consumptions are adjusted according to the climate conditions. Such provisions would also be appropriate in Lithuania.

7. Conclusions and recommendations

1. Technical analysis of the design and construction of the building's envelopes shows that it is possible to reduce heat losses through the envelopes by about 30% compared to a building designed according to national standards.
2. Adopted air heating system with efficient heat exchange device reduces the heating demand of the building for ventilation by six times. To achieve this value, a high level of air tightness is required.

3. With the correct combination of insulation of the building's envelope and heating – ventilation system, the energy consumption for heating is reduced approximately four times compared to a building conforming to the national requirements. Therefore such a building can be assigned to the category of very low energy houses.
4. In order to accelerate the construction of low energy houses, it is necessary to improve the technical Lithuanian construction regulations, to introduce more accurate calculation methods for heat losses through envelopes, methods of evaluation of solar heat gains and influence of heat release inside the buildings.
5. The definitions of low energy buildings and very low energy buildings should be established in Lithuania, as well as limits of energy consumption for heating of such buildings. Air tightness tests and recommended values of primary energy consumption must be established.
6. The practice of low energy building design and construction would enable a smooth transition to construction of net zero-energy buildings in Lithuania

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MAŽAI ENERGIJOS NAUDOJANČIO NAMO PROJEKTAVIMO IR STATYBOS LIETUVOJE GALIMYBIŲ TYRIMAS

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Santrauka. Šiuo metu Europoje skatinama mažai energijos vartojančių namų statyba. Esamos ir naujai kuriamos tokių namų projektavimo ir statybos koncepcijos dažniausiai pritaikytos konkrečios šalies arba regiono klimato sąlygoms. Europos Parlamentas įpareigojo šalis nares pasirengti mažinti pastatuose suvartojamos energijos kiekį. Todėl Lietuvoje, kaip ir kitose ES šalyse, turi būti išnagrinėta mažai energijos vartojančių pastatų projektavimo ir statybos patirtis, perimtos jau taikomos arba sukurtos naujos koncepcijos, tinkamos šio regiono klimatui. Straipsnyje išanalizuota populiariausia Vidurio Europos regione pasyviojo pastato koncepcija, pagal jos reikalavimus suprojektuoto ir pastatyto namo energiniai rodikliai, nustatyti pagrindiniai šios koncepcijos ir Lietuvos statybos norminių dokumentų reikalavimų skirtumai ir pateikti pasiūlymai gerinti sąlygas mažai energijos naudojančių pastatų statybai Lietuvoje.

Reikšminiai žodžiai: pasyvus namas, mažai energijos vartojantis namas, rekuperacinė šildymo sistema, vidiniai išsiskiriančios šilumos kiekiai, išorės oro temperatūra, sandarumas, šiluminės energijos suvartojimas, sutaupyta šiluminė energija.

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