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URBAN DEVELOPMENT EFFECT ON PASSIVE HOUSE ENERGY CONSUMPTION

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Abstract. The paper describes one of the energy-efficient building concepts – a passive house. In the course of the work, a multifamily residential house was simulated in order to determine its constructive and spatial parameters that would ensure a passive house with energy efficiency in compliance with the fixed standards. The climatic data of the Latvian capital, Riga, were applied to this building simulation. Initially, an optimal orientation and maximum theoretical insulation of the building were chosen. At the second stage, the external factors – the shade caused by the surrounding buildings and effect of the building orientation dictated by the existing urban conditions – were studied based on the previously achieved energy efficiency rating. The results evidenced that the layout of window apertures and change of orientation, as well as shading caused by the surrounding buildings, plaid a significant role in the rating of the building energy efficiency nonetheless it did not interfere with achieving the passive house standards.

Keywords: energy-efficient house, passive house orientation.

Introduction

In European architecture and construction industry an increasingly greater attention is being paid to the energy efficiency issues. This is facilitated both by the effect of global processes on the design practice and by low efficiency of the traditional designing practice, which is no longer consistent with surging prices of energy resources. In Latvia the energy efficiency of the housing fund is very low – the specific energy consumption by the mass residential buildings for heating per annum makes up about 180 kWh/m² (Blumberga 2006). Nevertheless, at present in Latvia a number of examples of implemented energy-efficient construction projects is still very low, while the number of renovated multifamily houses is increasing, and thus being actively reported in the Latvian media. More and more various training workshops are organized for architecture and construction industry professionals on the principles of designing of energy-efficient buildings, also updating issues on the possibilities of implementation of the passive house concepts in Latvian climatic conditions. Demand for the passive house design courses among professionals is high, because up to now the principles of passive house designing have not been included into the process of training of architecture specialists. Also the material and technical basis does not preclude from dissemination of the passive house concept in Latvia: the heating efficiency of structures can be ensured using traditional building materials, but more and more local companies offer to provide both a passive house quality control and production of windows and doors in accordance with the passive house standards. Thereby one can forecast that in years to come all the conditions will be fulfilled for successful implementation of the passive house concept on a wider scale than before. Besides, in the nearest ten years the designing of energy-efficient buildings will become a statutory provision, after enactment of the European Directive's requirements stating that after 2020 all newly erected buildings must be almost zero-energy buildings (Directive 2010/31/EU 2010).

A passive house as a type of an energy-efficient building is widely known in many European countries, particularly in Germany, Austria and Switzerland. In the Baltic States only the first implemented examples still exist. The passive house criteria under the conditions of Central Europe were defined at Passive House Institute in Darmstadt – the Research and Consulting Centre under the auspices of Dr Wolfgang Feist. The passive house concept is based on the idea, according to which comfortable to people indoor temperature can be provided without using any traditional heating system. This can be achieved by minimizing the building heat loss thanks to the high performance of the structures and air-tightness of the building (Table 1). Therefore the heat emitted from the equipment available indoors, the people and the solar thermal energy received through windows shall be enough to ensure the indoor temperature. During cold winter months an additional necessary heat quantity can be provided with warmed air supplied by the ventilation system. Ventilation is necessary because of the air-tightness of the building in order to provide necessary air change, but, to reduce the heat loss through the ventilation system the application of a recuperation system is a must (Feist *et al.* 2007).

Not only the individual parameters of the structure play the most important role in achievement of the passive house standard, but also the building's architectonic spatial organization, and particularly, the cardinal orientation of window openings, because a lot of energy is lost through the windows. Usually it is recommended to position the largest glazing in a building facing the south, as in this case windows with high thermal parameters can ensure that solar heat obtained through windows will be greater than the quantity of lost energy (Feist *et al.* 2001). However, it is necessary to consider that in summer there might be a risk of overheating therefore it is necessary to construct the shading of windows.

Table 1. Passive house parameters (Feist et al. 2007)

Walls, U-value	<0,15 W/(m²K)
Ground slab, U-value	<0,15 W/(m²K)
Roof, U-value	<0,15 W/(m²K)
Windows, total U-value	<0,8 W/(m²K)
Ventilation heat recovery efficiency, η_{HR}	≥75%
Air-tightness of the building envelope (Air leakage at the pressure differential 50 Pa)	0,6 h^{-1}
Specific heating energy consumption	≤15 kWh/(m²a)
Heating load	≤10 W/m²

Passive House Parameters Exposed to Latvian Climatic Conditions

The passive house standard was originally developed and widely used in the area of Central Europe, but the climatic conditions in the Baltic Sea region are much harsher. Different calculations have been made in Latvia in order to make certain on feasibility of achievement of the passive house standard under such climatic conditions.

The RTU specialists carried out a passive house simulation in TRNSYS software for the Latvian climatic conditions, taking as a basis a 160 m² one-family two-storey residential house. The paper describes two options of buildings with different building parameters. In both cases it was concluded that it is problematic to ensure the minimum heating load required by the passive house standard. This means that for such building a heating system is necessary, since warming by ventilation air would be insufficient (Kamenders 2007).

A bit more optimistic conclusions were made by a physicist Ainis Builevics, who made a passive house calculation for a 120 m² two-storey residential house with an ideal orientation, giving a desired indoor temperature of about 20 °C. According to the calculation in order to achieve the passive house standard it is required 700 mm of rockwool for thermal insulation of the walls and roof, 700 mm of polystyrene foam for thermal insulation of the floor and the double glazed windows with heat penetration U = 0,6 W(m²K), window frame heat penetration U = 0,7 W(m²K), and the ventilation thermal efficiency 92% (Builevics 2007).

Table 2. Passive house parameters under Latvian climatic conditions (Passive House Latvia 2010)

Walls, U-value	<0,10 W/(m²K)
Ground slab, U-value	<0,10 W/(m²K)
Roof, U-value	<0,10 W/(m²K)
Windows, total U-value	<0,8 W/(m²K)
Ventilation heat recovery efficiency, η_{HR}	≥80%
Air-tightness of the building envelope (Air leakage at a pressure differential 50 Pa)	0, 6 h^{-1}
Specific heating energy consumption	≤15 kWh/(m²a)
Heating load	≤10 W/m²

Since 2009, in Latvia, an association Passive House Latvia has been engaged in organization of the energy-efficient building design training workshops and mainstreamification of the idea. Passive House Latvia recommends the minimum requirements to observe in order to achieve the passive house standard under Latvian climatic conditions (Table 2). The first house designed pursuant to the passive house principles is the one-family residential building "Lielkalni" in Gipka village, Roja rural municipality (Fig. 1).

Fig. 1. Single family house "Lielkalni" in Ģipka, Latvia 2009 (late construction stage), E. Krauklis

The thermodynamic parameters of the house (Table 3) are very close to the passive house standards, however, they failed to achieve thereof, as the optimal orientation against the cardinal direction was not provided (due to the underground stream network), as well as due to the window position (architectural and practical considerations). Thus, at present, Latvia has no building built fully in accordance with the passive house standards. In comparison to the passive house criteria for the Central European climate condition defined by the Passive House Institute in Darmstadt, much higher criteria are necessary in order to attain the passive house standards in the Baltic region, as evidenced by the recently finished buildings designed applying the passive house principles (Table 3).

As evidenced by the listed theoretical and practical examples, the passive house criteria up to now have been considered mainly in architecture of single-family buildings located in the environment free from other spatial objects. Having studied the publicly accessible passive house database on the Internet, as well as various examples of passive houses constructed in Europe, one can conclude that the majority of passive houses have been designed in the environment free from other structures, and less frequently in an urban environment. Also, estimations performed in Latvia are mostly oriented to calculation of passive house parameters for free environment conditions, focusing on determination of technical parameters of a passive house. So far, less attention has been given to achievement of the passive house standard in a high-rise construction and the effect of the existing urban environment as an external factor on the building energy consumption. The consideration of this issue is essential for several reasons. First, the building compactness ratio or volume-to-size ratio, expressed in the building envelope area against the building heated area, is essential for the energy-efficient building design and achievement of the passive house standard. The bigger is the external surface area, the greater is heat loss through the external surfaces. A multifamily building per se is a more compact solution than a single-family low-rise building. Therefore, in architecture of a multifamily house, it is potentially easier to achieve the passive house standard, because the energy loss through the external surfaces, in relation to the heated area, is less than in one-family buildings. Secondly, insulation of a passive house in winter can provide an essential part of the building with necessary heat generation. Since in urban environment, other buildings cast additional shade to a projected building, a passive house placed in the real urban situation can receive a substantially smaller amount of solar heat radiation through windows, but this, as evidenced by the above referred practical example, can interfere with achieving the passive house standard. When designing a building in an undeveloped environment an architect is free to operate with cardinal orientation of window openings, estimating the balance of the building energy. Amid dense urban development this is much more difficult, because orientation of a building is restricted by the plot position, as well as the surrounding development situation. The character of

Table 3. Examples of the energy-efficient houses in the Baltic Region

	 *Single family house "Lielkalni" in Gipka (Latvia)	 **Single family house in Vilnius, Antakalnis (Lithuania)	 *Kindergarten in Valga (Estonia), reconstruction
Completion date	2009	2004	2009
Walls, U-value (W/m²K)	0,071	0,118	0,1
Roof, U-value (W/m²K)	0,053	0,076	0,07
Ground floor, U-value (W/m²K)	0,076	0,11	0,12
Windows, U-value (W/m²K)	0,8	0,67 (glazing) 0,65 (frame)	0,51 (glazing), 0,74 (frame)
Specific space heat demand (kWh/(m²a))	26	26	<30

* (Passive Through Active 2011)
** (Built Passive Houses 2011)

the impact of the surrounding development in such a case plays both negative and positive role. The shading cast by the surrounding buildings reduces the quantity of energy received through windows, thereby resulting in a negative effect on the building energy consumption index in winter, but mitigating the building overheating risk in summer. However, it is possible to fight overheating by applying basic arrangements, ensuring the window darkening, but, if it is necessary to position the building windows against the north, which is often unavoidable, the quantity of energy lost through windows might become very significant in the total balance of the building energy.

The fact that in the structure of urban development it is impossible to vary freely the orientation of the building, is another obstacle that interferes with accurate following of all of the passive house designing provisions and thereby theoretically compromises the achievement of the passive house standards as well. This article attempts to clarify the significance of spatial orientation of a plot and impact of surrounding development on the passive house parameters.

Objectives of the Project, tasks and applied methods

The objective of the Project was to analyze the building parameters thanks to which it would be possible to achieve the passive house standard in a multifamily house in the existing development structure under the Latvian climatic conditions, also finding out how much the urban spatial environment, as an external factor, affects the energy consumption by a passive house.

The Project was implemented in several stages:

- Theoretical definition of the building's geometrical parameters based on the Riga construction regulations and functional fundamental requirements.
- Definition of thermodynamic parameters of the building structures, ensuring the achievement of the passive house standard in a spatially free environment without shading and with optimal orientation.
- Placing the obtained building simulation in a real urban environment and simulation of energy consumption, with due allowance for the effect of the defined external factor of real urban environment, i.e., shade and orientation against the cardinal direction.

For the simulation of a passive house there was applied PHPP 2007 software, developed by the Darmstadt Passive House Institute for designing of a passive house. The software has a Table Excel file to enter various building design thermodynamic and geometric parameters. PHPP software has been tested in practice and improved, while designing many passive houses and comparing real results with calculations.

Definition of parameters of the simulated house

Since the climatic conditions play an essential role in the passive house simulation, already at the initial stage it was necessary to choose a particular geographic location with known climatic data. Within the framework of the Project, the climatic data of the capital of Latvia, Riga city, were applied. The initial house simulation was carried out, choosing the optimal orientation (orienting the front façade southwards) pursuant to the passive house designing principles and assuming that the building would be located in an environment completely free from other spatial objects. In this way, the building would receive the maximum quantity of solar thermal radiation, possible in the local climatic conditions.

The building spatial parameters were defined following the Riga construction regulations, which regulate construction in a perimeter development situation close to the historical centre of Riga. On this basis, the building height of 21,3 m to the eaves was selected, which accordingly meant that 6 storeys could be located in the building, (Fig. 2). As the building prototype, one section of a high-rise residential house (an apartment block grouped with one staircase) was chosen assuming that in a perimeter development situation only two facades would be the most common, as the other two would be blocked by the adjacent

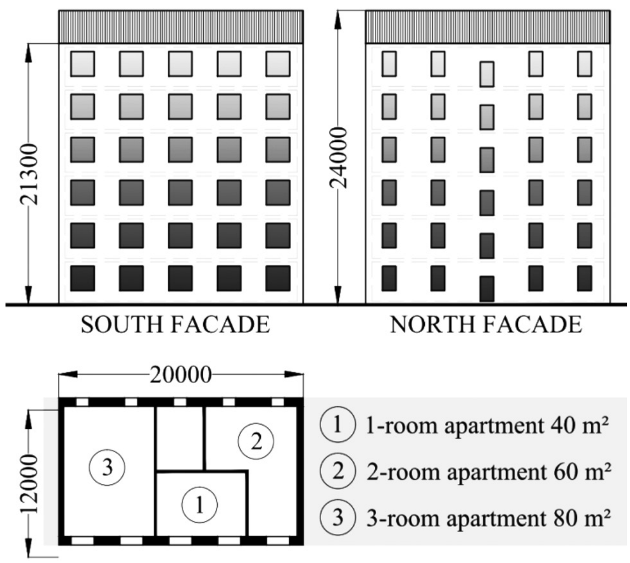

Fig. 2. Geometrical model of the simulated building

buildings. For the purpose of insulation requirements the depth of the building was assumed 12 m, but the section length 20 m, which enabled to connect to one staircase three apartments – one, two and three-room apartments. So, in total 18 apartments were planned in the building.

Table 4. Parameters of the simulated building

Walls, U-value*	0,093 W/(m²K)
Ground slab, U-value**	0,099 W/(m²K)
Roof, U-value***	0,068 W/(m²K)
Windows, total U-value	0,77 W/(m²K)
Ventilation heat recovery efficiency, η_{HR}	90%
Air-tightness of the building envelope (Air leakage at a pressure differential 50 Pa)	0, 6 h^{-1}
Specific heating energy consumption	7 kWh/(m²a)
Heating load	10 W/m²

* in situ reinforced concrete with 450 mm insulation
** reinforced concrete panel with 380 mm insulation
*** reinforced concrete panel with 500 mm insulation

The thermodynamic parameters of the simulated building design were assumed with due allowance for the recommendations of the Passive House Latvia (Table 4). Since due to the existing development situation it was impracticable to observe the optimal orientation of the building window openings, the area of windows was reduced to attain the passive house standard. As a result the minimum windows and floor area ratio was ensured according to the requirements by the Latvian statutory instruments. The area of the south-exposed windows was taken as 20% of the illuminated floor space, but the area of the north-exposed windows was 12,5% or 1/8 of the illuminated floor space. This was the maximum window area, with which it was possible to provide that the heat load for heating would not exceed 10 W/m² at the assumed design parameters. As a result, the building specific energy consumption was achieved 7 kWh/m² per annum ensuring the minimum criteria of the passive house standard. However, the reduced size of windows combined with significantly thicker than usually walls reduced the access of direct daylight into the room, as well as reduced the visual view angles through the windows. These problems in the process of real designing can be solved by changing the shapes of the edges of the window openings.

During calculations it was observed that even due to slight enlargement of the window area the heat load exceeds the passive house criteria and in order to compensate that it is necessary to increase significantly the heat insulating properties of the envelope structures. This could be explained by the fact that in a particular case assuming an abstract building layout and placing windows on both southern and northern facades of the building, within a year the total heat loss through the windows would be larger than the heat gain (13038 and 10633 kWh/a accordingly). If to place all windows only on the southern side, then the heat loss and gains would be 13083 and 14306 kWh/a accordingly. Therefore also the placement and orientation of windows in the design of an energy-efficient building refer to an essential factor to follow by when planning the building.

Urban Environment Impact on the Obtained Results

At the next stage it was assumed that the building with the resulting parameters will be placed in the perimeter development block in the centre of Riga. The centre of Riga is characterized by the perimeter development with the typical 21.3 m and 24 m maximum building volume height of the eaves. Selection of the site is determined by the factor that this urban development situation entails quite serious restrictions on the building insulation, the building orientation against the cardinal points, moreover, this is a typical development in the structure of Riga construction. For data entry it was assumed that the building would locate in a particular place in the Skolas Street, Riga (Figure 3). Due to the existing development situation the simulated building had to be rotated by 47° from the theoretically optimal orientation. As a result the specific heating energy consumption of the building per annum increased up to 8 kWh/m² or by 14%, the heat load remained unchanged, but the overheating risk increased by 4%, due to which it was necessary to provide for additional shading of windows in summer, unless shaded by the adjacent building. Therefore the next step was to evaluate shading cast by the surrounding buildings. As a result the specific heating energy consumption increased up to 9 kWh/m², but due to shading the overheating risk was mitigated and no other additional cooling arrangements were necessary. The heat load remained at the previous level. The passive house standard requirements were ensured.

The passive house standard was attained despite of non-observance of the optimal orientation of the building and additional shading from the surrounding urban development. Besides, the standard was achieved with comparatively similar parameters of the building structures as previously mentioned in calculations made by other authors. Here, obviously, an important role belongs to the factor of compactness of the building, because the works of other authors deal with small single-family houses, where the

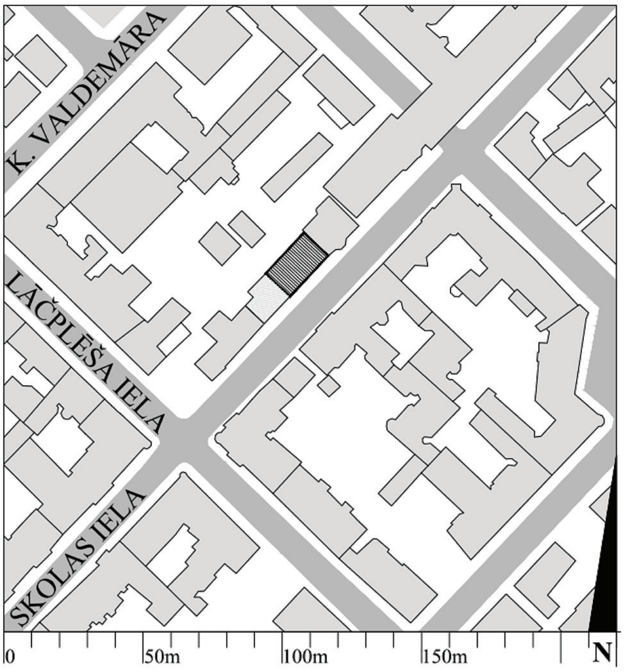

Fig. 3. The building location in Skolas Street, Riga

heat loss through the external surfaces if compared with the heated area of the building, in general, is higher than in a multi-storey apartment house. Besides, the results obtained in the course of modeling also do not significantly differ from already viewed examples of built passive houses in the Baltic region. Still, an urban environment creates additional encumbrances to achievement of the passive house standard, during designing it is necessary to reckon that the building must be much more compact and much greater reduction of sizes of the windows than estimated during designing a building in a free environment might be necessary, consequently involving more careful assessment of exposure of the interior to sunlight and of the façade composition.

The building model was developed in the abstract therefore it was not analyzed proceeding from the requirements of architectonic expression. However, the obtained front window proportions roughly correspond to the proportions of the historical development windows against the total façade area, which can be assessed positive. The façade architectonic composition in further designing should be solved by applying the façade plastics, finishing materials and differentiation of the window opening sizes, preserving the calculated area of window openings.

Conclusions

1. The passive house criteria for the multifamily house managed to be fulfilled with slightly lower design thermodynamic parameters than for the previously simulated one-family residential buildings in the same climatic conditions. This is explained by the fact that a multifamily residential house is a more compact construction type, where the heat loss through the external envelope is less in relation to the heated area, especially in the viewed perimeter development situation, where the building in fact has only two external walls.
2. Due to a specific multifamily house layout the windows were placed on both facades of the building, which produced a bottleneck to achieve the passive house standards. Therefore the sizes of windows in this house prototype were comparatively small. The building layout in the further work process should be more elaborated, with due allowance for the fact that it is not advisable to position windows on the northern side, in this way the façade composition to a larger degree depends on the functional organization of the layout.
3. The calculation process showed that the specific energy consumption for the chosen building parameters per annum will be provided with a reserve, but it would be more difficult to fulfill the minimum heat load requirements. This is also consistent with the passive house calculations made by other authors under the Latvian climatic conditions.
4. Placing the building in a real development situation, changing its orientation by 47 degrees and causing additional shade from the adjacent buildings, increased the specific energy consumption required for heating of the building by 22%, however, the passive house standards have been fulfilled. Despite the fact that surrounding buildings significantly affect the energy consumption of a passive house, their impact is not an obstacle to the implementation of a passive house concept also in the historical urban development.
5. The obtained results evidence that it is impossible to define precisely the spatial parameters of passive house architecture for the building in general within a particular climatic region, because the achievement of necessary parameters is significantly affected by the building three-dimensional composition, the façade window composition and orientation of the building against the cardinal points. In different situations and for different building types (a single-family building, a multifamily building) the passive house standard can be achieved with slightly different design parameters, therefore during the designing process an individual calculations must be always applied.

Aknowledgements

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MIESTO PLĖTROS ĮTAKA PASYVAUS NAMO ENERGIJOS VARTOJIMUI

E. Suvorovs

Santrauka

Straipsnyje nagrinėjama viena iš energiją tausojančių pastatų formų – pasyvus namas. Atliekant konstrukcijų ir erdvinio planavimo parametrų tyrimus, buvo imituojamas daugiabutis gyvenamasis namas, turėjęs užtikrinti pasyvaus namo energijos taupymą ir atitikti visus standartus. Imitaciniam modeliui buvo pasirinkti Rygos miesto klimatiniai duomenys. Rezultatų išvados byloja, kad langų padėtis ir aplinkinių namų šešėliavimas daro esminę įtaką energiniam namo efektyvumui, bet, nepaisant to, įmanoma atitikti pasyvaus namo standartus.

Reikšminiai žodžiai: energiją taupantis namas, pasyvaus namo orientacija.