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Architectural Changes that achieves Zero Energy Residential Building while ensuring Thermal Comfort

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Abstract

The paper is oriented on architectural changes that achieves zero energy residential building while providing thermal comfort. The research was carried out on searching for possibilities, which would approach the existing residential buildings to zero energy buildings. Existing residential buildings must remain competitive in the real estate market. Therefore, this paper is creation on progressive solutions, which application will significantly contribute to the approach towards zero energy balance. Research was carried out on a particular residential building in Bratislava in Slovakia. Individual phases of improvement of this residential building were scientifically analysed. The annual energy balance for individual phases was calculated and then it was evaluated. The basic improvement phases of energy balance of particular residential building were: insulation, regulation of heating system, application of heat pumps, application of solar collectors and photovoltaic modules. The scientific outputs are presented by well-arranged graphs. In each improvement phase is analysed the architectural creation in existing residential building and evaluated risks and contribution for energy balance. These improvements cannot be at the expense of the thermal comfort. Therefore, the other part of the research focused on the experimental measurements which evaluated the thermal comfort in the interior of the residential building. This research wants to focus on new possibilities for architectural creation in existing residential buildings.

Keywords:	Architectural changes; Improvements of existing residential building; Thermal comfort; Zero energy building

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1. Introduction

All new buildings should have almost zero energy balance in 2020 according to the directive 2010/31/EU. This goal can be achieved by application of progressive technologies. It will be necessary to apply progressive technologies also into existing buildings successively.

Architectural design of residential buildings will have to change significantly. Zero energy residential buildings will mean big challenge for architects. Creating harmony between architectural concept and progressive technologies is demanding process. Compositional solution in this process should remain interesting and inspiring.

Examples of new zero energy residential buildings are realized in abroad, thus the first realization and operational experiences exist [1]. In Slovakia is not old residential building with zero energy balance, so we do not have concrete knowledge, what the possibilities in this area are [2]. Existing residential buildings must significantly improve their energy balance in order to remain competitive with new buildings [3]. Utilization of progressive technologies brings for existing residential buildings the option to improve the energy saving significantly and even to approach to zero energy balance [4]. Therefore, this research was seeking for short term solutions how to improve energy balance but also for long term solutions by which existing old buildings might approach to zero energy balance.

The improvements of existing residential building cannot be at the expense of the thermal comfort. Therefore, the other part of the research focused on the experimental measurements which evaluated the thermal comfort in the interior of the residential building. The fundamental quantities for the evaluation of thermal comfort are internal air temperature, operative temperature, globe temperature, air relative humidity and air velocity [5]. Then the thermal comfort is evaluated with index PMV (Predicted mean vote) and index PPD (Predicted percentage dissatisfied) [6], [7].

2. Architectural change of existing residential building with realisation of thermal insulation

Reconstruction of residential buildings in Slovakia consists of just thermal insulation because state subsidies are just focused on insulation.

Architectural creation by realization of thermal insulation is very significant. In this process, the residential buildings get new facade, therefore coloured and expressional completion of facade will increase the quality of composition of existing facade significantly. This way the drabness of existing residential buildings might be eliminated. Aesthetic value of existing residential buildings will increase significantly by new interesting coloured composition of facade.

On the other hand, realization of thermal insulation brings significant energy saving and elimination of constructional faults of facade.

2.1. Characteristic of research

Residential building in Bratislava has ten floors, flats are located on the last seven floors. External cladding is from porous concrete panels with thickness 300 mm. Vertical bearing walls are made of concrete panels with thickness 150 mm, dividing walls are made of concrete panels with thickness 80 mm, ceilings of each floor are made of precast concrete slab with thickness 150 mm. Plastic windows are five-chamber. The flat roof is insulated with boards Polsid with thickness 70 mm. Heat transfer coefficient of the existing structures that change: external wall 0,60 W/m^{2}K, roof 0,51 W/m^{2}K. In the summer 2013 took place the reconstruction of a residential building, which is mainly focused on the insulation of external cladding. In reconstruction was included external wall insulation with EPS insulation with thickness 100 mm and roof with thickness 120 mm. Heat transfer coefficient of insulated constructions: external wall 0,24 W/m^{2}K and roof 0,19 W/m^{2}K.

In Figure 1 is south facade of residential building before realization of thermal insulation and in Figure 2 is north facade. Residential building after realization of thermal insulation is in Figure 3 – south facade and in Figure 4 – north facade.

The specific need of heat for heating in current state was calculated, which is $Q_{H,nd}^{C}$ = 62,2 kWh/(m^{2}year) with the factor of building shape of 0, 29. The specific need of heat for heating after reconstruction was calculated, which is $Q_{H,nd}^{R}$ = 32,3 kWh/(m^2.year) with the factor of building shape of 0,29. In Slovak Technical Standard STN 73 0540-2 [8] the normalized value is $Q_{H,nd,N}$ = 50 kWh/(m^2.year) and the recommended value is $Q_{H,nd,r1}$ = 25 kWh/(m^2.year). Because of evaluation of energy class the need of energy for heating and for warming of hot water was calculated. Total need of energy in current state is 105 kWh/(m^{2}year) and total need of energy after reconstruction is 64 kWh/(m^{2}year).

2.2. Analysis and results of research

The Figure 5 represents the comparison of specific need of heat for heating before realization of insulation, normalized value, after realization of insulation and recommended value.

It is obvious, that in terms of Standard STN 73 0540-2 the researched residential building after reconstruction

Figure 1. Residential building before realization of thermal insulation – south façade

Figure 2. Residential building before realization of thermal insulation – north facade

Figure 3: Residential building after realization of thermal insulation – south façade

Figure 4: Residential building after realization of thermal insulation – north facade

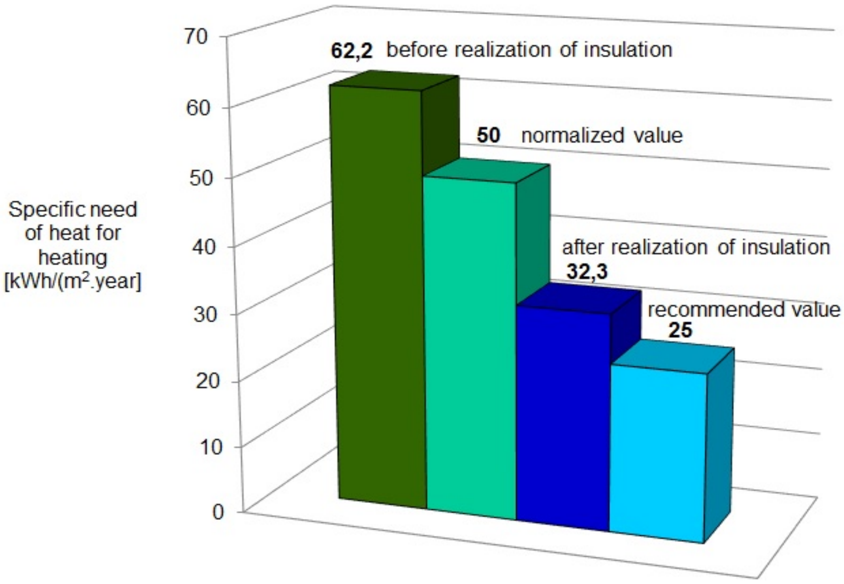

Figure 5. Comparison of specific need of heat for heating before and after realization of thermal insulation

Table 1: Comparison of energy class in term of ordinance n. 364/2012

Phase	Need of heat for heating [kWh/(m^2.year)]	Energy class for heating	Total need of energy [kWh/(m^2.year)]	Energy class for total need of energy
Before realization of insulation	**62,2**	**C**	**105**	**C**
After realization of insulation	**32,3**	**B**	**64**	**B**

meets normalized value, but does not meet recommended value. From the Figure 5, 48% saving in specific need of heat for heating is obvious after the reconstruction compared to current state. It is needed to hydraulically regulate the whole heating system.

Table 1 represents the comparison of energy class in term of ordinance n. 364/2012 [9] for researched building before and after realization of insulation. From the Table 1, it is obvious the improvement of energy class from C to B, thanks to insulation of residential building.

3. Research of thermal comfort after the architectural change of residential building with realisation of thermal insulation

Not fulfilling the parameters of the thermal comfort in the rooms of flats causes dissatisfaction of dwellers not only in the winter but also in the summer period [10]. Incorrect provision of the thermal comfort increases energy demands, which causes the problem in the effort of achieving the zero energy residential buildings in the future [11].

3.1. Characteristic of research

Experimental measurements were carried out in a flat of the new high residential building in Bratislava in the beginning of November 2016. The aim of measurements was to record the parameters of the thermal comfort: air temperature, air relative humidity, air velocity, globe temperature, index PMV (Predicted mean vote) and index PPD (Predicted percentage dissatisfied).

Measurements were carried out in the room with dimensns 4,05 x 4,75 m, 1,1 m above the floor level in these standpoints:

A – In the distance of 1,0 m from the external wall in the center of three-wings window; 1,1 m above the floor level, Figure 6,

B – In the center of the room; 1,1 m above the floor level, Figure 7.

Dimensions were as following: three-wing window 2,4 x 1,4 m; panel radiator 1,4 x 0,6 m.

The parameters of the thermal comfort were recorded with the device Testo 480. Input data in measurements were: metabolic rate 1,0 met, clothing insulation 1,0 clo. Measurements were carried out one by one in the individual standpoints.

Outdoor air temperature was measured and recorded by the separate device. Outdoor air temperature increased during the measurement from the value of 5,8 °C to the value of 5,4 °C.

3.2. Analysis and results of research

The values of air temperature, air relative humidity, air velocity, index PMV and index PPD are given in the Table 2.

Air temperature reached satisfactory values in the both standpoints. Standpoints were chosen in the critical places of rooms. Since the satisfactory air temperature was achieved in this room, it proved the correctness of architectural change of existing residential building with realization of thermal insulation. Better results were achieved in standpoint A than in standpoint B.

Figure 6. Measurement 1,1 m above the floor level in standpoint A

Figure 7: Measurement 1,1 m above the floor level in standpoint B

Table 2: Values of the parameters of the thermal comfort

Parameters	In standpoint A	In standpoint B
Air temperature (°C)	23,9	24,6
Air relative humidity (%)	46,9	49,1
Air velocity (m/s)	0,0	0,0
Index PMV	+0,38	+0,48
Index PPD	8,3	9,8

Air relative humidity reached satisfactory values in the both standpoints. Frequent natural ventilation could decrease the values of air relative humidity.

Air velocity achieved satisfactory value 0,0 $m.s^{-1}$ in the both standpoints.

Measured values of Index PMV and Index PPD were optimal, which definitely showed the correctness of architectural change of existing residential building with realization of thermal insulation. All the values of Index PPD were smaller than 10% that can be considered as excellent result. Values of Index PMV were more optimal in standpoint A than in standpoint B.

Architectural change of existing residential building with the realization of thermal insulation was not at the expense of the thermal comfort. On the contrary, it helped with the optimization of the parameters of the thermal comfort.

4. Architectural change of existing residential building with solar collectors and photovoltaic modules

Application of solar collectors and photovoltaic modules means significant step for extensive feasibility of zero energy residential buildings. With the utilization of the aesthetic dimension of photovoltaic modules, architects apply them intentionally on buildings as architectural elements. The aesthetic appearance of the photovoltaic segments offers new design aspects for the architectural facade composition. The most important element in terms of architecture is the photovoltaic facade.

4.1. Analysis of architectural integration of photovoltaic modules into the facade

Photovoltaic cells are conveniently integrated into building envelopes or infrastructure systems. They thus become an architectural element of the building or the system. In high rise buildings, the installation on the façade is self suggestive. The photovoltaic cells thus create the outer shield and at the same time replace conventional façade elements. For environmental reason, the option with rear ventilation, where there is a slight air flow between the photovoltaic cell and the wall construction, is preferable.

The traditional photovoltaic modules are often unsuitable for integration into the façade. Increasingly, however, photovoltaic modules are available which comply to these new requirements. For the installation of the photovoltaic elements, established systems of the conventional roof and facade construction should be used whenever possible. The integration into the facade is technically less difficult than that into the roof.

The integration of photovoltaic modules into the facade of building can be created in terms of construction:

a./ A shingled facade with an aluminium sub-construction.

b./ Any elements of facade – with or without photovoltaic cells – are fixed.

c./ Façade system with suspended adapters which can at best be fitted with photovoltaic cells.

d./ The so-called Rütihof facade system is only suitable for facades with smaller surfaces as the tolerance for the dilatation is low.

e./ The German product, Flagsol, uses photovoltaic cells placed between two glass screens. Depending on the requirement, insulation or noise insulation glass is used.

f./ Fassade 2000 is a combination of daylight use, power production with photovoltaic cells, heat protection in the summer due to a low g-value and shading as well as solar energy use through the windows (direct gain) in winter.

The integration of photovoltaic modules into the facade can be created in term of thermal insulation:

A./ Cold facade

This facade is hanging and all parts are constructed without thermal division. The façade doesn't have a connection with the insulated areas of the building. With this type of façade, the thermal insulated areas of a building with protection before the influence of weather are used. This facade consists generally of one safety glass. Glass can be substituted with photovoltaic modules.

B./ Cold – warm facade

In this façade cold and warm areas are alternated. Warm areas are created from insulating materials and thermal division profiles. Cold areas (sills) are insulated areas of a building by glass. Glass can be substituted with photovoltaic modules.

C./ Warm facade

This facade insulates and protects the building from weather conditions and noise, as well as serves its basic static function. The applying elements are: insulating panels, insulating glass and photovoltaic modules in conjunction with insulating glass.

4.2. Characteristic of research

For utilization of progressive technologies was proposed to apply these progressive technologies in the researched residential building: solar collectors and photovoltaic modules. It was proposed to locate 36 pieces of solar collectors with area of 72 m^2 on a flat roof. Furthermore, it was proposed to locate 82 pieces of photovoltaic modules with area of 132 m^2 also on a flat roof. Reaching the optimal south facing of solar elements on a flat roof will not be a problem. On the south external wall in the place of inter-ceiling installation, was proposed to place 68 pieces of photovoltaic modules, Figure 8. So the total surface of photovoltaic modules is 241,5 m^2. In Figure 9 and Figure 10 are marked further alternative options of position of photovoltaic modules on facade. Because of comparability, the need of energy for heating and for warming of hot water was calculated. Total delivered energy after the second phase of reconstruction is 38 kWh/(m^{2}year).

Figure 8. Residential building with marked application of photovoltaic modules

Figure 9. Building with marked application of photovoltaic modules in the place of sill

Figure 10. Building with marked location of photovoltaic modules on gable side wall

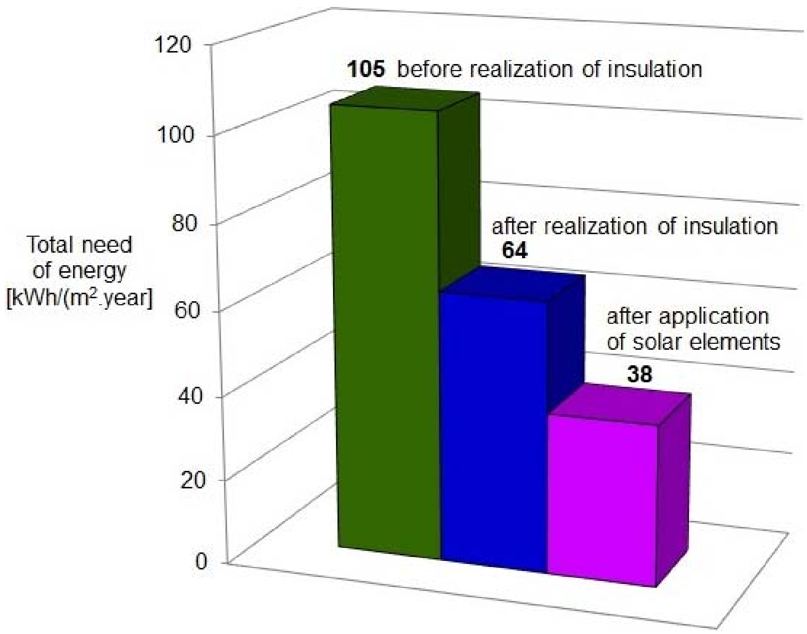

Figure 11: Comparison of total need of energy – before and after realization of insulation, – after application of solar elements

4.3. Analysis and results of research

Figure 11 represents the comparison of the specific need of heat before realization of insulation, after realization of insulation and after application of solar elements.

4.4. Discussion

From the Figure 11, the efficiency of utilization of progressive technologies is obvious, when solar collectors and photovoltaic modules significantly contribute to improvement energy balance and they approach the existing residential building to zero energy balance. Residential building would get to energy class A.

The advantage of this residential building is, that it has big enough, not shielded area of the roof for location of solar collectors and photovoltaic modules. The next advantage of this residential building is big enough, not shielded area of south peripheral wall with the possibility of location of photovoltaic modules. Residential building has excellent localization, because in front of south peripheral are only family houses, what guarantee that this face of building will not be in the future shielded by another high buildings.

Architectural integration of photovoltaic modules into the facade completed the composition of residential building significantly. As this example showed, by the appropriate incorporation of photovoltaic modules the residential building might gain interesting compositional solution, which will influence the overall artistic impression positively.

On the other hand, the application of solar elements has several problems, which are hardly reducible without the help of state. State should contribute on the increased investment costs on solar collectors, and photovoltaic modules in some way. In many countries of Europe, the state support of green energy is common; occupants pay only the part of the costs. Next, there should be formed better legislative conditions for disconnecting residential buildings from central district heating, to stop working exchange station. There should be also improved conditions for purchasing electrical energy from photovoltaic modules in summer season – when there is the surfeit of electrical energy and the bargain of electrical energy back in the winter season – when there is a lack of electrical energy.

5. Architectural change of existing residential building with heat recovery system

In this case, the application of heat recovery systems will influence architectural creation of existing residential building in interiors. In each flat under the ceiling, it will be necessary to place the device of heat recovery system and pipes, which will be appropriate to overlay with soffit. Proper architectural effect might be achieved by appropriate formation and material of soffit.

5.1. Characteristic of research

As the next improvement of energy balance was proposed to apply these progressive technologies in researched residential building - heat recovery systems. Into each flats under the ceiling will be placed heat recovery. Total delivered energy after the third phase of reconstruction is 23 kWh/(m^{2}year).

5.2. Analysis and results of research

Figure 12 represents the comparison of the specific need of heat before realization of insulation, after realization of insulation, after application of solar elements, after application of heat recovery systems.

From the picture, the efficiency of the application of heat pumps significantly improved energy balance and so the existing residential building would almost reach the zero energy balance.

6. Conclusions

Architectural change of existing residential building is very important process. This research pointed out, that by appropriate incorporation of progressive technologies the residential building might gain interesting compositional design, which will influence the overall artistic impression positively.

Finding solutions how to achieve zero consumption for existing residential buildings is very important because they make up large part from all residential buildings. Therefore, the research is aimed to highlight the possibilities of improvements of energy balance of existing residential buildings with the help of utilization of progressive technologies. Validity of realization of thermal insulation as improvement of energy balance is clear, therefore its application in the form of insulation is relatively extended. For utilization of progressive technologies in researched residential building, it was proposed to apply solar collectors and photovoltaic modules. As the next improvement of energy balance in researched residential building was proposed to apply heat recovery systems. Application of solar elements and heat pumps brings also problems, which can be eliminated mainly by the help of state. Some states can handle these problems. Therefore, these problems should get bigger attention also in Slovakia. Despite of these problems, there was pointed real way of possibility to approach to zero energy balance also in

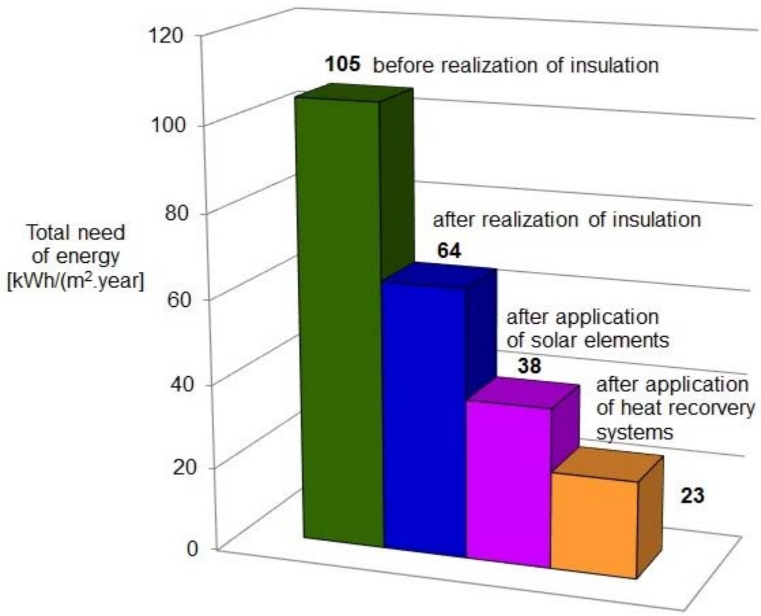

Figure 12. Comparison of total need of energy – before and after realization of insulation, – after application of solar elements, – after application heat recovery systems

existing old residential buildings. So the goal in the directive 2010/31/EU is possible to achieve, or just to approach to it also in the case of old residential buildings.

The utilization of progressive technologies cannot be at the expense of the thermal comfort. The research showed the architectural change of existing residential building with realization of thermal insulation was not at the expense of the thermal comfort. On the contrary, the optimization of the parameters of the thermal comfort was achieved.

This research showed the possibilities of architectural change of existing residential building. The research proved, that not only zero energy of residential building, but also valuable architectural work will be achieved by appropriate incorporation of progressive technologies.

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References

[1] Kraftwerk B, Plusenergie-MFH, Bennau. *Schweizer Solarpreis 2009*, (2009), pp. 30-31.

[2] Chmúrny I., *Tepelná ochrana budov*, *Thermal protection of buildings*, Jaga, Bratislava, Slovakia, 2003.

[3] Budiaková M., *Energeticky úsporné budovy*, *Energy saving buildings*, A- Projekt, Bratislava, Slovakia, 2003.

[4] Maclay W., *The New Net Zero*, CHGP, USA, 2014, p. 542.

[5] Bánhidi L., Kajtár L, *Komfortelmélet* (Comfort Theory), Muegyetemi kiadó, Budapest, 2000.

[6] STN EN ISO 7730 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, Slovak Office of Standards, Metrology and Testing, Bratislava, 2006.

[7] STN EN ISO 7726 Ergonomics of the thermal environment. Instruments for measuring physical quantities, Slovak Office of Standards, Metrology and Testing, Bratislava, 2003.

[8] Slovak Technical Standard STN 73 0540-2 Thermal protection of buildings. Thermal performance of buildings and components. Part 2: Functional requirements. 7.201.

[9] Ordinance n. 364/2012 of Transport, Construction and Regional Development of the Slovak Republic, 12.11.2012, Slovakia.

[10] Jokl M., *Zdravé obytné a pracovní prostředí* (Healthy Living and Working Environment), Academia, Praha, 2002.

[11] Voss K., Musall E., *Net Zero Energy Buildings,* EnOB, München, 2012.