Optimization of energy consumption and cost effectiveness of modular buildings by using renewable energy sources

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Problems of the temporary structures are generally dealt with by the use of modular buildings. These actually meet the terms of low costs, as appose to the terms of convenience of use, or energy efficiency in operation. Using the latest technologies in the production of the modular buildings has improved the operation sufficiently; it is now possible to use them entirely for purposes associated with the use of the buildings. Office buildings, warehouses, and conference rooms have become common standard. In Slovakia, we can already see it as a normal part of cities and municipalities: social housing, schools, and kindergartens, which were all built using this technology. During the assessment phase of these buildings, energy efficiency is always the priority. This article is aimed at establishing the economic potential of modular buildings in the field of use of renewable energy sources. For the formulation of the problem and the definition of borders of studied parameters, we proposed a four-dimensional competency decision-making space. This determines the examination process that should identify areas in which it is appropriate to consider and assess the use of renewable energy sources.

Key words: *The modular building, economy, heating, cooling, renewable energy, energy saving*

Introduction

In recent years, the continuing worldwide decline in economic indicators entails the crisis in the construction industry in the Slovak Republic, resulting in an increasing resonance of highly efficient construction of residential modules, alternatively called 'containers'. (Rafayová et al., 2012) These buildings are often wrongly called building units. Construction of container modules in Europe is not new; it has been used for more than fifty years, and their success is due to the speed of construction, minimal environmental disruption, and high variability. Today, when it is necessary to respond to situations flexibly and rapidly, the Modular construction directly offers an appropriate solution. (Tomčejová, 2012) The most prominent representative of container architecture in Europe is the German architect Han Slawik, who has to his credit some successful realizations. RES in this area are used only sporadically. The aim of this paper is to assess the real possibilities of using renewable energy in these buildings. (Tkáč et al., 2012)

The characteristics of modular building

Modular architecture responds to needs specific to the production of economically affordable housing, the lack of space in cities, an eco-friendly way of life a not least the pitfalls of legislative. The modular design is smart but is also a comfortable solution for today's lifestyle. (Buc, 2012) Modular construction from the very beginning was generally utilized because of its' immediate need to respond to the current situation.

Module

A module represents a unit of measurement. The term comes from the Latin word "modulus" - a small unit of measurement. A module in architecture is traditionally derived from the scale of a human figure or the fixed scale. The modules are a means of standardization of constituent component of the building. Modules used to build today's modular objects are referred to as prefabricated space modules. The most detailed element of the module is Le Corbusier module that expresses the specified system, which had merged a measure of human scale with conventional scale. In a modular design, the module is composed of multiple materials in a so-called sandwich system construction. The whole building is assembled from these modules of the same size.

Utilization of modular buildings

Modular constructions were born in the United States, where a relatively high percentage of houses and residential buildings are built by the use of this method. The most developed country in this particular field in Europe is the UK, where there are thus constructed primarily schools, kindergartens, nursing homes and other similar buildings. There are some administrative buildings under construction that the Slovak Republic started

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to inspire first by. School facilities in Slovakia are still built by the traditional method, which creates a problem of underutilization in the case of the young generation decreases. Another appropriate use of modular buildings is in the business sector, during the construction of hotels, restaurants, shops, car repair shops and so on.

Fig. 1. Administrative modular building (Source: Algeco).

Modern age demands modern approaches. The speed and flexibility of this system often determine the reasons why investors opt for modular construction projects. Rapid return on investment is their reward for progressive thinking. Modular constructions appeal to investors by their mobility with the possibility of disassembly and reassembly at the new location. This method of construction is also environmentally friendly because the construction site is quiet and clean. Air pollutants, which occur in the conventional constructions, are minimized. Use of modular construction is friendly on the surrounding area, with no large claims to the territory for setting up the construction site.

The energy demands of modular buildings

The operation of modular buildings, correspondents to permanent constructions, requires high costs. The largest share of operating costs requires ensuring thermal comfort as well as power supply. Heating and cooling of modular buildings costs just as much as the rental price of such buildings. At present, the standard method of heating in temporary modular buildings is a direct electrical heating unit. Cooling is provided by a separate air conditioning unit.

The energy demands represent the amount of energy required to operate the building. Here, we count every energy input entering the building for its purposeful use. (Braunmiller et al., 2009) This is the energy for heating, heat loss coverage, cooling - reducing heat gain, hot water, ventilation, lights and power necessary for the operation of other, mostly electrical appliances. Energy demands can be perceived in two ways.

The investment energy demands are difficult to determine and include energy consumed in the production of materials for the construction of the building and its liquidation.

In contrast, **the operating energy demands** are becoming a major indicator of economic operation of the building. Energy performance of the building represents the amount of energy consumed in its operation. Operating energy values may be affected already in the project phase when it can be modified by factors that cannot be edited in the already built objects, such as placement in the field, shape, methods of deployment of a glass surface, the composition of envelope structures, etc. Factors that can be modified in built objects are internal heating systems, hot water systems, air treatment and ventilation, air conditioning or heat gain utilization.

Energy consumption provided by Energy Performance of Buildings may differ from the actual values because they are considered as a standardized use of the building. In determining the energy performance of buildings, we need to address the areas that can correctly assess the current situation and recommend improvements. (Durdán et al. 2014) These areas are:

1. **Description and evaluation of the initial state** - except basic identification data of the building – the location, size, shape, age, it is necessary to identify ways of using and energy supply. It also requires characterization of the physical and structural condition of the object, as to the composition and characteristics of the envelope structure's condition, the roof, floor, and apertures. Another area is the technical condition of the building, which addresses an energy supply system, the manner of their usage and their technical specifications. It deals with the technical condition of the heating system, its parameters, hot water supply and lighting method.
2. **Energy balance** - for determining the energy intensity of the building it is necessary to balance the type, amount and purpose of energy including losses in the supply and distribution networks due to the influence of the efficiency.
3. **Selection of the energy source** - the optimal solution is a choice of energy source for each building separately. It should be considered in addition to the technical characteristics of the building, the site of a building location, the purpose of its use, the time of its operation, and so on. (Papučík et al., 2014) It is not appropriate to standardize the energy source. Renewable energy sources are usually financially

more demanding than traditional energy sources; it is, therefore, appropriate to consider its use in some aspects. (Rybár et al. 2015)

4. **The economic assessment** – the considered options should also be evaluated in terms of their economic efficiency of the use of investment funds and the saving effect achieved. This is based on the value of the building before and after the implementation of austerity measures and the determination of the internal rate of return, which is the ratio of the increase in value to the funds spent and determine the payback period for investments. It is clear that the optimal variant is the one that will bring the highest internal rate of return and shortest payback period.

Ad 1

The energy performance of the building operation in addition to those above can be majorly influenced by the shape of the building. (Kušnír et al., 2013) It can be a problem, especially for modular constructions. Investors are often requesting a design in such a variety of unusual shapes to increase the attractiveness of the building. However, the more building is fragmented; the more thermal losses are recognized. (Mesároš et al., 2013) Therefore, we examined five different shapes of modular buildings. These are shown in Fig. 2.

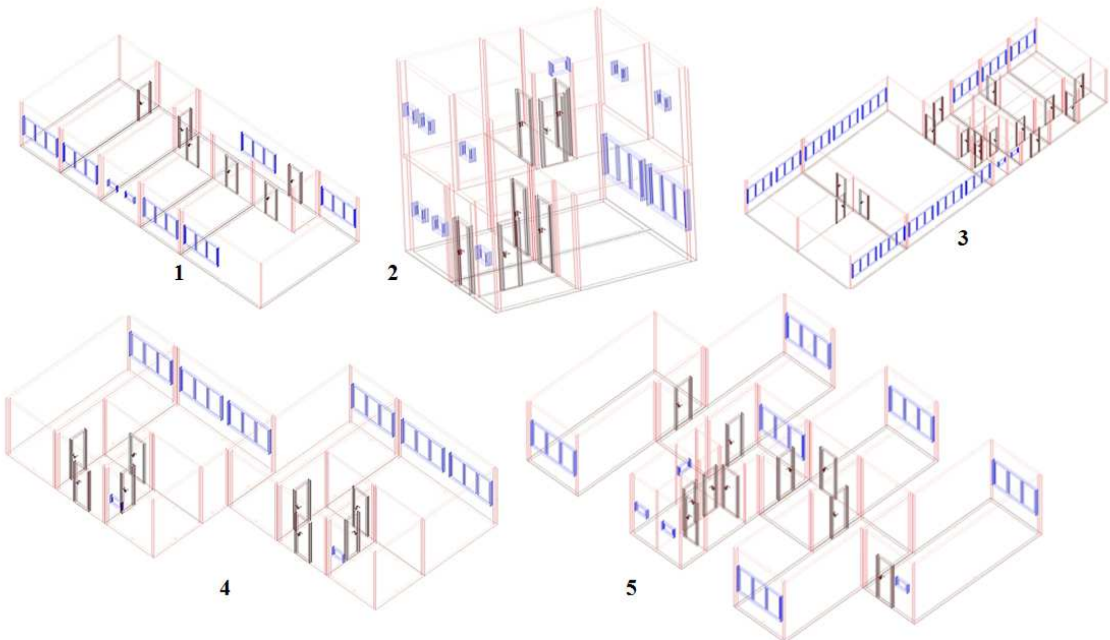

Fig. 2. The spatial arrangement of studied buildings.

The most energy-efficient and the most widely used alternative is the alternative no. 1. For this variant, the measurements were obtained for energy consumption in the 2013 and 2014 and compared with the calculations of the normalized energy consumption. For the other variants that are part of the research for the possibilities of using renewable energy sources, we established the values for energy consumption only by use of standardized calculation.

Ad 2

The first factor counted for the balance calculation is the calculation of building heat losses. We counted according to the technical standard STN EN 12831. The thermal loss calculation method for cases examined is based on the following assumptions:

a, air temperature and designed temperature are evenly distributed,
b, building heat losses are calculated for steady state assuming constant properties (temperature values, properties of building structures, etc.),
c, the height of the building must not exceed 5 m,
d, buildings are heated to a specified and lasting temperature interval,
e, we have to assume the same temperature and the resulting temperature of the air.

Total design heat loss of the heated area is calculated using the formula:

$$\Phi_i = \left(\Phi_{T,i} + \Phi_{V,i}\right) \cdot f_{\Delta\theta,i} \quad \text{[W]} \tag{1}$$

Legend:

$\Phi_{T,i}$ – designed thermal loss in the transition of heat in the heated space (W),

$\Phi_{V,i}$ – designed heat loss caused by ventilation in the heated space (W),

$f_{\Delta\theta,i}$ – temperature correction factor (-),

The total proposed thermal input of heated object is based on the relation:

$$\Phi_{HL,i} = \Phi_{T,i} + \Phi_{V,i} + \Phi_{RH,i} \quad [\mathrm{W}] \tag{21}$$

Legend:

$\Phi_{RH,i}$ - starting heat output required to offset the effects of the intermittently heated area (W).

Of course, the overall calculation consists of many sub-calculations. The method for calculating heat loss from building consists of these steps:

1. determination of the value of the external temperature and the average outside temperature values,
2. definition of the heated and unheated areas and entering the values of internal designed temperature for each heating room,
3. determination of dimensional and thermal characteristics of all building structures,
4. the calculation of projected heat loss by the transition of the heat, (Durdán et al., 2015)
5. calculation of the designed heat loss caused by ventilation,
6. calculation of total heat loss of the heated area,
7. calculation of the heat input to the heated area,
8. calculation of total projected heat input for the heated area.

Because of the required emphasis on the quality of the indoor environment, we considered in our calculation the heating as well as the cooling of the area. The results of calculations for the Scenario 1 are as follows:

Tab. 1. Annual energy requirements of modular buildings.

Annual energy requirements	Heat	Cold	Electricity (Other)	Overall
$(\mathrm{kWh \cdot a^{-1}})$	19 217	7 687	6 282	33 186

As mentioned above, the calculations for this variant were measured and obtained during the years 2013 and 2014. The results of the measurements are shown in Table 2. The table shows the average values for the years 2013-2014. They show that the actual energy consumption is lower than the calculated. This may be caused by warmer winter periods of operation, which are becoming more frequent in our country. On the other hand, these results confirm the correctness of the calculations of heat losses for other variants.

Tab. 2. Electricity consumption measurements in the studied building.

Month	Total consumption (kWh)	Energy consumption for heating (kWh)
January	3 242,22	2 945,16
February	3 425,54	2 459,87
March	2 258,72	1 857,95
April	1 594,50	1 462,50
May	1 410,52	315,90
June	934,65	0,00
Lujy	1 117,31	0,00
August	1 413,39	0,00
September	1 516,52	76,80
October	2 770,20	1 839,58
November	2 676,92	2 518,92
December	2 657,06	2 496,06
Totaly for Year	25 017,55	15 972,74

The course of the electricity consumption is similar in most modular buildings for administrative use and educational institutions. Therefore, it is intended to work primarily with renewable resources to enable comparison with the model used so far to respond flexibly to the consumer requirements and enable the production of heat but also cold.

Ad 3 Choice of energy source

The categorical imperative for the choice of energy source is in the nature of **temporary modular buildings**. This means that the priority is focused on an easily accessible link to the local energy and local renewable energy sources. Because of a need for labor resources for operating, cleaning and regulatory regimes, they have primarily excluded "primitive" renewable energy sources such as biomass and its derivatives. (Cehlár et al., 2014) (Šebo et al., 2007) A second approach was to exclude the orientation of the heat pump water/water, which is particularly expensive to install because of the need for two water wells, boreholes or meanders. For the third approach, we would select renewable resources that fulfill the requirements of modularity, the simplicity of installation and operation and are structurally acceptable. This condition was met in photovoltaic technologies that use solar energy. (Tošer et al., 2014) Each of the following energy-economical version will be considered in the final assessment of the contribution of PV equipment, designed according to the type of building and according to the method of electricity consumption in the building. The first criterion of the Quantifying was to determine the ranking order of the energy sources constituted, expressed by the unit costs for the variable component of the balance.

The appropriate resource systems in the area of the intended installation of the modular buildings are the following variants:

A. electricity only (cooling and heating), electricity (other)
B. natural gas - heating, electricity - cooling, electricity (other)
C. heat pump - air/water (RES), electricity (other)
D. district heating, electricity (other)

As it appears from the preceding, all the variants occur with the consumption of electricity and other electrical consumption, including the electrical appliances in the building. Thus, the use of photovoltaic equipment was considered in all tested varieties.

Photovoltaic equipment

In Slovakia, it is necessary to consider what kind of PV panel will be used to generate electricity. It is true that a monocrystalline cell has the highest efficiency from direct sunlight, which makes it suitable for use on the swing structures, also called "trackers". (Vaculík et al., 2014), (Dostál et al., 2012) This fact excludes the use of monocrystalline PV panels for the needs of modular buildings. A preferable alternative in our conditions is the use of polycrystalline, amorphous and thin-film PV technologies. The advantage of these types is the absorption of a higher proportion of diffused solar radiation. The disadvantage of amorphous and thin-film modules is the need to have around twice the area for an equal performance of the device compared to polycrystalline and monocrystalline PV. When selecting appropriate PV technology to the modular building, it is important to accept the significant factor that is the burden of the roof, because it is a sandwich construction. In this regard, it is appropriate to consider the use of polycrystalline panels integrated into the roof or amorphous PV modules used as a roofing membrane. In our work, we proposed the use of PV shingles as an integrated roofing material for modular buildings.

In practice, now used in place of the trapezoidal sheet that would have been fitted to the steel girder OSB category 3 of thickness 18 mm, the PV shingles is going to be installed instead. Such PV roof is completely acceptable and meets the standard properties of the roofing. Additionally, this generates electricity while, in our country, this can be considered as an area performance at 68 $Wp \cdot m^{-2}$. The total installed output of the roof module with standard six pieces of PV panels of installed output of 816 Wp, while respecting the distance from the edge of the module for a compulsory part of the PV installation that is the lightning conductor.

Fig. 3. Roof with PV system Tegola Solar (Ušák, 2014).

To determine the electricity production, there is already an available number of applications working with a more or less precise and comprehensive database. For the best estimate of the production of electricity, the greatest number of relevant data is needed. At present, the most widely used program for calculating the output of a PV system is a program called PVGIS (Photovoltaic Geographical Information System), which was developed by experts in the field of meteorology and PV systems. The application was launched in 1995. The source of the application is a database composed of information on solar radiation and climatological data for Europe homogenized by using a model r.sun and interpolation techniques s.vol.rst and a.surf.rst.

The mentioned program uses data on the intensity of sunlight during a clear sky, in various stages of a cloudy sky, and then further uses data about the reflectivity of different surfaces and position of the sun in the sky. All the data in conjunction with the GIS application to use for a particular location, while being processed into the output in the form of the energy output of the PV system. (PVGIS © European Communities, 2001-2012) In calculating the potential, we used baseline data from the results of the individual technologies. The calculation is executed in the program PVGIS; we chose Košice for the site installation. The application calculates results for this particular location and all the information necessary for the determining the production output:

PVGIS estimates of solar electricity generation

- Location: 48°44'13" North, 21°13'1" East, Elevation: 363 m a.s.l.,
- Solar radiation database used: PVGIS-CMSAF
- Nominal power of the PV system: 0.8 kW (thin film)
- Estimated losses due to temperature: 8% (generic value for areas without temperature information or for PV modules with unknown temperature dependence)
- Estimated loss due to angular reflectance effects: 3.5%
- Other losses (cables, inverter, etc.): 16.0%
- Combined PV system losses: 25.4%
- **Total for year electricity production from the given system: 763 kWh**

It follows that using an integrated PV system in a modular construction system, we can generate from one module roof an annual profit of 760 kWh of electricity. In the case of micro-drivers, it is only possible to use the electricity exclusively for its own consumption, in the case of a standard inverter we can sell the excess electricity to the public distribution network.

Ad4. Economic evaluation

The proposed option has to be assessed in terms of economic performance and energy security. The analysis is based on the "A" variant, in which it was proposed ensuring the heat, cooling and electricity in a simple way by the transformation of electricity directly into the heating bodies. This variant is economically the most difficult and prohibitively expensive solution without added value. Numerical costs of this option are then selected for a comparative base as an expression of the modeled and limited accessibility:

a, to another source of energy other than electricity in the area,
b, the one-off investment cost in the an optimal level.

The difference in the cost of this alternative to other options is to save the annual operating costs for energy.

Tab. 3. The economic energy intensity of the external system interface after transformation.

Variant	Way of transformation	Cost	Specific costs	Saving
		(€·year^{-1})	(€·kWh^{-1})	(€·year^{-1})
A	Electricity only (cooling and heating), electricity (other)	4 331,10	0,1305	0
B	Natural gas - heating, electricity - cooling, electricity (other)	2 308,33	0,0696	**- 2 022,77**
C	Heat pump - air / water (RES), electricity (other)	1 756,09	0,0529	**- 2 575,02**
D	District heating, electricity (other)	2 968,24	0,0894	**- 1 362,86**

An excellent solution shows only in terms of variable energy costs, for the existence of only a power connection to use technology based on heat pump air/water; air/air heat and refrigeration (Variant C). For the possible existence of connections between natural gas and electricity, it appears appropriate to use of condensing boiler technology for heat and electricity for cooling (variant B). Following this, the assessment of economic efficiency, we focus on options B and C with the fact that it is based on the value of savings to alternative A referred to in the last column of Tab. 3. In the column Specific costs, the resulting calculation of annual operating costs is presented. It excludes the costs of the supply unit, gas connection, electricity connection and so on.

Meaningful economic evaluation of the effectiveness of investments with an acceptable informative value for the client in terms of time is a period of an economic lifetime of the technology. (Tauš et al. 2009) (Csikósová et al. 2011) In this case, T = 25 years is selected for a financial evaluation lifetime. Thus the investments benefit from it, although their temporary character may be moved. They are also capable of condensing boiler technology and heat pumps - air conditioning units.

The calculation of economic and financial indicators for variant B (boiler, climate) and variant C (quad-split) was implemented in three cases:

- without using PV,
- using PV with a 100% consumption of production,
- using PV with a 70% consumption of production.

Tab. 4. Results of the analysis and evaluation of the economic efficiency of various types of energy supplies

Marker	M.U.	Variant							
		A	B			C			D
Consumption of heat	**(kWh/y)**	19 217							
Consumption of cold	**(kWh/y)**	7 687							
Other electricity consumption	**(kWh/y)**	6 282							
Energy costs	**(€/y)**	4 331,1	2 308,3			1 756,1			2 968,2
Savings directly to the var. no. A	**(€/y)**	0,0	2 022,8			2 575			1 362,9
Savings from PV - 100% consumption	**(€/y)**	1005,0	0,0	0,0	1005,0	0,0	0,0	1005,0	1005,0
Savings from PV - 70% consumption	**(€/y)**	825,6	0,0	825,6	0,0	0,0	825,6	0,0	825,6
The cost of the investment project	**(€)**	-	4 700,00			5 500,00			-
The evaluation time $T_ž$	**(Year)**	-	25			25			-
Simple payback period	**(Year)**		11,1	4,39	3,89	6,42	3,67	3,35	-
Simple payback period	**(Year)**	-	19	6	5	8	5	4,00	-
Discount rate	**(%)**	5							
The net present value	**(€)**	-	659,7	9735,4	11707,8	6036,3	15112,1	17084,5	-
Internal rate of return	**(%)**	-	1,40	16,49	19,44	9,30	21,05	23,52	-

Summary

Based on the results of the cost-benefit analysis, it can be concluded that variant C with a simple payback period of 6.42 years and an internal rate of return of 9.3% offers better results than variant B. In the case of the use of PV systems, the value of outcome indicators has improved. The best results are shown in a variant with the use of the PV 100% of the energy consumption, the payback (compared to the option C without the use of PV) is reduced to a value of 3.35, and the internal rate of return is raised to 23.52 %. Likewise, there is a positive change in the other monitored indicators (net present value, fair payback period), as shown by the results in Tab. 4. The production of PV roof of one building module is 763 kWh per year. Modular building in Option 1 has seven modules. In the calculation of savings, the saved energy and payments for electricity generated from a renewable source consumed at the production site were considered. PV system has no costs to the end user; the manufacturer offers PV roof for the price of the classic roof.

Based on this, we recommend to the investor to construct modular design, ensuring energy through heat pumps - air/water, while installing the PV system sized for the consumption of the entirely generated electricity. To sum up the proposed investment, it is highly attractive from an investor's viewpoint. We take into account the results of all the indicators of economic efficiency from a short payback period to the high internal rate of return, which visually shows an overview of cumulative cash flow over the entire lifetime of the modular building (fig. 3).

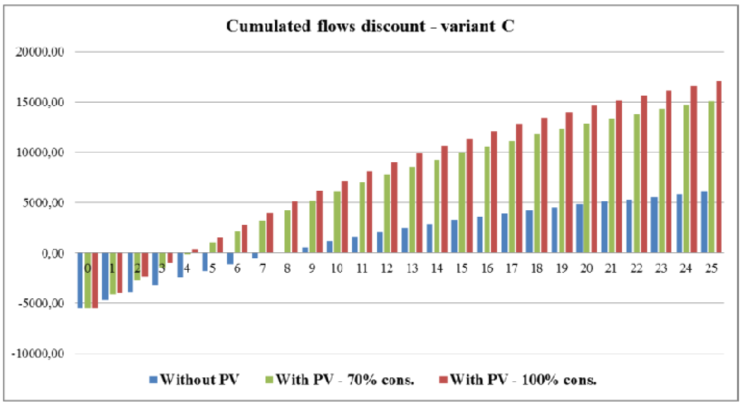

Fig. 3. Cash Flow overview in the C variant.

Conclusion

Energy consumption for heating, respectively the cooling of buildings is an essential part of the operating costs of buildings. The modular construction and other construction projects grow the need to reduce energy demands, which entails a reduction in CO_2 emissions.

It is inevitable to think about energy consumption already during the design phase - the location, climate impacts in the field, mountainous terrain surrounding the construction and building orientation, size of a glass surfaces, etc. The indicator could also be a ratio of the size of the cooling casing to the heating volume, which should be minimized. The most important factor is, of course, Thermal performance of the envelope structures and apertures. The use of building materials and components with a low coefficient of heat transfer and the right composition can prevent heat losses and thermal bridges. In particular, efficient and optimal use of available modern technology can be achieved by reducing energy consumption and the adverse impact of the conversion on the environment.

Nowadays, of course, the assessed factor in the success of an application for a building on the market becomes a contribution of renewable resources to ensure thermal comfort in the building. At the conclusions of the work, it is apparent that, even in temporary buildings and innovative solutions in the form of modular buildings, have renewable sources for their extensive use. Without thorough research and assessment of all the input factors, it may be that the violent promotion of renewables in the energy base of modular buildings will not use the optimal potential of these resources. While in the market economy, one cannot ignore the effectiveness of the investments made. (Štangová et al. 2006)

The ideal solution is to design and implement the optimal variant, which will articulate demands of the times on environmental requirements with the economy of modular buildings at the supplier level, or the level of the user.

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