MULTICRITERIA AND MULTILEVEL OPTIMIZATION TASKS APPLICATION TO CHOOSE BUILDING ENERGY STANDARD

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Summary

The paper presents possibilities of making use of a tool such as multicriteria optimization to evaluate energy quality of a building designed for one family. New presentation of architect – contractor cooperation was proposed, based on conscious, as far as energy evaluation is concerned, choice of design solutions.

The example compares one-family residential building designed in a traditional way to a building in which energy demand is lowered. The difference in the costs of energy quality change of a building was defined.

Keywords: multilevel and multicriteria optimization, energy saving buildings, low-energy buildings

1 Introduction

One of the main aims of the European Union policy within sustainable development strategy in building is limiting energy usage (frame programs, structural funds). The problem is especially important in municipal – living standards sector. Energy for building heating in Poland still constitutes a significant percentage of total energy usage. Activities in this sphere, those concerning thermo-insulation of the existing buildings and setting up new projects, are the most effective. Within newly designed buildings, depending on their character as far as energy usage goes, the choice is made in the phase of forming design assumptions (Fig.2). Information about the possibilities of choosing a building of a given energy consumption is now easily available for future investors (catalogues of energy efficient buildings, architects' help). However, there is still no wide enough knowledge on how the choice of low energy building (low energy or passive buildings) influences the initial costs of the project and what may be the savings (for the user) in comparison to a standard building exploitation.

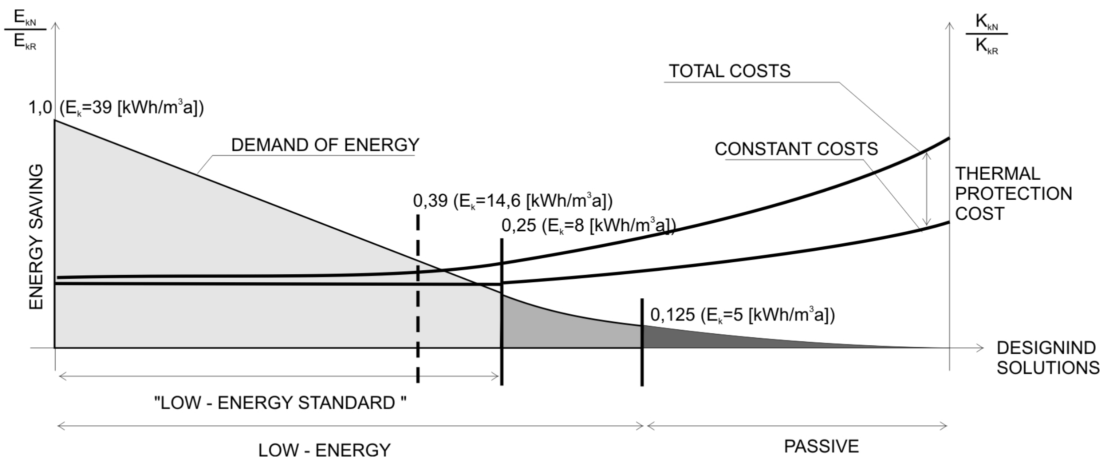


Fig. 1 Classification of buildings depending on E_0 value

Designing process is mainly dependent on the architect – investor cooperation. An architect has to take into consideration the client's expectations concerning the concept of the building, however he should also possess proper knowledge on how a choice of some functional and material solutions will influence energy consumption in the designed building. A conscious choice in this respect directly influences the investor's business, i.e. later exploitation costs.

In the process of project formation the architect should present to the investor how the changes in the concept of a dreamed of design will influence the initial costs as well as exploitation costs. He should also stress the ecological aspect connected with original energy usage. Thanks to such initial analyses, and then design motions introduced, the design documentation of the house is well thought over and it can fulfil the requirements of energy efficient, low energy or passive building (Fig. 1), at the same time ensuring optimum usage comfort for the residents, and first of all, it is a conscious choice of the investor.

Certainly the designer's task is not to carry out computer simulations or solving the problems of optimum shaping connected with thermal protection of the house. He should, however, have access to the information about thermal insulation design of the building. It refers to the decisions in design process elements shown in Fig.2. Such decisions provide positive results of the energetic evaluation of the project and the building.. Basic information about low energy building designing can in this scope be provided by computer simulation results (e.g.[2]) or by problem solutions of the optimum shaping of such buildings (e.g. [3,4]).

The paper presents how the change of a typical one-family house design into low energy one translates into original and final energy consumption in both cases. It was also shown how such a change influences the initial costs caused by the change of the building energy quality. The changes proposed for the project are the results of multicriteria and multilevel optimization analyses, in detail presented in [3], concerning the energy evaluation of one-family residential buildings.

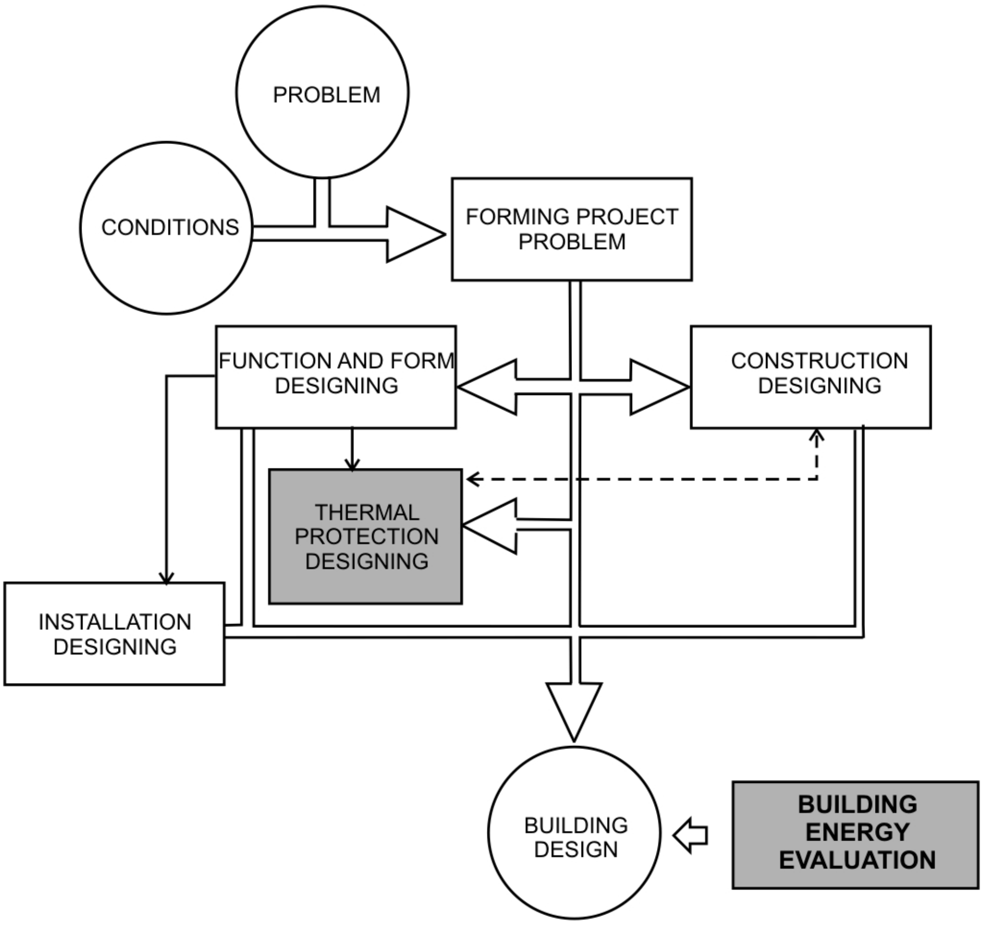


Fig. 2 Designing process general scheme

2 Using multicriteria and multilevel optimization to design buildings taking into consideration heating energy usage.

As a method of problem formulation of one-family low energy residential buildings optimum shaping a problem of multicriteria and multilevel optimization was used. The details of the problem are presented in [3]

2.1 Forming a problem, solving method

2.1.1 General formulation

The task was formulated as K_i two-criteria optimization problem

$$K(m^*) = \min_{m \in Q} K_i(m) \qquad (i=1,2) \tag{1}$$

where: $Q(m) = \{m: g(m) \geq 0\}$

Introducing division of M variables set into classes MA = V discreet variables set and MB = U continuous variables set, optimization task can be written as multilevel one:

$$K(m^*) = \min_{v \in V} [\min_{u \in Q} K_i (v,u)] \tag{2}$$

where: $Q(v_i, u) = \{(v_i,u): g(v_i,u) \geq 0\}$

$$K_i = \{K_1, K_2\} \text{ – vector objective function} \tag{3}$$

K_1- realization cost of the external partitions of the building [zł]
K_2- heating energy demand [kWh/a]

$V= \{v_i\}$, i = 5 - The set of discrete decision variables,
$U = \{u_i\}$, i = 8 - The set of constant decision variables,

$$G = \{g_j(v_i, u)\},\ j = 8 \text{ – The limits set.} \tag{4}$$

2.1.2 Discretet variables

v_1 – parameters of the external walls
v_2 – parameters of windows
v_3 – building form
v_4 – range buildings form
v_5 – azimuth N-S

2.1.3 Zmienne decyzyjne ciągłe

$u_1 – u_4$ - glazing coefficients
u_5 - thermal resistence of the wall
u_6 - base shape coefficient
u_7 - thermal resistence of the roof
u_8 - thermal resistence of the floor o the ground

2.1.4 Limitations

Limitations were imposed on all sets of continuous decision variables. All discreet decision variables are acceptable values.

Discreet variables values and limitation sets are presented in [3]

2.1.5 Discreet vector variable (synthetic)

Value set of all discreet variables (taken into consideration in the task) is a Cartesian set of values of particular variables:

$$W = \times V_i \quad i = 1,..,5 \tag{5}$$

The elements of this set are rearranged fives:
$(v_{1j}, v_{2k}, v_{3l}, v_{4m}, v_{5,n})$
j = 1,..,13; k = 1,..,4; l = 1,2,3,4 ; m=1,..,10; n=1,..,8

Each such set (rearranged five) was accepted as a definition of vector value of w decision variable, defining (characterising) in a synthetic way project solution of a building (building form)
np. j = k = l =m=n=1 $\Rightarrow$ $w_1 = (v_{11}, v_{21}, v_{31}, v_{41}, v_{5,1})$
"masonry building, double layer external walls: cell concrete construction, mineral wool insulation, standard windows, one storey detached building of 0^o azimuth ".

$$w_i \in W \quad i = 1,.., 12480 \tag{6}$$

Particular w_i values of w variable are determined by various and independent tasks of optimization level. Such a division of the initial task can be treated as its initial decomposition. Task (2) has been substituted by task:

$$K(v^*,u^*)=K(w^*,u^*)=\min_{w \in W} K[\min_{u \in U} K(w,u)] \tag{7}$$

decomposed on a bottom lub lower level for12480 independent optimization tasks due to continuous variables.

Such a big amount of considerated taks is result of general wording involving all possible paramters. The amount of decision-variables and a kind of criteria is possible to adjust depending on individual project tasks.

In W set, on the basis of an analysis of aim function dependency and limitations from particular v discreet variable value there can be introduced divisions leading to formulating multilevel decomposed task, thus achieving significant decrease of task number on the bottom lub lower optimization level.

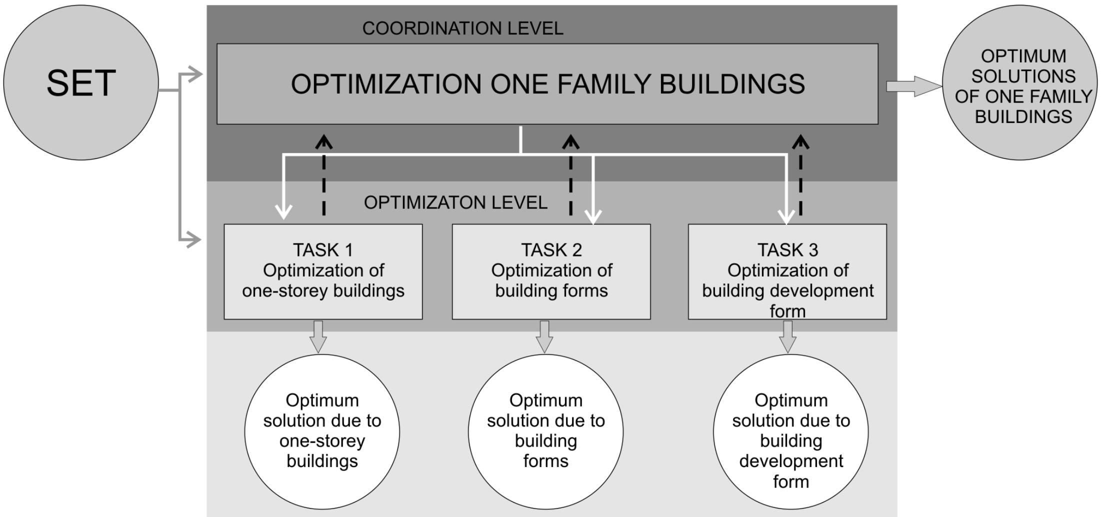


Fig. 3 The scheme of decomposition family buildings optimization task.

Task decomposition methods are presented in [3]

2.1.6 Project decisions evaluation in the range of continuous decision variables – Information defining method

Optimization tasks due to continuous decision variables values are non-linear programming tasks with restrictions.

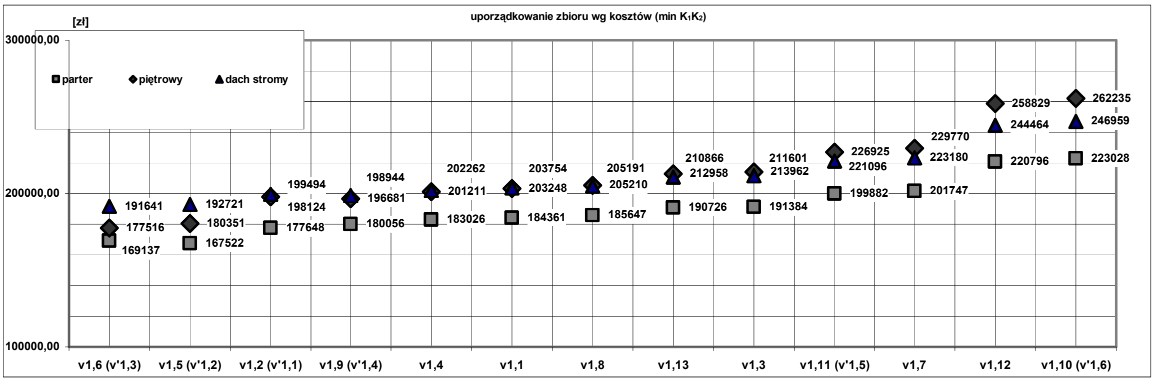
Conditions necessary for optimum solution are defined by Khun-Tucker's conditions.

These are also conditions sufficient for the tasks examined. Analysing these conditions it can be demonstrated that continuous variables optimum values are always within acceptable solution boundaries. This fact may be used to steer tasks solutions by changing restriction conditions.

2.2 Examples of solutions

The results were obtained in a numerical way, making use of CAMOS software package (author A.Osyczka). For calculations of one-criterion optimization tasks (bottom lub lower level: min K_1, min K_2) a combined method was used, consisting of random method and iterative method of tolerance variables. To find preferred solution (in polioptimization task) a method of global criterion was used. Below there are presented demonstration sets of solutions for chosen decision variables for optimization and coordination level.

<u>Demonstration results. Compromise solutions for v_1 and v_3 variables</u>



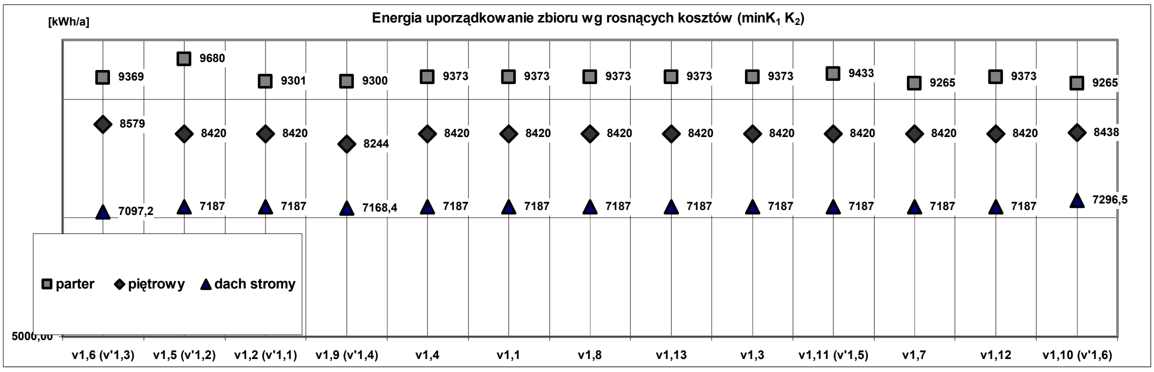


Fig. 4 min (K_1K_2). a) The value of the cost function b) the value of the energy function calculated on the base of the.

Demonstration results of stage 1 task

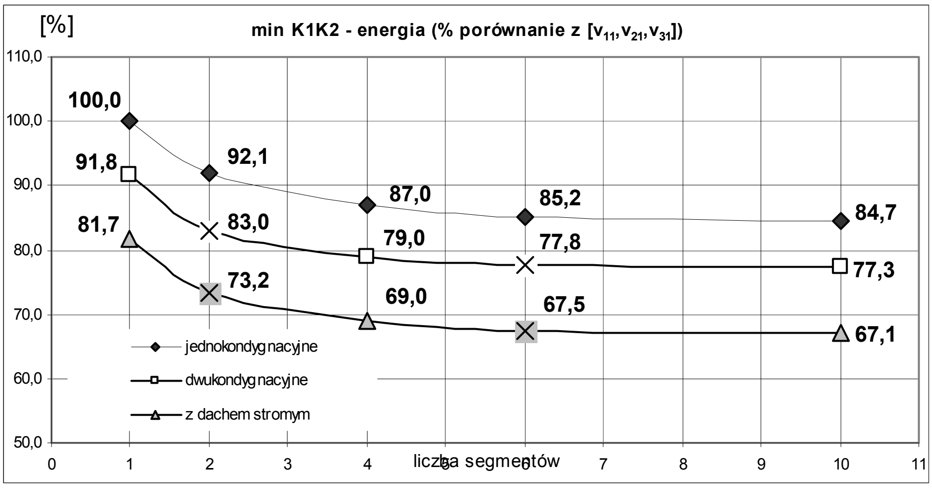


Fig. 5 The co-ordination on the top level with regard to optimum solutions in the lower level (for certain value of variable $v_3=v_{31}$)

Demonstration results of stage 2 task

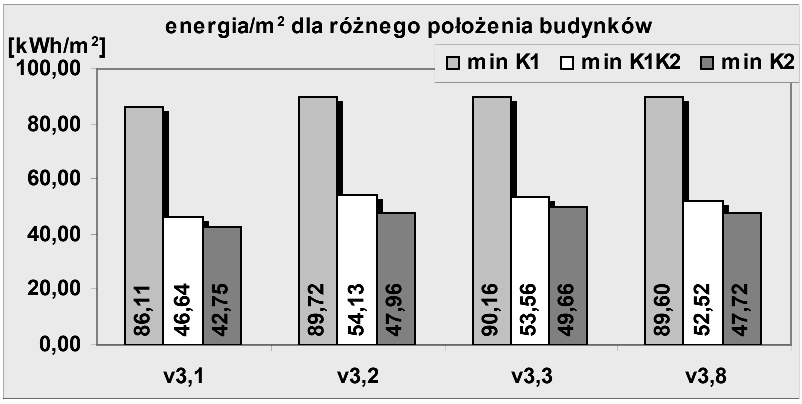


Fig. 6 Solution for value v_{3i}, (for certain value of variable v_{14} and v_{23}).

3 Process of conscious design decisions with solutions having influence on energy quality of the building

3.1 Initial design of energy saving building

Initial design is a design of one-family residential building, defining the needs of an investor and built according to his instructions. The building has 186m^2 of usable floor area and cubic capacity of 1010 m^3. It is topped with a gable roof of 36^0 slope. The external walls are made in the form of tri-layer partitions of Porotherm hollow bricks of 30cm, insulated with 7 cm thermo-insulation and finished with clinker elevation. Top floor was insulated with 15 cm thermo-insulation. The design fulfils standard demands concerning thermal insulation, by ensuring coefficient of heat permeating to the external partitions in accordance with [1], thus, according to the characteristics (Fig.1) it can be recognized as energy saving building. Heat demand calculations were done for the design, as well as for initial energy demand, in accordance with [5].

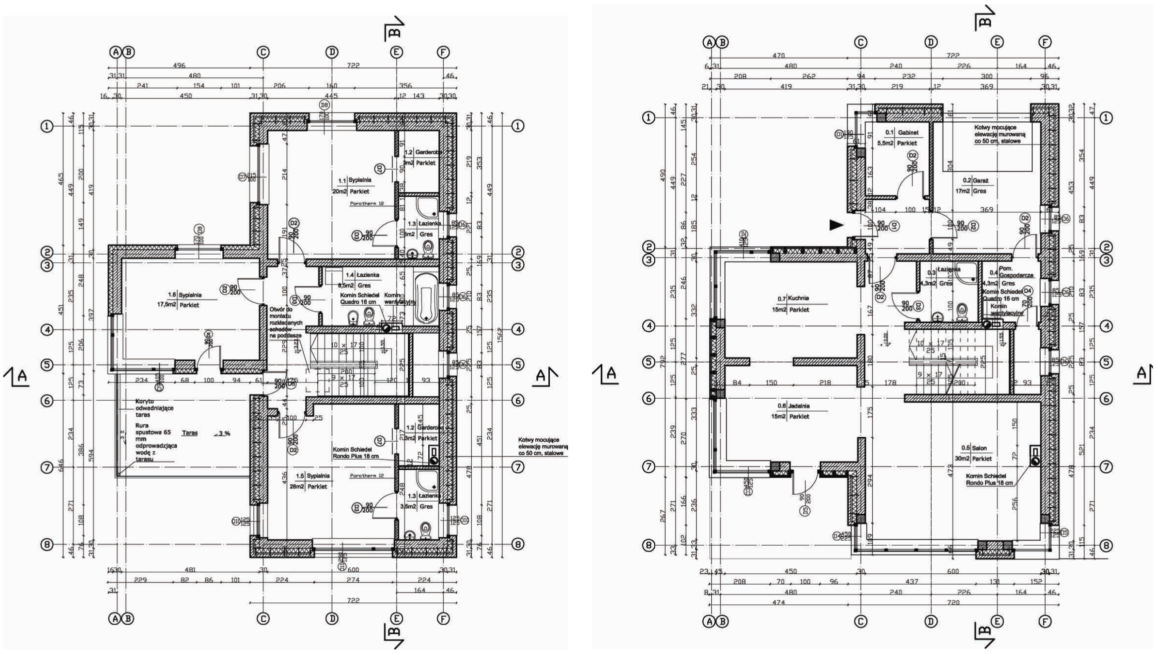


Fig. 7 Plan of the ground floor and the 1st floor [6]

Fig. 8 North-west elevation [6]

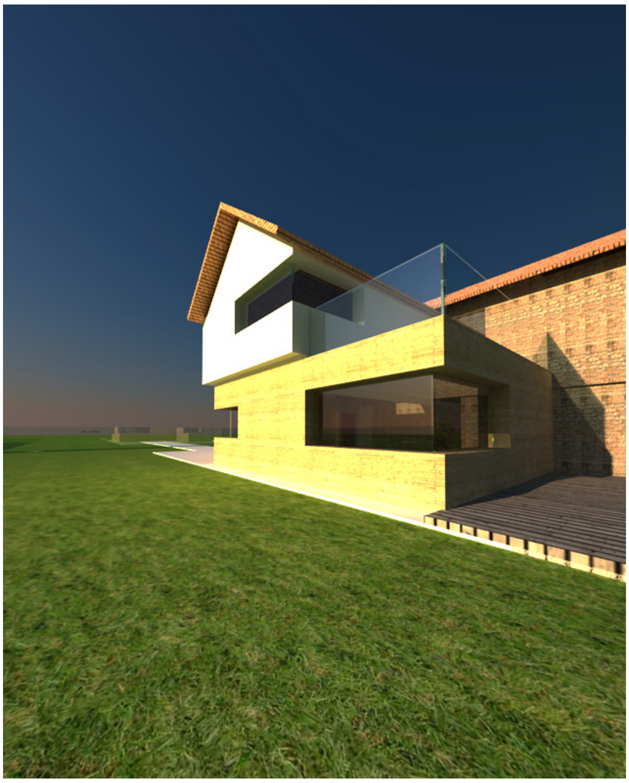


Fig. 9 South elevation [6]

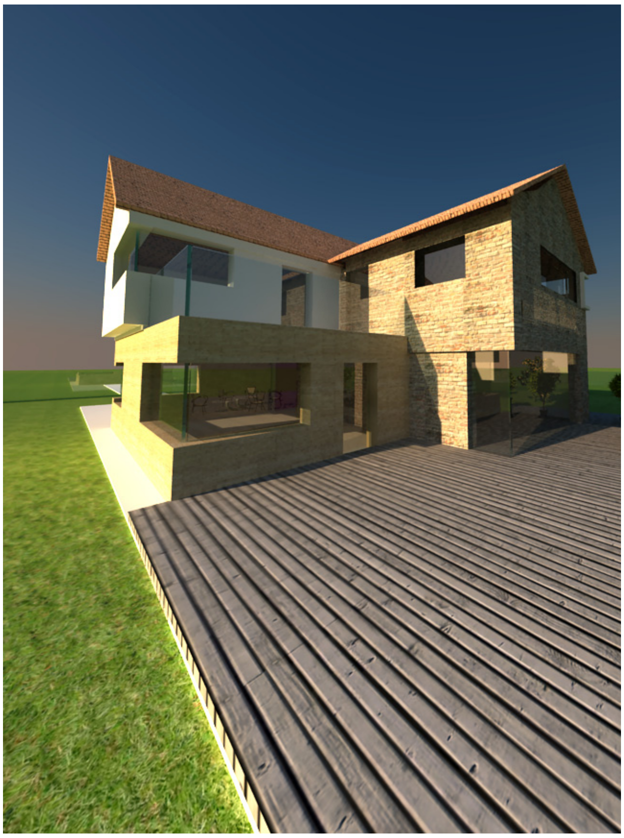


Fig. 10 South -west elevation [6]

3.2 Low energy building design

In accordance with optimization tasks results (3), changes has been brought in to the original project. Changes involved parameters accepted by investor which were:
v2 – windows parameters, u1-u4 – coefficient of glass surface (depending on orientation of the building, u5 – parameters of the thermal resistance.

In our optimalization tasks we skipped ventilation parameters assuming that only standard low energy „standart" buildings will be considered, however taking to account that big energy savings are possible because of heat restoration we proposed changing gravital ventilation to mechanical one with heat recuperation on the level of 75%.

Finally we proposed a change in thickness of the heating insulation in the external partitions was suggested, as well as a change in window and door frames. The wall between the garage and the rest of the building was also insulated.

Rectangle is an optimum solution for usable floor area when energy usage minimization is taken into account. However, the authors decided not to interfere in the change of the solid shape, assuming it to be the investor's conscious choice.

A change in coefficient of glazing in particular elevations was suggested in such a way that energy balance would make use of solar advantage on the southern and western side and minimize heat losses through the windows on the northern side. In order to reduce the losses of heat, a change in ventilation character and a recuperator was proposed.

Tab. 1 The changes proposed to investor

		Base design	**Change 1**	**Change 2**	**Change 3**
U [W/^{2}K]	Exterial walls	0,30	0,10	0,10	0,10
	roof	0,25	0,10	0,10	0,10
	windows	1,8	0,8	0,8	0,8
Glazing coeff. [%]	S	0,3	0,3	0,6	0,3
	E	0,08	0,08	0,08	0,08
	N	0,07	0,07	0,0	0,07
	W	0,17	0,17	0,17	0,17
ventilation		gravitation	gravitation	gravitation	mechnical with recuperator
E_K [kWh/(m^{2}a)]		158,31	100,30	95,59	52,89
EP[kWh/(m^{2}a)]		188	124,65	119,47	72,50

The exact costs of the proposed changes will be present during presentation.

4 Final reports

1. Designing process should involve not only form and function deliberations but also should be directly oriented towards energy efficiency matters.
2. Building documantation should involve (świadectwo charakterystyki energetycznej), however as architectural practice shows this document is commonly prepared after the whole project has been made. It would be reasonable to determine the quality of energy efficiency in the building at the begining of the process. This requires close

cooperation of architect and investor and more over the ability of showing how materials and form changes affect buildings's energy demends.

3. Optimalization is useful during valuating of building's energy efficiency, heating energy demends and costs of isolation changes. Basing on our optimalization tasks figures and criteria we have choosed, final solution has been recived. This solution can be useful during conscious architectural designing process and can have impact on investor's satisfatction along with important energy savings.
4. Basing on optimalization tasks figures, changes has been proposed. They included increasing of isolation of the wall and windows. Also ventilation changes has been adopted. This end up with 20% isolation and ventilation costs increase and while those changes are taken to account the difference between original EP and the final one is 61,4% .
5. Intuitive glass selection made by aware architects is often sufficient. The most beneficial effect can be achived (considering energy savings) when above the standard width of wall isolation is implemented along with adoption of mechanical ventilation with heat recuperation.

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