Vladimír GELETKA, Anna SEDLÁKOVÁ
Technical University of Košice

PARAMETRIC ANALYSIS TO PREDICT ANNUAL HEATING DEMAND OF SINGLE-STOREY HOUSE

**The quality of most buildings may be affected during the initial phase of architectural design. Therefore, it is important to optimize input parameters, which significantly influence energy efficiency. In principle, it is possible to speak of a deterministic approach, which considers input parameters to be fixed, or a stochastic approach, which takes a wider set of input parameters into account. A reference building
is evaluated in terms of energy performance, where input parameters are changed in order to determine a correlation coefficient. Regressions were written to express the impact architectural design has on energy performance.**

Keywords: **single-storey house, annual heating demand, architectural and constructional solutions, standard heating requirements, energy efficiency**

INTRODUCTION

The optimization of input parameters is necessary because the quality of most buildings may be affected during the initial phase of architectural design. Some guidance is available for architects to help them predict annual energy performance. These case studies have shown that the building shape dramatically impacts energy loads for heating and cooling [1]. For example Mahdavi [2] uses the relative compactness of buildings related to a specific shape to determine the energy performance of buildings. Ourghi et al. [3] have developed a simplified analysis tool to predict the effects of shape selection regarding annual energy use. Similarly, Adnan al Anzi at al. [4] set about a regression equation relating the shape of buildings, wall to window ratio, and solar heat gain coefficient, to the energy performance.

1. PARAMETRIC STUDY OF SINGLE-STOREY HOUSES

The study considers a single-storey house (bungalow), which as a structure has seen a surge in popularity in Slovakia. Based on the shape and structural analysis of 130 bungalow houses in Slovakia, several histograms were created describing the shape solutions of the houses and thermal quality of building envelopes.

1.1. Shape and construction solutions of single-storey houses in Slovakia

Shape solutions of the analysed single-storey houses (expressed through shape factor FT [1/m]) and thermal quality of building envelopes (using the average heat transfer coefficient U_{em} [W/(m^2·K)]) are shown in Figure 1.

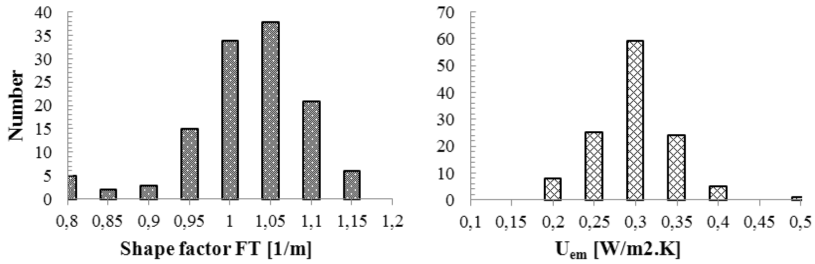

Fig. 1. Histogram of single storey-houses solution: left - shape solution FT, right - average heat transfer coefficient U_{em}

The effect that the percentage of envelope has on design and subsequent contribution to heat loss is illustrated in Figure 2.

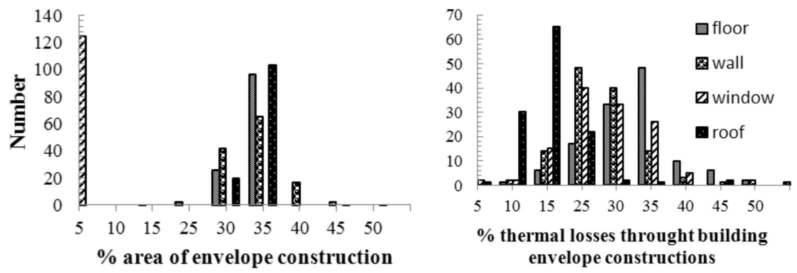

Fig. 2. Histogram of single storey-houses solution: left - % area of envelope construction, right - thermal losses through building envelope constructions

From a statistical processing point of view, it may be deduced that considering the form factor for the selected bungalows they are relatively disadvantaged in comparison to multi-storied residential properties. Thermal qualities of envelopes in contrast to traditional constructions can be overcome by implementing low-energy standards. Despite differences in percentage areas of individual envelope elements, the percentage of heat loss is relatively balanced, suggesting a lower quality of thermal and transparent structures.

1.2. Reference single-storey house - parametric study

The impact that the input parameters have on the annual energy demand is reviewed for a single-storey house depicted in Figure 3 by considering input parameters within the ranges as shown in Table 1. The range of values considered in the calculation was partly manipulated by the statistical analysis of existing single floor houses mentioned above. Heating was calculated on a monthly basis according to STN EN ISO 13790 [5] in MS Excel.

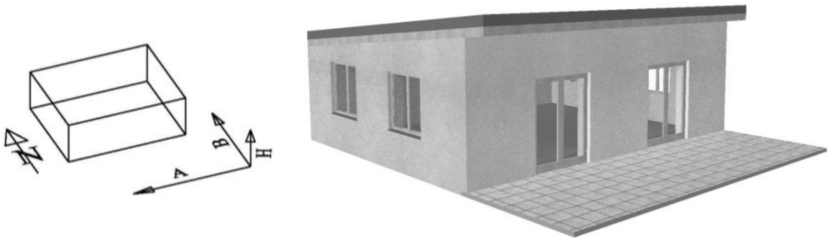

Fig. 3. Dimensions and orientation object

Table 1. **Input parameters and their ranges of values considered in the calculation of energy needed for heating a reference single-storey house**

PARAMETER			MED.	MIN.	MAX
INDEX	NAME	UNIT			
A	Width	[m]	10	2	18
B	Depth	[m]	10	2	18
H	Height	[m]	3.5	2.2	4.2
U_w	Heat tr. coeff. of window	[W/(m²·K)]	1.0	0.6	1.4
U_{floor}	Heat tr. coeff. of floor	[W/(m²·K)]	0.25	0.1	0.45
U_{wall}	Heat tr. coeff. of wall	[W/(m²·K)]	0.2	0.1	0.4
U_{roof}	Heat tr. coeff. of roof	[W/(m²·K)]	0.2	0.1	0.4
%win -N	% of window to wall - N	[%]	50	10	90
%win -S	% of window to wall - S	[%]	50	10	90
%win -E	% of window to wall - E	[%]	50	10	90
%win -W	% of window to wall - W	[%]	50	10	90
G_{win} - N	Solar heat gains coeff. - N	[–]	0.5	0.1	0.9
G_{win} - S	Solar heat gains coeff. - S	[–]	0.5	0.1	0.9
G_{win} - E	Solar heat gains coeff. - E	[–]	0.5	0.1	0.9
G_{win} - W	Solar heat gains coeff. - W	[–]	0.5	0.1	0.9
ΔU	Thermal bridges	[W/(m·K)]	0	–0.04	0.1
Cm	Thermal capacity	[J/K]	100 000	76 000	124 000

1.3. Computing method

Standard heating requirements in Slovakia, depending on the shape factor FT are depicted in standard [6]. Residential buildings are distinguished mainly by the shape, size and number of storeys, which differences can be expressed by the shape factor FT of the building. Heating is considered continuous with a standardized degree days 3422 K·day. Rising coefficient of heat transfer affects the reduction of energy demand. Buildings meetthe requirements if the shape factor fulfills the condition $E \leq E_N$ (need for heating must be equal to or less than the need for heating stated in the regulations). This standard specifies the maximum heat transfer coefficient U for building envelope constructions. Thermo-technical qualities of building envelope structures defines the mean heat transfer coefficient U_{em}. The method of calculation used in this study was based on quasi-stationary simplified monthly method dictated by STN EN ISO 13790: 2008 [5]. A bungalow is considered to consist of a single thermal zone.

1.4. Development of alternatieves

The facilitation of the calculation of different input parameters combinations required the use of the Monte Carlo optimization method based on stochastic random selection. The Monte Carlo method analysis is based on repeated simulations; the outputs are evaluated for each element of sample matrix. Simulation 4.0 [7] was used to generate a combination of input parameters. Annual heating requirements were calculated by utilizing the above mentioned quasi-stationary seasonal method in compliance with standard STN 73 0540 [6]. The inputs for the optimization model are the dimension of building sides, the envelope construction U - value window to wall area, solar properties of windows etc. All input parameters meet the criteria of minimum thermal properties according to standard [6].

2. RESULTS OF PARAMETRIC ANALYSIS

The sensitivity of input parameters required for heating can be expressed using the standardized regression coefficient, which determines the order of sensitivity. As shown in Figure 4 in this case, the correlation coefficient was determined implementing a combination of 20 000 input parameters. From this combination, it was possible to develop regression models to predict heating demands for a single-storey house. This regression can be helpful for optimizing energy efficiency for architects or design engineers during initial design stages.

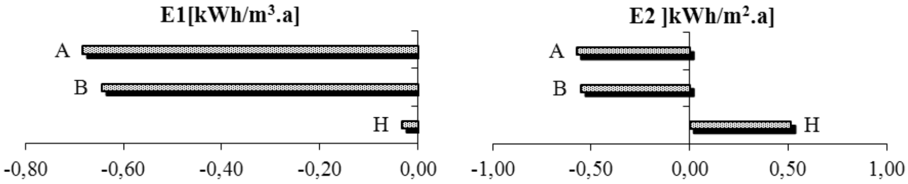

Fig. 4. Standardized regression coefficient reflecting the sensitivity of input parameters (regarding the dimension of a single-storey house) for heating requirements, left - E1, right - E2

Sensitivity parameters regarding thermal properties of the building envelope constructions of a single-storey house are shown in Figure 5. For comparisons of different climates three different Slovak climate locations were observed in compliance with STN EN ISO 13790/NA [8]. Selected cities included: Bratislava - BA (I. climatic zone), Košice - KE (II. climatic zone) and Stropkov - ST (III. climatic zone).

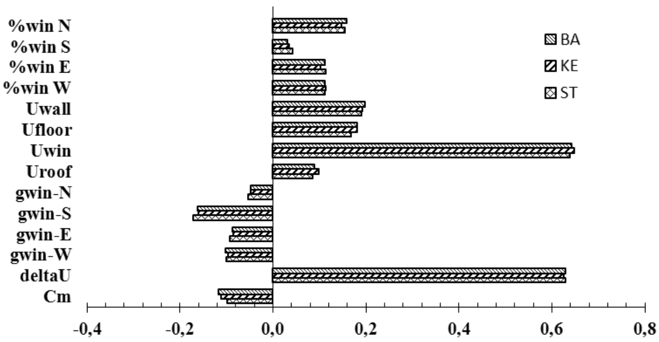

Fig. 5. Standardized regression coefficient sensitivity for input parameters (regarding the thermal properties of building envelopes) based on heating loads and expressed as: E1 [kWh/m^3·a]

From the results of the parametric analysis it is possible to develop a regression equation (1) of energy demand for the modeled building (Tab. 2). In this equation the above mentioned parameters are included.

$$y = \alpha_1 + \sum_{i=1}^{4} \beta_i \cdot \%\mathrm{win}_i + \sum_{i=1}^{4} \gamma_i \cdot \mathrm{Gwin}_i + \sum_{i=1}^{4} \delta_i \cdot U_i + \varepsilon \cdot A + \xi \cdot B + \eta \cdot H \qquad (1)$$

Table 2. **Regression coefficient of modeled building**

Regression constant		E_1 [kWh/(m^3·a)]	E_2 [kWh/(m^2·a)]	E_1N [kWh/(m^3·a)]	E_2N [kWh/(m^2·a)]
α_1	–	11.2497	–23.7711	62.02555	92.4434
β_1	%win - N	0.027392	0.09603	–0.00075	–0.00292
β_2	%win - S	0.00795	0.028128	–8.2E-05	–0.00019
β_3	%win - E	0.020019	0.070444	–7.2E-05	–0.00031
β_4	%win - W	0.022452	0.079203	0.000139	0.00052
γ_1	G_{win} - N	–0.88669	–3.12467	0.023479	0.061003
γ_2	G_{win} - S	–3.14043	–11.0274	0.079507	0.257434

γ_3	G_{win} - E	–1.88903	–6.54575	0.012969	0.066267
γ_4	G_{win} - W	–1.72758	–6.02722	0.008813	0.042546
δ_1	U_{win}	12.84802	45.02377	–0.00925	–0.00231
δ_2	U_{floor}	17.41174	60.97351	–0.1205	–0.32549
δ_3	U_{wall}	12.80278	44.73585	–0.1063	–0.4796
δ_4	U_{roof}	17.1769	59.55964	0.210858	0.722702
ε	A	–0.5084	–1.78113	–0.59435	–2.08273
ζ	B	–0.53842	–1.88515	–0.59185	–2.07126
η	H	–0.16685	17.45102	–4.19531	20.88809
R^2		0.83786	0.86031	0.94677	0.9546

CONCLUSION

Knowledge of parameter sensitivity can facilitate optimal design by quantifying tradeoffs between differing parameters, and focusing attention on the parameters that are most likely to affect energy goals of the project.

Regression analysis models developed in the buildings´ design predict the need for heating and promote the exploration of potential design and quantitative feedback generated by regression methods. This assists designers with energy efficient decision-making processes during conceptual design stages. The regression equation can be used in a multi-criterion decision analysis as a tool to predict annual heating demand.

Future work is needed to validate, refine and expand on the proposed method to deal with a building´s shape and determine regression coefficients for parameters of dynamic variables for each climatic zone.

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ANALIZA PARAMETRÓW DETERMINUJĄCYCH ROCZNE ZAPOTRZEBOWANIE NA CIEPŁO DLA BUDYNKÓW JEDNOKONDYGNACYJNYCH

W pracy przedstawiono analizę wpływu wybranych rozwiązań architektonicznych i materiałowo-konstrukcyjnych na wartość rocznego zapotrzebowania na ciepło do ogrzewania jednokondygnacyjnych budynków mieszkalnych (typu bungalow). Analizie poddano współczynnik kształtu, izolacyjność cieplną przegród - współczynnik przenikania ciepła, orientację w stosunku do stron świata, mostki termiczne, wielkość przeszklenia budynków, zyski ciepła od promieniowania słonecznego. Przedstawiono histogramy oraz współczynniki regresji.

Słowa kluczowe: **jednokondygnacyjne budynki mieszkalne (typu bungalow), roczne zapotrzebowanie na energię, rozwiązania architektoniczne i materiałowo-konstrukcyjne, wymagania ochrony cieplnej, efektywność energetyczna**