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# Simplified evaluation method for energy efficiency in single-family houses using key quality parameters

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ABSTRACT

In practice a number of calculation tools are used to calculate annual energy flows in buildings. Their use yields accurate results but requires the input of a large number of parameters in the complex calculation procedures involved. The values of these parameters are usually known only after the planning process of a building has been completed.

A simplified evaluation method for energy efficiency in single-family houses has been developed with the aim of using as few building parameters as possible with the simplest calculation procedures possible. The calculation model was created on the basis of results obtained in a research study conducted on a large statistical sample of Slovenian single-family houses. The correlation analysis carried out showed that the heat balance energy flow values calculated are closely related to certain building quality parameters. The energy balance complexity makes normal quantity parameters less related to energy flows, and they cannot be used in simplified evaluation models.

The new evaluation method can be used in two modes by applying different quality parameters, depending on their availability. If more complex input parameters are used, the results of the method are more accurate, and so it can also be used for a preliminary assessment of individual projects.


## 1. Introduction

The energy efficiency of buildings is regulated by the EU acquis [1] and national legislation [2]. By 2018 buildings in the public sector will be nearly zero-energy (nZEB) and, by 2020, this will apply to all buildings. The definition of a nZEB will be, at least, within the limits of the requirements set for buildings which are currently optimally energy-efficient, including passive houses. A passive house is a scientifically proven path that leads to a sustainable building [3], and has been recognised in Europe, in terms of its methodology, for two decades [4]. Owing to energy flow optimisation, passive houses save 80–90% of space heating energy in comparison with conventional buildings [3]. The energy efficiency of the passive house standard is demonstrated by the large number of passive houses (39,390) that have been built in Europe as of 2012 [5], and their number continues to grow.

A passive house [4] requires a maximum of 15 kWh/(m$^2$a) of useful energy for heating purposes. Low transmission heat loss is achieved by well-insulated and airtight building envelopes without thermal bridges. A passive house has an integrated controlled ventilation system with exhaust air heat recovery, which reduces heat loss due to ventilation. Heat loss under a peak heating load in the heating season is kept under 10 W/m$^2$ and can be covered by hot air heating [6]. Such houses eliminate the need for conventional heating systems [7]. Heat pumps are increasingly used to generate heat [8].

The authors of the articles deal with a passive house and its components from different aspects, such as its energy efficiency and the influence of the building envelope structure on heat loss [7], the thermal bridge types and their impact on energy efficiency [9], the integration of internal heat sources in energy balance [10], and heating and ventilation optimisation [6]. They analyse the influence of external wall thermal inertia on the energy performance of well-insulated buildings, and have found that the use of walls with high thermal inertia results in reduced heating and cooling energy consumption. Passive houses may become overheated during the summer months [11]. The measurements [12] indicate that, in the summer, thermal comfort can be provided by opening the windows at night by installing sun shades on south- and west-facing windows, and by reducing internal heat sources. Living comfort is an added value associated with passive houses, an assertion upheld by several research studies focused on the experience of users living in such houses. The results of the European project CEPHEUS [7], based on physical measurements performed in over 100 dwelling

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**Nomenclature**

| | |
|---|---|
| $U_i$ | thermal transmittance coefficient ($W\,m^{-2}\,K^{-1}$) |
| $g$ | total solar transmittance factor of the glazing (%) |
| $U_m$ | mean thermal transmittance coefficient of the building envelope ($W\,m^{-2}\,K^{-1}$) |
| $H'_T$ | specific transmission heat loss coefficient of the building envelope ($W\,m^{-2}\,K^{-1}$) |
| $\psi_i$ | linear heat loss coefficient of thermal bridges ($W\,m^{-1}\,K^{-1}$) |
| $\mathbf{l_i}$ | length of linear thermal bridges (m) |
| $f_{t,i}$ | temperature weighting factor for transmission heat losses (-) |
| HDD | heating degree days ($K\,d\,a^{-1}$) |
| $j$ | solar radiation on horizontal surface during the heating season ($kWh\,m^{-2}\,a^{-1}$) |
| $T$ | heating season length ($d\,a^{-1}$) |
| $A_w$ | window surface ($m^2$) |
| $A_u$ | building treated floor area ($m^2$) |
| $A$ | heat loss surface of the building envelope ($m^2$) |
| $A_i$ | heat loss surface of the building envelope element ($m^2$) |
| $V_e$ | net volume of the building ($m^3$) |
| $P$ | number of occupants (-) |
| $z$ | share of window surfaces in the building envelope ($m^2\,m^{-2}$) |
| $f_0$ | surface area-to-shape ratio ($m^2\,m^{-3}$) |
| $f_d$ | building envelope surface area-to-heated surface area ratio ($m^2\,m^{-2}$) |
| ASF/$A_u$ | weighted window surface-to-building treated floor area ratio ($m^2\,m^{-2}$) |
| $F_{w,i}$ | weighting factors for the glazed areas (-) |
| $S_i$ | shading reduction factor of glazed areas (-) |
| $Q_{NH}$ | annual heat demand for space heating ($kWh\,a^{-1}$) |
| $Q_L$ | total annual heat losses ($kWh\,a^{-1}$) |
| $Q_T$ | annual transmission heat losses ($kWh\,a^{-1}$) |
| $Q_V$ | annual ventilation heat losses ($kWh\,a^{-1}$) |
| $Q_g$ | total annual heat gains ($kWh\,a^{-1}$) |
| $Q_s$ | annual passive solar gains ($kWh\,a^{-1}$) |
| $Q_i$ | annual internal heat gains ($kWh\,a^{-1}$) |
| $q_i$ | internal heat sources (W) |
| $n_v$ | total equivalent air exchange per hour in the building ($h^{-1}$) |
| $n_{v-v}$ | air exchange of mechanical ventilation airflow without heat recovery ($h^{-1}$) |
| $n_{v-inf}$ | air exchange of envelope infiltration airflow ($h^{-1}$) |
| $\eta_G$ | energy efficiency of heat recovery in ventilation system (%) |
| $r$ | sample Pearson correlation coefficient (-) |

units in fourteen projects from different European countries, and the experience of users, all indicate a high level of satisfaction with air quality and temperature in the premises, during both the winter and summer. In particular, the users expressed a high degree of satisfaction after having lived in a passive house for a few months when they became well acquainted with the functioning of the house, particularly the ventilation and heating systems [13]. User concerns may also be a consequence of inappropriate use of the building's energy systems [14]. The users' evaluation of their quality of life proved to be particularly important for accepting or rejecting the advanced energy concepts in the buildings [15].

Several methods of energy evaluation, involving different levels, have been developed to assess highly energy efficient buildings and their components. These methods evaluate the energy efficiency of buildings [16], their heating systems [17], ground heat exchange [18] and active solar heating system [19]. Simulation and design tools and other software used for planning low-energy buildings [20] were developed for dynamic simulation of the relevant processes in buildings [21], for design support of passive solar house systems [22], for zero energy building design [23], etc.

The evaluation of the energy efficiency of residential buildings through the use of different simulation tools, as well as a partial methodological evaluation for the energy efficiency of individual building components, requires the use of a large number of parameters. This is also true for the PHPP'07 tool, i.e. the Passive House Planning Package – The energy balance and Passive House design tool [24], which had been developed in Europe to provide support to designers in the overall planning of highly energy efficient buildings. Since the use of the tool requires more project data, it cannot, for example, be used in the preliminary design phase for planning a building. When designing with high-precision simulation tools, a number of different parameters need to be provided for reliable calculations. Most of the required parameters are usually not available before the closing stages of a project, when optimisation of building components is in progress and already involves many designers of various professions.

Given the above mentioned evaluation methods for the energy efficiency of new residential buildings, our research study examined the possibility of modelling a calculation method that would make it possible to evaluate a building's energy efficiency by using only a small number of key quality parameters, and through simplified calculation procedures. By using this new method, the energy efficiency of a designed building could be evaluated as soon as the preliminary design phase. The assessments obtained would allow for timely modifications of less favourable design solutions and bring them closer to the energy efficiency of a passive or low-energy house. This method could also be used for a simplified evaluation for the energy efficiency of buildings after the designing process has been completed in the event that detailed energy balances had not yet been prepared.

## 2. Methodology

The modelling of this new simplified evaluation method for energy efficiency is based on a statistical analysis of a large number of Slovenian very low-energy and passive single-family houses, which were studied for a linear correlation between the key quality parameters of these new houses and their energy flow balances. A similar approach for evaluating the energy efficiency of apartment and office buildings using linear regression models has been suggested by the authors of several studies. Energy efficiency can be estimated using simple polynomial functions, for which regression coefficients are extracted from the results of dynamic simulations [25]. Regression models that require only a small number of key parameters can also be used for predicting monthly heating demand for single-family houses [26]. In comparison with time-consuming dynamic simulations, the suggested regression models are ideal for parametric studies and optimisation [27]. The final energy use in office buildings can be optimised in the planning stages of a project by using parametric studies with polynomial models, also known as meta-models [20].

In our research, unlike the rest of the approaches mentioned, we sought a quick calculation method that would enable us to evaluate the key balance flows in energy efficient single-family houses in a simple manner. The results of the research are presented in the form of balance and parameter analyses derived from the correlations identified between the energy flows and parameters of the sample of buildings studied. The results obtained served as a basis for modelling the method of simplified energy evaluation of