A Simplified Approach Towards Net Zero Energy Buildings:
The Early Stage Primary Energy Estimation Tool

NAVID GOHARDANI, FOLKE BJÖRK

Department of Civil and Architectural Engineering, Royal Institute of Technology, Stockholm, Sweden

ABSTRACT: The economic impacts of energy production and usage and its detrimental environmental effects have instigated a great interest in net zero energy buildings and their future usage within the built environment. In this article a simplified calculation tool is presented aimed at stakeholders, policy makers and decision-makers. This tool makes use of user input parameters in order to determine the primary energy usage within a net zero energy building. The simplistic methodology presented herein, allows for a first step energy analysis of a net zero building based on its energy demand and expected usage and provides an overview of the renewable energy ratio and building energy use patterns.

Keywords: net zero energy building, primary energy calculation, renewable energy ratio

1. INTRODUCTION

Amid the economic challenges, one vision shared by the majority of the building community is to develop buildings that produce the same amount of energy as they utilize. These buildings are called net zero energy buildings (NZEBs). In the U.S. only, the energy usage within the commercial sector is expected to grow by 1.6% annually. In addition, buildings are responsible for 40% and 70% consumption of primary energy and electrical energy, respectively. These factors all contribute to energy conservation measures which include both energy conservation and refurbishment. ASHRAE has a vision of implementing market-viable NZEBs by 2030. This measure calls for implementation of the NZEB strategies in existing and new buildings (ASHRAE, 2008).

2. THE EARLY STAGE PRIMARY ENERGY ESTIMATION TOOL (ESPEET)

While numerous articles have been devoted to the definition of NZEBs (Torcellini et al., 2006), there has been a paucity of articles with focus on exemplified calculations of the primary energy of a NZEB. Therefore, this article seeks to outline a few of these calculations with focus on obtaining the primary energy for NZEBs. Recently Kurnitski et al., (2011) presented a number of equations pertaining to calculation of primary energy in NZEBs. The methodology is partially based on user input data and with additional modules added for estimation of different parameters. In order to analyze whether or not a building will qualify under the net zero energy building categorization, the Early Stage Primary Energy Estimation Tool henceforth referred to as ESPEET, has been developed. The model is based on two different metrics for net zero energy buildings: the primary energy and the renewable energy ratio. A complete overview of the different inputs and outputs of a NZEB and an insight into calculation of the primary energy has been provided by the REHVA team (Kurnitski et al, 2011; Voss et al., 2012).

The developed ESPEET in this study is based on four distinct modules. These provide data about on-site resources, the delivered energy, the exported energy and the required net energy, for the NZEB. The flow of data for ESPEET is shown in Fig. 1.

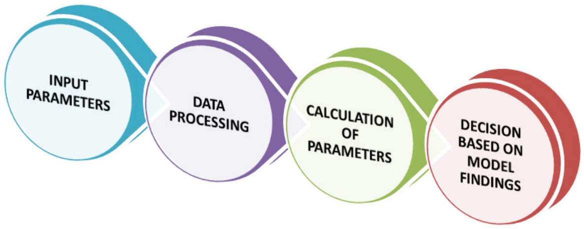

Fig. 1: Flow of data within the Early Stage Primary Energy Estimation Tool (ESPEET).

The main purpose of the developed tool is to provide the user with an overview of the influences of the different factors based on a limited number of input parameters. The full methodology of ESPEET is shown in Fig. 2.

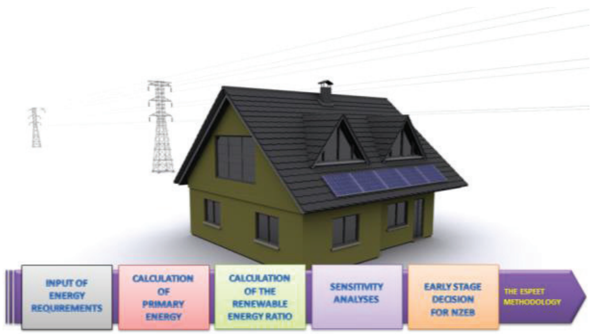

Fig. 2: Flow of data within the Early Stage Primary Energy Estimation Tool (ESPEET).

Initially the methodology utilizes a limited number of input parameters whereupon the primary energy can be calculated. In addition, the methodology establishes the renewable energy ratio and enables sensitivity analyses based on a parameter of interest. Based on the findings from each simulation, a primary early stage decision can be made concerning whether or not a building may qualify for a NZEB or not.

2.1. Input parameters

An exemplary overview of some of the input parameters to ESPEET is shown in Table 1. It should be noted that the extent of these parameters may very well extend beyond those presented in the table, as each added module may require additional inputs to that specific model.

TABLE 1: EXAMPLE OF ESPEET INPUT PARAMETERS

Parameter	Parameter description
A_{Net}	Building area [m^2]
$E_{N,H}$	Net energy need for heating and ventilation [kWh]
$E_{N,C}$	Net energy need for cooling and ventilation [kWh]
E_A	Electricity for appliances [kWh]
E_L	Electricity for lighting [kWh]
$E_{S,T}$	Energy, solar thermal [kWh]
α_{SPF}	Ground source heat pump, seasonal performance factor
β_{SPF}	Free cooling, seasonal performance factor
γ_{SPF}	Seasonal energy performance factor (fans)
δ_{SPF}	Seasonal energy performance factor (ventilation)
χ_{SPF}	Gas boiler performance factor
$f_{Del,Exp,i}$	Primary factor delivered or exported (i=1, fuel) (i=2, electricity) where i is the specific type of carrier

2.2 Calculation of primary energy

The primary energy can be calculated based on processing of the input data. In particular the calculation of primary energy is actualized by utilizing Eqn. 1:

$$E \equiv \frac{\{\sum_i E_{Del,i} \cdot f_{Del,i}\} - \{\sum_i E_{Exp,i} \cdot f_{Exp,i}\}}{A_{Net}} \qquad (1)$$

In Equation (1), $E_{Del,i}$ and $E_{Exp,i}$ denote the delivered and exported energy for carrier *i*, respectively. Moreover, the equation considers the primary energy factor for delivered energy $f_{Del,i}$ and exported energy $f_{Exp,i}$ and the useful floor area A_{Net}.

2.3 Calculation of the renewable energy ratio

The renewable energy ratio $\tilde{R}$ can further be defined as

$$\tilde{R} \equiv \frac{\psi}{\psi + (N_{C,Off} - N_{C,Exp})} \qquad (2)$$

with

$$\psi \equiv (R_{C,On} - R_{C,Exp}) + R_{C,Off}$$

In the context of Equation (2) $R_{C,On}$ and $R_{C,Exp}$ refer to the collection of renewable energy produced on site and collection of renewable energy produced on site and exported, respectively. Further, $R_{C,Off}$ denotes the collection of imported non-renewable energy produced off-site, $N_{C,Off}$ the collection of delivered non-renewable energy carriers, and $N_{C,Exp}$ the collection of exported non-renewable energy carriers. The amount of $R_{C,On}$ in Equation (2), captured by the heat pump from ambient heat sources is given by

$$E_{Rc,on} \equiv Q_u \cdot \left(1 - \frac{1}{f_{SP,h}}\right) \qquad (3)$$

where Q_u is the estimated total heat delivered by the heat pump and $f_{SP,h}$ the estimated average seasonal performance factor. In this context the condition imposed on the performance parameter according to Szabó (2012), is that it needs to fulfill $f_{SP,h} > 1.15 \cdot \eta^{-1}$, where the parameter $\boldsymbol{\eta}$ is the ratio between total gross production of electricity and the primary energy consumption for electricity consumption.

An alternative representation of defining a net zero energy building, NZEB (Kilkis, 2007), is

$$NZEB \equiv \left(\sum_i E_{f,i} - \sum_i E_{t,i}\right) + \left(\sum_i H_{f,i} - \sum_i H_{t,i}\right)$$

where $E_{f,i}$ and $E_{t,i}$ is the electrical energy received from and returned to the district, during the time increment *i*. Similarly, $H_{f,i}$ and $H_{f,i}$ represent the thermal energy from and returned to the district, respectively. With this designation $NZEB \leq 0$, identifies a zero energy building. The caveat however with utilizing Equation (4) stems from its indifference to exergy levels between electrical and thermal energy.

In order to introduce exergy analysis, the net zero exergy building factor $XZEB$ is defined as

$$XZEB \equiv \left(\sum_i \epsilon_{Ef,i} - \sum_i \epsilon_{Et,i}\right) + \left(\sum_i \epsilon_{Hf,i} - \sum_i \epsilon_{Ht,i}\right) \quad (5)$$

designating the building as a net zero exergy building if $XZEB \leq 0$. In this article however, solely the primary energy analysis and renewable energy ratios for a detached dwelling and an office building with different energy demands will be discussed.

3. CHOICE OF OBJECTS FOR ANALYSIS

In order to determine the usefulness of ESPEET, at least two different categories of dwellings have been chosen, namely single detached dwellings and office buildings. The choice of these two building types stems from the interest in obtaining different initial requirements for each building. Moreover, the combination of different on-site resources and their respective influence on the resulting primary energy can be determined. The single detached building, in this context refers to a building with a useful floor area less than that of an office building. This type of building usually features solar thermal energy and a ground source heat pump.

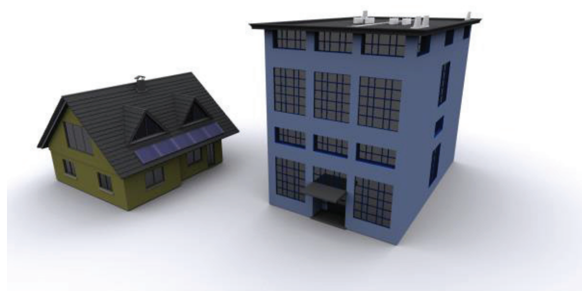

Fig. 3: Example of a detached dwelling and an office building.

An office building is designated by its larger useful floor area, in comparison to the detached building. As a baseline in this study, a useful floor area for an office building was considered to be 500 m^2. Heating is in this context often provided by means of a gas boiler, although the presence of solar energy also is possible.

3.2. Choice of locations

In order to fully assess the capabilities of ESPEET, different countries at different geographical locations in the world were chosen. This choice was based on their latitudinal global placement and attention was also devoted to whether the specific building was situated in the Northern Hemisphere, Southern Hemisphere and Western and Eastern Hemispheres. The different considered locations and their corresponding energy parameters are shown in Table 2.

TABLE 2: EXAMPLE OF ESPEET INPUT PARAMETERS FOR DIFFERENT COUNTRIES (European Environment Agency, 2013; Swedish Energy Agency, 2013; BBC; 2013)

Country	A_{Net} [m^2]	$\bar{E}_{N,H}$ [kWh/m^2]	$\bar{E}_{N,C}$ [kWh/m^2]	$\bar{E}_{S,T}$ [kWh/m^2]
Australia	206	58	13	18
Denmark	137	51	6.4	8.4
France	113	35	8.0	9.4
Ireland	88	24	5.5	4.0
Spain	97	9.8	4.2	3.6
Sweden	149	43	5.4	7.1
UK	76	24	4.2	3.9
USA	214	64	21	20

4. RESULTS AND DISCUSSION

The presented results herein have solely been based upon the outputs from the developed tool. In essence, two different studies have been carried out in which a detached building and an office building in different countries have been subjected to analyses, with the input parameters presented in the preceding section.

4.1. Detached dwelling

Based on the findings of the developed tool, Fig. 4, depicts the primary energy usage within the considered countries.

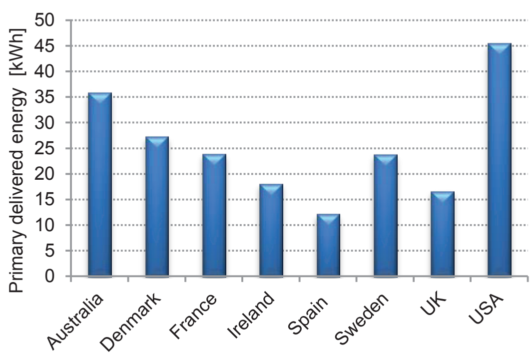

Fig. 4: Primary energy usage for the considered detached dwellings in the given countries simulated by ESPEET.

Similarly, the ratio of the renewable energy is shown in Fig. 5.

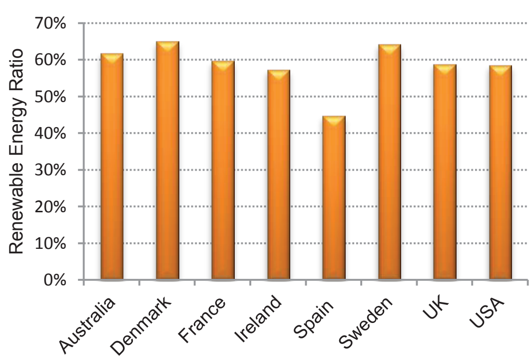

Fig. 5: Ratio of the renewable energy for the considered detached dwellings.

The findings of the simulation results based on ESPEET stem from the choice of input parameters in Table 2. It is noteworthy that the chosen parameters are partially based on retrieved data from the literature. The large area of some of the considered countries in the study made the choice of input parameters convoluted. For the United States, the chosen value was an estimated averaged value chosen for the entire country. Given the vast areal extent from the east coast to the west coast, a single chosen parameter cannot incorporate the entire spectra of encountered energy conditions across the nation. Hence, the findings of the primary delivered energy for the United States do not necessarily entail that the detached building is less of a NZEB, in comparison to other countries.

In Fig. 4, the least value of the primary delivered energy is indicative as the building which serves as the most NZEB. With the given input parameters, the simulated values suggest that the primary energy usage for Spain closely resembles NZEBs. The most NZEBs as determined by the simulation results are encountered in the following countries: Spain, UK, Ireland, Sweden, France, Denmark, Australia, and U.S.A.

From Figure 5, the ranking of the highest value of the ratio of the renewable energy is encountered for Denmark, followed by Sweden, Australia, France, U.K., U.S.A., and Spain.

An interesting analysis pertaining to usage of the developed tool is a sensitivity analysis based on a single specific parameter. These parameters have been considered in order to analyze the impact of the different parameters on the overall primary energy and renewable energy ratio.

In particular the sensitivity analysis presented herein explores the influence of the building area. Hence the remaining parameters have been kept constant. For the building area, a minimum and maximum building area of 150 m^2 and 500 m^2 has been considered, based on possible existing building area values of detached dwellings for the considered countries.

As shown in Fig. 6, it is evident that in the case of the detached building, a change in useful floor area for the same heat input values renders the building as more prone towards the net zero energy building definition, as a comparatively less energy input is utilized in the analysis.

Nevertheless, this statement should be viewed against the simple fact of whether or not the utilized input parameters indeed are sufficient for the energy demand of a large building with the building area of 500 m^2. From a net zero energy building viewpoint, utilizing a combination of large building area in conjunction with a limited energy input, renders the building as more NZEB friendly.

Explicitly for the given range and extension of the useful floor area, corresponding to a 233% increase, the building becomes 61.3% more NZEB-friendly. For the same increase in the useful floor area, a decrease of 11.7% is experienced concerning the renewable energy ratio.

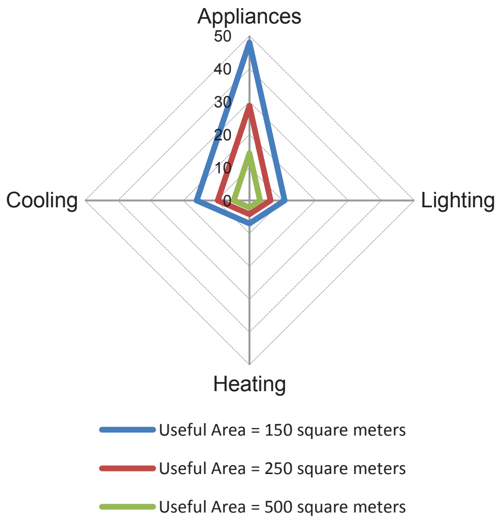

Fig. 6: Sensitivity analysis conducted on the building area with all other input parameters remaining constant using ESPEET.

This simple example illustrates that there are certain limitations with utilizing the primary energy equation without devoting attention to the input parameters and realistic energy demands of the building. Therefore, although the literature indicates that the primary energy can be viewed as a single metric for NZEBs, consideration has to be taken in order to ensure that realistic heat demands are utilized in ESPEET.

Although the geographical location of the building is considered in the developed methodology, ESPEET does not account for advanced site specific weather analysis and temperature ranges, in its current state. Hence, this fact places more emphasis on adequate input data provided by the user for a more accurate analysis. Despite this limitation, it should be emphasized that ESPEET is not intended as a detailed assessment tool, which incorporates advanced calculations of the heat transfer, occurring in NZEBs. Instead it is intended as a first analysis tool which provides a baseline for NZEBs. The usefulness of ESPEET can be placed in its simplistic nature and its adaptation to incorporate other relevant analyses pertaining to NZEBs, such as exergy and CO_2-analysis.

For the considered office building, a sensitivity analysis was conducted based on the gas boiler and seasonal performance factor $\chi_{SPF} \in [0.5,0.9]$. A decrease of the aforementioned performance factor with 44% yields that an increase of 18% is evident in the primary energy factor. The corresponding decrease in the renewable energy factor is 36%.

By utilizing ESPEET, stakeholders, policy makers and decision-makers can robustly obtain a preliminary platform for decision making based on specific criteria. Upon calculation of the primary energy and the renewable energy ratio, a sensitivity analysis can be carried out in order to enhance the net zero energy aspect of a new or existing building.

The findings of this study have highlighted the manner in which ESPEET can be utilized in order to assess NZEBs based on a simple yet effective methodology.

5. CONCLUSION

In light of the findings of this study, it has been shown that the developed tool is able to provide a preliminary overview of the primary energy usage and the ratio of renewable energy based on a limited number of input parameters. A number of limitations pertaining to a mere energy difference and large influence of input parameters of the developed model are also addressed in this study.

It should be noted that the tool is intended solely as a first approach analysis tool, for determining whether or not a building can be considered as a NZEB and in order for the user to perform simple analyses on both existing and new developed buildings, at an early stage. The tool is therefore not intended as a comprehensive tool for analysis of NZEBs, due to its simple nature. The full potential of ESPEET can be realized upon its usage by the aforementioned users. This approach will provide a prospect of developing NZEBs in a broad range of the existing building stock.

More in-depth NZEB calculations are referenced to commercial codes as they will account for both the influence of climate, geographical location and other relevant factors for a more precise analysis.

7. REFERENCES

ASHRAE Vision 2020 Ad Hoc Committee. 2008. ASHRAE Vision 2020 - Providing tools by 2020 that enable the building community to produce market-viable NZEBs by 2030.

European Environment Agency, viewed 3 February, 2013, <http://www.eea.europa.eu>.
Kilkis, S. A New Metric for Net-Zero Carbon Buildings. 2007. ASME 2007 Energy Sustainability Conference (ES2007) July 27–30, 2007 , Long Beach, California, USA.

Kurnitski, J. Allard, F. Braham, D. Goeders, G. Heiselberg, P. Jagemar, L. Kosonen, R. Lebrun, J. Mazzarella, L. Railio, J. Seppänen, O. Schmidt, M. Virta, M. 2011. How to define nearly net zero energy buildings nZEB – REHVA proposal for uniformed national implementation of EPBD recast. REHVA Journal - May 2011.

Passive House Institute US, viewed 1 February 2013, <http://www.passivehouse.us>.

Swedish Energy Agency, viewed 2 February, 2013, <http://energimyndigheten.se>.

Szabó, M. 2012. Low Energy Buildings and Cost Optimality in Building Energetics. Building Energetics, HUHR/1001/2.2.1./0009.

Torcellini, P. Pless, S. Deru, M. Crawley, D. 2006. Zero Energy Buildings: A Critical Look at the Definition. ACEEE Summer Study Pacific Grove, California, August 14−18, 2006.