Energy modelling of the building

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Abstract. The paper is focused on the modelling of energy consumption of buildings depending on outside weather and depending on the insulation of buildings. Based on the values of the outside temperature changes, schedule room-temperature set point and the measurement of the energy supply to the building it is possible to calculate the energy performance of buildings. In the calculations, it is necessary to consider not only the energy entering a building but also all the internal resources of the individual consumers as well as energy radiating from individuals living in the building. It is also necessary to take into account the intensity of solar radiation and also wind speed and direction. On the basis of precise measurements, it is possible to create a model of the building in terms of energy consumption, which can be compared with the theoretical losses imposed by the technical parameters of the building. This model can be used to actively control the operation of power equipment in a building according to the outside weather and the needs of the population. Based on the parameters it is possible to design a system of basic and additional heating based on renewable resources or recuperative technologies.

Keywords: energy consumption, the energy model of the building, loss of energy, renewable energy, additional resources

1 Introduction

One of the main problems of building maintenance is their efficient use, in compliance with the required temperature regime. They must comply with all conditions sufficient energy not only in winter but also dissipate heat from the building during the summer. Energy supply, not only in industry but also in public services is one of the main tasks. The cost of energy required for full operation of buildings is one of the existing components of current expenditure. The main objective of this paper is an energy model and existing buildings on the basis of lessons learned highlight the potential for renewable energy [1].

From the measured values of energy consumption will be made energy model of the building. This model will be used to analyze the possibility of the use of power equipment to improve the energy balance of the building.

adfa, p. 1, 2011.
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2 Creating energy model

The energy model of the building can be obtained in several ways. One is the creation of a model by measuring the power consumption and obtaining additional energy from man-made or the external environment. The other way is to create a model based on the parameters of buildings, various building materials and the temperature gradient between the room temperature and outside temperature.

To create a model based on consumption measurements

In this case, assume that a particular building is a black box on the values of input and output variables, it is possible to create a model of the object.

By measuring the energy inputs assume an energy model type

$$\mathbf{y} = \mathbf{A}*\mathbf{x} \tag{1}$$

Where **y** - is the measured energy consumed in buildings, **A -** energy model of the building, which characterizes the dependence of energy from the outside temperature, **x** - is the measured outside temperature.

If input quantities are several types of energy and measures the number of external parameters / temperature, wind speed and direction, solar radiation intensity / given model has the form:

$$\mathbf{Y} = \mathbf{A}*\mathbf{X} \tag{2}$$

where the vector $\mathbf{Y} = (y_1, y_2, \ldots y_n)$ is the vector of input energy - calculated on the single unit e.g., kWh; $\mathbf{X} = (x_1, x_2, \ldots x_m)$ is a vector of measured variables of weather, for example. outside temperature, wind speed, wind direction, solar radiation intensity, humidity, pressure and so on, **A** - energy model of the building

This model does not always accurately reflect the dynamic changes in energy dependence from changes in weather parameters. Large deviations of model outputs and real systems may arise when rapid changes in weather parameters. Certain variables, for example outside temperature, not too rapid changes in its value. Therefore there is no need to bring in the model and previous values. A greater impact on power consumption changes can have a change of wind speed or change in intensity of solar radiation. The house has a relatively high inertia and therefore consumption energy depending on the wind speed and direction may not be sufficiently precise. Accurate results showed a model that takes into account current and passing the values of the wind speed. A similar impact on consumption may also change in the intensity of solar radiation. A rapid increase in intensity in cloudy weather may not result in a rapid change in supply of energy.

It is therefore preferred to create dynamic energy model that takes into account the last power state / output / and the last state of some selected weather parameters / input /.

It is therefore preferred to create dynamic energy model that takes into account the past of consumption and the last state of some selected zones.

$$y(t+1) = A*(y(t), x(t), x(t-1), x(t-2), .. x(t-i),...), \quad (3)$$

Different types of input variables can have different temporal history.

We assume that the more of the species is possibly faster change, the more historical values should be placed in a model system.

If the house uses several types of energy / electricity, gas, hot water / from external sources (hot water - domestic hot water from a central system, thermal energy from the central distribution), we can create the following model type:

$$\begin{pmatrix} y_{1\,(t+1)} \\ \vdots \\ y_{n(t+1)} \end{pmatrix} = \begin{pmatrix} a_{1,1} & \cdots & a_{1,m} \\ \vdots & \ddots & \vdots \\ a_{n,m} & \cdots & a_{n,m} \end{pmatrix} * \begin{pmatrix} y_{1(t)} \\ \vdots \\ y_{1(t-m_1)} \\ \cdot \\ y_{n(t)} \\ \cdot \\ y_{n(t-m_n)} \\ \cdot \\ x_{1(t)} \\ x_{1(t-1)} \\ \vdots \\ x_{1(t-m_{n+1})} \\ \vdots \\ \vdots \\ x_{k(t-m_{n+k})} \end{pmatrix} \quad (4)$$

Where n- is the number of types of energy used;
k - is the number of external parameters;
$m = \sum_{i=1}^{n+k} m_i$ the number of entries of A.

Model (4) represents one possible, simple energy building model that allows us to calculate the expected performance of individual funds depending on the weather conditions and the state of the building.

Making energy model based on measured values of the energy (Fig. 1) over a period of time, preferably at least a year. However, the formation of the model may not be dependent on the number of measurement days, if we use an adaptive model, or at least the calculation of the adaptive algorithm of the model and the continuous modification.

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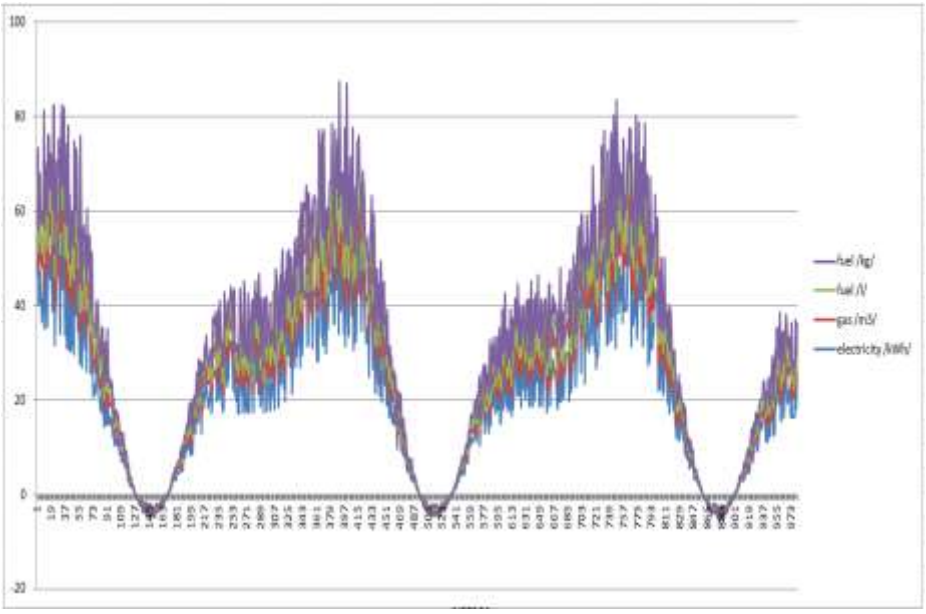

Fig. 1. Individual consumption of energy in natural units three years [2]

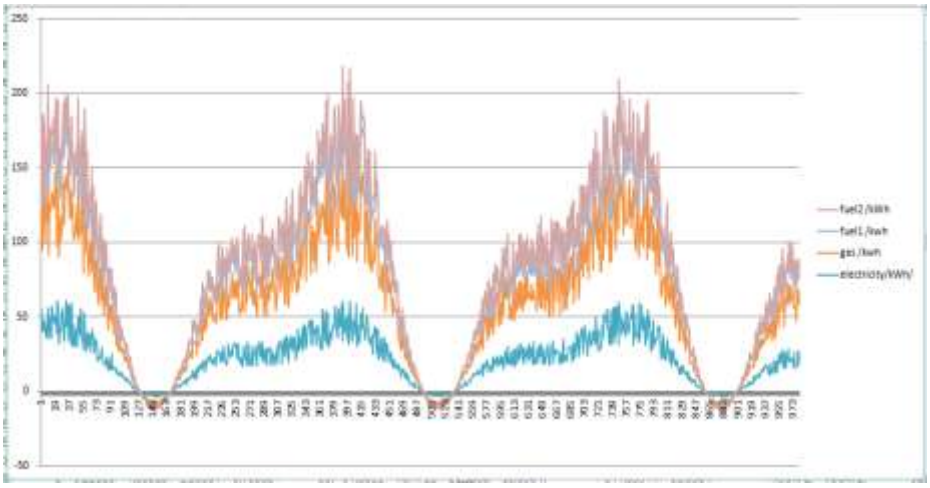

Fig. 2. Individual energy consumption in kWh three years

In that house on the recovery of the heat is used for heating oil. During the transition period and in winter, heated by burning wood in the fireplace. In addition, the connection of gas boiler. The gas is also used to prepare the food in a. Electricity is mainly used for lighting, appliances at work, preparing the water when cooking or reheating water in the reservoirs.

The energy consumption of each resource is measured in different quantities, and therefore they need to calculate the single value - kWh (Fig. 2). For creating the model is suitable individual variables have the same dimensions.

Simultaneously measured weather parameters, which include e.g. wind speed, intensity of sunlight, humidity, pressure and so on. The graph (Fig. 3) is an example of the measured data to be used in creating the model [3]. This is the temperature, wind speed and direction and cloud.

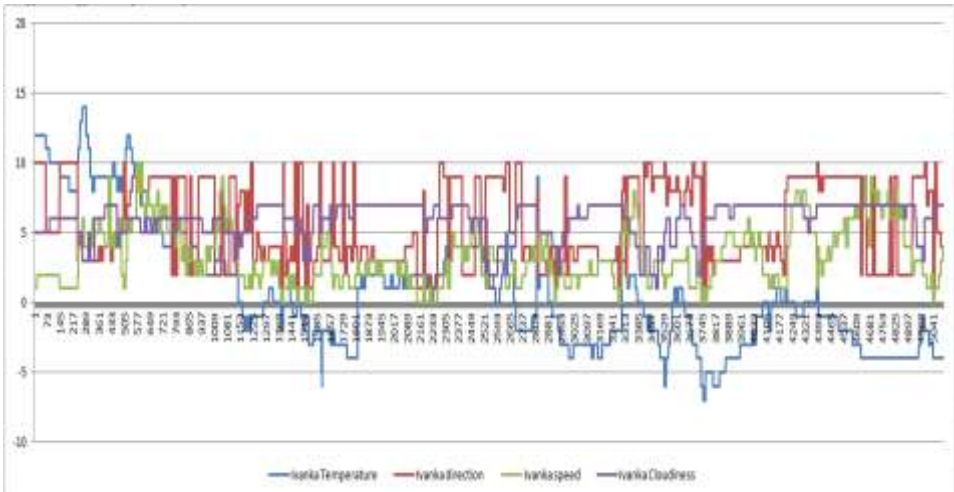

Fig. 3. Measurements of weather parameters

For proper model creation it is necessary to record the number of residents in the apartment / house /. Every person is a generator of thermal energy and have an impact on the overall energy balance.

For the purposes of model building it is therefore necessary to have the following information:

$$E = (E_1, E_2, ...E_i, ... En,) \quad (5)$$

$$P = (P_1, P_2, ...P_i, ... Pm,) \quad (6)$$

$$Ob = (ob_1, ob_{2,}, ..., ob_{i,} ....) \quad (7)$$

$$T = (t, t\text{-}dt, t\text{-}2*dt, ... t\text{-}i*dt...) \quad (8)$$

Where $E_i = (e_i(t), e_i(t-1), e_i(t-2) .... e_i(t-j)....)$ the data on the consumption of energy types, $P_i = (p_i(t), p_i(t-1), p_i(t-2) .... p_i(t-j)....)$ the data on the status of individual weather parameters, Ob - is a quantity that represents the number of persons in the house, T – vector of various time points, including the date when the variables measured.

Parameter dt is levied on the technical possibilities of inertia of the system and criteria of stability while driving.

The data on population affect the energy balance of the house and it is therefore necessary to create a vector which measures the number of residents in the house. This is a vector that needs to be formed as a time sequence.

Number of switching on the light, or other activities, and their power consumption is part of the vector Pi.

The calculation of the model and calculate the relationship:

$$\mathbf{Y} = \mathbf{A}*\mathbf{X} \tag{9}$$

Where $$\boldsymbol{Y} = \begin{pmatrix} \boldsymbol{e_{1,1}} & \cdots & \boldsymbol{e_{1,n}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{e_{k,1}} & \cdots & \boldsymbol{e_{k,n}} \end{pmatrix} \tag{10}$$

$$\boldsymbol{X} = \begin{pmatrix} \boldsymbol{p_{1,1}} & \cdots & \boldsymbol{p_{1,m}ob_1} & \boldsymbol{t_1} \\ \vdots & \ddots & \vdots \quad \vdots & \vdots \\ \boldsymbol{p_{k,1}} & \cdots & \boldsymbol{p_{k,m}ob_k} & \boldsymbol{t_k} \end{pmatrix} \tag{11}$$

The approximation line segment

The energy consumption depending on the weather, can be considered a non-linear system. There are many nonlinear models of real systems, which could be used for computationally consumption depending on the weather.

In this post lists a relatively new model - a model of linear intervals.

To identify non-linear energy systems can also use the method with linear models [4], [5]. Such an approach is for example an interval linearization method. Nonlinear systems modeled as a set of linear models. Each linear model represents a nonlinear system in certain area - ***area of linearization***.

This section shows the basic methods of linearization of an interval of two scalar variables - input quantity u (t) and the corresponding output variable y (t) obtained by measurement to identify non-linear system. At the beginning we choose the number of intervals of input variables **mu,** and number intervals of output variables **my**. Then select the limits of individual intervals uh_r a $yh_{s,}$ for r = 0,1,2,..mu, s = 0,1,2,...my. The boundaries defining the different sections of linearization $D_{r,s,}$ which may also be referred to as D^k. Calculation serial number model using parameters r and s for systems with one input and output is given in (16). Non-linearity of the

system is expressed in the form of linear equations (12) and the number of linearization segments is expressed in the equation (15).

Choice of thresholds uh_r a yh_s for r = 0,1,2, .. it, s = 0,1,2, ... we define intervals linearization (uh_{r-1} - uh_r) and (yh_{s-1} - yh_s) (from them name derived methods) that define the relevant ***sections linearization*** Dr, s, representing a D^k. Calculation serial number model using parameters races for systems with one input and output is given in (16) Model non-linear system is expressed in the form of a linear equation (12) and the total number of sections linearization is expressed in the equation (15)

Equivalent linear model system with an input and an output variable for the k-th interval linearization we express the difference equation

$$y(t) = q_0^k + \sum_{i=1}^{ny} q_i^k y(t - iT) + \sum_{j=1}^{nu} q_{ny+j}^k u(t - (j - d + 1)T) \qquad (12)$$

or a shorthand form

$$\mathbf{y}(t) = \mathbf{z}(t)\, \mathbf{q}^k \qquad k=1,2...,kk \qquad (13)$$

where

$\mathbf{z}(t)= [1,y(t-1),...,y(t-ny),u(t-d),...,u(t-d-nu+1)]$

$\mathbf{q}^k$ is a vector model system in the k-th interval linearization, while

$$\mathbf{q}^k = (q_0^k, q_1^k ..., q_{nu+ny}^k) \qquad (14)$$

nu - number of starting variables entering the model

ny - number of samples the output variables entering the model

t - time

T - sampling time

d - input variable displacement

k - index interval linearization

The total number of sections for linearization kk where nu =1 a ny= 1 calculate

$$kk = mu.my \qquad (15)$$

index k - serial number linearization section express the relationship

$$k = (r-1).my + s \qquad (16)$$

Where there are more input quantities and more output quantities nu> 1 a ny > 1

$$kk = mu^{nu}.my^{ny} \qquad (17)$$

The value of index linearization is calculated as follows. If the output quantity y (t-i), i = 1,2, .., ny is the amplitude of the area (yk_{s-1},yk_s), s =1,2,...,my, we then denote the character area with I_i= s. Similarly, if the value u(t-j-d+1), j=1,2..,nu is from zone (uk_{r-1},uk_r), r =1,2,...,mu, then the this area shall indicate the I_{ny+j} = r. The values of these intervals inserted into a vector I=(I_1, I_2,..I_{nu+ny}). Index linearization interval calculated according to

$$k = I_1 + \sum_{l=2}^{nu+ny} (I_l - 1).\delta_l \qquad (18)$$

where

$\delta_l = my^{(l-1)}$ for l=1,2,...,ny

$\delta_{l+ny} = my^{ny}.mu^{(l-1)}$ for l=1,2,...,nu

l - auxiliary index

From the measurement of the long-term operating u(t), y(t) we know the dependence of f = f (u (t), y (t)) generally does not pass all the possible areas of Dk, k = 1,2, ..., kk. Therefore, it is usually necessary to construct a smaller number of linear models, such as the maximum number kk.

Construction of the linear model (12), respectively (13) for the k-th interval, the linearization is to determine the coefficient of linearization of the vector (14) from the measured values y(t-i) and u(t-j-d+1) for i = 1, ..., ny, j = 1,. .. nu with the k-th interval linearization..
The model is obtained from the relationship $\mathbf{A}^k\mathbf{q}^k = \mathbf{b}^k$, of which expresses the vector model $\mathbf{q}^k$ for k- section linearization method of least squares. It is necessary to create a matrix $\mathbf{A}^k$ from measured value y(t-i) a u(t-j-d+1) and vector $\mathbf{b}^k$ from measured value y(t).
For r- line of matrix $\mathbf{A}^k$ we can write

$a^k_{r,i+1} = y(t-i)$ for i=1,2,..,ny

$a^k_{r,j+1+ny} = u(t-j-d+1)$ for j=1,2,...,nu

$a^k_1 = 1$

For element of vector $\mathbf{b}^k$

$b^k_r = y(t-r)$

where r = 1,2... n ; ny+nu+1 < n

The results of such a simulation model is shown in Fig4.

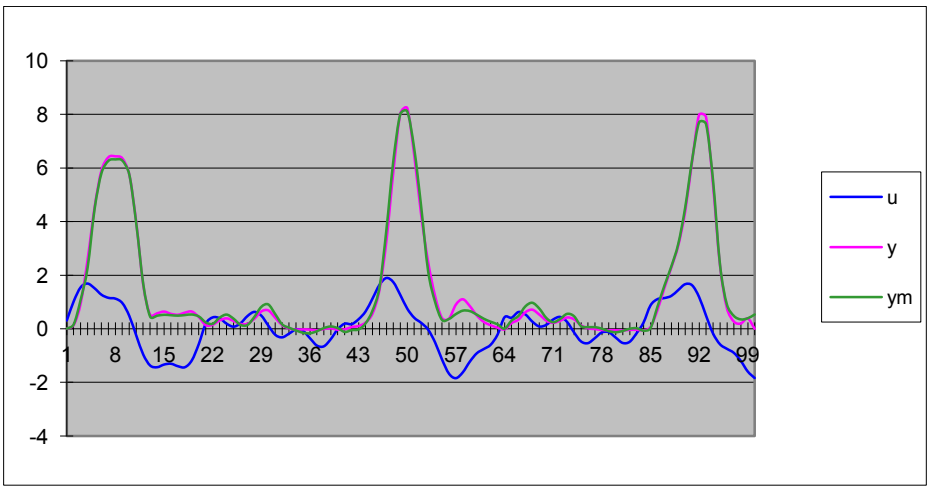

Fig. 4 Modeling of energy consumption depending on external conditions

The essential features of the method is the dependence of the accuracy of the identified model, the number of selected intervals, which divide the input and output signal, and the choice of the borders of the selected intervals. Their appropriate change we are trying to achieve the highest accuracy of models that quantify example. the sum of

quadrates of deviations given patterns you-degrees values of the respective samples - originálu and the model output for a given interval of independent variable.

Energy model system based on physical properties

This model represents a system of equations and inequalities building on the basic physical patterns on the transfer of heat between the flat panel composed of several layers. In this case, it is necessary to know the thermal conductivity and thermal resistance of the material, number of layers of which the house is composed. Then, on the basis, according to such relations, it is possible to calculate the energy loss of the house.

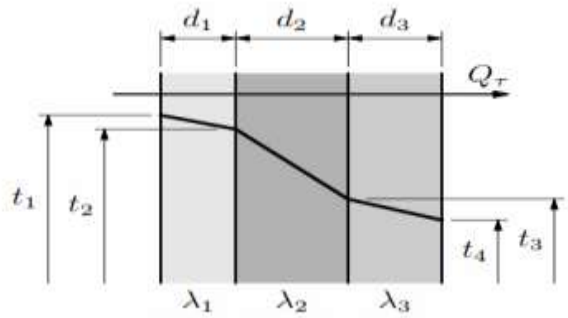

Fig. 5. Calculation of heat transfer wall

These energy losses compared with the total loss of the house in accordance with the commanding remove energy.

3 Use of models

The resulting mathematical model may be used in the design of additional energy sources for the building or the design of the switch from traditional sources for renewable energy. Based on weather data for the measured period can be calculated in available energy from various renewable sources. Based on the course during the design and the additional resource, it is possible to remodel cover the consumption of energy in the house. The information thus obtained are the basis for the design and implementation of such devices.

To reduce the energy dependence of the house from primary sources, it is possible to select multiple wind farms (Fig. 6) with different diameter rotor (VET1, VET2, ..VET4), which differ not only the size but also the price of the connection method, operating costs, etc.

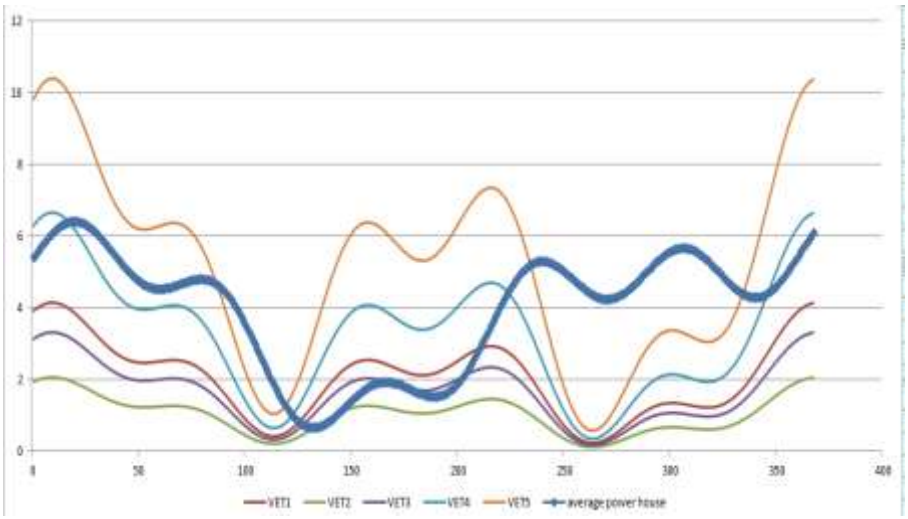

Fig. 6. Comparison of household consumption and possibilities of energy production from wind power

Based on the curves of energy production from wind and average consumption of the house during the whole year, you can choose a suitable VET so that each source to make the most. The following diagram (Fig. 7) is shown the available amount of energy that can deliver different sources that can absorb the house. These figures can be seen what part the energy can be covered with an energy source.

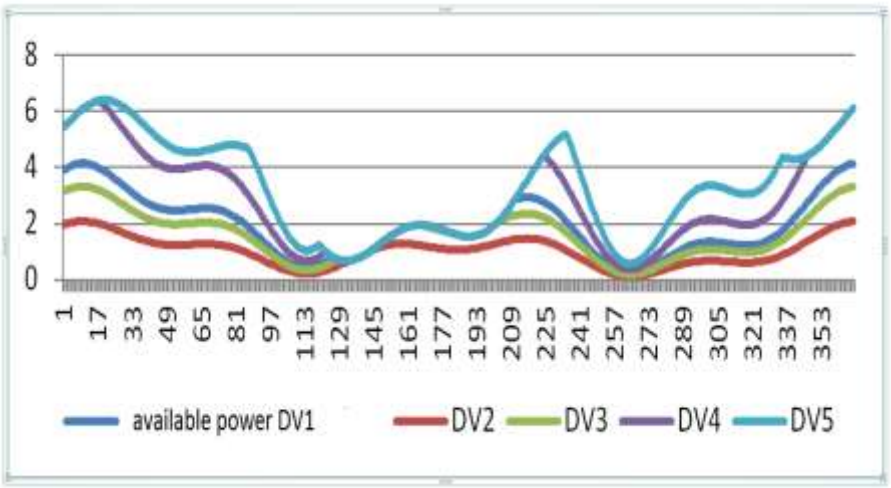

Fig. 7. The projected amount of energy VET

4 Conclusion

Creating energy model allows each building to carry out an analysis of the technical condition of buildings and the proposal to establish an effective additional energy source. On analysing the technical condition to be compared created model energy system based on the input-output characteristics with model created by physical calculation of the house. In the event of a significant deviation can be assumed aging materials or damage insulation properties. For analysis of additional resources it is appropriate to calculate the estimated consumption of the house during a certain period and the possible energy yield and substantial financial savings for the introduction of selected types of renewable sources. Compare the cost of installing and operating the supply with energy savings can be calculated the overall economic return.

Creating energy model for individual houses is not the ultimate goal but a means to implement economically efficient energy management of buildings.

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