Changes of the Operating Costs during the Life Cycle in Existing Housing Stock

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Changes of the Operating Costs during the Life Cycle in Existing Housing Stock

D Vytlačil

Department of Engineering Informatics, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague, Czech Republic

vytlacil@fsv.cvut.cz

Abstract. The paper describes the dynamic model of the changes of the operating and investment costs that are associated with the energy consumption in the building. These costs are assessed for the building structure and HVAC systems. The aim of the research is to find the time dependent energy consumption and the cash flow that depends on the investments to energy saving arrangements and operations. The solution is based on the system dynamics method. The method makes possible to interconnect technical and economic parts of the problem. The main parameter in the model is the energy consumption in the building per floor square meter and year. This parameter is influenced by a deterioration of the building structure and the components of the active elements. Another influence are the investments that are realized with the aim to decrease the energy consumption. The example of the calculation of the main system parameters during the building life cycle with two projects is presented in the paper. The main output from this research is the developed model which makes possible to investigate the influence of multiple energy saving projects during the building life cycle.

1. Introduction

The energy savings efforts in the buildings are nowadays more focused on the existing housing stock. The new buildings are built according to the technical standards that ensure low energy consumption. The prediction of the energy consumption during the building life cycle deals also with the economic evaluation as the life cycle cost analysis [1]. It has the relationship to the decision about energy saving projects. Investors are usually interested in payback period that is well understandable. Another parameters are based on outputs from net present value and internal rate of return methods.

The aim of the paper is to develop the model for the description of the dynamic behaviour of the system including building structure and HVAC system where the key parameters are heating energy use [kWh.m^{-2}.year^{-1}] and the cash flow generated by the projects. The calculations uses the system dynamics method.

The solution has to include the changes in the external environment as energy price changes and the decision about investment activities that will influence the future energy consumption [2]. Another important issue is the influence of the maintenance level that can change the effectiveness of HVAC systems [3]. The building structure suffers from ageing construction materials. The thermal materials are made as fibrous materials or cellular materials. The thermal conductivity in the fibrous materials are influenced by the moisture and in the cellular materials by a diffusion of air into the cells. It causes slow resistivity decreasing during the building life cycle.

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2. Method

The developed model is based on system dynamics. This method allows to interconnect technical calculations and the economic parameters calculation in one model [4]. The main elements in the model are stocks (levels) that are the key parameters in the investigated problem and flows influencing the stocks. The auxiliary element are convertors for the other parameter calculations and logical functions applications. The main equation (1) describes the changes in one stock during the time interval from t_0 to t [5].

$$Stock(t) = \int_{t_0}^{t} [Iflow(s) - Oflow(s)]ds + Stock(t_0) \qquad (1)$$

3. Model description

The model covers above described issues and it is used for the simulation in the case study.

3.1. Model elements

The dynamic model is depicted in figure 1. The element *Energy consumption/m2/a* is the annual energy consumption per quadrat meter of the floor space. The stock changes are described by equation (2).

$$Energy\_consumption/m^2/a(t) = Energy\_consumption/m^2/a(t - dt) + (increasing - decreasing)\cdot \mathrm{dt} \qquad (2)$$

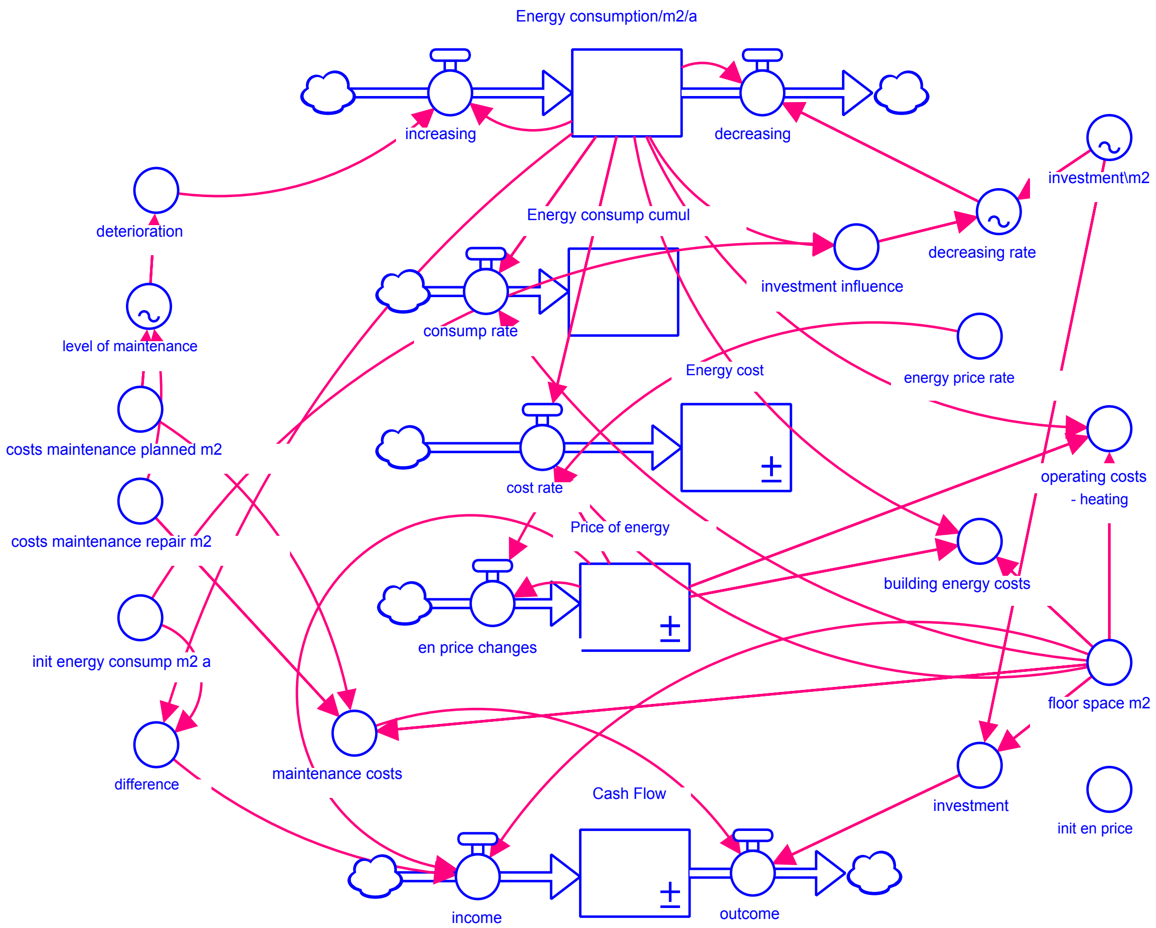

Figure 1. Dynamic model with main elements.

This stock is influenced by *increasing* and *decreasing* flows. The *deterioration* element includes ageing of the structure materials (thermal insulation) and HVAC systems. The rate of the changes depends on level of the planned maintenance and level of the repair maintenance. These inputs create the basis for the calculation of *increasing* flow. *Decreasing* flow is derived from *investment* element where the time-dependent changes of investment costs are entered. It is possible to use any level of investments in desired number of the refurbishment projects. The implementation of the project will cause the step change of the energy consumption.

The *Cash Flow* is calculated as the difference between *income* and *outcome* element values. This value presents the cash flow of the energy saving project, it means, it does not include all operating costs occurring during the service period of the building. *Income* is equal to the saved money after the implementation of the project. The important influence has also the initial energy price and the annual change of the price. *Outcome* is the sum of the investment costs and the maintenance costs.

3.2. Input parameter values

The simulation was performed for the family house for the time period 40 years. In this time period the investor implemented two energy saving projects (named Project 1 and Project 2) with the goal to reduce the energy consumption in the house. The reason for the second project is the wearing of the elements which influence the energy consumption and the possibility to use new more effective structure/HVAC elements.

The dwelling is 45 years old and the initial specific energy consumption is 250 kWh.m^{-2}.year^{-1}. For the planned maintenance is spent 38 CZK.m^{-2}.year^{-1} and for the repair maintenance 20 CZK.m^{-2}.year^{-1}. The value of deterioration element value is derived from these inputs and it is 2%.

Table 1. Input values – energy.

Initial price of energy [CZK.kWh^{-1}]	Initial consumption of energy [kWh.m^{-2}.year^{-1}]	Annual change of energy price [%]
1,22	250	2,5

Table 2. Input values – projects.

Investment activities	Investment costs [CZK]	Implementation [year]
Project 1	600000	3
Project 2	600000	23

4. Results

The resultant values from the simulation are depicted in figure 2 and figure 3. The first figure presents specific energy consumption and year operating costs (heating) during the 40 years. The realized projects caused the reduction of the energy consumption and accordingly also the operating costs. Because of expected energy price rise this benefit disappears after same time. The final value of the specific energy consumption is 88,6 kWh.m^{-2}.year^{-1}.

In figure 3 the projects cash flow is presented. The cash flow for the first project did not reach the zero value during the observed time. The second project has the higher outcome due to higher price of energy in the last years of the time period. The development of the energy price is also drawn in figure 3.

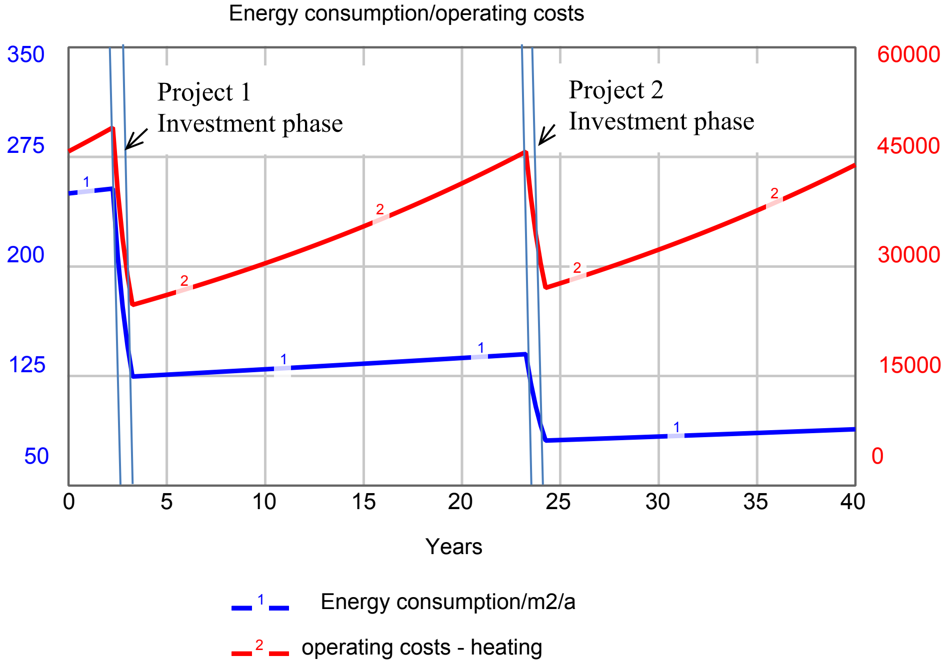

Figure 2. Energy consumption [kWh.m^{-2}.year^{-1}] and year operating costs – heating [CZK].

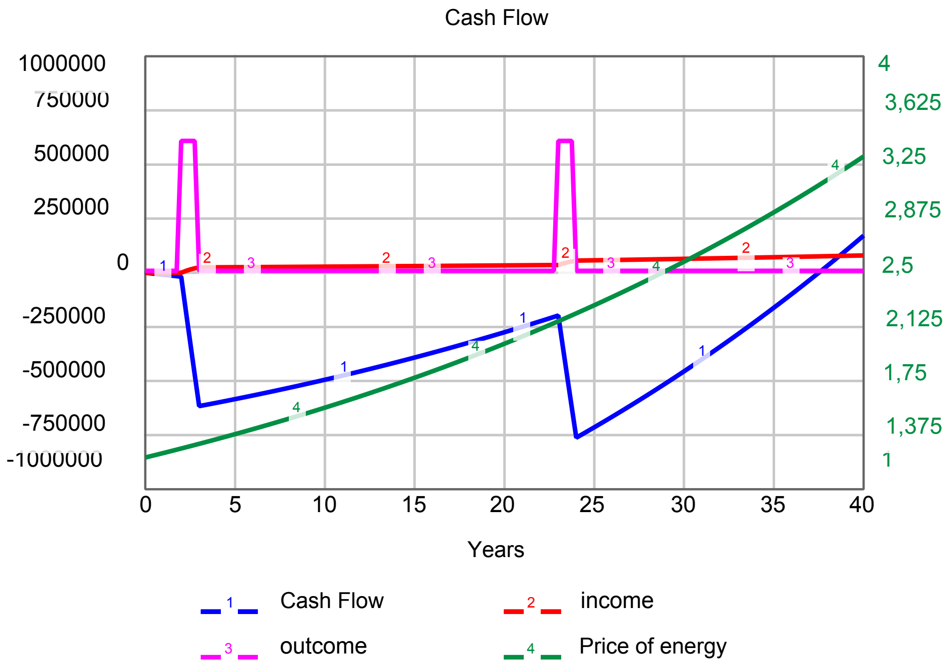

Figure 3. Cash flow of the projects [CZK] and price of energy [CZK.kWh^{-1}].

Because of expected high sensitivity to *energy price rate* parameter the calculation was performed with the aim to demonstrate this influence. The simulation of cash flow for different values of energy price rate has been done. The input parameter values were changed from 1% of the year increasing to 5%. The resultant values are in figure 4 and final values are in table 3.

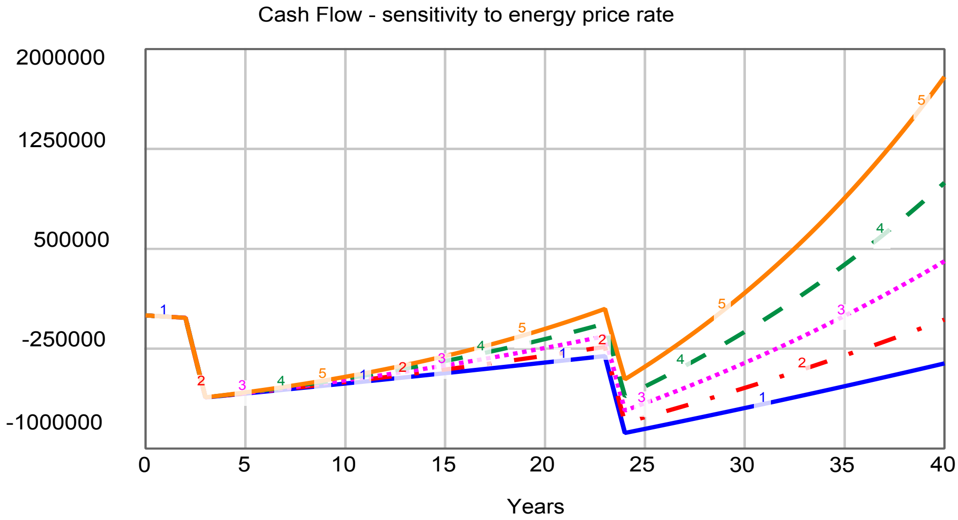

Figure 4. Cash flow [CZK] for different values of year energy price rate – from 1% to 5% (the curve 1–5).

Table 3. Output values – Cash Flow final value.

Energy price rate [%]	Cash Flow [CZK]
1	-360515
2	-31822
3	407023
4	996313
5	1791746

5. Conclusions

The dynamic model has been developed. It allows us to perform simulation of the complex system behaviour. The system dynamics model can work with any number of energy saving projects during the life cycle of the building. It makes possible to investigate the relationship among all projects. The output from the model is the energy consumption per square meter of the floor space, the energy consumption in the building and total energy consumption during the certain time period.

Another output is the cash flow, which is influenced by the energy saving projects implemented during the investigated time period. It is the important result because it helps us to make decision when to refurbish the building and how much to spent for the passive and active elements. The main output is to find the feasible alternatives for the energy consumption decreasing and the affordable investment costs.

Acknowledgments

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