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System Model for Prediction of Energy Consumption in Cities

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System Model for Prediction of Energy Consumption in Cities

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 number of inhabitants in cities has been increasing in the past years and this tendency will be in the future even more significant. We need a tool for the prediction of the energy consumption. The paper describes the system model that includes sub models: the energy consumed for housing, inhabitants services, city services and transport. These sub models are interconnected to one system. The solution is based on the system dynamics methodology which is suitable tool for solving problems of economic and technical systems. Special focus is given on the description of the energy consumptions in the residential houses, in the buildings providing city service and on the migration of people from rural area and small cities to big cities. The number of inhabitants influences the energy consumption and the density that is connected to the energy consumption for the transport. The simulation includes the refurbishment of the existing building stock. Main output parameter is the energy consumption in the sub models and in the whole city. The model can help to improve the strategy decision making concerning city development.

1. Introduction

The paper deals with the prediction of the energy consumption in the cities. The cities are responsible for two-thirds of global energy consumption. The key influences of the final consumption of urban energy are: the level of economic development and the distribution of income, urban form and density profiles, culture and climate, demographic growth and age structure, [1]. The big issue is the migration from rural area to the cities.

The results include the energy that is related to the number of inhabitants in the city and to the building stock. It means, the calculations do not include the energy consumed in the industry. Industrial buildings and the production processes are more connected to economic activities.

The main aim is to develop the system model that covers all important elements influencing energy consumption. The outputs from the simulation are important for the design of all capacity elements and also for the investigation of the influence of changes in the number of inhabitants and the buildings stock. It can help to find the strategy for energy consumption decreasing in the existing building stock.

2. Model

The first step is do the list of all factors influencing the behaviour of this complex system. These factors are connected to the objects in the real world. After simplification and identification of the key objects it is possible to design the model elements.

2.1. Method
The model is based on the system dynamics methodology that is suitable tool for describing the dynamic system with technical and economic elements. The method includes the creation of the cause diagrams for the realization of all dependencies and understanding the causal loops in the system [2].

The next step is the design the model with the stock elements and the flow elements. The initial model is validated for the existing data from the past and after it, the model can be used for the simulation [3].

2.2. Model description and input data
The designed model is in figure 1. It includes the main elements influencing energy consumption in the cities. It is based on the number of inhabitants and on the existing building stock together with the future new house construction activities. This two inputs influence the four key parts of the energy consumption:

- Energy consumption – housing: energy consumed in the houses, it depends on the floor area
- Energy consumption – inhabitant services: energy embodied in services and goods used by city inhabitants
- Energy consumption – transport: it depends on the number of the city inhabitants, [4]
- Energy consumption – city services: public service provided by local authority [1], (the energy for lighting, water supply, waste and the energy consumed in buildings as schools, government offices, hospitals), [5], – it is derived from the number of city inhabitants and city area

The important subsystem is the stock *City inhabitants* and its inflows and outflows. The inflows are migration to the city and the birth flow. The migration depends on the attractiveness of the cities compare to rural area and small cities. The outflows are migration from the city and the dead flow [6]. The initial values for Prague in 2017 year are 1295000 inhabitants, *migration in* 36923, *migration out* 25529 people.

Another important subsystem is created by all building stock elements [7]. The buildings are considered as the residential buildings. The stock *Existing stock* includes buildings built till 2017. The *Refurbish stock* covers 27 % of the whole building stock and is calculated from existing building stock. New buildings are in the stock *New stock*. The refurbishment rate is assessed from the investment costs spent for the refurbishment and from the investment evaluation. This evaluation is rate between the energy savings project output and the investments. The parameter value influences the owner decision on launching the refurbishment project. The input values are in table 1. *City service savings* element represents efforts for energy consumption decreasing in the buildings that are part of the city service. The amount of refurbished buildings depends on the available budget. The target value is 40 % of the original value during next 10 years. Another inputs for the calculation are the city area and the number of city inhabitants.

The energy consumption for the transport in the city depends on the number of inhabitants and on the density of the inhabitants.

Table 1. Input values – building stocks.

	Floor area [10^3.m^2]	Energy consumption [kWh.m^{-2}.year^{-1}]
Existing building stock	27884	280
Refurbished stock	8329	130
New stock	6000	50

The simulation was performed for 10 years in the city Prague.

3. Results
The changes of the building stocks are depicted in figure 2. The stock of existing buildings is decreased by 59% during ten years. The refurbished buildings are moved to the stock of refurbished buildings. At the same time the refurbishment rate is decreased because of the lower amount of the existing buildings

that is used for the calculation. In this case, the influence of the subsides is not considered. The subsidy programmes can change the project evaluation and to increase the refurbishment rate.

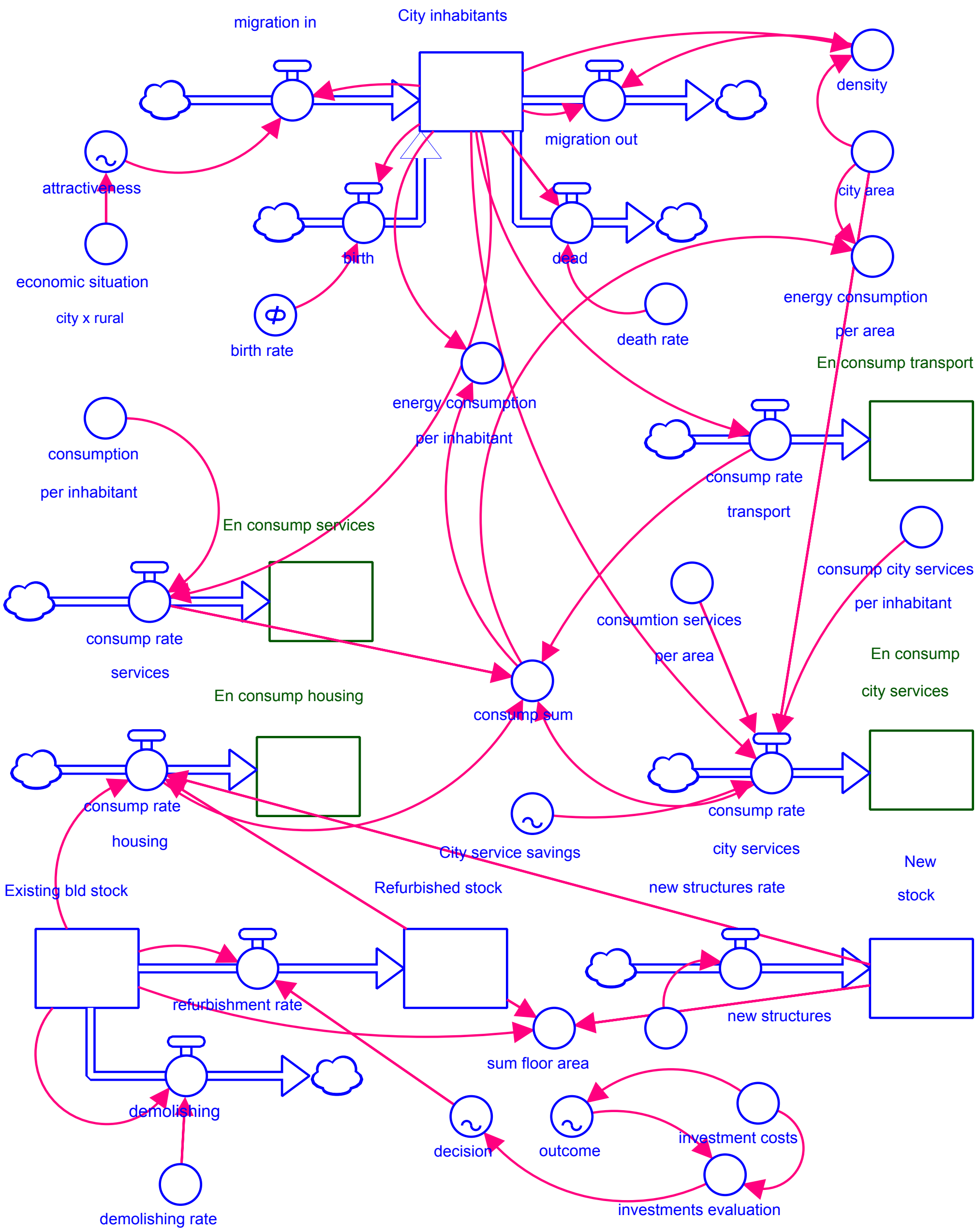

Figure 1. Dynamic model for city energy consumption assessment.

Figure 3 presents the resultant values of the building stocks rates. Only the consumption rate for the housing goes down because of the energy savings arrangements are considered. Other parts of the whole energy consumption do not apply any changes in the specific consumption. It is the motive for the next model improvement.

Figure 4 depicts the consumption rates and the cumulative values of the energy consumption for all parts of the city energy consumption. The future changes in city inhabitants are described by the figure 5 together with the energy consumption per inhabitant. The relative consumption decreased nearly by 10 % due to the savings in the building stock.

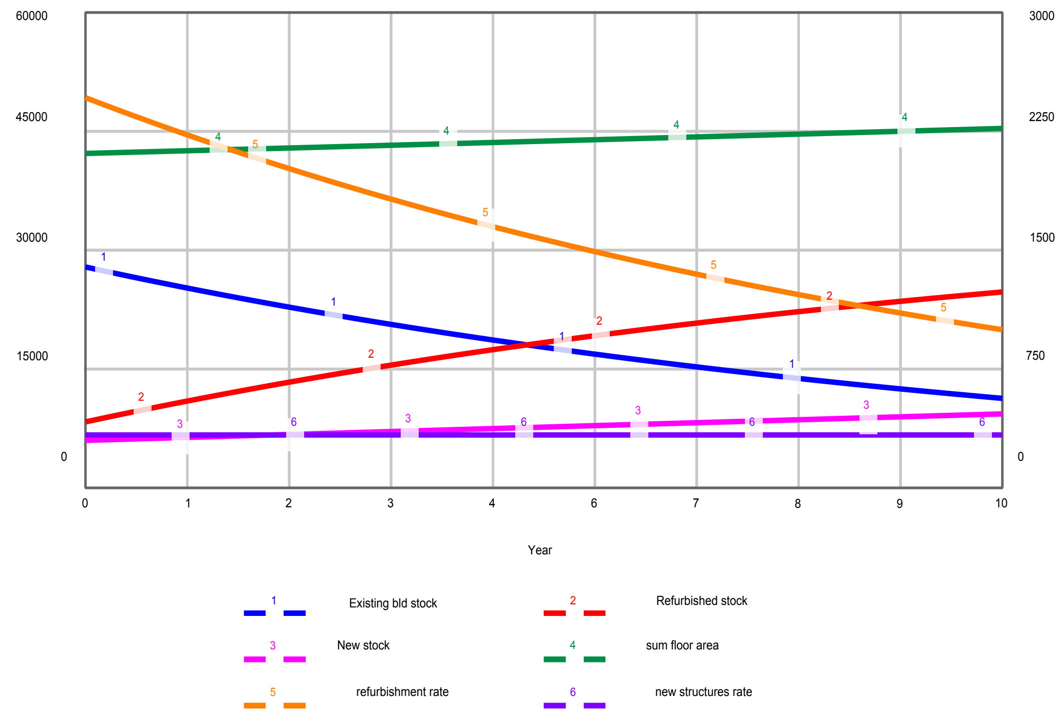

Figure 2. Building stocks [10^3.m^2], right axis – rates [10^3.m^2.years^{-1}].

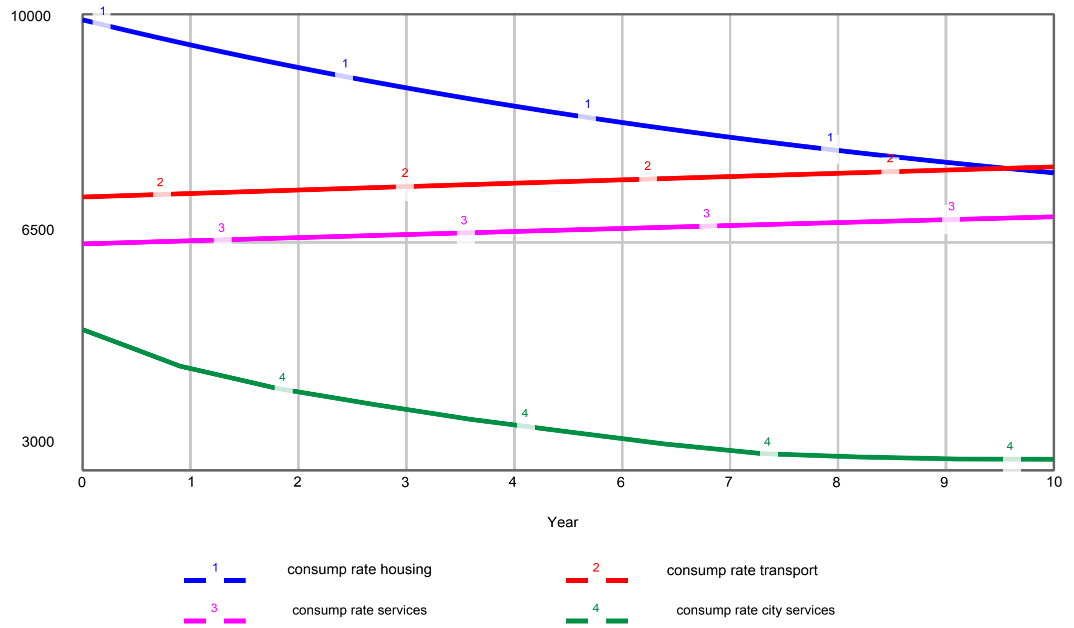

Figure 3. Consumption rates for housing, transport, services, city services [MWh.year^{-1}].

4. Conclusions

The developed model helps to perform effectively the investigation of the problems concerning the consumption energy in the cities. The main goal was to introduce elements describing changes in the number of city inhabitants and in the building stock elements. The number of inhabitants is important driving force for the energy demand. The possible solution for energy demand decreasing is to refurbish the existing building stock.

The simulations save time and the financial resources to obtain the output parameter values for strategy decision making. These outputs from the model can help to propose the energy efficient urban development. It will help to design the capacities of the infrastructure, to find the strategy for low emission production (from the buildings).

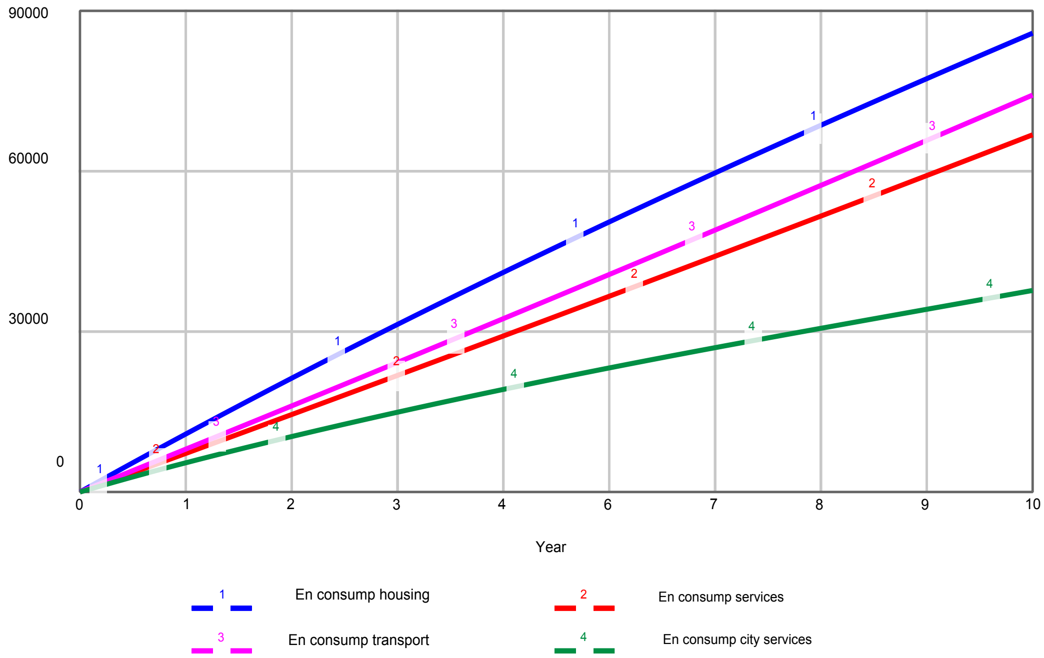

Figure 4. Energy consumption for housing, transport, services, city services [MWh].

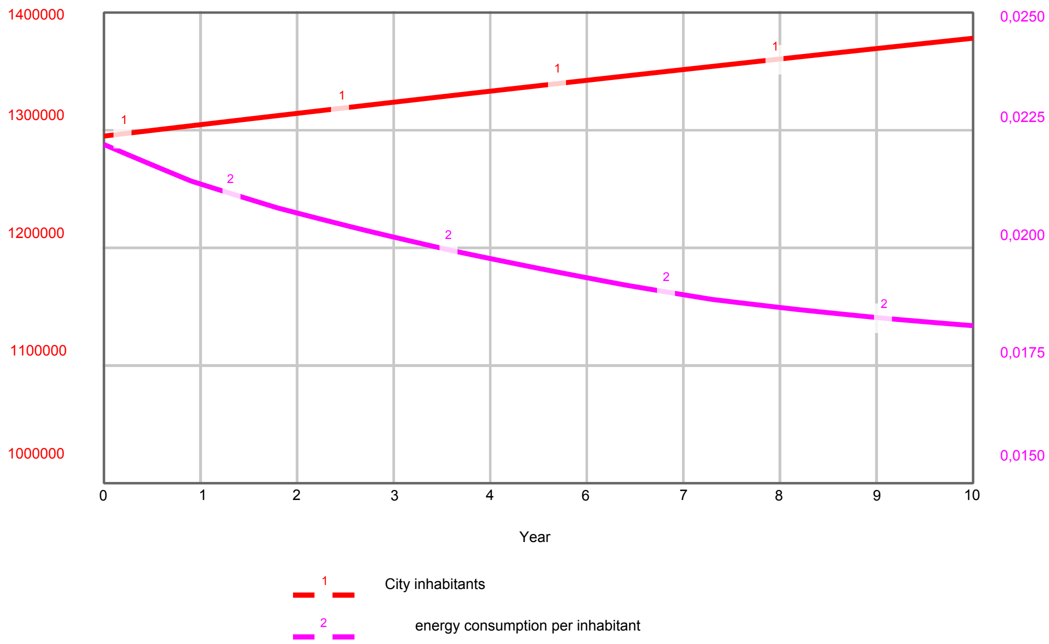

Figure 5. Changes in the number of city inhabitants, right axis – energy consumption per inhabitant (relative energy consumption) [$MWh.year^{-1}.i^{-1}$].

The next development will be focused on the introduction new elements that will describe the changes of the energy consumption by the investments to new technologies. Another improvement can bring using financial resources elements because all activities depend on the level of available resources.

The system dynamics model is one possible approach for solving problem. The solution needs also another methods of system analysis and optimization methods. Together it can bring the final solution and after the implementation it ensures the improvement of the life in the cities.

Acknowledgments
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References

[1] Gadonneix P 2010 *Energy and Urban Innovation* (World Energy Council)

[2] Morecroft J 2008 *Strategic Modelling and Business Dynamics* (Chichester: England John Wiley & Sons) p 39

[3] Sterman J D 2000 *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Boston: Massachusetts Irwin/McGraw-Hill)

[4] Peltan T, Maier K, Franke D and Tucek I 2013 On commuting related energy consumption and its assessment *CESB 13 – Central Europe towards Sustainable Building* (Praha: GRADA) pp 903–6

[5] Pereira I M and Sad de Assis E 2013 Urban energy consumption mapping for energy management *Energy Policy* **59** 257–69

[6] *Fluctuation of Inhabitans in Prague and State* 2017 (Czech Statistical Office)

[7] Nemec M 2010 *Housing Stock in Prague* (Prague: Prague Local Authority Office)