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Energy Consumption Modeling in Residential Buildings

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ABSTRACT: In recent years, the issue of energy consumption modeling techniques in the building sector has been widely considered by researchers and managers. Researches indicate that energy consumption in residential sector is one of the main parts of the total consumption. Moreover, the urban residence is supposed as a significant consumer of energy in every country and therefore a focus for energy consumption efforts. For over increasing building energy consumption there can be some causes including : climate change, increase in household electricity load, fast-growing household electrical appliances, huge energy consumption of the buildings, and the lack of strict government supervision.
Recently the issue of assigning different prices to different time-periods of energy consumption has been taken into consideration for energy prices of consumers' bills. Therefore, in this paper a model for multi-prices and multi-periods single-type energy consumption in urban residential sector is presented; also an efficient heuristic method is provided for solving the mentioned model.

Keywords: *Energy Consumption, Buildings, Network Models, Multi-prices; Multi-periods.*

INTRODUCTION

Countries accessibility for energy can be indicated as a sound development index, as well as political and economical power. High energy prices and its capital costs, as well as countries ever increasing energy demands, have all encouraged countries to consider energy productivity; they try to prevent uncontrolled and inefficient energy consumption, reduce production costs, and increase the public welfare (Yao and Zhu, 2011). Furthermore, buildings account for 45% of worldwide energy use and the urban residential sector is a significant consumer of energy in every country, and therefore a focus for energy consumption efforts (Jebaraj and Iniyan, 2006).

Applying a proper and reasonable management of consumption, not only can provide the economic growth of the country, but also will lead to a more sustainable supply of energy for all users. Fig. 1 illustrates energy consumption trend in residential sector.

In Fig. 2, the percent energy consumption by residential sector end-uses is illustrated. Some reasons for over increasing building energy consumption can be listed as: climate change, increase in household electricity load , the growth of real estate, fast-growing household electrical appliances, changes in industrial structure, huge energy consumption of the existing buildings ,and the lack of strict government supervision (Yao and Zhu, 2011). In previous years, the issue of assigning different prices to different time-periods of energy consumption has been taken into consideration for energy prices of consumers' bills. The present paper aims to model energy consumption of multi-prices and multi-periods single-type energy (with the limitation in amount). The model is a mathematical one, and a heuristic solving method is then stated.

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The remainder of the paper is organized as follows. In section 2, a literature review is presented, and sections3 illustrates the mathematical model of the problem. Moreover the solving method is detailed in the third section. Finally, section 4 contains the concluding remarks.

Literature Review

Energy Consumption in Residential Buildings

In their article, Eichen and Tukel (1982) emphasized that whatever future energy path is chosen, it will be critical to know energy supply and demand patterns at the micro (family) level, i.e. residential sector. They examined public surveys which gathered information at micro (family) level and then suggested the possibilities for further research. (Eichen and Tukel, 1982). Using statistical data, Zhang (2004) analyzed the annual consumption of electricity, coal gas, LPG, natural gas, and coal as well as energy for district heating in urban residences of different regions. The relationship between the annual energy consumption per household (UEC) and heating degree-days was examined for China, Japan, Canada, and the United States. Furthermore, regression equations of energy consumption in each household were developed for the four countries (Zhang, 2004). Jinghua et al. (2008) employed EQUEST software to analyze the effects of energy saving strategies on air conditioner electric consumption of different orientation rooms in hot summer and cold winter zone in China.

A critical review of various modeling techniques of energy consumption in residential sector was presented by Swan and Ugursal (2009). A focus on the strengths, shortcomings and purposes, was provided along with a review of models reported (Swan and Ugursal, 2009). By using residential

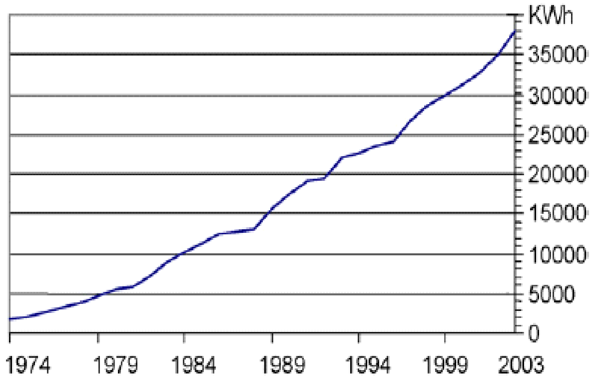

Fig. 1: Energy consumption trend in residential buildings (Iran) (Source: Azadeh and Faiz, 2011)

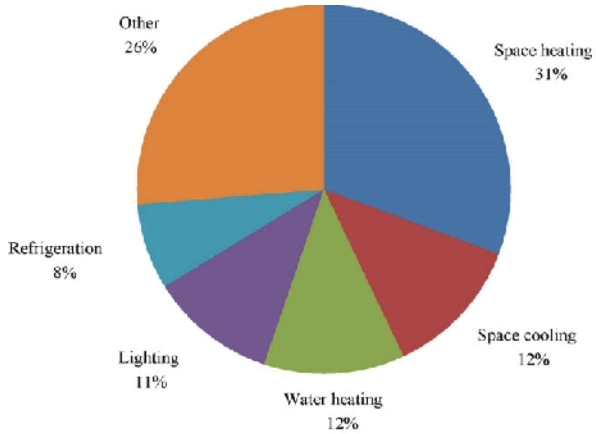

Fig. 2: The illustration of percent energy consumption by residential sector end-uses (Source: Soratana and Marriott, 2010)

energy consumption survey data from the Energy Information Administration, Kaza (2010) used quintile regression analysis to tease out the effects of various factors on entire distribution on the energy consumption spectrum instead of focusing on the conditional average (Kaza , 2010).

In their paper, Hirst et al. (2010) summarized and analyzed the National Interim Energy Consumption Survey (NIECS) data on household energy consumption- total energy use, electricity use, and use of the primary space heating fuel. The regression equations constructed explained roughly half the variation in energy use among households (Hirst et al., 2010). However, the data collected on energy consumption are often very few or non-normal. Hence, Lee and Tong proposed a forecasting energy consumption using a grey model improved by incorporating genetic programming. A real case of Chinese energy consumption was considered to demonstrate the effectiveness of the proposed forecasting model (Lee and Tong, 2011). There are few studies that have analyzed the consumption of energy by groups of buildings. In their research, Pereira and Sad de Assis (2013) developed a model able to estimate the energy consumption by residential sectors, in different areas inside a city, through the adoption of an energy planning methodology.

Moreover, low-income housing constitutes an important but often overlooked area for energy use reductions within the residential sector. Given the scarcity of existing information on this subject, a study was conducted using a semi-structured interview format to explore the key behavioral tendencies (Langevin,2013).

However, collections of building energy consumption data are often uncertain due to unavoidable measurement errors. Lu et al. (2013) presented a survey in which on the basis of the quantitative uncertainty and Monte Carlo uncertainty propagation methods, the uncertainty of building energy consumption data was quantified. A real case study was conducted on the electricity and gas consumptions of buildings in Ma'anshan city in China (Lu et al., 2013).

MATERIAL AND METHOD

The proposed article presents a planning model of consuming each type of energy in the form of multi-periods and multi-prices, with the capacity limitation. Moreover, the model's solving method, based upon network models, and value of energy-bearers type is then provided as an appropriate solution in the modeling of energy consumption.

RESULTS AND DISCUSSION

The planning mathematical model of single type energy consumption is here presented; the related planning parameters and variables are as follows:

$$\left(\sum_{i=0}^{n} C_{i1}R_{1},\sum_{i=0}^{n} C_{i2}R_{1},\ldots\sum_{i=0}^{n} C_{it}R_{1}\right) = \left(C_1',C_2',\ldots C_t'\right) \quad (1)$$

i:energy type (i.e. electricity, gas, etc.); Here i=1

t: the number of the periods of the planning horizon (t=1,2,…,T)

m: the number of ranges of the stage prices (j= 1,2,…,m)

S_{jt}: the amount of energy supply in the range of j and period of t.

X_{jt}: the amount of energy consumption in the range of j and period t

I_{jt}: the amount of energy asset with the price of j in the end of the period t

Y_{jt}: if the amount of the energy consumption with the price of j in the period t reaches its highest limit. Otherwise it's 0.

C_{it}: the amount of accessible energy in the period t

$C2_{t}$: the amount of accessible energy in the period t

A_{jt}: the fixed cost of energy in the range of j and in the period t V_{jt}: the variable cost of consuming each unit of energy in the range of j and period t.

Based on the above parameters and variants, the objective function and the other limitations of each single energy problems will be as follows (Minimizing the sum of fixed and variable costs of consuming energy):

$$Minz = \sum_{j=1}^{m}\sum_{t=1}^{T} A_{jt}\cdot y_{jt} + V_{jt} + I_{jt} \quad (2)$$

$$I_{j,t-1} + S_{j.t} = I_{j,t} + X_{j,t} \quad (3)$$

Indicates that the sum of the output flows from each node in one network is equal to the sum of the input flows to that node.

$$X_{jt} \le y_{jt}\cdot C_t' \quad (4)$$

Causes to prevent the increase of the amount of energy consumption out of the considered capacity.

L_{jt}£$X_{ij}U_{jk}$ L¢$_{jt}$£I_{jt}£U¢$_{jt}$ Y_{jt}=0,1

$L_{it,}$ $L2_{jt}$: the lower limit consumption/ jt: the energy asset

U_{jt}, $U2_{jt}$: the upper limit consumption/ jt: the energy asset

Energy consumption structure for single energy type is illustrated in Fig. 3.

Solving Method of the Model (Single Energy)

A combination of both mathematical and heuristics algorithm is presented to solve the mentioned model; In Fig. 4 the schematic step of the solving method is illustrated.

After deploying the releasing method of zero and one variants, the mathematical model of energy converts into a network model with a linear cost through releasing zero and one variants and by changing the variant. This model can be solved by the method of the highest flow and the lowest cost.

The consequent results from the network model include the contiguous variants Yjt between zero and one. It means that

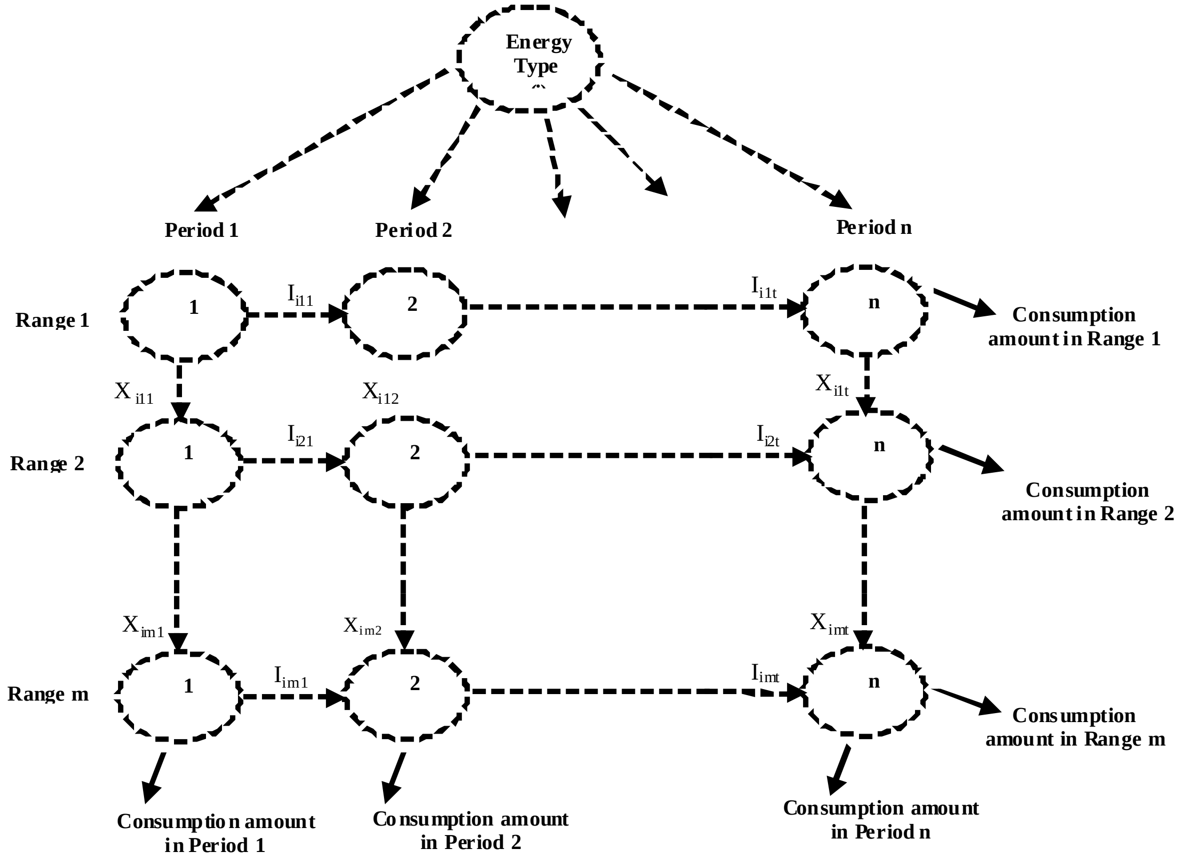

Fig. 3: Energy consumption structure for each energy type

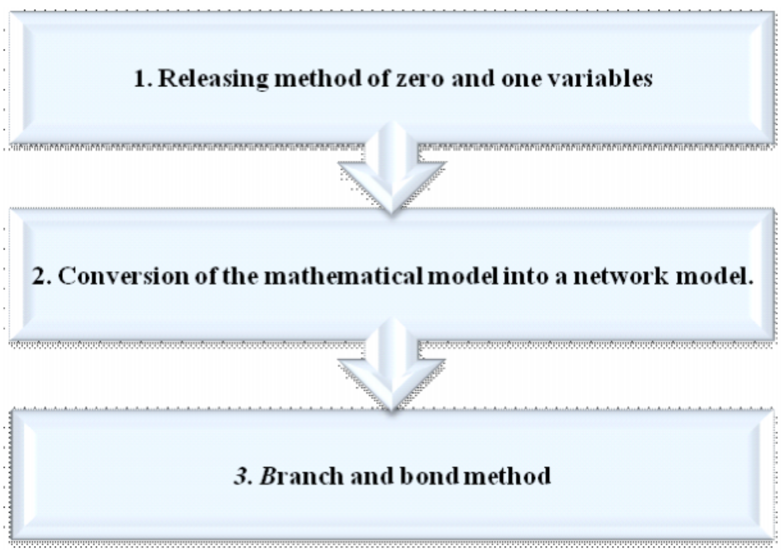

Fig. 4: The schematic step of the solving method

in the result of the network model, there are a number of Yjt variants which are zero, some are ones, and some are between zero and one. In order to determine the situation of Yjt variants which does not include zero and one variants, the branch and bond method was employed.

CONCLUSION

With the development of the economy, the demand for energy is increasing very fast while the energy supply is going short. Furthermore, with the increasing of population, and the improvement of living standards, as well as the urbanism, the percentage of residential buildings' energy consumption has increased in a great amount. Thus, energy consumption in urban residence is one of the main parts of the total consumption, so this sector has attracted great attentions toward itself in the relevant studies during the previous years.

The present study aimed to model energy consumption in the case of multi-prices and multi-periods energy (one type of energy) with the limitation in amount. The proposed solving method was heuristic. Recommendations for future study are to conduct experimental work by taking test cases.

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