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Analysis and Evaluation of Energy Losses in Living Environment on the Basis of Cognitive-Expert Classification

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Abstract: *The integration of heterogeneous and distributed data to prevent or reduce losses of energy in the context of European initiatives for energy efficient buildings is discussed in the paper. A model, based on the cognitive-expert classification of integrated data about different building characteristics and measurement of energy consumption, is proposed. The analysis of the integrated data can be useful for the development of improved algorithms for monitoring and control of energy consumption.*

Keywords: *Information resources, heterogeneous data, cognitive-expert classification.*

Introduction

The energy consumed in buildings accounts for approximately 30-40% of the global energy consumption. Some of the major consumptions are lighting, ventilating, space heating/cooling and water heating [1]. Recent investigations show that the construction technology, regulation and people's behaviour have significant effect on the energy efficiency and environmental impacts associated with dwellings [3]. The actual energy use for heating, which is influenced by different behavioral factors, is discussed in [2]. Theoretical energy conservation potential is investigated in [4]; the theoretical potential includes various ways of saving: alteration of the building standards, improvement of the quality of construction and maintenance, increase of the efficiency of heating appliances, etc. The need for establishing energy policy on the basis of analytical tools and goals that must obligatorily be ranked alongside the technological, economic, social, environmental and political costs and benefits of the results, is pointed out in [6].

The purpose of the paper is to investigate the application of information technologies for analysis and evaluation of the potential for economy of energy consuming in the living environment. As a result of the estimating, monitoring, optimizing and automatic controlling of the building elements, better comfort and convenience for inhabitants together with economization of energy can be provided.

The assessment of possible energy losses can be obtained through integration of various data from independent information sources. These unrelated sources contain information on various aspects of energy use for different types of buildings, data of total energy consumption and data on energy consumption per unit related to lighting, hot water and used appliances. The data belongs to different administrative departments. Additionally, the data on consumption of electricity and heat, depending on the architectural and structural elements, can be provided from different local databases. Thus the data can be obtained from both the specifications of the building components and the direct measurements by instruments such as thermovision, for example. However, the heterogeneous and distributed nature of the information concerning different aspects of energy consumption makes the estimation of energy losses a complicated problem. The information contains qualitative and quantitative parameters. The description of the data does not allow its direct integration.

A model for estimation of energy consumption in living environment by integration of heterogeneous information is proposed in the paper. Different qualitative and quantitative indices are discussed. Local repositories of heterogeneous information relating to buildings structures, their orientation directions, climate data of the area, the materials used for insulation and energy – all these can be integrated into a model based on the cognitive-expert classification. Its construction will help the development of better solutions for the design of buildings, energy use and adopting standards for energy saving in buildings.

Problem statement

The complex structure of the living environment [9] has the purpose to ensure comfort, security and economy. It is characterized by various distributed data flows (Fig. 1).

The problems of modern living environment are spacious and they cover various scientific, technological and psychological aspects. The main challenges in the context of both information and energy saving technologies can be formulated as:

- *integration of infrastructure* of the intelligent living environment and services that provide energy savings [11];
- consideration of characteristics of distributed information networks [10] and presence of *heterogeneous data and processes*;
- necessity of integrated solutions for *heterogeneous interfaces* [12].

There are various factors that have influence on energy efficiency, such as geographical location of the buildings, orientation, brightness, overall size and shape of the houses and surrounding objects, characteristics of the construction materials and specifications of the structural elements (thermal quality of buildings), heating degree days, the building type (single or multi-family dwellings), etc. Besides the technical parameters, the consumer behavior is the most important issue with respect to energy consumption in households [5]. All of the energy-related processes and factors are influenced by changing climatic conditions [7].

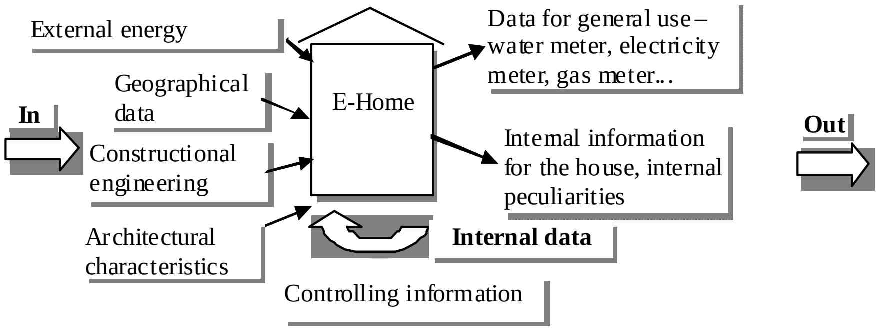

Fig. 1. Information flows in a digital house

The information about this data belongs to different administrative units; it is described in a manner which does not allow its immediate integration. For example, image data from thermal imaging measurements [14] cannot be directly combined with information from databases that contain data about energy consumption. Moreover, the total energy consumption depends on the habits of its residents – they may forget to switch off electrical appliances or leave some windows open when running air conditioners.

Therefore, monitoring and evaluation of energy efficiency consists in collecting data from:

- measurements of intra-building indicators;
- measurements of environmental factors – temperature, humidity, wind speed, light radiation, geographic location, etc.;
- measurements of energy concerning the consumers' habits, which reflect on the measurable energy savings and/or heating costs;
- measurements of buildings in an infrared range;
- analysis of thermo graphical efficiency, thermal properties of the materials and insulation used;
- construction and architectural features of buildings (the volume of rooms, number of walls, area, glazing, surface, shading device, etc.).

The complicated decisions about energy effectiveness may be reduced to the set of consistent estimations which are used to synthesize the result. A set of possible variants, analysis of advantages and disadvantages in accordance with the iterative nature of the assessment process options has to be systematically considered. The integrated presentation of the data may be achieved by applying of cognitive–expert classification of the information. It will give the possibility to evaluate the qualitative and quantitative aspects of the data and to analyze the data on the basis of a fairly structured set of relatively independent directions which may help making informed decisions about energy consumptions.

A model based on the cognitive-expert classification

During analysis of energy efficiency it is necessary to consider all factors and criteria simultaneously. Aggregation of heterogeneous data concerning various aspects of energy use, targets the construction of a tool that will help the adoption of better informed decisions about energy efficiency.

In the proposed cognitive-expert classifications based model (Fig. 2), both quantitative and qualitative indicators are combined. Beside this, the qualitative indicators are based on quantitative parameters.

The links between quantitative and qualitative indicators in the evaluation of energy efficiency reflect the complexity of the task. Besides, there is a variety of uncertain information associated with the estimation process.

For example, the qualitative assessment of energy includes quantitative values of costs for various energy and coolant used for heating or cooling the building. Evaluation of heating forms the basis for estimating the influence of external factors (geographical location, climatic conditions and location of the building) as an apriori assessment of potential losses. These estimations are combined with the values obtained from thermal imaging measurements.

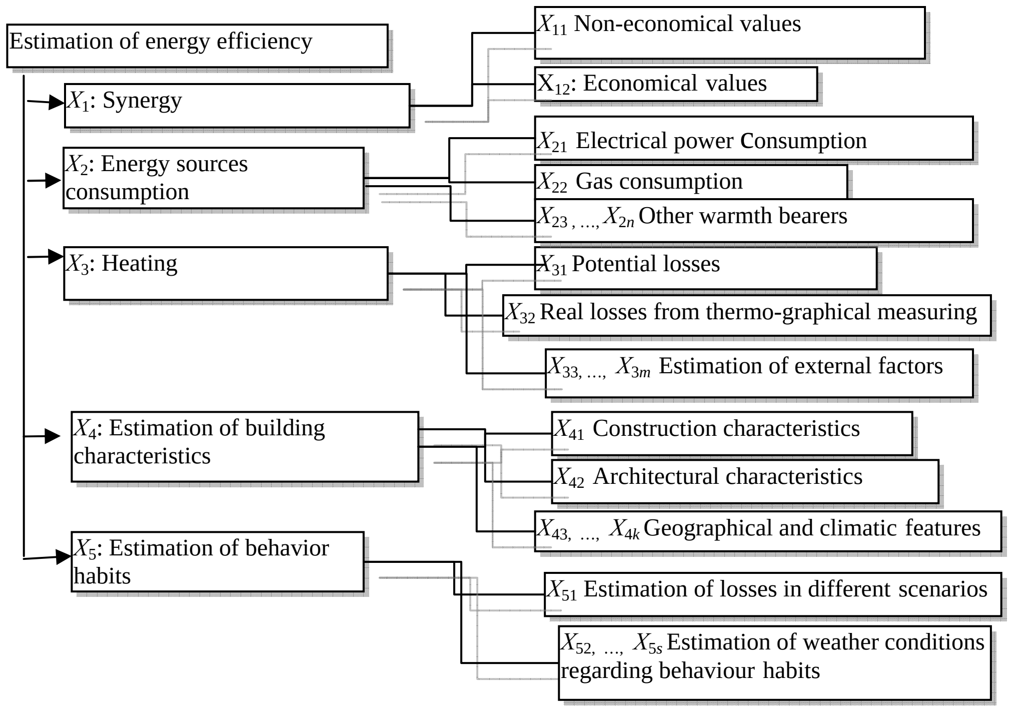

Fig. 2. A model based on the cognitive-expert classification

In the model proposed the *quantitative* indicators are:

- amount of electricity consumption;
- quantity of heat consumption;
- outside temperature values;
- values of the coefficient of thermal conductivity of building materials;
- a coefficient of external glazing, etc.

The *quality* indicators are:

- conformity with the European standards for energy efficiency;
- evaluation of thermo visual analysis;
- assessment of the efficient use of electricity and others.

The quantitative values of X_{ij} indices are aggregated into quality assessments X_i.

The quality indicators are inaccurate and not quantified [13]. Fuzzy values of these data may be determined by linguistic variables. Thus, a system of quality indicators $X = \{x_i\}$ for evaluation of the energy efficiency is based on descriptive variables $L_i = \{l_{ij}\}$, i=1, ..., n, j=1, ..., m, with features belonging to linguistic values $\mu_{l_{ij}}(x)\ \forall l_{ij}$.

Rules "*IF-THEN*" are used to define the links between linguistic variables describing the quality indicators in the evaluation of energy efficiency. The rules are established on the basis of expert procedures, for example:

IF the effects of synergy is *beneficial*
AND (thermo visual analysis is *good*
OR heating costs are *low*)
THEN energy efficiency is *high*.

A set of rules R of the type "*IF-THEN*", $R{:}\times_i L_i \rightarrow \times_i L_i$ define the assessment of energy efficiency.

Each linguistic attribute is described by fuzzy numbers. The shape of the fuzzy number and quantity of the linguistic variables (attributes) is defined by an expertise during the construction of the model. The linguistic evaluations are represented by triangular fuzzy values that give fuzzy quantification. The corresponding values for qualitative parameters are defined by an expertise. The normalized values are in the interval [0, 1]. The range of linguistic attributes for all quality indicators can be determined using a statistical calculation of the distribution of all values around their averages [15].

The levels of activation of the linguistic attributes are degrees of a membership function. The membership function defines how each point of the entrance area is compared with the number in the interval between 0 and 1. In the set X of inputs x, the fuzzy number A on X is defined by ordered pairs $A = \{x, \mu A(x) \mid x \in X\}$.

A modular approach is used where different factors come together in groups to create intermediate variables through the activation of rules.

Assessment on the energy efficiency of a building $N \in q$ is formed as

$$\langle s_q, e_q, t_q, \mu_q (s_q), g_q, \rangle\ \forall\ N \in q,$$

where:

s_q is the fuzzy vector of synergy;
e_q – estimation (assessment) of used energy;
t_q – evaluation of heat;
g_q – assess the performance of the building;
μ_q (s_q) – assessment of behavioral patterns.

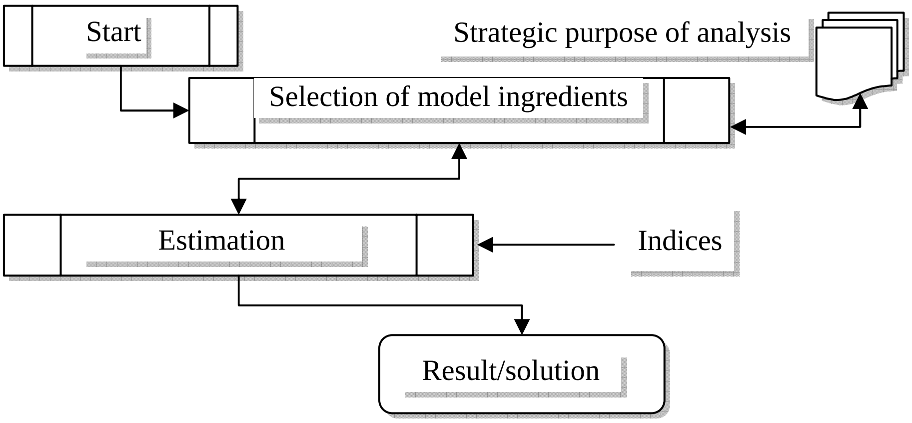

Fig. 3. Evaluation process

The model (Fig. 3) organizes as hierarchy the input data, the purpose of analysis and the evaluation criteria. The presented model integrates the financial, construction, climatic and behavioral factors and it processes quantitative and qualitative variables. Their combination with *IF-THEN* rules leads to the definition of energy efficiency ratings. Fuzzy evaluations of energy efficiency allow testing and experimenting with different strategies in different configurations of data.

The output can be used for:

- obtaining an estimation of energy efficiency in separate directions;
- comparison of the individual components of the assessment of energy efficiency

Conclusion and future work

Standard building and apartments in Bulgaria (and other countries in Eastern Europe) still rarely rely on standards, as it happens in other parts of the continent. It is very difficult to say whether they satisfy the standards or not without a complicated expertise that evaluates the required thermal power for heating and cooling. The reason for this is not only because all homes or offices do not always meet the standard, but each part of the expertise is responsible only to some extent of the standard, for example, its heating needs. Typical building audits with infrared images deal only with heat loss when the building has a different function in the summer. Therefore it is very difficult to make an accurate assessment of energy losses and, for example, the choice of power conditioning which can be used for economical heating or cooling, and making other decisions causing energy efficiency.

Heterogeneous collection of information may provide data on the consumption of electricity and heat depending on the position of the building, architectural and construction elements, the behavior of residents. The aggregation of data will allow adopting standards for energy saving in buildings and developing better solutions for energy use.

The work has led to conclusions that it might be useful to involve dynamic content from the global net for monitoring different aspects of energy consumption and development of algorithms for resource management.

Future work may include:

- Constructing metadata schemes for integrated view of the distributed heterogeneous data, its semantic description, searching and matching of the relevant information on the base of real data related to energy consumption.
- Developing of methods and tools for collecting and processing of the distributed heterogeneous data regarding energy losses; recognition of possible sources of energy waste; technical solutions for improving the thermal building efficiency.
- Developing a comprehensive data base containing different representative types of ventilation or heating systems, as well as construction types.
- Energy conservation measure, change in consumer habits which produces quantifiable savings of energy and/or of heating expenses, without lowering the standard of living.

The model based on the cognitive-expert classification may help in monitoring of the resources and introducing the best energy saving practices as well as in the development or improvement of technologies in order to reduce or prevent energy losses.

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Анализ и оценка потерь энергии в жилой среде на основе когнитивно-экспертной классификации

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(Р е з ю м е)

В работе компьютерные системы и технологии применяются для интеграции гетерогенных и распределенных данных, с целью предотвратить или уменьшить потери энергии в контексте европейской инициативы для энергоэффективных зданий. Предложен метод для организации интегрированных данных, содержащих различные характеристики здания и потребления энергии. Оценки интегрированных данных могут быть полезны для разработки улучшенных алгоритмов для контроля эффективности использования энергии.