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THE MODEL OF DECISION SUPPORT IN CENTRALIZED HEATING MANAGEMENT ON THE CONSUMER SIDE

To manage centralized heat supply on the consumer side, it is necessary to implement an energy management system as an instrument for reducing the consumption of energy by using energy resources efficiently. The implementation of the energy management system requires monitoring, accounting, analyzing and making decisions in the management of heating system. The **subject** matter of this study is the information support of decision making in the management of centralized heat supply. The **aim** of the work is to develop a model for decision support in the management of heat supply modes on the consumer side. The tasks of the research include the selection of methods, the development of a model for making decisions while managing heat supply modes and its implementation in the decision support system (DSS). The current state of information technologies used for solving the problem of decision making support in centralized heating management is analyzed. A model for determining a regulating variable for establishing the necessary heat supply mode with the use of fuzzy set theory and methods of fuzzy logic is developed. On the basis of the expert survey, the term sets of linguistic variables of the model of fuzzy logic decision making in managing heat supply modes were determined, membership functions of each linguistic variable of the model and rules of logical deduction were developed. The **result** of the model operation is making the recommendation as for controlling the current mode of heat supply, which can take the values "below the required", "acceptable", "optimal", "exceeds the optimum" up to the required one among the probable values of "acceptable", "optimal" uner the temperature conditions of the environment "very cold", "cold", "moderate" or "warm". The developed model is implemented in the information technology of decision support in the management of heat supply of public sector objects. On the basis of this technology, the decision support system whuch ensures the automatization of the tasks of monitoring the current state of the heating system was developed, the assessment of the predicted volume of heat energy consumption as well as decision support of the heat supply management on the customer side. The use of the developed model in the decision support system while managing the heat supply systems on the consumer side enables reducing the level of heat energy consumption necessary to heat buildings while preserving the necessary temperature mode in heated premises.

Keywords: energy saving, heat supply, model, fuzzy logic, decision support.

Introduction

Today there is a tendency of increasing the volume of heat energy consumption along with the growth of prices for primary energy resources. At the same time, the efficiency of the use of energy resources is low, due to a number of factors, such as: lack of information about energy and operational parameters of buildings, lack of financial resources required to implement energy saving procedures; absence of motivation among the personnel of facilities, which results in failure to observe comfortable conditions in premises.

The implementation of energy saving procedures in centralized heat supply systems on the consumer side is aimed at reducing heat consumption by reducing the amount of heat energy is an urgent task. The realization of these procedures requires the implementation of energy management according to the standard ISO 50001:2011 [1], which, in turn, requires creating organizational and informational conditions that enable selecting the best options of management. The use of information technology in managing heat supply on the consumer side is aimed at automating such energy management tasks as accounting the amount of consumed heat, analyzing heat demands and making recommendations as for the management of heat supply in order to maintain comfortable conditions in heated premises and eliminate excess heat consumption.

Analysis of literary data and problem statement

Managing the centralized heat supply system on the consumer side is carried out at an individual thermal point (ITP) and is aimed at providing end consumers with the mode they need, that is, at ensuring sanitary standards of air temperature in heated premises. The heat management system at the ITP is designed to change the coolant rate. The management is maintained on the basis of the current state of heat supply, taking into account the change in the factors of influence on the demand for thermal energy to establish the required heat supply mode [2]. In the process of making administrative decisions and preparing for their realization by a building energy manager, information decision support should be provided, which is due to a large number of subordinate objects and, as a consequence, the necessity of timely response to the trends in the change of heating demands.

Information support of managing heat supply requires the development of simulating, optimizing and forecasting models, as well as decision support models that enable developing various management options. Due to the complexity of the centralized heat supply system and the uncertainty of the factors affecting the demands for thermal energy, methods of artificial intelligence are widespread in solving various problems in heat engineering. Systems based on fuzzy logic are used to support decisions made while selecting insulating material for elements of piping systems and for assessing their performance [3, 4], for managing the heat energy transmission [5], and detecting deviations in energy consumption [6]. Proactive and framing models [3] are used to support decisions as for normal operating the heat supply network.

Although most of researches is aimed at solving the problem of optimizing the operation of the centralized heat supply system at the stages of production and transmission of heat energy, in recent years more and more attention has been paid to centralized heat supply management on the customer side [7].

Decisions in managing centralized heat supply on the consumer side are made under a priori uncertainty due to inaccuracy and incompleteness of input data, the stochastic nature of external influences, lack of an adequate mathematical model of heating system operation, ambiguity of the purpose and a human factor. This leads to the increased risk of ineffective decisions, which may have negative economic, technical and social consequences. Therefore, while managinhg energy supply on the customer side, the use of online approaches is efficient; these approaches should provide continuous monitoring of the indicators of heating system operation and supporting decisions in real-time management of heat supply [8].

The analysis of literary sources which deal with solving the problem of centralized heat supply management has shown that the problem of managing heat supply on the consumer side is not sufficiently investigated. Improving the informational support of decision-making processes for centralized heat supply management on the customer side increases the efficiency of decisions made, which, in turn, reduces the heat energy consumed in a building while providing comfortable conditions in heated premises.

The goal and objectives of the study. The goal of the research is to develop a model of decision support for managing centralized heat supply on the customer side. In order to achieve the goal, particular methods should be selected, a model for making a decision as for managing heat supply modes should be developed and implemented in the system of decision support.

Methods and materials of research

Methods of the theory of fuzzy sets and fuzzy logic are selected in order to develop the system of decision support while managing the operation of the centralized heating system on the customer side. Such methods use linguistic values and statements to describe decision-making strategies. This enables using expertise about managing heat supply modes on the customer side, if there is no mathematical model for making decisions.

The model of fuzzy logic decision-making in order to manage the modes of heating public sector objects can be described as a function

$$Z=F\ (ZY,\ BY), \qquad (1)$$

where Z – is the value of a control parameter;

ZY – is a variable characterizing an actual mode of heating;

BY – is a variable characterizing a required mode of heating.

Linguistic variable ZY "actual heating mode" is determined on the universal set U(ZY) = [0, 50] (Gcal). The term set of linguistic variable T(ZY) = T(ZY1) ∪ T(ZY2) ∪ T(ZY3) ∪ T(ZY4) consists of terms of linguistic variables ZY1, ZY2, ZY3, ZY4. The term set of linguistic variable T(ZY1) =< ZYC1, ZYM1, ZYO1, ZYH1> determines the actual modes of heat supply "below the required", "acceptable", "optimal", "exceeds the optimum" under temperature conditions "very cold". The term sets T (ZY2), T (ZY3), T (ZY4) determine the same heating modes as the term set T (ZY1), but under temperature conditions "cold", "moderate", "warm".

Linguistic variable BY "actual heating mode" is defined by the universal set U (Y) = [0, 50] (Gcal). The term set of a linguistic variable T(BY) = T(BY1) ∪ T(BY2) ∪ T(BY3) ∪ T(BY4) consists of terms that determine the permissible and optimal modes for heating the linguistic variables BY1, BY2, BY3, BY4. The term set of linguistic variable T(BY1) =<BYM1, BYO1> determines the necessary modes of heating, "acceptable", "optimal", under the temperature conditions "very cold". The term sets T (BY2), T (BY3), T (BY4) determine the same heating modes as the term-set T (BY1), but under temperature conditions "cold", "moderate", "warm". The linguistic variable Z is defined on the universal set U (Z) = [-50, 50] (Gcal). The term set of linguistic variable T(Z) =<D1...D8, NC, I1...I8>. The functions of the terms of the linguistic variables ZY, BY, Z are developed on the basis of expert assessments according to the method [9]. For variables ZY and BY, a trapezoidal membership function is selected, and for a Z-variable a triangle one is selected.

The mode of heat supply according to the amount of heat energy consumed in a building and temperature conditions of the environment is determined with the use of the model presented in [10].

The structure of the fuzzy logic decision-making in order to control the heating mode on the consumer side is shown in the form of a tree in fig. 1.

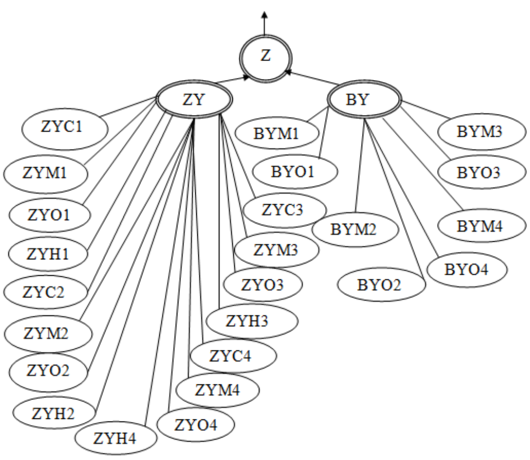

Fig. 1. The structure of a fuzzy logic model of decision-makingfor managing the mode of heating in the form of a tree

To determine the value of a control parameter, the following rules are developed:

If ZY is ZYM1 **and** BY **is** BYM2 **then** Z=NC. (2)

Rule (2) has the preconditions: ZY is ZYM1, BY is BYM2. The rule is interpreted as: if mode "Acceptable 1" is curremtly set and tomorrow "Acceptable 1" should be also set, the control parameter should be "Kept unchanged". A fragment of the rule database for making a decision for managing the heating mode is given in table 1.

Table 1. *A fragment of the rule database to make a decision for managing the heat supply mode*

№ rule	input variables		output variables
	ZY	BY	Z
1	ZYC1	BYM1	I4
2	ZYC1	BYO1	I6
3	ZYM1	BYM1	NC
4	ZYM1	BYO1	I2
…	…	…	…
125	ZYO4	BYM4	D8
126	ZYO4	BYO4	NC
127	ZYH4	BYM4	D6
128	ZYH4	BYO4	D7

Research results

To implement the suggested model of fuzzy logic decision-making, the package of extension of software application Matlab Fuzzy Logic Toolbox is used, which enables developing fuzzy logic systems in graphical mode.

The characteristic surface for the rule database, the fragment of which is given in Table 1, is shown in fig. 2.

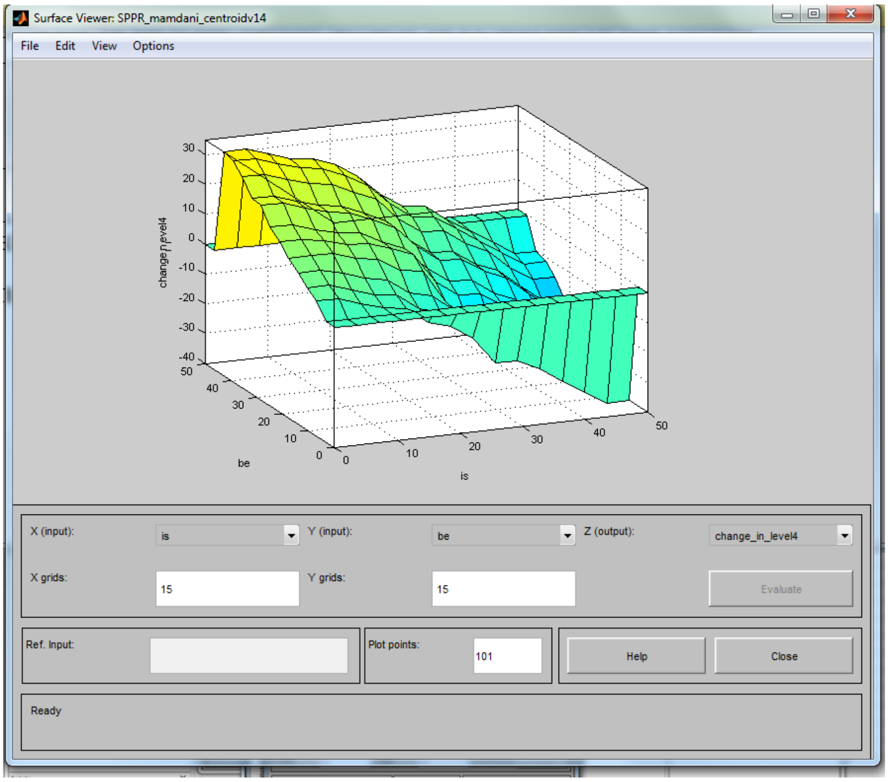

Fig. 2 The characteristic surface of dependence of the initial value on the input values of the model for determining a control parameter

The result of the model (1) is making a recommendation to adjust the current mode of heating to the required selecting between possible values "Acceptable" and "Optimal".

The developed model of decision support in managing centralized heat supply on the consumer side has been used for the development of information technology [11], on the basis of which a decision support system was developed for managing heat supply of public sector objects (DSS "HeatCAM").

DSS "HeatCAM" is implemented as a web-application with authorized access on the basis of client-server architecture.

The generalized architecture of DSS "HeatCAM", which includes data storage and manipulation, a web server, a client browser, as well as a set of software modules that implement data processing are presented in fig. 3.

The main functions of DSS "HeatCAM" implemented by its relevant subsystems are real-time monitoring of heat consumed in a building, calculating the daily monitoring indicators based on the data collected in the operational mode, determining the predicted value of heat consumption for the next day, determining the current mode of heating and making recommendations for managing heat supply mode [12].

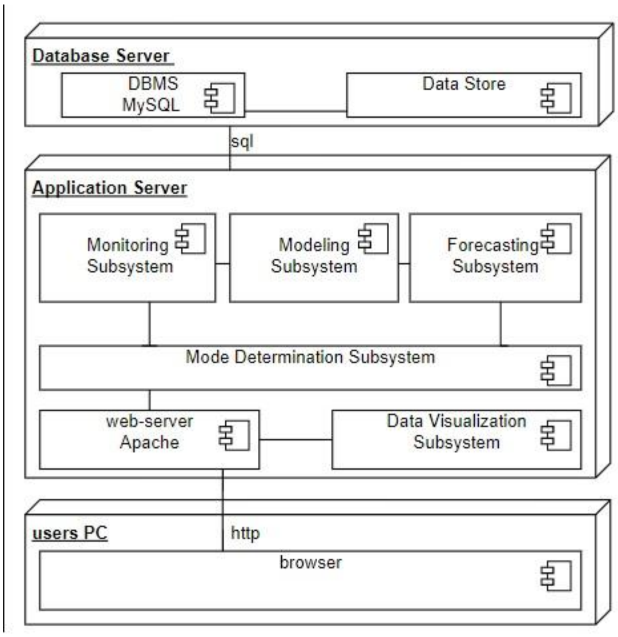

Fig. 3. General architecture of DSS "HeatCAM"

An engineer is usually a decision-maker who is responsible for energy auditing and energy conservation. He monitors the current heating mode and, on the basis of the recommendations made by DSS "HeatCAM", makes a decision as for adjusting the heat supply mode.

A decision maker can work with DSS "HeatCAM" from any computerized workplace that has access to the Internet through the web-interface of the system.

The result of determining the current mode of heating and comparing the obtained value with the planned one is reviewed. The mode of heat supply which should be set for the next day can also be selected; the value of a control parameter can be obtained, namely, the amount of heat energy that a building should consume in one day, and the coolant costs.

To decide on managing a heating mode, a consumer should first select which heat supply mode (optimal or acceptable) should be installed for the next day and start the calculation. Then the program module for determining the mode requests the database and receives the input data for the model for determining a control parameter. After receiving the input data, the program module of a mode definition page launches the command file * .bat that transmits the input parameters to the model implemented in MatLab. The result of the fuzzy logic decision making is entered into the database and displayed on the web page.

The social economic effect of DSS implementation is determined by heat energy consumption saved by public sector objects when standard temperature conditions are maintained in premises that are heated.

In order to assess the quality of decisions made with the help of the developed model, an experimental study was carried out, in the course of which it was found out that while analyzing 700 desicions suggested by DSS "HeatCAM" a number of correct decisions was 671. Thus, the risk of making incorrect decisions is 4.1 %.

The average value of the amount of heat energy spent for heating a building during the heating season without the use of DSS was calculated as well as the amount of heat energy that would be spent if the decisions suggested by DSS was made.

The calculated values of the level of heat consumption were compared, and it was established that the management of heat supply on the customer side with the use of DSS "HeatCAM" as a decision support tool enabled reducing the consumption of thermal energy in natural parameters by 15 % when standard temperature conditions are maintained in premises that are heated.

Conclusions

The research resulted in the development of a model of fuzzy logic decision-making in order to manage the supply of heat. The developed model is implemented in the system of decision support in the management of heat supply of public sector objects with the help of DSS "HeatCAM". The reliability of the suggested model is practically proved while using DSS "HeatCAM" as a tool for decision support.

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МОДЕЛЬ ПІДТРИМКИ ПРИЙНЯТТЯ РІШЕНЬ ПРИ УПРАВЛІННІ ЦЕНТРАЛІЗОВАНИМ ТЕПЛОЗАБЕЗПЕЧЕННЯМ НА СТОРОНІ СПОЖИВАЧА

Для ефективного управління централізованим теплозабезпеченням на стороні споживача необхідно впроваджувати систему енергетичного менеджменту як інструмент досягнення мети скорочення споживання енергетичних ресурсів шляхом їх раціонального використання. Впровадження системи енергетичного менеджменту потребує здійснення контролю, обліку, аналізу та прийняття рішень при управлінні системою теплозабезпечення. **Предметом** даного дослідження є інформаційне забезпечення підтримки прийняття рішень при управлінні централізованим теплозабезпеченням. **Метою** роботи є розроблення моделі підтримки прийняття рішень при управлінні режимами теплозабезпечення на стороні споживача. **Задачі дослідження** полягають у виборі методів, розробленні моделі формування рішення щодо управління режимами теплозабезпечення та реалізації її в системі підтримки прийняття рішень. Проведено аналіз сучасного стану застосування інформаційних технологій для розв'язання задачі підтримки прийняття рішень при управлінні централізованим теплозабезпеченням. Розроблено модель визначення регулюючого параметру для встановлення необхідного режиму теплозабезпечення з використанням методів теорії нечітких множин та нечіткої логіки. На основі експертного опитування визначено терм-множини лінгвістичних змінних моделі нечіткого логічного виведення рішення щодо управління режимами теплозабезпечення, побудовано функції належності кожної лінгвістичної змінної моделі та правила логічного виведення рішення. **Результатом** роботи моделі є рекомендація щодо регулювання поточного режиму теплозабезпечення, який може приймати значення "нижче за необхідний", "допустимий", "оптимальний", "перевищує оптимальний" до необхідного серед можливих значень "допустимий", "оптимальний" за температурних умов навколишнього середовища "дуже холодно", "холодно", "помірно" чи "тепло". Розроблену модель реалізовано в інформаційній технології підтримки прийняття рішень при управлінні теплозабезпеченням об'єктів соціально-бюджетної сфери. На основі цієї технології розроблено систему підтримки прийняття рішень,що забезпечує автоматизацію задач моніторингу поточного стану системи теплозабезпечення, оцінки прогнозованого обсягу споживання теплової енергії, а також підтримки прийняття рішень щодо управління теплозабезпеченням на стороні споживача. Використання розробленої моделі у складі системи підтримки прийняття рішень щодо управління теплозабезпеченням на стороні споживача дозволяє досягти зменшення рівня споживання теплової енергії на опалення будівель при збереженні необхідного температурного режиму в опалюваних приміщеннях.

Ключові слова: енергозбереження, теплозабезпечення, модель, нечітка логіка, підтримка прийняття рішень.

МОДЕЛЬ ПОДДЕРЖКИ ПРИНЯТИЯ РЕШЕНИЙ ПРИ УПРАВЛЕНИИ ЦЕНТРАЛИЗИРОВАННЫМ ТЕПЛООБЕСПЕЧЕНИЕМ НА СТОРОНЕ ПОТРЕБИТЕЛЯ

Для эффективного управления централизованным теплоснабжением на стороне потребителя необходимо внедрять систему энергетического менеджмента как инструмент достижения цели сокращения потребления энергетических ресурсов путем их рационального использования. Внедрение системы энергетического менеджмента требует осуществления контроля, учета, анализа и принятия решений при управлении системой теплоснабжения. **Предметом** данного исследования является информационное обеспечение поддержки принятия решений при управлении централизованным теплоснабжением. **Целью** работы является разработка модели поддержки принятия решений при управлении режимами теплообеспечения на стороне потребителя. **Задачи исследования** заключаются в выборе методов, разработке модели формирования решения при управлении режимами теплообеспечения и реализации ее в системе поддержки принятия решений. Проведен анализ современного состояния применения информационных технологий для решения задачи поддержки принятия решений при управлении централизованным теплоснабжением. Разработана модель определения регулирующего параметра для установки необходимого режима теплообеспечения с использованием методов теории нечетких множеств и нечеткой логики. На основе экспертного опроса определены терм-множества лингвистических переменных модели нечеткого логического вывода решения по управлению режимами теплообеспечения, построены функции принадлежности каждой лингвистической переменной модели и правила логического вывода решения. **Результатом** работы модели является рекомендация по регулированию текущего режима теплобеспечения, который может принимать значения "ниже необходимого", "допустимый", "оптимальный", "превышает оптимальный" до необходимого среди возможных значений "допустимый", "оптимальный" в зависимости от температурных условий окружающей среды "очень холодно", "холодно", "умеренно" или "тепло". Разработанную модель реализовано в информационной технологии поддержки принятия решений при управлении теплоснабжением объектов социально-бюджетной сферы. На основе этой технологии разработана система поддержки принятия решений, которая обеспечивает автоматизацию задач мониторинга текущего состояния системы теплообеспечения, оценки прогнозируемого объема потребления тепловой энергии, а также поддержки принятия решений по управлению теплоснабжением на стороне потребителя. Использование разработанной модели в составе системы поддержки принятия решений при управлении теплоснабжением на стороне потребителя позволяет достичь уменьшения уровня потребления тепловой энергии на отопление зданий при сохранении необходимого температурного режима в отапливаемых помещениях.

Ключевые слова: энергосбережение, теплообеспечение, модель, нечеткая логика, поддержка принятия решений.

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