Control of Thermal Energy Consumption Mode for Multifunctional Buildings

Nurmammad Mammadov and Oleg Yurin

Abstract At present there are many mathematical models of optimal control, planning and distribution of thermal energy, however in real conditions, their use is often difficult. First of all it concerns prompt control and distribution of thermal energy among consumers when there arises a problem of prompt correction of initial information and feedback on actual consumption. At the same time, one has to deal with uncertainties of goals arising on simultaneous execution of various management tasks and providing necessary values under extreme climatic conditions or emergency situations. As a result of impact of disturbing factors (climatic parameters of environment, operating conditions of buildings, organizational factors, emergency situations and so on), and also incompleteness and inaccuracy of initial information, controlled parameters turn out to be fuzzy. Obviously, further improvement of the system of planning, control and distribution of thermal energy among consumers of different categories, improving the efficiency and reliability of the operation of modern buildings especially in extreme cases, are related to transition to a new modeling system, in particular to new information technology and creation on its basis new systems of optimal and prompt control, distribution and exploitation. In the paper we analyze possibility of using expert systems for regulating heat consumption mode in modern buildings. We often a structure of hybrid expert system of thermal energy control for modern multifunctional buildings.

Keywords Modern multifunctional buildings · Expert systems · Thermal energy consumption mode · Database · Operational dispatch control · Emergency situations

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1 Introduction

Complication of the structure, spread in extension and increase in energy intensity of modern buildings and also intensification of operational modes reduce to the fact that traditional control methods applied in these buildings have ceased to be an effective means of rational distribution of thermal energy among consumers. This led to sharp increase in unproductive costs of material and energy resources, to a decrease in degree of satisfaction of thermal energy consumers.

As management objects, modern residential and public multifunctional buildings belong to the class of multidimensional multiplyconnected nonlinear stochastic systems with distributed parameters whose specific feature is their multilevel structure, high level of uncertainty of the structure, parameters and states of the control object (building), availability of continuous and discrete components in the control vector.

At present there is a considerable experience in modeling and optimization of the mode of distribution and control of thermal energy in modern buildings [1, 2]. However, the worked out optimization methods as a rule are deterministic, ignore real operating conditions of the buildings related to uncertainty both of the control object and environment.

Optimal solution on distribution and control of thermal energy among consumers obtained by means of these methods correspond only to specific boundary conditions and are as a rule are on the border of the feasible area. Practically, this led to the fact that even minor variations of boundary conditions could essentially change not only optimal solution but also to take it out of the area of technological feasible modes: i.e. to lead to an emergency situation. Naturally, such optimal solutions are unacceptable for practice.

At present, there are many mathematical models of optimal control, planning and distribution of thermal energy, however in real conditions, their use is often difficult. First of all it concerns prompt control and distribution of thermal energy among consumers when there arises a problem of prompt correction of initial information and feedback on actual consumption. At the same time, one has to deal with uncertainties of goals arising on simultaneous execution of various management tasks and providing necessary values under extreme climatic conditions or emergency situations. As a result of impact of disturbing factors (climatic parameters of environment, operating conditions of buildings, organizational factors, emergency situations and so on), and also incompleteness and inaccuracy of initial information, controlled parameters turn out to be fuzzy.

Traditional regulation, control and exploitation methods applied in modern centralized heat supply systems ceased to be effective and there was a sharp increase material and thermal power resources, decrease in the quality of uninterrupted provision and degree of satisfaction of consumers.

Obviously, further improvement of the system of planning, control and distribution of thermal energy among consumers of different categories, improving the efficiency and reliability of the operation of modern buildings especially in extreme cases, are related to transition to a new modeling system, in particular to new information technology and creation on its basis new systems of optimal and prompt control, distribution and exploitation.

2 Methodology

The main goal of prompt control of thermal energy distribution for residential buildings is to ensure more complete satisfaction of continuously changing requirements of consumers. As known, the existing mathematical models of optimal planning and control in real conditions are often not workable. Especially it concerns operational scheduling where there arises a problem of feasibility of models and necessity of their prompt correction with regard to feedback information on actual heat consumption. This time, one has to face with uncertainty of goals arising from the desire to perform simultaneously unattainable tasks for providing consumers with necessary amount of thermal energy on one hand, and providing extreme value of the selected economic criteria on the other hand. Furthermore, as a result of impact of disturbing factors and also incompleteness and uncertainty of initial information the basic system parameters (thermal energy consumption, limitations, coefficients) turn to be fuzzy. In this connection, production planning specialists tend to use in practice their own decision rules based on their experience and intuition. Although such heuristic rules do not guarantee mathematical optimality, turn out to be adequate to real conditions.

The structure of the process of prompt control of thermal energy distribution can be represented in the form of two main stage or level of management:

1. Prompt control of thermal energy distribution with regard to prevailing influence of some criteria on the given planning period (minor operating costs, maximum heat energy supply of consumers, etc.).
2. Stabilization of all or at least of some phase coordinates (consumption, temperature) providing minimum variance of these coordinates related to the calculated or planned settings.

The solution of such problems, is usually separated in time and space, requires various volume and character of prompt information, mathematical models describing the control objects (buildings or placements), various methods or criteria.

In this direction we have studied new approaches to the solution of problems of planning and distribution of thermal energy based on the conception of L. Zadeh's fuzzy sets [3, 4]. The offered approaches allow to consider such factors as experience and intuition difficult to formalize.

Further improvement of the system of planning and control, their efficiency and reliability are related to transition to a new information technology and creation on its basis qualitatively new systems based on buildings. As noted above, a modern building with continuous character of exploitation is a complex production system consisting of a dozen of maintenance services. The goal of an operational-dispatcher control of a building with continuous exploitation is to provide trouble-free, rhythmic and uninterrupted functioning of all communal systems. A great majority of specific decisions on the actions of these systems is accepted by the dispatcher on duty. He constantly analyzes the incoming information to reveal deviations from normal functioning of the system. If such a deviation happens, the dispatcher should necessarily find the reason for its occurrence. After identifying the reason, the dispatcher develops a sequence of actions to eliminate the unfavorable situation. Thus, the dispatcher constantly performs the tasks of tracking the progress of operation, analysis of situation and planning of actions. Furthermore, he has periodically deal with calculated computational problems. It should be noted that unlike other modern mathematical tools, the expert systems model human thinking mechanism in relation to the solution of the problem, form certain considerations and conclusions based on the knowledge they have. These systems unlike traditional approaches, offer a set of conceptions fit for solving complex problems in the cases when mathematical solutions are either unknown or ineffective.

The operating experience of automated operational-dispatcher control systems in modern buildings showed that the used traditional "rigid" formal mathematical models are not sufficiently adequate to the control object. Therefore there arises a need to create dispatcher room that controls the expert technological system, that combines in itself such advantages of modern computers as high performance, large memory and huge computing power and also a highly qualified specialist accumulating experience and knowledge of an expert in this field [5–7].

Functionally, dispatching control expert technological system is intended to help the dispatcher in the process of his work and provide him with advices, recommendations on actions in the established situation, with prompt and reliable information and also possibility to perform calculated character tasks. The process of expert system building can be divided into 5 stages (Fig. 1).

Stage 1 is the definition of goals and objectives for which the system is structured. Here, first of all the spectrum of problems and their typical features are established. The precise technical task for the system under development will help in future to outline correctly the area of knowledges of the expert, necessary to define actual energy consumption. Secondly, it is important to define potential users of the system that also influences on necessary level of the work of the expert system and consequently on the level of required knowledges.

Stage 2 is highlighting the main concepts of the subject area that reflects the knowledge of experts. Highlighting of such concepts allows to analyze what type knowledges uses the expert when defining heat energy consumption. This helps engineers to select the formal means of representation of knowledges and procedures for getting decisions that are the most suitable for the decision making process by the expert in the field of exploitation of communal systems of buildings.

Stage 3 is the selection of the language of representation of knowledges and a solver that in our opinion to a large extent causes the success of the creation of the expert system to accurately define heat energy consumption.

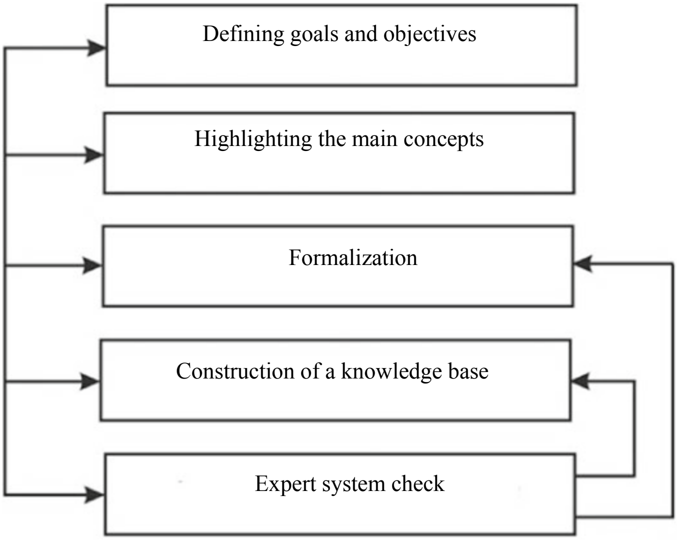

Fig. 1 Expert system building stages

Stage 4 is the direct construction of knowledge base of the expert system. A knowledge engineer being actually a translator between the expert and computer brings the knowledges in the field of exploitation of buildings obtained from the expert and written in the language of representation of knowledges.

Stage 5 consists of checking the work of the expert system. Verification is carried out by solving the benchmarks on control of heat energy consumption mode by the expert system. Evolution of views on the problem of control of complex systems in the context of the use of these or other formalisms to construct adequate models of controlled objects, passing through the stage of creating the need to take into account the human factor in them led the specialists in the field of engineering and construction to formation of the concept of construction of "intellectual" knowledges.

Expert systems, as the most actively developing areas of ideology of classic artificial intelligence, imitating human ways of reasoning are capable to solve control problems no worse than a man, an expert. Moreover, such systems intelligently combining dignity of human – machine dialogue systems with heuristic models get a number of principally new and extremely important properties. This, first all, is the possibility to represent the expert knowledges in the language close to the natural language of human communication, to solve the problems based on these knowledges and perhaps the most important thing to verify the goals of control, i.e. to confirm the correctness of the adopted decision [8]. The fact is that the level of complexity of operation of modern buildings, uncertainty of their functioning parameters, large dimension of their management problems do not allow to create such universal knowledge base of the expert system that could give solutions adequate to frequent emergency situations out of bounds.

It was natural to look for ways out of this situation by imparting some dynamism to the expert system in the sense of the possibility of a more flexible and prompt response to changing comfortable conditions inside the building in real time. And moreover periodically updated knowledge base models should allow based on the analysis of trends in the change in the parameters of the outside air, to predict possible changes in the parameters in the rooms and generate appropriate decisions.

For the purpose of prompt data processing in a real time environment and solutions of the problems of control of thermal mode in modern buildings, the general problem of control was decomposed by us into a number of narrowly focused subproblems as:

- Recognition of all operational events uniquely associated with some unforeseen problems that lead to existing changes in the mode of thermal energy consumption;
- Arbitration of the priorities of these events;
- Analysis of the event for the purpose of recognition and identification of the corresponding unforeseen problem;
- Arbitration of the priorities of the basic problems;
- Coordination of above processes.

Efficiency of thermal energy consumption mode control largely depends on the timeliness and promptness of the recognition of unforeseen operational problems.

Traditionally, to solve the optimal control problem, the accumulated experience of preliminarily prepared plan of exploitation measures and the way of life of people living in this building is used. However, practical implementation of prompt and optimal control of thermal energy consumption mode for modern buildings does not allow to get desired results, rhythmic control and stability of provision of all consumes with necessary amount of thermal energy and this is accompanied with violation of comfort of individual consumers and promptness of the work of the heat supply system of the building as a whole.

The problem of real world, its problematic areas as urban planning, environmental protection, ecology of the city and others are characterized by weak structurenedness and fuzzy formalization, the knowledge in these areas are insufficient. The greatest practical results in the solution of above problems can be achieved by means of expert systems being in essence one of the methods of artificial intelligence.

The offered technique for constructing a mathematical model of an ecologically friendly model of "intellectual" and safe modern building with efficient use of thermal energy based on expert system allows to solve the above problems.

In this connection, we developed a hybrid expert system based on a complex exploitation of a building and that will be implemented on the base of experience and knowledge of experts in the given field and optimization methods.

The given hybrid expert system is intended for solving the problems of control regulation of thermal energy consumption problems based on combination of knowledge of experts and optimization conditions, ensuring the development of practically acceptable control formulations.

The structure of the hybrid expert system includes the following blocks (Fig. 2):

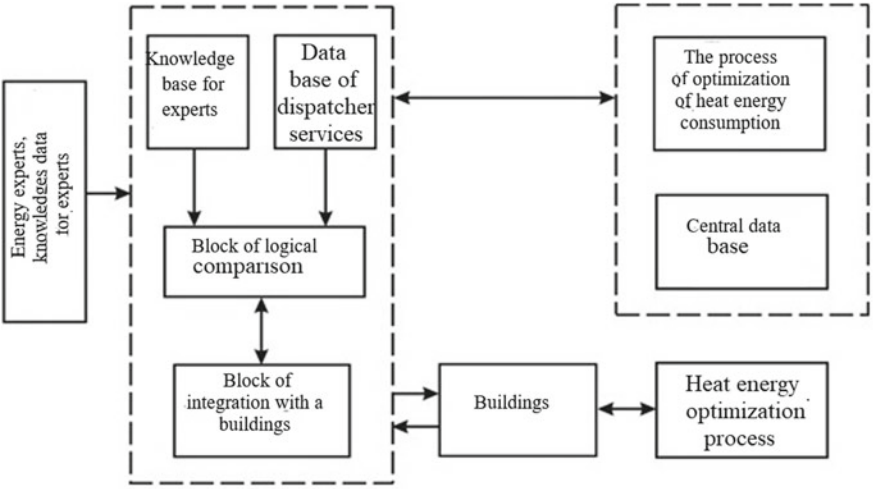

Fig. 2 Approximate scheme of the hybrid expert system of thermal energy control in modern buildings

1. Expert system. It consists of a knowledge base, database, inference block and interface unit with a user.
- Optimization calculation block.
- A dispatcher participates in a hybrid expert system to organize the thermal energy control mode. He performs the following actions:
- Filling the data file containing the current values of indicators for the thermal energy consumption, transfer of the file to the optimization block.
- Activation of optimization and control procedures.
- Interpretation of optimization and control results.
- The knowledge base contains the rules that use experts when composing optimal forecast value of thermal energy consumption.

The database of the system contains current data on thermal energy consumption. The logical comparison block implements the procedure of comparison of expert and archive data. The integration unit with a building includes a dialogue system and a subsystem of explanations on divergence of expert and archive data on thermal energy consumption of the building.

The dialogue subsystem allows to implement input and interpretation of data that can be entered from the central database. The subsystem of explanations on divergence of expert and archive data forms the text of explanation, recommends formulations based on tracing of inference. The block of optimizational calculations allows to solve a optimization problem consisting of determination of such relations between climatic parameters of inner air under which thermal energy consumption for ensuring data of climatic conditions would be optimal.

Working session with a hybrid expert system starts with input of dialogue subsystem of current data on thermal energy consumption, that are send to database. The inference block based on current data forms admissible value of consumption and admissible norms of deviation. If the value given by the system sharply differs, then the subsystem of explanations forms the reason of deviation. Based on the standard optimization package the optimization block performs calculations within admissible norms. The knowledge base contains informal expert calculations based on the construction of "abstract" plan on heat energy consumption.

3 Conclusions

According to this plan, the process of solution of the problem is decomposed into three levels. The principle on the base of which internal parameters components are chosen on each level is that qualitative and quantitative parameters of thermal energy correspond to the values required on this level. Such on approach allows to highlight the purposes in the solution of the problem, that can be implemented in less detail, in a general form. To implement these goals the procedure of formation of forecast value of thermal energy consumption can be decomposed into the following stages:

- analysis of outside air, thermal energy and inside air parameters;
- formation and definition of optimization parameters;
- formation of optimal output values of thermal energy consumption.

The system constantly comparises the output values with the contents of the knowledge base, monitors to have not been violations of the norms of marginal admissible values. When solving the problem one can return to the beginning, to correct the optimal output value and then again to solve the problem. If the obtained value sharply differs from archive data and the explanation does not satisfy the expert, he makes necessary corrections and the solution process starts over.

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