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Construction and realization of the knowledge base and inference engine of an IDSS model for air-conditioning cooling/heating sources selection

Liu Ying[1] Wang Ruzhu[1] Li Yunfei[1] Zhang Xiaosong[2]

([1] Institute of Refrigeration and Cryogenics, Shanghai Jiaotong University, Shanghai 200030, China)

([2] Department of Power Engineering, Southeast University, Nanjing 210096, China)

Abstract: The knowledge representation mode and inference control strategy were analyzed according to the specialties of air-conditioning cooling/heating sources selection. The constructing idea and working procedure for knowledge base and inference engine were proposed while the realization technique of the C language was discussed. An intelligent decision support system (IDSS) model based on such knowledge representation and inference mechanism was developed by domain engineers. The model was verified to have a small kernel and powerful capability in list processing and data driving, which was successfully used in the design of a cooling/heating sources system for a large-sized office building.

Key words: air-conditioning; cooling/heating sources; intelligent decision support system; knowledge base; inference engine

Cooling/heating sources selection is critical for the design of heating, ventilating and air-conditioning (HVAC) systems, which aims at choosing an optimum scheme from all feasible schemes with the help of qualitative analysis and quantitative analysis. The traditional process of decision-making is very complicated and is affected by a lot of subjective factors. Thus when facing this problem it is necessary to develop an intellective decision support system, which can extract and synthesize the intelligence and experience of HVAC experts and help the users to make their decisions more objectively and reasonably. Since the 1970's, a new type of knowledge-based system (KBS) named intelligent decision support system (IDSS) has been presented[1], which integrates the decision support modes of qualitative analysis of expert systems (ES) and quantitative analysis of decision support systems (DSS) and is available for air-conditioning cooling/heating sources selection.

Knowledge base and inference engine are the most important parts of a KBS. They can exert a direct impact on the availability of the model. Most knowledge bases and inference engines for HVAC system design were built using commercial ES shells, which were limited in the applicability and transportability of the KBSs developed for specific use[2-6]. Several attempts had been made in recent years as a tendency to develop KBSs with artificial intelligence (AI) programming languages for the applications of air-conditioning project design and equipment selection of direct-fired absorption chillers[7,8]. The ES and IDSS developed were all prototypical models that were still immature in knowledge representation and inference mechanism and could only be used under particular conditions in certain climatic regions and building types.

Our objective was to design a knowledge base of air-conditioning cooling/heating sources selection for large-sized buildings located in urban districts of Nanjing and Shanghai while the corresponding inference mechanism was given simultaneously. The knowledge base and inference engine were constructed and realized using the C language. An IDSS model was developed and was applied to the practical design of cooling/heating sources system for an office building to demonstrate the feasibility of the knowledge representation and inference mechanism.

1 Knowledge Base and Inference Engine Construction

1.1 Knowledge base structure

The knowledge domain of cooling/heating sources selection mainly involved in the regularity knowledge with certain hierarchical specialty. The production rules were adopted for knowledge representation while the rules were sorted and arranged according to the characteristics of the field problem through which the hierarchical specialty of the knowledge could be shown.

Fig.1 illustrates the basic structure of the knowledge base of the IDSS model for air-conditioning cooling/heating sources selection. The knowledge base consisted of the bases of rules and facts. Considering the multiformity of cooling/heating source types, the rule base had different parts corresponding to different

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Biographies: Liu Ying (1967—), female, graduate; Wang Ruzhu (corresponding author), male, professor, rzwang@mail.sjtu.edu.cn.

inference processes of forward reasoning and backward reasoning, respectively. The rule base for backward reasoning consisted of five subbases named as subbase 1 for air source heat pump (ASHP) units scheme selection; subbase 2 for absorption chillers/heaters scheme selection; subbase 3 for electric driven water-cooled chillers scheme selection; subbase 4 for modular water chillers scheme selection; subbase 5 for water source heat pump (WSHP) units scheme selection. Every subbase had its own structure system while the modification and extension of one subbase could not affect the others. The fact base was composed of a static fact base and dynamic fact base (intermediate fact base), which were written by the software before or after the reasoning process, respectively.

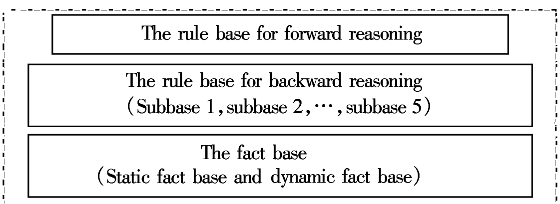

Fig.1 Structure of the knowledge base

1.2 Reasoning process

The IDSS model adopted the basic strategies of forward reasoning and backward reasoning simultaneously to solve the problem. The main task of backward reasoning was to draw feasible schemes by starting the process of backward reasoning corresponding to each cooling/heating source type in turn. The forward reasoning was served for forming the collection of feasible schemes which could be used as data switch to control the running of the multi-objective decision model in model base.

Fig.2 shows the reasoning process of the IDSS model. At the beginning of system running, the process of backward reasoning was started while the real-time data from user input were written into the static fact base as basic inference facts. The basic facts were linked with the rules required in reasoning process to form a new data file which was stored in the dynamic data base created temporarily and could be used in the searching and matching process to achieve the feasible scheme. Another process of backward reasoning was started up once the first matching operation was finished successfully with the inference results written into the dynamic fact base. All of the inference results from the processes of backward reasoning were gathered in the rule base linked with the dynamic fact base to form another temporary data file for forward reasoning.

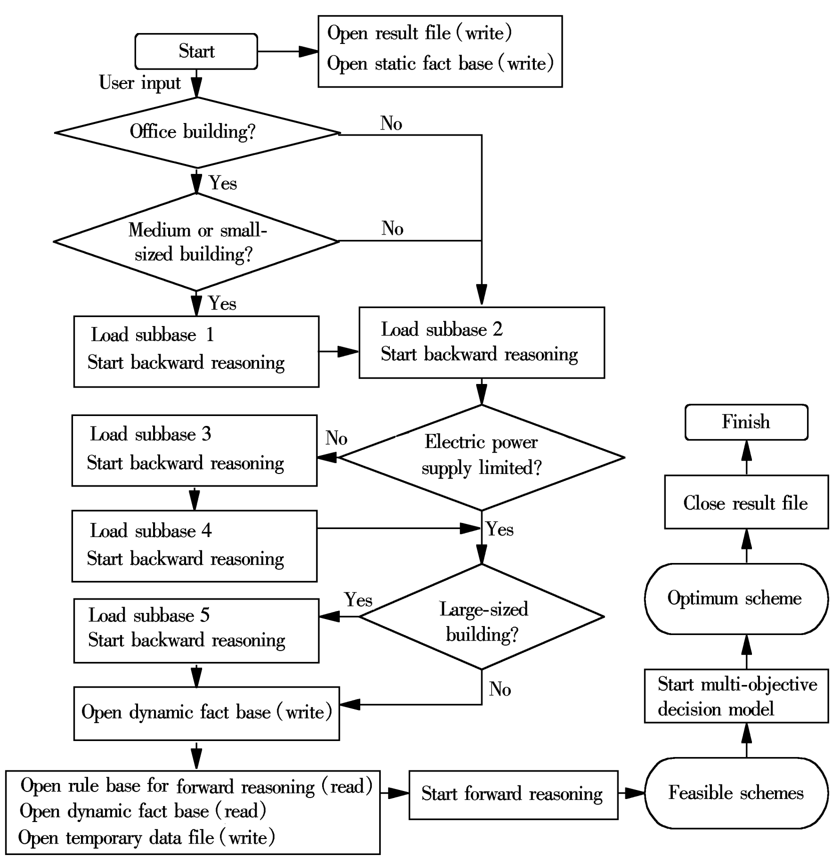

Fig.2 Reasoning process of the IDSS model

2 Knowledge Base and Inference Engine Realization

2.1 Developing environment selection

The IDSS model for air-conditioning cooling/heating sources selection had both processive and descriptive characteristics in its working procedure which asked the environment (programming language) selected for system developing to simultaneously have a satisfactory interface for descriptive functions calling and to be powerful in data processing. The C language had its perfect integrated developing environment as well as the notable advantages of powerful character processing and data processing supported by the mathematical function base, which ensured the high compiling efficiency, excellent transportability and friendly operating interface of the program developed. More and more KBSs were programmed using the C language instead of the traditional AI languages PROLOG and LISP in recent years[7,8]. Thus the IDSS model for cooling/heating sources selection was determined to be realized with the C language in the Windows operation system.

2.2 Symbol manipulation

The main task of the IDSS model was to deal with the symbols acting as knowledge carriers with the help of the powerful string handling function of the C language. Each of the symbols was encoded as a list cell indicated at the symbol cell as a pointer, so that the basic symbol structures of atom (symbol atom, numerical atom, string atom or function atom), dotted pair and list could be defined. The symbol atoms were stored in the form of a sorting binary tree by which the ambiguity error might be avoided for only one memory address could be found in the operation of founding, quoting and deleting of the atoms. The function operations involved in list processing were performed with the function mapping list which could be taken as a data calling or a function calling for data driving. The list input and output were done with the loading and printing functions built specially to make conversions between the internal form and external form (character string) of the list. In order to achieve a data driving in problem solving, the data stored in data files were loaded using the loading function then evaluated for one time before the corresponding reasoning process was started. The destination of the list output might be either text files or buffer area of strings[9]. It was shown in the program test and practical application that the IDSS model using such symbol manipulation method was efficient in running with small kernel and powerful capability in list processing and data driving.

2.3 Knowledge representation and knowledge base loading

The rules in the rule base were represented in the list form with the general description as

(RULE Rule_name (clause_1 clause_2 …)
(action_1 cf_1 action_2 cf_2 …))

where RULE is the keyword of rule representation, Rule_name is the rule name, clause_1,…,clause_n are rule premises consisting of rule conditions arranged as "and", action_1,…, action_n are rule conclusions with the confidence factors cf_1,…, cf_n. Each clause and action could be a function calling, a constant or a variable followed with "^". For example, the No.6 rule in the rule base of the IDSS model is represented as follows:

(RULE rule_6 ((= Have boiler installed with capacity rich in summer?[y/n]^ n)
(= Have steam supplied or waste heat utilized? [y/n]^ y)
(= Have temporary load or frequent varying daily load?[y/n]^ n))
((:= Cooling/heating sources scheme 2^ Indirect-fired absorption chiller/heater with oil fired boiler)1.0))

The keyword RULE could also be taken as a function calling by which the external form of the rules could be converted into the internal characteristic lists with the rule names put into the rule base at the same time. The rule premises and conclusions were stored in the characteristic lists so that they could be taken out directly to serve the reasoning process if needed.

As the rule representation, both of the facts set for reasoning and generated in inference process could also be described in the list form shown as follows:

(FACT(var_1 value_1 cf__1) …(var_n value_n cf__n))

where FACT is the keyword of fact representation, var_1,…, var_n are variables with the values of value_1,…, value_n. For example, a fact generated as the result of forward reasoning might be represented as follows:

(FACT (Cooling/heating sources scheme 1^ Air source heat pump unit 1.0)
(Cooling/heating sources scheme 2^ Direct-fired absorption chiller/heater 1.0)
(Cooling/heating sources scheme 3^ Water-cooled centrifugal chiller with oil fired boiler 1.0)
(Cooling/heating sources scheme 4^ Modular water chiller 1.0))

The rules and facts were stored in the rule base and fact base built in text files for easy editing and modifying of the knowledge base before they were loaded to the computer memory in system running. The knowledge base was loaded using the loading function after the function mapping lists were built to search the executive functions corresponding to the keywords RULE and FACT by which the rules and facts were defined[9].

2.4 Inference control strategy and algorithm

The inference engine of the IDSS model was realized with the recursive algorithm using the C language to describe the recursive processes of forward reasoning and backward reasoning while an inference tree could be built to give information for explanation facility of the system.

In the process of forward reasoning with data driving, the rules in the rule base were quoted based on the basic facts with their conclusions executed once the premises were met. If new facts occurred, another process of forward reasoning would be carried out based on the new facts in the same way. In order to avoid the production of an inference chain, a control strategy was adopted that each rule could only be successfully quoted one time before canceled from the rule base while the driving facts were accessed with a stack method of depth-first search.

The backward reasoning was done in the way of goal-directed which had the developing form as goal → subgoal establishing → ··· → subgoal solving → goal solving. Fig.3 illustrates the backward reasoning process corresponding to WSHP units' selection. The depth of backward reasoning was not limited because the number of subgoals occurring could not be expected in reasoning process. The final subgoals were actually basic facts which might be set beforehand or from real-time user input and need not be certified by rule quoting. The cycle designation method was used as control strategy to ensure the finish of backward reasoning under certain conditions[10].

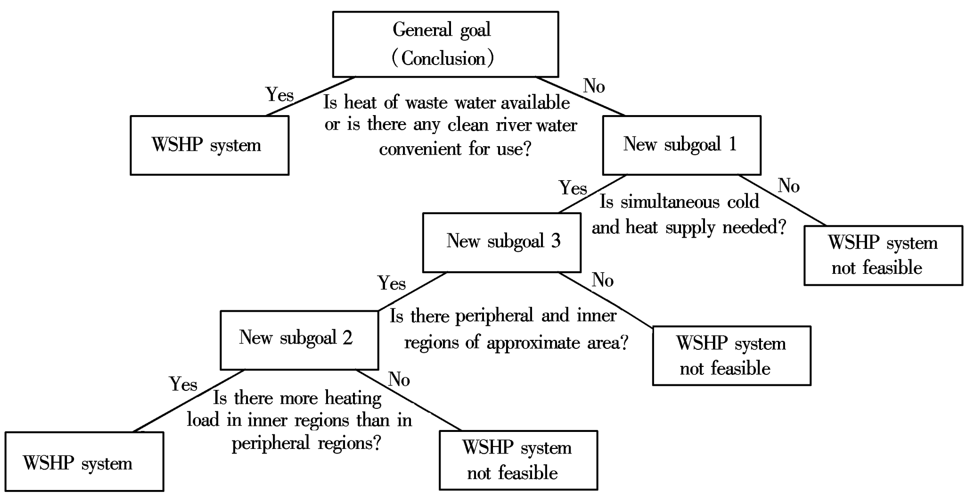

Fig.3 Backward chaining for WSHP system selection

3 Model Verification

3.1 Running test

In order to verify the reasoning capacity of the IDSS model, a running test was done to compare the reasoning results of the model with the existing examples of cooling/heating sources selection investigated from the HVAC projects in Nanjing and Shanghai[10]. Some of the project cases used in the test are given in Tab.1. It is shown that the conclusion drawn from the reasoning process of the program meets well with the practical choice. The model could ask questions according to the practical situation of different projects and could give attention opinions to the users under error input conditions to stop system running in time in a safe mode.

Tab.1 Project cases of cooling/heating sources selection used for model test

Chief usage of the building	Total area/hm^2	Levels of main building	Cooling/heating sources scheme
Bank	2.0	20	ASHP units
Restaurant	4.5	35	Indirect-fired double-stage cycle absorption chillers/heaters with oil-fired boiler
Shopping and entertainment	14.7	58	Water-cooled centrifugal chillers with oil fired boiler
Shopping and dining	10.5	57	WSHP units with oil fired boiler
Hotel	3.0	12	Water-cooled screw chillers with oil fired boiler
Office work	1.8	25	Water-cooled reciprocating chillers with oil fired boiler
Office work and living	3.5	27	Direct-fired absorption chillers/heaters
Office work and shopping	4.8	29	Water-cooled centrifugal chillers with electric boiler

3.2 Practical application

The IDSS model was applied to a practical HVAC project of a school building in downtown Nanjing for cooling/heating sources selection to demonstrate the feasibility of the knowledge representation and inference mechanism[10]. The building with 20 levels was mainly used for office work and scientific research which had the total area of 2.2 hm^2 as well as the estimated cooling load of 3.5 MW. The main conversation between the user and system in reasoning process was shown with inference result as follows ("↙" illustrated the user input):

Is the building located in the downtown district? [y/n]^ y↙

Is domestic heated water needed? [y/n]^ n↙

(Start the first backward reasoning process …)

Feasible cooling/heating sources scheme: air source heat pump units (According to rule_2)

Has boiler installed with capacity rich in summer?[y/n]^ n↙

Has steam supplied or waste heat utilized?[y/n]^ n↙

Power supply limited in summer and is difficult or expensive to increase supply?[y/n]^ n↙

Has temporary load or frequent varying daily load?[y/n]^ n↙

(Start the second backward reasoning process …)

Feasible cooling/heating sources scheme: direct-fired absorption chillers/heaters with oil fired boiler (According to rule_12)

Sufficient supply of power? [y/n]^ y↙

The maximum unit capacity you wish would be: [kw]^ 1000↙

(Start the third backward reasoning process …)

Feasible cooling/heating sources scheme: water-cooled screw or centrifugal chillers with oil fired boiler (According to rule_14)

(Start the forward reasoning process …)

The collection of feasible cooling/heating sources schemes:

Scheme 1: water-cooled screw or centrifugal chillers with oil fired boiler

Scheme 2: direct-fired absorption chillers/heaters with oil fired boiler

Scheme 3: air source heat pump units

(Start the multi-objective decision model …)

The optimum scheme recommend will be: [scheme 3] air source heat pump units

The scheme recommend by the system was reviewed by a group of HVAC experts to be reasonable for the application. The questions asked by the program were thought to be relevant while the rules in the rule base were believed to be organized and arranged appropriately for quoting in the reasoning process. An analysis report of air-conditioning cooling/heating sources scheme selection for the building was presented based on the inference results of the IDSS model which had received a high opinion from the owner and correlative departments.

4 Conclusion

The knowledge base and inference engine made up the core parts of the IDSS system. The knowledge expression and organization in the knowledge base were critical for the program, which affected directly the model availability as well as the construction and implementation of the inference and explanation mechanism. The knowledge expression mode was chosen based on the specialties of the domain problem while the inference mechanism was determined by the fact method of problem solving and the method of expert thinking. The IDSS model was verified to achieve satisfactory decision support of air-conditioning cooling/heating sources selection for HVAC projects in an urban district of Nanjing and Shanghai with powerful capability in character handling and heuristic reasoning, by which the rationality of knowledge representation and inference mechanism adopted for knowledge base and inference engine construction and realization was confirmed. It is necessary that further studies will not be stopped to improve the existing program in both structure and function until an IDSS system for commercial usage was developed.

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空调冷热源选择智能决策支持系统知识库与推理机的构造与实现

刘 颖[1] 王如竹[1] 李云飞[1] 张小松[2]

([1] 上海交通大学制冷与低温工程研究所,上海 200030)
([2] 东南大学动力工程系,南京 210096)

摘 要 根据空调冷热源方案选择的特点,对面向该领域问题的知识表达方式和推理控制策略进行了分析,提出了知识库和推理机的构造思想和工作过程,探讨了C语言开发环境下的实现方法.采用领域工程师为主体的开发方式,开发了一个基于此知识表达和推理机制的空调冷热源选择智能决策支持系统模型软件.经测试表明,该软件具有内核小、表处理及数据驱动能力强的特点,在某大型办公楼空调冷热源系统设计中获得了成功应用.

关键词 空调; 冷热源; 智能决策支持系统; 知识库; 推理机

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