CONTRIBUTIONS TO THE DEVELOPMENT OF KNOWLEDGE-BASED SYSTEMS APPLIED TO BUILDING SERVICES DESIGN AND ANALYSIS

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Such a work even if is personally realized, it cannot have the consistency, the actual substance and the results would have been less valuable, if the support of other persons with a various training and individual characters, with the help of whom my experience of life and knowledge has growth.

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Chapter 1. INTRODUCTION

1.1 Overview
The explosive development of the Information Technology (IT) leads today to the development of more and more complex and performing computer programs in all the domains, and also for the building services. All these applications have improved their own characteristics over time: programming language, GUI (Graphical User Interface), data management etc., to decrease the human design endeavor. However, nowadays a long series of questions may arise:

- Is this the maximum of performance?
- How accurate these computer programs can model the reality of building services?
- Can these applications extract logical conclusions from a technical point of view?
- Can these programs offer the same answers as a high qualified and experienced human operator into a specialized field?
- Can these programs “learn” from the knowledge provided and the results obtained?

1.2 The proposal
This work proposes to use the solution offered by the AI (Artificial Intelligence) to implement the expert systems into the building services field. The combination between the human experience and intelligence + the computing power and understanding capabilities of modern computers can lead to the high, unexpected performances & gains (see figure 1.1).

![Figure 1.1 Performance equation in the third millennium](image)

1.3 Artificial Intelligence basics
1.3.1 Defining AI
Artificial Intelligence (or shortly AI) represents one branch of computer science targeting the conception of computer programs and hardware components to produce the same “reasoning effect” as the human being [1], [23].

1.3.2 TURING test

1.3.3 AI domains

![Figure 1.3 AI domains](image)

1.3.4 Short historic of AI and expert systems development
1.3.5 The AI future
A future vision of Francis HEYLIGHEN predicts that [28]: “Such a global brain will function as a social super-organism put together by the entire human society”.

Chapter 2. ACTUAL RESEARCH STAGE OF THE COMPUTER PROGRAMS APPLICATION INTO THE BUILDING SERVICES FIELD

2.1 Computer applications classification for building services
Today, a large number of computer applications is used into the building services field. Choosing several criteria such as: specialization and capabilities, degree of complexity, shipping method, selling price etc., one can classify these computer programs into the following main categories: general CAD and CAD&D programs, workbooks, computer programs conceived for thermal and hydraulic calculations, specialized CAD programs for...
building services, computer applications for choosing installation components, computer programs for building services monitoring, database management systems, knowledge-based systems (KBS).

2.2 General CAD and CAD&D programs

From this category, a short description of the well-know AutoCAD application created by Autodesk [2], [15], [25], [27] is given, altogether with mentions regarding the ArchiCAD program for architectural drawings, and other recently developed, like IntelliCAD, TurboCAD, and SmartSketch.

2.3 Workbooks

2.3.1 Generalities

2.3.2 Workbooks created for the design of sanitary and heating plants

By using the Microsoft Excel program, the author has conceived two kinds of workbooks for the design of sanitary and heating plants (see figure 2.2). For the heating plant, the 2005 version workbook contains 17 worksheets that have different roles such as general working data, dimensioning the heating radiators (elements or panel radiators), pivot tables for centralization of results, hydraulic calculations and balancing, linear expansion etc.

2.4 Computer programs planned for thermic and hydraulic calculations

2.4.1 Computer applications designed in Romania

2.4.2 Computer applications designed by the author

Using the TURBO BASIC and later TURBO C computer programming languages, the author has designed between 1990-1993 and 1995-1998 several prototype educational programs, operated afterwards at the university lab hours: for the sanitary plants (INAR, INAC, CANI, REX_AR, REX_AC, and REX_CAN), for the heating plants (SUPRAF_ST, INSTGRAV, INSTCF, and REX_INC) and for thermal equipments (BURN, CAZAN). Later, using the C programming language (preferred author’s language), some professional applications were made, like HR90 (1996-1997), HR97 (1998-2003, see figure 2.4), CHAOS (1997-2005) and GRAPH2000 (1999-2001).

2.5 Specialized CAD programs for building services

From this category the following commercial applications characteristics were studied and presented: AC PLANT DESIGNER, Pit-cup, Softdesk Building Services and IMI.

2.6 Computer applications for choosing installation components

Some specialized programs for choosing installation components like Wilo SELECT 3.1, TA Select II and OVselect are shortly described here, with their essential characteristics.

2.7 Computer programs for building services monitoring and database management systems

2.8 Knowledge-based systems (KBS)

At the Technical University of Cluj-Napoca, the author of Ph.D. thesis [19] has realized an expert system prototype called BPC, in order to automate the search and selection process of the computer programs existing into the civil engineering library. In addition, another ES, called AIC Info was created [19], to centralize the Internet resources for constructions, using the HTML language to represent the informations. In work [3], a computer tool called SURTEF is described. This expert system was written in C++ language, can deal with temporal and fuzzy knowledge, and it is used within the automation of building services field.

2.9 Conclusions (summary)

The author has several contributions to the development of computer applications for designing sanitary & heating plants (see §2.3.2 and §2.4.2). The computer programs used nowadays in building services field, despite the fact that have many remarkable and enhanced characteristics, do not have the ability to “learn” from the existing knowledge, can only partially operate the resources to extract some logical technical conclusions, cannot easily help one with a little training to improve his experience and don’t have as a main purpose to reuse the conclusions into similar situations. The solution? To develop and implement knowledge-based systems (KBS) into building services field, by following some important research directions: KBS categories being capable to be used in the target field; methods to represent the building services knowledge in KBS; construction of an knowledge base and a database for an ES designed for heating plants; usage of numerical relations and implementation of the numerical methods for solving the building services design aspects; new theoretical relations for the supply and return pipe temperatures.
Chapter 3. BASICS OF EXPERT SYSTEMS

3.1 Defining expert systems

There are many definitions given to this concept, expert systems (ES). The Ph.D. thesis shows about 25 definitions taken from the literature & the Internet, and a new author’s definition. Many of them deal with subjects like knowledge, knowledge base, inference engine, rules, human expert etc.

Author’s definition

An expert system (ES) is basically composed of a collection of methods and techniques, with the help of which the specific reality of a subject can be formalized and captured into a knowledge base, used by an inference engine with the main purpose to solve a problem or a problems category using “intelligent reasoning”, by simulating the human expert solving mode.

3.2 General components of an ES/KBS

![Figure 3.1 General components of an ES/KBS](image1)

![Figure 3.4 KBS components for building services](image2)

3.3 Main functions of KBS

Work [1], after HAYES-ROTH, WATERMAN and LENAT (1983), and work [17], enumerate a long series of KBS application fields like: design, diagnosis, monitoring, scheduling, instructioning&perfectioning, control. For building services field, the following application domains were retained as attractive: design, diagnosis and instructioning&perfectioning.

3.4 Motivations for using the KBS

There are many reasons to build and use KBS [1], [17]. These advanced computer systems can substitute the human expert in some situations, the knowledge can be acquired at any moment, the knowledge can be accessed without restrictions, KBS can participate to rise up the training level of a specialist in the field or even help a human expert in solving difficult problems, or they can be seen as an alternative solution to human expertise (when that is life threatening or very expensive).

3.5 Specific characteristics of KBS

This section investigates how KBS [1], [4], [17], [25] can use a symbolic reasoning, heuristic reasoning, a fuzzy reasoning, can solve different problems categories, use generalized inference techniques, offer a good separation between knowledge and control, and also offer a high specialization into a very narrow field.

3.6 Programming languages and KBS “shells”

3.6.1 LISP language

3.6.2 PROLOG language

3.6.3 KBS shells

KBS shells represent collections of specific tools used to build and develop expert systems. They are called also as “AI tools”, “skeletons” or “expert system generators”. This section presents the following shells characteristics: CLIPS (C Language Integrated Production System), FuzzyCLIPS 6.10d and wxCLIPS with Fuzzy Extensions, FLEX, Guru, e2gLite (accessed by the Internet).

3.7 KBS successfully examples

3.8 Conclusions (summary)

The KBS or ES represents an advanced computer tool having a various definition in today literature. For the building services field, a KBS used for design or analysis must fulfill supplementary conditions like: to implement the knowledge using a very organized and compact representation; the generic named “knowledge base” must be composed by specific design or analysis knowledge sub-bases; besides the strictly speaking knowledge-base, there must be created a powerful support building services database with equipment specifications; and also from the technical point of view, there must be implemented a calculation pack for specific thermic, hydronic, balance and analysis building services calculations. Therefore, a new scheme was proposed and developed into the next chapters (see figure 3.4).
Chapter 4. KNOWLEDGE REPRESENTATION IN EXPERT SYSTEMS

4.1 Primary conditions for knowledge representation

Definition
Knowledge representation is a knowledge implementation process into the KB of the expert system throughout organization and aggregation of them, for solving a problem like a human expert reasoning.

For a successfully implementation, knowledge must accomplish some important conditions: to have a pragmatic sense into the real world [1]; the representation must be very efficient; unfortunately, even a small problem solving can demand a large quantity of knowledge.

![Figure 4.1 Knowledge categories](image)

4.2 Knowledge categories to be represented in KBS

4.2.1 Declarative knowledge

Example 3
To describe a pipe, one can supply the principal properties, such as type, inner diameter, wall thickness etc.

(deftemplate conducta "Definire conducta"
(slot tip ;Camp pentru tipul conductei
(type STRING) ;Tip camp: sir de caractere
(default ?DERIVE)) ;Valoare implicita
(slot material ;Camp pentru material
(type STRING) ;Tip camp: sir de caractere
(default ?DERIVE)) ;Valoare implicita
(slot diametru-exterior ;Camp valoare diam. exterior [mm]
(type FLOAT)  ;Tip campului: nr. real
(default ?DERIVE)) ;Valoare implicita
(slot grosime-perete ;Camp grosime perete [mm]
(type FLOAT) ;Tipul campului: nr. real
(default ?DERIVE)) ;Valoare implicita )

Using the template:
(assert (conducta (tip "PEXAL") (material "PEx") (diametru-exterior 20.0) (grosime-perete 2.0) ...))

4.2.2 Structural knowledge

See Ph.D. thesis figure 4.2 Simplified taxonomy of heating plants.

4.2.3 Procedural knowledge

Example
To compute the flow rate, one can use the well-know formula (4.1)

\[ w = \frac{4 \cdot q}{\pi \cdot d^2} \]  

(4.1)

where
- \( w \) – flow rate[m/s];
- \( q \) – flow [m³/s];
- \( d \) – inner diameter of the pipe [m].

(deffunction viteza "" ; Nume functie
(?debit ?diam-int) ; debit [mc/s]; diam-int [m]
(/ (* 4.0 ?debit) (* (pi) (** ?diam-int 2)))))

Calling the function for the flow \( q=300 \text{ l/h} (8.333 \times 10^{-5} \text{ m}^3/\text{s}) \) through an example 3 pipe:
(printout t "Viteza=\( (\text{viteza 8.3333e-5 0.016) " \text{m/s crlf})")

4.2.4 Heuristic knowledge

Heuristic knowledge or the “rules-of-thumb” are knowledge gained by experience and provided usually by the human expert [1], [18], [21].

Example:
(defrule exista-cos-de-fum ""
(cos-de-fum ?cos&nu-exista)
=>
(assert (montaj-centrala Interzis))
(printout t "Nu se monteaza centrala termica cu camera de ardere deschisa" crlf)
(printout t "Explicatie" crlf)
(printout t "Cos de fum: " ?cos crlf))

4.2.5 Meta-knowledge

Meta-knowledge represent knowledge about how the knowledge can be used, and in which way the control of knowledge flow must go to [1].
4.3 Methods for building services knowledge implementation in KBS

4.3.1 Facts

4.3.2 Propositions and declarations

Example
(assert (stare-pompa oprita))

4.3.3 Object-Attribute-Value configuration (O-A-V)

Object-Attribute-Value configuration is a more advanced method to represent the knowledge by assigning a value for the property of an object [1]. Therefore, the pipe from example 3 can be graphically represented by this O-A-V method like in figure 4.5.

![Figure 4.5 Pipe object with four attributes](image)

4.3.4 Production rules

A production rule (or briefly, rule) is composed by two main parts [1], [16]:
- IF – antecedent, premise/hypothesis or LHS (Left Hand Side);
- THEN – conclusion, consequence or RHS (Right Hand Side).

Example
(defrule verifica-racord-radiator ""
(tip-tronson este racord-radiator)
(material-tronson este teava-multistrat)
(viteza-agent ?viteza; (> ?viteza 0.30))
=>
(assert (tronson este subdimensionat))
(calculeaza-diametru debit-agent 0.30))

4.3.5 Frames

The frame defines a data structure in relation to an object or concept, first introduced by Minski in 1975 [1].

Example
The implementation of heating radiators for a heating plant can be made by generating an abstract object class CORP-INCALZIRE, then classes that are more specialized (see figure 4.7) like CORP-INCALZIRE-STATIC, RADIATOR, ..., RADIATOR-ELEMENTE-ALUMINIU etc.

```lisp
(defclass CORP-INCALZIRE (is-a USER)
  (role abstract) ; Nu se definesc direct instante
  (slot tip
    (create-accessor read-write)
    (type STRING)
    (default "X"))
  ................................................ )

(defclass CORP-INCALZIRE-STATIC (is-a CORP-INCALZIRE)
  (role abstract); Nu se definesc direct instante
  (slot tip
    (create-accessor read-write)
    (type STRING)
    (default "X"))
  ................................................ )
```

![Figure 4.7 Heating radiators taxonomy](image)

4.3.6 Propositions logic and predicate calculus

4.4 Imperfect knowledge representation. Fuzzy logic basics

4.4.1 Vagueness of informations

4.4.2 Uncertainty of informations

4.5 Conclusions (summary)

Almost all the required knowledge for building services design and analysis can be represented in KBS using a variety of knowledge categories: declarative, structural, procedural, heuristic and meta-knowledge, via specific knowledge implementation methods: facts, propositions, O-A-V structure, productions rules and frames, fuzzy logic.
Chapter 5. THE KNOWLEDGE BASE AND THE DATABASE OF THE EXPERT SYSTEM FOR THE HEATING PLANTS

5.1 The human expert vs. the artificial expert
5.1.1 Introduction
5.1.2 Parallels between human expertise and expert system
5.1.3 Demands for the heating plant human expert

Because the knowledge used by the KBS came from the heating plants human expert, this one must fulfill some important demands for achieving the goal: the expert must be a reputed specialist into the field, having also strong knowledge about other connected domains; he must be capable to understand the essence of the problem proposed to be solved; he must identify from the problem objectives the ways by which the knowledge can contribute to solve the problem; he must convert the problem into a conception and solving adequate model; and not at last, the expert must explain his reasoning, and communicate the obtained results.

5.2 Knowledge base elements
5.2.1 Overview
5.2.2 Knowledge acquisition methods
5.2.2.1 Validation lists
5.2.2.2 Flowcharts
5.2.2.3 Decision tables
5.2.3 Other sources of knowledge acquisition
5.2.4 Knowledge base for heating plants expert system

The heating plant design represents itself a very complex problem. The best solutions to deal with the necessary knowledge are:

- To split the big knowledge base into more knowledge sub-bases strictly oriented to solve the specific design aspects;
- A complex database, which can memorize the numerical or textual informations about the heating plant materials, components and equipments.

5.2.4.1 Heating load
Firstly, there are necessary objects, rules and informations to deal with the heating load of the building and the physical properties of it: number of outer walls, the window positions, room surfaces etc.

5.2.4.2 Choosing the heating system
For choosing the heating system, mainly the prescriptions of norm 113 [29] are used, and function of the building integration group, the heating agent and radiators are chosen. At this stage, one can appreciate that the rules-of-thumb gained by the human expert are a good option for the best solution identification and choosing.

5.2.4.3 Heating radiators dimensioning
5.2.4.4 Choosing the heating plant model
The ES prototype is focused on forced circulation heating plants (circulation by pumps) which can be separated in two main classes: installations with centralized distribution and installations with individual distribution. Each of these classes has its specific particularities that must be treated separately. Again, because of the large diversity of level plans, the rules-of-thumb provided by the heating plants human expert are essential.

5.2.4.5 Dimensioning the pipes
After the pipe network configuration is establish, one can proceed to dimensioning the pipes. This can be made by applying a series of rules, which control the application of heating plants specific computing routines for: the flow calculation, choosing the inner pipes diameter, computing the head loss and so on.

5.2.4.6 Dimensioning the energy source
The dimensioning of the energy source is by itself another complex goal. This one can be split into separate sub-problems, in function of the total necessary load of the building and the required source complexity. So, for the total load less then 30-35 kW, the energy source can be chosen as a micro-plant with all the necessary components and a thermal efficiency at least equal to 90% in accordance with norm 113 [29]. For higher required power (35-100 kW, 100-2000 kW and over 2000 kW) is essential to size separate equipments: heating boilers, circulation pumps, closed expansion tank, domestic water heating cylinder, control valves, balancing valves, distributor-collector etc.

5.2.4.7 Balancing the plant
5.2.4.8 Thermal expansion
5.2.4.9 Thermal insulation

5.3 The support database of the KBS
5.3.1 Databases overview
5.3.1.1 Tables, records and fields
5.3.1.2 The database creation process
5.3.2 KBS database structure
5.3.2.1 Introduction
5.3.2.2 Database initial structure
5.3.2.3 Database current structure
The current database (DB), relocated into Microsoft Excel application, is composed by 86 worksheets with different functions and 336 tables. This database contains a lot of information about: heating radiators (elements and panel radiators); pipes used in heating plants networks; different categories of valves; \( \zeta \)-values coefficients for different local resistance items; energy sources: micro-plants and heating boilers; closed expansion tanks; water properties. The memo arrangement of informations is structured hierarchically, using on-top levels. On the first level, there are fundamental primary tables, on the second level, secondary tables, and sometimes when situation requires this, on the third level, particular tables. The DB contains also a series of independent tables and assisting tables (see figure 5.3). The DB can be accessed also from other workbooks created in Excel, computer application that uses the ODBC or ActiveX technology.

![Diagram of DB structure](image)

**Figure 5.3 Generic representation of DB infos memo structure**

### 5.3.2.3.1 Heating radiators

The information configuration for heating radiators is made by using autonomous tables for correction coefficients defined by STAS 1797 [30], [31] and 2 separate table sets, organized by three and four levels.

### 5.3.2.3.2 Pipes

### 5.3.2.3.3 Valves

### 5.3.2.3.4 \( \zeta \)-values coefficients (local resistance coefficients)

### 5.3.2.3.5 Energy sources: micro-plants and heating boilers

The energy sources were organized starting from their producers, using a primary table with links to models secondary tables. Each model has an electronic sheet implemented as a particularly table. For some micro-plants or central heating boilers models there are supplementary tables, which retain the info about the H-Q curve (see figure 5.4).

### 5.3.2.3.6 Closed expansion tanks

![Digitized H-Q curve for HERMANN SUPERMICRA 23E/24SE](image)

**Figure 5.4 Digitized H-Q curve for HERMANN SUPERMICRA 24 SE micro-plant**

### 5.4 Conclusions (summary)

The human expert into the heating plant field must certainly have some abilities in order to ensure the knowledge confidence and accuracy. The knowledge base is an important module of the heating plant KBS, being one of the most complete tool for the storage of the knowledge about a field, and there are several knowledge acquisition methods to accomplish this task. The heating plant design problem represents a complex problem, which can be solved by splitting it into specialized sub-problems, resolved by using knowledge sub-bases, focused on specific design aspects, supported by a complex building services database, which memorizes the numerical and textual informations required.

Practically, for the ES knowledge base, one can take into account the following phases: the heating load, choosing the heating system, heating radiators dimensioning, choosing the heating plant model, dimensioning the pipes, dimensioning the energy source, balancing the plant, taking care of system thermal expansion and solve the thermal insulation aspect.

The KBS database is currently structured hierarchically, using information on-top levels (central levels, secondary levels and particularly levels), and contains today many characteristics of heating plants equipments and characteristics like: heating radiators, pipes, valves, local resistance coefficients, energy sources: micro-plants and heating boilers, closed expansion tanks and so on.
Chapter 6. DEVELOPMENT OF AN EXPERT SYSTEM BASED ON FRAMES AND RULES FOR THE HEATING PLANTS

6.1 General development phases of an expert system

6.2 Automated reasoning and inference methods in KBS

6.2.1 Reasoning and inference

According to [16], reasoning can be watched as a complex process, which deals with the facts, knowledge and strategy methods, having as a main target to solve the problems and obtain the right conclusions.

Definition

Inference is the process by which the knowledge-based system obtains new knowledge from the known informations.

6.2.2 Forward chaining. Example

Forward chaining is the inference modus operandi, which starts with some facts or known values of properties, and applies this knowledge, by using them into the antecedent of rules, usually grouped into a set. The rules are activated, fired and then are producing other facts, which can be applied to valid following rules. The process is continued until there are no more conclusions to find, or a solution of problem is discovered.

Figure 6.4 Forward chaining: Final step

Figure 6.12 Backward chaining: Problem solution

6.2.3 Backward chaining. Example

Backward chaining represents an alternative approach method of automated reasoning, which assumes that the conclusions are known, and tries backwards to find the premises (starting hypothesis) [1]. This complex process is completed in several successive phases.

Problem 1

The system must find the flows from target-node N3; the flows from nodes N1, N5, N6 are not initially specified.

Problem 2

Let us make node N2 as the target-node, but this time the flow values from nodes N1 and N5 are specified by introducing some particular assertion into file Fapte Nod Tronson.CLP.

6.3 Building an KBS based on frames and production rules

6.3.1 Short programming considerations

6.3.1.1 Classes hierarchy

6.3.1.2 Object properties (attributes)

6.3.1.3 Inheritance mechanism

6.3.1.4 Combining objects and production rules

For the heating plant expert system, one can appreciate that a hybrid KBS, which combines the knowledge representation using the frames, with the powerful “pattern-matching” rules mechanism, is one of the best solutions.

6.3.2 General problem description

6.3.3 Problem space analysis

Problem space analysis has as a main target to find the important objects necessary to describe the application: general objects and then specialized objects (instances of the classes).

Firstly, a building object (CLĂDIRE) is required to describe the building in which the heating plant is set. A building has several levels, so again, at least one level object (NIVEL) as “a part of the building” must be created. Then the levels are constituted by rooms, therefore, a room object name ÎNCĂPERE is implemented as “a part of the level”, these rooms are assembled by several construction elements such as outer walls (PERETE-EXTERIOR), inner walls (PERETE-INTERIOR), ceiling (PLAFON) etc., implemented as “parts” of the room.

The heating plant is viewed as a series of elements such as heating radiators, pipes, fittings, valves, energy sources, all having their own base classes, from which specialized objects are created later. For the heating plant components, one can define the characteristic attributes of an item in accordance with its specificity. As an example,
the heating radiators have to load (in addition to the properties collected from the DB) the following: the thermal power in design conditions, the spatial location (X, Y, Z) of the gravity center, the correction coefficients etc.

The pipes segments, in addition to the material properties loaded from the DB, require to specify supplementary attributes (found after the completion of other design phases) like: ID, role, initial and final node, length, the thermal power transported, the flow, the flow rate, types of local resistances etc.

6.3.4 Classes and objects instances descriptions

After the objects are clearly set, using an adequate programming language or the specific KBS shell language, one can describe them, and then review these objects, to map them on the problem demands as good as possible.

6.3.5 Introducing production rules and computing procedures

6.3.6 User interface (UI)

6.3.7 Testing and expanding the KBS

6.4 Calculation pack considerations

6.4.1 Dimensioning the heating radiators

6.4.2 Computing the flow

6.4.3 Flow rate calculation

6.4.4 Finding the flow regime

6.4.5 Computing the friction coefficient

For the transition domain 2300<Re<3500, work [22] proposes the relation (6.26)

$$\lambda = \frac{64}{2300} (3500 - Re) + \lambda_{nurb} (Re - 2300)$$

where the friction coefficient $\lambda_{nurb}$ is calculated from the COLEBROOK-WHITE formula.

6.4.6 Linear, local and total head losses

6.4.7 Computing the closed expansion tank volume

6.4.8 Thermal expansion calculations

6.5 New theoretical relations for setting the supply and return temperatures

6.5.1 Thermal power in real working conditions

6.5.2 Return agent temperature

6.5.3 Final formulas

$$t_r = t_i + 0.5 \cdot \frac{t_i - t_w}{t_{ic} - t_{rc}} \cdot \frac{k}{k_e} \cdot (t_{ic} - t_{rc}) + \left[ t_i + 0.5 \cdot \frac{t_i - t_w}{t_{ic} - t_{rc}} \cdot \frac{k}{k_e} \cdot (t_{ic} - t_{rc}) \right]^{0.5}$$

$$- t_i \left[ t_i + \frac{t_i - t_w}{t_{ic} - t_{rc}} \cdot \frac{k}{k_e} \cdot (t_{ic} - t_{rc}) \right] + \frac{t_{rc} - t_i}{t_{ic} - t_{rc}} \cdot \frac{k}{k_e} \cdot (t_{ic} - t_{rc})$$

$$t_r = t_i - \frac{t_i - t_w}{t_{ic} - t_{rc}} \cdot \frac{k}{k_e} \cdot (t_{ic} - t_{rc}) \quad [\text{C}]$$

If in relations (6.66) and (6.67) we can approximate the variation $\frac{k}{k_e} \approx 1.0$, one can find the simplified formulas (6.68) and (6.69)

$$t_r = t_i + 0.5 \cdot \frac{t_i - t_w}{t_{ic} - t_{rc}} \cdot (t_{ic} - t_{rc}) + \left[ t_i + 0.5 \cdot \frac{t_i - t_w}{t_{ic} - t_{rc}} \cdot (t_{ic} - t_{rc}) \right]^{0.5}$$

$$- t_i \left[ t_i + \frac{t_i - t_w}{t_{ic} - t_{rc}} \cdot (t_{ic} - t_{rc}) \right] + \frac{t_{rc} - t_i}{t_{ic} - t_{rc}} \cdot (t_{ic} - t_{rc})$$

$$t_r = t_i - \frac{t_i - t_w}{t_{ic} - t_{rc}} \cdot (t_{ic} - t_{rc}) \quad [\text{C}]$$
6.6 Conclusion (summary)

The process that leads to the development of an expert system is very complex and it imposes to go through consecutive phases, by codifying the knowledge provided by the human expert or alternative sources.

Two main inference methods are the most used in KBS. One of them, so-called modus ponens, operates with a series of initial data and a set of production rules, to make logical assertions strings, which lead to the discovery of new facts. The inference process one may say that is a data-driven process. The second method is called modus tollens and represents the type on inference having as target to demonstrate an assertion, following a goal driven process.

The frames represent usually a better solution to “capture” the knowledge (thanks to the compact method of implementation) than other techniques, as simple facts declaration or using only the production rules. The hierarchical organization of frames is done on levels: at top levels, there are abstract frames, and on inferior levels, frames more and more specialized. The best solution for heating plants KBS is represented by an hybrid ES, based mainly on frames, but also containing production rules having a control and interaction role. The building process of the heating systems KBS must go through the following phases: general problem description; problem space analysis; classes and objects instances descriptions; production rules and computing procedures introduction; user interface finalization; testing and later expanding the KBS.

The calculation routines contained into the KBS computing pack are made following the technical current norms, and are implemented using the CLIPS language and the C programming language. For agent properties, the author proposes to use some numerical relations, instead of large properties interpolation tables. For solving the specific building services non-linear equations, one can use the techniques provided by the numerical methods literature, as Newton’s method combined with traditional relations.

Two new theoretical relations for computing the supply and return temperatures of the heating radiators were deduced, implemented and used to produce the numerical and graphical results shown in the annexes.

Chapter 7. FINAL CONCLUSIONS, ORIGINAL CONTRIBUTIONS AND FUTURE RESEARCH DIRECTIONS

7.1 Final conclusions (summary)

Watching the evolution of computer programs used in our days in building services field, one can see that these applications have experienced major improvements concerning the human-computer interface, programming languages and overall performances, leading to the decreasing of the design endeavor and rising up the results confidence degree. However, these programs, by their structure and target design, are not the optimum solution to deal with the knowledge required and embedded into these kinds of installations.

On the other hand, the solution to implement the knowledge-based systems or expert system into the building services field, referring to the heating plants, is a suitable one, even very necessary, if we want to be the owner of the progress key into the near future. Nowadays, and especially in the near future, the accent will be put more and more on the knowledge and the intelligent use of this knowledge.

Nevertheless, do not make the mistake to dream with the open eyes. The expert system prototype can be materialized into a successful product only by the conjugate effort of an homogenous team, composed from building services human experts, building services engineers, knowledge engineers, programming specialists and of course, the end-user. This team must be heavily supported by all the means: human, material and financial.

7.2 Original contributions

7.2.1 Major contributions

The author of this work has several major contributions:

1. Watching carefully the actual stage of computer programs application into the field of building services, and finding the lack of systems capable to deal with the knowledge, the author proposed the adoption of the solution offered by the AI, to implement the expert systems into the building services field, for design and analysis goals;
2. The author gave another definition to the concept of expert system, from the building services engineer point of view, to enhance the explanation, in accordance with the actual level of knowledge;
3. The general structure of the knowledge-based system was modified and enlarged, preparing it to be used for the design and analysis activity of the heating plants. This was made by dividing the general concept of knowledge base into multiple separate knowledge sub-bases, and introducing two essential modules, each specific to the building services field: the equipments database and the calculation pack;
4. Many examples were given to show the principal categories of heating plants knowledge which can be implemented into KBS;
5. The methods of representation of the above knowledge were materialized for the heating plant KBS;
6. Because the proposed knowledge-based system prototype will mainly use the heating plants expert human knowledge, the author pointed out the requirements to be fulfilled by the human specialist in order to be the trusty “generator” of the knowledge;
7. Furthermore, the knowledge-base structure required by an expert system for the heating plant design and analysis was introduced. Because this activity it’s a very complex one, the author stresses the requirement to split this huge knowledge-base and adopt a more efficient way, by representing the needed knowledge of the focused phases into much smaller knowledge sub-bases. These sub-bases were then characterized, by the point of view of what knowledge must be embedded into every one;
8. A support database containing the heating plants materials, components and equipments was then constructed and developed. This database, that is structured by on-top information levels and completed with additional structures with support and control role, was tested using auxiliary test tools and then used for real heating plants design projects;
9. The author presented the automated reasoning methods like forward chaining and backward chaining used in expert systems, and then has applied them for solving some heating plant specific problems;
10. Next, the real solution for the heating plants KBS prototype (based on a hybrid ES constructed with frames and production rules) was proposed, the author describing the creation process substantiated on modeling the heating plant by object classes who interact between them by rules and calculation routines;
11. Finally, two new theoretical formulas were deduced, for the supply and return temperatures of the heating radiators, when the design parameters are changing in real working conditions against the design conditions.

7.2.2 Other contributions

7.3 Future research directions (selections)

The topics covered by this thesis, the solutions found and the obtained results open many new research ways to go further, like:
1. Materialization of concepts, models and working methods exposed, by transforming the prototype KBS into a real heating plants field KBS, by the endeavor of a complex and well-welded specialists team;
2. “Deeping-knowledge” the ES knowledge base, e.g. by introducing the needed rules-of-thumb used to describe new and different way to choose the heating system, the techniques for positioning the heating radiators in different room configurations etc;
3. Enhance the informations regarding the heating plants equipments categories and developing furthermore the existing database structure;
4. Working on a structure and implementation of a new KBS based on production rules, which can be used to diagnose the heating plants from the technical point of view.

7.4 Final word

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