OPTIMUM SELECTION OF AN AIR CONDITIONING SYSTEM

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Abstract— Air conditioning system consisting of components arranged in sequential order to satisfy the various space conditions required for comfort as well as industrial air conditioning. More demands for air conditioning have brought about rapid increase in number of air conditioning systems and air conditioner manufacturers. the selection of air conditioning system is very much important.In this thesis work, a new methodology has been developed that is optimum selection of an air conditioning system from the different alternative designs available in the global market. it is based on Multi Attribute Decision Making (MADM) approach. Pertinent attributes which describe the wholeair conditioning system are identified in an exhaustive way. A n-digit coding scheme basedon all the pertinent attributes for a given air conditioning system is suggested, that is usefulfor the development of a comprehensive database of available air conditioning systems, andtheir subsequent retrieval. the selection procedure proceeds to evaluate and rank the shortlistedalternatives by employing the TOPSIS approach. Three graphical techniques of comprehensive comparison namely histogram, graphical and radar are also presented to better educate the decision makers. The proposed 3-stage selection methodology is explained with the help of an illustrative example. This methodology provides good insight to the air conditioning system manufacturer so that he can improve his product or introduce new product to fulfill the need of costumer.

Keywords— Air conditioning; N – Digit Coding Scheme; Graph Theoretic Modeling.

I. INTRODUCTION TO AIR CONDITIONING

With the development of society and economy, living standard of people is improving, and higher living conditions are demanded. So, more attention is paid towards treating the indoor air for the comfort of the occupants. Apart from comfort air conditioning required for comfort of persons, air conditioning is also used to provide conditions that some industrial processes require. Merely lowering or raising the temperature does not provide comfort in general to the machines or its components and living beings in particular. In case of the machine components, along with temperature, humidity also has to be controlled and for the comfort of human beings along with these two important parameters, air motion and cleanliness also play a vital role. Air conditioning, therefore, is a broader aspect which looks into the simultaneous control of all mechanical parameters which are essential for the comfort of human beings or animals or for the proper performance of some industrial or scientific process.

The precise meaning of air conditioning can be given as the process of treating air in an internal environment to establish and maintain required standards of temperature, humidity, air movement and air cleanliness for the health and comfort of the occupants for product processing, or both. In some applications, even the control of air pressure falls under the purview of air conditioning. Depending upon the requirement, air conditioning is divided into the summer air conditioning and the winter air conditioning. In the summer air conditioning, apart from cooling the space, in most of the cases, extra moisture from the space is removed, whereas in the winter air conditioning, space is heated and since in the cold places, normally the humidity remains low, moisture is added to the space to be conditioned. The summer air conditioning thus uses a refrigeration system and a dehumidifier. The winter air conditioning uses a heat pump (refrigeration system operated in the reverse direction) and a humidifier. Depending upon the comfort of the human beings and the control of environment for the industrial products and processes, air conditioning can also be classified as comfort air conditioning and industrial air conditioning. Comfort air conditioning deals with the air conditioning of residential buildings, offices spaces, cars, buses, trains, airplanes, etc. Industrial air conditioning includes air conditioning of the printing plants, textile plants, photographic products, computer rooms, etc.

1.1 The Need for Air Conditioning

Although some people might regard air conditioning as a luxury, in certain areas having air conditioning is a must. One does not feel comfortable if the temperature and humidity level is too high. Air conditioning affects not only personal comfort, but also economics. . If people feel comfortable, their productivity is generally better than if they work under uncomfortable conditions. Apart from comfort air conditioning required for comfort of persons, air conditioning is required in many industries to provide conditions that some processes require. The life and efficiency of electronic devices increases at lower temperatures. Computer and microprocessor-based equipment also require air conditioning for efficient operation. Thus, air conditioning is and will be

1.2 History of Air Conditioning

For prehistoric people, open fires were the primary means of warming their dwellings; shade and cool water were probably their only relief from heat. No significant improvements in humankind's condition were made for millions of years. The fire-places in the castles of medieval Europe were hardly an improvement. They only heated the area immediately around them. Paintings from those times show that the kings and queens wore furs and gloves indoors in winter. There were a few exceptions to this lack of progress. The ancient Romans had remarkably good radiant heating in some buildings, which were achieved by warming air and then circulating it in hollow floors or walls. In the dry climate of Middle East, people hung wet mats in front of open doorways and achieved a crude form evaporative air cooling. In Europe, Leonardo da Vinci designed a large evaporative cooler.

1.3 Air Conditioning System

A system consisting of components and equipment arranged in sequential order to satisfy the various space conditions required for comfort as well as industrial air conditioning is known as air conditioning system. In order to provide complete air conditioning, a year-round system must have following functions: heating, cooling, dehumidification, humidification, ventilation, filtration, and air circulation. The size and complexity of the air conditioning system may range from a single space heater or window unit for a small room to huge system for building complex, yet the basic principles are same.

1.4 Working Principle of Air Conditioning System

There are many methods to implement air conditioning, such as the vapour compression refrigeration process and the absorption refrigeration system. The most common method in practice is the vapour compression refrigeration process. Simple vapour compression refrigeration cycle consists of four main components, which are cooling coil or evaporator, compressor, condenser and an expansion valve as shown in figure 1.1.

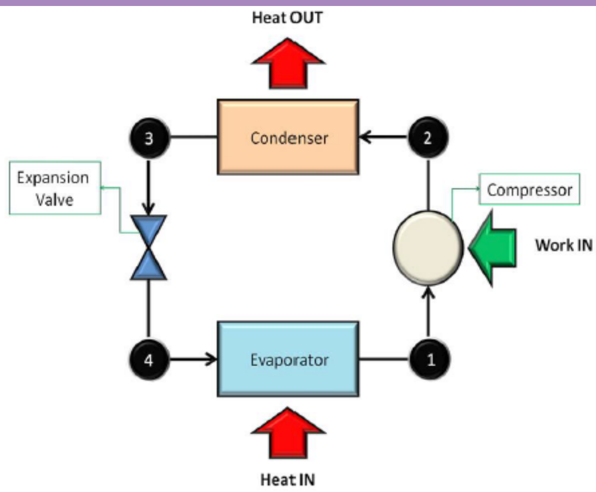

Figure 1.1 Schematic of a Vapour Compression Refrigeration Cycle

II. EVALUATION, COMPARISON, RANKING AND SELECTION OF OPTIMUM AIR CONDITIONING SYSTEM

2.1 Introduction

With the development of human society and economy, living standard of people is improving day by day, and higher living conditions are demanded. So, more attention is paid towards treating the indoor air to establish and maintain required standards of indoor air quality (IAQ) indexes such as temperature, humidity, air cleanliness, etc. Air conditioning system is used to improve IAQ. Apart from comfort air conditioning required for comfort of persons, air conditioning systems are also used to provide conditions that some processes require. These processes require certain air temperature and humidity for successful operation. Amongst the several methods employed for air conditioning, the most commonly used are air conditioning systems based on vapour compression and vapour absorption. There has been rapid increase in the number of air conditioning systems and air conditioner manufacturers. Air conditioning systems with vastly different capacities and specifications are available for a wide range of applications. The selection of air conditioning system to suit a particular application, from the large number of air conditioning systems available in the market today has become a difficult task. Also, in air conditioning system design, there are many forms and types of choice for air conditioning subsystems, therefore air conditioning designers often face problem during selection of optimum subsystems, which meet global market requirements with a variety of decision-making program. Therefore there is need of a mathematical tool in selection of an air conditioning system.

In global market, commercial air conditioning may be provided by a variety of equipment ranging from low horsepower self-contained systems to very large built-up central systems of several thousand ton capacity. User‘s ultimate objective is to acquire and utilize an air conditioning system that will provide the most appropriate performance on a whole of life basis, in terms of capital, replacement and maintenance costs. For instance residential apartments, shopping complex, office complex, hospital, hotel, airport or industry; all have different functional requirements, occupancy pattern and usage criteria. The geographical location of the building, ambient conditions, indoor requirements, building materials, dimensional parameters, aesthetic requirements, noise and environment issues need different treatment. Therefore, the optimum selection of an air conditioning system for a particular application is going to affect the overall performance of the system and at the same time the selection of air conditioning system is mainly dependent on its different attributes, e.g. efficiency, cost effectiveness and eco-friendliness, etc., which affect its performance characteristics. It shows that, for evaluating and comparing the various alternative air conditioning systems, the proper identification of the system attributes is very much important. Selecting the best air conditioning system for a particular building must be carefully considered and researched by the consultant or engineer in close co-ordination with the architect, electrical and plumbing consultants and owners before freezing the basic air conditioning system and building layout. It is difficult for an engineer to select an air conditioning system for a given space and requirements.

III. N – DIGIT CODING SCHEME

To ensure effective and efficient use of proposed attributes for identification, classification, comparison, evaluation and ranking of an air conditioning system and to make this procedure user friendly, an n – digit coding scheme is developed. Such a 173 digit coding structure gives a complete attributes profile of the air conditioning system. The first column represents the block number corresponds to the 173 attributes, the second column represents the name of the attribute, the third column represents information about the attribute in a particular application, and the fourth column represents the alphanumeric code based on the type of attribute. The classification of the attributes is done either quantitatively or qualitatively.

Useful life of system (in years)	Code
0 – 5	1
5 – 10	2
10 – 15	3
15 – 20	4
20 – 25	5
>25	6

Reliability	Code
Poor	1
Below average	2
Average	3
Above average	4
Good	5

IV. STRUCTURAL MODELING AND ANALYSIS OF AIR CONDITIONING SYSTEM

4.1 Need for Structural Modeling and Analysis of Air Conditioning System

In general, the air conditioning systems are mechanical systems providing artificial environment for either operational requirement, or health and comfort of the occupants. An air conditioning system consists of a number of components. These components are having different functionalities and are from different disciplinary backgrounds like mechanical, electrical, electronics, IT etc. or combination of these. In physical systems, interactions exist among these components. The components are connected in certain configurations that allow thermal energy to be transported and air to be conditioned and distributed. Over the last century, many types of air conditioning systems and system configuration have been developed. The topology of how the components are connected effects the performance of the configuration.

4.2 Introduction to Graph Theoretic Approach

To fill the research gap and to unveil the importance of a structure based air conditioning system design, a graph theory based air conditioning system model is proposed. The model can include all the subsystems along with the interactions therein and thus becomes a tool for total air conditioning system analysis. A graph is useful for visual analysis of an air conditioning system, but quantification of these interactions is necessary for design and

analysis. Matrix algebra is used for quantifying these interactions.

4.3 Identification of Structural Constituents of the Air Conditioning System and their Interactions

A normal air conditioning system consists of a large number of components. These components are having different functionalities and are from different disciplinary backgrounds like mechanical, electrical, electronics, etc. or combination of these. In physical systems interactions exist among these components. In normal room air conditioning system, indoor cooling is achieved using a refrigeration loop comprised of five main components. compressor, condenser, evaporator, expansion valve, and drier. The compressor receives low pressure refrigerant gas and delivers high pressure gas to the condenser (also a heat exchanger), where it condenses, and dissipating energy to the outside air. The high pressure liquid then flows to the evaporator through an expansion valve, which maintains the pressure difference in the loop. As the refrigerant expands, heat energy is absorbed through the evaporator, which is another heat exchanger over which warm indoor room air is passed. The drier is located in the high pressure section of the system, usually in the plumbing between condenser outlet and the expansion valve inlet. The function of the drier is to absorb moisturethat may have gotten inside the air conditioning system during manufacture, assembly, or service.

Table 4.1 Structural constituents of an air conditioning system

Component	Function
Compressor (S_1)	The compressor transfers energy, in form of increased pressure, to the refrigerant before it is passed to the condenser.
Heat Rejection system (S_2)	The condenser, with the help of condenser fan, dissipates refrigerant system heat energy, via forced convection, to the outside surroundings in order to cool/liquefy the refrigerant. The condenser fan draws outside air and provides airflow across the condenser.
Control System (S_3)	The control system provides temperature control, humidifying/dehumidifying controls, air flow controls, safety controls, etc.
Expansion valve (S_4)	The expansion valve accepts refrigerant from the condenser via drier and maintains the pressure difference in the loop by reducing the pressure levels within the system and it also controls the amount of refrigerant flow into the evaporator.
Heat Absorption System (S_5)	It contains the evaporator core which absorbs heat energy, via forced convection, from the room indoor air (to the refrigerant) to provide cooled air for the room interior and the blower which provides the circulation of indoor air to the evaporator core.

In the present work, four generic interaction types are considered as follows:

1) Spatial: A spatial-type interaction identifies needs for adjacency or orientation between two elements. Associations of physical space and alignment.

2) Energy: An energy-type interaction identifies needs for energy transfer between two elements.

3) Information: An information-type interaction identifies needs for information or signal exchange between two elements.

4) Material: A material-type interaction identifies needs for materials exchange between two elements.

Hierarchical tree structure of a system is useful in identifying components at each level and for thorough understanding of physical structure. These subsystems are connected with each other through different interaction types as discussed above.

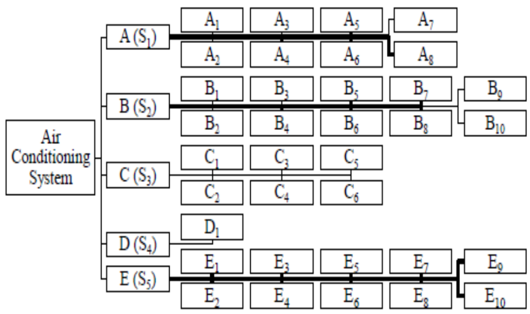

Figure 4.1 Hierarchical classification of the air conditioning system

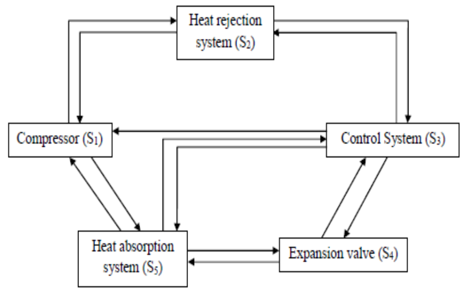

Figure 4.2 Schematic representation of the structure of air conditioning system

4.4 Graph Theoretic Modeling of an Air Conditioning System

Though the schematic diagram of air conditioning system as shown in Figure 4.2 is a good representation of different identified components and their interactions which provides the better understanding of the structure of air conditioning system, but it is not a mathematical entity. To overcome this problem, a graph theory based modeling of an air conditioning system is proposed. A graph theory based mathematical model is derived for representing the physical structure of air conditioning system along with interactions.

The air conditioning system graph is a useful mathematical entity and is highly useful for comprehensive understanding of total air conditioning system through for visual analysis. But for computational analysis, the necessary information cannot be sorted in a computer directly. For achieving this objective, the air conditioning system graph can be represented in the form of matrix.

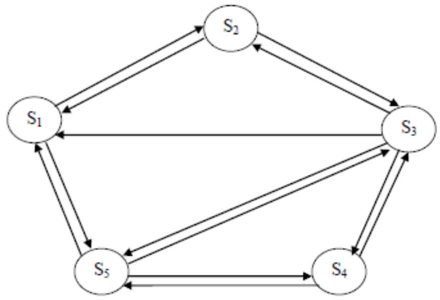

Figure 4.3 Air conditioning system digraphs

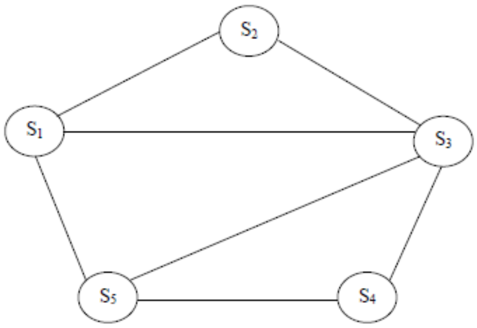

Figure 4.4 Undirected graph representation of the structure of air conditioning system

4.5 Matrix Representation for the Air Conditioning System Graph

To quantify sub systems and interactions in air conditioning system graph an equal mathematical representation known as Matrix is used. The matrix representation permits to carry out storage, retrieval and analysis of air conditioning systems. In general the graph is represented by a matrix called adjacency matrix. Since adjacency matrix represents the physical structure of an air conditioning system, it is termed as System Structure Matrix.

$$\begin{array}{c} \quad 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad \text{subsystems} \end{array}$$

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 \end{bmatrix} \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{matrix}$$

4.6 Air Conditioning System Analysis

1. Consider the desired air conditioning system. Study the complete air conditioning system and its subsystems (compressor, heat rejection system, heat absorption system, etc.), and also their interactions.

2. Logically develop a system graph of the air conditioning system with subsystems as vertices and edges for interaction between the vertices.

3. Using the graph in step 2, develop matrix similar to air conditioning system variable permanent matrix given in Equation (6). This matrix consists of Si's as diagonal elements and Sij as edges or interactions.
4. Obtain air conditioning system permanent function i.e. multinomial similar to Equation (4), which considers all the subsystems simultaneously.

5. The numerical index of an air conditioning system would be obtained by substituting the numerical values of subsystems and their interactions. The numerical values depend on the type of structural analysis.

6. Various air conditioning systems can be compared on the basis of permanent numerical index thus obtained. Necessary improvement strategies may be implemented ahead for enhancing the dimension chosen for analysis of air conditioning system. The dimension may be efficiency, reliability, quality, etc.

7. From the different alternatives of air conditioning systems, the alternative with highest value of numerical index is the best choice for the given application satisfying all the product lifecycle issues.

4.7 Structural Modeling and Analysis

By using Graph Theoretic Approach and by following the same procedure as discussed presented earlier, the modeling and analysis of existing air conditioning is presented. The central air conditioning system taken of study consists of a large number of components ranging from small thermostatic expansion valve to large cooling tower. In order to better understand the system along with its components and their interactions, schematic diagram of this library air conditioning system has been developed as shown in the Figure 4.8, which is useful for understanding the basic structure and functionality of an air conditioning system. All the interactions existing among the components are equally important in design and analysis of an air conditioning system. Schematic gives us a good visualization of interactions between the various components. The different colored lines show the flow of different materials within the system in different loops. The flow of material is essential for the functionality of the air conditioning system.

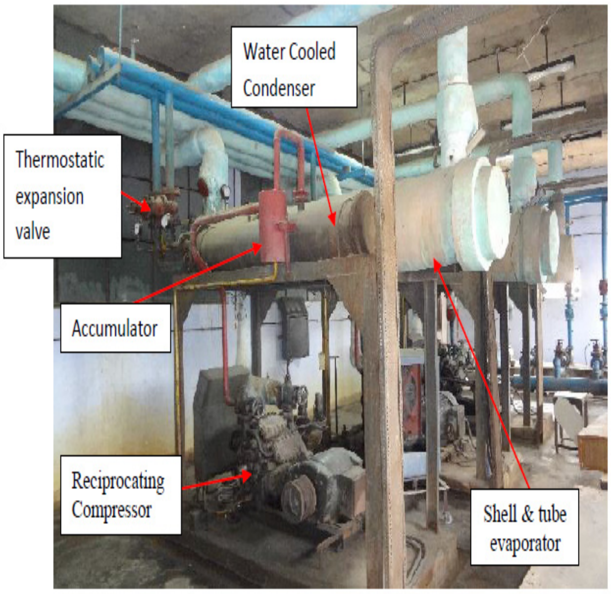

Figure 4.7 Chilled Water Central Air Conditioning System

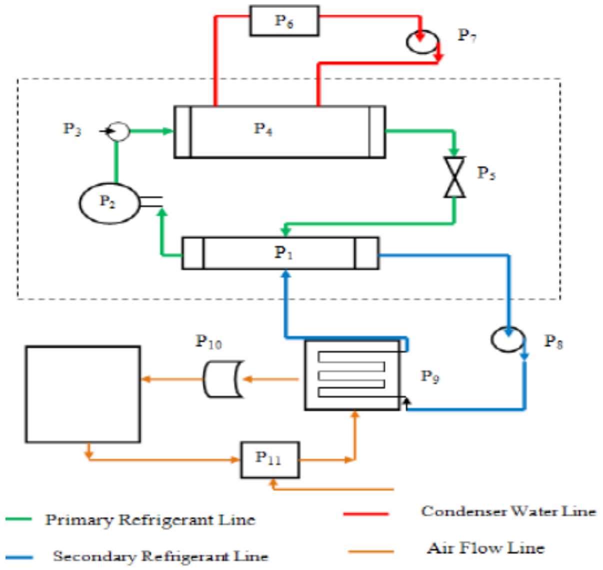

Figure 4.8 Schematic of Library air conditioning system

Here, P1=Evaporator, P2 = Reciprocating Compressor, P3= Accumulator, P4= Shell and tube type Condenser, P5= Thermostatic Expansion Valve, P6= Cooling Tower, P7= Condenser water pump, P8= Evaporator Circulator Pump, P9= Cooling Coil, P10= Supply Fan, P11= Mixing box.

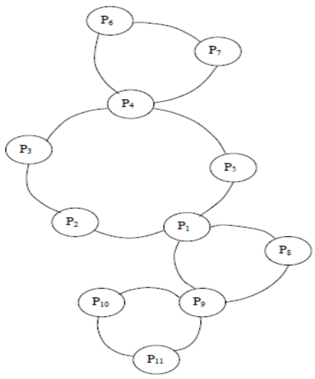

Figure 4.9 Undirected graph representation of the structure of Library air conditioning system

Now, the system structure matrix X is constructed for this library air conditioning system. This matrix represents connectivity/interaction between different sub systems of air conditioning system. If the connectivity/interaction exists between two sub systems, it is represented by a binary number □1‘ and by □0‘ if there is no connectivity/interaction between two sub systems.

1 2 3 4 5 6 7 8 9 10 11 subsystems

$$X = \begin{bmatrix} 0&1&0&0&1&0&0&1&1&0&0 \\ 1&0&1&0&0&0&0&0&0&0&0 \\ 0&1&0&1&0&0&0&0&0&0&0 \\ 0&0&1&0&1&1&1&0&0&0&0 \\ 1&0&0&1&0&0&0&0&0&0&0 \\ 0&0&0&1&0&0&1&0&0&0&0 \\ 0&0&0&1&0&1&0&0&0&0&0 \\ 1&0&0&0&0&0&0&0&1&0&0 \\ 1&0&0&0&0&0&0&1&0&1&1 \\ 0&0&0&0&0&0&0&0&1&0&1 \\ 0&0&0&0&0&0&0&0&1&1&0 \end{bmatrix}_{11\times 11}$$

CONCLUSION

The foremost outcome of this work is that approaching the system, as a whole is absolutely indispensable in order to acquire a better picture of the operation of every system component and the interaction. The thesis is focused on modeling, evaluation, optimum selection and analysis of air conditioning system using system approach. Two different methodologies are presented to achieve the objectives of this work. Multi-Attribute Decision Making (MADM) approach is presented in Chapter 3 in order to achieve the objective of evaluation and optimum selection of air conditioning system from different alternatives. It identifies the various attributes needing to be considered for the optimum evaluation and selection of air conditioning systems. It also provides an n-digit coding scheme for air conditioning systems depicting the various attributes. It recognizes the need for, and processes the information about, relative importance of attributes for a given application without which inter-attribute comparison is not possible. It presents the result of the information processing in terms of a suitability index, which is used to rank the air conditioning in the order of their suitability for the given application.

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