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OPTIMIZATION OF HEATING, VENTILATION AND AIR CONDITIONING (HVAC) SYSTEM CONFIGURATION

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ABSTRACT

Today, a substantial amount of world‘s energy is being consumed by the building sector. In buildings, energy share of Heating, Ventilation and Air-Conditioning (HVAC) systems is dominant. Various aspects of HVAC system optimization are analyzed in several studies; however the optimization of HVAC system configurations is rarely analyzed. Moreover, no systematic approach is developed for evaluating different HVAC system design alternatives to decide the optimal configuration for a specific building load demand and climate conditions. The research paper is aimed to develop a methodical simulation-based optimization approach for the effective and efficient evaluation of various HVAC system alternatives at the initial system design stage to result in an optimal configuration. The approach is implemented at both system design level as well as at the configuration level. It is concluded from literature review that the equation-based object-oriented (EOO) modeling and simulation approach provides a conducive environment for evaluating HVAC system configurations. In the developed approach, two methods are proposed with respect to HVAC system modeling and simulation characteristics. The first method conditional declaration of component models‘ is used for automated selection of optimal system configurations. It uses the coupling between modeling tool Dymola / Modelica and the optimization tool GenOpt through an appropriate algorithm. The second method re-declaration/replaceable component models‘ is also proposed for HVAC system modeling in which several types of a specific component class can be varied to define various system configurations It includes empty component models of all system component with connecting ports and without heat and mass transfer. The presented systematic simulation-based optimization approach significantly helps to handle the complex task of optimal selection of HVAC system configurations. Such development would be supportive for the HVAC design practitioners to evaluate various system alternatives and select the optimal system configuration and design parameters at the initial design stage under various building load demands and climate conditions. Moreover, the methodology signifies a step forward toward the design of software systems able to synthesize new and optimal system configurations.

Key words: HVAC, ENERGYbase, GenOpt, Component Models

1 INTRODUCTION

Heating, Ventilation, and Air-Conditioning (HVAC) systems control the indoor environment throughout the year to ensure comfortable conditions in homes, offices, and commercial facilities. Beside the fact that HVAC systems are making human life healthier and more productive but various products could also be produced faster, better, and more economically in an appropriately controlled environment. Almost each residential, institutional, commercial, and industrial building has a year-round controlled environment in the developed countries of the world.

2 Problem Statement

The HVAC system configuration is a conceptual design of HVAC system including the active components, airflow set-up, and the control strategies with set points. Selection of HVAC system configuration is typically decided in the early stage of the design process.

However the system configuration design has substantial impacts on the performance of the final system. The maximum opportunities for energy efficiency exist at the design stage for HVAC systems in a new building facility. It is generally cheaper to install energy efficient HVAC equipment during the building construction compared to the up gradation of an existing building with an efficient system.

HVAC system design is a process of decision making. Normally, it consists of four sequential stages depending on the level of detail. In conceptual design, general HVAC system selection is involved. In preliminary stage, schematic design with preliminary component sizing is completed. Detailed design includes load calculation, ductwork and pipe work layout, detailed component sizing, and control system design. Fully detailed layout drawings are finalized with co-ordination of architectural and allied services layouts during engineering design stage. Impact of decisions diminishes with the progress of each design stage and on contrary, the cost of modification increase sharply for the latter design stage along with the level of knowledge as shown in Figure. Thus, it is more difficult to make decisions in the beginning. Therefore, it is very critical to make appropriate decisions in the early stages for the overall success of a HVAC system. Good decisions in the design and operation of buildings can substantially improve their energy performance. HVAC system configuration selection during earlier stages of design would cost less and have a more impact on final system performance.

Figure 1(a) Impact of cost and decisioins for HVAC system design

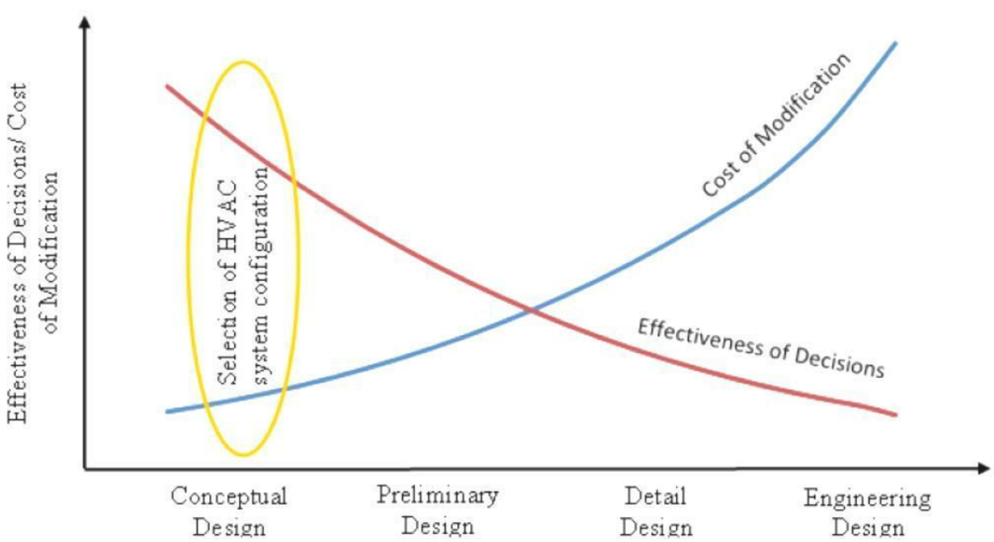

Figure 1: Impact of cost and decisioins for HVAC system design

3 Energy Demand of HVAC systems

The buildings energy demands are the main source of substantial increase of the electricity consumption due to rising space heating, cooling, ventilation, and refrigeration requirements. Energy consumption in buildings is directly related with energy demands of HVAC systems. HVAC is the largest energy end use both in the residential and non-residential sector. Studies indicate that air-conditioning is responsible for 10% to 60% of the total building energy consumption, depending on the building type . In developed countries, HVAC systems are the most energy consuming devices, accounting for about 10–20% of final energy use. In the buildings account for 50% of the site energy consumption for combined space heating and cooling as shown in Figure. The share of HVAC in the residential sector is 61% of site energy consumption and 41% of primary energy consumption as shown in Figure.

The geographical distribution of new housing has contributed to greater electricity consumption in the residential sector from 53% of total primary energy in 1980 to 69% in 2009 as more homes come with electricity-intensive heating and cooling equipment installed. The percentage of new single-family homes with air conditioning has increased from 62% in 1980 to 79% in 1995 and 88% in 2010. Recently, heat pump heating systems have also gained market share, from 23% in 2001 to 38% in 2010. Similarly, in non-residential sector, space heating, lighting, and space cooling are the top three end uses representing around half of site energy consumption as shown in Figure

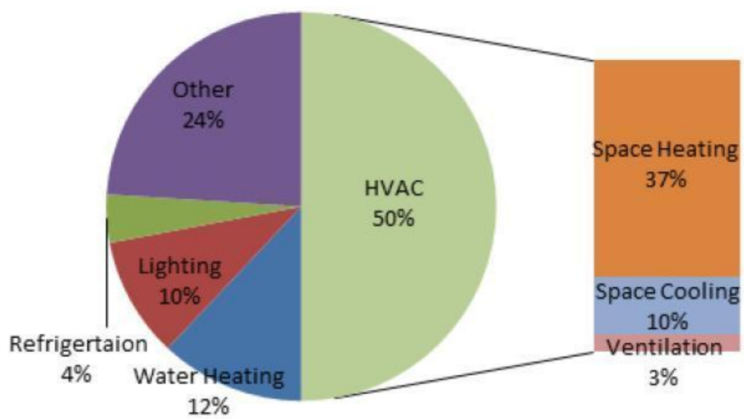

Fig.2 Site Energy Consumption

4 HVAC equipment demand

World demand for HVAC equipment is projected to rise 6.2% per year, reaching a total of $93.2 billion in 2014. Cooling equipment will continue to overtake heating equipment worldwide with increasingly hot climatic conditions. It is also predicted that demand in the Asia-Pacific region will outpace the average global demand, rising 7.1% yearly through 2014. China will be the fastest growing national market, comprising 40% of global demand. China has become a leading producer in the room air conditioner segment, exporting products to the United States, Western Europe, and throughout Asia. In addition, the USA and Japan are also considered major producers, each with annual shipments of more than $5.5 billion during 2007. Demand for HVAC equipment is expected to rise 8.1% annually through 2014. The HVAC equipment annual growth demand is projected at 3.0% and 4.9% from 2009 to 2014 in Western Europe and other regions, respectively . In Europe, Germany and Italy were leading with more than $2 billion shipments in 2007. In EU annual sale of HVAC equipment was more than $2.4 Billion during 2009.

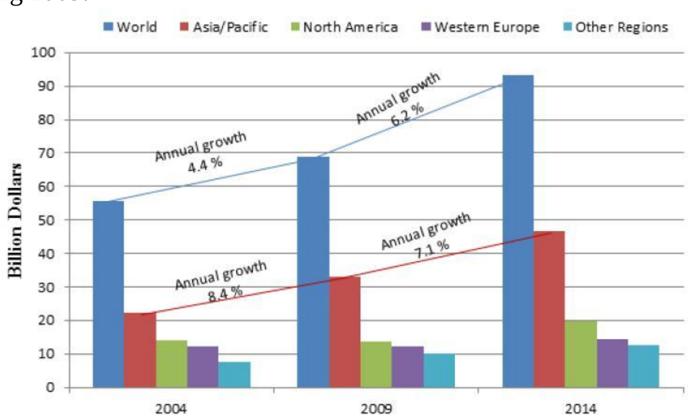

Figure 3: HVAC equipment demand and annual growth

5 HVAC system modeling and simulation

Modeling of HVAC systems is rapidly gaining more interest for system performance evaluation. Especially, at the conceptual design stage, that often requires evaluating various system alternatives to decide the best system configuration. Modeling and simulation tools for HVAC system design and analysis could be categorized with respect to the problems they are meant to deal with. For example, tools for pipe/duct design, equipment sizing and selection, energy performance analysis, system optimization, and control analysis and optimization. Each tool has its own limitations and could only be applied for a certain range of applications. Therefore, available tools are not fully suited for modeling and simulation of all relevant aspects and possible design analyses. In general, HVAC modeling approaches can be categorized into three classes as, modeling approaches for HVAC components, modeling approaches for HVAC control and modeling approaches for HVAC systems. Different HVAC system modeling approaches required different levels of user skills, modeling resolutions, and user customization capabilities. To solve different models, simulation tools have also been seen as promising solutions for establishing the baseline performance prediction which can be used during initial design stages of HVAC systems. Solution techniques for HVAC system simulation model can also be classified as, simultaneous modular solution, independent modular solution, and equation-based solution using manipulation. However, HVAC modeling and simulation is relatively complex from a user and developer point of view. For a user, the complications grow with the level of explicitness due to increasing requirement of user knowledge of HVAC system and the number of system definition parameters. But the availability of data pertaining to those parameters from manufacturer is decreasing and analyses have become more complicated. Similarly, the difficulties increase with the explicitness and detail for a developer. This is due to the interactions among the components of the HVAC system or HVAC system with the building.

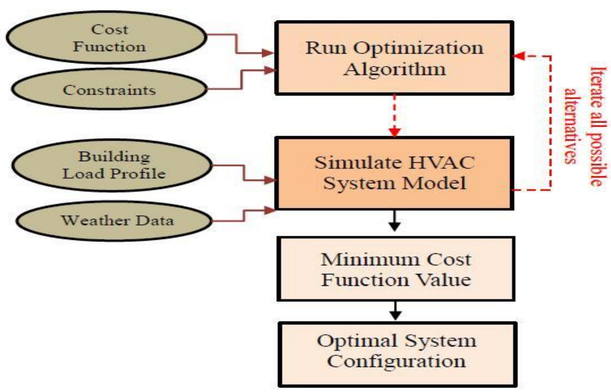

Fig. 4. Flow chart of the implemented approach

6 HVAC design optimization

Optimization techniques have been extensively studied and practiced on HVAC design problems. The automatic simulation-based optimization, especially at HVAC system configuration level is a new concept. HVAC design optimization problems can be classified into two types. The first type is optimization of static design parameters and the second type is optimization of the dynamic input variables, which usually comprise control scheduling and set points. The static variables are generally system design parameters that are fixed in each simulation. Design of building envelopes, HVAC system and components, ductwork and hydraulic systems, lighting is included in such type of problems. HVAC model-based optimization approach is extensively studied during the last decade. An optimization of thermal performance of a building with ground source heat pump system was performed through TRNSYS to reduce building heating and cooling energy costs . The developed models of cooling coil unit and cooling tower were also used for real time control and optimization of HVAC systems. Similarly, global optimization of overall HVAC systems was performed using developed component models . Another optimization study was performed for optimal water-cooled chiller and cooling tower combination. Cooling tower approach and design wet bulb was determined as key parameters along with condenser water flow rate for optimal performance and to improve system life cycle costs.

7 Conclusions

The chapter reviewed the several configurations of conventional and innovative HVAC systems. In general, HVAC system equipment and components are categorized into primary and secondary system equipment. The primary equipment and components are the major source of energy consumption. They include chillers, boilers, furnaces, cooling towers, etc. The secondary HVAC equipment and components consist of airhandling units, liquid distribution systems, and air distribution systems. The components include humidifiers, cooling and heating coils, fans, etc. Numerous types of primary and secondary equipment and components exist with wide range of capacities. The HVAC system designer not only has to decide the suitable type of the component for a certain outcome but also the number as well the arrangement of the components to find the best system configuration. Decision of an appropriate overall HVAC system configuration involves both the primary and secondary systems configuration. Chillers of the primary systems and air-handling units of the secondary systems are the key elements to define the overall system configuration. In view of rising energy demands in HVAC sector, various alternative and innovative systems gained increased consideration due to their low energy requirements and environmental implications. Such systems include desiccant and solar air conditioning systems. Various configurations of such systems are established to achieve the desired comfort requirements in the different climate conditions. Therefore it can be concluded from the numerous existing HVAC system configurations that the selection of a suitable system configurations is really complicated at the initial design stage. The evaluation of all available options requires considerable amount of time and efforts. Therefore, it is important to propose an effective and efficient approach in terms of automated system selection. In the following chapter, a research methodology is described that could help the HVAC system designers for the automatic selection of optimal HVAC system configuration.

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