Review Paper on Energy Efficiency Technologies for Heating , Ventilation and Air Conditioning (HVAC)

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REVIEW PAPER ON ENERGY EFFICIENCY TECHNOLOGIES FOR HEATING, VENTILATION AND AIR CONDITIONING (HVAC)

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Abstract

Decreasing the energy consumption of heating, ventilation and air conditioning (HVAC) systems is becoming increasingly important due to rising cost of fossil fuels and environmental concerns. Therefore, finding novel ways to reduce energy consumption in buildings without compromising comfort and indoor air quality is an ongoing research challenge. One proven way of achieving energy efficiency in HVAC systems is to design systems that use novel configurations of existing system components. Each HVAC discipline has specific design requirements and each presents opportunities for energy savings. Energy efficient HVAC systems can be created by re-configuring traditional systems to make more strategic use of existing system parts. Recent research has demonstrated that a combination of existing air conditioning technologies can offer effective solutions for energy conservation and thermal comfort. This paper investigates and reviews the different technologies and approaches, and demonstrates their ability to improve the performance of HVAC systems in order to reduce energy consumption. For each strategy, a brief description is first presented and then by reviewing the previous studies, the influence of that method on the HVAC energy saving is investigated. Finally, a comparison study between these approaches is carried out.

Introduction

Increased standards of living coupled with dwindling supplies of fossil fuels, have forced researchers and engineers to focus on the issue of energy use in buildings. Heating, ventilation and air conditioning (HVAC) systems, which play an important role in ensuring occupant comfort, are among the largest energy consumers in buildings. Performance enhancements to traditional HVAC systems therefore offer an exciting opportunity for significant reductions in energy consumption. Almost 50% of the energy demand is used to support indoor thermal comfort conditions in commercial buildings [1]. Furthermore, as most people spend more than 90% of their time inside [2], the development of energy-efficient HVAC systems that do not rely on fossil fuels will play a key role in reducing energy consumption. A closer look at worldwide energy consumption by HVAC equipment shows noticeable values.

The growing reliance on HVAC systems in residential, commercial and industrial environments has resulted in a huge increase in energy usage, particularly in the summer months. Developing energy efficient HVAC systems is essential, both to protect consumers from surging power costs and to protect the environment from the adverse impacts of greenhouse gas emissions caused by the use of energy inefficient electrical appliances. With rapid changes in science and technology today, there are several methods that can be used to achieve energy-efficient HVAC systems. In order to develop efficient systems, however, a clear understanding of building comfort conditions is necessary. Thermal comfort is all about human satisfaction with their thermal environment. The design and calculation of air conditioning systems to control the thermal environment in a way that also achieves an acceptable standard of air quality inside a building should comply with the ASHRAE standard 55-2004 [13].

According to this standard, thermal comfort conditions are acceptable when 80% of the building's occupants are satisfied. In order to predict appropriate thermal comfort conditions an index called a predicted mean vote (PMV), which indicates mean the thermal sensation vote on a standard scale for a large group of people, is used. PMV is defined by six thermal variables for an indoor environment, subject to human comfort: air temperature, air humidity, air velocity, mean radiant temperature, clothing insulation and human activity.

Different techniques need to be implemented on HVAC systems to improve their energy efficiency and reduce their environmental impact. In recent years, different control and optimization strategies have been used to improve the energy consumption rates of these systems [15] . However, these approaches are either expensive or very complicated to implement, and require constant monitoring [16]. One option to achieve this objective is to combine different HVAC components to create an energy-efficient configuration. Because building cooling load varies with the time of the day, an HVAC system should be designed in tandem with an optimum design scheme that will keep the process variables to their required set-point in order to maintain comfort under any load conditions. While optimizing the mechanical design of the traditional HVAC system results in extra upfront costs, these modifications can actually provide substantial savings in the long term by reducing ongoing maintenance costs associated with control and optimization strategies.

Fig. 1 shows strategies used to achieve greater HVAC energy efficiency discussed in this study. Various technologies in which different configurations, component combinations and mechanical designs are used to improve the energy performance of HVAC systems are also discussed in this paper. For each strategy, a brief description is first presented and then by reviewing the previous studies, the influence of that method on HVAC energy saving is investigated. Finally, a comparison study between these approaches is carried out.

1. Evaporative cooling systems

Evaporative cooling technology has been widely used since more than a century [17]. Direct evaporative cooling (DEC) systems have low set-up and running costs, and have been proven to significantly improve a building’s cooling and ventilation capacity with minimal energy use. Using water as the working fluid, one can avoid the use of ozone-destroying chlorofluorocarbons and hy-dro chlorofluorocarbons. Other benefits from this system include easy maintenance, easy installation and operation as well as obviating CO2 and other emissions. Evaporative cooling systems can provide thermal comfort via the conversion of sensible heat to la-tent heat; however, the lowest temperature DEC systems can reach is the wet-bulb temperature of the outside air. Therefore, the temperature of the supply air after cooling would be just on the edge of comfort and could rise a few degrees in passing through space, taking the temperature beyond the comfort zone. Therefore, the idea is to investigate both the possibility of increasing the utilization potential of the evaporative cooling system by combination of different components with this system and the capability of improving the performance of other HVAC systems when integrating with evaporative cooling system.

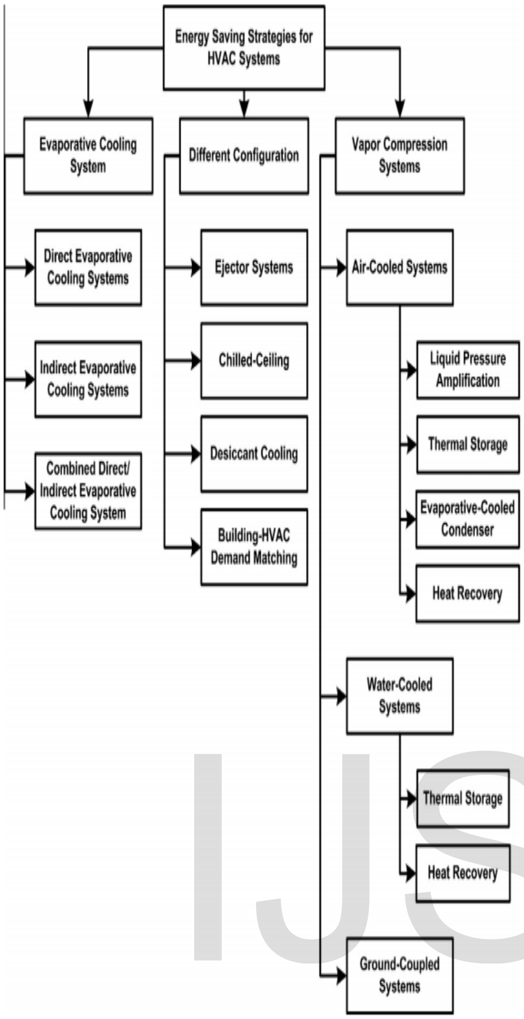

Fig. 1. HVAC energy saving strategies discussed in this study.

2. Evaporative-cooled air conditioning system

Recent research reveals that air conditioning systems based on mechanical vapor compression consume significant amounts of electricity. Therefore, increasing the coefficient of performance (COP) of these air conditioning systems with air-cooled condensers is a challenging problem. By pre-cooling the air before it reaches the condenser coil, the condenser is able to reject more heat. As a result, cooling capacity increases while energy demand and usage falls. As condensing temperatures are lowered, head pressure is reduced. This allows the compressor to run less frequently, resulting in an energy saving. The standard design for these systems requires a frame to be built and filled by evaporative media pads which are installed in front of the air-cooled condenser. A water circulation system, consisting of a small pump, a tank and pipes, is added. The water then is injected on the top of the media pad. Hot ambient air passes the wet pad and then the condenser to improve the system performance. As the hot, ambient air is drawn through the media, the water absorbs heat and evaporates, lowering the temperature of the ambient air and creating a cooler operating environment for the air-cooled condenser which allows the condenser to reject additional heat into the atmosphere. The compression ratio is then reduced, resulting in reduced energy usage when the compressor is run. In a similar design, mist ware is sprayed directly into the ambient air before passing through the air-cooled condenser.

Hajidavallo and Eghtedari [25] built an evaporative cooler and coupled to the existing air-cooled condenser of a split air-conditioner in order to measure its effect on the cycle performance under various ambient air temperatures up to 49°C as shown in Fig. 2. Their experimental results showed that the power consumption of the air-conditioner can be reduced up to 20% and the system COP can be improved around 50%. Youbi-Idrissi et al.[26] developed a numerical model for a sprayed air-cooled condenser coupled to the refrigeration system to study the effect of sprayed water flow rate on the energy performance of the system. They found that compared to a dry air-cooled condenser, both the calorific capacity and system COP increase by 13% and 55% respectively.

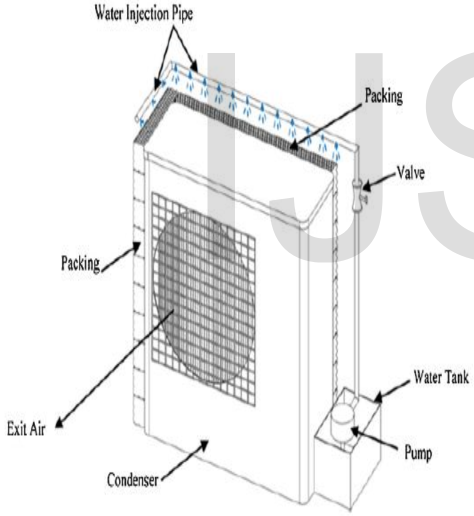

Fig.2 schematic view of evaporative-cooled air conditioning system (Ref[25])

3. Ground-coupled HVAC systems

Ground-coupled technology relies on the fact that, at depth, the Earth has a relatively constant temperature that is colder than the air temperature in summer and warmer than the air temperature in winter. In this system, under cooling mode, operation heat is discharged to a ground loop that provides a lower temperature heat sink than ambient outdoor air temperature. During winter heating operations, heat is extracted from a source that is at a higher temperature than ambient outdoor air. This system has been used on a residential and commercial scale since the 1920s [31]

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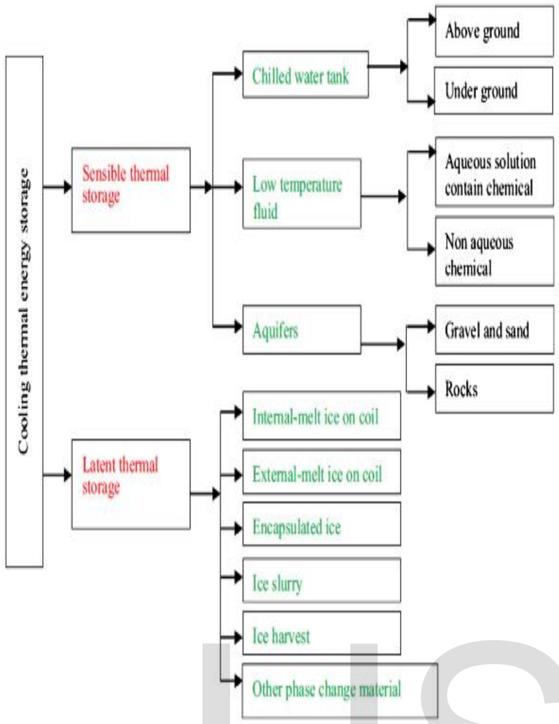
4. Thermal storage systems

Thermal storage systems (TSS) shift the energy usage of the HVAC systems from on-peak to off-peak periods to avoid peak demand charges. TSS are also able to rate variance between energy supply and energy demand to conserve energy [52]. In this system, Energy for cooling is stored at low temperatures normally below 20° C for cooling, while energy for heating is stored at temperatures usually above 20°C [53]. Compared to conventional HVAC systems, TSS offers various advantages for heating and cooling systems, such as energy and capital cost savings, system operation improvements, system capacity extending and equipment size reduction, resulting in a technology that is widely used. Yau and Rismanchi reported that in early 1990s, about 1500–2000 units of TSS were employed in the US for office, school and hospital buildings [54]. Cooling thermal storage can be classified according to the thermal medium as presented by Al-Abidi et al. [55] and shown in Fig. 3



. Fig.3classification of cooling thermal energy storage (Ref [55])

Ice and chilled-water storage systems are two most commons TSS. In these systems, ice or chilled water is stored in tanks to cool buildings during peak electricity usage periods. In an ice storage system, ice is usually generated using glycol or brine solutions. There are various types of ice storage systems. An ice harvester system uses an open insulated storage tank and a vertical plate surface which is located above the tank. During the charging period, water flows on the outside surface of the evaporator and forms ice sheets. Ice slurry is another type of the ice storage system in which a glycol–water solution passes through pipes submerged in an evaporating refrigerant to form the ice. The generated ice particles are then dropped into the storage tank

5. Heat recovery systems

ASHRAE standards recommend the amount of required fresh air for different buildings. Unconditioned air greatly increases the building's cooling needs, which ultimately leads to an increase in the overall energy consumption of the building's HVAC systems. In the central cooling plant, the amount of fresh air is determined based on the upper limits of the concentrations of indoor air pollutants which normally is between 10% and 30% of the total air flow rate [69]. In modern buildings the ventilation losses can become more than 50% of total thermal losses [70]. However, mechanical ventilation can consume up to 50% of electrical power used in residential buildings [71]. In addition, in hot and humid regions mechanical ventilation systems appropriate about 20–40% of the total energy usage of the air conditioning systems[72]. Nasif et al. [75] studied the annual energy consumption of an air conditioner coupled with an enthalpy/membrane heat exchanger and compared it with a conventional air conditioning. They found that in humid climate, the annual energy saving of up to 8% is possible when using the membrane heat exchanger instead of a conventional HVAC system. An experimental analysis was carried out by Fernandez-Seara et al. [76] on an air-to-air heat recovery unit equipped with a sensible polymer plate heat exchanger for ventilation systems in residential buildings. The layout of their system with its heat recovery unit is shown in Fig. 4.

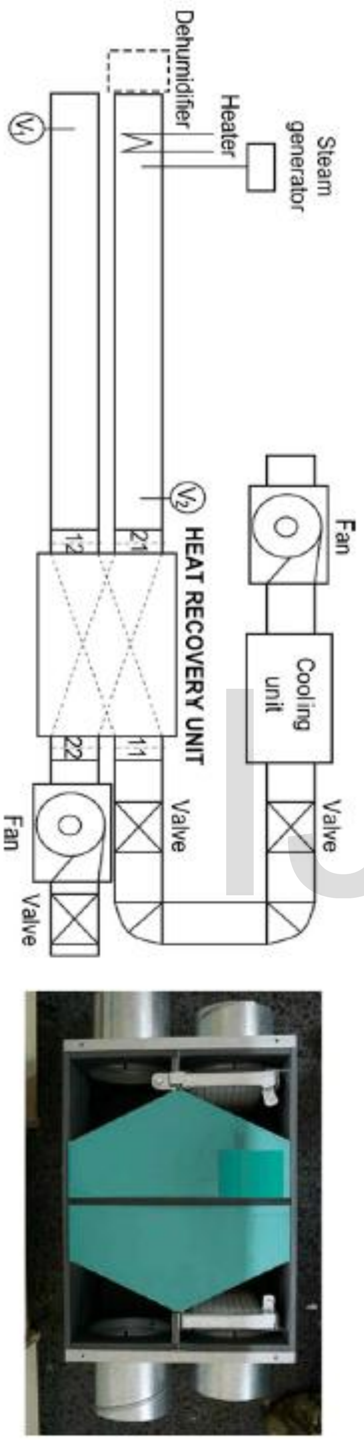


Fig4. Left: Layout of the experimental facility of the heat recovery unit, Right: Heat recovery unit (Ref. [76]).

6. Effect of building behavior

The energy consumption of an HVAC system depends not only on its performance and operational parameters, but also on the characteristics of the heating and cooling demand and the thermo dynamic behavior of the building. The actual load of the HVAC systems is less than it is designed in most operating periods due to building behaviour. Therefore, the most important factors that contribute to HVAC energy usage reduction in a given building is proper control of the heating and cooling demand. Integrated control of building cooling load components, such as solar radiation, lighting and fresh air, can result in significant energy savings in a building's cooling plant. It is estimated that around 70% of energy savings is possible through the use of better design technologies to coordinate the building demand with its HVAC system capacity. Korolija et al. investigated the relationship between building heating and cooling load and subsequent energy usage with different HVAC systems. Their results indicated that the building energy performance cannot be evaluated only based on building heating and cooling demand due to its dependency on HVAC thermal characteristics. Huang etal. developed and evaluated five energy management control functions programmed according to the building behavior and implemented for a variabl air volume HVAC system. Their simulation results demonstrated that energy saving of 17% can be achieved when the system is operated with these control functions.

Discussion

Energy-efficient HVAC system designs depend on new configurations of traditional systems that make better use of existing parts. One effective way of achieving energy efficiency has been

the design of HVAC system configurations that combine a range of different traditional HVAC system components. Recent research has demonstrated that a combination of existing air conditioning technologies can offer effective solutions for energy conservation and thermal comfort. Each HVAC discipline has specific design requirements and each presents opportunities for energy savings. It must be understood, however, that different configurations

in one area may augment or diminish savings in another.

Conclusion

Conventional HVAC systems rely heavily on energy generated from fossil fuels, which are being rapidly depleted. This together with a growing demand for cost-effective infrastructure and appliances has necessitated new installations and major retrofits in occupied buildings to achieve energy efficiency and environmental sustainability. Therefore, finding novel ways towards green buildings without compromising comfort and indoor air quality remains a challenge for research and development. The overall attainable reduction in energy consumption and enhancement of human comfort in the buildings are dependent on the performance of HVAC systems. One proven way of achieving energy efficiency in HVAC systems is to design systems that use novel configurations of existing system components. Recent research has demonstrated that a combination of existing air conditioning technologies can offer effective solutions for energy conservation and thermal comfort. In this paper various energy saving strategies for HVAC systems were investigated and their potential to improve the system performance were discussed. It was found that several factors such as climatic conditions, expected thermal comfort, initial and capital cost, the availability of energy sources and the application.

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