Techno-Commercial and Compatibility Analysis of Energy Efficient Technologies in HVAC for Indian Scenario

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Abstract

Global warming has led to severe climatic changes worldwide, including rise in sea level, depletion of ozone layer and many others. As a consequence of the same, the scientific community is focusing its efforts towards harnessing renewable energy resources and development of environment friendly energy efficient systems. However, the initial cost and specific operating conditions for adapting these innovative technologies are of major concern towards their practical implementation. Based on the climatic conditions in India, heating, ventilation and air conditioning (HVAC) is a major contributing factor in total power consumption of residential, commercial and industrial sectors. Anticipating the rise in per capita consumption in the decade to come, the conventional energy sources would not only be insufficient to make ends meet, but also affect climatic conditions. The present work describes a few innovative technologies in the HVAC industry which includes improvement in products with conventional energy sources as well as combination of traditional and renewable energy systems. The working principle, methodology of product design and return on investment (ROI) analysis are discussed. Summarizing the same, an optimum technology is recommended for specific applications under given conditions.

Keywords
Global warming, energy efficient systems, heating, ventilation and air conditioning (HVAC), return on investment (ROI) analysis, India.

1. Introduction

Energy is undoubtedly an important asset for a developing country like India, which is the third largest energy consumer in the world after China and the United State of America [1]. In spite of the same, with a population of 1.27 billion [2], India has one of the lowest per capita energy consumption in the world, which is one-third of the world's average per capita energy consumption [1]. The present energy scenario in India is characterised by frequent power cuts, especially in rural areas, and large disparity between the urban and rural consumption. In spite of having almost self-sufficient capacity of power generation currently, the main reasons for this situation are inadequate infrastructure

for transmission, disruptions in domestic fuel transport, transmission and distribution losses, theft of power and technical problems in moving electricity between various states. The per capita consumption in India has almost doubled in the current millennium [3]. With the rapid growth of industrialisation in India, energy consumption is bound to increase further expeditiously. The rise in India's GDP forecasts considerable increase in the purchasing power of the people in India. This will ultimately lead to even higher energy demands, and meeting the supply and demand would be a truly challenging task.

India was the first country in the world to set up a ministry of non-conventional energy resources, in the early 1980s. Despite the same, renewable energy accounted for only 18.2% of the total installed power capacity in India in 2017 [4]. For a developing country like India, with ever increasing demand, every attempt is encouraged to harness renewable energy resources towards partial reduction of dependence on conventional energy. Industrial sector consumes highest percentage of the total electricity produced in any country, a substantial amount of which is consumed by HVAC equipment. Commercial and urban residential areas in India consume about 55 % of its total electricity consumption for HVAC appliances [5]. By developing and employing energy conserving products for HVAC applications, preferably by partial replacement through renewable energy sources, the energy consumption can be substantially reduced, and the government of India can divert its attention on electrification of rural areas, power required for agriculture in the villages and to cater to the future energy needs.

The present work reports three such innovative technologies in the domain of HVAC that would yield substantial amount of savings in the electrical energy consumption. The prime emphasis while selecting these techniques is given towards the atmospheric conditions in a country like India which offers diversified ambient environment. Such energy efficient systems are of high significance due to the potential of large amount of energy saving in the considerable share of the total power consumption of the country.

2. Innovative HVAC Technologies

2.1 Vortex Generator

2.1.1 Principle of Operation

The technology reported in the present work is preliminarily based on subcooling through vortex generation. The preliminary concept is to create a low pressure area on the back side of a vessel incorporated between the condenser and the evaporator, thereby subcooling the refrigerant to enhance the performance of the system [6]. It further accommodates a refrigerant valve into the refrigerant circuit downstream of the expansion valve and before the evaporator to develop a vortex that continues through the refrigerant circuit to enhance the heat transfer.

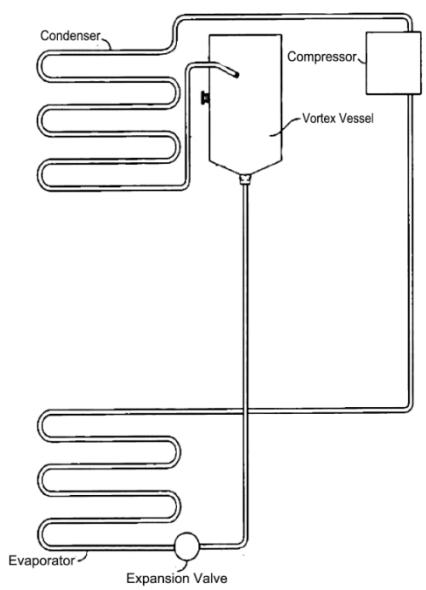

Figure 1. Schematic of the Vortex Generator Equipment [6]

2.1.2 Product Design

As shown in Figure 1, the liquid refrigerant enters the vessel which is positioned in the heat exchange system between the condenser and the evaporator. The liquid refrigerant from the condenser is made to enter in the vessel and flow through the exit at the bottom of the vessel in a swirling manner. The blades of the turbulator at the bottom of the vessel further add in the turbulence. The refrigerant bypass path apparatus is used to subcool the portion of the refrigerant inside the vessel. As depicted in Figure 2, it comprises of a disc positioned in the refrigerant entrance line having an aperture connected to the bypass tube extending till the center of the vessel. The aperture helps to develop a low pressure area on the back side of the refrigerant line resulting in reintroduction of the bypass refrigerant to the rest of the liquid at the bottom of the vessel. The refrigerant starts developing a shallow-well vortex at the bottom of the vessel while passing through the exit, where it develops low pressure area in the center of the vortex. The strength of the pressure differential created this way is directly proportional to the strength of the vortex generated, which thereby governs the extent of subcooling passing over the heat exchanger at the bottom of the bypass tube. The bypass refrigerant helps to subcool the main stream of the refrigerant and further offers the heat bubbles carried by the refrigerant to condense and ensure less non-condensed refrigerant downstream to expansion valve. This, eventually, offers reduction in the suction and discharge pressures of the system, thereby reducing the pressure ratio across the compressor, which yields reduction in power consumption for the compressor in the refrigeration circuit. This ultimately yields performance improvement of the system. Summarising the development reported, it could be concluded that similar to a thermostatic expansion valve that controls the varying conditions at the evaporator, this condenser control device helps the condenser to be adjusted according to varying conditions as well.

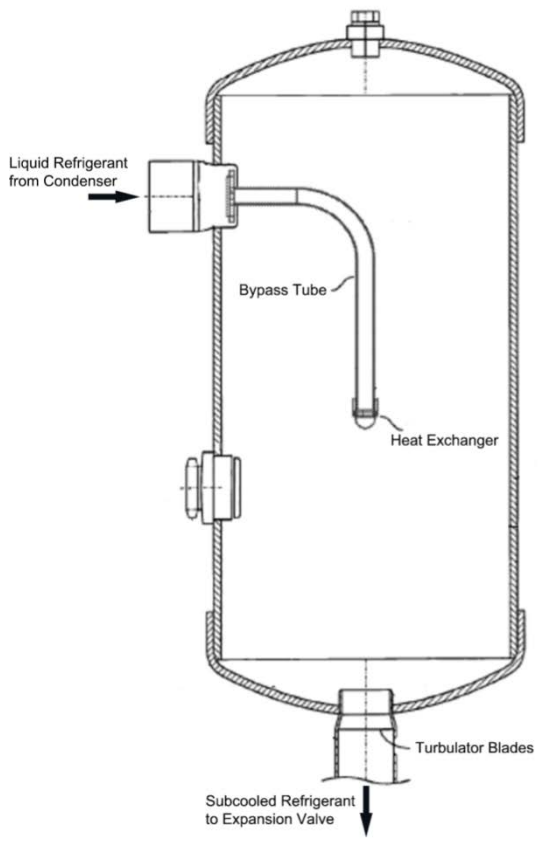

Figure 2. Schematic of Vortex Vessel [6]

Another valve incorporated in the flow circuit is downstream the expansion valve and before the evaporator coil. This valve includes another incremental expansion device disk to create a low pressure area on the back side and forces the refrigerant to flow in a spiral manner by a set of fixed blades. This helps to develop a vortex that ensures uniform flow through the cooling coil to enhance the coil efficiency. This ultimately raises the efficiency and economy of the system.

2.1.3 RoI Analysis

Assuming a 25 TR chiller plant consuming 27.5 kW of electricity, for 30 working days a month, operating for 18 hours per day with 100 % load, the total monthly electricity charge would be ₹ 18 X 30 X 27.5 X 7.0 = ₹ 103,950, for the average cost of electricity in industrial sector in India to be around ₹ 7.01 per kW-hr [7]. The Vortex Generator System is reported to offer up to 18.2 % of energy consumption [8]. Taking an average value of 15 % savings, the monthly charge would be reduced by ₹ 15,593. Based on the market inquiries in India, the total installation cost for such equipment for 25 TR chiller plant is about ₹ 280,000. This will, thus, offer the recovery of the investment in 18 months (₹ 280,000 / ₹ 15,593 ≈ 01 years 06 month).

2.2 Integrated HVAC System

2.2.1 Principle of Operation

Principle of operation of this system is that the intelligent control system automatically selects the mode of HVAC operation towards maintaining the desired indoor conditions, which ultimately offers most economical outcome.

2.2.2 Product Design

The product deals with a smart control technique to regulate the diversified conditions to be maintained. In a country like India, which experiences large variations in the ambient conditions on daily as well as annual basis, such kind of setup would prove to save substantial amount of energy consumption to attain with most comfortable indoor conditions. The 5 modes of operation in the setup, based on the ambient conditions, are as follows:

- Ventilation mode comprises of only fresh air circulation, and electricity input is used by blowers and dampers only.
- Indirect evaporative cooling mode deals with the sensible heat exchanger.
- The combination of indirect and direct evaporative cooling.
- Air conditioner mode: cooling with dehumidification supported by recirculation air.
- Fresh air pre cooling mode includes the indirect evaporative cooling of fresh air followed by cooling with dehumidification i.e. conventional air conditioning system.

Figure 3 reflects the 5 modes of HVAC Operations under consideration.

The system senses the external weather conditions and switches to the most desired mode of operation, ensuring consistent performance, high efficiency and significant energy savings. Taking into consideration the large climatic variations at regions like Indian subcontinent, such hybrid cooling technology can be applied anywhere in the world, providing energy efficient cooling without compromising the performance.

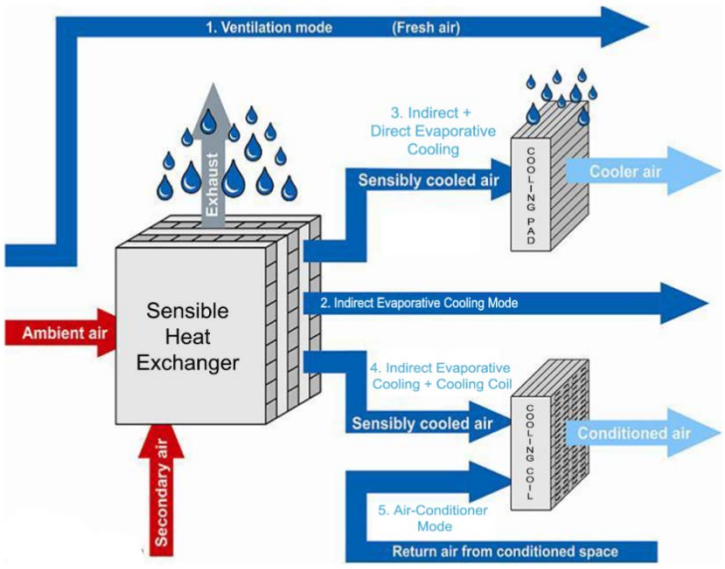

Figure 3.Schematic for 5 modes of HVAC Operations.

The control system creates a virtual psychometric chart considering the specific elevation of the site. Thus, the control strategy is location specific anywhere in the world. This allows the system to instantly plot an effective comfort zone for that location based on a series of desired indoor environmental input parameters, including indoor temperature and

humidity. The system then uses state-of-the art electronic controls and sensors to plot the outdoor condition on the virtual psychometric chart. This system combines outdoor conditions and the established comfort zone to instantly select the most efficient cooling strategy, thus assuring the highest equipment efficiency. As ambient conditions or comfort zone inputs change, the system recalculates and chooses the best available cooling strategy. Depending on the equipment, these strategies can include the following 5 modes, as depicted in Table 1.

Table 1. Summary of Operation of 5 Integrated HVAC Modes

Mode of operations	Blower	Pump for indirect evaporative cooling	Pump for Direct evaporative cooling	Cooling coil (Conventional air conditioner)	Fresh air damper	Return air damper	Secondary air damper
Ventilation Mode	On	Off	Off	Off	On	Off	Off
Indirect Evaporative Cooling Mode	On	On	Off	Off	On	Off	On
Indirect + Direct Evaporative Cooling Mode	On	On	On	Off	On	Off	On
Fresh Air Precooling Mode	On	On	Off	On	On	On	On
Air Conditioner Mode	On	Off	Off	On	On	On	Off

This system can also be upgraded to incorporate heating mode as well. In heating mode fresh air as well as recirculated air is heated sensibly to increase its temperature only. In heating and humidification mode the fresh air is passed through a cooling pad i.e. direct evaporative cooling, and then the air that comes out along with the recirculated air is sensibly heated to increase the temperature as well as the humidity. Psychrometric representation of all these seven modes is as shown in Figure 4.

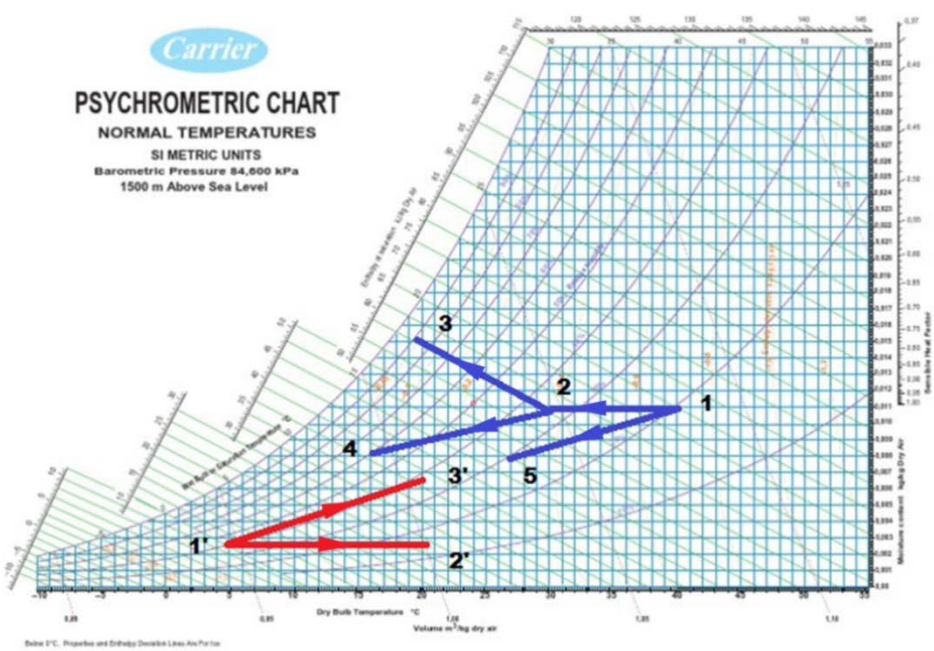

Figure 4. Psychrometric representation of seven HVAC modes

2.2.3 RoI Analysis

All the seven modes could be integrated in a single system. However, depending on the geographical location and its corresponding climatic conditions, less than seven modes could also be employed for giving maximum comfort and

optimum economy. For example in a city like Mumbai, situated along the seashore, considering the annual average ambient conditions, the combination of indirect and direct evaporative cooling mode would not be required as the humidity would always be high. Similarly, there would not be any requirement for the two heating modes due to reasonably higher average ambient temperature throughout the year. Due to the selection of operating modes based on diverse ambient conditions as well as the air flow required for a specified application, there would be possibility of permutations of designs of the equipments. Hence, a typical schematic would not be feasible to report to represent the system. On the similar lines, the cost analysis would also be highly difficult to account. Such a system comprising of integration of multiple HVAC techniques is the best candidate for any geographical location all over the world where substantial variation in the annual average ambient conditions could be experienced. New Delhi, the capital city of India, is a fine example where all the 7 modes could be executed to achieve optimum performance along with maximum economy.

2.3 Solar Thermal Hybrid Air Conditioner

2.3.1 Principle of Operation

The principle of operation could be summarised as to replace a percentage of mechanical energy required to power the compressor, thereby saving electricity consumption [9]. This is done by partially raising the pressure and heat content of the working fluid using solar thermal energy. The hot gas discharge line from the compressor is connected to the top inlet of a Smart Solar Panel. Heat and pressure are added to the refrigerant, generated by the sun and the hot and pressurized refrigerant is returned from the panel outlet to the condenser of the air conditioning unit. By this method, compressor's energy consumption can be reduced by up to 40% [10]. This solar thermal system displaces a portion of the mechanical energy used by variable capacity, multi stage, and variable speed compressors, which keeps the compressor in low stage, low range or low capacity, while delivering full and part-load cooling requirements. This ultimately offers significant energy savings. The schematic of this system would be as shown in Figure 5.

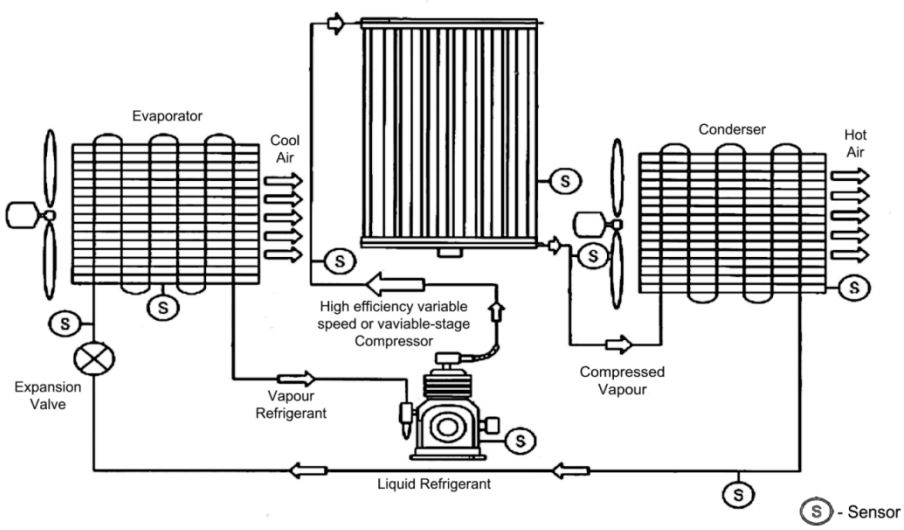

Figure 5. Schematic of Solar Thermal Hybrid Air Conditioner [9]

2.3.2 Design of Solar Thermal Panel

It is a patented computer-controlled parabolic concentrator which produces more energy than other panels of the same size [11]. This technology has solved two major issues with solar thermal panels: degradation and stagnation. Solar Thermal Panels currently in use cannot regulate the amount of heat being added to the working fluid. When systems are not in use they can cause extreme heat build-up and even damage the coatings of an evacuated tube panel. When integrated with HVAC equipment this could cause severe damage to the refrigerant which may cause the compressor to fail. It includes a plurality of elongated parabolic reflectors mounted within a glass-topped enclosure for pivotal movement such that each reflector is incrementally pivoted throughout the course of a day to remain substantially perpendicular to the sun for optimal collection of solar radiation which is used to heat liquid carried by the tubes positioned at the axis of generation of the parabolic reflectors. The schematic of the panel would be as shown in Figure 6.

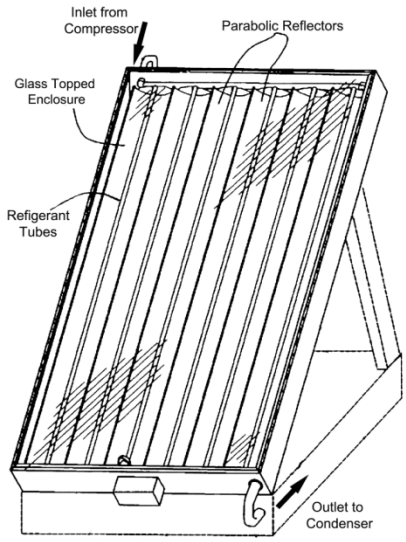

Figure 6. Schematic of the Solar Thermal Panel [11]

The equipment includes a temperature sensing system to monitor and control the heat added to the refrigerant, thereby allowing the system to constantly maintain refrigerant temperatures and pressures in their optimum range for the most economical output. The temperature sensing system measures temperatures across various locations in the system, solar panels and ambient conditions, with a feedback control to modulate the relative position of the parabolas with the sun, in order to maintain, increase, or decrease the amount of solar thermal energy being generated by the solar panel.

2.3.3 RoI Analysis

Assuming a 8 TR VRV air conditioning unit consuming 11 kW of electricity, working for 25 working days, operating for 10 hours per day with 60 % load, the total monthly electricity charge would be ₹ 0.6 X 10 X 25 X 11 X 9.5 = ₹ 15,675, for the average cost of electricity in urban residential sector in India to be ₹ 9.5 per kW-hr [7]. The Solar Hybrid Thermal System is reported to offer up to 40 % of energy consumption [10]. Taking an average value of 30 % savings, the monthly charge would be reduced by ₹ 4,703. Based on the market inquiries in India, the total installation cost for such a panel to cater for 8 TR air conditioning unit is about ₹ 175,000. This will, thus, offer the recovery of the investment in 37 months (₹ 175,000 / ₹ 4,703 ≈ 03 years 01 month)

3. Concluding Remarks

The present work discusses about three innovative technologies in the HVAC industry towards improvement in the performance using conventional energy sources as well as combination of traditional and renewable energy sources. The principle of operation, methodology of product design and return of investment analysis are also presented. While selecting the product, not only the initial cost plays a vital role but also due consideration is to be given towards the diverse annual ambient conditions in a country like India, based on the geographical locations. In industrial and commercial sites, huge chiller plants are employed. The capacity of such cooling equipment ranges from 25 tonnes to a few hundred tonnes. By upgrading the chiller using vortex generator, substantial reduction in energy consumption is achieved. As it increases only the extent of subcooling of the refrigerant, this equipment could be employed at any location in India. Another innovative approach is by integration of various HVAC processes towards significant energy saving by choosing the most economical operating mode. This is a smart way to improve indoor conditions, and demands for considerable attention in the near future. The major advantage of this type of equipment is that it can be adapted for residential, commercial as well as industrial applications. Accordingly, such equipments could be designed for any tonnage capacity. Such product can be employed at any location in India which experiences considerable climatic variations on daily as well as annual basis. This would ultimately yield extensive amount of national saving in terms of energy. The third product reports about an advanced technique of combining the

conventional and renewable energy. Conventional air conditioner is partially assisted with a renewable energy source to reduce its impact on global warming and assist energy saving. India is blessed with substantial amount of availability of solar energy throughout the year and over a large territory. Accordingly, residential places having considerable space to install solar panels and commercial as well as industrial sites could easily employ this equipment and save energy consumption by harnessing solar thermal energy. Such equipment could be designed for any medium range applications.

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