CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The vast majority of refrigeration, air-conditioning and heat pump equipments for both residential and commercial rely on vapour compression system and use halogenated refrigerants. These refrigerants will soon be phased out, mainly due to their Ozone Depletion Potentials (ODPs) and Global Warming Potentials (GWPs). The International Protocols (Montreal and Kyoto) restrict the usage of Chlorofluorocarbon (CFCs) and Hydro Chlorofluorocarbon (HCFCs) types of refrigerants and established the time limit to completely phase out these refrigerants. Powell (2002) has reported that as per the Montreal Protocol 1987, developing countries like India, with a per capita consumption of less than 0.3 kg of ozone depletion substance have been categorizes as Article-5 countries. These countries are required to phase out all CFCs by 2010 and all HCFCs by 2040. Johonson (1998) has reported that Hydro fluorocarbon (HFC) refrigerants are considered as one among the six targeted green house gas under Kyoto Protocol of United Nations Framework Convention on Climate Change (UNFCCC) in 1997.

The refrigeration and air conditioning systems indirectly contribute to global warming by way of consumption of 10 to 20 % electrical energy produced for its operation and it is estimated that the average of main
green house gas CO₂ released from an electrical power plant (based on fossil fuel) is to be 0.6 kg per unit kW hr of electrical energy produced. The demand for Heating, Ventilation and Air conditioning (HVAC) equipment by people and industry are increasing day by day as the technological revolution based on information technology and globalization impact upon the societies and people.

A leading international industry market research company in USA “The Freedonia Group”, estimated that global demand for HVAC equipment is projected to rise 6.2 percent per year through 2014 to $ 93.2 billion and for fluoro chemicals will rise 2.7% yearly by volume through 2013. The cooling equipments growth will continue to outpace heating equipment gains through 2014, reflecting the lower penetration rates of air conditioning equipment. Among the products, room air conditioners will post the strongest gains worldwide. In India, annual report of Voltas limited company for the year 2009 stated that the trend in sales of room air conditioning system indicates a doubling of sales from 995,000 units in the year 2004-05 to 20.5 million units in the year 2007-08 (a growth of 27%) and according to a research carried out by Credit Rating Information Services of India Limited (CRISIL), the volume growth of air conditioners in the 5 years in India from the year 2003-04 to 2007-08 was 21 %. As the fossil fuel reserves are getting depleted at a faster rate and considering the global warming also, it is an urgent need to improve the energy efficiency of vapour compression system based equipments.

With the above objectives in mind a detailed literature survey has been carried out to assess the ongoing research in the area of alternative refrigerants for R22 and the possibility of adopting Electronic Expansion valve (EEV) as an expansion device in lower capacity (3.45 kW) window air conditioner to improve its performance and energy efficiency.
2.2 REVIEW ON STUDIES WITH ALTERNATIVE REFRIGERANTS

The first documented, systematic search for refrigerant offering a practical design with improved performance came in the year 1920s, with examination of refrigerants for chillers by Carrier and Waterfill. During the process of selecting potential alternate refrigerant mixtures to replace R22, certain screening approaches have been followed. In such an attempt Vineyard et al (1989), applied criteria like toxicity, instability, ozone depletion potential, flammability, boiling point and commercial availability to more than 200 pure compounds that would make up the components of zeotropic mixtures. Didion et al (1990) have reported the role of three categories of refrigerant mixtures (azeotropes, near azeotropes and zeotropes) as alternatives to CFCs.

Hwang et al (1997) have reported that there are no pure alternative refrigerants for HCFC 22. Formeglia et al (1998) reported that, it is possible to mix Hydrocarbon (HC) refrigerants with Hydro fluorocarbon (HFC) refrigerants to replace the halogenated refrigerants. Granryd (2001) presented an overview of various pure HC refrigerants used for refrigeration and air conditioning applications. Wang and Li (2007) summarized the perspectives of natural working fluids in China for refrigeration and air conditioning applications, which includes both compression and absorption based refrigeration systems. Calm (2008) compiled the historical development of pure refrigerants from early use to the present and also addressed future options as given in Figure 2.1.
Figure 2.1 Development of refrigerants (Calm 2008)

Using the cycle-II, Pannock and Didion (1991) and Domanski and Didion (1993) studied the performance of nine R22 alternatives. Sagia (2001) developed an algorithm on the basis of heat and thermodynamics theory to define the blend with the most favourable composition, as an environmentally acceptable solution for R22 replacement. Corberan et al (2008) reviewed the standards followed for vapour compression refrigeration systems working with HC refrigerants and reported existing standards, maximum charge, room area limits and specific requirements.

Palm (2008) compared the properties and performance of hydrocarbons as refrigerants in small-size heat pump and refrigeration systems (< 20 kW cooling) and reported that usage of hydrocarbons will result in COPs equal to, or higher than, those of similar HFC systems. Also suggested that reduced charge through indirect systems and compact heat exchangers, outdoor placing of the unit, hydrocarbon sensors and alarms and forced ventilation are the steps which may be applied to reduce the risks under normal operation.

United Nation’s Environmental Program (UNEP’s) Technology and Economic Assessment Panel (TEAP) progress report (2010) decision XIX/8 stated that HC-290 has successfully been commercialized as an HCFC-
22 replacement in low charge, room and portable air-conditioner applications of less than 4 kW.

Prapainop and Suen (2012a) have reviewed the effects of thermophysical properties and derived parameters of refrigerants on system performance and noted that to obtain a high COP, combinations of high values of latent heat, liquid thermal conductivity and vapour density and low values of liquid viscosities and molecular weight are required. Critical temperature and vapour specific heat are important properties when considering trade-offs between capacity and COP.

2.2.1 Hydro Carbon (HC) and its Mixtures as Alternatives

Purkayastha and Bansal (1998) experimented with R290 and LPG mixture (R290 - 98.95 %, R170 - 1.007 %, R600A - 0.0397 %) as substitute for R22 in a 15 kW heat pump. It has been reported that for R290, COP is 18 % higher, volumetric refrigeration capacity is 16 % lower and condenser capacity is 13 % lower when compared to that of R22. For LPG mixture, COP is 12 % higher, volumetric refrigeration capacity is 14 % lower and condenser capacity is 10 % lower when compared to that of R22.

Chang et al (2000) have experimentally investigated the performance and heat transfer characteristics of HC mixtures composed of R290, R1270, R600 and R600A as alternatives to R22 in heat pump. Their results concluded that cooling and heating capacities of R290 were smaller and COP was slightly higher than that of R22. The capacity and COP of the R1270 were slightly greater than R22. The COP of the zeotropic mixture R290/R600A with 50% mass percentage of R290 was enhanced by 7 % and R290/R600 at composition of 75:25 (by mass percentage) showed 11% improved performance. It has been found that system is degraded for zeotropic HC mixtures due to composition variation in phase change.
Devotta et al (2005a) tested R290 as a substitute to R22 in 5.13 kW (1.5TR) window air conditioner and reported that for R290, cooling capacity was 6.6 - 9.7 % lower than that of R22 and energy consumption was 12.4 - 13.5 % lower than that of R22. But COP for R290 was 2.8 - 7.9 % higher than that of R22. Pressure drop in both evaporator and condenser for R290 were found to be lower than R22. R290 has the condenser capacity of 12.3 - 18.7 % lower than that of R22. Simulation results for heat exchangers for R290 and R22 were compared.

Park and Jung (2006) studied the thermodynamic performance of two hydrocarbon refrigerants and seven mixtures composed of R1270, R290, RE170 and R152A as alternatives for R22 in residential air conditioning applications and reported that all the pure and mixed fluids tested have low GWP of 3 - 58 as compared to that of R22. Also their results showed that except R1270 all the other refrigerants have higher COP with lower discharge temperature and similar refrigeration capacity.

Park et al (2008) investigated the performance of R22 based residential air conditioner and heat pumps working with R433A (near azeotropic mixture composed of R1270 and R290, in the ratio of 70: 30 by mass) as an alternative. It has zero ODP and very low GWP with a low temperature slide of 0.4 °C. The results reported that COP of R433A is 4.9 - 7.6 % higher than that of R22 with 1 - 5.5 % higher capacity. The charge requirement is about 57 % lower than that of R22 due to its lower liquid density. R433A was reported as good energy efficient and environment friendly alternative option to replace R22 in air conditioning and heat pump applications.

Park et al (2009 a) have experimentally investigated R432A (near azeotrope mixture composed of R1270 and RE170 in the ratio 80: 20, by mass) as an alternative to R22 in residential air conditioner and reported that
R432A has 8.5 - 8.7 % higher COP than that of R22 with 1.9 - 6.4 % higher refrigeration capacity. The compressor discharge temperature of R432A was lower in the range of 14 - 17 °C and refrigerant charge requirement was found to be 50 % lower than that of R22 and it have zero ODP and GWP of less than 5. Hence R432A was a good eco friendly refrigerant and energy efficient alternative to replace R22 in air conditioners and heat pumps.

The major setback reported with HCs is the flammability. James and Missendan (1992) claimed that in case of the household refrigerators, the possibility of explosion by flammability can be negligible because half the amount of HCs can be charged compared to general CFC. Also, some simple safety devices such as a ventilation system and a leak detector can be installed to overcome the flammability problem in large sized air conditioning systems. Extensive studies on flammability of hydrocarbons have been conducted by Richard and Shankland (1992). Studies on the use of hydrocarbon in refrigeration system have also been done by various investigators including Chen et al (1994), Colbourne (2000) and Jung (1996).

The short atmospheric lifetime of HC refrigerant mixtures makes their GWP close to zero and their favorable thermodynamic and thermophysical properties assure that the efficiencies are comparable to the halogenated refrigerants. The charge requirement of HC refrigerants is also reported to be half of the halogenated refrigerants due to its lower liquid density. HC mixtures such as R432A and R433A are accepted as environment- friendly option for replacing R22 in air conditioning and heat pump applications.

2.2.2 Hydro Fluoro Carbon (HFC) and its Mixtures as Alternatives

HFC mixtures are not miscible with mineral oil, which is used as a lubricant in CFC and HCFC systems. HFC mixtures require synthetic lubricant
like polyolester. Hence, a major modification is required for HFC mixture to retrofit in HCFC systems.

Bivens (1996) conducted performance test for HCFC-22, R407C and R410B in a split system heat pump to suggest alternative refrigerants for building air-conditioning and concluded that it is possible to exceed the energy efficiency of HCFC-22 with either R407C or R410B if appropriate equipment design changes are made. The future choice of these alternatives will be based on economics and difficulty of design changes for specific equipment. Mongey et al (1996) compared the performance of R407C and R22 in vapour compression based refrigeration system and reported that the performance of R407C approached that of R22 at higher evaporator temperature. Also the temperature glide of R407C in evaporator will change the composition and reduce s evaporator capacity and COP.

Pande et al (1996) tested three refrigerants, R32, R410A (R32 / R125, 50/50 wt %) and R410B (R32 / R125, 45/55 wt %) in a residential heat pump system and compared their performance with R22. It was found out that R32 yielded the best performance. R32 showed cooling seasonal performance 5 % better than R22 and heating seasonal performance 3 % to 4 % better than R22. R410A and R410B showed 2% to 3% better cooling seasonal performance and equivalent heating performance than those of R22.

Greco et al (1997) analyzed the problem of HCFC-22 phase-out in refrigeration plant by comparing the performance of R22 and R407C in a water cooled vapor compression plant and reported that COP for R407C is 5 - 17% lower than that of R22 and compression ratio for R407C is 5 - 21% higher than that of R22. In order to provide the same refrigerating load, a plant working with R407C requires higher electric-power consumption and R407C is a good R22 substitute in all applications requiring high evaporation temperatures, such as air- conditioning plants.
Many refrigerants were assessed through the Alternative Refrigerant Evaluation Program (AREP) of Air-Conditioning and Refrigeration Institute (ARI), USA in the year 1997 as potential replacements for HCFC-22. The most promising alternative refrigerants that emerged were R-410A, R407C, HFC-134a, and HC-290. The list has since been revised to include HFC-32 and a non-azeotropic refrigerant mixture of HFC-125, HFC-134a, and HC 600(46.6/50.0/3.4, % by mass fraction).

Aprea et al (1998) examined the problem of R22 substitution in terms of global warming effect in vapour compression refrigeration effect and reported that at higher condensation (over 50 °C) and evaporation temperature (2–10 °C), the Total Equivalent Warming Impact (TEWI) of R407C is even slightly lower than of R22 and its substitution for R22 is convenient from the point of view of the green house effect.

Chin and Spatz (1999) conducted the tests in residential and light commercial equipment and noted that the performance of R410A is higher than R22 when ambient temperature is lower than 35 °C. Due to the compressor efficiency degradation, the performance of R410A is inferior to that of R22 at high ambient temperatures.

The performances of some new refrigerant mixtures like R32/125/152a, R125/290 and R32/125/290 have been theoretically and experimentally investigated by Yang Zhao et al (1999) under varying working conditions and they can be suitable replacements for R22. The evaporator temperature range considered is –35 °C to 10 °C and condenser temperature range from 30 °C to 60 °C. The performances of the R32/125/152a mixtures are close to that of R22 under all range of operating conditions.

Yajima et al (2000) selected the low GWP refrigerant R32 as alternative to R410A based on concept that the higher the non flammability of
refrigerant is, the larger its GWP and the lower its energy efficiency and tested its performance and TEWI in a 16 kW prototype with a variable speed compressor. Test analysis showed that COP of R32 was higher than that of R410A not only under the rated capacity condition, but also under the capacity reduction by compressor speed control. The analysis also shows that its heating COP at a low ambient temperature and its cooling COP under the overload condition are superior and the refrigerant charge can be reduced by adoption of smaller diameter heat transfer tubes for heat exchangers. In Tokyo area, its TEWI dropped by 18 % in comparison with that of R410A and direct impact portion of R32 decreased to 7 % of the total impact. Also stated that since R32 has a potential to economically satisfy the requirements of safety and environmental protection simultaneously, R32 is likely to become the major refrigerant for the future air conditioning equipment.

Dongsoo et al (2000) reported that R 407C, a non azeotropic refrigerant mixture is having gliding temperature difference of roughly 6 °C. Its vapor pressure is similar to that of R22 and hence it is expected that R407C may be used in existing equipment without major changes. At present it seems that instead of R407C, R410A can be adopted in new systems. Due to high pressure, compressor need to be redesigned completely and also the heat exchangers need to be optimized to accommodate lower volumetric flow rates associated with use of R410A. HFC 407C is a close match to HCFC22 in existing equipment with respect to energy efficiency and other performance parameters such as compressor discharge temperature and pressure.

Henderson et al (2001) compared the performances of a domestic and commercial heat pumps working with R22 and its alternatives R410A and R290 and suggested that R410A is a good substitute compared to R290 to replace R22 in domestic and commercial heat pump due to increase in performance and comparable global warming potential.
Devotta et al (2001) assessed the suitability of some selected fluids as alternatives to R22 for air conditioners, using NIST CYCLE_D thermodynamic analysis. The refrigerants studied are R134a, HC290, R407C, R410A and three blends of R32, R134a and R125. Evaporator and condenser temperatures were fixed as 7.2 °C and 55 °C respectively by neglecting the pressure drops. Pressure ratio of R407C is higher than R22 for the range of evaporator temperatures due to higher discharge pressure. They also have reported that discharge temperature of R407C is considerably lower than R22. Specific compressor displacement of R407C is same as that of R22. Hence it may be possible to retrofit R22 compressors with R407C. Also reported that the better vapor compression system performance of R410A gave high evaporation heat transfer coefficient, compressor efficiency and low system pressure drop. Table 2.1 shows the summary of derived thermodynamic data of the refrigerants studied by Devotta et al (2001) relative to R22.

Table 2.1 Summary of derived thermodynamic data (Devotta et al 2001)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Refrigerant</th>
<th>% Relative to HCFC 22</th>
<th>COP</th>
<th>Cooling Capacity</th>
<th>Pressure Ratio</th>
<th>Compressor Power</th>
<th>Discharge Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R407C</td>
<td>-1.76</td>
<td>1.72</td>
<td>6.60</td>
<td>1.75</td>
<td>7.67</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>R410A</td>
<td>-8.90</td>
<td>41.21</td>
<td>-2.29</td>
<td>9.81</td>
<td>55.60</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>HFC-134a</td>
<td>4.40</td>
<td>-33.00</td>
<td>13.75</td>
<td>-4.27</td>
<td>-31.45</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>HFC-290</td>
<td>1.00</td>
<td>-14.13</td>
<td>-6.87</td>
<td>-1.00</td>
<td>-12.42</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>HFC-32/HFC-34a (30/70 by Wt% )</td>
<td>1.00</td>
<td>-1.00</td>
<td>8.80</td>
<td>-1.00</td>
<td>1.30</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>HFC-32/HFC-125 (60/40 by wt% )</td>
<td>-8.32</td>
<td>45.40</td>
<td>2.00</td>
<td>8.30</td>
<td>57.72</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>HFC-32/HFC-125/HFC-134a (30/10/60 by wt% )</td>
<td>0.34</td>
<td>2.93</td>
<td>7.44</td>
<td>0.35</td>
<td>6.71</td>
<td></td>
</tr>
</tbody>
</table>
Aprea et al (2003) analyzed the performance of R22 and R407C in a vapour compression plant using semi-hermetic compressor. COP as a function of outlet water temperature at the condenser shows that the overall energetic performance of R22 is always better than that of R407C and the difference is in the range 8 - 14 %. This study also shows that R407C has smaller actual volumetric efficiency due to smaller mass flow rate and lower iso-entropic compressor efficiency than that pertaining to R22.

Calm et al (2004) reported that HFC based mixtures such as R404A, R407C and R410A are the potential alternatives to R22 in refrigeration, air-conditioning and heat pump applications.

Devotta et al (2005b) conducted experiments on 5.13 kW (1.5 TR) window air conditioner retrofitted with R407C and concluded that for R407C, the cooling capacity was lower in the range of 2.1 - 7.9 %, power consumption was higher in the range of 6 - 7 %, COP was lowered by 8.2 - 13.6%, discharge pressure was higher in the range of 11 - 13 % and evaporator capacity was lower by 3.3 - 6 %. Their results indicated that the pressure drop of R407C in condensers and evaporators was lower than that of R22.

Han et al (2007) investigated with ternary HFC mixture composed of R32/R125/R161 as an alternative to R407C and reported that the pressure ratio and power consumption are found to be lower than R407C and the above mixture has high refrigeration capacity and COP compared to R407C. The slightly higher discharge temperature of the mixture than R407C might affect the life of the compressor.

Chen (2008) made a comparative study of performances of R410A and R22 in residential air conditioners and reported that the use of R410A will reduce the size of heat exchangers, improved power saving and
also the overall environmental impact of R410A is 4 - 11 % lower than that of R22.

Chen and Yu (2008) theoretically compared the performance of a new modified refrigeration cycle composed of a compressor, a phase separator, a sub cooler, two condensers, two evaporators, two recuperators and two expansion valves with the conventional refrigeration cycle using non-azeotropic mixture R32/ R134a in residential air conditioner and reported that the refrigerant mixture composed of R32/R134a in the ratio of 0.3 : 0.7 (by mass fraction) has 9.5 % higher volumetric refrigeration capacity with 8 - 9 % higher COP compared with the conventional refrigeration cycle. In the conventional cycle, the performance of the mixture was closer to R22.

Wu et al (2009) experimentally studied the performance and flammability of a new refrigerant mixture (composed of R152a/R125/R32 in the ratio of 48:18:34 by mass respectively) in a R22 based domestic air conditioner and concluded that COP of the mixture was slightly lower than that of R22. The variation of COP and gliding temperature under leakage conditions (leaking ratio between 0 and 20 %) was reported to be very low. The flammability test of refrigerant mixture reported that it could safely use in domestic air conditioners.

Bolaji et al (2011) selected three ozone friendly Hydrofluorocarbon (HFC) refrigerants (R32, R134a and R152a) tested in a vapor compression refrigeration system and compared the performance. The results obtained showed that R32 yielded undesirable characteristics, such as high pressure and low COP. Comparison among the selected refrigerants confirmed that R152a has higher COP than those of R134a and R32 by 2.5% and 14.7% respectively.
Taira et al (2011) tested room air conditioner with R32 as alternative to R410A based on Japanese Industrial Standards JIS-C 9612 Standard and confirmed that the performance of R32 is higher than R410A due to its pressure drop and heat exchange characteristic in evaporator and condenser and also the charge amount of R32 is lesser than R410A.

Tu et al (2011) compared the performance using R32 and R410A in a thermodynamic model and conducted experiments at different operating conditions in a 3.2 kW residential heat pump unit. Experimental results showed that R32 outperformed R410A by 8 % and 3 % in cooling and heating capacities, respectively, and by 3 % and 2 % in cooling and heating COPs, respectively.

Pham and Rajendran (2012) conducted various drop in system tests with different heat exchangers and scroll compressors by using R32, R410A and Hydro Fluoro Olefins (HFO) blends such as R1234yf and R1234ze and compared the system performance theoretically and experimentally on basis of Life Cycle Climate Performance (LCCP), system economics, compressor discharge temperature and A2L refrigerants ( refrigerants with flame velocity below 10 cm/s were recently classified as “2L” by ASHRAE 34) flammability safety aspects. They suggested that the performance of R32 can be improved by finding new compatible lubricating oil and optimizing the compressor and system towards achieving its theoretical potential as well as mitigating its higher compressor discharge temperature. Qualitative high level comparison summary by them for R32, R410A, R290, CO$_2$ and HFO blends is given in the Table 2.2.
Table 2.2 Low-GWP options assessment (Pham and Rajendran 2012)

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>R410A</th>
<th>R32 (HFC)</th>
<th>HFO Blends</th>
<th>Carbon Dioxide</th>
<th>HC (R290)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2080</td>
<td>675 (&lt; 500 Charge Required)</td>
<td>-500</td>
<td>1</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>2</td>
<td>Compressor Design &amp; Cost</td>
<td>Heat Mitigation</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Efficiency</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Pump + HX Losses</td>
</tr>
<tr>
<td>4</td>
<td>Safety</td>
<td>Mildly Flammable</td>
<td>-</td>
<td>-</td>
<td>Highly Flammable</td>
</tr>
<tr>
<td>5</td>
<td>Refrigerant Cost</td>
<td>-</td>
<td>Higher</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>System Cost</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Secondary Loop Required</td>
</tr>
</tbody>
</table>

Barve and Cremaschi (2012) tested R32, R1234yf and R410A in a 5 Ton heat pump with TXV or TEV and compared their drop in energy performance and capacities. The experiments were conducted for cooling and heating mode of the unit and the outdoor temperature was varied from -8 °C to 46 °C. Cooling tests at Air conditioning, Heating and Refrigeration Institute (AHRI) standard rating conditions were performed and the refrigerant charge was optimized. The findings from this suggested that for refrigerant drop in applications, R32 has comparable heating cooling capacities as those of R410A and also similar COPs. The discharge pressures and discharge temperatures were higher than those for R410A, especially for moderate to extreme high temperature conditions. Too high discharge temperature and pressure of R32 in extreme high temperature conditions was a concern for the safe operation of the unit and might be a concern for the compressor lifetime cycle. Refrigerant R1234yf provided similar COPs as R410A but this refrigerant had rather low capacities with respect to those for R410A. Optimizing the expansion valve improved the R1234yf capacity by
up to 10%, with respect to drop in capacities but it was still 46% lower than that for R410A at similar operating conditions.

Guo et al (2012) tested the compressor used for air conditioning applications in China by using the refrigerants R32, R22 and R410A and compared the compressor performance and reliability impact. For the development of R32 compressor, design improvements suggested are, selection of polyol ester (POE) B oil as lubricant to minimise the wear, Enhanced Vapour Injection (EVI) technology to improve the EER/COP and to control compressor discharge line temperature, optimization of scroll suction inlet to get lower suction superheat and optimization of scroll wrap to take care of higher R32 running temperature, internal heat management and also proved that the performance of R32 compressor is increased.

Okido et al (2012) developed new POE oils such as RM68EA and RmM68EA by modifying molecular structure of existing POE oil to improve the anti wear performance and these can be used with both R32 and R410A.

Most of the studies reported in the literature are using HFC32 and HFC mixtures such as R404A, R407C and R410A as alternatives to R22. R404A can be used as alternatives to R22 in low temperature refrigeration applications. R32, R407C and R410A can be used as alternative to R22 in air-conditioning and heat pump applications. However R410A cannot be used for high temperature heat pump applications due to its lower critical temperature. The HFC refrigerant mixtures have zero ODP with significant GWP. Owing to the GWP, HFC refrigerant mixtures are considered as interim alternatives to phase out the CFC and HCFC based refrigerants.
2.2.3 HFC/HC Mixtures as Alternatives

To overcome the problems faced (oil miscibility and flammability) with HFC and HC refrigerants, many investigators tried with HFC/HC mixtures as alternatives to HCFC and CFC refrigerants by retaining the mineral oil as lubricant. The flammable nature of HC refrigerants can be reduced by mixing it with HFC refrigerants. On the other hand, the miscibility of HFC refrigerant with the mineral oil can be tackled.

Dongsoo et al (2000) have tested 14 refrigerant mixtures composed of R32, R125, R152a, R290 and R1270 in a breadboard heat pump in an attempt to find a substitute for R22 used in residential air conditioners. The capacity of heat pump was 3.5 kW and heat transfer fluid has been water both in evaporator and condenser. It has been reported that R407C has 0.8% more COP than R22. Also the capacity of R407C is 8% more than that of R22. In the application of alternate refrigerants, the lifetime and reliability of the system as well as the stability of the refrigerant and lubricant should be considered. These characteristics can be examined indirectly by measuring the dome and discharge temperatures. The dome temperatures measured during this study for R22 and R407C are found to be 50 °C and 45 °C respectively. The compressor discharge temperatures with R22 and R407C have been found to be 116 °C and 91 °C respectively.

Jabaraj et al (2006, 2007) experimented a new refrigerant mixture composed of R407C with 10, 15, 20 and 25 % of HC blend (composed of R290 and R600a, in the ratio of 45.2: 54.8, by mass) as alternatives to R22 in a window air conditioner and reported that R407C with 20 % of HC blend demands an increase in condenser tube length of 19 % compared to R22. The energy consumption of 10 and 20% of HC blend were 1.31 - 2.5% and 4.83 - 9.46 % respectively lowers than R22. The COP for the mixture was 8.19 - 11.15% and 1.68 - 3.23 % respectively higher than R22 and the
discharge temperatures were 7.95 - 9.81 % and 10.79 - 12.37% lower than R22 respectively. Pull-down time was respectively reduced by 32.51 % and 13.88 % . The refrigeration capacity was 9.54 - 12.76 % and 4.02 - 5.85 % respectively higher than R22. Higher compressor life can be expected with the new refrigerant due to its lower compressor discharge temperature and also oil miscibility of R407C/HC mixture working with mineral oil was good. Due to its lower liquid density, the charge requirement of the refrigerant mixture was lower than that of R22 by 300 grams.

Park et al (2009b) studied the performance of a vapour compression system working as an air conditioner and heat pump using R431A (a mixture of R290 and R152a, in the ratio of 71: 29, by mass) as an alternative to R22 and reported that the COP of the mixture was 3.5 - 3.8 % higher than that of R22 with similar refrigerating capacity under both conditions. The compressor discharge temperature was observed to be lower in the range of 21- 27 °C.

Arora and Sachdev (2009) made thermodynamic analysis of a vapour compression refrigeration system working with R22 and its alternatives (R422A, R422B, R422C and R422D). It has been reported that R422A and R422C have lower compressor ratios compared with R22, whereas R422B and R422D have higher pressure ratio compared to R22. The compressor discharge temperatures of the R422 series of refrigerants are lower than that of R22. Hence, R422 mixtures will offer better system reliability and longer compressor life. The COP and exergy efficiency of R422 series of refrigerants are lower than that of R22. R422B has better COP and exergy efficiency compared with R422 series of refrigerants. The volumetric cooling capacities of R422 mixture are greater than that of R22, which requires change in compressor design. R422 series refrigerants have more exergy destruction in compressor and expansion valve. Hence, the
operating parameters of the compressor and expansion valve are to be optimized to improve the performance of the system. R422 series of refrigerants are the HFC/HC mixtures, which can be used in the existing R22 compressors without changing the lubricant.

The HC/HFC refrigerant mixtures can be used to replace CFC and HCFC refrigerants to extend the life of the existing systems. Low volatile HC refrigerants are preferred to be used as an additive with HCFC refrigerants to tackle the oil miscibility issue and also reduce the flammability of HC mixture. Mohanraj et al (2011) suggested the refrigerants such as R432A (mixture of R1270 and RE170 in the ratio 80:20 by mass) and R433A (mixture of R290 and R1270 in the ratio 30:70 by mass) as alternative to R22 in air conditioners because of their zero ODP and lower GWP properties compared with R22.

2.3 REVIEW ON STUDIES WITH ELECTRONIC EXPANSION VALVE

As vapour compression cycle is widely used in modern cooling and heating equipments, improving the energy efficiency of this cycle has the potential for significant economic and environmental impact. Most residential, automotive and industrial air conditioning and refrigeration systems are direct expansion units and have protection against liquid slugging in the compressor by utilizing about 60% to 90% of the evaporator capacity for cooling and the remaining for superheating the refrigerant. This superheating portion of the evaporator provides only little contribution to the total cooling capability. This practice also results in excessive evaporator volume. To maximize the capacity of the system for cooling application, the portion of the evaporator with the two phase flow needs to be maximized. However, to ensure safe and reliable operation of the compressor, the fluid entering the compressor must be completely vaporized. Systems with an
accumulator at the portion of the evaporator exit can ensure safe operation of the compressor while maximizing the evaporator performance. For systems without an accumulator, a generally acceptable compromise is for the fluid to be 5 °C above the saturation temperature or 5° C of superheat.

In 1989, Carrier introduced EEV controlled by microprocessor with sensors in evaporator, compressor and condenser. This system was called as “Flotronic”. Aprea and Mastrulla (2002) conducted experiments using R22 and R407C to evaluate the energetic performances in steady-state and in transient operating modes of an EEV and TEV assembled to feed an air cooled evaporator connected to an experimental vapour compression plant with water cooled condenser and semi hermetic compressor. The performances of both valves are practically equal in terms of COP for both R22 and R407C in steady state. The COP of R407C is about 10% smaller than the COP of R22. While in the transient conditions, for both refrigerants the EEV shows a better global performance than the TEV. Better performance of EEV is related to smaller oscillations in the superheating degree at steady state and in the transient conditions examined. After all the advantages of the EEV are in the quicker response to variation in operating conditions, in the facility to set the required superheating and in a better control of the superheat in the steady state conditions chiefly when non-azeotropic mixtures are used as working fluids. Though EEV is giving higher COP than TEV, the cost of EEV with controls is five times greater than TEV. The choice of EEV can be justified, if the payback period is at least equal to the operative life of a medium size refrigeration plant.

Choi and Kim (2004) compared the performance of heat pump having an EEV as an expansion device with that of heat pump having a capillary tube for various refrigerant charge conditions and concluded that for a wide range of operating conditions, the EEV system showed much higher
system performance and reliability than the capillary tube system due to an active electronic control of refrigerant flow rate through EEVs to obtain an optimum super heat level.

Hu and Yang (2005) reported the results from the development and performance testing of cost effective, energy efficient, multi type air conditioner that connected five evaporator units, which provides wide ranges of capacity options; to one condenser with digital scroll compressor and five EEVs. The measured results for this innovative design showed: (i) Relationship between the degree of opening of the EEVs and compressor output ratio (%) could be represented by regression functions, which formed the basis parameters of the system control. (ii) The developed system provided true zoning capability because it could run indoor units under part load conditions, therefore wasting little energy. The power consumption of the developed system was reduced from 100 % to 25% when the full load was reduced to a partial load of 17 % saving more than 95 % of the work required using a conventional un-loading method.

Ma et al (2005) conducted the experiments and developed a correlation to predict the mass flow co efficient for the flow of refrigerants R22, R407C and R410A through EEVs of six different geometries made of copper. By choosing the parameters such as EEV head geometry, EEV inlet conditions, EEV outlet conditions and refrigerant properties and using Buckingham pi Theorem, the correlations for the refrigerant mass flow coefficient (C_D) for EEV was predicted. The performance of the EEVs with several half taper and inner diameter combinations for R22 and its alternatives R407C and R 410 A were experimentally investigated. The mass flow rates of R407C are greater by 4.25 %, and those of R410A are greater by 22.70 % on average, than those of R22. R410A shows the highest flow co efficient (C_D)
for given condensing temperatures mainly because of its higher saturation pressure than the other fluids.

Zhang et al (2006) developed a dimensionless correlation on the basis of experimental data to predict the mass flow rate of R22 and its alternative R407C through an EEV. The mass flow rate was measured at a series of condensing temperatures, evaporating temperatures and degree of sub cooling at the EEV inlet with five opening setting degrees of the EEV such as 100, 200, 300, 400 and 500 pulses. By analyzing the experimental data and found that the operating conditions, flow area and the thermo physical properties of the refrigerant would affect the mass flow rate through the EEV. The predicted correlations based on Buckingham pi Theorem, can be used to predict the mass flow rate through EEVs whose biggest flow area is less than 2.544 mm$^2$.

Yip et al (2006) conducted experiments using the Tour de France throttle body fluid test-bed for different valve head structure to determine the mass flow characteristics of R410A through 4 kinds of EEV under different operating conditions. Expansion valve flow area, valve head structure, import and export expansion valve condition and the refrigerant properties were considered to predict the correlation for mass flow rate and compared with the experimental data. The relative deviation is between -7.6 % - 0.5%.

Liu et al (2007) experimentally investigated a new model to depict the mass flow rate characteristics of EEV for R22 by combining the homogeneous equilibrium fluid model (HEM) and the frozen flow model (FEM). On basis of tested data, an equation of meta- stability coefficient ($C_m$) is proposed. The meta-stability co efficient increases linearly with increase in sub cooled degree and it increases first and then decreases as the flow area increases.
Park et al (2007) developed an empirical correlation to predict the mass flow rates of R22 and R410A through EEVs. Mass flow rates through six EEVs having different orifice diameters and lengths were measured by varying the EEV opening (steps) as 100, 150, 200, 300, 400 and 480, inlet and outlet pressure and sub-cooling and found that the ratio of orifice length to orifice diameter in an EEV is a very important geometric parameter that determine the mass flow characteristics of EEVs. The mass flow rates passing through EEVs increased with the increase of EEV inlet and outlet pressure of refrigerant and sub cooling of refrigerant at EEV inlet. Mass flow rates of R410A were compared with those of R22 at the same test conditions. Based on the experimental data, an empirical correlation for the mass flow predictions through EEVs was developed by modifying the orifice equation to include the correction coefficient generated in a power law form of dimensionless geometric and operating parameters.

Zhifang et al (2008) developed a mass flow correlation for R134a through EEV using the water source heat pump (WSHP) fitted with two types of EEVs. The refrigerant mass flow characteristics of the EEV are an important issue in heat pump/refrigeration system operation because the EEV regulates the refrigerant flow to match various operating conditions. Based on the throttling mechanism and thermodynamics analysis, the mass flow rate is a function of various parameters selected such as valve’s geometric parameters, the inlet refrigerant pressure and temperature, the outlet refrigerant pressure, and refrigerant thermo physical properties represented by the dynamic viscosity and the surface tension. The semi theoretical correlations can be adopted to investigate the mass flow characteristics of other types of EEVs and for other refrigerants.

Lazzarian and Nore (2008) proved that EEVs fitted in eight air conditioners having a total cooling capacity 120 kW installed at a telephone
control room enables an appreciable energy saving with respect to the same installations equipped with traditional TEV, when the plant was operated in different modes, to analyze different aspects during considered time period using the refrigerants R22 and R417A. This is due to the fact that EEVs allow a lower condensation pressure in system equipped with air cooled condensers, which is adjusted to variations in outside air temperature. Furthermore, PID control over the superheating leads to the best use of evaporator under every condition (lower super heating level of the vapour refrigerant), thus increasing the refrigerating capacity. Energy savings with EEV are varying as functions of the outer air temperature and, for a given site, of the period of the year as given in Figure 2.3.

![Figure 2.3 Monthly electrical energy saving for the three European climate (Lazzarian and Nore 2008)](image)

A simulation model adjusted on the experimental measurements, demonstrated more significant advantages under different climate conditions. Energy savings allow also important economic savings, as required investment cost is not particularly high with respect to EEV.

Lazzarian et al (2009) experimentally evaluated the performances of EEV and TEV using R404A in 75 kW and 325 kW capacity supermarket refrigeration systems under different climate and operating conditions and
proved considerable energy savings due to superior control characteristics of the EEV and the favorable type of applications. As the required investment cost for EEV is not particularly high, energy savings also allow important economic savings and a short payback period (1.5 years).

Elliott et al (2009) reported that the literature examining superheat control largely consists of examining the TEV or EEV-controlled evaporators.

Chen et al (2009) experimentally studied the mass flow characteristics of EEVs for R22, R407C and R410A in a wide operating condition range. It was found that flow choking always occurs under common operating conditions in refrigeration systems. Based on meta-stability in EEVs, a new model predicting mass flow rate was proposed under flow choking conditions. Different from the conventional models using Bernoulli equation which employed downstream pressure at the EEV exit and a corrected mass flow coefficient, the present model considered meta-stable liquid flow caused by rapid depressurization, and employed single phase incompressible flow coefficient and meta-stable pressure at the throat. An empirical correlation of the meta-stable pressure, based on the experimental data for R22 and its alternatives R407C and R410A were developed in a power law form of dimensionless parameters including upstream operating parameters, refrigerant thermo physical properties and throat area. The predictions of the present model were found to be in good agreement with the measured data, and approximately 95 % of the mechanical data fall within a relative deviation of ± 7%. The comparison with a prior model shows that, in terms of flashing mechanism application and predicting accuracy, the present model is better the conventional model without considering meta-stability. It is notable that the present model can theoretically be used for other types of EEVs, such as TEV and metering manual expansion valve.
Zhiyuan et al (2010) conducted a series experiments and theory studies on EEVs and found that the refrigerant mass flow rate through EEV is increasing with increase in sub cooling of refrigerant, increase in condenser temperature and increase in number of pulses and decreasing with increase in evaporator temperature. Also, refrigerant mass flow rate is depending upon the method of EEV connection (i.e. shaft in and side out method or side in and shaft out method).

### 2.4 REVIEW ON STUDIES WITH MODELING OF COMPONENTS OF AIR CONDITIONING SYSTEM

With the advent of computers, the study of various components of a domestic air conditioning system under a range of operating conditions has become possible through mathematical modeling, saving thus a huge amount of time and money. Subsequently, simulation of an air conditioning system demands a thorough knowledge on simulation techniques. Hence an elaborate literature survey has been conducted and it is presented in this section.

Jameel and Syed (1999) have developed a thermodynamic model to simulate the working of actual refrigeration system. Simple cycle used for the analysis showed that the super heating has more influence on the COP of the system. Using this model, the COP and other system parameters were calculated with ± 2% accuracy.

Liang and Wong (2001) conducted experiments and developed a model to exploit the possibility of applying the equilibrium two-phase drift flux model to simulate the flow of refrigerant R134a in the capillary tube expansion device. The details of flow characteristics of R134a in a capillary tube, such as distribution of pressure, void fraction, dryness fraction, phase’s velocities and their drift velocity relative to the center of the mass of the mixture are presented.
Corberan et al (2004) predicted a model to calculate the mass flow rate of refrigerant in a capillary tube by means of the conservation equations (mass, momentum and energy) over individual control volumes and included in IMST-ART, software for simulation and design of refrigeration equipment. The addition of capillary tube model allows calculating the superheat at the evaporator giving the capillary tube geometry. A simulation with different operative conditions and capillary geometry is done and the results are compared for R22 with those given by ASHRAE correlations.

Li et al (2004) presented a general model format for Adjustable Throat Area Expansion Valves (ATAEV), including TEV and EEV that utilizes manufacturer’s rating data. Model structures for three types of valve geometries are derived. The model format for ATAEV was validated by using manufacturer performance rating data and the flow through the adjustable-area expansion device is not choked. Two model formats and parameter estimation procedures were considered and their predictions were compared with laboratory measurements. The non linear modeling approach only requires data at a rating condition to obtain parameters and gave good predictions over a wide range of operating conditions when compared with laboratory data.

Sarntichartsak et al (2007) conducted experiments on inverter air conditioner with variation of capillary tube using R22 and R407C and predicted model. The two zone model, the distributed model and combined model were compared to estimate the optimal charge inventory. The model prediction agrees with the experimental data in the range of 40 - 50 HZ.

Beghi et al (2009) reported some results of a research project aimed at deriving simple, high-performance, adaptive and robust control algorithms for EEV to control dry expansion evaporators superheat temperature. The adaptation scheme is based on the on-line identification of a
simplified, first order plus dead time (FODPT) model of the process. The Zhaung-Atherton method is then used to derive a new set of Proportional-Integral-Derivatives (PID) parameters, which allow the system to improve the closed-loop performance. The control algorithm has been evaluated by restoring to a detailed, a particular virtual prototyping software environment. The algorithm exhibits better performance than other auto tuning approaches, such as the one based on relay feedback. The performance has been evaluated by resorting to standard indexes such as Integral Squared Error (ISE) and Integral Squared Time Weighted Error (ISTE). Qiao et al (2010) presented an overview of the methodologies and developments of HVAC component modeling and different system solvers for steady-state simulations.

Kim and Braun (2012) developed three virtual refrigerant mass flow sensors (VRMF) by using a mathematical model to estimate the flow rate using low cost measurements and evaluated these three VRMFs for estimating refrigerant mass flow rate, fault detection and diagnostics. The first model uses a compressor map that relates refrigerant flow rate to measurements of inlet and outlet pressure, and inlet temperature measurements. The second model uses an energy-balance method on the compressor that uses a map for power consumption which is relatively independent of compressor faults that influence mass flow rate. The third model is developed by using an empirical correlation for TEV and EEV based on orifice equation. Refrigerant mass flow rate estimates given by these three VRMF sensors can be utilized to diagnose and track the following faults: (i) loss of compressor performance, (ii) fouled condenser or evaporator filter, (iii) faulty expansion device, respectively.

Prapainop and Suen (2012b) have showed two approaches of refrigerant comparison for retrofit replacement. One is the screening based on refrigerant thermo-physical properties and cycle performance analysis,
another method is the full simulation. The impact of component sizes on the refrigerant temperatures and performance is included in the full simulation while it is ignored in the former analysis. The methods are exemplified by comparing some common refrigerants, including R32, R410A, R125, R1270, R22, R407C, R290, R134a, R600a and R600. They concluded that in retrofit, the same original performance and/or capacity may not be attained due to the use of the existing heat exchangers and compressors, unless the two refrigerants have very similar properties.

Santa (2012) presented and analyzed the behavior components of the vapor compression refrigeration system in case of refrigerants R22, R134a, R407C and R410A. The simulation programme is based upon steady state mathematical-models of the refrigeration circuit including the compressor, heat exchangers and thermostatic expansion valve and concluded that the refrigerant that meets all the requirements fully is non-existent and in each case the conditions and requirements must be examined in order to choose the most suitable and favorable refrigerant.

Qiao et al (2012) stated that transient modeling methods can be classified into two categories based on equation specifications and developed a transient system model for a simple vapor compression cycle using three commercially available modeling environments such as Modelica(R), Simulink(R) and Simscape(TM) and compared the simulation results obtained by these three tools and found that the results are in good agreement, but the computation time varies significantly due to underlying model reduction and solution scheme used. These three platforms demonstrate quite different modeling concepts. Simulink is based on causal modeling approach wherein a strict input-output relationship must be defined in the model; whereas the Simscape model and Modelica model are based on the acausal modeling approach wherein no signal flow is needed to be specified.
The air conditioning system modeling discussed in the above papers show that the performance of the air conditioner with the new alternative refrigerants can be evaluated using a modeling program.

2.5 CONCLUSION FROM THE LITERATURE REVIEW

(a) Based on studies related to alternative refrigerants:

(i) The demand for the HVAC equipment are increasing year by year and vast majority of refrigeration, air-conditioning and heat pump systems for both residential and commercial, rely on vapour compression systems which uses halogenated refrigerants. These refrigerants will soon be phased out, mainly due to their ODPs and GWPs.

(ii) While attempting to find replacement for CFCs and HCFCs, two broad approaches have been tried, viz., alternative refrigerants with totally new refrigeration system design, and retrofitting the existing machines with alternative refrigerants.

(iii) Considerable studies have been reported for CFC and HCFC replacements with totally new system design and limited studies have been reported on the retrofitting approach.

(iv) The short atmospheric lifetime of HC refrigerant mixtures makes their GWP close to zero and their favourable thermodynamic and thermo-physical properties assure that the efficiencies are comparable to the halogenated refrigerants. The charge requirement of
HC refrigerants is also reported to be half of the halogenated refrigerants due to its lower liquid density. HC 290 has been successfully been commercialized as an HCFC-22 replacement in low charge, room and portable air conditioner less than 4 kW. HC mixtures such as R432A and R433A are accepted as environment friendly option for replacing R22 in air conditioning and heat pump applications. But, HC refrigerant mixtures are highly flammable in nature.

(v) Most of the studies reported in the literature used HFC32 and HFC mixtures such as R404A, R407C and R410A as alternatives to R22. R404A can be used as alternatives to R22 in low temperature refrigeration applications. R32, R407C and R410A can be used as alternative to R22 in air-conditioning and heat pump applications. However R410A cannot be used for high temperature heat pump applications due to its lower critical temperature. Too high discharge temperature and pressure of R32 in extreme high temperature conditions was a concern for the safe operation of the unit and might be a concern for the compressor lifetime cycle. The HFC refrigerant mixtures have zero ODP with significant GWP. Owing to the GWP, HFC refrigerant mixtures are considered as interim alternatives to phase out the CFC and HCFC based refrigerants.

(vi) The HC/HFC refrigerant mixtures can be used to replace CFC and HCFC refrigerants to extend the life of the existing systems. Low volatile HC refrigerants are preferred to be used as an additive with HCFC
refrigerants to tackle the oil miscibility issue and also reduce the flammability of HC mixture.

(vii) To obtain a high COP, the refrigerant should have the properties of the combinations of high values of latent heat, critical temperature, liquid thermal conductivity, vapour specific heat and vapour density and low values of liquid viscosities and molecular weight are required. Critical temperature and vapour specific heat are important properties when considering trade-offs between capacity and COP.

(viii) In retrofit, the same original performance and/or capacity may not be attained due to the use of the existing heat exchangers and compressor, unless the two refrigerants have similar properties.

(ix) Technical difficulties of the alternative refrigerant mixtures reported in the literature are listed below:

- Non–isothermal behavior of the refrigerant mixtures creates ambiguity in selecting the components of the refrigeration system from the manufacturer’s catalogue.

- Reduction in condenser and evaporator effectiveness due to non linear variation in properties of refrigerant mixtures and occurrence of the pinch points in the condenser and evaporator during phase change.

- Zeotropic refrigerant mixtures are having high temperature glide due to the difference in boiling
points and require an increased heat exchanger area to achieve the desired capacity.

- Further study is required on compatibility of the alternative refrigerant mixture with lubricants and the construction materials.

- HC refrigerant mixtures are identified as good substitutes to replace the halogenated refrigerants. But HC refrigerant mixtures are highly flammable in nature.

(b) Based on studies related to the use of EEV

(i) EEV regulates and modulates the refrigerant feed according to the load requirements by maintaining a pre selected constant suction gas superheat.

(ii) Comparing the performance of EEV with the other expansion devices such as capillary tube, AEV and TEV, EEV gives the better performance and energy saving due to precise refrigerant flow metering or precise valve opening adjustment and more steady operation.

(iii) In case of small capacity systems, the efficiency improvements are offset by the cost factors. Hence least attempts have been made earlier. In the recent times, few studies have been reported due to increased energy costs and increased awareness on reducing CO$_2$ emissions.

(iv) Test data and mass flow models of EEV are very limited in open literature. An empirical correlation to predict the mass flow coefficient and mass flow rate for the flow of
refrigerants R22, R134a, R404A, R407C and R410A through EEV were developed based on Buckingham pi Theorem and using operating conditions, EEV’s geometry parameters, refrigerants properties, method of connecting pipe and choking flow conditions of refrigerants and compared with experimental values.

(c) Based on studies related to modeling the system/ components

(i) The study of various components of a domestic air conditioning system under a range of operating conditions has become possible through mathematical modeling, saving thus a huge amount of time and money.

(ii) In order to model system behavior more accurately and effectively over a wide range of conditions, more accurate models are necessary and more general model methodology is desired. The compressor model is a map-based model. The heat exchangers are modeled using the finite volume method. The literatures on modeling changeable area expansion devices are not sufficient. The Expansion valves are modeled using empirical correlations. Expansion device models tend to be correlation based and the simplest component model when compared with other components of vapour compression system. Expansion device models tend to calculate a refrigerant mass flow rate given the refrigerant inlet condition and outlet pressure.

(iii) To investigate system’s transient response to sudden disturbance, transient or dynamic modeling work is
required. Steady state modeling is often based on modular formation in which the components of the system are separately modeled and accurate enough for simulation or design optimization for most system.

(iv) Numerical simulation has been widely used for the design and optimization of advanced products. They have combined the disciplines of thermodynamics and heat transfer. A number of attempts have been made by researchers to improve the efficiency, robustness and accuracy of simulation models.

2.4.1 Background and Objectives of the Present Work

To avoid the global warming and ozone depletion, environment friendly alternative refrigerants should be used in HVAC equipment and also new system design or method should be implemented to save the energy and improve the performance of the system. Hence, based on refrigerant property details given in the Appendix 1, the refrigerants R32, R407C and R290 are considered as a suitable alternative for R22 for room air conditioner. To improve the performance of the system and save the energy, EEV is used as expansion device instead of capillary tube (CT) and TEV. Keeping the above aspects in mind it has been decided to carry out the following in the present research work.

(i) Creating an experimental facility to study the performance of 3.45 kW (1TR) capacity room air conditioner having facility to use any one of the expansion device among CT, TEV and EEV at a time at the required indoor and outdoor conditions.

(ii) With the experimental facility created, tests to compare the performance of R22 with CT alone in the system and then with TEV alone in the system and then finally with EEV alone
in the system by changing its valve opening settings and degree of super heat of refrigerant at inlet to compressor.

(iii) Repeating the above experiments by retrofitting the same system with R407C, R290 and then with R32.

(iv) Presenting and discussing the expansion device models, characteristics of refrigerant mass flow through expansion devices, simulation and results to arrive at certain conclusions regarding the background which stimulated this research work. The following chapters present these details.