Effect of Geographical Climatic Condition on the Exergetic Efficiency of Vapor Compression Refrigeration cycle based Vehicle Air Conditioner

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Abstract-Automobile say car, bus etc normally travelles through different regions and thus encounters different geographical climatic conditions. In the present work, exergetic efficiency of vapour compression refrigeration (VCR) based air conditioner (A/C) for vehicle is presented under the effect of different climatic conditions from where automobile passed through. For this purpose six different cities have been selected situated in six different climate zones of India as per Köppen system. Exergy analysis and modelling of vehicle A/C has been done in Engineering Equation Solver (EES) software. Considering the global warming refrigerants- R1234yf and R134a have been taken for this analysis. The exergetic efficiency of the VCR system with R1234yf is found to be better as compared to R134a in all the climates considered in this work. Exergetic performance of VCR system is coming out to be somewhat lower for cold region as compared to warm regions.

Keywords-*Vapor Compression Refrigeration; Exergetic efficiency; Geographical location; Climate conditions*

I. INTRODUCTION

Second law performance of the system can be measured in terms of exergetic efficiency (Bejan et al., 1996). And as per Bejan (1996) the exergetic efficiency is the ratio between exergy rate of product and fuel. Exergy is defined as the measure of usefulness, quality or potential of a stream to cause change and an effective measure of the potential of a substance to impact the environment (Dincer, 2003). In other words exergy is the maximum acquirable or useful work potential from the amalgamation of system and environment. The work potential of the energy contained in a system at a specified state, relative to a reference state, is simply the maximum useful work that can be obtained from the system. The useful work potential of a given amount of energy at a specified state is called exergy. The exergy analysis is widely accepted as a useful tool in obtaining the improved understanding of the overall performance of any system and its components (Bolaji 2010). So, true efficiency of any thermodynamic system is depicted by the exergy (Kushik, 2011) not by energy as it merely does the book keeping of incoming and outgoing energy streams.

Vapor compression refrigeration (VCR) based vehicle A/C- a thermodynamic system, is being studied in this work. Since, auto mobiles like buses, cars etc traverse across the country so vehicle's different systems must operate in different climatic conditions as these vehicles are plying in different weather conditions prevails in those geographically different regions. These automobiles have air-conditioners (A/C) as integral part for the comfort of fellow passengers who inhabit the vehicle for the purpose. This A/C is predominantly vapour compression refrigeration (VCR) cycle based system. Different places, cities, regions vehicle travel through have varied climatic conditions as these regions situated in different geological states have different climatic /weather conditions affecting the performance of A/C. The effect of geological climate conditions on the exergetic efficiency of vehicle say car A/C is presented in this work. For this, different locations have been considered as per the different climate regions/subtype of India.

Due to the vast size of India, it has large variation in climate from region to region. India's varied geography and geology is climate sensitive. World climate is classified on Köppen system (Introduction to climate, n.d.); based on the same pattern India has six climate subtypes i.e. Montane, Humid Subtropical, Tropical wet and dry, Tropical wet, Semi-arid and Arid. Although, ECBC (ECBC 2005) clubbed six climate regions into five zones but in this work Köppen system of classification is followed. Places under study are based or situated in these said climate regions. Based on the Köppen system, India's climatic region spreads from arid desert in the west, alpine tundra and glaciers in the north, and humid tropical regions supporting rainforests in the southwest and the island territories. Based on the six climatic subtypes accordingly six different cities have been selected from them. The selected cities are Delhi, Dehradun, Dibrugarh, Chennai, Panjim and Jaisalmer. Table 1 summarized theses cities according to their respective climate subtype and same is marked on map of India in Fig.

Table I: Selected cities from six climatic zones

Climate Zone	Temperature Range	City
Montane	< 20 ºC	Dibrugarh
Humid Subtropical	20 ºC – 22.5 ºC	Dehradun
Tropical wet and dry	22.5 ºC – 25 ºC	Chennai
Tropical wet	25 ºC – 27.5 ºC	Panjim
Semi-arid	25 ºC – 27.5 ºC	New Delhi
Arid	> 28 ºC	Jaipur

Vehicle's VCR based A/C run on refrigerants. To address the global warming concern one needs to have low GWP based refrigerants. Open literature witness several work on this. Reddy et al. (2012) has investigated the exergetic analysis of vapour compression refrigeration system with

R134a, R143a, R152a, R404A, R407C, R410A, R502, and R507A. In this work it was found that R134a performed better. Padmanabhan and Palanisamy (2013) has performed exergy analysis of an air conditioner containing refrigerant R22, substituted by R134a, R290, and R407. Results indicated that COP and exergy efficiency of R290 vapor compression refrigeration system (VCRS) was higher, R407 and R134a VCRS were lower respectively in comparison with R22. Esbri et al. (2013) accomplished experimentally R1234yf as a drop-in replacement for R134a in a vapor compression system. Ansari (2013)

Fig 1: India's map showing different climate zones and selected cities

Studied the HFO-1234yf (2, 3, 3, 3-Tetrafluoropropene) and HFO-1234ze (trans-1, 3, 3, 3-tetrafluoroprop-1-ene) with R-134a exergetically for theoretical analysis of a traditional vapour-compression refrigeration system. They reported between condenser temperature 313K and evaporator temperature 223K - 273K that HFO-1234yf and HFO-1234ze can be good replacement of R-134a in vehicle A/C set up. So, R134a is being used in care A/C and R1234yf could be its potential replacement. And R1234yf and R134a have comparable thermophysical properties as shown in Table 2.

Table II. Thermophyscial properties of R1234yf and R134a (**Richter, 2011; Akasaka, 2011**)

Properties	R 1234yf	R 134a
Boiling Point , T_b (ºC)	-29	-26
Critical Point , T_c (ºC)	94.7	101
P_{vapor} (MPa) @ 25ºC	0.682	0.665
P_{vapor} (MPa) @ 80ºC	2.519	2.635
Liquid Density (25ºC) (kg/m^3)	1092	1207
Vapor Density (25ºC) (kg/m^3)	37.94	32.034

Since, R1234yf has 4 global warming potential (GWP) whereas R134a has 1430 as GWP (Brown,2009) so these refrigerants have been considered in this work. The objective of this paper is to evaluate the effect of geographical location based climate conditions on the exergetic efficiency of vehicle/car air conditioner using R1234yf and R134a and present the comparison among the refrigerants. In this regard second law modelling of vapour compression cycle has been done in Engineering Equation Solver (EES). Climate data for different location's i.e. Delhi, Dehradun, Dibrugarh, Chennai, Panjim and Jaisalmer, were obtained from NREL and used in the analysis (NREL, nd; USDOE, nd).

System Description and Exergy Modelling

Air conditioner works on simple vapour compression cycle. The VCR system can consists of five components such as evaporator, compressor, condenser, liquid-vapor heat exchanger (LVHE) and expansion valve. These components connected in a closed loop through piping in the open atmosphere so that heat transfer can take place with the surrounding. The schematic view of the system (Reddy, 2012) is shown below in Fig. 2. Working of cycle is conventional –refrigerant at low pressure and low temperature vapour state (may be super heated) enters into compressor at state point 2 via LVHE ; compressor raised the low pressure if refrigerant to condenser pressure i.e. high pressure and this leads to increase in temperature so superheated vapor refrigerant from compressor enters into condenser . And their (in condenser) superheated refrigerant loses degree of super heat, latent heat and may be sub-cooled with the application of LVHE and enters for throttling process at state 6; refrigerant vapour expanded from high pressure to low pressure in isenthalpic process and at 7 low vapor refrigerant at low temperature again enters into evaporator and cycle continues.

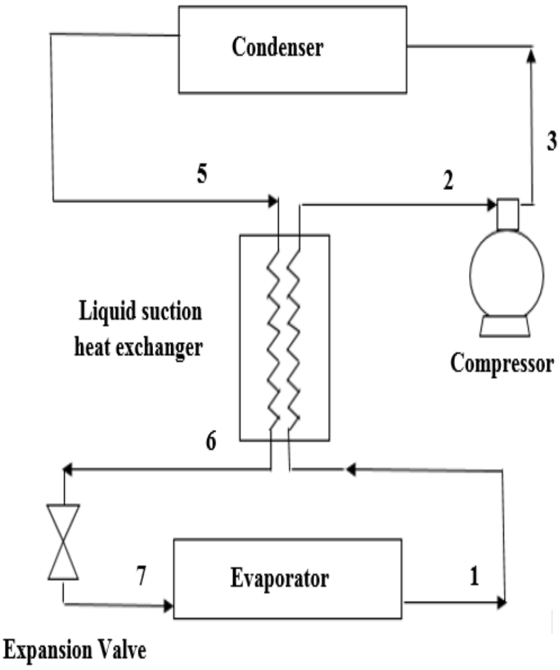

Fig 2: Schematic diagram of VCR system

The Temperature-entropy diagram shown in Fig. 3 for R134a has been presented for mentioned cycle as explained in Fig. 2 depicting system various parameters like evaporator and condenser pressure, various temperature at various shown state points etc.

For the analysis following assumption have been considered

1. Steady state operations are considered in all components of the system.
2. Kinetic and potential energy changes are zero.
3. Mass flow rate is constant throughout.
4. Pressure drops considered in this analysis from compressor discharge to condenser outlet it is 0.05kg/cm^2 and from expansion to compressor inlet it is 0.11kg/cm^2 taken from air conditioning test rig (Permesh, 2014).

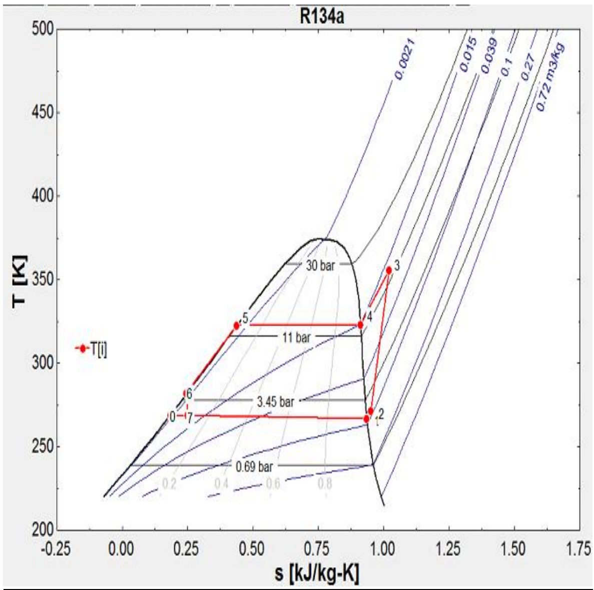

Fig 3: Temperature entropy (T-s) diagram of R134a based VCR cycle (Pooja 2015)

5. Temperature of evaporator is taken as 278 K.
6. Temperature at exit of condenser is taken as 323 K.
7. Degree of subcooling and superheating in LVHE i.e. $\Delta Tsub$ and ΔTsup is 5 K.
8. LVHE 's effectiveness is assumed to be 100%
9. Isentropic efficiency of compressor is 0.85.
10. Mechanical efficiency of compressor is 0.9.

The modelling of the system has been done in Engineering Equation Solver (EES) Version 8.629 (Klien, 2010)

Exergetic Modelling of System-

Exergy balance for a control volume undergoing steady state process is expressed as (Lee and Sherif, 2001).And various components of VCR system shown in Fig. 2 are open systems exergy balanced equations (Arora and Kaushik 2008; Reddy et al. 2012) are employed for the various components of vapour compression refrigeration system.

Exergy balance for Compressor

$$-\dot{W}_c = \dot{m}_1(\psi_2 - \psi_3) - T_0 S_{gen} \qquad \text{...... (1)}$$

The irreversibility or exergy loss in compressor is presented as

$$I_{dest\_c} = T_0 S_{gen} = \dot{m}_1(\psi_2 - \psi_3) + \dot{W}_c \qquad \text{...... (2)}$$

$$I_{dest\_c} = \dot{m}_1 T_0 (s_3 - s_2) \qquad \text{...... (3)}$$

The exergetic efficiency of compressor can be obtained as

$$\eta_{II\_C} = 1 - \frac{I_{dest\_c}}{\dot{W}_c} \qquad \text{...... (4)}$$

Where W_c is power (W); $\dot{m}_1$ is mass flow rate of refrigerant (kg/s); ψ is flow exergy (kW); T_0 is the ambient temperature (K); S_{gen} is the entropy generation (kJ/K);

I_{dest_c} is exergy destruction in compressor (kW); s is the specific entropy (kJ/kgK); T_0 is the dead state of the system (K); η_{II_C} is the exergetic efficiency of compressor.

Exergy of balance in condenser-

$$0 = \dot{m}_3(\psi_3 - \psi_5) - \sum_{K=1}^{n}(1-\frac{T_0}{T_k})Q_k - T_0\dot{S}_{gen} \quad ...... (5)$$

The irreversibility or the exergy loss in condenser is presented as

$$I_{dest\_con} = T_0 S_{gen} = (\dot{m}_3((h_3 - h_5) - T_0(s_3 - s_5)) - Q_5(1-\frac{T_0}{T_5}) \quad ...... (6)$$

The exergetic efficiency of condenser is

$$\eta_{II,con} = 1 - \frac{I_{dest\_con}}{\dot{m}_3(\psi_3 - \psi_5)} \quad ...... (7)$$

Where Q_5 heat transfer rate in condenser (kW); T_5 is the condenser outlet temperature (K); I_{dest_con} is the exergy destruction of condenser (kW); $\eta_{II,con}$ is the exergetic efficiency of condenser.

Exergy balance equation for Liquid Suction heat exchanger-

$$0 = \dot{m}_5(\psi_5 - \psi_6) - \dot{m}_1(\psi_2 - \psi_1) - T_0 S_{gen} \quad ...... (8)$$

The irreversibility is given as:

$$I_{dest\_hx} = T_0 S_{gen} = (\dot{m}_5(h_5 - h_6) - \dot{m}_1(h_2 - h_1)) - T_0(\dot{m}_5(s_5 - s_6) - \dot{m}_1(s_2 - s_1)) \quad ...... (9)$$

The exergetic efficiency is:

$$\eta_{II\_hx} = 1 - \frac{I_{dest\_hx}}{\dot{m}_5(\psi_5 - \psi_6)} \quad ...... (10)$$

Where I_{dest_hx} is exergy destruction of liquid suction heat exchanger (kW); η_{II_hx} is the exergetic efficiency of liquid suction heat exchanger.

Exergy balance of Expansion valve-

$$0 = \dot{m}_6(\psi_6 - \psi_7) - T_0 S_{gen} \quad ...... (11)$$

The exergy destruction in expansion valve is given by

$$I_{dest\_exp} = T_0 S_{gen} = \dot{m}_6((h_6 - h_7) - T_0(s_6 - s_7)) \quad ..... (12)$$

The exergetic efficiency is

$$\eta_{II\_exp} = \frac{\psi_7}{\psi_6} \quad ...... (13)$$

Where I_{dest_exp} is exergy destruction of expansion valve (kW); η_{II_exp} is exergetic efficiency of expansion valve.

Exergy balance for Evaporator can be written as

$$0 = \dot{m}_7(\psi_1 - \psi_7) - \sum_{K=1}^{n}(1-\frac{T_0}{T_k})Q_k - T_0\dot{S}_{gen} \quad ...... (14)$$

The exergy destruction in evaporator is given by,

$$I_{dest\_eva} = T_0 S_{gen} = \dot{m}_7((h_1 - h_7) - T_0(s_1 - s_7)) - Q_7(1-\frac{T_0}{T_7}) \quad ...... (15)$$

The exergetic efficiency is:

$$\eta_{II\_eva} = 1 - \frac{I_{dest\_eva}}{\dot{m}_1(\psi_1 - \psi_7)} \quad ...... (16)$$

Where Q_7 heat transfer rate in evaporator (kW); T_7 is the temperature at exit of expansion valve (K); I_{dest_eva} is the exergy destruction in evaporator (kW); η_{II_eva} is the exergetic efficiency of evaporator.

For the Exergetic efficiency of the VCR system which is -

$$\eta_{exergetic} = \frac{\text{Exergy output}}{\text{Exergy input}} \quad ...... (17)$$

The total exergy destruction rate (X_t) obtained (Bolaji, 2010) would be summation all the exergy destruction of the components. From equations (3), (6), (12) and (15) and assuming LVHE working with 100 % effectiveness so no exergy destruction in LVHE (this is for simplicity). Net exergy destruction obtained as

$$X_t = I_{dest\_c} + I_{dest\_con} + I_{dest\_exp} + I_{dest\_eva} \quad ...... (18)$$

The overall system exergetic efficiency is the ratio of exergy output (X_{out}) to exergy input (X_{in}). Equation (17) can be written as $\eta_{exergetic} = (\frac{X_{out}}{X_{in}}) \times 100\%$ ...... (19)

Whereas Exergy output can be expressed as,

$$X_{out} = X_{in} - X_t \quad ...... (20)$$

$\eta_{exergetic}$ is the exergetic efficiency of the VCR system. Exergy input to the system is supplied through the compressor work(Bolaji, 2010).

$$X_{in} = \dot{W}_c \quad \text{...... (21)}$$

From equations (19), (20) and (21)

$$\eta_{exergetic} = (1 - \frac{X_t}{\dot{W}_c}) \times 100\% \quad \text{...... (22)}$$

Exergetic efficiency of the system is obtained using equation (22).

II. RESULTS AND DISCUSSION

The exergetic efficiency of vehicle/car air conditioner has been calculated using properties of refrigerants- R1234yf and R134a. It is assumed that car travelled across different (said) cities in the month of April and May. Climate data for the different cities used in this study are TMY2 data set of hourly weather observation. TMY2 data set was created by Indian Society of Heating, Refrigeration and Air Conditioning Engineers (ISHRAE) for Indian cities and is made available by US department of energy (USDOE n.d.). This data can be downloaded using System advisor model (SAM) software. This software is developed by National Renewable Energy Laboratory (NREL) of US department of energy and can also be downloaded from their website (NREL n.d.).

Exergetic modelling of VCR based vehicle A/C has already been discussed in previous section; dead state used for getting exergy of different components is an environment dependent parameter. So, based on the climate data (which is hourly temperature data)-the dead states for the different cities have been calculated. Like study/analysis is done for week for this - dead state of week would be the average of the minimum temperature of the all seven days; same way for the month long analysis the dead state would be the average of the minimum temperature of all the days comprising of month. For this study it is assumed that vehicle spent first week in Delhi then next week in Dehradun, then Dibrugarh after it Chennai and then in Panjim and last week in Jaisalmer. The overall exergetic efficiency of the VCR based A/C system has been calculated for two refrigerants i.e. R1234yf and R134a for different locations and the effect of geographical climate condition on exergetic efficiency has been summarized (Pooja, 2015) in tables 3, 4,5,6,7 and 8. In these said tables the exergetic efficiency obtained at day's minimum temperature. For example in table 3, exergetic efficiency calculated for R1234yf is 37.12% using dead state as 290 K which is minimum temperature of day 1. Same way table also present the comparison of exergetic efficiency using week minimum temperature as well as week's average value of minimum temperatures.

It has been found from the table that with the increase in value of dead state there is increase in exrgetic efficiency. This trend is observed in all the tables i.e. 3, 4,5,6,7 and 8. The tables 3,4,5,6,7 and 8 illustrates that refrigerant R1234yf is having higher exergetic efficiency as compared to R134a by 2%, 1.7%, 1.9%, 2%, 2.3%, 2.4% for Delhi, Dehradun and Dibrugarh, Chennai, Panjim and Jaisalmer respectively. Table 9 summaries the comparison of exergetic efficiency obtained based on the avg. week temperature prevails in the specific city.

Table III: Comparison of Exergetic efficiency of an automobile A/C working on R 1234yf and R134a for Delhi for the first week of April

Week 1		Dead State (K)	$\eta_{exergetic}$ (%)	
Day			R1234yf	R134a
1		290	37.12	36.38
2		290	36.80	36.07
3		292	39.36	38.51
4		291	38.08	37.29
5		291	37.76	36.99
6		295	44.47	43.40
7		293	41.92	40.96
Week	Minimum	290	36.80	36.07
	Average	292	39.36	38.51

From table 9 it is observed that average temperature of Delhi (i.e. first week of April) find out to be slightly on the lower side i.e. 292 K than Chennai, Jaisalmer which are observed to be almost same i.e. 298 K and 299 K respectively. It is because of this reason exergetic efficiencies comes out to be same for Chennai and Jaisalmer and lower for Delhi region. Whereas, in Dehradun $\eta_{exergetic}$ low because of minimum temperature is lower than that rest of the cities i.e. 288 K; because of its proximity to hills, cold nights, so, average comes out to be low for Dehradun. Whereas in case of Delhi due to large deviation in temperature variation in week the average value of Delhi is at higher side i.e. 292 K as compared to Dehradun.

Table IV: Comparison of Exergetic efficiency of an automobile A/C working on R 1234yf and R134a for the second week of April spent in Dehradun

Week 2		Dead State (K)	$\eta_{exergetic}$ (%)	
Day			R1234yf	R134a
1		290	36.88	36.23
2		290	37.36	36.68
3		287	31.28	30.89
4		286	30.80	30.43
5		287	31.60	31.19
6		286	30.17	29.82
7		287	32.24	31.80
Week	Minimum	286	30.80	30.43
	Average	288	32.90	32.43

Those regions where spread of minimum temperature is at lower side that resulting in a low average temperature of week and it observed low $\eta_{exergetic}$ of the system. This is evident from the table 4 for Dehradun where avg. temp. shown as 288K and $\eta_{exergetic}$ is 32.90% while using R1234yf and 32.42% for R134a. Whereas in those regions where avg. week temp is on higher side as shown in table 6 and 8 i.e. for Jaiselmer and Chennai the $\eta_{exergetic}$ of the VCR system found to be 51.46% at 299 K, and 50.28% at 298 K respectively in case of R1234yf . Reason attributed to the fact that overall spread of temperature is on higher side owing to geographical conditions e.g. Chennai is in hot and humid climate and Jaiselmer is lying in hot and dry. Delhi comes under composite climate but April is somewhat colder as it is the end of winter and beginning of summer so at 298K (as avg. temp.) the $\eta_{exergetic}$ with R1234yf reported to be 39.76%. Dehradun is a hilly area and mean temperature may drop more as compared to the other regions i.e. why avg. of minimum temp. reported to be low among all the chosen cities and thus lower exergetic efficiency of VCR system.

Table V: Comparison of Exergetic efficiency of an automobile A/C working on R1234yf and R134a for the third week of April spent in Dibrugarh

Week 3		Dead State (K)	$\eta_{exergetic}$ (%)	
Day			R1234yf	R134a
1		291	38.80	38.06
2		291	38.00	37.29
3		292	39.92	39.12
4		291	39.12	38.36
5		293	41.84	40.96
6		293	41.20	40.35
7		292	41.52	39.12
Week	Minimum	291	38.00	37.29
	Average	292	39.82	39.03

The refrigerant R1234yf is having higher exergetic efficiency as compared to R134a for all the cities i.e. Delhi, Dehradun and Dibrugarh, Chennai, Panjim and Jaisalmer respectively. This can be attributed to the properties of R1234yf (mainly enthalpies) which are lower in value than R134a at the same temperature and pressure. As GWP of R1234yf is very less i.e. 4 as compared to R134a having GWP of 1430 which is much higher. It can be inferred that R1234yf would be better replacement of R134a.

Dehradun having lowest dead state temperature among the cities witness the least exergetic performance of the automobile VCR based A/C system and Jaiselmer having highest dead among Chennai, Panjim, Jaiselmer observing high value of avg. temp, reported better exergetic performance as shown in Table 9 and out of them Jaiselmer observed the best exegetic performance in terms of maximum exergetic efficiency of the system.

Performance of the VCR based A\C can be improved in regions where $\eta_{exergetic}$ reported to be low by shutting off the A/C some times. Install automatic sensor which senses the climate variation and switch off the A/C. This can be done for the Delhi (for the week chosen)

Table VI: Comparison of Exergetic efficiency of an automobile A/C working on R1234yf and R134a for the fourth week of April spent in Chennai

Week 4		Dead State (K)	$\eta_{exergetic}$ (%)	
Day			R1234yf	R134a
1		299	50.47	49.19
2		298	50.75	48.89
3		299	51.43	50.11
4		297	48.23	47.06
5		298	48.87	47.67
6		298	49.83	48.50
7		300	53.03	51.63
Week	Minimum	297	48.23	47.06
	Average	298	50.28	49.01

Table VII: Comparison of Exergetic efficiency of an automobile A/C working on R 1234yf and R134a for the first week of Mayspent in Panjim

Week 5		Dead State (K)	$\eta_{exergetic}$ (%)	
Day			R1234yf	R134a
1		295	45.35	44.31
2		296	46.95	45.84
3		297	48.07	46.91
4		295	45.35	44.31
5		296	45.99	44.92
6		294	42.80	41.87
7		295	44.23	43.24
Week	Minimum	294	42.80	41.87
	Average	295	45.53	44.48

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Table VIII: Comparison of Exergetic efficiency of an automobile A/C working on R 1234yf and R134a for Jaisalmer for second week of May i.e. 6th week of journey

Week 6		Dead State (K)	ηexergetic (%)	
Day			R1234yf	R134a
1		297	48.23	47.06
2		298	49.83	48.58
3		297	48.39	47.21
4		297	48.71	47.52
5		302	55.58	54.08
6		301	55.11	53.62
7		301	54.39	53.01
Week	Minimum	297	48.23	47.06
	Average	299	51.46	50.14

Table 9: Exergetic efficiency of automobile A/C using R1234yf and R134a in different cities with mean temperature of a week as dead state

Places	Dead State (K)	R1234yf ηexergetic (%)	R134a ηexergetic (%)
Delhi	292	39.36	38.51
Dehradun	288	32.90	32.43
Dibrugarh	292	39.82	39.03
Chennai	298	50.28	49.01
Panjim	295	45.53	44.48
Jaisalmer	299	51.46	50.14

III. CONCLUSIONS

The exergy analysis of an automobile air conditioner has been carried out with geographical climate condition. For this purpose six different cities have been selected from six different climate zones of India based on Koppen system. The system's second law modeling has been done in Engineering Equation Solver (EES) Version 8.629. The refrigerants R1234yf and R134a have been taken for analysis. It has been concluded from the results that refrigerant R1234yf performed better than R134a in all geographically different climatic conditions.

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Nomenclature

W_c is the work given to the compressor (W)

$\dot{m}_1$ is mass flow rate of refrigerant (kg/s)

ψ is flow exergy (kW)

T_0 is the ambient temperature (K)

S_{gen} is the entropy generation (kJ/K)

T_0 is the dead state of the system (K)

T_5 is the condenser outlet temperature (K)

T_7 is the temperature at exit of expansion valve (K)

Q_5 heat transfer rate in condenser (kW)

Q_7 heat transfer rate in evaporator (kW)

I_{dest_con} is the exergy destruction of condenser (kW)

I_{dest_hx} isexergy destruction of liquid suction heat exchanger (kW)

I_{dest_eva} is the exergy destruction in evaporator (kW)

I_{dest_c} is exergy destruction in compressor (kW)

I_{dest_exp} is exergy destruction of expansion valve (kW)

η_{II_C} is the exergetic efficiency of compressor

$\eta_{II,con}$ is the exergetic efficiency of condenser

η_{II_hx} is the exergetic efficiency of liquid suction heat exchanger

η_{II_exp} is exergetic efficiency of expansion valve.

η_{II_eva} is the exergetic efficiency of evaporator.

$\eta_{exergetic}$ is the exergetic efficiency of the whole actual vapour compression cycle

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Area of interest in refrigeration and air conditioning and research area is analysis and design development of vapour absorption refrigeration system and exergy analysis of vapour compression system and refrigerants.