Isı Bilimi ve Tekniği Dergisi, 39, 1, 31-38, 2019
J. of Thermal Science and Technology

ISSN 1300-3615

# COMPARATIVE EXPERIMENTAL EVALUATION ON HEATING PERFORMANCE OF A MOBILE AIR CONDITIONING SYSTEM USING R134A, R1234ZE(E), R152A and R444A

**Mehmet DİREK and Fikret YÜKSEL**
Yalova University, Department of Energy Systems Engineering 77200 Yalova, Turkey
mehmet.direk@yalova.edu.tr, fyuksel@yalova.edu.tr

(Geliş Tarihi: 13.09.2018, Kabul Tarihi: 23.01.2019)

**Abstract**: In this study, the use of R1234ze(E), R152a and R444a as alternative to R134a in a mobile air conditioning (MAC) system are tested. The performance characteristics of R134a, R444a, R1234ze(E) and R152a were experimentally examined in a MAC system by changing the air temperatures. Besides, the influence of compressor volume when the system operates with R1234ze(E) was investigated. The results show that the heating performance of R152a are higher than those obtained from R134a, R444a, R1234ze(E). Additionally, R1234ze(E) has lowest heating capacities among the low GWP refrigerants investigated. The heating performance of R1234ze(E) increased along with increasing the total compressor volume. Finally, R444a, R152a and R1234ze(E) can be used as alternative to R134a in MAC systems when the necessary improvements are made.
**Keywords**: Mobile air conditioning system, R134a, R1234ze(E), R152a and R444a

# R134A, R1234ZE(E), R152A ve R444A SOĞUTUCU AKIŞKANLARINI KULLANAN BİR MOBİL İKLİMLENDİRME SİSTEMİNİN ISITMA PERFORMANSININ KARŞILAŞTIRMALI DENEYSEL DEĞERLENDİRİLMESİ

**Özet**: Bu çalışmada, R134a'ya alternatif olarak R1234ze(E), R152a ve R444a soğutucu akışkanlarının bir mobil iklimlendirme sisteminde kullanımı test edilmiştir. Hava sıcaklıkları değiştirilerek R134a, R444a, R1234ze(E) ve R152a'nın performans özellikleri deneysel olarak incelenmiştir. Ayrıca, sistem R1234ze(E) ile çalışırken kompresör hacminin etkisi araştırılmıştır. Sonuçlar, R152a'dan elde edilen ısıtma performansı değerlerinin R134a, R444a ve R1234ze(E)'den daha yüksek olduğunu göstermektedir. Ayrıca, R1234ze(E) en düşük ısıtma performansı değerlerine sahiptir. R1234ze(E)'nin ısıtma kapasitesi, toplam kompresör hacminin artmasıyla birlikte artmıştır. Son olarak, R444a, R152a ve R1234ze(E), gerekli iyileştirmeler yapıldığında mobil iklimlendirme sistemlerinde R134a'ya alternatif olarak kullanılabilir.
**Anahtar kelimeler**: Mobil iklimlendirme sistemi, R134a, R1234ze(E), R152a ve R444a

## NOMENCLATURE

| | |
|---|---|
| $h$ | Enthalpy [kJ/kg] |
| $\dot{m}$ | Mass flow rate [kg/s] |
| $P$ | Pressure [kPa] |
| $\dot{Q}$ | Heat transfer [kW] |
| $T$ | Temperature [K] or [°C] |
| $\dot{W}$ | Work [kW] |

***Subscript***

| | |
|---|---|
| a | Air |
| comp | Compressor |
| cond | Condenser |
| e | Exit |
| evap | Evaporator |
| ind | Indoor |
| outd | Outdoor |
| ref | Refrigerant |

## INTRODUCTION

One of the biggest problem humankind facing today is the increase of the greenhouse effect and global warming. European union has approved some regulation for the usage of chlorofluorocarbon (CFC), hydrocloroflorocarbon (HCFC) hydrofluorocarbon (HFC), which are directly related to global warming. The most of the existing MAC systems generally use R134a which belongs to HFC family that have high impact on the increase of the greenhouse effect. However, those brought some restrictions for the refrigerants, which have global warming potential GWP values higher than 150, using in MAC systems (EC 517/2014).

The refrigerants of R1234yf, R1234ze(E), R152a, R444a can be alternatives for R134a due to their thermophysical properties and low GWP values (Table 1). Among them, R1234ze(E), which has very low GWP, is one of the most promising candidate that could be as alternative of R134a in MAC systems (Direk and Soylu, 2018). Jankovic et al. (2015) performed experiments in a vapor compression refrigeration (VCR) system operating with R1234ze(E) as a replacement of R134a. The results illustrated that the R1234ze(E) cooling performance is 27% lower and the COP was very close to that of R134a. Moreover, R1234ze(E) provided the same cooling performance as R134a at 34% - 39% higher compressor speeds. In a similar study, Mato-Babiloni et al. (2017) figured that R1234ze(E) provided the same cooling performance values as R134a at 36% higher compressor speeds. In order to improve of the system performance, R1234ze(E) can be used as blend with some refrigerants. Lee et al. (2015) studied a MAC system with the refrigerants of R152a, R444a and R445a, respectively. The highest COP was obtained when the system worked with R152a. In another study, Scherer et al. (2003) observed that R152a can provide similar performance values compared to R134a.

As defined by international standard (ASHRAE 34), R444a is composed of 83%-R1234ze(E), 12%-R32 and 5%-R152a. Therefore, international standards were taken as reference in this study. Devecioğlu and Oruç (2017) theoretically performed an energy assessment of a VCR cycle using R1234yf, R444a and R445a. They found that R444a and R445a had lower cooling capacity, but higher COP value than that of R1234yf.

Meanwhile, in order to heat passenger comportment, the vehicles employ the heating system, relying on the usage of the waste heat of the internal combustion engine. However, in case of both low engine speed and torque, engine coolant can not be sufficient for the desired heating performance (Hosoz et al. 2015). On the other hand, heat pump system can be used in vehicles to heat the passenger compartment (Hosoz and Direk, 2006). Meng et al. (2018), tested a MAC system using R1234yf/R134a (mass ratio of 89/11), as a refrigerant. They determined that compressor outlet temperature of R1234yf/R134a was about 10 °C lower compared to R134a. Lee et al. (2016) investigated the COP and heating capacity of a MAC system under transient and steady state conditions. COP and heating capacity were obtained as 3.26 and 3.10 kW, respectively at -10 °C. As a result, they recommended the usage of heat pump system along with resistive type electric system when the outside temperature below -10 °C. Wanga et al. (2017) tested a MAC system at ambient temperatures of 0, -5 and -15 °C in transient conditions. They observed that the system was inadequate at -15 °C. Qin et al. (2014) tested a MAC system at -20 °C. The result showed that even when the outdoor unit's inlet air temperature is -20 °C, the COP value of the system was still above 1.7. Additionally, even at very low air temperatures outdoor unit of the heat pump system can be defrosted by reversing the operating system. Experimental results illustrated that at -20 °C ambient temperature defrosting time took 100 s (Zhou et al. 2017). When the engine coolant used as heat source in heat pump system, it can provide higher air temperature values than the baseline heating system in the transient regime (Hosoz et al. 2015). In a typical electrical vehicles, resistive type electric systems are used for cabin heating. However, Qi (2015) investigated that the heat pump system can be used for better energy management of the electrical vehicles. When the heat pumps are used instead of resistive type electric system in electric vehicles, consumption can be reduced up to 52% (Sara et al. 2018).

In this study, performance characteristics of a MAC system utilizing R134a, R444a, R1234ze(E) and R152a were comparatively investigated in heating mode. Besides, the influence of compressor volume on the performance characteristics of the MAC system was investigated when the system operates with R1234ze(E).

## EXPERIMENTAL SYSTEM

The system is composed of equipment used in air conditioning system of a typical compact automobile as seen in Figure 1. The specifications of the components used in the MAC system were demonstrated in Table 2.

**Table 1.** Refrigerant properties at 25 °C (Lemmon et al. 2014)

| **Property** | **R134a** | **R152a** | **R1234ze(E)** | **R444a** |
|---|---|---|---|---|
| ASHRAE safety classification | A1 | A2 | A2L | A2L |
| ODP | 0 | 0 | 0 | 0 |
| GWP | 1300 | 124 | 4 | 93 |
| Critical temperature (K) | 374.21 | 386.4 | 382.51 | 374.39 |
| Critical pressure (kPa) | 4059.28 | 4516.8 | 3634.9 | 4235.8 |
| Vapor density ( $kg.m^{-3}$) 25 °C | 32.35 | 18.47 | 11.65 | 28.5 |
| Liquid density ($kg.m^{-3}$) 0 °C | 1294.8 | 959.11 | 1240 | 1199.1 |
| Latent heat of vaporization ($kJ.kg^{-1}$) | 177.78 | 279.36 | 166.92 | 180.5 |

In order to function the indoor unit of the MAC system as a condenser when operating in heat pump mode, a four way valve was introduced. To provide desired air flow velocities and temperatures, the indoor and outdoor units were placed in the air ducts which are equipped with fans and electric heaters inside. To determine the mean air velocity of both the indoor and outdoor unit, air velocities 9 different regions were measured by using an anemometer. The procedure during the heating application seen in Figure 1 can be explained as follow. In heating application, firstly, refrigerant is send to the indoor unit. While the refrigerant goes through the indoor unit (condenser) it releases its heat when condensation occurs. Afterward, it reaches to the expansion valve and diminishes its temperature and pressure. Then, refrigerant gains heat from the environment in the outdoor unit (evaporator) and finally the cycle of the heating process is over.

Experimental system was equipped with temperature and pressure sensors. Temperatures and pressures of the refrigerants were recorded via data acquisition device. Temperatures at given spots were measured using K-type thermocouple. The compressor used in MAC system was powered by a belt driven by a 2.2 kW electrical motor. The speed control of the electrical motor was controlled by a Frequency inverter. The photo of experimental MAC system and measuring devices are demonstrated in Figure 2. Table 3 shows the ranges and precisions of measuring devices.

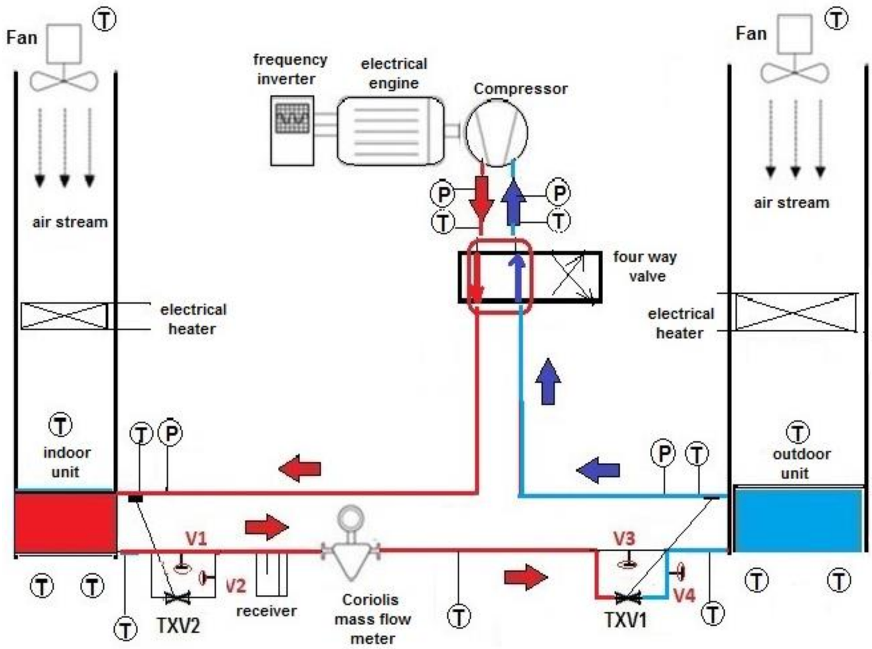


**Figure 1.** Schematic diagram of MAC system in heating mode

**Table 2.** Specifications of components

| **Components** | **Specifications** |
|---|---|
| Compressor | Swash-plate type 138 cc<br>Number of Cylinders: 5<br>(belt-driven by 2.2 kW electrical motor, φ=0.85) |
| Outdoor unit (evaporator) | 580 x 350 x 20 $mm^3$ |
| Indoor unit (condenser) | 220 x 260 x 60 $mm^3$ |
| Expansion valve | TXV (Internally equalized with bulb 5.27 kW) |

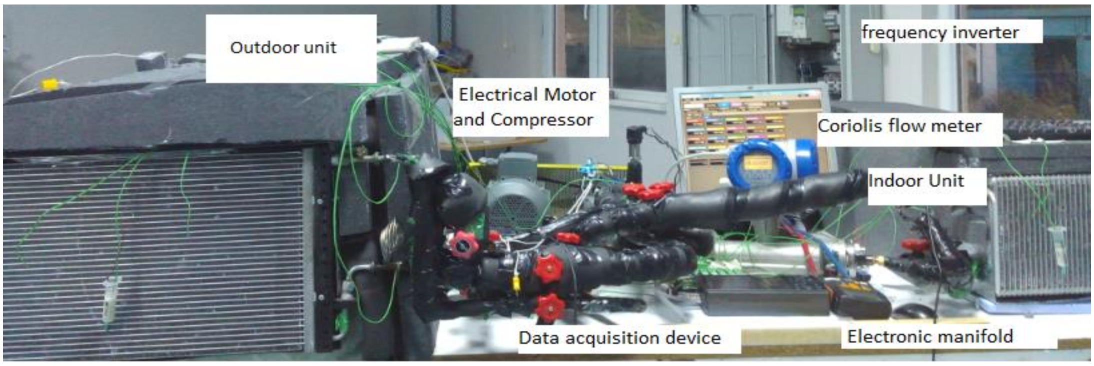


**Figure 2.** The photo of experimental MAC system and measuring devices

**Table 3.** Measuring device characteristics

| Measurement | Device | Range | Precision |
|---|---|---|---|
| Temperature | K-type Thermocouple | -100 - 1370 ºC | ± 0.8 ºC |
| Pressure | Electronic Manifold | -1 - 60 bar | ± 0.5% |
| Air Flow Rate | Anemometer | 0 - 30 $ms^{-1}$ | ± 2% |
| Refrigerant Fluid Flow | Coriolis mass flow meter | 0 - 5 $kg.s^{-1}$ | ±0.1% |
| Power Measurements | Brymen BM-157 Clamp Meter | 0-600 kW | ±2% |
| Frequency Inverter | ABB-ACS 355 | 10 Hz - 50 Hz | ±0.2% |

## THERMODYNAMIC ANALYSIS

In order to determine the thermophysical properties of refrigerants, REFPROP 9.1 was used (Lemmon et al. 2014). The heating capacity was determined using enthalpy difference at the indoor unit.

$$\dot{Q}_{heating} = \dot{m}_{ref}\,(h_{ind,unit,e} - h_{ind,unit,i}) \qquad (1)$$

Compressor power was evaluated by the following equation.

$$\dot{W}_{comp} = \dot{m}_{ref}\,(h_{comp,e} - h_{comp,i}) \qquad (2)$$

At the same time, heating COP can be evaluated as follows.

$$COP_{heating} = \frac{\dot{Q}_{heating}}{\dot{W}_{comp}} \qquad (3)$$

## EXPERIMENTAL CONDITIONS

REFPROP 9.1 was used to determine the thermophysical properties and enthalpies of refrigerants (Lemmon et al. 2014). In order to determine the amount of charged refrigerants into the system we considered the reference liquid density values given in Table 1. Therefore, 625g R134a, 600g R1234ze(E), 512g R444a and 460g R152a were charged into the system. Before the heat pump system is activated, the airflow temperatures passing through the indoor and outdoor units are set to the specified values. During the experiments, the inlet $T_{air}$ of the indoor unit were at 5 and 20 °C, while the outdoor unit temperature was at 5° C. Steady state tests were carried out between 750 and 2250 rpm compressor speeds by increments of 500 rpm intervals. Prior to heating experiments the system was pumped down. And the vacuum pull was completed when the electronic manifold stabilized. First, a number of tests were carried out for the system R134a. After this step, same test were carried out for R1234ze(E) and R152a, R444a under the same conditions.

Air flow velocity at the inlet of the indoor and outdoor unit were maintained at 2.6 $ms^{-1}$ and 2.4 $ms^{-1}$, respectively. The ideal conditions of the system was prepared within 10-15 minutes. The heating capacity and COP uncertainty ratio obtained as 1.35% and 4.6% by using the measurement of precision data collected from Table 3. Superheat values of refrigerants is illustrated in Table 4.

**Table 4.** Superheat values of refrigerants ($T_{ind\ unit\ ain}$ =5 °C, $T_{outd\ unit\ ain}$ =5 °C)

| | Superheat degree (°C) | | | |
|---|---|---|---|---|
| **Compressor speed (rpm)** | R134a | R1234ze(E) | R444a | R152a |
| **750** | 4.57 | 6.31 | 11.95 | 4.32 |
| **1250** | 11.22 | 13.96 | 18.05 | 9.68 |
| **1750** | 15.98 | 15.29 | 22.55 | 13.82 |
| **2250** | 18.47 | 20.89 | 25.51 | 16.76 |

## RESULTS AND DISCUSSION

In this section, the investigated performance characteristics of MAC system are presented for the refrigerants of R152a, R1234ze(E), R444a and R134a. During the experiments, compressor speeds were kept at the ranges from 750 to 2250 rpm (by increments of 500 rpm intervals). $T_{air}$ at the inlet of the indoor unit were kept 5 °C and 20 °C, respectively. Air flow velocity and $T_{air}$ at the inlet of the outdoor unit were maintained at 2.4 $ms^{-1}$ and 5 °C, respectively. Figure 3 illustrates the changes in performance characteristics as a function of the compressor speeds. Figure 3a presents that the heating performances increased with increasing compressor speeds. The heating performances of R152a are higher than that of R444a, R134a and R1234ze(E) in the range of different compressors speeds. The main reason of this, the latent heat of R152a is higher than that of R134a by 50-55% during condensation. Thus, heating capacity obtained from R152a is the highest. Besides, when Figures 3c and 3d are examined together, it is observed that the $P_{cond}$ obtained from R444a are higher because of higher $m_{ref}$ (Figure 3d). Figure 3d presents that R444a has highest mass flow rate among the other refrigerants. R444a has higher condenser pressure and mass flow rate compared to R134a. Compressor power values of R444a are higher than R134a due to high mass flow rates and high condenser pressures (Figure 3f).

On the other hand, the vapor density and the latent heat values of R1234ze(E) 19% and 7% lower compared to the R134a (Lemmon et al. 2014). Besides, condensation and evaporation pressures of R1234ze(E) are smallest among considered refrigerants due to the less vapor density. Therefore, R1234ze(E) has the lowest heating capacity values among the low GWP refrigerants investigated. The compressor power obtained with R1234ze(E) is lower than that of R134a, R152a and R444a and the highest compressor power are obtained with R152a and R444a. Although it is figured that R152a has a better heating performance compared to the other refrigerant. Extra safety precaution should be taken because it has the classification of burning A2 as seen in Table 1.

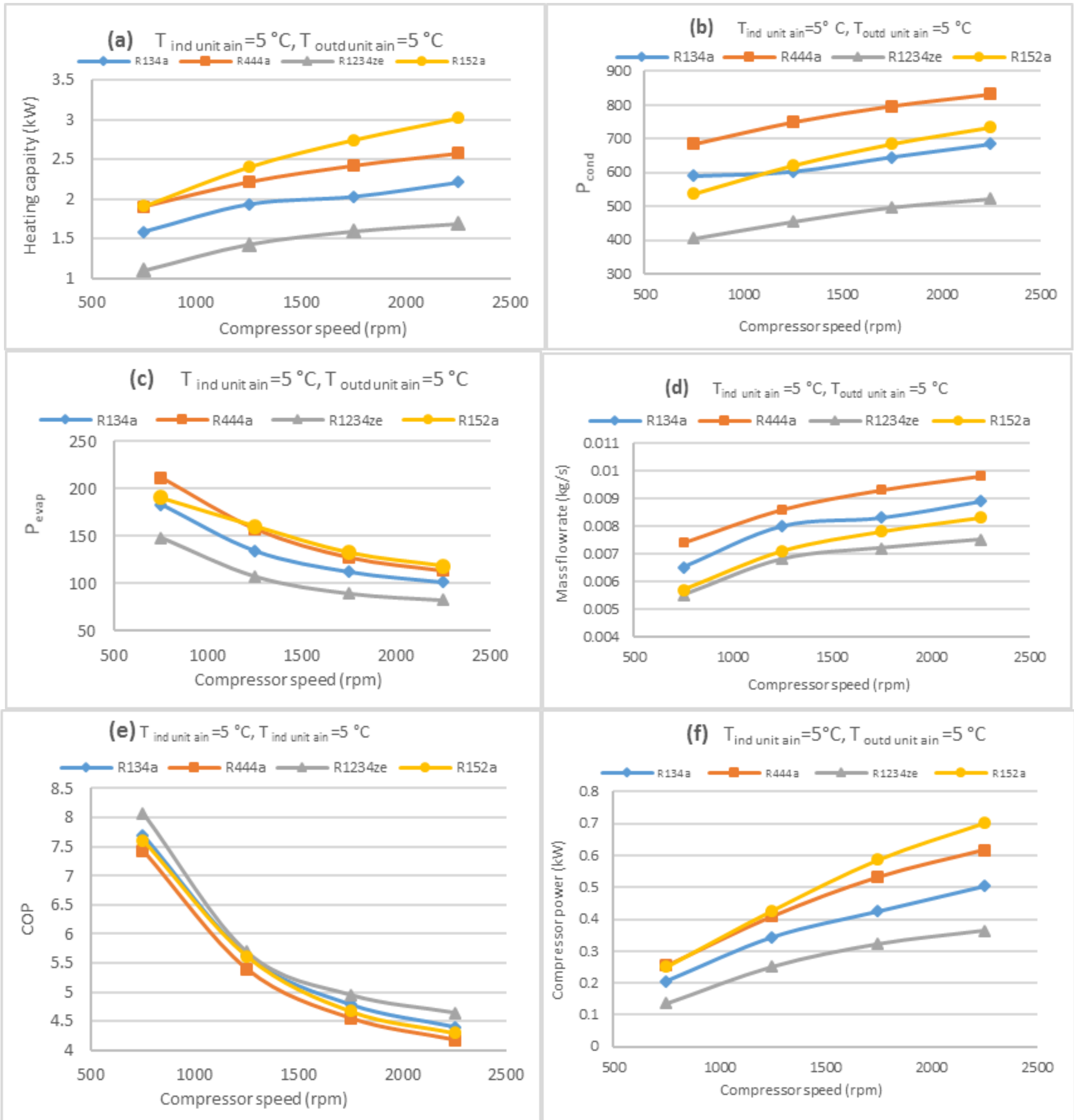


**Figure 3.** Variations of the performance characteristics with compressor speeds a) Heating capacity b) $P_{cond}$ c) $P_{evap}$ d) Mass flow rate e) COP f) Compressor power

Figure 4 presents the influences of the compressor speed on the performance characteristics when the air temperature is 20 °C. The heating capacities are improved with the raise of the air temperature and it can be ascribed to the increasing of condensation pressures (Figure 4a). As the condensation and evaporation pressures increase, the density of the refrigerant increases, and the $m_{ref}$ increases as well (Figure 4d).

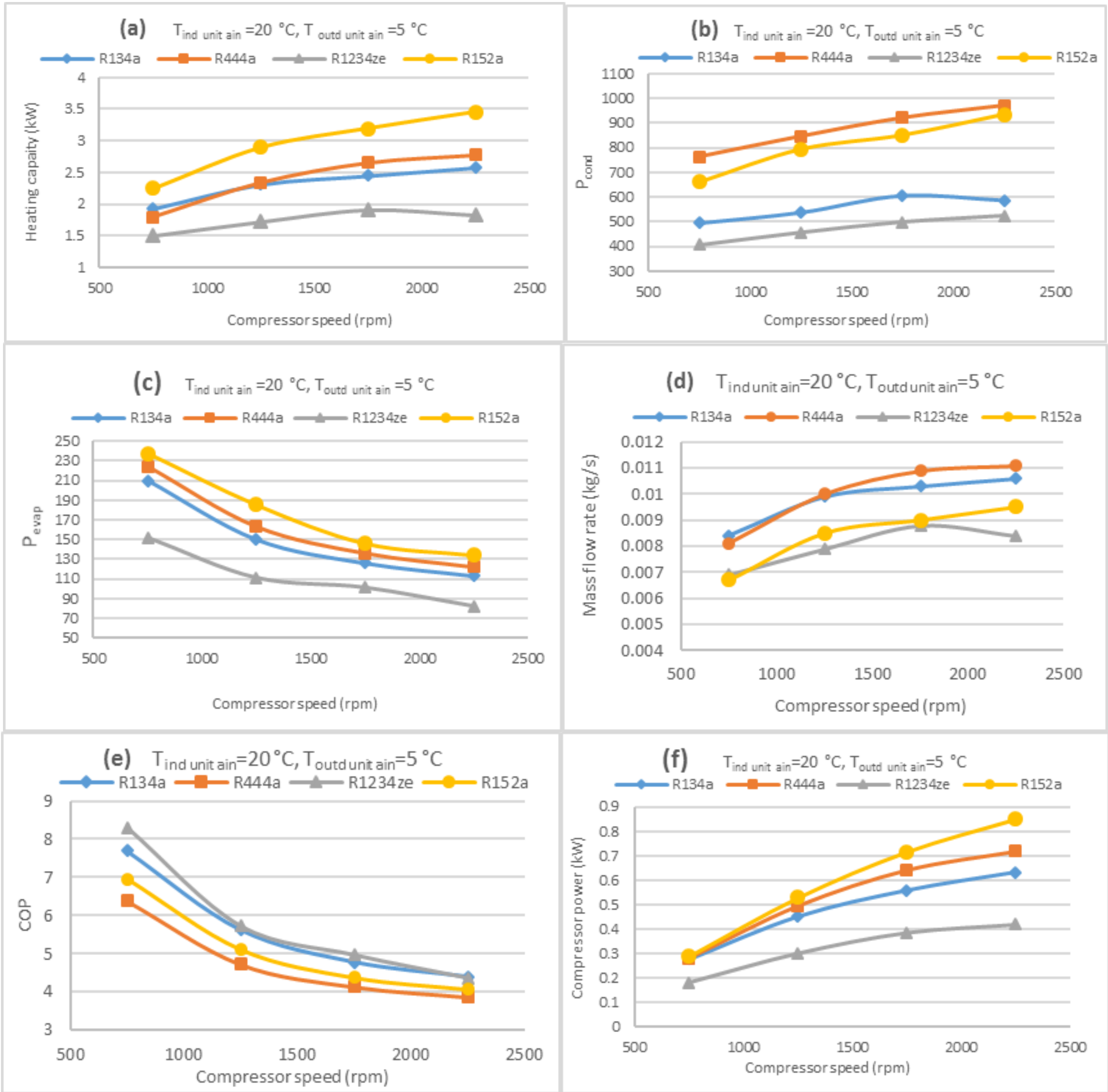


**Figure 4.** Variations of the performance characteristics with compressor speeds a) Heating capacity b) $P_{cond}$ c) $P_{evap}$ d) Mass flow rate e) COP f) Compressor power

Consequently, the heating capacity and the compressor power are increased with the boosted $m_{ref}$.

The heating capacity for R152a is higher than R134a and R444a. On the other hand, the COP of refrigerants are very close to each other (Figure 4e). As expected, the COP decreases with increasing values of the compressor speed. R1234ze(E) has very low compressor power consumption when compared to other refrigerants. Compared with R134a, vapor density of R1234ze(E) is very low and thus the $m_{ref}$ and compressor power are lower.

The performance values of R1234ze(E) presented above was tested with 138 cc volume of compressor. As seen in Figures 3 and 4, the heating performance of the R1234ze(E) is lower than the considered refrigerants. To boost the heating performance of the system, the R1234ze(E) was tested with compressor with volume of 155 cc and the identical tests were repeated. In case of using R1234ze(E) in the MAC system, the influence of the total compressor volume on the performance characteristics is given in Figure 5. In the experiments, the air temperatures at the inlet of the both units are 10 °C. Air flow velocity at the inlet of the indoor and outdoor unit were maintained at 2.6 $ms^{-1}$ and 2.4 $ms^{-1}$, respectively. Figure 5a presents that the heating capacities increased with increasing the total compressor capacity. The main reason is that the increment in compressor volume results in increased pressure ratios. As the pressure ratios increase, the refrigerant $m_{ref}$ and the heating capacity of the system increase. With the influence of $m_{ref}$, the increase in heating performance became higher than the increase in compressor power. For example, the increase in $\dot{W}_{comp}$ at 2250 rpm is about 25% of the increase in $\dot{Q}_{cond}$. It is also observed decrease in the COP of R1234ze(E) in experiments with a 155 cc compressor. It is understood that performance characteristics of R1234ze(E) was improved when the compressor volume increased. Comparable cost, low burning value, and low GWP value of R1234ze(E) makes it as an promising alternative refrigerant.

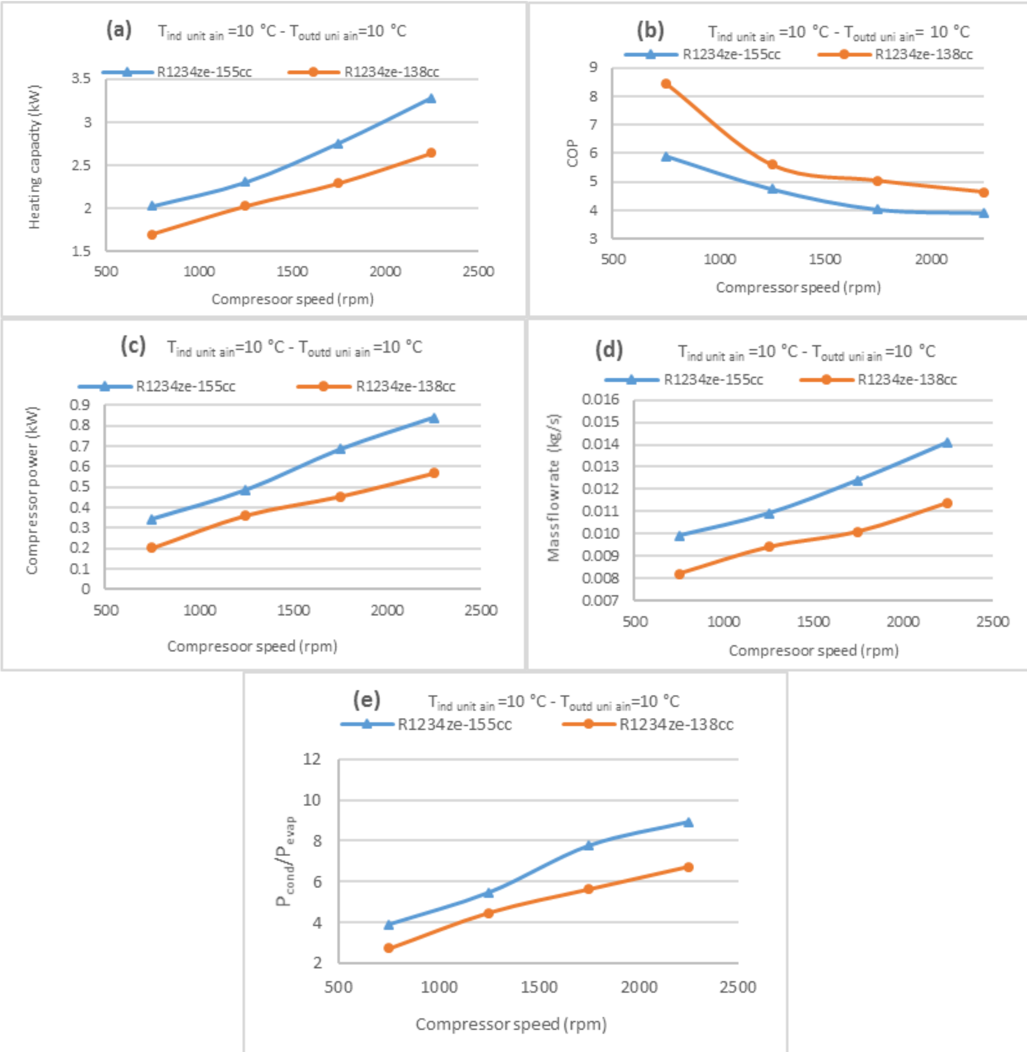


**Figure 5.** Variations of the performance characteristics as a function of compressor speed and compressor volume under the system using R1234ze(E) a) Heating capacity b) COP c) Compressor power d) Mass flow rate e) $P_{cond}/P_{evap}$

## CONCLUSIONS

Performance parameters of two different condenser and evaporator with their air inlet temperatures and varying compressor speeds have been discussed and the results are presented below;

- The heating capacity of R152a and R444a are higher than those for R134a.
- The heating capacity of R1234ze(E) was the lowest among the low GWP refrigerants, while the COP of the R1234ze(E) is the largest.
- The heating performance of R1234ze(E) is increased by increasing the total compressor capacity.
- The compressor power obtained with R1234ze(E) are lower than those of R134a, R152a and R444a.

R152a and R444a can be good substitutes of R134a for MAC system. R1234ze(E) with very low GWP values, can be used in MAC systems when the necessary modifications are made.

Safety precautions should be determined with the reference of A2 for the future study of R152a. Related arrangements are on the sizing for the demanded capacity for compressor, condenser, evaporator capacity, and connections equipments.

## ACKNOWLEDGEMENT

This work was supported by the Scientific and Technological Research Council of Turkey (TUBITAK) (Project Number: 216M437)

## REFERENCES

American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2013, *Standard 34 Designation and Safety Classification of Refrigerants*, ASHRAE.

Bellocchi S., Guizzi G. L., Manno M., Salvatori M. and Zaccagnini A., 2018, Reversible heat pump HVAC system with regenerative heat exchanger for electric vehicles: Analysis of its impact on driving range, *Applied Thermal Engineering*, 129, 290–305.

Direk M. and Soylu E., 2018, The Effect of Internal Heat Exchanger Using R1234ze (E) as an Alternative Refrigerant in a Mobile Air-Conditioning System, *Strojniški vestnik-Journal of Mechanical Engineering*, 64, 114-120.

Devecioğlu A. G. and Oruç V., 2017, An analysis on the comparison of low-GWP refrigerants to alternatively use in mobile air-conditioning systems, *Thermal Science and Engineering Progress*, 1, 1–5.

European Parliament and the Council, 2014, No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing regulation (EC) No 842/2006 text with EEA relevance, *Journal of the European Union,* L 150/195–230.

Janković Z., Atienza J. S. and Suárez J. A. M., 2015, Thermodynamic and heat transfer analyses for R1234yf and R1234ze (E) as drop-in replacements for R134a in a small power refrigerating system, *Applied Thermal Engineering*, 80, 42–54.

Hoşöz M. and Direk M., 2006, Performance evaluation of an integrated automotive air conditioning and heat pump system, *Energy Conversion of Management*, 47(5), 545–559.

Hoşöz M., Direk M., Yiğit K.S., Çanakçı M., Türkcan A., Alptekin E. and Şanlı A., 2015, Performance evaluation of an R134a automotive heat pump system for various heat sources in comparison with baseline heating system, *Applied Thermal Engineering*, 78, 419–427.

Lee H., Hwang Y., Song I. and Jang K., 2015, Transient thermal model of passenger car's cabin and implementation to saturation cycle with alternative working fluids, *Energy*, 90, 1859–1868.

Lee H. and Lee M., 2016, Steady state and start-up performance characteristics of air source heat pump for cabin heating in an electric passenger vehicle, *International Journal of Refrigeration*, 69, 232–242.

Lemmon E.W., Huber M.L. and McLinden M.O., 2014, *NIST Standard Reference Database 23 Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 9.1, National Institute of Standards and Technology*, Standard Reference Data Program, Gaithersburg.

Meng Z., Zhang H., Lei M., Qin Y. and Qiu J., 2018, Performance of low GWP R1234yf/R134a mixture as a replacement for R134a in automotive air conditioning systems, *International Journal of Heat and Mass Transfer*, 116, 362–370.

Mota-Babiloni A., Navarro-Esbrí J., Mendoza-Miranda J. M. and Peris B., 2017, Experimental evaluation of system modifications to increase R1234ze(E) cooling capacity, *Applied Thermal Engineering*, 111, 786–792.

Qin F., Shao S., Tian C. and Yang H., 2014, Experimental Investigation on Heating Performance of Heat Pump for Electric Vehicles in Low Ambient Temperature, *Energy Procedia*, 61, 726–729.

Qi Z., 2014, Advances on air conditioning and heat pump system in electric vehicles - A review, *Renewable and Sustainable Energy Reviews*, 38, 754–764.

Scherer L.P., Ghodbane M., Baker J.A. and Kadle P.S., 2003, On-vehicle performance comparison of an R-152a and R-134a heat pump system, *SAE Technical Papers*, Paper code: 2003–01–0733.

Wanga Z., Wei M., Guo C. and Zhao M., 2017, Enhance the heating performance of an electric vehicle AC/HP system under low temperature, *Energy Procedia*, 105, 2384–2389.

Zhou G., Li H., Liu E., Li B., Yan Y., Chen T. and Chen X., 2017, Experimental study on combined defrosting performance of heat pump air conditioning system for pure electric vehicle in low temperature, *Applied Thermal Engineering*, 116, 677–684.

**Mehmet DİREK** received his B.Sc. degree in Mechanical Education from Kocaeli University in 2002, M.Sc. degree and Ph.D. degree from Kocaeli University in 2004 and 2011, respectively. He currently works as Asst. Prof. Dr. in Energy Systems Engineering Departments of Yalova University. His research interests Automotive air conditionings, heat pumps, internal combustion engines.

**Fikret YÜKSEL**, received his B.Sc. degree in Mechanical Engineering from Karadeniz Teknik University in 1986, M.Sc. degree and Ph.D. degree from Atatürk University in 1992 and 1996, respectively. He currently works as Professor in Energy Systems Engineering Departments of Yalova University. His research interests thermodynamics, air conditionings and internal combustion engines.