

# Performance Prediction of Domestic Refrigeration System using R436A Refrigerant as alternative Refrigerant to R134a with ANN

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**ABSTRACT:** Refrigeration industry is changing fast owing to the continuing debate on environmental issues such as global warming, the depletion of the ozone layer and energy efficiency. It results in new refrigerants appearing in the market as replacements for eco-friendly refrigerants. The most commonly used refrigerant in small hermetically sealed units is R134a, but it has high Global Warming Potential (GWP). In this scenario, research has to be carried out to develop an eco-friendly refrigerant mixture with low ODP and low GWP values with performance that is as good as R134a. In present work, attempted to find a binary mixture of refrigerant R436A (R290/R600a)(54%/46%) which could be an alternative to R134a. Efforts have been made to specify a particular composition of binary mixtures and to study their performance compared to R134a. By using experimental values to generate the enthalpies values at a different processes are analysed using REFPROP 9.0 refrigerant software. It has been found that pure hydrocarbon refrigerants cannot replace R134a. Hence the binary mixtures of R436A (R290/R600a) (54%/46%) and CARE30 (50%R290/50%R600a) with the mass fractions are considered. The performance characteristics such as refrigeration effect, compressor power, Coefficient of Performance (COP) and pull down time of the proposed mixtures were compared with those of the R134a. Back Propagation Neural Network (BPNN) algorithm with bipolar sigmoid activation function is used for validation of experimental values. BPNN constructs with the input-output mapping based on both human knowledge and stipulated input-output data pairs. It is observed from the simulation results that the ANN approach gives accurate results in predicting the performance of Domestic Refrigeration System. The proposed mixture R436A seems to be an appropriate and ecofriendly alternate refrigerant for replacement of R134a.

**KEYWORDS:** GWP, ODP, R436A, COP, Back Propagation Neural Network (BPNN) ANN.

## I. INTRODUCTION

Domestic refrigerators are major energy consuming appliance in household environment [1]. R134a is the most widely used refrigerant in domestic refrigerators, due to its excellent thermodynamics and thermo physical properties. But, it must be phased out soon according to Kyoto protocol due to its high global warming potential (GWP) of 1,300 times more than CO<sub>2</sub>. Many researchers [2–4] have reported that GWP of hydro fluorocarbon (HFC) refrigerants is more significant even though it has less than that of chlorofluorocarbons (CFC) refrigerants. Regarding the issue of high GWP of R134a, thermal storage using secondary refrigerants or phase change materials can relieve this issue by reduction of R134a charge for domestic refrigerators [5–7]. Another option for this issue is to find promising environmentally-friendly R134a alternatives. Some R134a refrigerant substitutes that meet these requirements are a key process in this investigation. Many researchers have reported that hydrocarbon-mixed refrigerants are found to be an energy efficient and environmentally-friendly alternative option in household refrigerators. Pure hydrocarbon refrigerants are not suitable as drop-in substitutes for R134a due to its mismatch in volumetric cooling capacity and

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operating pressure [8]. Experiment conducted with R290/R600a (in the ratio of 60:40, by mass fraction) as an alternative to R12 in 299 and 465 domestic refrigerators and reported that coefficient of performance (COP) and energy efficiency were improved by 2.3 and 4 %, respectively [9]. Experimented with LPG (composed of R290, R600, and R600a, in the ratio of 30:55:15, by mass) as an alternative to R12 in domestic refrigerators at various mass charges 50, 80, and 100 g. The results reported that 80 g of LPG showed the best performance compared to that of R12 [10]. Lee, etl. [11] Carried out an experimental study on the performance of a domestic vapor compression refrigeration system with isobutene (R600a) as the refrigerant. The COP of the system was improved better than R12 and R134a. Wongwises and Chimres [12] investigated with hydrocarbon mixtures and HC/HFC mixtures at different mass ratios in a 239l domestic refrigerator at an ambient temperature of 298 K to replace R134a. It has been reported that R290/R600mixture (in the ratio of 60:40, by mass fraction) is the most appropriate alternative. Fatouh and Kafafy [13] experimented with LPG (composed of 60 % of R290 and 40 % of commercial butane) as an alternative to R134a in a 280l domestic refrigerator at 316 K ambient temperature. The results reported that COP of the refrigerator using LPG was higher than that of R134a by about 7.6 % with lower values of energy consumption by about 10.8 %. Based on the theoretical investigation, it has been reported that capillary tube length using ternary hydrocarbon refrigerant mixture (composed of R290, R600, and R600a) with 60 % R290 mass fraction requires 30 % increase in capillary tube length compared to R134a. Considering the performance study of commercial refrigeration equipment and comparative studies of the behaviour of R134a have shown that R134a exhibits the worst performance when comparing with R290 at the same original working conditions in a system designed for R12. Mani and Selladurai [14] carried out a performance study of vapor compression refrigeration system with the new R290/R600a refrigerant mixture as drop-in substitute compared with R12 and R134a. Mohanraj et al. [15] experimental results showed that the R290/R600a refrigerant mixture had 28.6–87.2 % higher refrigerating capacity than R134a. M. Rasti et al. [16] conducted an experimental investigation with R290/R600a mixture as an alternative to R134a in a domestic refrigerator system and reported that the COP of the system was improved with R290/R600a mixture than R134a. The results also revealed that the life of the compressor is improved due to lesser discharge temperature of R290/R600a mixture.

## II. RELATED WORK

Above Literature work refers in this paper brings out the fact that many types of research using conventional approaches (analytical and experimental methods) for the energy and exergy analysis of refrigeration systems. The conventional analytical approach involves more complicated analytical equations and theoretical assumptions, whereas experimental studies are more expensive and time-consuming. During last two decades, the use of artificial intelligence systems such as Artificial Neural Network (ANN) in refrigeration and air conditioning field is increasing gradually to solve the complicated problems. Adnan Sozen, etl. [17] Reported that the FIS and ANN could be used effectively to estimate the faulty conditions of the vapor compression refrigeration system. Furthermore, the artificial neural network (ANN) thus having an extended prediction capability compared to experimental values. The main advantages of ANN are its speed, simplicity, and ability to model a multivariable problem to solve complex relationships between the variables and can extract the nonlinear relationships using training data [18-19]. Many investigators have developed the models for the performance of refrigeration and thermal systems using ANN technique the results reported that the ANN model predictions yield good agreement with the experimental data.

Artificial Neural Networks (ANN) is based on the basic model of human brain with capability of generalization and learning. The purpose of simulation to the simple model of human neural cell is to acquire the intelligent features of these cells. The term "artificial" means that neural nets are implemented in computer programs that are able to handle the large number of necessary calculations during the learning process. The connections between the adoptive, what means that the connection structure is changing dynamically. It is commonly acknowledged that the learning ability of the human brain is based on this adaptation. Stimulated by the structure of the brain, an ANN consists of a set of highly interconnected processing units, called nodes or units. Each unit is designed to mimic its biological counterpart, the neuron. Each accepts a weighted set of inputs and responds with an output. ANN resembles the biological neuron in acquiring knowledge by learning from examples and storing this information's within inter-neuron connection strengths called weights. The performance parameters such as RE, POWER and COP, are predicted by using artificial

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neural network. The architecture of an ANN used for the performance prediction of VCR indicating input and outputs and shown in fig: 1

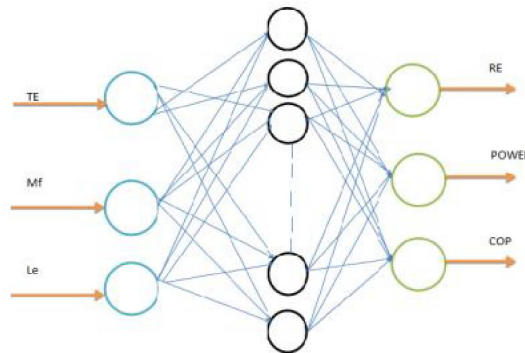


Fig.1: Structure of the ANN of Domestic refrigeration system.

The back propagation algorithm is used in feed forward single hidden layer network. The back propagation algorithm has different variants. The back propagation algorithms gradient descent and gradient descent with momentum are too slow for practical problems because they require small learning rates for stable learning. The faster algorithms such as Levenberg Marquardt (LM) are used in the study. The performance of ANN is affected by two important characteristics of the network (number of hidden layers and number of neurons in the hidden layers). In the training an increased number of neurons from 10 to 18 are used in hidden layer to define the output accurately. The output of network is compared with the desired output at each presentation and errors are computed. These errors are back propagated to the neural network for adjusting the weight such that the errors decrease with each iteration and ANN model approximates the desired output. After enough trials with the different configurations the number of neurons in hidden layer, changing the transfer functions (log-sig and tan-sig), it is decided that the network consists of one hidden layer with 18 number of neurons and Levenberg Marquardt (LM) variant is optimum for this system. The neurons in the hidden layer have no transfer functions. The inputs and outputs are normalized in the range 0-1. Logistic sigmoid (log-sig) transfer function is being used in ANN.

### III. EXPERIMENTAL METHODOLOGY

The aim of the present work is to evaluate experimentally, the effect of hydrocarbon (mixture of R290 and R600a) as refrigerant mixture. Fig.1 shows a experimental setup of a single door household refrigerator work with R134a with the total capacity of 175L. It consists of deep freezer, hermetically sealed reciprocating compressor air cooled condenser, strainer, and 5 capillary tubes with different length via ball valves. Initially the different length of capillary tubes are fixed after filter with the help of brazing method the specifications of for this tubes are maintained constant diameter (0.78 mm) and varying lengths (4m, 4.5m, 5m, 5.5m & 6 m) can be used. In this way to estimate the refrigerating effect, power consumption and coefficient of performance to household refrigerator. In this context a ball valves also fixed at the capillary inlet for operating with different combinations. The capillary outlet connected to evaporator then the refrigerant flows it (in the refrigerator cabin or calorimeter). The two Compound pressure gauges are connected with refrigerator at compressor inlet and outlet with precision is  $\pm 0.25\%$  to measure pressures. Seven thermocouple sensors are used for calibrate the (RTD Pt100) temperatures at inside the freezer, refrigerator cabin, evaporator, compressor and condenser inlets & outlets, the accuracy is  $\pm 0.25$  K. During the experimentation the total experimental system is located in an open to atmosphere.

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Fig:2.Experimental setup of the test rig.

Initially the system was evacuated by vacuum pump up to -30psi pressure. After that hydrocarbon refrigerant mass 100 g of R600a/ R290 (56/44 by wt %) mixture used alternatively to the system. First we charged R600a/ R290 (56/44 by wt%) of 100 g mass in the system and calculate cooling capacity, compressor work and COP for different length (4,4.5,5.5,6m) and 0.036 inches diameter of capillary tube. First to perform pull down test for optimizing capillary length and mass of refrigerant at the door is kept open until the temperature of the refrigerator has to reach the steady state situation. As per design expert's suggestions R134a charge 100g of refrigerant was filled in the system for performing reference test. however throughout conducting tests with R134a, 4, 4.5, 5.5, &6m capillary tube length be used at different weights i.e. 60, 70, 80, 90 &100grams. The continuous tests were carried out all through above conditions the evaporator temperature reached up to  $-15^{\circ}\text{C}$ . Initially the pull down characteristics can be determined and the performance parameters such as cooling capacity, power consumption and performance of the system. For reference, the ambient temperature can be maintained around at  $29^{\circ}\text{C}$  for changing capillary tube and varying weight of refrigerant. Total experimental values are collected after reaching the steady state circumstances. The performance tests to be carried out at different evaporator temperatures ( $-15, -12, -9, -6$  and  $-3^{\circ}\text{C}$ ). In this experimental analysis there is no need to change major modification in a household refrigerator. Therefore, in the experimental observations the possibility of HCM used polyesters as lubricant oil. In this opinion the blended is with hydrocarbon refrigerants in the form of liquid state and this blends is calibrated with the help of electronic balancing machine, having a precision is  $\pm 0.01$  g. In order to minimize the investigational work, to take average values to be measured. The dissimilarity in investigational values from the regular values be maintained within  $\pm 5\%$  error. The observation values are recorded by every ten minutes. The experimental data are used to investigate the performance of a household appliance.

#### IV. RESULTS AND DISCUSSION

As per the procedure discussed in the previous chapter, tests were performed with pure R134a and Hydro Carbon Refrigerant mixtures such as CARE (50%R290/50%R600a) and R436A (54%R290/46%R600a). Initially conduct with was a baseline test and then with CARE and R436A were kept at the same ambient temperature of  $29^{\circ}\text{C}$  in a Domestic refrigerator. The original lubricating oil is not changed throughout the experiment. The predicted system performance is compared with the experimental values. The performance parameters such as pull down time, refrigeration effect, power consumption and COP of the refrigerants are suitably analysed for different evaporator temperatures, mass of refrigerant and different length of capillary tubes. The performance of the alternative mixtures is also compared with R134a.

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## 1. Performance Characters of a Domestic Refrigeration system

As per experimental work the system is runs at varying the evaporator temperature (-15°C) to ambient temperature (29°C) according to IS1476 part-1 achieved in a household refrigerator for a different refrigerants such as R134a, CARE and R436A

### 5.1 Comparisons between Experimental Values with ANN for Refrigeration Effect with a Refrigerant as R134a.

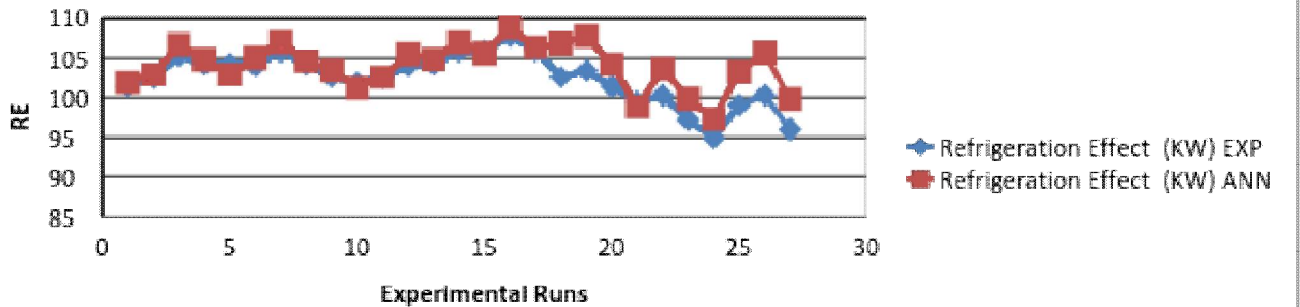


Fig. 5.1: experimental values of refrigeration effect with ANN values for R134a

A plot of the predicted versus experimental values for the refrigeration effect is depicted in Fig.5.1: For this parameter, the ANN results in average error of 1.23 which are better than the experimental values had been predicted directly by the ANN. Instead, these parameters were predicted independently in order to assess the performance of the ANN in both groups of predictions.

### 5.2 Comparisons Between Experimental Values With ANN For A Power Consumption With A Refrigerant As R134a.

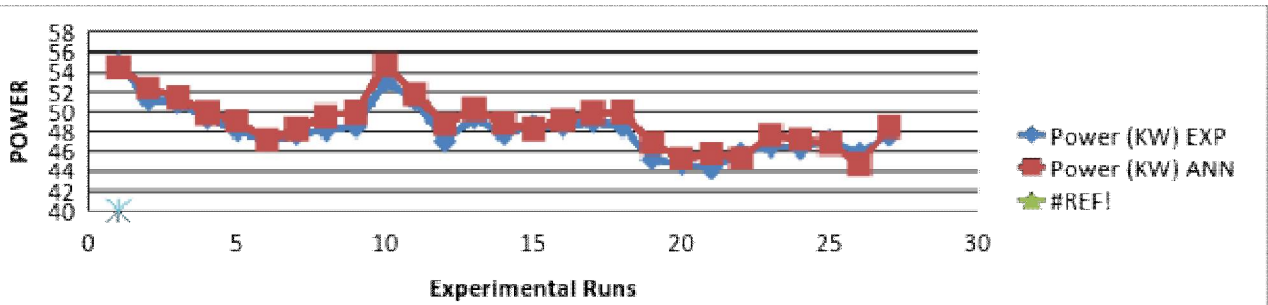


Fig. 5.2: Experimental values of power consumption with ANN values for R134a

The predicted compressor power as a function of the experimental value is shown in Fig. 5.2: The ANN predictions for the compressor power yield average error of 2.51%, with the experimental data. These values reveal that the ANN predicts the power absorbed by the refrigerant in the compressor quite well despite the wide ranges of operating conditions. It is obvious that if a higher number of test runs had been performed to provide larger amount of experimental data for network training, the performance of the ANN would have been even better.



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### 5.3. Comparisons between experimental values with ANN for a COP with a refrigerant as R134a.

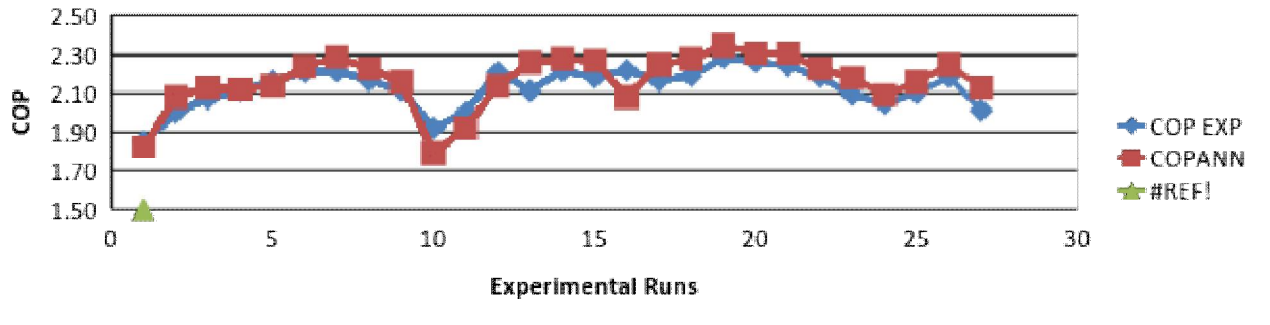


Fig 5.3: Experimental values of COP with ANN values for R134a

The ANN predictions for the COP against the experimental one are shown in Fig 5.3. These predictions yield a average error of 1.23. In this study, the COP, probably the most important performance parameter of a domestic refrigeration system was not directly predicted. Instead, it was determined from the ratio of the evaporator capacity to the predicted compressor power. Despite this, the ANN predictions for the COP are as accurate as the predictions for the other performance parameters.

### 5.4 Comparisons between experimental values with ANN for a refrigeration effect with a refrigerant as CARE30.

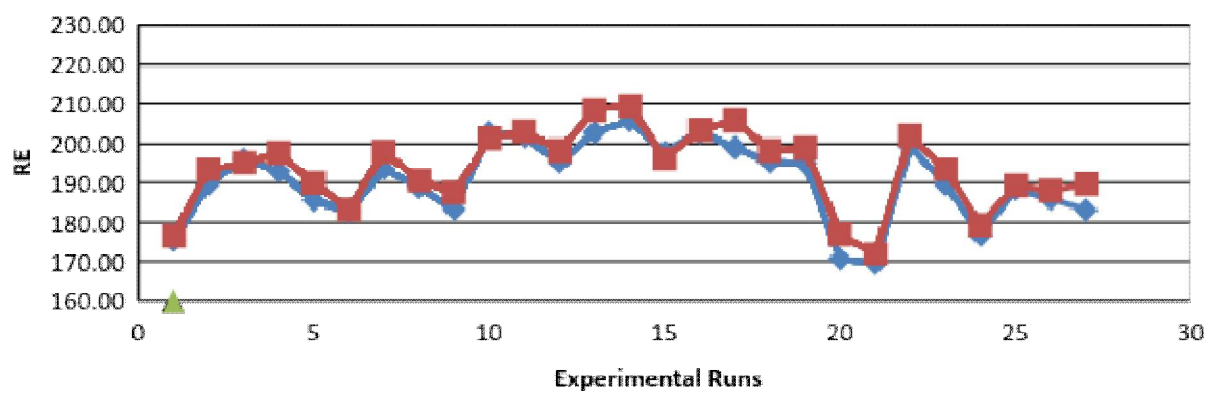


Fig.5.4: experimental values of refrigeration effect with ANN values for CARE30

A plot of the predicted versus experimental values for the refrigeration effect is depicted in Fig. 5.4: For this parameter, the ANN results in a average error of 1.153 which are better than the experimental values had been predicted directly by the ANN. Instead, these parameters were predicted independently in order to assess the performance of the ANN in both groups of predictions.

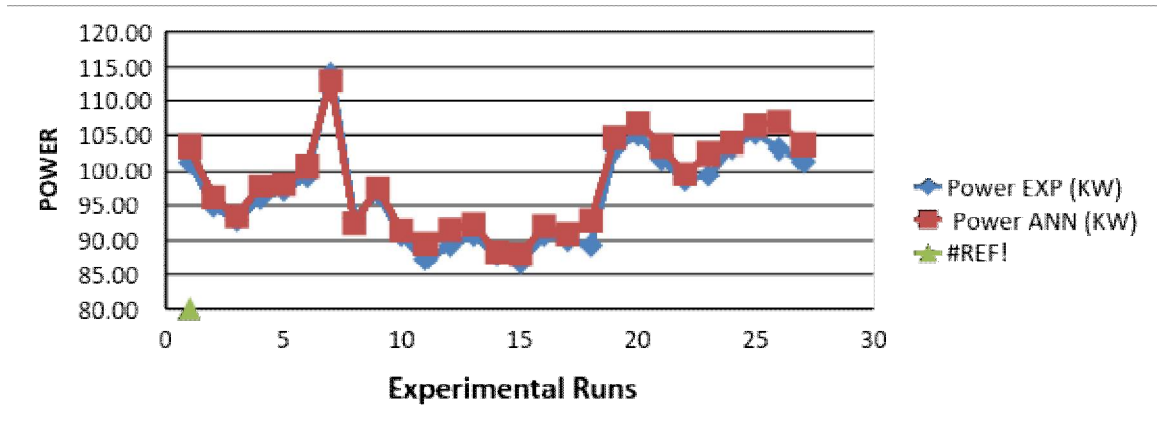
### 5.5: Comparisons between experimental values with ANN for power consumption with a refrigerant as CARE30.

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Graph 5.5: Experimental values of power consumption with ANN values for CARE30

The predicted compressor power as a function of the experimental value is shown in Fig. 5.5. The ANN predictions for the compressor power yield average error of 1.981, with the experimental data. These values reveal that the ANN predicts the power absorbed by the refrigerant in the compressor quite well despite the wide ranges of operating conditions. It is obvious that if a higher number of test runs had been performed to provide larger amount of experimental data for network training, the performance of the ANN would have been even better.

### 5.6: Comparisons between experimental values with ANN for a COP with a refrigerant as CARE30.

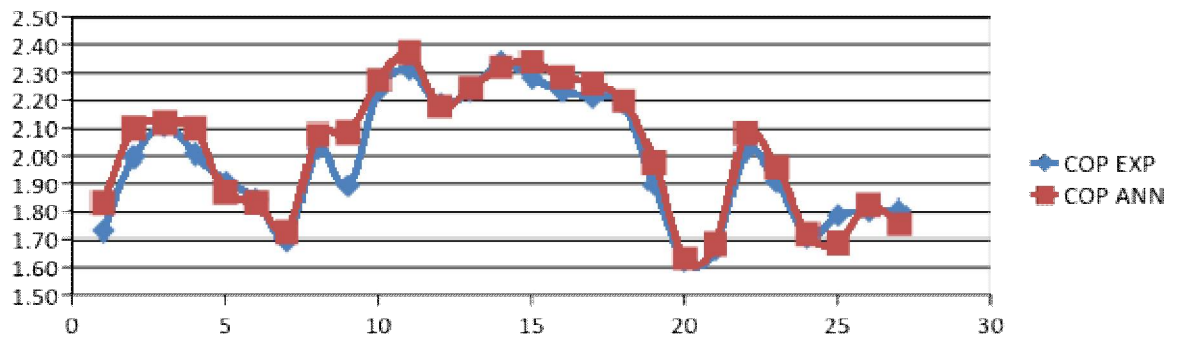


Fig.5.6: Experimental values of COP with ANN values for CARE30

The ANN predictions for the COP against the experimental one are shown in Fig.5.6. These predictions yield average error of 1.043. In this study, the COP, probably the most important performance parameter of a domestic refrigeration system was not directly predicted. Instead, it was determined from the ratio of the evaporator capacity to the predicted compressor power. Despite this, the ANN predictions for the COP are as accurate as the predictions for the other performance parameters.

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### 5.7: Comparisons between experimental values with ANN for a refrigeration effect with a refrigerant as R436A

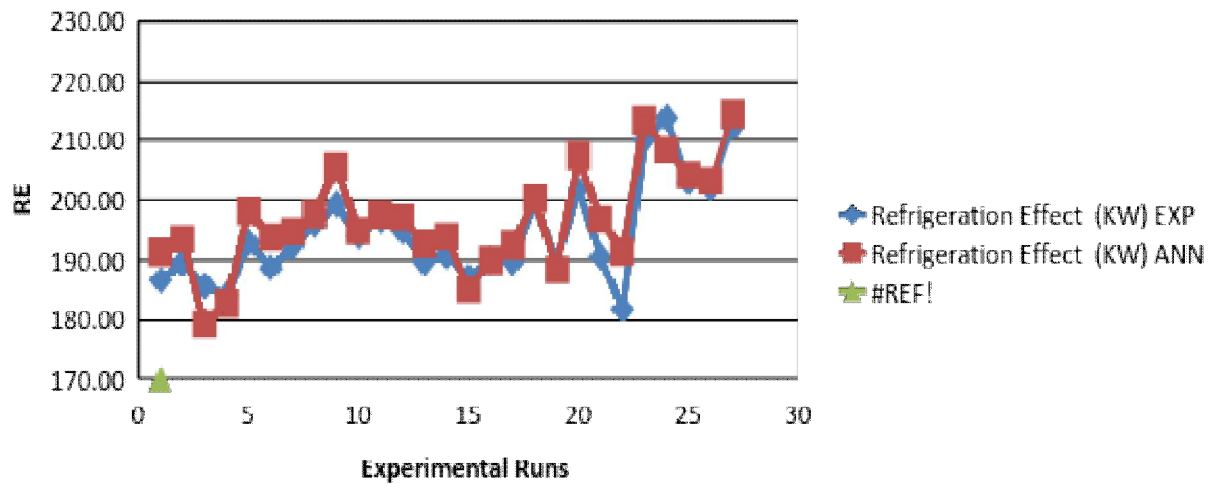


Fig. 5.7: experimental values of refrigeration effect with ANN values for R436A

A plot of the predicted versus experimental values for the refrigeration effect is showed in Fig.5.7: For this parameter, the ANN results in an average error of 1.15 which are better than the experimental values had been predicted directly by the ANN in both groups of predictions.

### 5.8: Comparisons between experimental values with ANN for power consumption with a refrigerant as R436A.

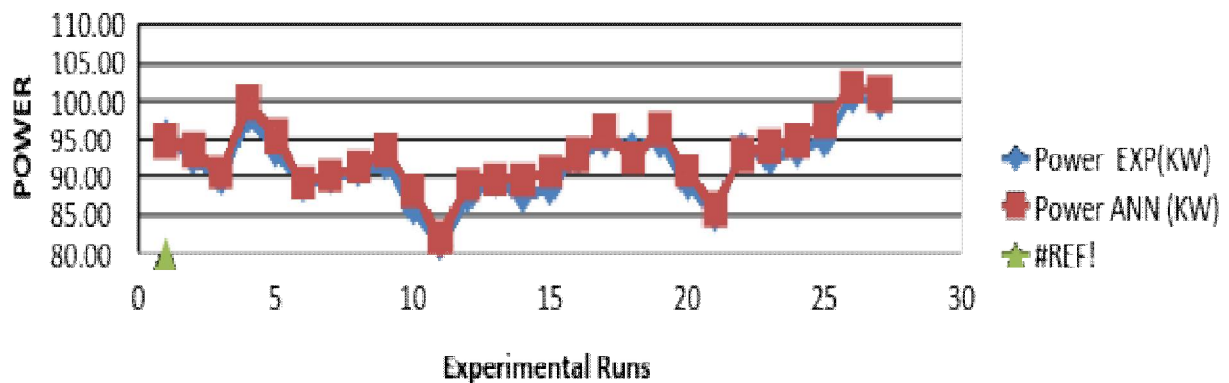


Fig. 5.8: Experimental values of power consumption with ANN values for R436A

The predicted compressor power as a function of the experimental value is shown in Fig. 5.7: The ANN predictions for the compressor power yield average error of 2.211%, with the experimental data. These values reveal that the ANN predicts the power absorbed by the refrigerant in the compressor quite well despite the wide ranges of operating conditions. It is obvious that if a higher number of test runs had been performed to provide larger amount of experimental data for network training, the performance of the ANN would have been even better.



**5.9: Comparisons between experimental values with ANN for a COP with a refrigerant as R436A**

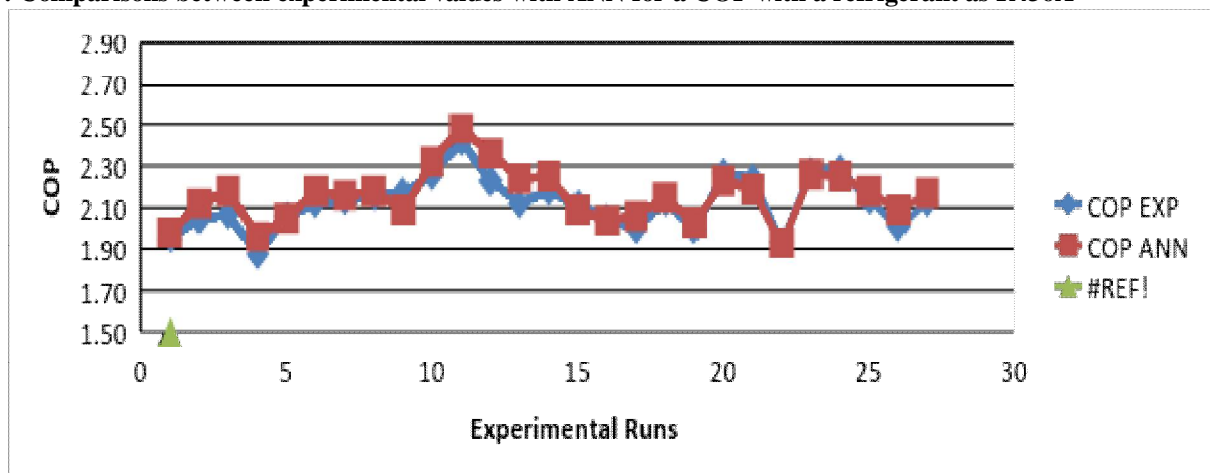


Fig. 5.9: Experimental values of COP with ANN values for R436A

The ANN predictions for the COP against the experimental one are shown in Fig.5.9. These predictions yield a average error of 1.243. In this study, the COP, probably the most important performance parameter of domestic refrigeration system was not directly predicted. Instead, it was determined from the ratio of the evaporator capacity to the predicted compressor power. Despite this, the ANN predictions for the COP are as accurate as the predictions for the other performance parameters.

**V. CONCLUSION**

Based on the experimental investigations the following conclusions are drawn:

Thus the results prove that the hydrocarbon refrigerant mixture R436A gives best performance than R134a in domestic refrigeration system. The ANN gives good response for a few input values and fairly average error. Thus it can be concluded that the R436A could be energy efficient, ozone friendly, safe and long term replacement fluid instead of R134a in system. In domestic refrigerator all the hardware remains same except the length of the capillary tubes and without changing the lubricating oil with R436A as the refrigerant.

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