The comparison of performance by using alternative refrigerant R152a in automobile climate system with differant artificial neural network models

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Abstract. Due to the refrigerant gas R134a which is used in automobile air conditioning systems and has greater global warming impact will be phased out gradually, an alternative gas is being desired to be used without much change on existing air conditioning systems. It is aimed to obtain the easier solution for intermediate values on the performance by creating a Neural Network Model in case of using a fluid (R152a) in automobile air conditioning systems that has the thermodynamic properties close to each other and near-zero global warming impact. In this instance, a network structure giving the most accurate result has been established by identifying which model provides the best education with which network structure and makes the most accurate predictions in the light of the data obtained after five different ANN models was trained with three different network structures. During training of Artificial Neural Network, Quick Propagation, Quasi-Newton, Levenberg-Marquardt and Conjugate Gradient Descent Batch Back Propagation methodsincluding five inputs and one output were trained with various network structures. Over 1500 iterations have been evaluated and the most appropriate model was identified by determining minimum error rates. The accuracy of the determined ANN model was revealed by comparing with estimates made by the Multi-Regression method.

1. Introduction

Today, cooling systems stand out as increasingly important systems and they are needed in many areas. The advancement of technology and the development of faster systems make the need for better cooling capacity. As well as cooling systems are meeting the technological needs, they meet an important need to improve important factors of living standards in terms of climate and comfort. Among them, air conditioning systems that provide in-cab comfort become even more important with also considering more than ‘1 billion vehicles’ [1] on the world.

In a world where the number of vehicles exceeded 1 billion, while refrigerants used in air-conditioning systems in these vehicles are providing comfort, these refrigerants need to be used by considering environmental factors of them. In recent years, fluorinated gases damaging the ozone layer are banned and gases which have less decay time in the atmosphere are preferred with considering the global warming factor [2]. These gases or gas mixtures must be compatible with over 1 billion vehicles already used and work efficiently, safely and environmentally friendly without causing significant changes.

In this regard, many gases are being tested and recommended as alternative refrigerants. One of these gases is the refrigerant R152a. An artificial neural network model has been designed by using thermodynamic properties of this fluid and estimates close to real were obtained in wide ranges.

2. Artificial neural networks

Artificial neural networks (ANN) are implementation technique as a computable model based on the human brain by imitating the biological nervous system. In general, neurons are the basic elements of an artificial neural network model. These neurons are connected by synapses with specific weights [3]. ANN models are composed of 3 main layers. Although the task and function of each layer are different, they are associated with each other.

2.1. Input Layer

There are entries in this layer in accordance with the principle of human brain. These entries consist of raw data waiting to be processed like our data that we get in communication with the outside world by 5 sense. These entries will be processed in ANN and they will have lots of weights that take us to an output value in the algorithm. Artificial neural network model input values should only be introduced as mathematical values and not contradict with learning of the model. These values in the input layer are transmitted to the intermediate layer without being subjected to a process in the input layer.

2.2. Hidden Layer (Intermediate Layer)

This layer is the layer where the input values which came connected with certain weights are processed and evaluated. The number of nodes within this layer affects the relationship condition and the weight value between inputs and nodes. In this regard, it is being tried to produce estimates with minimal error by increasing or decreasing the number of nodes for an optimal network model.

2.3. Output Layer

Values entered in the input layer are carried out to the output layer with another weight value after processed in the intermediate layer. The desired output value is given by ANN in this layer [4].

Many important issues pose while ANN modeling. It is aimed to build a network model with minimum error distribution for ANN models. As a result of access to the local values of this stage, it can be detected that a better distribution of errors is blocked. Important factors emerge for the best estimate of the model, such as the teaching network is starting from which value, how many iterations are performed and at which stage of learning the system would stop. At this stage, the working of artificial neural network model is not known exactly so which method and model are the most appropriate must be found with experiments. In this context, different models are used for different neural network analysis.

3. ANN modeling

ANN models which will allow for the best estimate of the thermodynamic properties of R152a refrigerant for automobile air conditioning systems was trained and the different models of ANN were compared. Created ANN models were given in Table 1.

The importance of the generated data sets for ANN models affects the estimate accuracy of the model. In this context, an adequate number of data collection in a wide range and then the desired estimating values must be in the solution space of the input value.

The number of data in the modeling phase in the input layer of ANN is 5 for all modeling and the output layer is designed to be 1. Network was trained at every turn with 3, 5 and 7 nodes in the intermediate layer, respectively. At this stage, the unused test data in the training stage given and the system was asked to estimate. The results of error rates after estimates were compared and each model which correctly estimated with minimum error was determined. Due to the use of different ANN structures, it was determined to have a different estimate error rates. Evaporator Temperature (Te), Condenser Temperature (Tk), Condenser Heat Load (Qk), Evaporator Heat Load (Qe) and Mass Flow (m) were used as input values. That's why the input values in all methods and models are 5 pcs. Output values are Cooling Coefficient of Performance (COP), the Compressor Work (Wk) and Compression Ratio (Pr).

Table 1. Representation of ANN models used in this research (for a single output value)

ANN No	Method Name	Naming of ANN Models	Number of Nodes in Layers		
			Input Layer	*Inter Layer*	*Output Layer*
1	Quick Propegation	QP 531		3	
2	Quick Propegation	QP 551		5	
3	Quick Propegation	QP 571		7	
4	Back Propegation	BP 531		3	
5	Back Propegation	BP 551		5	
6	Back Propegation	BP 571		7	
7	Levenberg Marquerdt	LM 531		3	
8	Levenberg Marquerdt	LM 551	5	5	1
9	Levenberg Marquerdt	LM 571		7	
10	Quasi-Newton	QN 531		3	
11	Quasi-Newton	QN 551		5	
12	Quasi-Newton	QN 571		7	
13	Conjugate Gradient Descent	CG 531		3	
14	Conjugate Gradient Descent	CG 551		5	
15	Conjugate Gradient Descent	CG 571		7	

3 different individual ANN models were developed for 3 different outputs. So ANN was trained by asking only one output value with 5 input values every time. Therefore, ANN models were created separately for the COP, Wk and Pr values. The total number of training was done by 5 inputs and 3 individual outputs for each. it was identified as 45, as a result of the calculation with 15 different ANN models. 45 ANN modeling and training were made and the same training set and the same testing set were used for each. All ANN models were limited with 1500 iterations and training was completed in 1500 iterations. Besides training of 45 ANN models, estimates were made by the Multi-Regression method separately for COP, Pr and Wk values and it has participated in the evaluation to make comparisons.

4. Calculations of cooling system

The knowledge of thermodynamic properties of the fluid in a cooling cycle gives an idea in terms of where the fluid can be used. In calculations made by using COOLPAC program, variations were calculated and simulated by including compressor constant speed n = 1000 rpm, n = 0.7 for a volumetric efficient system, the fluid pressed to system between Tk 40 °C to 60 °C and Ta -20 °C to -6 °C with a 4-cylinder compressor. Pressure Ratio (Pr), the compressor work (Wk), and Cooling Efficacy Coefficient (COP) values were determined by the results of calculations and modeling and calculations were completed.

R152a which may be used as an alternative gas in automobiles instead of R134a is also required to have high value up to R134a in terms of COP. In this regard, the load on the compressor and the compression ratio are also required to have close to the values of R134a gas. Because a system in a vehicle is established and being used according to the compression ratio and compressor work of currently used R134a gas. Pr and Wk values are essential to be close to R134a to charge of R152a gas without making major structural changes in the car. In this regard, COP, Wk and Pr values were estimated in our ANN model.

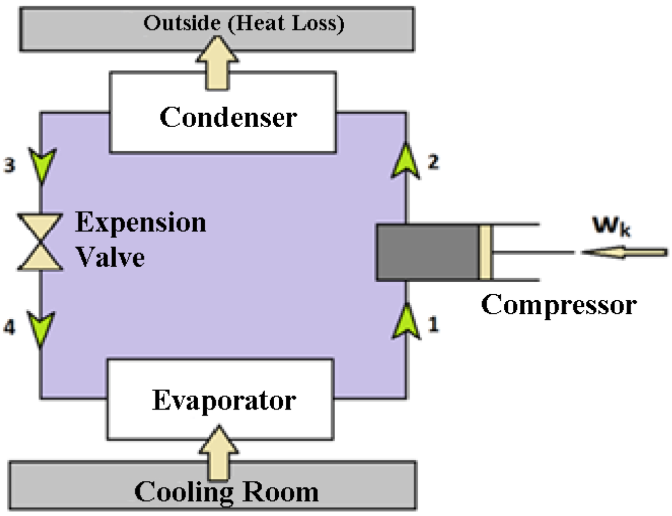

Figure 1. The General Design of a Cooling System [5]

5. Creation of ANN model

89 data were used in models. 49 of these data were separated for training data, 40 of them were used as test data to be used for control purpose subsequently in trained ANN models. The obtained data were mixed in completely mixed form and randomly selected without being subjected to a particular sequence. Determined ANN models and structures were trained with obtained data respectively and finally a suitable model for this system was identified and the system was designed. In performed application, formulas were created by using the same values in the calculation of Multi-Regression method and these results were compared with results of ANN.

Applied ANN models are Conjugate Gradient Descent, Levenberg Marquardt, Quick Propagation, Batch Backpropagation and Quasi Newton. They were trained with a maximum of 1500 iterations. The system was trained repeatedly and best results were obtained by using structures with the number of 3, 5 and 7 nodes individually in the intermediate layer in general methods.

6. Operating Data

Indications of the completion of training for ANN models are Correlation and R^2. The case of these values are close to 1 shows that the ANN model is well trained.

As shown in Table 2, correlation and R^2 values are close to 1 and it is understood from these values that our networks are very well trained and tested. After the training phase accuracy of trained and tested networks was evaluated with never trained 20 non-tested data. Root Mean Square Error (RMSE) value is a value that indicates the estimated error rate for the test data made by each trained structure. The case that this value is close to zero shows that the closest estimate was made to the real value. RMSE (obtained from Equation 1). In Equation 1; N: the estimate number, t: the estimate value and y: the actual value [6].

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(t_i - y_i)^2} \tag{1}$$

Regression was performed by using Multi Regression (MR) method with the same training data to perform the comparison of the ANN models. COP, Wk and Pr values were found for the test data as a result of multiplying the input values with related coefficients. Related formula and training data for MR developed for each output value are as follows.

Table 2. Correlation and R^2 values of the trained ANN methods and models

Name of	Correlation			R-Square		
ANN Method	COP	Wk	Pr	COP	Wk	Pr
QP 531	0,995511	0,994809	0,998055	0,990534	0,988507	0,995887
QP 551	0,998361	0,99901	0,997789	0,996444	0,997898	0,995294
QP 571	0,996581	0,995502	0,998354	0,992887	0,989918	0,996589
BP 531	0,964123	0,97711	0,975913	0,784525	0,90767	0,922974
BP 551	0,973479	0,986111	0,978356	0,891928	0,958919	0,932567
BP 571	0,989038	0,988618	0,978116	0,976656	0,967273	0,934104
LM 531	0,99133	0,997268	0,992393	0,982422	0,993948	0,984604
LM 551	0,984679	0,993045	0,992754	0,96551	0,981259	0,98543
LM 571	0,985546	0,992786	0,999995	0,965478	0,985459	0,999988
QN 531	0,996561	0,999897	0,998921	0,992956	0,999784	0,99779
QN 551	0,996426	0,999983	0,998912	0,99267	0,999965	0,997802
QN 571	0,997125	0,999723	0,998823	0,994184	0,999432	0,997555
CG 531	0,996586	0,998863	0,998749	0,99301	0,997557	0,997435
CG 551	0,996798	0,99992	0,998835	0,993379	0,999832	0,997613
CG 571	0,997205	0,999916	0,998721	0,994379	0,999822	0,997344

Table 3. Multi Regression Training Data Set

Regression Statistics			*Coefficients*	*P-value*
Multiple R	0,995777752	Intercept	11,55384695	7,17E-05
R Square	0,991573331	Tk	-0,011123381	0,147668
Adjusted R Square	0,990893761	Te	0,15328854	0,002431
Standard Error	0,061958923	Qk	-23,73707892	0,003187
Observations	68	Qe	19,3153009	1,78E-05
		M	1412,804823	0,145967

In tables 4, 5 and 6, RMSE values of estimates done by ANN models created with different models and structures for COP, Wk and Pr output values were calculated and given below respectively. To make a comparison for RMSE values of created ANN models, RMSE values of estimates made by MR method were also added to the tables and the comparison was made with performed ANN models. Structures which have the best RMSE values were determined for each structure from the ANN models indicated in the table below. Then, the structure and the model which estimated closest to the actual were determined by evaluating determined models with the best structure among themselves.

When we examine RMSE values of each model in the tables, they are marked in bold. The best value is shown underlined among these values. The real-estimate graphic is given in test data of a model that has the best results and structures were shown.

As seen in Table 4, an optimal ANN model is 7 knotted and intermediate layered CG model structure. For the COP output values, 7 knotted intermediate layers showed good results for all other methods except QN. As it can be seen in Chart 1, the estimation curve decomposes for 1 value. All other estimates are consistent with the actual values and it was seen that a good learning was provided. While RMSE value obtained with the MR method was 2.99, RMSE value in the CG model decreases to 1.46. This shows that the ANN models are very successful. The model structure is as shown in Figure 2.

Table 4. COP estimate RMSE values for ANN models

COP			
Model	QP 531	QP 551	QP 571
RMSE	*1,952573*	*2,966885*	***1,510595***
Model	BP 531	BP 551	BP 571
RMSE	*4,143737*	*2,759268*	***2,154733***
Model	LM 531	LM 551	LM 571
RMSE	*2,965355*	*2,991904*	***2,368911***
Model	QN 531	QN 551	QN 571
RMSE	*2,025418*	***1,673851***	*1,944325*
Model	CG 531	CG 551	**CG 571**
RMSE	*1,813621*	*1,504902*	***1,462868***
Model	MR		
RMSE	***2,990578***		

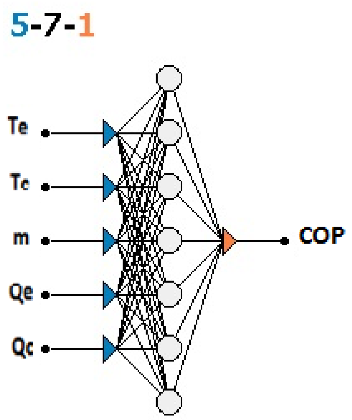

Figure 2. 5-7-1 ANN structure with Conjugate Gradient Descent method

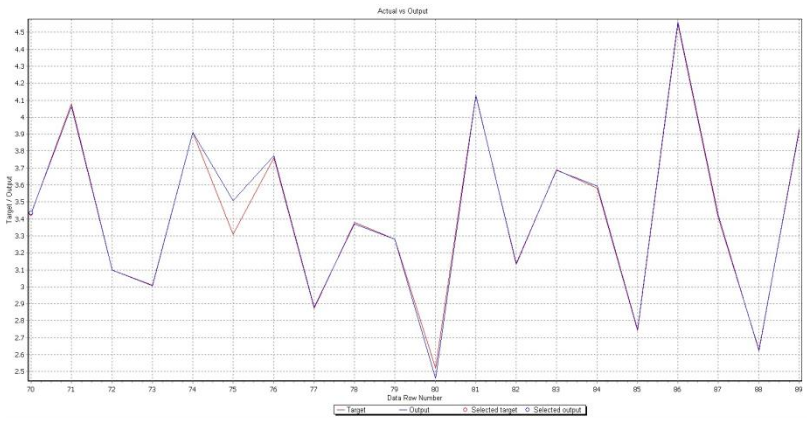

Chart 1. "The Real-Estimate Values" Chart for Test Data

As seen in Table 5, an optimal ANN model is 5 knotted and intermediate layered QN model structure. Number of nodes in the intermediate layers were found to vary among the best-estimate models for Wk output values. What number of nodes will give the better results were not determined for the intermediate layer. As it can be seen in Chart 2, estimated values were found to be very close to the actual results for all values. RMSE value in the QN model was calculated as low as 0,15 while RMSE value obtained with MR method was 0,19. In this respect, the ANN models was shown to be much more successful. Model structure is as shown in Figure 3.

Table 5. Wk estimate RMSE values for ANN models

	Wk		
Model	QP 531	QP 551	QP 571
RMSE	*1,021062*	***0,50382***	*0,840244*
Model	BP 531	BP 551	BP 571
RMSE	*2,305302*	*1,371869*	***1,229686***
Model	LM 531	LM 551	LM 571
RMSE	***0,818307***	*0,956933*	*1,184893*
Model	QN 531	**QN 551**	QN 571
RMSE	*0,180927*	***0,158108***	*0,561539*
Model	CG 531	CG 551	CG 571
RMSE	*0,376303*	*0,183277*	***0,176379***
Model	MR		
RMSE	***0,199599***		

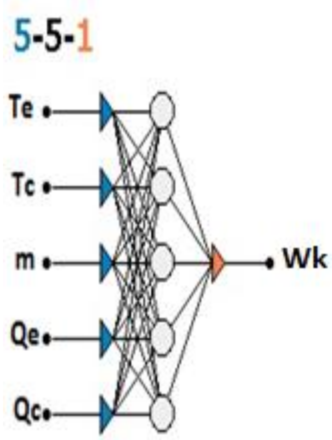

Figure 3. Created ANN structure with 5-5-1 structure with Quasi-Newton method.

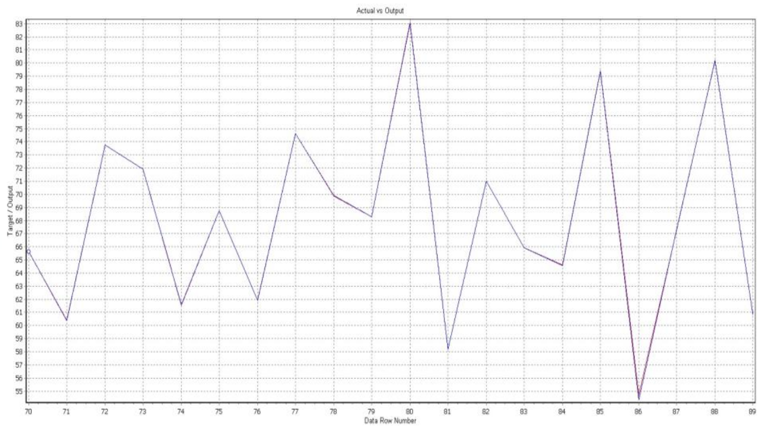

Chart 2. "The Real-Estimate Values" Chart for Test Data

Table 6. Pr estimate RMSE values for ANN models

	Pr		
Model	QP 531	QP 551	QP 571
RMSE	*0,77135*	*0,987961*	***0,442178***
Model	BP 531	BP 551	BP 571
RMSE	*3,221279*	***3,06141***	*3,180418*
Model	LM 531	LM 551	LM 571
RMSE	*2,625556*	*2,738073*	***0,692605***
Model	QN 531	**QN 551**	QN 571
RMSE	*0,607295*	***0,403461***	*1,003959*
Model	CG 531	CG 551	CG 571
RMSE	**0,515271**	0,574139	0,52654
Model	MR		
RMSE	***2,531808***		

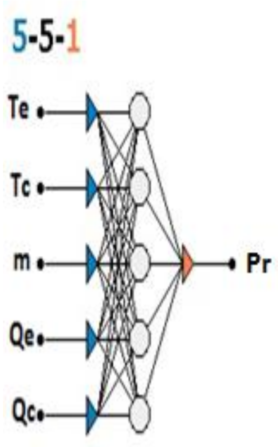

Figure 4. Created ANN structure with 5-5-1 structure with Quasi-Newton method.

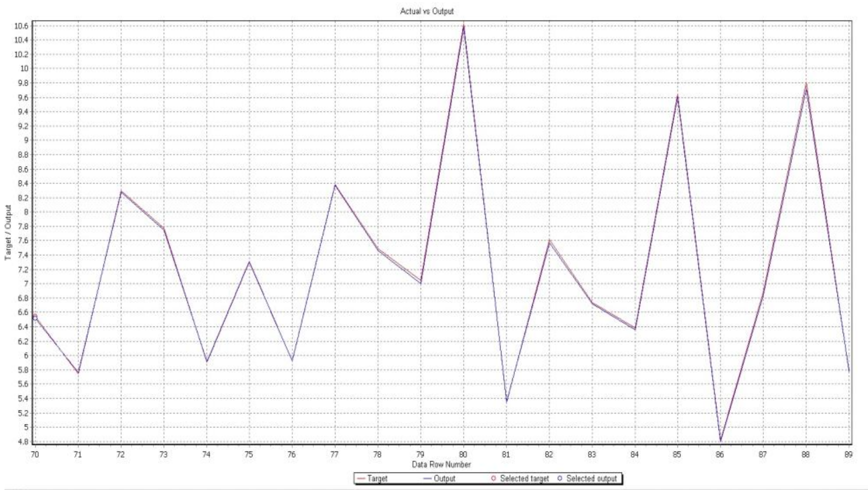

Chart 3. "The Real-Estimate Values" Chart for Test Data

As seen in Table 6, an optimal ANN model is 5 knotted and intermediate layered QN model structure. Number of nodes in the intermediate layers were found to vary among the best-estimate models for Pr output values. What number of nodes will give the better results were not determined for the intermediate layer. As it can be seen in Chart 3, estimated values were found to be very close to the actual results for all values. RMSE value in the QN model was calculated as low as 0,40 while RMSE value obtained with MR method was 2,53. In this respect, ANN models were shown to be much more successful. Model structure is as shown in Figure 4.

7. Conclusion

Because network models are made separately for *COP*, *Wk* and *Pr*, it was found that different models gave good results for each output value. For this reason, when determining the best ANN models, the difference between the percentages of RMSE error rates was taken into account. The same training data, the same validate data and the same test data were used when determining the network design which made the best estimation for 3 different output values. Networks with 3 different structures were created to determine the best model. Results were obtained by also making comparisons with values calculated with Multi Regression for 45 different network models.

It was observed that ANNs estimated unseen data with very minor differences with the success of our training set. The most suitable ANN model was identified as QN model in our system for the alternative refrigerant R152a for car cooling systems. When looking at the RMSE value, it was determined that it is 27% more successful at Pr value estimation and 11% more successful at Wk value estimation. It was seen that it made 14% poor estimation in the COP value according to the CG model. Also, QN 551 model yielded the average of 210.6% better results compared to estimations made by MR method. Second model providing the best results is CG and it yielded the average of 169.33% better results compared to estimations made by MR method.

It was determined that the QN model within trained 15 network models with 5 intermediate nodes was the model providing best average results across all models for 3 different output values with the number of iterations limited to 1500.

References

[1] http://www.worldometers.info/cars/
[2] Talley E 2010 *R1234yf Refrigerant* Fall 2010 ICAIA Conference.

[3] Kamar H M, Ahmad R, Kamsah N B and Mustafa A F M 2013 *Artificial Neural Networks for automotive air-conditioning systems performance prediction* Applied Thermal Engineering pp 63-70

[4] Kuzucuoglu A E 2010 *İklimlendirme Deney tesisatının Neuro-Fuzzy Yöntemi ile Kontrolü* (İstanbul: Marmara Üniversitesi Press) pp 20-52

[5] Kalkisim A T 2015 *Otomobil Klima Sistemleri için Alternatif Soğutkan R152a ve ANFIS Uygulaması*, (Erzurum : Ataturk University Press) p 5

[6] Kuo Y M, Liu C W 2004 *Evaluation of the ability of an artificial neural network model to assess the variation of groundwater quality in an area of blackfoot disease in Taiwan*, Water Research pp 148-154