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Hourly cooling load prediction of a vehicle in the southern region of Turkey by Artificial Neural Network

Ozgur Solmaz [a,*], Muammer Ozgoren [b], Muharrem Hilmi Aksoy [b]

[a] Selcuk University, Technology Faculty, Mechanical Engineering Department, Konya, Turkey
[b] Selcuk University, Faculty of Engineering, Mechanical Engineering Department, Konya, Turkey

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ABSTRACT

In this study, Artificial Neural Networks (ANNs) method for prediction hourly cooling load of a vehicle was implemented. The cooling load of the vehicle was calculated along the cooling season (1 May–30 September) for Antalya, Konya, Mersin, Mugla and Sanliurfa provinces in Turkey. For ANN model, seven neurons determinated as input signals of latitude, longitude, altitude, day of the year, hour of the day, hourly mean ambient air temperature and hourly solar radiation were used for the input layer of the network. One neuron producing an output signal of the hourly cooling load was utilized in the output layer. All data were divided into two categories for training and testing of the ANN. The 80% of the data was reserved to training and the remaining was used for testing of the model. Neuron numbers in the hidden layer from 7 to 40 were tested step by step to find the best matching ANN structure. The obtained results for different numbers of neurons were compared in terms of root mean squared error (RMSE), coefficient of determination (R^2) and mean absolute error (MAE). The best matching results for the training and testing were obtained as 8 neurons for the minimum testing RMSE value for the prediction of cooling load by the ANN model on the 23rd day of each month along the cooling season. For the model with 8 neurons RMSE, R^2 and MAE (Training/Testing) were found to be 0.0128/0.0259, 0.9959/0.9818 and 78.81/174.71 W/m^2, respectively. It is shown that the cooling load of a vehicle can be successfully predicted by means of the ANNs from geographical characteristics and meteorological data.

1. Introduction

Air conditioning systems significantly increase the energy consumption of a vehicle and affect the engine's performance negatively. These systems can be considered as a main auxiliary load on a vehicle engine when operating [1]. Lambert and Jones [2] reported that the compressor of an air conditioning system for mid-size vehicles could increase the fuel consumption of the vehicle around 12–17%.

Cooling load in a vehicle is affected by many parameters such as dimensions and thermal properties of the vehicle and the meteorological conditions. Because of the complexity and variety of these affecting parameters, it is very difficult to consider all of them exactly in the vehicle cooling load calculation process, which makes the hourly calculation of the cooling load a challenging task [3,4].

In recent years, the ANNs are used as a predictive model for specific applications such as forecasting because of its special ability in simulating and mapping complicate systems [5]. Also, ANN method can be very effective as it is simpler and does not use so many input parameters like the analytical model. Their ability to learn by examples makes them so feasible and flexible. ANNs also have been successfully used in various fields of mathematics, engineering, medicine, economics, meteorology, neurology, social/psychologycal sciences, load predictions, and many other subjects [6,7].

There are many types of ANNs such as Feed Forward Neural Networks (FFNN), Radial Basis Neural Networks (RBNN) and Generalized Regression Neural Networks (GRNN) [8,9]. As an alternative to analytical and mathematical modeling approaches, ANNs were used for prediction of various parameters such as performance parameters of a cascade vapor compression refrigeration system by Hosoz and Ertunc [10], performance and emission parameters on a gasoline engine by Tasdemir et al. [11], hourly solar radiation in six provinces in Turkey by Solmaz and Ozgoren [12] and global solar radiation over Turkey by Ozgoren et al. [13]. In addition, ANN method was used to prediction of the cooling load of buildings [14–18] and energy consumption of buildings [19,20].

There are some studies on the estimation of thermal loads in vehicle cabins. However hourly cooling load prediction of a vehicle

* Corresponding author.
E-mail addresses: osolmaz@selcuk.edu.tr (O. Solmaz), mozgoren@selcuk.edu.tr (M. Ozgoren), muharremaksoy@selcuk.edu.tr (M.H. Aksoy).

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using meteorological and geographical data for different provinces by ANN is not encountered in the literature. Zheng et al. [21] designed a method to calculate a vehicle's thermal loads using solar radiation, ambient loads ventilation and metabolic loads. The cooling load temperature differential method was used by taking into account the geometrical configuration of the vehicle compartment including glazing surfaces (shading), windshield and roof angle, and vehicle orientation. It was expressed that the predicted cooling load was very close to the tested value which was validated using wind tunnel tests. Arici et al. [22] developed a software package for the design and simulation of an Automotive Climate Control System. They considered that the transition of both the cabin temperature and the relative humidity were predicted using the principles of thermodynamics. Fayazbakhsh and Bahrami [23] compared models to provide a new comprehensive model for estimating thermal loads in vehicle cabins. Ding and Zito [24] used a model for calculation of heat transfer and heat capacity of a cabin. Khayyam et al. [25,26] collected different models to calculate the different types of thermal loads encountered in a vehicle. These models were used to estimate the overall cooling load of a vehicle.

In this study, hourly cooling load of a vehicle along the cooling season for Antalya, Konya, Mersin, Mugla and Sanliurfa were calculated according to meteorological data by using energy balance equations. Later, the hourly cooling load of the vehicle in mentioned provinces was predicted by using ANN method and the results were compared. In the present study, an ANN model has been developed to obtain closer prediction results than other nonlinear regressions or optimization methods. Also the FFNN method has been used in order to investigate the applicability of the best method. The different model for training and testing were formed and their results were discussed. An in-house developed software was used to train and test the model by using meteorological data of the provinces. In addition, the approach of the model and the calculated values were given for the sake of comparison on 23rd day of each month along the cooling season (1 May–30 September) for Konya.

2. Materials and methods

2.1. Model of the vehicle

All surfaces and their angles with the horizontal axis of the analyzed vehicle are given in Fig. 1. In the calculation of the cooling load, the front side of the vehicle was assumed to be directed toward the south while travelling with the speed of 120 km/h.

2.2. The cooling load calculation

The cabin of the vehicle can be treated as an air-conditioned ambient to which various energy loads occur to the vehicle as shown in Fig. 2. The energy balance of the cabin is expressed in Eq. (1). To obtain comfort conditions, the inside temperature of the cabin assumed constant as 23 °C during calculations [1].

$$m * C_{cabin}\frac{dT_{cabin}}{dt} = \dot{Q}_{trans} + \dot{Q}_{I}(t) + \dot{Q}_{occ}(t) + \dot{Q}_{equp}(t) + \dot{Q}_{inf}(t) - \dot{Q}_{evap}(t) \quad (1)$$

Overall heat gain calculation of the vehicle is briefly given in the following sections.

2.2.1. Heat gain by transmission

The transmission energy influences the cabin temperature through convection and conduction through the vehicle root: glass surfaces, bottom surface, and doors. Transmission load is a function of time requiring a host of information about the vehicle geometry and characteristics. Heat gain by transmission occurs by interaction between ambient temperature and inside air temperature as follows. In this study, the vehicle assumed to be moving with the speed of 120 km/h. For a moving vehicle convection heat transfer coefficient on the outer surfaces were taken from McAdams [27]. Overall heat transfer coefficient was calculated separately for each surface.

$$\dot{Q}_{trans,k,j} = A_k * U_k * (T_{o,j} - T_{i,j}) \quad (2)$$

where $\dot{Q}_{trans,k,j}$ is the transmission heat gain of the kth surface at jth hour of the day (W); A_k is area of kth surface (m^2); U_k is overall heat transfer coefficient of kth surface (W/m^2 C); $T_{o,j}$ is ambient outside air temperature at jth hour of the day; and $T_{i,j}$ is the inside air temperature of the vehicle at jth hour of the day. $T_{i,j}$ was taken as 23 °C to maintain comfort conditions [23,28,34].

Transmission heat gain from the baggage side of the vehicle was calculated from the following equation

$$\dot{Q}_{trans,bag,j} = A_{bag} * U_{bag} * (T_{o,j} + 10 - T_{i,j}) \quad (3)$$

Here, inside temperature of the baggage was assumed as 10 °C higher than the ambient outside temperature from the point of a real working condition approach [28].

Transmission heat gain from the engine side of the vehicle was calculated from the following equation

$$\dot{Q}_{trans,eng,j} = A_{eng} * U_{eng} * (60 - T_{i,j}) \quad (4)$$

where the air temperature of the engine side was taken constant as 60 °C from experimental results [23,28,29].

2.2.2. Heat gain by radiation

For design and analysis, the solar radiation amount coming from the tilted surfaces must be known. Therefore, equations developed by geophysical and trigonometric rules derived from the measured meteorological radiation data are commonly used in calculations [30]. In the present study, the solar radiation amount coming on the vehicle surfaces were determined by using different models. "Orgill and Hollands" model was used for the calculation of the diffuse radiation on the horizontal surface, "Koronakis" model was used for the calculation of the hourly diffuse radiation ($I_{d,\beta,j}$) on the tilted surfaces, and "Liu and Jordan" model was preferred to calculate the hourly beam ($I_{b,\beta,j}$) and reflected ($I_{r,\beta,j}$) radiations on the tilted surfaces [31,32] which were suggested by Durmaz [33]. After above explanation, overall radiation amount existed at the kth surface ($I_{k,j}$) can be calculated as follows.

$$I_{k,j} = I_{d,\beta,j} + I_{b,\beta,j} + I_{r,\beta,j} \quad (5)$$

Heat gain by the radiation from the glass and opaque surfaces of the vehicle were calculated as follows

$$\dot{Q}_{I,k,j} = A_k * k_y * I_{k,j} \quad (6)$$

Here, $\dot{Q}_{I,k,j}$ (W) is heat gain of kth surface by radiation at jth hour of the day, A_k (m^2) presents the area of the surface, k_y displays a radiation transmission coefficient of the glass and opaque surfaces, taken as $k_y = 0.7$ and $k_y = 0.5$, respectively [33]. $I_{k,j}$ (W/m^2) is the incoming horizontal radiation on the kth surface at jth hour of the day.

2.2.3. Heat gain by occupants

$$\dot{Q}_{occ,j} = Z * (\dot{Q}_{lat,occ} + \dot{Q}_{sens,occ}) \quad (7)$$

Here, Z is the number of people in the vehicle and assumed to be 4 in present case. $\dot{Q}_{sens,occ}$ and $\dot{Q}_{lat,occ}$ present, in sequence, sensible and