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Estimation by ANN of Luminous Efficacy of Lamps Used for Lighting

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***Abstract*—The increase in energy production costs, and the increasing demand for energy have made energy saving necessary. Energy saving in lighting is able to be actualized by providing economically the same level of light without decreasing the illumination quality. A good lighting is possible by directing required amount of light to spaces desired to be lit. For a good lighting, efficiency factor is a significant measure. By adjusting the luminous efficacy in lamps, the electric energy to be consumed by the lamps is able to be minimized. The electric energy consumed for producing luminous energy will be less at the extent of greatness of luminous efficacy. In this study, the luminous efficacy of lamps of different brands were estimated by the use of data regarding voltage rating, power rating, and total luminous rating of lamps. According to the results of the analysis made by the developed ANN model, the luminous efficacy of lamps of different brands were estimated with an accuracy rate of above 98%. Regarding the lighting systems to be developed, the selection of lamps will be made based on their ability to provide economically the same level of light without decreasing the lighting quality, and to provide the required luminous efficacy for increasing the luminous efficacy.**

Index Terms—**Luminous Efficacy, Energy saving, Lighting quality, Artificial Neural Network (ANN)**

I. INTRODUCTION

ELECTRIC energy has been one of the essential factors required in each phase of our lives [1,2]. In our daily lives, electric energy is used in each field such as lighting, heating, communication health, traffic, workplaces, schools, hospitals, water distribution, security systems, energy production, and transportation [3]. When we consider the challenges faced in transmitting the electricity to consumers along with the high cost of electric energy production techniques, it is able to be observed that economical and efficient use of electric energy is required [4,5]. While 20% of the total electric energy consumption is used for lighting in general in developing countries, about 19% of the total electric energy consumption is used for interior and exterior lighting across the globe [6, 7]. The technology is renewed rapidly by the increasing population of the world, and accordingly the amount of energy required for indoor and outdoor lighting increases. Lighting is one of the most significant factors required for people to maintain their lives and affairs at many locations such as buildings, tunnels, hospitals, workplaces, establishments, factories, roads etc. [8,9]. In buildings, actualization of lighting without going to extremes, and making the design as to obtain sufficient light in a manner that will minimize the electric energy costs are the main objectives. For the efficient use of energy in lighting, it is required to make the lighting design as conforming to the intended purpose in the installation phase of the buildings [10]. By doing so, the fields of electricity and architecture are being merged, and environment-friendly new buildings are being created [11]. During the design of lighting systems, it is required to consider their compatibility with the purpose of work to be performed along with energy saving, and the presence of suitable lighting mechanisms. While creating the suitable lighting conditions, criteria such as the direction of light along with its colour, and the sharpness and softness of shades in the light level obtained are also important. It is required to consider these [12]. Moreover, the minimization of the preparation phase and usage period of the lighting systems, and regular maintenance and cleaning of lighting elements are also required. On the other hand, energy saving in lighting is able to be ensured when lamps with high efficiency factor are used, in a well designed lighting system, with a correct maintenance method [13]. Lamps with high luminous efficacy should be preferred in lighting. Because the electric consumed for procurement of equal luminous energy will be less at the extent of greatness of efficiency factor. The lamps with low luminous efficacy will use more electricity from the network. Briefly, in lighting, energy saving is able to be ensured with fixtures of high luminous efficacy [14]. As the type of lamp used on the fixture affects the electrical power and luminous flux, the efficiency will also vary. As the type of lamp used on each fixture, and as the electrical power they consume and their luminous flux are different, the luminous efficacy (efficiency factor) will also be different. For this reason, as the characteristics of lamps such as fluorescent lamp, incandescent lamp, halogen lamp, high-pressure sodium vapor lamp, or LED lamp are different, the luminous efficacy will be directly affected. Moreover, as the additional pieces used on the fixture such as lens, reflector or diffuser keep the light under control,

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they affect the luminous efficacy [15]. There are many studies in literature with respect to lighting systems, new lighting lamps and equipments. Considering the similar studies in literature, O. Olgun et al. evaluated the luminous and electrical performances of lighting fixtures with passive infrared sensor. As the result of their study, they determined that the most efficient fixtures with PIR sensor were ones with LED chip according to the results of electrical and luminous analyses. And they specified that fixtures with E27 lamp base on which LED lamps were used followed the fixtures with PIR sensor. They concluded that the results of economic analyses were parallel with the results of electrical and luminous analyses [16]. And K.M.M. Hasan et al. examined the LED lamps, compact fluorescent lamps, fluorescent lamps, and incandescent lamps, and performed detailed analyses with respect to these lamps. And as the result of their analyses, they obtained the highest efficiency value by the LED lamps. They determined that incandescent fixtures had higher power factor, and that total harmonic distortion (THD) values of LED lamps were higher compared to fluorescent and incandescent lamps [17]. S.Akın examined the fluorescent lamps, and the locations where they were being used in architecture. In the study, the types of fluorescent lamps used today were classified, and it was determined that they were more economic compared to incandescent lamps due to their high luminous efficacy and longer life. As such lamps are highly various in terms of their characteristics of size, shape, power, efficiency, colour etc., they concluded that they were being used in various lighting systems, and that they were able to meet various requirements [18]. Ç.Perdahcı performed energy analysis, through computer simulation program, of a lighting system formed by the use of conventional fixtures at a metal processing industrial plant after replacing the fixtures with fixtures using LED lamp by preserving the level of light. Design of lighting project of the plant was performed by the use of LED fixtures, and fluorescent fixtures operating with electronic ballast. The power consumed by the fixtures used, and value of luminous flux and luminous efficiency of the fixtures were calculated separately for each scenario. The values of luminous flux were compared with the amount of power consumed by two types of lighting fixtures, and electrical power consumption was analyzed. According to the results of simulation of lighting system's design performed for evaluating the efficiency of fluorescent fixture and LED fixture, the luminous efficacy of fluorescent fixture was found as 67.02 lm/W, and the luminous efficacy of fixture with LED lamp was as 141.94 lm/W [19]. And M.T. Gençoglu et al. emphasized the importance of energy saving and energy efficiency, and specified the benefits of energy saving in lighting. They determined the things required to be performed for a correct and efficient lighting, and the things required to be considered while obtaining energy saving. Moreover, they suggested the preference of lamps with high luminous efficacy, with long lifetime, and with low value of luminous flux that arise in time [20]. Ö. Güler et al. showed that the photometric values of fixtures significantly affected the installation and operating costs of fixtures as the result of calculations obtained with a design actualized by forming a sample route model. Moreover, they specified that the values required to be considered in terms of installation and operating costs during the selection of lamps were economic life, colour characteristics and luminous efficacy. It was specified that the luminous efficacy and especially lives of normal types of metal halogen lamps were lower compared to other lamps. But it was also specified that the new types of metal halogen lamps operated with electronic units recently reached to very good values in terms of lifetime and luminous efficacy [21]. S. Gün Çam examined different lighting techniques that may be used for lighting of building façades. Buildings located in various countries were determined as samples, and lighting systems were examined as per the determined techniques by addressing the buildings in Istanbul lit with LED. It was concluded that LED lamps were being preferred due to their high luminous efficacy, and long lifetime [22]. M. Winterbottom et al. specified that lighting with inefficient fluorescent lamps decreased the visual performance by causing headache. And they specified that, in order to prevent that, automatic blackout lamps should be present in the classes to be built provided that they are non-vibrant. Moreover, it was specified that the values obtained in the beginning vanish in time due to environmental conditions, decrease of luminous efficacy and lifetimes of lamps, and fouling factor [23]. Ç. Perdahcı et al. examined the LED technology, and the value of this technology in terms of energy saving by examining the efficient lighting, energy saving in lighting, and the control systems along with energy efficiency. Moreover, it was pointed out that it is required for the luminous efficacy to have high efficiency classification during selection of lamp [24]. M. Ş. Küçükoğlu examined the effective use energy in lighting by considering that it would be possible through mitigating the formation burden of lighting system, and through minimizing the usage period of artificial lighting systems. Moreover, it was specified that lamps play a significant role in energy consumption especially by their efficiency values. It was specified that, at plants that are being used for a long period continuously along the days or at nights, the selection of lamps, from among the ones having the required quality in terms of colour characteristics, with highest efficiency value is extremely important in terms of effective use of luminous energy [25]. B. Taşkan performed analyses for the determination of required spans in order to prevent the formation of flicker effect in road lighting due to speed, and evaluated the results. He specified that the luminous efficacy of each lamp or fixture was different [26].

Following the examination of all these studies, the luminous efficacy of lamps were defined in general, and they were compared with the luminous efficacy of different lamps. The benefit of luminous efficacy, and its effect in lighting were emphasized.

The change that makes this study different from the others is the estimation of the luminous efficacy of a lamp by ANN model. In here, the ANN model was defined by deeming the power, voltage, flux and brand of lamps as input values, and by deeming the luminous efficacy as output value. It was concluded that the luminous efficacy estimated also by the use test data was compliant at a rate of 98%. By the use of ANN model, the lamp which will provide the luminous efficiency suitable for the environment, as per specific values without the requirement of making calculation each time, will be determined much easier in this manner, and energy saving in lighting will be ensured.

II. Material and Methods

Examining only one lamp for observing the effect on the lighting of lamps used in lighting systems is not being sufficient. Examining the effects of luminous efficacy on lighting by the use of numerous lamps will enable use to get better results. Moreover, the use of numerical methods during such calculations enables us to reach to more accurate data and solution methods. Working with ANN is being more suitable in numerical and experimental studies in terms of both cost and use of time. In the study performed, the luminous efficacy of lamps were estimated by the use of machine learning method. For the development of the model, the ANN model in the MATLAB (Neural Network Toolbox) software was used.

A. Luminous Efficacy (Efficiency Factor)

The luminous efficacy, as specified in Equation (1), is defined as the value obtained by dividing the luminous flux radiated from a lamp to the power used by the source.

$$e = \frac{\Phi}{P} \tag{1}$$

In the Equation;

e indicates the luminous efficacy (lm/ W);
Φ indicates the luminous flux (lumen);
P indicates the power of lamp (W).

Wind This expression, that expresses the lamp's luminous efficacy in lm/w, should be the most basic criterion required to be considered primarily regarding efficiency. The luminous efficacy is a physical quantity that indicates how well the visible light radiated by a light source is. Factors such as change of outer environment's temperature, differences in lighting manner of the lamp, changes in mains voltage, utilization time affect the efficiency of lamp. The luminous efficacy is one of the most important criteria characterizing a lamp. The electric energy consumed for producing threshold luminous energy will be less at the extent of greatness of luminous efficacy. In theory, the greatest luminous efficacy is obtained in case of a radiation with a single wavelength of λ_0=555 nm. In this case, it is V_λ=1 for the whole radiation, and e=683 lm/ W is found. But in practice, it could be reached only to the level of 200 lm/W. The cause of this is the loss of temperature on lamp, and the wavelength of radiation being 589 nm (in case of 589 nm, then V_λ=0.76) Lamps with high luminous efficacy (lumen/Watt) should be preferred in lighting. Because the electric consumed for procurement of equal luminous energy will be less at the extent of greatness of luminous efficacy. The lamps with low luminous efficacy will use more electricity from the network. And this implies that energy saving is able to be ensured through fixtures with high luminous efficacy in lighting [27-29]. As the type of lamp used on the fixture affects the electrical power and luminous flux, the efficiency will also vary. As the type of lamp used on each fixture, and as the electrical power they consume and their luminous flux are different, the luminous efficacy will also be different. For this reason, as the characteristics of lamps such as fluorescent lamp, incandescent lamp, halogen lamp, high-pressure sodium vapor lamp, or LED lamp are different, the luminous efficacy will be directly affected. Moreover, as the additional pieces used on the fixture such as lens, reflector or diffuser keep the light under control, they affect the luminous efficacy [30,31]. Each source of light has different luminous efficacy as per the manner and nature of radiation. The parameters such as temperature of outer environment, ballast characteristics, changes in mains voltage, and utilization period cause changes in luminous efficacy.

In this study, brands, and voltage, power, luminous flux values of lamps, and luminous efficacy values of such values were used as data. Regarding the data used in the study, market search was performed for the label values of different types of lamps, and the data was obtained from the catalogues. The luminous efficacy values were formed as being calculated with Equation (1) by the use of catalogue values of lamps subjected to examination. In Fig.1-4, the graph of change of luminous efficacy, used in the ANN training, as per the flux, power, voltage and brand of lamps is shown.

B. Artificial Neural Network (ANN)

ANN has a characteristic similar to neurons in human brain, and it consists of complex systems formed by coherence of artificial neurons with a different connection geometry. By these complex systems, it is being tried to solve the problems that cannot be solved by classic methods [30,32]. ANN is a well accepted method also in the solution of poorly conditioned problems along with complex problems. And the algorithms used are based on the solution of complex differential equations, and powerful computers and time are required for the obtainment of accurate results [33]. Compared to very complex mathematical methods and algorithms, ANN may learn the key information examples from multi-dimensional database [34]. In addition to these, the error tolerance of ANN is high as it can process noisy and deficient data. The weights adjusted each time with each input from outside are representative of actualization of learning. Mathematically, the weight values form the most determinant points of the geometrical figure which tries to best represent all the input values, and which is represented by the regression curve where the sum of distances of all input values is minimum. By this means, the most accurate answer is able to be provided for the value entered [35]. Another factor playing an effective role on learning in ANN is the number of layers used on ANN. Even if the number of layers change among models, a ANN model, consisting of 3 layers, is sufficient even for the most complex problems.

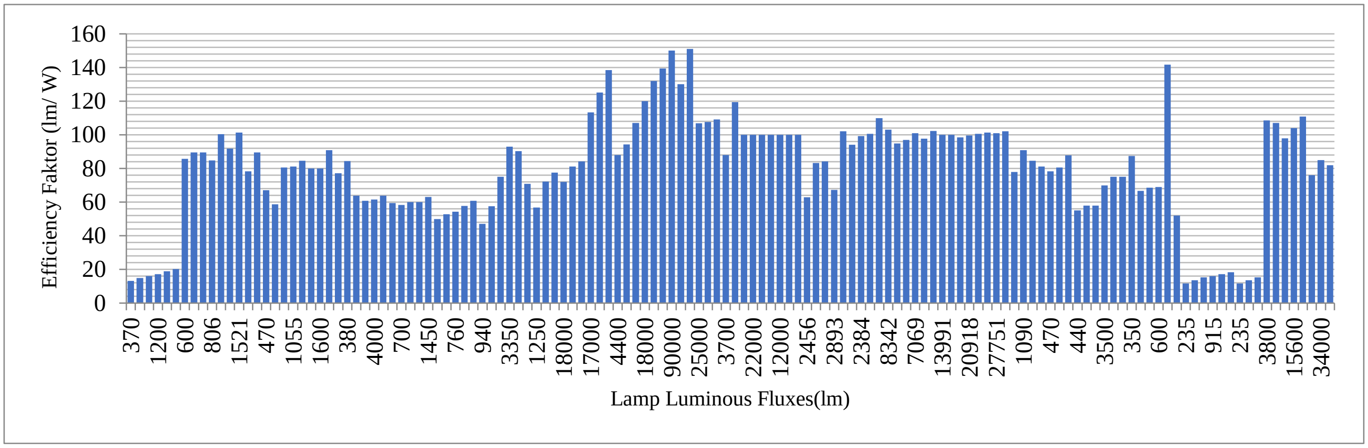

Fig.1. Graph of Change of luminous efficacy as per Luminous Flux of Lamps

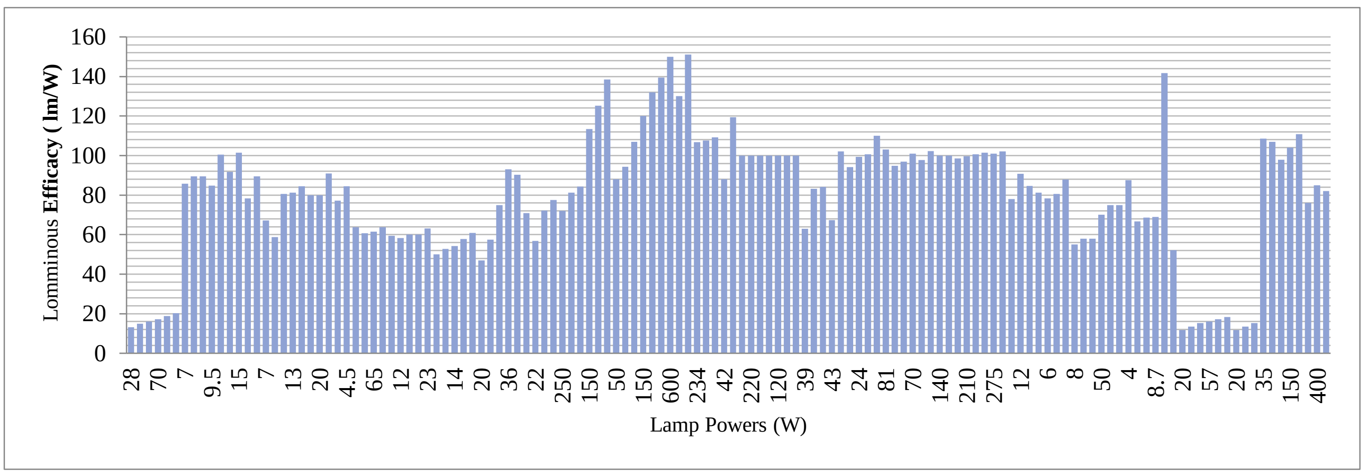

Fig.2. Graph of Change of luminous efficacy as per Power of Lamps

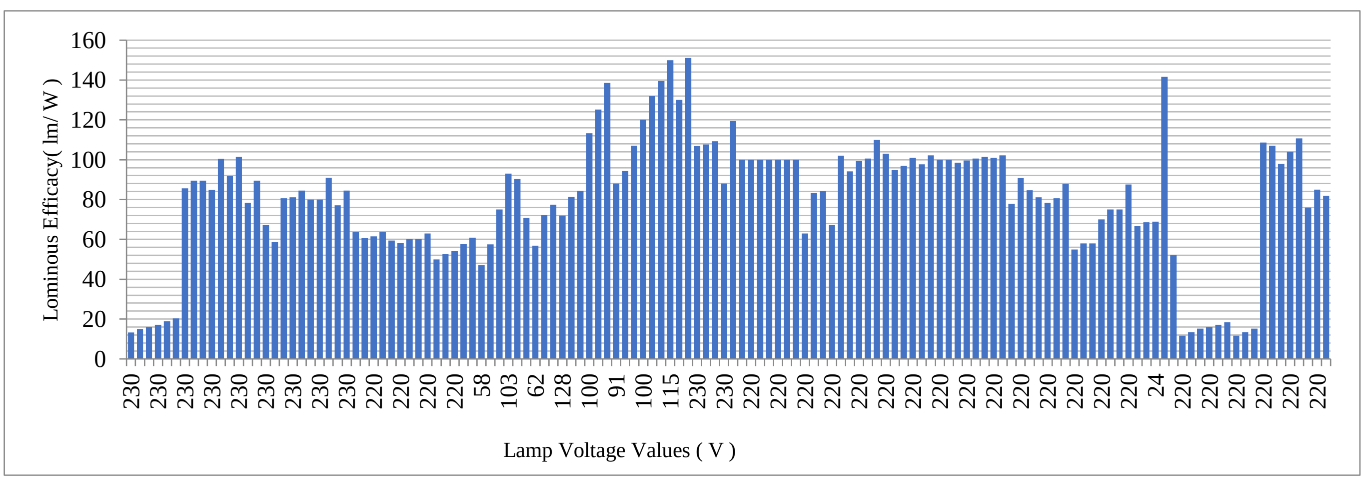

Fig.3. Graph of Change of luminous efficacy as per Voltage of Lamps

This doesn't mean that the problems may not be solved by YSA models with layers below 3 or more than 3. In this 3 layered ANN, there are input layer, hidden layer, and output layer. If it is a 4 layered structure, the 1st layer is called the input

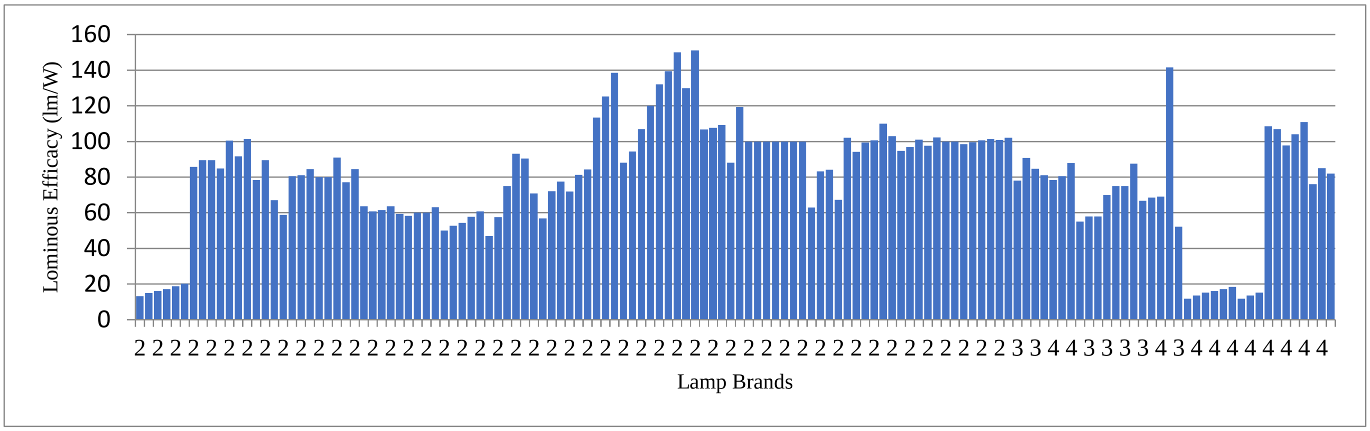

Fig.4. Graph of Change of luminous efficacy as per Brands of Lamps

layer, the 4th layer is called the output layer, and the layers between them are called the hidden layers. In ANN, number of iterations also varies among problems, and as per the self-sensitivity of the problem. High number of cycles will decrease the network performance, and will extend the time of reaching the result, and low number of cycles will cause generation of rough results as to hinder reaching the result. For this reason, while applying ANN for each problem, number of iterations is being tried to be determined by the trial-and-error method [36].

In order to make estimation with ANN, first it is required to train the ANN to be formed. In this study, the variables used for ANN training are input (weight) values, and output (target) values. Brands, and values of voltage, power, total luminous flux of lamps were used as ANN input values. Luminous efficacy values (lumen/Watt) of different lamps were assigned as ANN output values. Input and output variables, used in the estimation of luminous efficacy by ANN, are as observed in Table 1.

In Fig.5, the input (weight) and output (target) values of ANN model, formed for the estimation of luminous efficacy, are observed. In ANN, it is required to transform the verbal

TABLE I
INPUT (WEIGHT) AND OUTPUT (TARGET) DATA USED IN ANN TRAINING, AND THEIR INTERVAL OF CHANGE

Inputs	Weight and Target	Max.	Min.
X_1	Brands of lamps	4	2
X_2	Voltage values of lamps	230	12
X_3	Power values of lamps	2000	3
X_4	Total luminous flux values of lamps	180000	235
Y_1	Luminous efficacy values of lamps	151.11	11.75

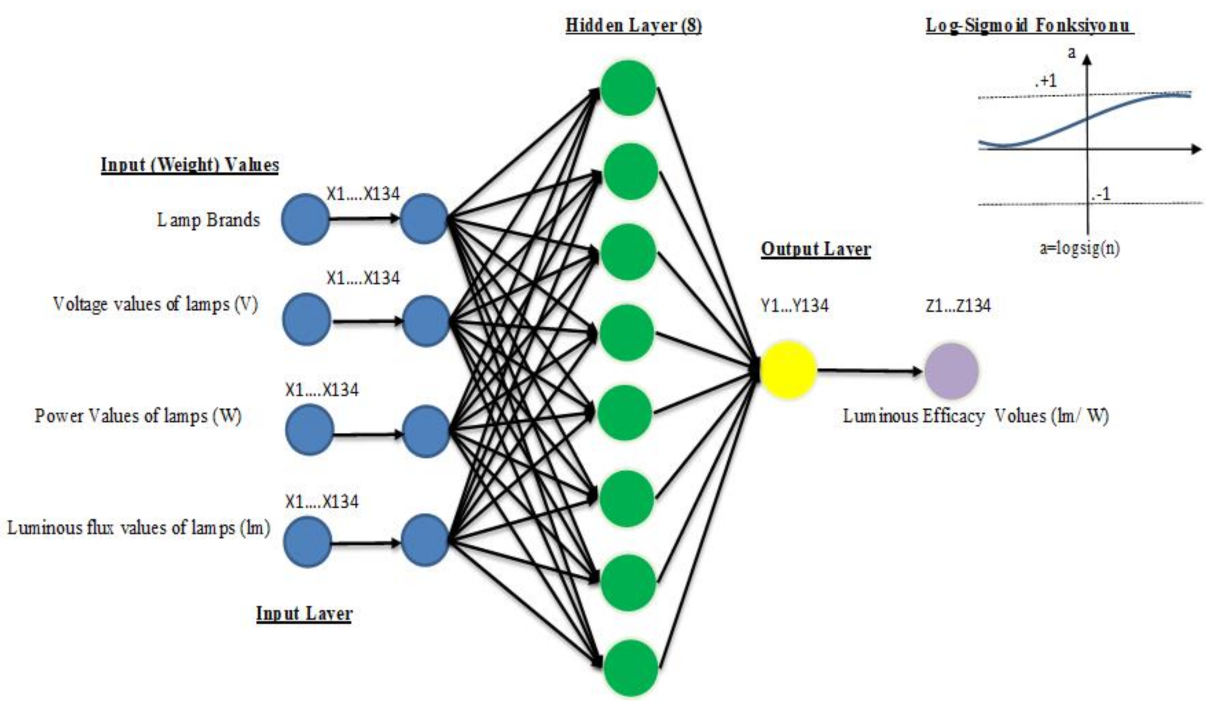

Fig.5. The weight and target values of ANN model for the estimation of luminous efficacy

data to numeric data. Without the transformation, it will not be possible for us to introduce these values to ANN.
In ANN, operation is performed between values of "0" and "1". For this reason, identification was made by assigning values other than "0" and "1" for the brands. The values assigned are as shown in the below Table 2.

TABLE II
VALUES ASSIGNED TO BRANDS OF LAMPS USED

Brand:	Values
Philips	2
Nade	3
Ostram	4

In ANN, values much greater or much smaller than the normal are able to be observed between the weight and target data. When these are mistakenly entered in the training set, they cause the rise of excessively great or small values during the calculation of net inputs, and they are able to mislead the network. The scaling of all the training data at a specific interval, namely mostly at the interval of 0-1, will assist both the reduction on the same scale of information from different environments, and the elimination of the effect of incorrectly entered excessively great and small values. Thus, before the ANN training phase, the learning performance of ANN is able to be increased by performing some preliminary operations.

The training of ANN is able to be made more efficient by subjecting the weight and target data, to be used in the training of network, to specific operations. This operation is called the normalization operation. The normalization operation is applied on raw training data. Because raw training data is not directly used in ANN training [37]. In this study, the training data was reduced to the interval of (0 and 1) by the use of min.-max. normalization method. Equation 2 was used to reduce the training data to this interval.

$$X' = \frac{(X_i - X_{min})}{(X_{max} - X_{min})} \quad (2)$$

In the Equation;

X' is the normalized value,
X_i is the input value of ANN,
X_{min} is the smallest value of input value,
X_{max} is the greatest value of input value [38,39].

In this study, following the normalization operation of data used for the training of ANN, the real values were found by making inverse transformation. Change graphs of input and output values, subjected to normalization, used in the training of ANN are shown below. The graph of change of the value of luminous efficacy subjected to normalization in comparison with luminous flux values of lamps subjected to normalization is as observed in Fig.6.

The minimum and maximum values of data, used in ANN training, and subjected to normalization, are as observed in Table 3.

TABLE III
MIN. AND MAX. VALUES OF DATA USED IN THE ANN TRAINING, AND SUBJECTED TO NORMALIZATION

Inputs	**Weight and Target**	**Max.**	**Min.**
$\mathbf{X_1}$	Brands of lamps	1	0
$\mathbf{X_2}$	Voltage values of lamps	0	0
$\mathbf{X_3}$	Power values of lamps	1	0
$\mathbf{X_4}$	Total luminous flux values of lamps	1	0
$\mathbf{Y_1}$	Luminous efficacy values of lamps	1	0

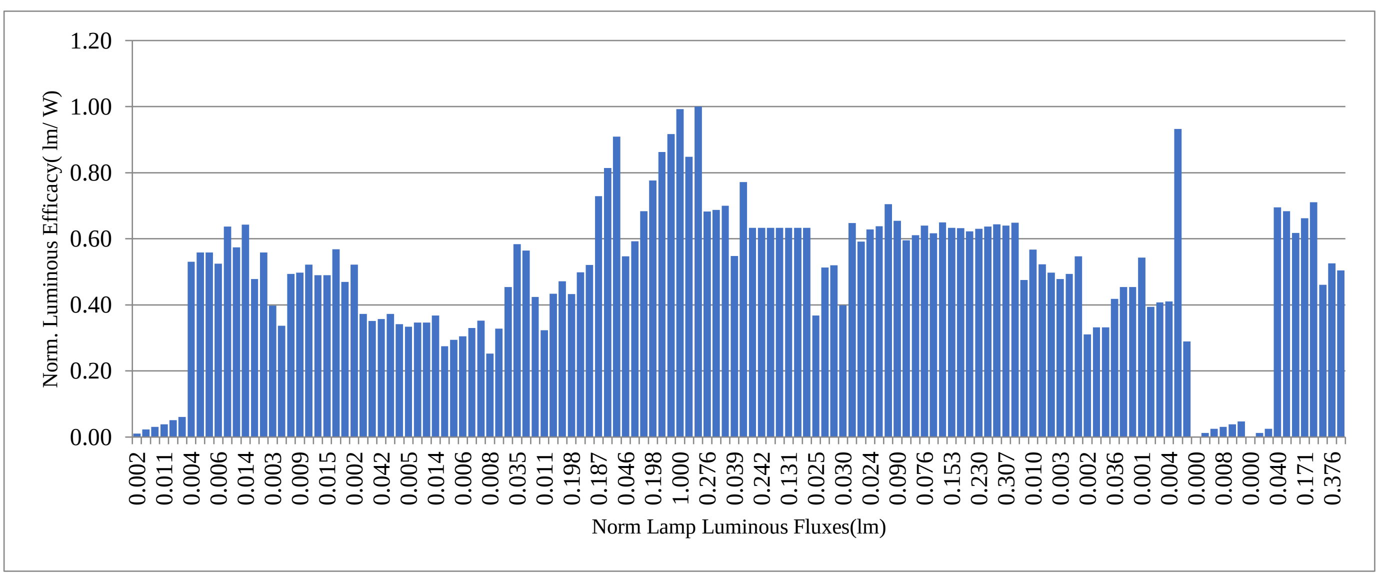

Fig.6. Graph of change of luminous efficacy subjected to normalization in comparison with luminous fluxes of lamps subjected to normalization

The graph of change of the value of luminous efficacy subjected to normalization in comparison with power values of lamps subjected to normalization is as observed in Fig.7.

The graph of change of the value of luminous efficacy subjected to normalization in comparison with voltage values of lamps subjected to normalization is as observed in Fig.8.

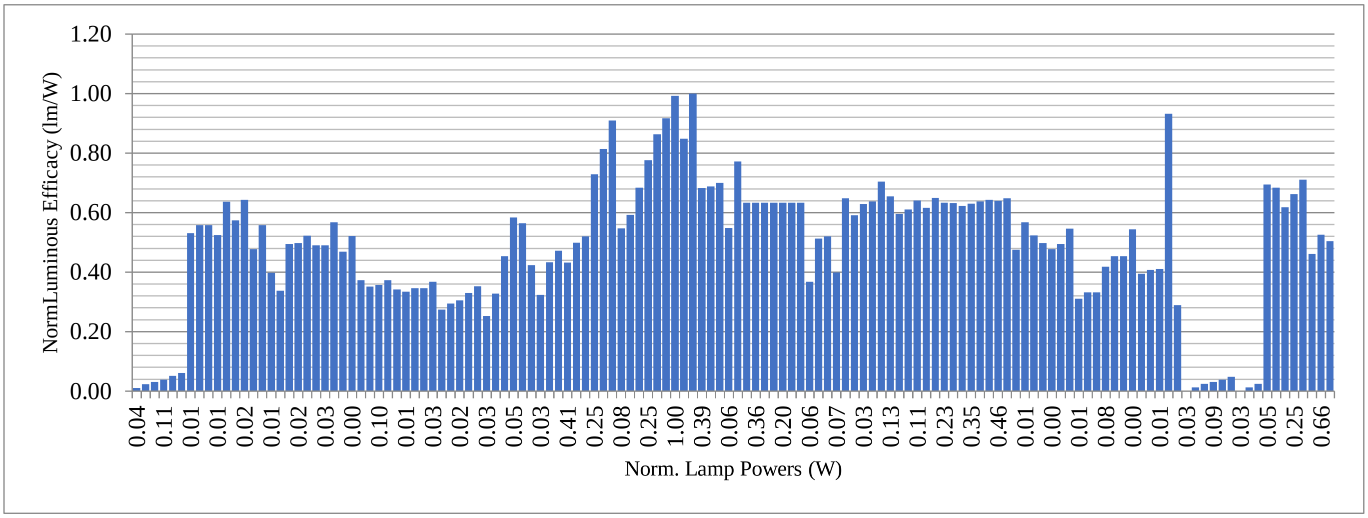

Fig.7. Graph of change of luminous efficacy subjected to normalization in comparison with powers of lamps subjected to normalization

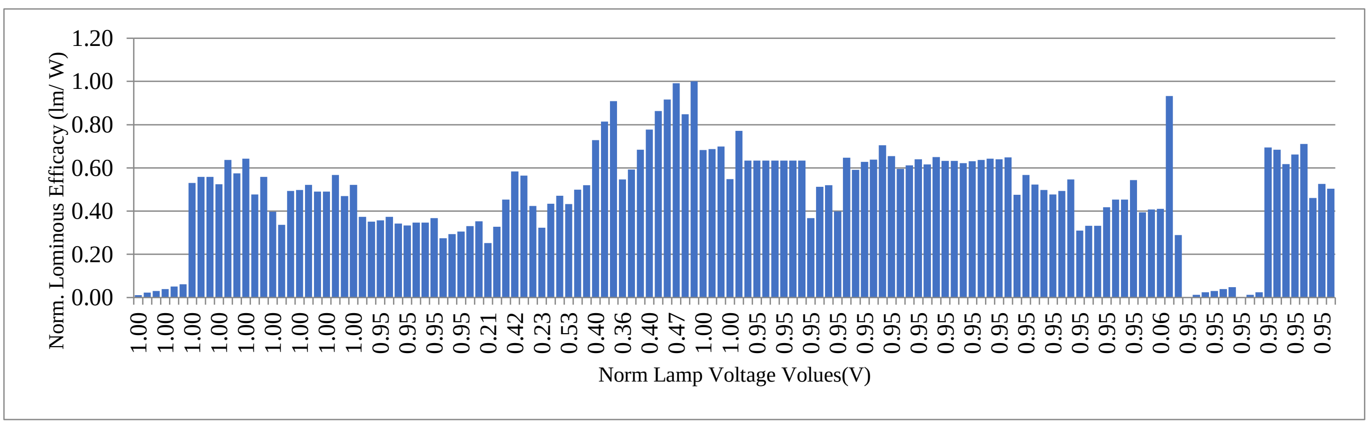

Fig.8. Graph of change of luminous efficacy subjected to normalization in comparison with voltages of lamps subjected to normalization

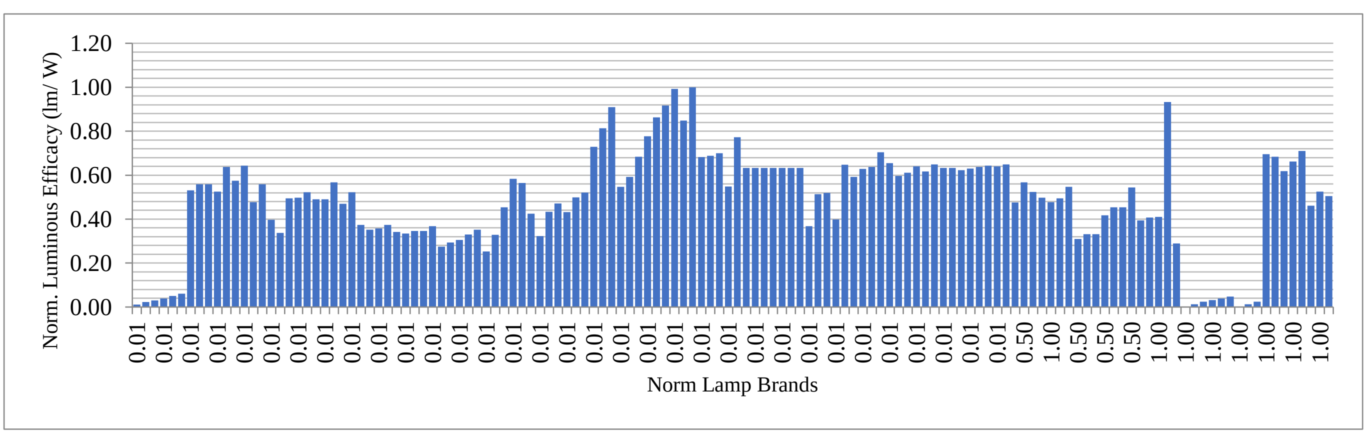

Fig.9. Graph of change of luminous efficacy subjected to normalization in comparison with brands of lamps subjected to normalization

The graph of change of the value of luminous efficacy subjected to normalization in comparison with brands of lamps subjected to normalization is as observed in Fig.9.

III. FINDINGS AND DISCUSSION

In the defined model, feed-forward backpropagation was selected as ANN model for the estimation of luminous efficacy. On the network formation screen, Training function TRAINLM, Adaption learning function, namely LEARNGDM was preferred. And MSE (mean squared error) was used as performance function. And the LOGSIG (Log-Sigmoid Transfer Function) function, observed in Fig.10, was used as transfer function.

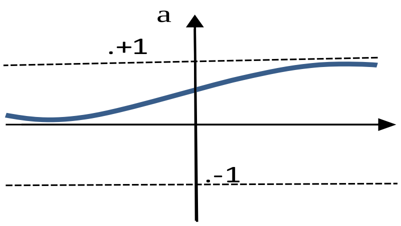

Fig.10. Log-Sigmoid Function

The functions and data used in ANN training are as observed in Table 4.

TABLE IV
FUNCTIONS AND DATA USED IN ANN TRAINING

Network Properties		
Network Type	:	Feed-Forward backpropagation
Training function	:	TRAINLM
Adaption learning function	:	LEARNGDM
Performance function	:	MSE
Number of layers	:	2
Properties for	:	Layer 1
Tranfer Function	:	LOGSIG

The view of neural network of the defined ANN model is given in Fig.11. In the ANN, there are 4 input values, and 1 output value.

In Fig.12, training, validation, test, and ALL values of the estimation are observed. ANN training value of input values was actualized with a regression of 0.99771. The set up 4x1

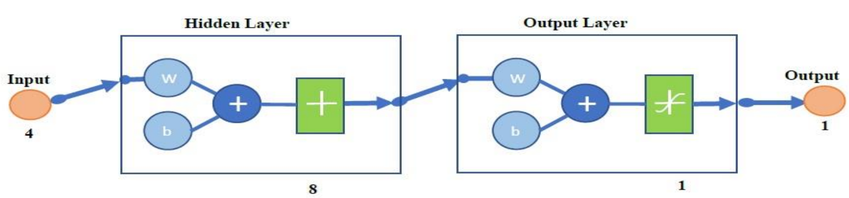

Fig.11. Schematic representation of the defined ANN

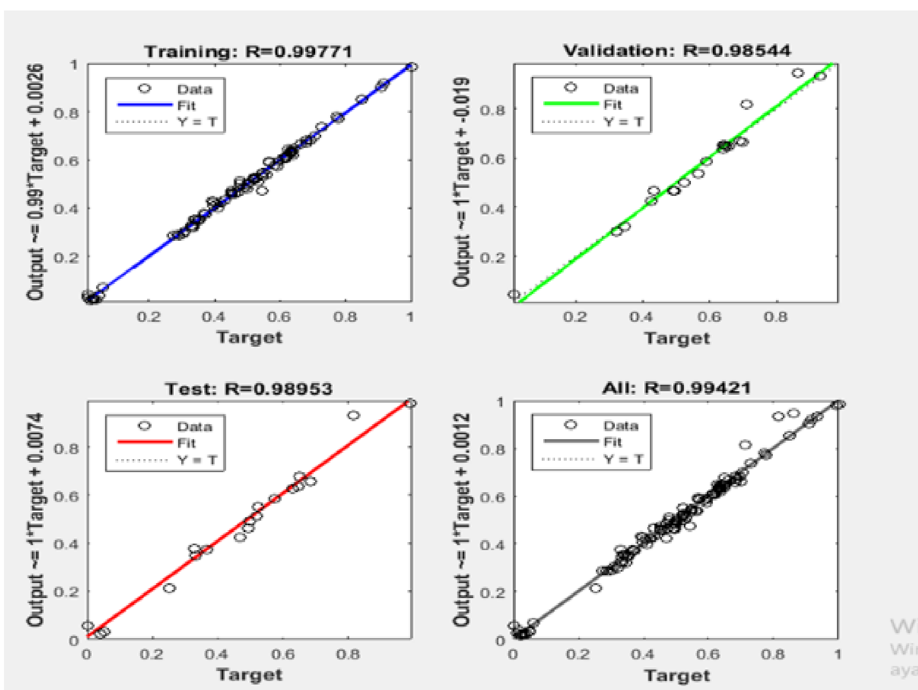

Fig.12. Training, Validation, Test, and All Values in the Estimation Made

ANN estimated validation value was actualized by 0.98544. Test regression value of values, determined as target, was actualized with a high validity as 0.98953. All input regression value was found as 0.99421. When we consider Fig.12, we observe that the training values were found to be correct at a rate of 99.771%. Validation value is also important.

When we consider it, it is observed that it was found correct in ALL, namely in total, at a rate of 99.54%. As the correlation value is equal to one as it is observed, it is observed that there is perfect similarity between network output and target output. As observed in Fig.13, it is observed that the closest value was obtained at about 100th iteration. In the model developed, the best performance value was determined as 0.0013004. In here, it was intended to estimate the lamps' luminous efficacy by the ANN model developed through the use of specific input variables of lamps.

The graph, indicating that the luminous efficacy values estimated by ANN, after entering weight and target values in ANN, and the currently known luminous efficacy of lamps tally with each other, is observed in Fig.14.

In Fig.15, the 3D graph, indicating that the luminous efficacy provided ANN and the estimated luminous efficacy tally with each other at a rate of 99.771%, is observed.

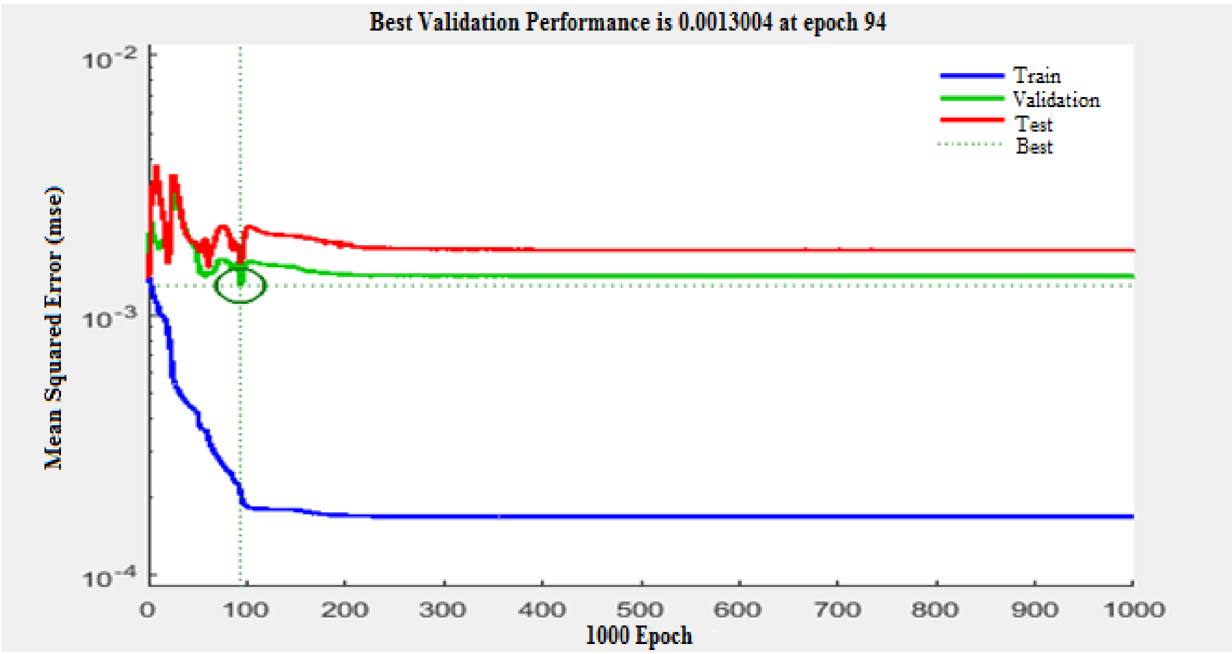

Fig.13. Graph of the Estimation Made

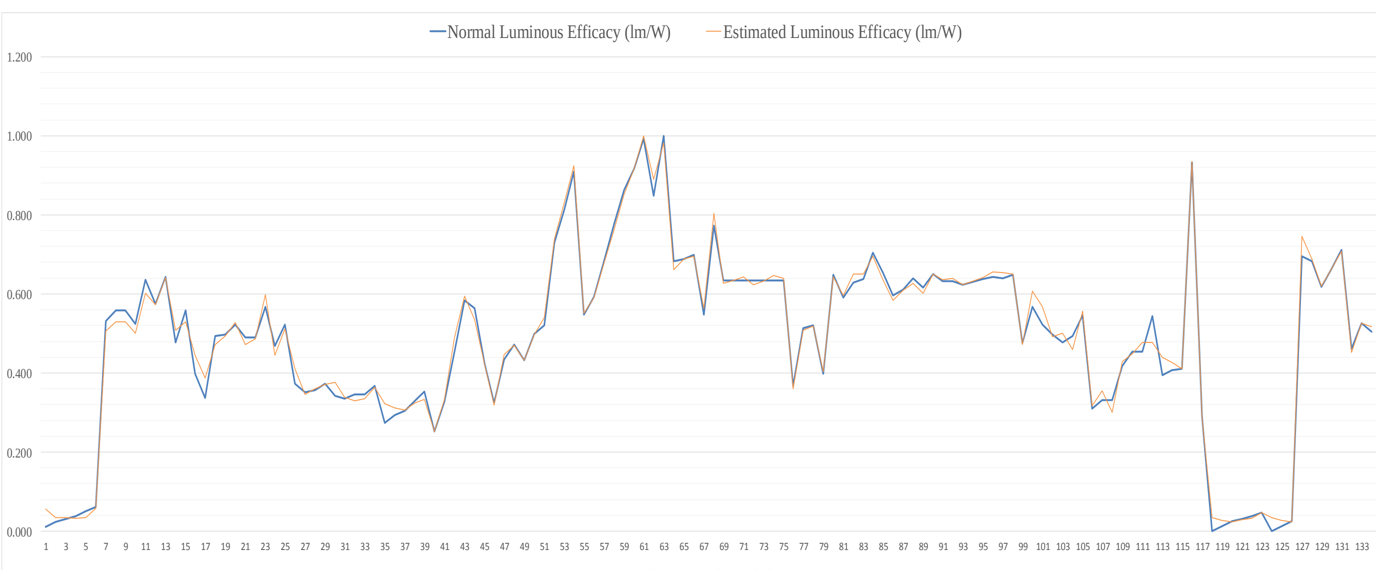

Fig.14. Graph of current values of luminous efficacy, and values of luminous efficacy estimated by ANN

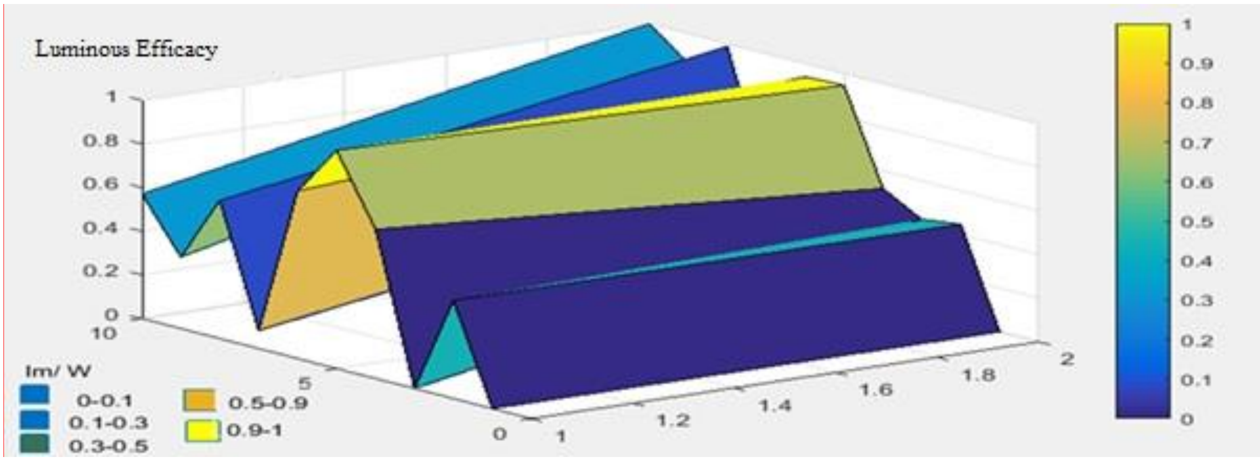

Fig.15. 3D graph indicating that the test values of luminous efficacy, and the estimated values of luminous efficacy tally with each

VI. CONCLUSION

In this study, it was intended to estimate the lamps' luminous efficacy by the ANN model developed through the use of specific input variables of lamps. During the development of ANN model, 536 units of data (4 different characteristics) were evaluated according to 4 different input variables. In the evaluation of ANN model developed, brands, and values of voltage, power, total luminous flux of lamps were used as input values. Luminous efficacy values of different lamps were determined as ANN output values. The set up 4x1 ANN estimated validation value was actualized by 0.98544. Test regression value of values, determined as target, was actualized with a high validity as 0.98953. All input regression value was found as 0.99421. In the model developed, the best performance value was determined as 0.0013004. According to the results of analysis performed by ANN, in the determination of luminous efficacy, the values were estimated correctly at a rate of 99.771% in comparison with input variables. In this manner, for the calculation of luminous efficacy, estimation is made by ANN by entering specific values instead of making calculation one by one. The luminous efficacy of the lamp used will be able to be estimated, and accordingly, utilization of more suitable lamp will be ensured. In addition, both cost saving and energy saving will be ensured due to use of lamp of sufficient power without the utilization of a lamp with higher power. The energy consumed will be less at the extent of greatness of luminous efficacy. By the study, it was observed that the real values, and the values obtained through estimation were very close, and that they were nearly close to 1. It is being considered that this will serve as a model for the future similar studies.

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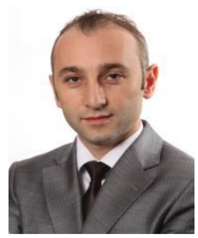

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