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Best Performance Evaluation and Linear Regression Modelling Of Cooling System Capacity and Latent Heat Load: Neural Network/Matlab Approach.

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ABSTRACT

The study, best performance evaluation and linear regression modeling of cooling system capacity and latent heat load using Neural Network/MATLAB approach was successfully carried out. The researchers adopted a survey design approach and randomly selected 10 buildings within Owerri Municipal. Measurements of room space dimensions, number of occupants, etc were taken and the values were used to determine latent heat load and cooling system capacity. Neural Network/MATLAB was used to analyze the tabular data. Training of latent heat load and cooling system capacity data was done using levenberg marquardt algorithm at 70% training data, 15% test data and 15% validation data respectively. Results revealed that the best performance level was 0 at epoch 0 and this suggested lower values of the latent heat load for optimal capacity operation of cooling system. Furthermore, the study showed that for best performance of cooling system, the latent heat load was evaluated to be 5 kW with optimal cooling system capacity below 40 Tons. The regression coefficient of 1 from graph indicated that there is a close and random relationship between cooling system capacity and latent heat load. MATLAB analysis also computed the linear regression model between cooling system capacity and latent heat load. The standard error was observed to be 12.897 when root mean square error was 21.1 as shown in the general power model, linear model, regression and ANOVA models. The P-value and degrees of freedom of the regression model are consistent with the P-value and degrees of freedom of ANOVA model, that proves the correctness of the generated regression model. However, the level of significance of 0.0056 at confidence interval of (-46.4371, -10.6851) gave hypothesis of 1, which accepted alternative hypothesis that there is no significant relationship between cooling system capacity and latent heat load.
Researchers made the following recommendations: Manufacturers should build cooling systems whose capacity varies beyond the evaluated latent heat load and this study can also be done in future using other training algorithms and advanced software for better application.

Keywords ---- MATLAB, regression model, neural network, latent heat load, cooling system capacity, algorithm, ANOVA.

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1. INTRODUCTION

BACKGROUND OF THE STUDY

Napoleon, Odinah & Takao (2020) stated that the selection and installation of the most appropriate air cooling system to support indoor environment requirements are crucial to maintaining a healthy and comfortable indoor environment. Heavy demand on optimal energy consumption combined with a demand for better indoor thermal comfort and air quality; require cooling systems to operate at their best performance level. Acceptable level of latent heat load is an important consideration in any built environment, as it affects cooling system capacity; that is, ability to remove heat from the required space.

Desai (as cited in Efosa and Ewurum, 2022) opined that latent heat load is any heat source that adds water vapor to the air of enclosed space. The latent heat gain may occur due to the following reasons: (a) The heat gain due to the moisture in the outside air entering by infiltration. (b) The heat gain due to condensation of moisture from occupants. (c) The heat gain due to condensation of moisture from any process such as cooking foods which takes place within the conditioned space.

Linear regression modeling here represents a linear approach for modeling the relationship between a scalar response (latent heat load) and one explanatory variable (cooling system capacity).

Neural network as per the study is a command tool in matlab window used to study the underlying relationships in a set of data through a process that mimics the way the human brain functions. Neural networks can adapt to changing input; so the network generate the best possible result without needing to redesign the output criteria.

There are no doubts that latent heat load influences cooling system capacity. Reviewed literatures also claimed that the value of load on cooling system due to infiltration is 49.1 times the value of room volume under one unit difference of relative humidity. Hence, this research aimed at studying best performance evaluation and linear regression modeling of cooling system capacity and latent heat load using neural network/matlab approach.

2. STATEMENT OF THE PROBLEM

Undoubtedly, increasing room volume tends to increase infiltration and hence, latent heat load that increases energy consumption. Heavy demand on optimal energy consumption combined with a demand for better indoor thermal comfort and air quality; require cooling systems to operate at their best performance level. Acceptable level of latent heat load is an important consideration in any built environment, as it affects cooling system capacity; that is, ability to remove heat from the required space.

Desai (2012) also claimed that the value of load on cooling system due to infiltration is 49.1 times the value of room volume under one unit difference of relative humidity. It is on this note that the researchers aim at determining the best performance evaluation and linear regression modeling of cooling system capacity and latent heat load using neural network/matlab approach.

PURPOSE OF THE STUDY

The general purpose of this study are to evaluate the best performance level and determine the linear regression model of cooling system capacity and latent heat load using neural network/ MATLAB approach.

SIGNIFICANCE OF THE STUDY

The result of this study will be beneficial to building engineers and air conditioner manufacturing engineers in the following ways:

1. This study will help building/structural engineers to make use of appropriate dimensions of room/spaces to regulate infiltration, number of occupants, etc.
2. Air conditioner designers/ builders may deploy the result of the study to build cooling systems that will operate at optimal energy level.

RESEARCH QUESTION

Is there any relationship between latent heat load and performance (capacity) of a cooling system?

Hypothesis

Null hypothesis, H_0 = there is a significant relationship between latent heat load and performance (capacity) of a cooling system versus **Alternative hypothesis,** H_i = there is no significant relationship between latent heat load and performance (capacity) of a cooling system.

SCOPE OF THE STUDY

The data used in this work are gotten from analysis of buildings within Owerri Municipal in South East of Nigeria and hence, the result of the study may not be applicable to other parts of Nigeria or Western World.

3. REVIEW OF RELATED LITERATURE

The review of the related literature is discussed under the followings: conceptual framework and empirical framework.

(A) Conceptual Frame

- **Concept of cooling load**

The two main components of a cooling load imposed on an air conditioning plant operating during hot weather are as follows:

Sensible heat gain: When there is a direct addition of heat to the enclosed space, a gain in the sensible heat is said to occur. The sensible heat gain may occur due to the following reasons:

(a) The heat flowing into the building by conduction through exterior walls, doors, windows, floors and ceiling are due to temperature difference on their two sides. (b) The heat received from solar radiation. It consists of

1. The heat transmitted directly through the glass of windows and
2. The heat absorbed by walls and roofs exposed to solar radiation and later on transferred to the room by conduction.

(c) The heat conducted through interior partition from rooms in the same building which are not conditioned.

(d) The heat given off by lights, motors, cooking operations, etc.

(e) The heat liberated by the occupants.

(f) The heat gain from the fan work.

Latent heat gain: When there is an addition of water vapor to the air of enclosed space, a gain in latent heat is said to occur. The latent heat gain may occur due to the following reasons: (a) the heat gain due to the moisture in the outside air entering by infiltration. (b) The heat gain due to condensation of moisture from occupants. (c) The heat gain due to condensation of moisture from any process such as cooking foods which takes place within the conditioned space. (d) The heat gain due to moisture passing directly into the conditioned space through partitions or permeable walls from the outside (Prathibha, Kodliwad, Busi, & Naga, 2017).

Empirical Framework

Efosa and Ewurum (2022) studied estimate of infiltration rate for best performance of an indoor air conditioning sysyetm. They concluded that the estimated infiltration rate was 15 meter cube per hour with optimal cooling load capacity. Prathibha et al. (2017) studied design of air conditioning system for residential/office building. The classified air conditioning system operation into part A, basic principles of thermodynamics and part B, cooling load calculation. They concluded that accurate cooling load calculations, determine effectiveness of a cooling system. Napoleon et al. (2020) investigated review of the advances and applications of variable refrigerant flow heating, ventilating, and air-conditioning systems for improving indoor thermal comfort and air quality. They concluded that heating, ventilating and air conditioning system can provide a healthy indoor thermal environment with good air quality. Desai (2012) studied refrigeration and air conditioning for engineers. The results of his studies showed that infiltration is 46.1 times the value of room volume under one unit of relative humidity.

4. RESEARCH METHODOLOGY

The research methodology is discussed under the following headings: research design, area of the study, sample and sampling techniques, method of data collection, validation of data and method of data analysis.

Research Design

The study followed a survey design approach. Survey design is one in which a group of buildings are studied by collecting and analyzing data from only selected buildings that serves as the representative of the entire buildings and findings are generalized. Measurements taken from selected buildings would represent the entire buildings within the study area.

Area of the Study

The research was conducted within Owerri Municipal Council which is one the local government areas in Imo State. It is between Owerri North and Owerri West. The representative buildings are located at No. 128 West layout Prefab Uratta Housing Estate.

Method of Data collection

The researchers personally went to the selected buildings, after obtaining permission from the relevant authorities, measured and recorded the dimensions of room sizes, occupant's capacity, room services. 10 buildings were selected within the study area and measurements were taken from a randomly chosen room in each building and were labeled RA, RB, RC up to RJ respectively. The obtained measurements were used to generate the tabular data for cooling capacity and latent heat load that was subjected to neural network/MATLAB analysis.

Method of Data Analysis

The tabular data was gotten based on the following specifications: outside temperature is 35 ℃DBT, 22% RH, inside temperature is 16 ℃DBT, 40% RH. It must be noted that 10% of total heat load was added to take care of various contingencies. Levenberg Marquardt was used as a training algorithm.

DESIGN ANALYSIS

Heat from occupants = Number of occupants× factor from table …(1.0)

$$\boldsymbol{Infiltration} = \frac{H\times L\times W\times G}{60}\ m^3/min \quad …….(1.1)\ \text{(Desai,2012)}$$

Where H = height of the room;
L = length of room;
W= width of room;
G = number of air changes/hr

Load due to outside air will be both sensible as well as latent. It is given as below:

$$\boldsymbol{outside\ air\ sensible\ heat} = 20.43 \times Q_m(t_o - t_i) \quad ….(1.2)$$

$$\boldsymbol{outside\ air\ latent\ heat} = 50Q_m(W_O - W_i) \quad ….(1.3)$$

W and t means humidity ratio and temperature respectively and Q is outside air volume flow rate.

$$\boldsymbol{Latent\ Heat\ Load} = m_a \times h_{fg} \times \Delta W \ \text{ in kW} \quad ….(1.4)$$

Where m_a mass flow rate of air and h_{fg} is enthalpy difference.

$$\boldsymbol{Product\ Load, in\ kW} = \frac{m\times C_p\times(t_1-t_c)}{cooling\ \ time\ \ in\ seconds} \quad ….(1.5) \quad \text{(Desai,2012)}$$

Where $m\ is\ product\ mass, C_p\ is\ specific\ heat\ of product\ above\ freezing$
$t_1\ is\ initial\ temperature\ and\ t_c\ is\ chiller\ temperature.$

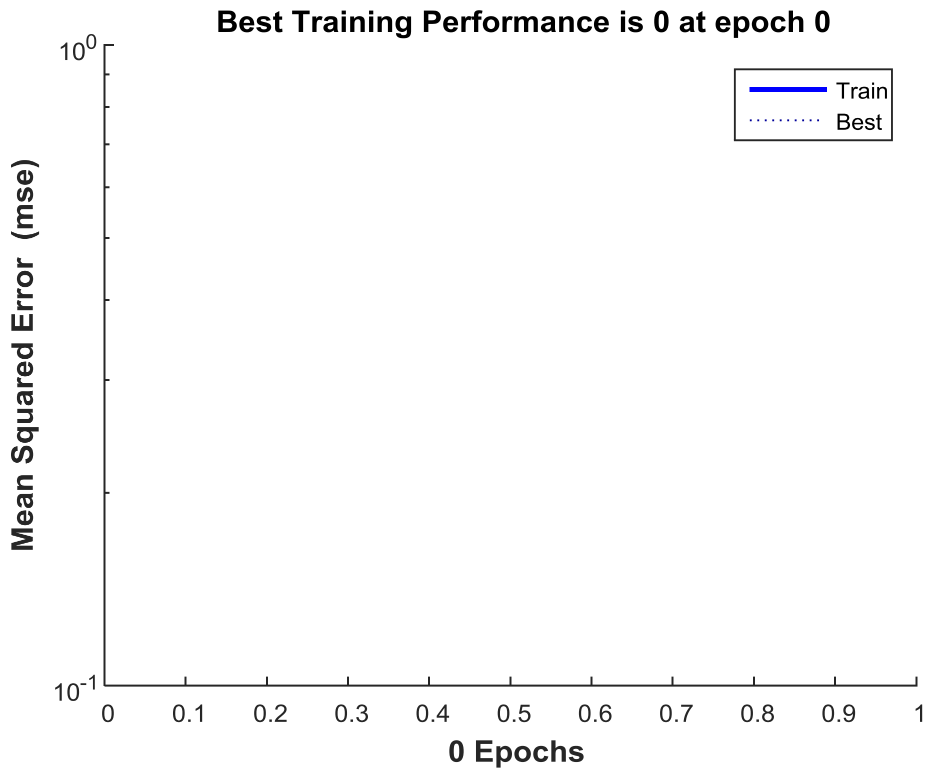
$$\boldsymbol{System\ Capacity\ in\ Tons} = \frac{Total\ \ Heat\ \ Load}{3500} \quad ……(1.6)$$

5. PRESENTATION OF DATA ANALYSIS

The tabular data gotten from the study is presented as shown below.

Table 1.0: below shows room label, capacity and latent heat load.

BUILDINGS	CAPACITY (Tons)	LATENT HEAT LOAD, RLH(kW)
RA	**35.75**	**1.4089**
RB	**10.669**	**2.6333**
RC	**18.1145**	**3.3333**
RD	**65.9798**	**6.9740**
RE	**5.3126**	**2.9033**
RF	**25.5709**	**7.9011**
RG	**16.0056**	**2.542**
RH	**90.0967**	**8.9054**
RI	**19.7903**	**3.506**
RJ	**40.4089**	**1.9801**



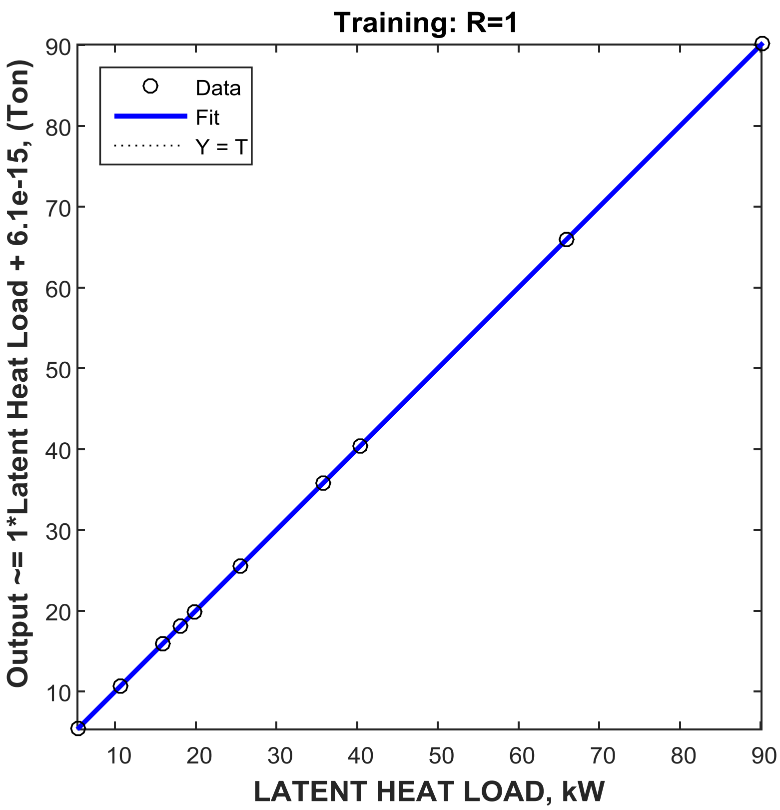


Fig. 1.0: Regression graph of Cooling System Capacity against Latent Heat Load is shown below.

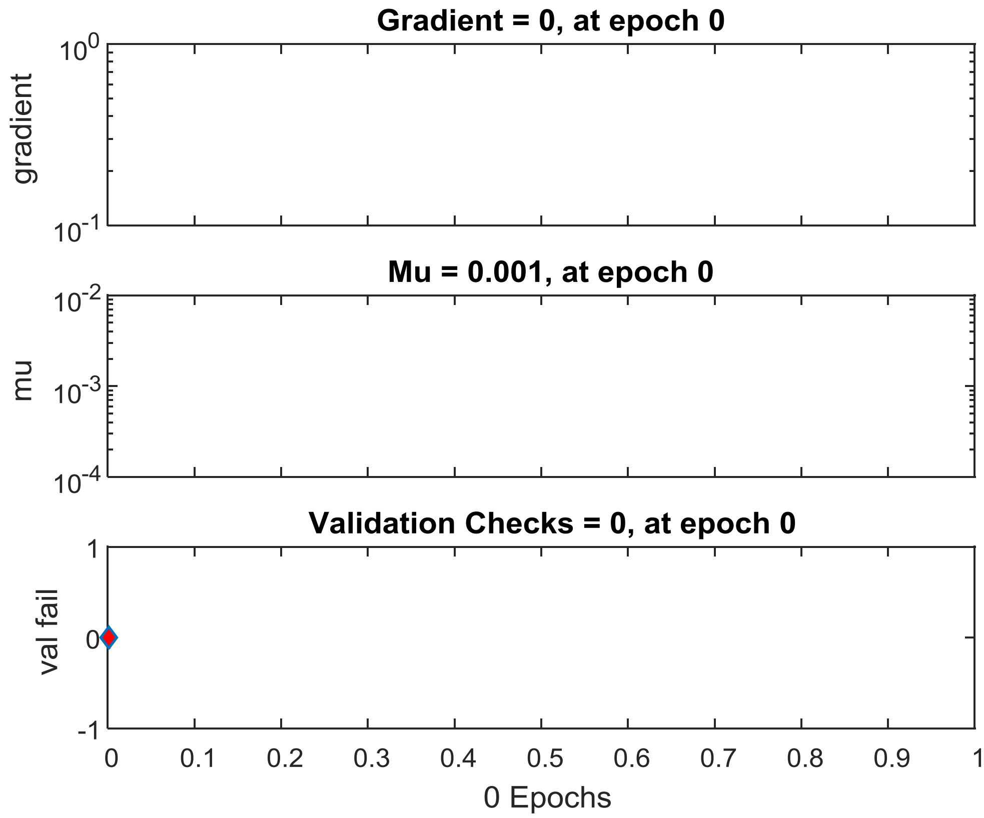
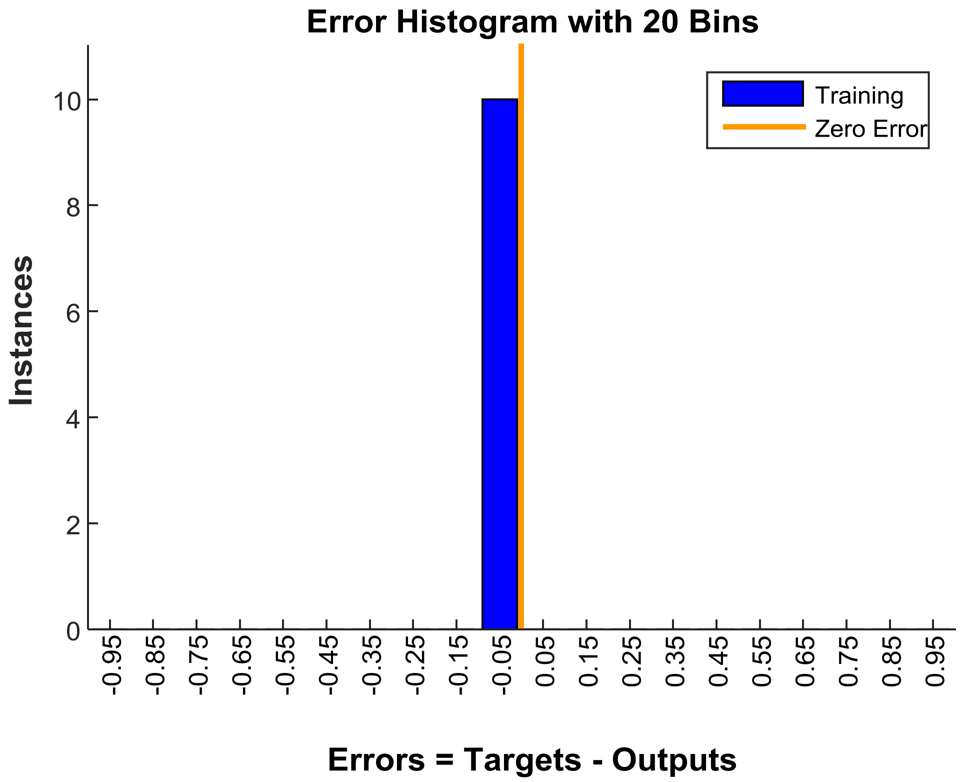


Fig. 1.1: Shows training state of Cooling System Capacity and Latent Heat Load.



Matlab Function for neural network model and training performance graph is shown below.

```
function [Y,Xf,Af] = myNeuralNetworkFunction(X,~,~)
%MYNEURALNETWORKFUNCTION neural network simulation function.
%
% Neural Network Toolbox function genFunction, 23-Oct-2022 04:38:42.
%
% [Y] = myNeuralNetworkFunction(X,~,~) takes these arguments:
%
%   X = 0xTS cell, 0 inputs over TS timsteps
%
% and returns:
%   Y = 0xTS cell of 0 outputs over TS timesteps.
%
% where Q is number of samples (or series) and TS is the number of
timesteps.

%#ok<*RPMT0>

% ===== NEURAL NETWORK CONSTANTS =====


% ===== SIMULATION ========

% Format Input Arguments
isCellX = iscell(X);
if ~isCellX, X = {X}; end;

% Dimensions
TS = size(X,2); % timesteps

% Allocate Outputs
Y = cell(0,TS);

% Time loop
for ts=1:TS

end

% Final Delay States
Xf = cell(0,0);
Af = cell(0,0);

% Format Output Arguments
if ~isCellX, Y = cell2mat(Y); end
end

% ===== MODULE FUNCTIONS ========
```

Matlab Script for neural network model and training performance graph is shown below.

```
% Solve an Input-Output Fitting problem with a Neural Network
% Created 23-Oct-2022 04:41:59
%
% This script assumes these variables are defined:
%
%   data - input latent heat load.
%   data – cooling system capacity.

x = data;
t = data;
```

```
% Choose a Training Function
% For a list of all training functions type: help nntrain
% 'trainlm' is usually fastest.
% 'trainbr' takes longer but may be better for challenging problems.
% 'trainscg' uses less memory. Suitable in low memory situations.
trainFcn = 'trainlm';  % Levenberg-Marquardt backpropagation.

% Create a Fitting Network
hiddenLayerSize = 10;
net = fitnet(hiddenLayerSize,trainFcn);

% Setup Division of Data for Training, Validation, Testing
net.divideParam.trainRatio = 70/100;
net.divideParam.valRatio = 15/100;
net.divideParam.testRatio = 15/100;

% Train the Network
[net,tr] = train(net,x,t);

% Test the Network
y = net(x);
e = gsubtract(t,y);
performance = perform(net,t,y)

% View the Network
view(net)

% Plots
% Uncomment these lines to enable various plots.
%figure, plotperform(tr)
%figure, plottrainstate(tr)
%figure, ploterrhist(e)
%figure, plotregression(t,y)
%figure, plotfit(net,x,t)
```

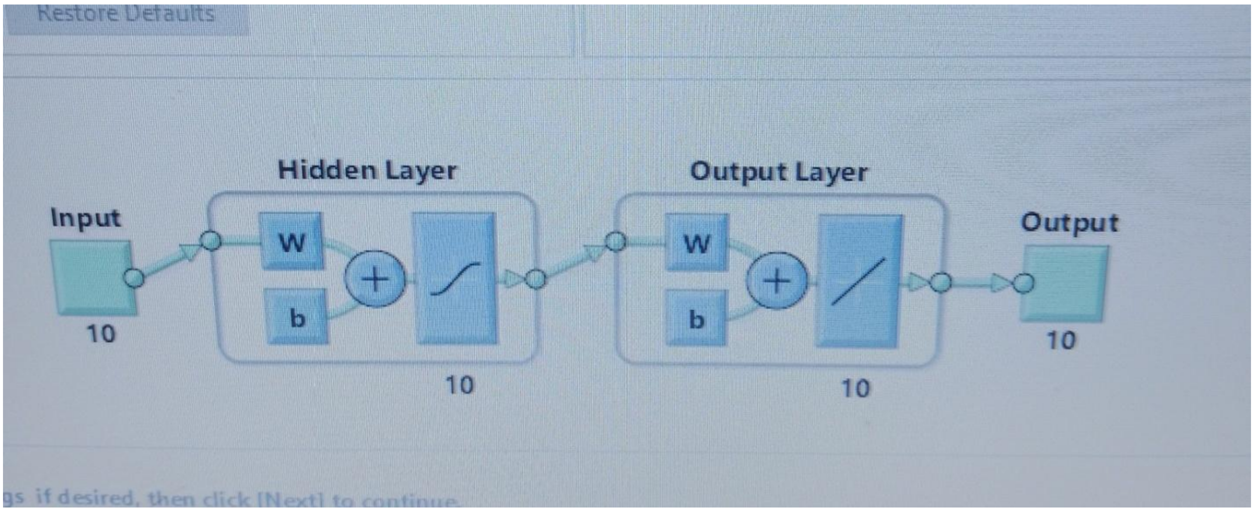


Fig. 1.2: Neural Network Layer

CURVE FITTINGS

LINEAR MODEL:

f(x) = a*(sin(x-pi)) + b*((x-10)^2) + c

Coefficients (with 95% confidence bounds):

a = -16.26 (-55, 22.47)

b = -0.6007 (-1.298, 0.09693)
c = 49.01 (11.15, 86.88)

Goodness of fit:
SSE: 3677
R-square: 0.4268
Adjusted R-square: 0.263
RMSE: 22.92

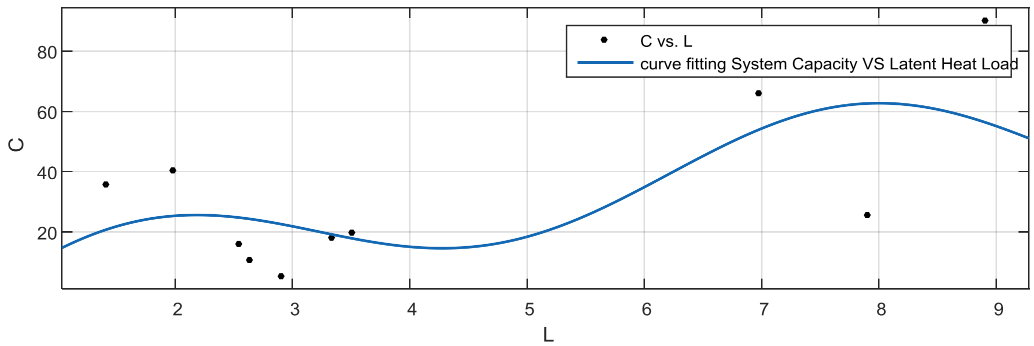


Fig. 1.3: Linear Model Graph

GENERAL MODEL POWER1:
f(x) = a*x^b
Coefficients (with 95% confidence bounds):
a = 7.358 (-6.184, 20.9)
b = 1.01 (0.0515, 1.968)

Goodness of fit:
SSE: 3605
R-square: 0.438
Adjusted R-square: 0.3678
RMSE: 21.23

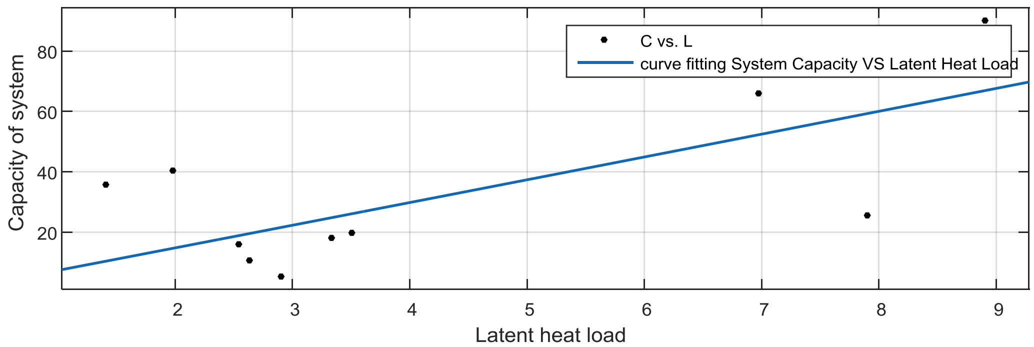


Fig. 1.4: General Power Model 1 Graph

LINEAR REGRESSION MODELING

```
>> L = [1.4089 2.6333 3.3333 6.9740 2.9033 7.9011 2.5420 8.905 3.5060 1.9801];
>> C = [35.7500 10.6690 18.1145 65.9798 5.3126 25.5709 16.0056 90.0967 19.7903 40.4089];
>> mdl = fitlm(L,C)

mdl =
```

```
Linear regression model:
    y ~ 1 + x1

Estimated Coefficients:
                   Estimate     SE      tStat     pValue
                   ________   ______   ______   ________

    (Intercept)    4.6753     12.897   0.3625    0.72637
    x1             6.6753     2.6245   2.5435   0.034524


Number of observations: 10, Error degrees of freedom: 8
Root Mean Squared Error: 21.1
R-squared: 0.447,  Adjusted R-Squared 0.378
F-statistic vs. constant model: 6.47, p-value = 0.0345
>> tbl = anova(mdl)

tbl =

             SumSq    DF    MeanSq     F        pValue
             ______   __    ______   ______   ________

    x1       2868.1    1    2868.1   6.4692   0.034524
    Error    3546.8    8    443.35

>>end
```

The computed linear regression model between latent heat load and cooling system capacity is shown below;

$$\boldsymbol{Y = 6.6753X + 4.6753}$$

Where Y = Cooling System Capacity in Tons and X = Latent Heat Load in kW.

```
>> [h,sig,ci] = ttest(L,C)

h =

     1


sig =

    0.0056


ci =

  -46.4371  -10.6851
```

6. DISCUSSION OF FINDINGS

The outcome of the study best performance evaluation and linear regression modeling of cooling system capacity and latent heat load using Neural Network/ MATLAB approach was discussed here. The data was analyzed using Neural Network in MATLAB command window. According to table 1.0, the original data was trained using levenberg marquardt algorithm at 70% training data, 15% test data and 15% validation data respectively. Results revealed that the best performance level was 0 at epoch 0 and this suggested lower values of the latent heat load for optimal capacity operation of cooling system. **Fig 1.3** and **Fig 1.4** indicated that for best performance of cooling system, the latent heat load should maximum to 5 kW with optimal cooling capacity below 40 Tons. The regression coefficient of 1 from **Fig 1.0** showed that there is a close and random relationship between cooling system capacity and latent heat load.

The MATLAB analysis also computed the linear regression model between cooling system capacity and latent heat load;

$$\boldsymbol{Cooling\ System\ Capacity\ = 6.6753 \times Latent\ Heat\ Load + 4.6753}$$

The standard error was observed to be 12.897 when root mean square error was 21.1 as shown in the general power model, linear model, regression and ANOVA models. The P-value and degrees of freedom of the regression model are consistent with the P-value and degrees of freedom of ANOVA model, that proves the correctness of the generated regression model.

However, the level of significance of 0.0056 at confidence interval of (-46.4371, -10.6851) gave hypothesis of 1, which accepted alternative hypothesis that there is no significant relationship between cooling system capacity and latent heat load.

7. CONCLUSION

Obviously, results from the study revealed that the evaluated value of latent heat load for best performance of a cooling system is maximum of 5 kW with system capacity not exceeding 40 Tons and this is in line with Efosa and Ewurum (2022) who stated that the best performance level of cooling system capacity was 8.7406 Tons at infiltration rate of 14.263 m^3/hr .

8. RECOMMENDATIONS

1. Manufacturers should build cooling systems whose capacity varies beyond the evaluated latent heat load.
2. This study can also be done in future using other training algorithms and advanced software better application.

RESEARCH QUESTION
Is there any relationship between latent heat load and performance (capacity) of a cooling system?
Hypothesis
Null hypothesis, H_0 = there is a significant relationship between latent heat load and performance (capacity) of a cooling system versus **Alternative hypothesis,** H_i = there is no significant relationship between latent heat load and performance (capacity) of a cooling system.

```
>> [h,sig,ci] = ttest(L,C)

h =

     1


sig =

    0.0056


ci =

  -46.4371  -10.6851
```

At hypothesis of 1, we accept alternative hypothesis that there is no significant relationship between cooling system capacity and latent heat load.

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