SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

# The ARX and ARMAX Models for Thermoelectric Cooling on Glass Windows: A Comparative Study

Mohd Saifizi Saidon[1,*], Nasrul Amri Mohd Amin[2], 'Aqilah Che Sulaiman[1], Mohd Rizal Manan[1], Siti Marhainis Othman[1], Wan Azani Mustafa[1], Norfariza Ab Wahab[3]

[1] Faculty of Electrical Engineering Technology, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[2] Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[3] Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

**ARTICLE INFO**

***Article history:***
Received 18 March 2022
Received in revised form 22 May 2022
Accepted 30 May 2022
Available online 29 June 2022

***Keywords:***
Thermoelectric; glass windows; ARX; ARMAX; cooling

**ABSTRACT**

Thermoelectric cooling (TEC), in particular, can be combined with a heat sink for local cooling, but they can also be integrated into electronic chips for point-to-point cooling. The study aims to develop a dynamic model of a cooling system integrated with TEC for glass window. The main target of this study is to develop a dynamic model of a cooling system integrated with TEC. The black box modelling approach in producing a mathematical model was selected based on the ARMAX and ARX model that corresponds to the actual dynamic state of the cooling system. The best model was finalized based on the best match on curve patterns when comparing the real and estimated models using the system identification tools in MATLAB, and also having the least error. The accuracy of the models was compared and analysed. The results showed that the 4$^{th}$ order of the ARMAX model produced a higher best fitting and standard deviation values of 80.23% and 0.027592 compared to the 4$^{th}$ order of the ARX model of 78.14% and 0.030769 respectively. This system accuracy is almost within the acceptable range for most error calculations in the validation method. Yet, this cooling system integrated with TEC is found more suitable for the 4$^{th}$ order of the ARMAX model when compared to the ARX model due to the noise parameter in the ARMAX model. Nevertheless, the noise order in this system is not dominant, therefore, whenever the noise order of the system in the ARMAX model is high than the second structure ($n_b$), the number of errors is also high. In addition, the ARMAX model is found incapable of achieving the highest fitting due to the losses from the dynamic environment and losses from the TEC itself. Still, the use of this black box model used in this study is a significant variation where system parameters can be identified even offline.

## 1. Introduction

The comfort temperature can be assessed by parameters categorized into two: environmental factors and personal factors where the outdoor temperature gives a high impact to the indoor temperature that contributes to the low comfort temperature of the occupant [1]. Many researchers

* *Corresponding author.*
*E-mail address: saifizi@unimap.edu.my*

https://doi.org/10.37934/arfmts.97.1.105118

have also concluded that solar radiation absorption at the glass window surface is depended upon the properties of the glazes, the orientation, the geometry and the opaque surface [2–6]. Yet, energy can be saved more by collecting the highest solar radiation during daylight for later use though can be useful in the winter. A simple formulation model to estimate the solar energy absorbed suitable to a room with a single glazed surface and clear double glazing has been produced. It has been proven that glass window is one of the sources of high sunlight absorption that affects room temperature.

The heat transfer occurs from outside to the inside room through the glass window when the solar radiation takes place on the outer surface of the glass window by radiation, conduction and convection. The climate condition also affects the needed human comfort in the air-conditioned space. The large part of heat gain from solar radiation in a building is through the glazed window [7–9], and trapped the heat inside the building. The absorption from the sunlight to the indoor surface can increase the glass temperature up to 40°C [10]. Due to that, the heat directly passes straight to a glass surface then dissipated into the indoor space. The advance in the glazing technology for the solar problem is divided into several types such as low-emissivity, insulated glass, body tinted glass and solar reflective glass [11,12]. In other study, Chavhan and Mahajan [13] discussed a finding of Bulow Hube which detailing about the window glazing size in the building influenced the heat gain by 20% and thermal comfort by 40%. Therefore, the comfort of the occupant got effected due to the negative influence of poor indoor temperature.

Beside of many researchers conducted and all the suggested solutions, in this project, the focus is emphasized for a room with an exposed to sun glass window. A room space near the glass window had always shown a temperature difference between the area at the center of the air-conditioned room and area near the window, due to heat dissipations through the glass window. Therefore, the space temperature near the glass window is hardly reaching 26°C, apart than the setting temperature of air conditioning unit. Thus, the cooling system integrated with TEC is introduced to reduce the negative influence of heat from the glaze window. Consequently, the dynamic behavior of a cooling system integrated with thermoelectric cooling (TEC) to reduce the temperature at the window area in the air-conditioned room could be implemented by placing the TEC at the external side of the window. Furthermore, placing the TEC at the glass window will help reduce the heat load that absorbs by the window from outside of the room. Therefore, the data collected from the experimental work are all validated through system identification and simulations.

## 2. Methodology

Three TEC modules were placed at the glass windows (each), outside of the experimented room. The size of the glass windows is 360mm × 480mm, separated by frame, while the TEC module used in this study is TH51B model (12V 5A, 51Watt). The room was empty without occupant and tested during the daytime starting from 8 am to 6 pm with good weather conditions (no rain nor cloudy weather). Hence, the experimental sampling time at 20 seconds interval is found sufficient for temperature response applications [14,15]. In this study, three TEC units were used to determine the significance effect of TECs on the glass window surfaces at three different places. In addition, the comparison of TEC cooling effect was analyzed using the input variable of duty cycle in simulation which is 50%, 70% and 100%. Variation of the duty cycle were tested to find the TEC temperature within the desired 26℃ temperature. The experiment was also tested by assuming time delay of zero.

The experimental work was performed by measuring the temperature at the glass window surface of an air-conditioned room with the volumetric space of 3m × 4m × 2m. The experimental works were conducted at the Faculty of Electrical Engineering Technology, Universiti Malaysia Perlis, Perlis, Malaysia. The room was cooled using a conventional unit of 1 hp AC unit (Acson model-Non inverter) with 26°C setting temperature. Meanwhile, the black-box model of the cooling system integrated with TEC was simulated using MATLAB software. The lumped parameter was used where the temperature inside the room is assumed to be constant when the real data does not reflect the physical characteristic of the system. Furthermore, increasing the order parameter results to better fit data to measurements of ARMAX and ARX models. The simulation models are verified by comparing the room temperature obtained from the simulation to the data collected during experimental works.

The output data from the step response experiment were used as an input design to the PRBS. After that, the PRBS experiment was conducted to gain the input and output data in real time of cooling system integrated with TEC. Based on that, the temperature within the operating point of 26°C is selected as input-output of ARX and ARMAX model. Nevertheless, if the input and output data is not desirable the flow need to be repeated as Figure 1. Therefore, the input and output data will be used to simulate the model based on ARX and ARMAX models.

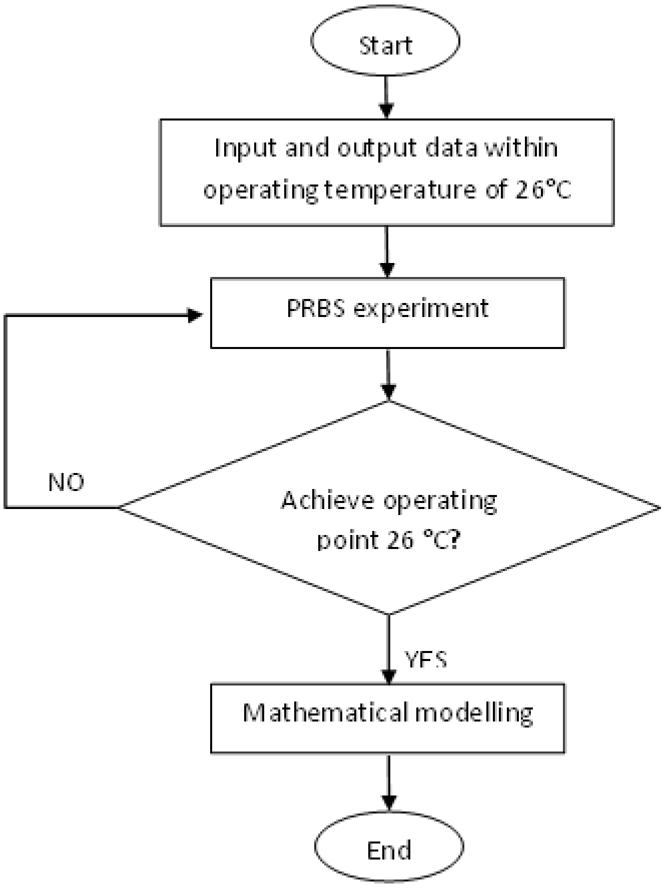



**Fig. 1.** Flow chart of collecting the PRBS input and output data

*2.1 Identification of ARX and ARMAX Models of Cooling System Integrated with TEC*

Figure 2 shows the process flow that has been followed for the simulation work. The first flow is by selecting and defining a model structure between ARX and ARMAX. For the parameter estimation, it is to define the best fitting percentage between real model and simulated model. The next flow, the model validation was compared for the less error between the real data and estimated data using

SSE, MSE, RMSE and standard deviation. Therefore, the selected of correct model structure used to represent the best model of the cooling system integrated with TEC at the glass window.

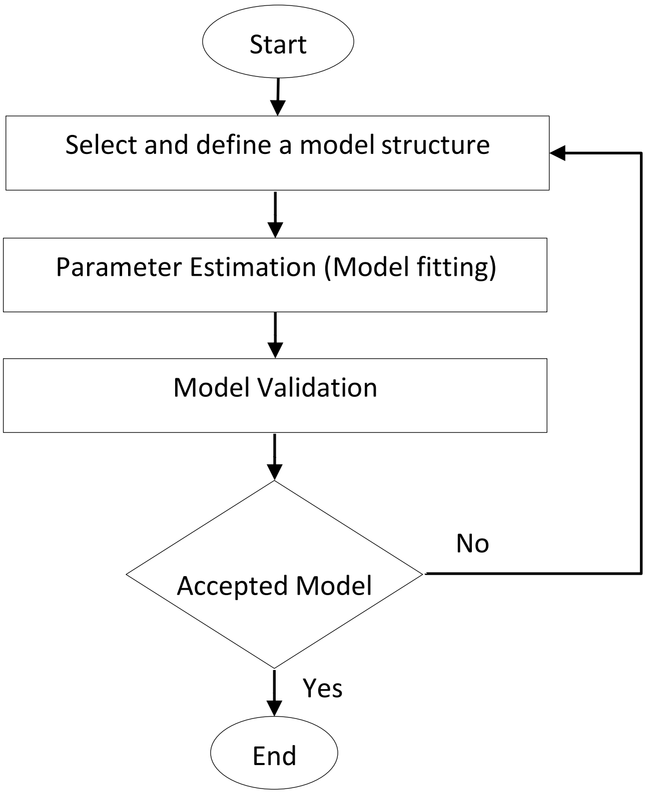



**Fig. 2.** System identification procedure

The model of ARX and ARMAX are considered in this study to compare and investigate the accuracy of model parameters. This model also provides an opportunity for this research to delve deeper into simulation studies especially at the modelling level. Input and output data collected from the tested cooling system integrated with TEC are used in the least square computer programs to verify the model and estimate the unknown parameters.

Input and output data collected from the tested cooling system integrated with TEC are used in the least square computer programs to verify the model and estimate the unknown parameters. In this work, ARX is tested first where the parameter of the model structure is $n_a$ and $n_b$. This trial and error test from 1st up to the 4th order as shown in Table 1.

**Table 1**
The structure of ARX model

| System order | $n_a$ | $n_b$ |
|---|---|---|
| 1st Order | 1 | 1 |
| 2nd Order | 2 | 2 |
| 3rd Order | 3 | 3 |
| 4th Order | 4 | 4 |

The polynomial order is used to analyse ARX models is shown in Table 1. The ARX model was developed using a linear differential equation where the $n_c$ known as noise properties are not involved as in the following Eq. (1) [16, 17].

$$y(t) + a_1 y(t-1) + \cdots a_{na} y(t-n_a) = b_1 u(t-1) + \cdots + b_{nb} u(t-nb) + e(t) \quad (1)$$

The ARX model structure is then can be expressed as Eq. (2) and Eq. (3) can also be rearranged as Eq. (4)

$$A(q^{-1}) = 1 + a_1 q^{-1} + \cdots a_{na} q^{-na} \quad (2)$$

$$B(q^{-1}) = b_1 q^{-1} + \cdots b_{nb} q^{-nb} \quad (3)$$

$$y(t) = \frac{B(q^{-1})}{A(q^{-1})} u(t) + \frac{1}{A(q^{-1})} e(t) \quad (4)$$

Subsequently, the cooling system is also tested with ARMAX model with the order system from 1st up to 4th order as shown in Table 2 where the noise, $n_c$ are added on the model structure.

**Table 2**
The structure of ARMAX model

| Parameter | $n_a$ | $n_b$ | $n_c$ |
|---|---|---|---|
| 1st Order | 1 | 1 | 1 |
| 2nd Order | 2 | 2 | 2 |
| 3rd Order | 3 | 3 | 3 |
| 4th Order | 4 | 4 | 4 |

The polynomial order is used to analyse ARMAX models is shown in Table 2. The ARMAX model is developed by Eq. (5) [18]

$$\begin{aligned} &y(t) + a_1 y(t-1) + \cdots + a_{na} y(t-na) \\ &\quad = b_1 u(t-1) + \cdots + b_{nb} u(t-nb) + e(t) + c_1 e(t-1) + \cdots + c_{nc} e(t-nc) \end{aligned} \quad (5)$$

The ARMAX model can be interpreted as the noise $e(t)$ and $u(t)$ are subjected to the same dynamic (same poles) in $A(q^{-1})$. This is a reasonable interpretation if the dominating disturbances enter early in the process together with the input. In order to confirm the simulation data with cooling system output, the connection between all of the parameters is examined. The parameter structure of ($n_a$, $n_b$, $n_c$) ARMAX model was expressed as Eq. (6) below

$$\begin{aligned} A(q^{-1}) &= 1 + a_1 q^{-1} + \cdots a_{na} q^{-na} \\ B(q^{-1}) &= b_1 q^{-1} + \cdots b_{nb} q^{-nb} \\ C(q^{-1}) &= 1 + c_1 q^{-1} + \cdots c_{nc} q^{-nc} \end{aligned} \quad (6)$$

where $q^{-1}$ is the backshift operator. Therefore, the mathematical structure of ARMAX model system was run as Eq. (7) and then rearranged to become to Eq. (8)

$$A(q^{-1}) y(t) = B(q^{-1}) u(t) + C(q^{-1}) e(t) \quad (7)$$

$$y(t) = \frac{B(q^{-1})}{A(q^{-1})} u(t) + \frac{C(q^{-1})}{A(q^{-1})} e(t) \quad (8)$$

Eq. (7) show the presence of noise properties, $C(q^{-1})$ as a parameter of $n_c$ in the system. In this case, the system needs to be tested whether the absence of the noise is dominant to the model structure.

In addition, this method used parameter estimation approach where errors can be minimized between the estimated and the real system predictions. Meanwhile, the non-parametric methods do not require any model to describe the relationship between input and output data. In this sub chapter, the simulation is performed to identify the open loop of dynamic system in the cooling system integrated with TEC. It is to develop the mathematical model using the data collected which will adequately represent the dynamic system. In addition, this simulation is also to find characteristic features of duty cycle relations as input to temperature as output of the cooling system integrated with TEC.

### *2.2 Model Validation*

Validation is done by comparing the real model against the estimated model using system identification tools in MATLAB. The real data were imported into the system identification tools, then the structure parameters were changed and tested according to ARX and ARMAX models. The parameter structure for ARX model is $n_a$ and $n_b$ while for ARMAX model $n_a$, $n_b$ and $n_c$ (added as noise for the system). Then, the best model was selected based on based on the best match on curve patterns when comparing the real and estimated models using the system identification tools in MATLAB, and also having the least error.

The output error of the model also will be analysed to improve and validate the structure of the cooling system to determine the accuracy according to Sum Square Error (SSE), Mean Square Error (MSE), Root Mean Square Error (RMSE) and Standard deviation as calculated in Eq. (9) to Eq. (12) where $C_e$ represent the experimental data, $C_p$ reperesent the model's predicted data and n is the number of the data analysis [19–21].

$$\mathrm{SSE} = \sum_{i=1}^{n}[C_e - C_p]^2 \tag{9}$$

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}[C_e - C_p]^2 \tag{10}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}[C_e - C_p]^2}{n}} \tag{11}$$

$$S_n = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(C_e - C_p)} \tag{12}$$

Based on the above criteria, the minimum prediction error of the model will be selected as the best model representing the cooling system integrated with TEC. This method is used to measure the error difference between values predicted by the model of ARX and ARMAX with the accepted value. It is to make sure the model chosen for designing the controller is correct.

## 3. Results

Identification of a cooling system integrated with TEC has been successfully carried out for different duty cycles. An input-output model was properly selected that suitable for modelling. The best fitting graph, SSE, MSE, RMSE and standard deviation were used to compare the estimated model. The performance of ARX model (4, 4) is then compared to ARMAX model (4, 3, 3) as shown in Table 3. From the observation of Table 3 analysis, the TEC cooling system performance of ARMAX model shows that 80.23% of best fitting between real model and estimated model, compared to ARX model with the lower 78.14% best fitting. With the adding of the noise ($n_c$) to model structure ARMAX, the cooling system is found to produce better arrangement between the real and estimated models than that of the ARX model in system identification tools.

The 4th model structure (4, 3, 3) is found to significant to represent the best for the system. The 4th order of the ARMAX model is the most practical model for real-time application in terms of its model structure, even though ARMAX is not the best model structure derived in the experiment. It is conclusive when considering the accuracy of the estimated parameter for each model that varies according to the estimation used in the algorithm. Therefore, it is expected that the overall performance may not be significant by adding the noise to the model order. This has been proved by the modelling error values calculated in the model validation process in term of error analysis was made.

**Table 3**
Comparison of ARMAX and ARX model best fitting and error value

| Model | Best fit (%) | SSE | MSE | RMSE | Standard Deviation |
|---|---|---|---|---|---|
| ARX (4, 4) | 78.14 | 0.124817 | 0.002080 | 0.045610 | 0.030769 |
| ARMAX (4, 3, 3) | 80.23 | 0.102112 | 0.001702 | 0.041254 | 0.027592 |

The cooling system is also estimated with ARMAX model order up to 4th order. The observations for all of the ARMAX models reveal that all of the error analysis resulted to a smaller value and produce the best fitting of the cooling system when compared to the ARX model. Table 4 shows the 1st order with the best fitting is 75.81% and the value of SSE = 0.15275, MSE = 0.00255, RMSE = 0.05046 and standard deviation of 0.03074.

**Table 4**
The error result of 1st order of ARMAX model

| Model structure ($n_a$, $n_b$, $n_c$) | Best fit (%) | SSE | MSE | RMSE | Standard deviation |
|---|---|---|---|---|---|
| (1,1,1) | 75.81 | 0.15275 | 0.00255 | 0.05046 | 0.03074 |

Based on Table 5, the 2nd order of model structure (2, 1, 2) gets the lowest value for 2nd order where the error analysis resulted to: best fitting = 78.64%, SSE = 0.11916, MSE = 0.00199, RMSE = 0.04456 and standard deviation of 0.02848. Meanwhile, the 3rd order of the model structure (3, 2, 3) has the highest best fitting value of 79.7% where SSE = 0.10760, MSE = 0.00179, RMSE = 0.04235 and standard deviation of 0.02723 is shown in Table 6. In order to differentiate between the 1st, 2nd ,3rd and 4th order, Table 8 shows only the 4th order of structure (4, 3, 3) which produced the lowest error value and the best fitting is 80.23%.

Therefore, the 4th order of ARMAX model is selected for this type of cooling system. In other word, it shows that the 4th order of the ARMAX model structure (4, 3, 3) has a better fit to the real time model of cooling system when compared to the 1st, 2nd and 3rd model.

**Table 5**
The error result of 2nd order of ARMAX model

| Model structure ($n_a$, $n_b$, $n_c$) | Best fit (%) | SSE | MSE | RMSE | Standard deviation |
|---|---|---|---|---|---|
| (2, 1, 1) | 78.49 | 0.09338 | 0.00156 | 0.03945 | 0.02659 |
| (2, 1, 2) | 78.64 | 0.11916 | 0.00199 | 0.04456 | 0.02848 |
| (2, 2, 1) | 78.59 | 0.11966 | 0.00199 | 0.04466 | 0.02782 |
| (2, 2, 2) | 78.60 | 0.11961 | 0.00199 | 0.04465 | 0.02854 |

**Table 6**
The best error result of 3rd order of ARMAX model

| Model structure ($n_a$, $n_b$, $n_c$) | Best fit (%) | SSE | MSE | RMSE | Standard deviation |
|---|---|---|---|---|---|
| (3, 1, 2) | 79.13 | 0.11375 | 0.00190 | 0.04354 | 0.02815 |
| (3, 2, 2) | 79.57 | 0.10904 | 0.00182 | 0.04263 | 0.02745 |
| (3, 2, 3) | 79.70 | 0.10760 | 0.00179 | 0.04235 | 0.02723 |
| (3, 3, 3) | 79.55 | 0.10920 | 0.00182 | 0.04266 | 0.02711 |

**Table 7**
The best selected result of 4th order of ARMAX model

| Model structure ($n_a$, $n_b$, $n_c$) | Best fit (%) | SSE | MSE | RMSE | Standard deviation |
|---|---|---|---|---|---|
| (4, 1, 2) | 79.31 | 0.11178 | 0.00186 | 0.04316 | 0.02857 |
| (4, 1, 3) | 79.93 | 0.10519 | 0.00175 | 0.04187 | 0.02595 |
| (4, 1, 4) | 79.39 | 0.11089 | 0.00185 | 0.04299 | 0.02852 |
| (4, 2, 3) | 79.87 | 0.10582 | 0.00176 | 0.04200 | 0.02810 |
| (4, 2, 4) | 79.99 | 0.10460 | 0.00174 | 0.04175 | 0.02670 |
| (4, 3, 2) | 79.53 | 0.10939 | 0.00182 | 0.04270 | 0.02929 |
| (4, 3, 3) | 80.23 | 0.10211 | 0.00170 | 0.04125 | 0.02759 |
| (4, 3, 4) | 79.93 | 0.10515 | 0.00175 | 0.04186 | 0.02740 |

According to Table 7, the higher the noise ($n_c$) than $n_b$, the greater the error for the model but if the $n_c$ value is higher than 3 the error shows oppositely. While the observations on the identification diagram in Figure 3 indicates that the 4th order is the success of the model identification process. Ultimately, further analysis on the convergence of 4th order of ARMAX model parameter is required to ensure that the model order chosen is appropriate for the controller design purpose.

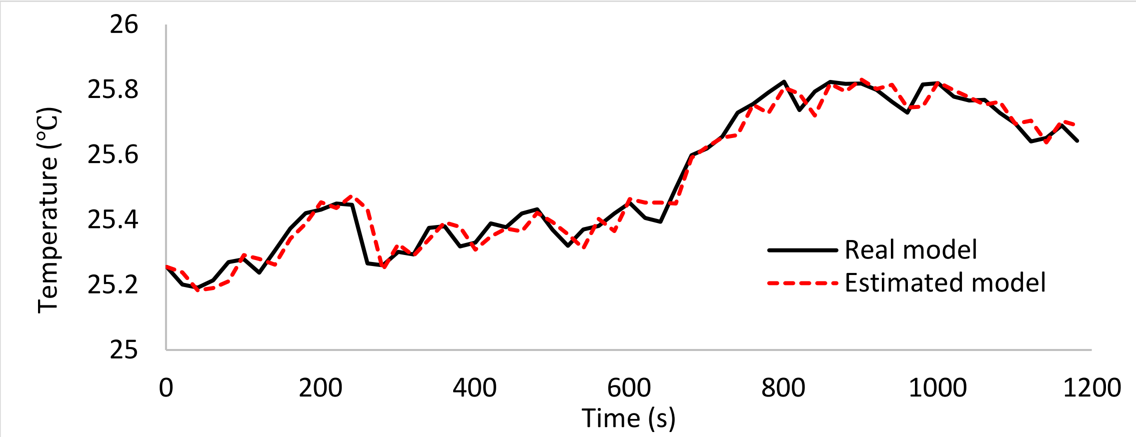
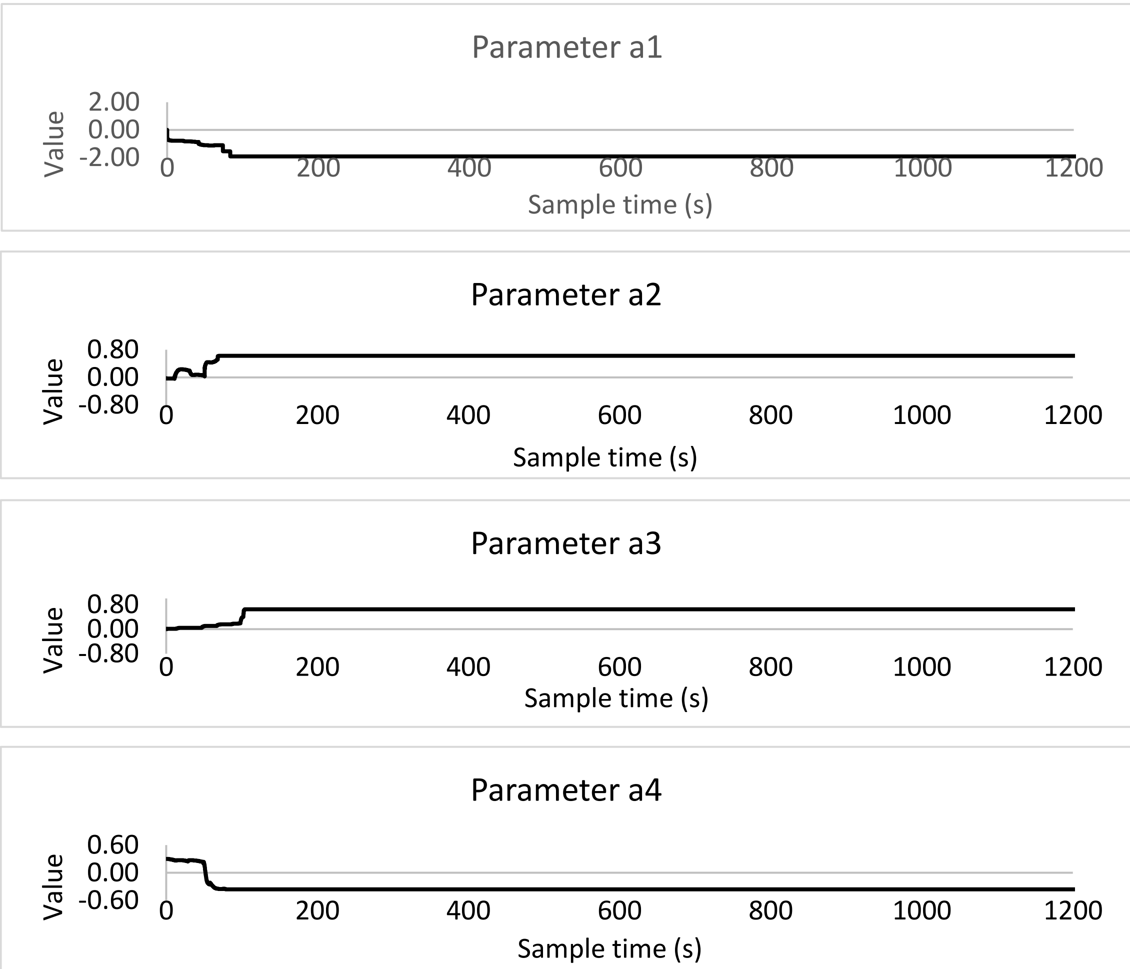
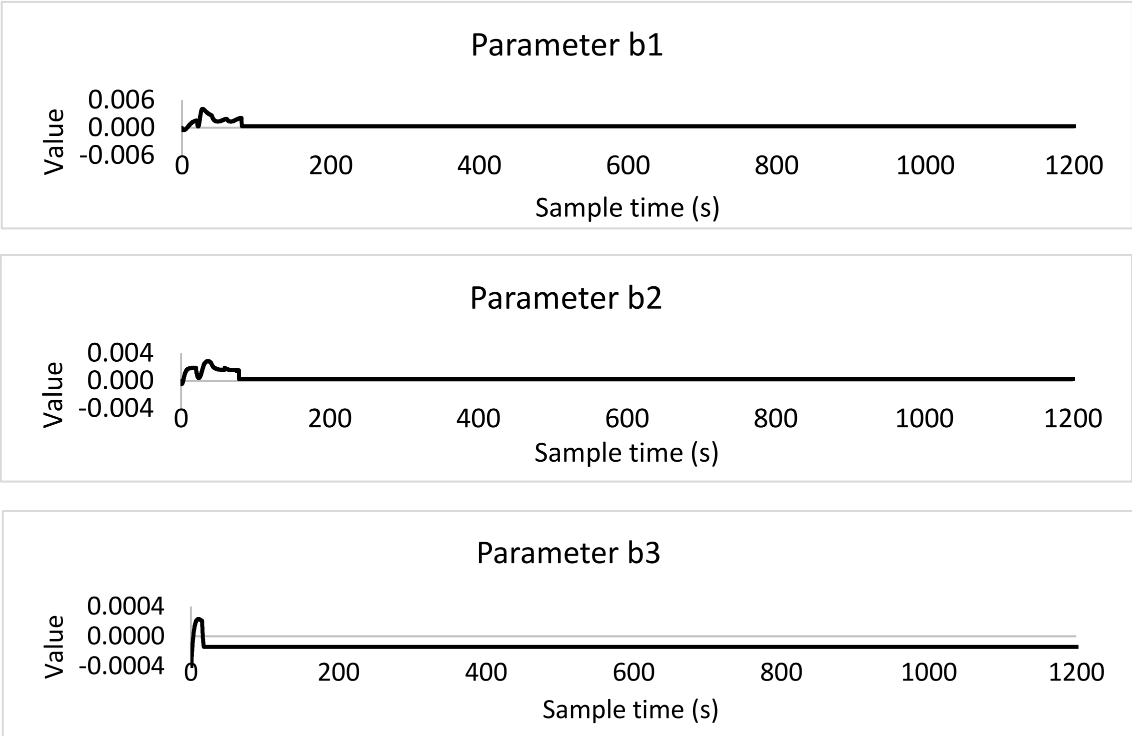



**Fig. 3.** The 4rd order of ARMAX model structure (4,3,3) with 80.23% best fitting between real and estimated model

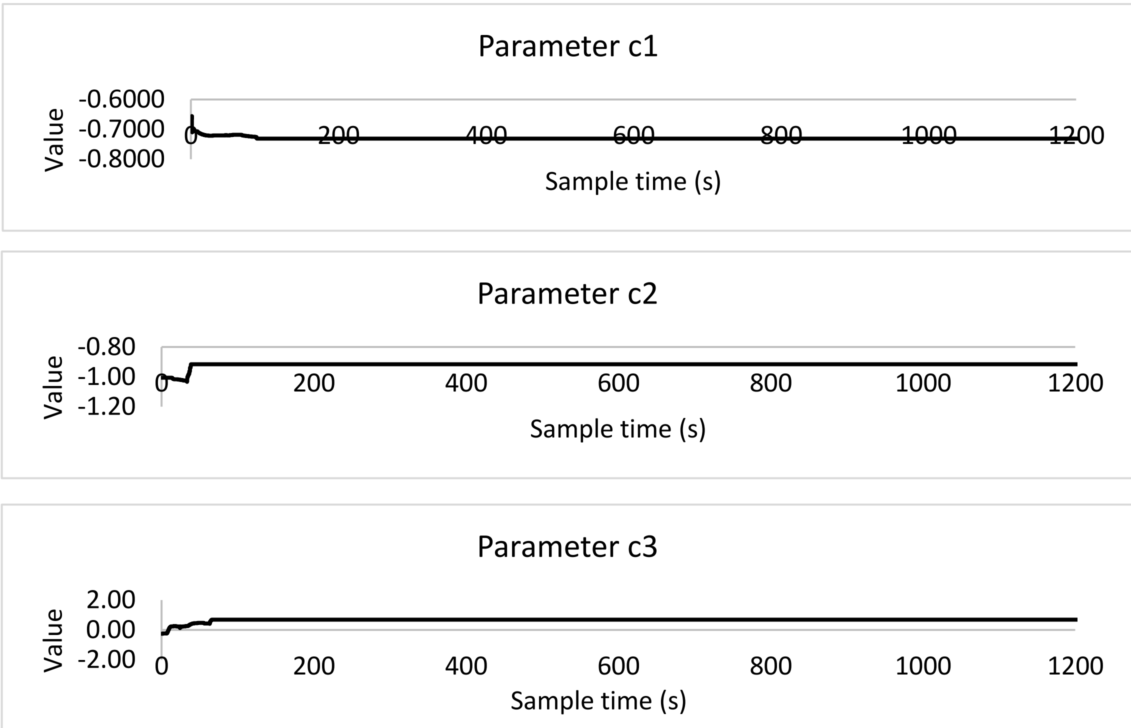
Figure 4 shows the computation time taken by the identification program for the 4th order of ARMAX model (4,3,3). The approximate convergence time for the second order is less than 100s.




(a)



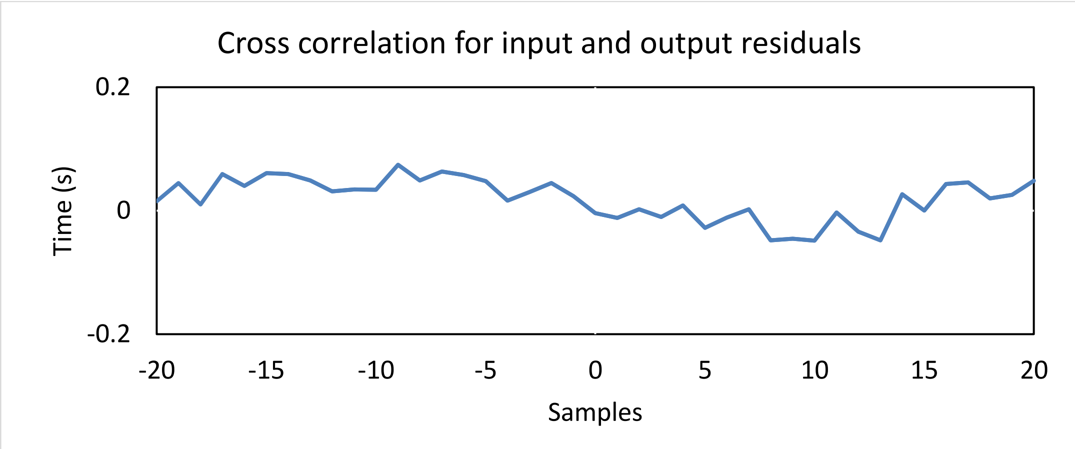

(b)



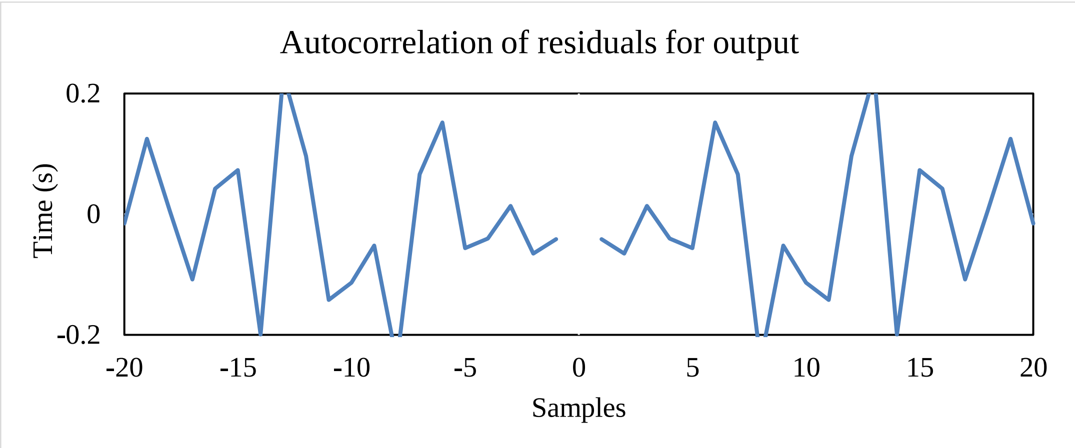

(c)

**Fig. 4.** Parameter estimation convergence rate of 4$^{th}$ order of ARMAX model for (a) A polynomial, (b) B polynomial, (c) C polynomial

In addition, Figure 5 shows the residual test had also been demonstrated with real model and estimated model of 4$^{th}$ order of ARMAX model (4, 3, 3). This test is meant to confirm whether this is indeed the correct model for the cooling system. The results are shown in both Figure 5(a) and 5(b) indicating the autocorrelation and cross correlation tests are within the confidence bounds, remarking that both the system and noise models are acceptable. Based on Figure 4(a), it reasonable that due to noise in the data, one term cannot be estimated. If more data is available, a confidence level for the residual test will be available.




(a)




(b)

**Fig. 5.** Residual tests for 4th order of ARMAX model of TEC cooling system (a) cross correlation, (b)autocorrelation

Theoretically, incorporating the noise term in the model equation will give better results than the deterministic model. Therefore, it can be concluded that the parameter $n_c$ is not dominant for this cooling system. In addition, based on the poles and zeros diagram also shows the 4th order model ARMAX (4, 3, 3) is in a stable state. Nonetheless, the validation process indicates that the identified model is a sufficient representation of the cooling system integrated with TEC. The ARMAX model obtained in this work is useful for designing and analysing the control for cooling systems integrated with TEC.

The better model performance and accuracy is expected if the model structure is run with the noise ($n_c$) inclusive, during the observation of this ARMAX model. Reviewing the poles and zero plots in Figure 6 for the 4th order model, it can be seen that all the poles are inside the z -plane unit circle, which indicates that the transfer function is stable. This requirement is important if this model is meant to be used for controller design.

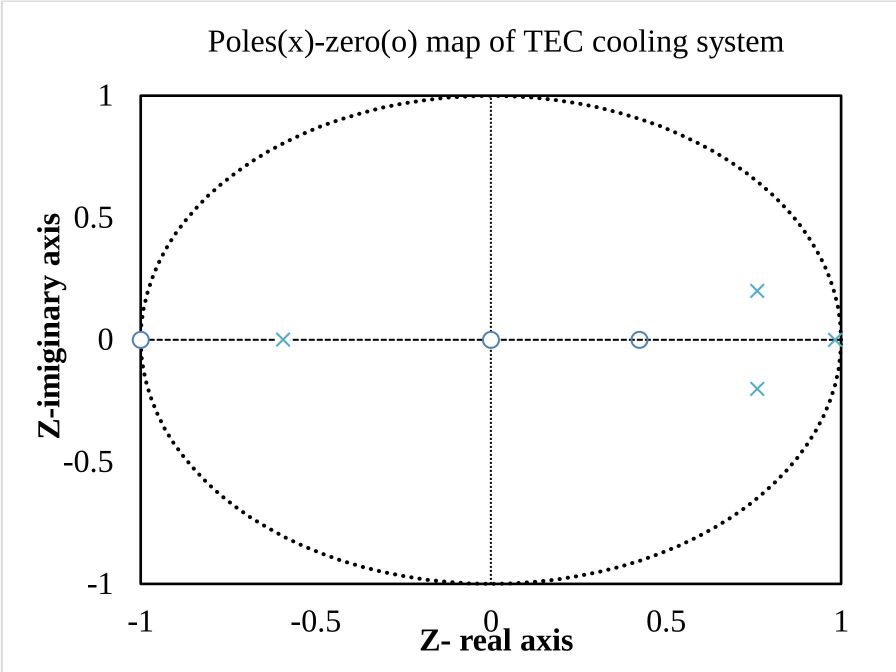



**Fig. 6.** Pole-zero diagram in z-plane of 4$^{th}$ order of ARMAX model of TEC cooling system

## 4. Conclusions

The dynamic identification procedure was developed to ensure the best model fit the cooling system integrated with thermoelectric. The system needs to be represented by minimum error, representing the accuracy of the model even when variation occurs since the parameter of the actual system is changed due to the dynamic environment.

In this work, the linear identification system used is ARX and ARMAX model. The mathematical structure based on ARX and ARMAX models has been estimated through the performance of the dynamical behaviour of this cooling system integrated with TEC. The model was chosen due to having the best fitting graph generated in system identification tools in MATLAB and least error between real and estimated outputs. The results indicated that the 4th order of ARMAX model showed the best fit of 80.23%, with a standard deviation of 0.027592 compared to the best fit of 4th order ARX which is 78.14% and standard deviation of 0.030769.

Furthermore, the influence of noise from the ARMAX under high value from $n_b$ structure may give the largest inaccuracy to the system response. Therefore, the 4th order of ARMAX (4, 3, 3) model was selected from this cooling system due to the error value produced was smaller compared to the ARX model. Besides, the result of poles and zeros diagram of 4th order of ARMAX (4, 3, 3) model also representing the stability of the cooling system and that the system is acceptable due to the autocorrelation and correlation comparisons. There are several factors that resulted for the 4th order of ARMAX models for not be able to achieve the highest fitting between the actual model and the estimated model. That is due to the losses to and the changes of dynamic environment, with additional noises depicted from the temperature of the air condition. Besides, the TEC module takes a long time to cool and there is a lot of heat loss during the cooling process, is also one of the reasons, as this the weakness of the TEC itself.

Although it is not the best model structure and estimation algorithm obtained from the experiments, it is the most practical model for adaptive applications in terms of time convergence rate of its parameters, simple structure, and ease of implementation for computing programs. The mathematical models developed in this study present an analysis and simulation tools in the linear of dynamic cooling system that forms the foundation for a systematic approach to the analysis, simulation and synthesis of cooling system integrated with TEC. Nevertheless, the final decision will be based on the adaptive controller design.

**Acknowledgment**
This work is supported by Research Management Centre of Universiti Malaysia Perlis.

**References**

[1] Zuhari, Zuhairah, and Low Sheau-Ting. "Indoor thermal comfort in university classroom: A case of universiti teknologi malaysia." *International Journal of Real Estate Studies* 13, no. 2 (2019): 34-41.
[2] Ulpiani, Giulia, Diego Giuliani, Alessandra Romagnoli, and Costanzo di Perna. "Experimental monitoring of a sunspace applied to a NZEB mock-up: Assessing and comparing the energy benefits of different configurations." *Energy and Buildings* 152 (2017): 194-215. https://doi.org/10.1016/j.enbuild.2017.04.034
[3] Wang, Ling, Xiuling Jiao, Dairong Chen, and Ting Wang. "A Solar Water-Heating Smart Window by Integration of the Water Flow System and the Electrochromic Window Based on Reversible Metal Electrodeposition." *Advanced Science* 9, no. 6 (2022): 2104121. https://doi.org/10.1002/advs.202104121
[4] Rativa, Diego, and Luis A. Gómez-Malagón. "Colloidal plasmonic structures for harvesting solar radiation." *Renewable energy* 118 (2018): 947-954. https://doi.org/10.1016/j.renene.2017.10.112
[5] Jebir, S.K., Abbas, N.Y. and Khudheyer, A.F. (2020) Effect of different nanofluids on solar radiation absorption. Journal of Mechanical Engineering Research and Developments, 44, 190-206.
[6] Mustafa, Wan Azani, Syahrul Affandi Saidi, Mustaffa Zainal, and Ragunathan Santiagoo. "Experimental study of composites material based on thermal analysis." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 43, no. 1 (2018): 37-44.
[7] Grynning, Steinar, Arild Gustavsen, Berit Time, and Bjørn Petter Jelle. "Windows in the buildings of tomorrow: Energy losers or energy gainers?." *Energy and buildings* 61 (2013): 185-192. https://doi.org/10.1016/j.enbuild.2013.02.029
[8] Kim, Soojung, Puyan A. Zadeh, Sheryl Staub-French, Thomas Froese, and Belgin Terim Cavka. "Assessment of the impact of window size, position and orientation on building energy load using BIM." *Procedia Engineering* 145 (2016): 1424-1431. https://doi.org/10.1016/j.proeng.2016.04.179
[9] Alwetaishi, Mamdooh. "Impact of glazing to wall ratio in various climatic regions: A case study." *Journal of King Saud University-Engineering Sciences* 31, no. 1 (2019): 6-18. https://doi.org/10.1016/j.jksues.2017.03.001
[10] Liu, Mingzhe, Per Kvols Heiselberg, Yovko Ivanov Antonov, and Frederik Søndergaard Mikkelsen. "Parametric analysis on the heat transfer, daylight and thermal comfort for a sustainable roof window with triple glazing and external shutter." *Energy and Buildings* 183 (2019): 209-221. https://doi.org/10.1016/j.enbuild.2018.11.001
[11] Qahtan, Abdultawab, Nila Keumala, S. P. Rao, and Zulkiflee Abdul-Samad. "Experimental determination of thermal performance of glazed façades with water film, under direct solar radiation in the tropics." *Building and Environment* 46, no. 11 (2011): 2238-2246. https://doi.org/10.1016/j.buildenv.2011.05.001
[12] Hu, Yue, Per Kvols Heiselberg, and Rui Guo. "Ventilation cooling/heating performance of a PCM enhanced ventilated window-an experimental study." *Energy and Buildings* 214 (2020): 109903. https://doi.org/10.1016/j.enbuild.2020.109903
[13] Chavhan, D. K., and S. D. Mahajan. "Testing and validation of thermoelectric coolers." *Int. J. Eng. Res. Appl* 5, no. 8 (2015): 5-9..
[14] Saifizi, M., Sazali Yaacob, M. S. Mohamad, and M. Z. Ab Muin. "Linear Dynamic Modelling and Identification of Hybrid Thermoelectric Refrigerator System." *International Journal of Mechanical and Mechatronics Engineering* (2013).
[15] Barratt, B. I. P., V. C. Moran, F. Bigler, and J. C. Van Lenteren. "The status of biological control and recommendations for improving uptake for the future." *BioControl* 63, no. 1 (2018): 155-167. https://doi.org/10.1007/s10526-017-9831-y
[16] Tran, Ngoc-Tham, Abdul Basit Khan, and Woojin Choi. "State of charge and state of health estimation of AGM VRLA batteries by employing a dual extended kalman filter and an ARX model for online parameter estimation." *Energies* 10, no. 1 (2017): 137. https://doi.org/10.3390/en10010137
[17] Amran, M. A. N., A. A. Bakar, M. H. A. Jalil, M. U. Wahyu, and A. F. H. A. Gani. "Simulation and modeling of two-level DC/DC boost converter using ARX, ARMAX, and OE model structures." *Indonesian Journal of Electrical*

*Engineering and Computer Science* 18, no. 3 (2020): 1172-1179. https://doi.org/10.11591/ijeecs.v18.i3.pp1172-1179

[18] Li, Bowen, Paul Franzen, Yongjin Choi, and Christopher Cheng. "Receiver behavior modeling based on system identification." In *2018 IEEE 27th Conference on Electrical Performance of Electronic Packaging and Systems (EPEPS)*, pp. 299-301. IEEE, 2018. https://doi.org/10.1109/EPEPS.2018.8534310

[19] Aboelkhair, Hassan, Mostafa Morsy, and Gamal El Afandi. "Assessment of agroclimatology NASA POWER reanalysis datasets for temperature types and relative humidity at 2 m against ground observations over Egypt." *Advances in Space Research* 64, no. 1 (2019): 129-142. https://doi.org/10.1016/j.asr.2019.03.032

[20] Chemura, Abel, Onisimo Mutanga, Mbulisi Sibanda, and Pardon Chidoko. "Machine learning prediction of coffee rust severity on leaves using spectroradiometer data." *Tropical Plant Pathology* 43, no. 2 (2018): 117-127. https://doi.org/10.1007/s40858-017-0187-8

[21] Cheng, Ke-Sheng, Yi-Ting Lien, Yii-Chen Wu, and Yuan-Fong Su. "On the criteria of model performance evaluation for real-time flood forecasting." *Stochastic Environmental Research and Risk Assessment* 31, no. 5 (2017): 1123-1146. https://doi.org/10.1007/s00477-016-1322-7