IJIE

UTHM Penerbit

INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

Vol. 18 No. 5 (2026) 40-52
https://publisher.uthm.edu.my/ojs/index.php/ijie

Artificial Neural Network Based Energy Optimisation for Smart Building Energy Management Systems in Commercial Buildings

Sim Sy Yi[1]*, Neo Qi Yuan[2], Loh Wei Kiat[1], Siti Nur Afifah Mohd Suhaimi[2], Law Kah Haw[3], Husam S. Samkari[4], Ammar Alamshah[6]

[1] *Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA*
[2] *Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600, Pagoh, Johor, MALAYSIA*
[3] *Electrical and Electronic Engineering Programme Area, Universiti Teknologi Brunei, Bandar Seri Begawan BE1410, BRUNEI*
[4] *Department of Electrical Engineering, University of Tabuk, Tabuk, 47713 SAUDI ARABIA*
[5] *ARES Energy Sdn Bhd, 56000, Kuala Lumpur, MALAYSIA*

*Corresponding Author: sysim@uthm.edu.my
DOI: https://doi.org/10.30880/ijie.2026.18.05.005

Article Info

Received: 28 September 2025
Accepted: 15 June 2026
Available online: 7 July 2026

Keywords

Smart building energy management, commercial building rehabilitation, building construction, AI control, sustainable energy

Abstract

As the population grows and human needs increase, so does the number of buildings, leading to higher energy demand and challenges for sustainable use. Therefore, it is essential to develop strategies to reduce energy consumption. Previous studies indicate that poor control of energy use in commercial buildings has resulted in significant energy waste. To address this issue, energy management systems have been developed in recent years, playing a critical role in optimising energy use in various building types. The PID controller, known for its simplicity and ease of use, has become the standard controller in many energy management systems. However, its performance limitations in complex tasks and the overshoot problem in system output reduce overall energy efficiency. This paper proposes an Artificial Neural Network (ANN) controller to replace the PID controller for managing and monitoring HVAC and lighting systems, which are the two largest energy consumers in commercial buildings. The controllers were designed and implemented using MATLAB Simulink, where their performance was evaluated under different operating conditions, including step changes and ramp behaviours. The ANN controller was compared to the PID controller to evaluate its effectiveness in energy management. In the HVAC system, it eliminates overshoot at 15°C, whereas the PID controller shows 41.00%. For the lighting system, it achieves zero overshoot at 250 Lux, while the PID controller reaches 26.67%. These findings confirm its effectiveness in enhancing energy efficiency in commercial buildings by minimising energy fluctuations and improving system stability, making it a reliable solution for optimising energy use.

1. Introduction

Energy consumption is rising steadily. In 2018, global energy use increased by about 2.3%, nearly doubling the average growth rate since 2010, according to the International Energy Agency [1]. This increase can lead to higher greenhouse gas emissions and higher electricity bills. Commercial buildings, especially offices, use significantly more energy than other building types. This is mainly due to their cooling and lighting systems. The cooling system in these buildings is called the Heating, Ventilation, and Air Conditioning (HVAC) system. Studies show that HVAC and lighting systems are among the most energy-consuming devices worldwide [2], [3].

To address rising energy consumption, an energy management system is necessary. The energy management system is an automated system that conserves energy by tracking and monitoring energy use in a building [4]. The energy management system plays a vital role in reducing operational costs within a building by facilitating efficient energy utilisation. A critical component of this system is the control device, which computes the discrepancies between reference data and the actual data observed in the area. By assessing these variances, the control device ensures optimal energy usage and enhances overall system performance. The control device will stabilise the system's output to follow the required value. Normally, the control device is a proportional–integral–derivative (PID) controller.

The PID controller is the most prevalent control algorithm utilised in energy systems. Nevertheless, it possesses inherent weaknesses that may compromise the accuracy of system performance. In pursuit of improved outcomes, recent studies have explored replacing PID controllers with Artificial Neural Network (ANN) controllers, which offer improved adaptability and learning capabilities. Unlike PID controllers, ANN controllers can dynamically adjust to changing conditions without requiring precise system modelling. Previous studies have shown that ANN-based control systems outperform PID controllers in stability, response time, and energy efficiency. However, most research focuses on specific applications, with few studies comparing their performance in HVAC and lighting systems under real-world operating conditions [4]-[11].

Energy management is the process of conserving a building's energy through tracking and monitoring energy use [12]. The advantages are reduced operating costs in the building, increased productivity and competitiveness, and improved staff comfort [6]. In an office building, the HVAC and lighting systems are the electrical systems with the highest energy consumption [2], [3]. The energy management system in this study will focus on the HVAC and lighting systems, using PID and ANN controllers.

The HVAC system will provide thermal comfort and high air quality to the building. Normally, it has a central control system that manages a building's overall temperature. Ventilation is the process of exchanging indoor and outdoor air to ensure good air quality in the building. The HVAC device consists of an alternating-current motor and two direct-current motors. The alternating current motor is a fan motor, and its function is to control the rate of temperature change in the building. The two direct current motors are the condenser and compressor motors, and their function is to control the rate of temperature change outside of the building [7]. The study examined a DC motor air compressor, specifically a scroll compressor. This scroll motor operates at 2400 RPM [8]. Additionally, a lighting system will be installed to illuminate the building. The importance of lighting systems lies in providing humans with clear sight for daily life. However, as a commonly used lighting system, it accounts for about 15% of the building's total energy consumption [9]. The lighting devices in the buildings can be fluorescent lamps, which provide high illumination, or light-emitting diode (LED) lamps, which have low energy consumption and high illumination. The basic illumination in a workplace is 400 lux [10].

The PID controller continuously monitors the error and calculates the proportional, integral, and derivative components based on it. These three values are then combined to generate the controller's output, thereby regulating the system's response [11]. In contrast, the ANN controller is an advanced mechanism that employs intricate calculations to optimise output performance. It is developed from a programmed computational model designed to emulate the neural architecture and function of the human brain. This replication enables the system to enhance decision-making processes and improve efficiency in various applications. The advantage of the ANN is that it can learn and model nonlinear and complex relationships. This is important because many of the system's inputs and outputs in daily life are non-linear and complex. Second, the ANN can generalise. When an ANN learn relationships from input data, it can predict on unseen data and generalise [13]. Modern energy management is a complex yet essential field due to rising energy consumption in buildings, requiring optimisation for efficiency, cost reduction, and sustainability, where machine learning (ML) and intelligent energy management systems (IEMS) play a crucial role in balancing energy demand, renewable integration, and user comfort through smart predictive models [14], [15].

High energy consumption without proper energy management, such as keeping the lamp and HVAC system on all day, leads to significant energy waste. Additionally, this can reduce the lifespan of electrical devices. The PID controller is a conventional and simple controller, but it suffers from high overshoot [5]. As HVAC and lighting systems are the largest energy consumers in commercial buildings, this paper addresses how to use an ANN controller to replace the PID controller and reduce energy waste in HVAC and lighting systems in rehabilitated or newly constructed commercial buildings.

Effective energy management systems are particularly crucial given the dynamic nature of energy demand and the need for sustainable development practices. During rehabilitation, older buildings often undergo upgrades to their energy systems to meet modern efficiency standards, while new construction aims to integrate advanced energy-saving technologies from the outset. This study directly contributes to these efforts by addressing energy inefficiencies in HVAC and lighting systems, which are common in both scenarios. By proposing an ANN controller to replace the conventional PID controller, this research provides a pathway to optimise energy usage and reduce wastage during building retrofits and in newly constructed environments. The findings of this study support adopting smart energy management solutions that enhance system performance while ensuring compliance with energy regulations and sustainability goals during the construction and rehabilitation of commercial buildings.

2. Proposed Smart Building Energy Management Systems

In this study, the controller controls two systems: the direct current (DC) motor compressor in the HVAC system and the lamp in the lighting system. Fig. 1 shows the block diagram combining the HVAC and lighting systems. The load consists of a DC motor compressor for the HVAC system and a lamp for the lighting system. The PID controller is first constructed as a conventional system for these two systems and then compared with the proposed ANN controller under the same load.

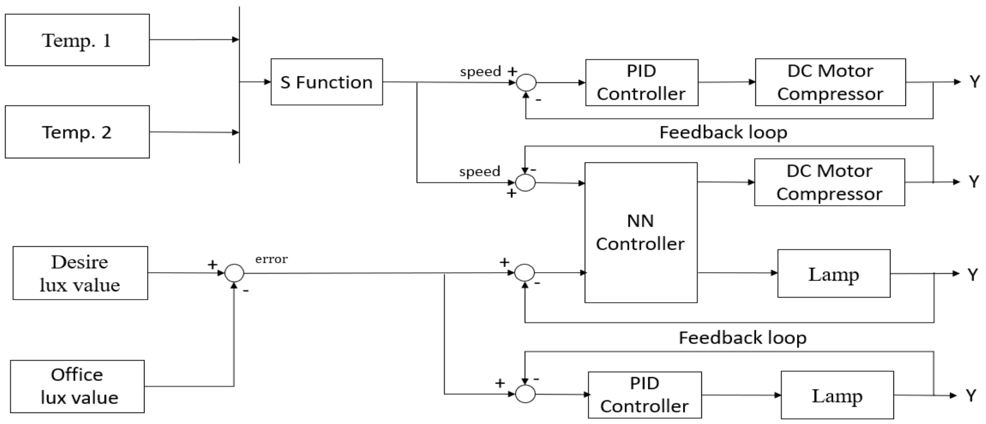


Fig. 1 *Proposed smart building energy management system with HVAC system and the lighting system*

2.1 HVAC System

In the HVAC system, the air compressor motor (DC motor compressor) is controlled by a PID or an ANN controller. These two controllers will receive error signals from the speed function (s-function) and the feedback loop and use them to determine the actual energy required by the DC motor compressor. After that, those energies would be provided to the DC motor compressor. For energy management, the PID and ANN controllers will provide high accuracy in controlling the DC motor compressor's speed and supply only the energy required for operation. However, without a controller, the DC motor compressor speed may become inaccurate, leading to inefficient energy usage. If the compressor operates at too high a speed, it wastes energy, while if it runs at too low a speed, it fails to maintain the desired room temperature. A controller ensures optimal speed regulation, improving both energy efficiency and system performance.

The DC motor compressor speed is adjusted by monitoring room temperature to maintain a comfortable indoor environment. The room temperature (Temp. 2) represents temperature variations throughout the day, generated using a predefined coding algorithm and formula. The speed function (S-function) calculates the required compressor speed based on the reference temperature (Temp. 1) and the actual room temperature (Temp. 2). In the HVAC system, the reference temperature serves as the target temperature that the system aims to achieve for optimal comfort and energy efficiency. The room temperature in the HVAC system is represented in Eqn. (1).

$$\begin{gathered}\text{For } 0\text{s} \le t \le 2\text{s} \Rightarrow Y = 3t + 22 \\ \text{For } 2.1\text{s} \le t \le 5\text{s} \Rightarrow Y = 31 \\ \text{For } 5.1\text{s} \le t \le 6\text{s} \Rightarrow Y = -2t + 41 \\ \text{For } 6.1\text{s} \le t \le 10\text{s} \Rightarrow Y = 28\end{gathered} \tag{1}$$

where Y denotes the ambient temperature in the office, and t denotes the time of change, measured in seconds (s). This equation has been formulated based on the data referenced in [13]. The subsequent stage involves the speed function used to quantify the direct current (DC) motor's speed. The speed function utilised in the HVAC system is given by Eqn. (2).

$$\begin{gathered}Y = 180n + [180(\text{reference temperature} - 24) + 2400) \\ \text{if } n = 0 \Rightarrow Y = 180(\text{reference temperature} - 24) + 2400 \\ \text{if } n > 0 \text{ or } n < 0 \Rightarrow Y = 180n + [180(\text{reference temperature} - 24) + 2400]\end{gathered} \tag{2}$$

where n = room temperature – reference temperature. Based on this equation, the variable n represents the difference between the reference and ambient room temperatures. This measurement is crucial for calculating the error data. Once the error has been determined, it will be incorporated into Eqn. (2) to ascertain the actual motor speed. In this context, the actual motor speed is denoted by the variable Y.

2.2 Lighting System

In the lighting system, a straightforward calculation is used to derive the error signal from the desired lux value, the actual office lux value, and the feedback loop. This error signal is subsequently transmitted to the PID and ANN controllers to regulate the office lamps. The target lux value for the lighting system is set to 400 lux, ensuring that the controllers activate and deactivate the lamps to maintain the office lux level at this target. In the absence of a control mechanism, the lamps may operate sporadically. This inefficiency not only leads to energy wastage but also undermines overall operational efficiency.

By monitoring the office's lux level, the controller can maintain it at 400 lux, as this is a suitable value for the office [10]. In the study, the office lux value is designed based on ramp behaviour to reflect actual office conditions. The formula is designed based on the data from [16], [17]. The office lux value in the lighting system is represented in Eqn. (3).

$$\begin{gathered}\text{For } 0\text{s} \le t \le 2\text{s} \Rightarrow Y = 65t + 220 \\ \text{For } 2.1\text{s} \le t \le 5\text{s} \Rightarrow Y = 350 \\ \text{For } 5.1\text{s} \le t \le 7\text{s} \Rightarrow Y = -76.67t + 733.35 \\ \text{For } 7.1\text{s} \le t \le 10\text{s} \Rightarrow Y = 197\end{gathered} \tag{3}$$

This formula is designed for ramp behaviour, where Y is the output lux value in the office. The lux value increases over the time interval (t) from 0 to 2s. This increase is illustrated by the sun's morning rise. At this time, sunlight enters the office, causing the office's lux to increase linearly. Then, the next step, 2.1s to 5s, is set to a constant lux value of 350, representing the optimum lux achieved in the afternoon. From 5.1s to 7s, the lux value in the office decreases because it is the afternoon-to-evening transition, and sunlight in the office is reduced. At 7.1s to 10s, there is no sunlight, so the lux value is only 197 [16], [17].

2.3 Controller

In this study, two types of controllers are used: (i) a PID controller, and (ii) an ANN controller. A PID controller consists of three types of controllers, namely proportional (P), integral (I), and derivative (D). The P controller compares the setpoint with the output signal from the control loop. The I controller is used to manage the speed of the response, while the D controller anticipates future errors and reacts to changes in process variables that occur at very high rates, helping to prevent oscillations. Finally, the output of the PID controller is a sum of the outputs of these three controllers. Fig. 2 shows the circuit of the PID Controller, and Eqn. (4) is used to calculate the output of the PID Controller.

$$\text{Output}, u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \tag{4}$$

where K_p represents the gain of the P-type controller, K_i is the gain of the I-type controller, K_d is the gain of the D-type controller, and e(t) denotes the error over time.

The ANN controller consists of several elements, including a neuron that performs the weighted sum of the input signal and the connecting weight. The sum is added with the bias or threshold, and the resultant signal is then passed through a non-linear element. In the neural network system, there are three parameters that need to be adjusted based on the system's results: the weights, the biases, and the slope of the nonlinear activation function. In this study, the neural network model used to control the HVAC and lighting system is shown in Fig. 3.

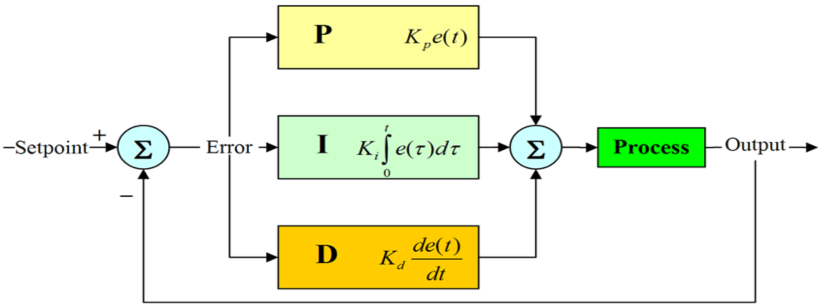


Fig. 2 *The circuit of the PID controller*

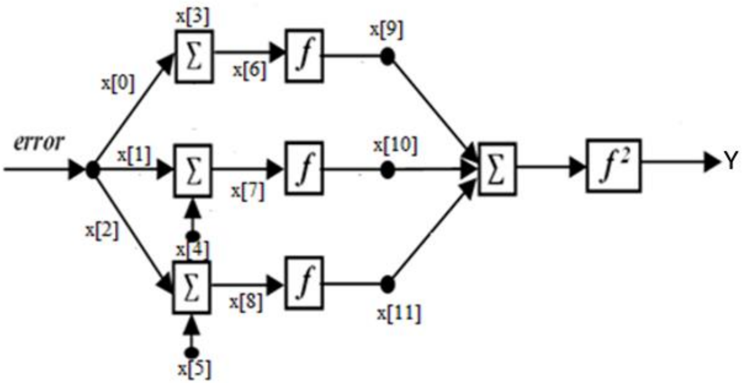


Fig. 3 *Neural network model that is used to control HVAC and lighting systems*

This neural network is known as the 1-3-1 model, consisting of one input node, a hidden layer with three neurons, and one output node. Each layer of neurons has its own bias and weights that are adjusted to produce the correct output value. The relationship among the connections in the system can be expressed as Eqn. (5).

$$
\begin{aligned}
\text{First Output} &= [\text{weight} \times \text{error}] + \text{bias} \\
\text{Second Output} &= \frac{2}{1 + e^{-2 \times \text{first output}}} - 1 \\
\text{Final Output} &= \text{Sum of all second outout}
\end{aligned}
\quad (5)
$$

where x[0], x[1] and x[2] are the weights, x[3], x[4], and x[5] are the biases, x[6], x[7], and x[8] are the first output, x[9], x[10], and x[11] are the second output, and Y is the final output which is the output that is connected to the HVAC and lighting system.

3. Simulation Modelling

The controller controls the speed of the DC motor compressor. Fig. 4 shows the complete Simulink diagram of the proposed energy management system for the DC motor compressor (PID and ANN compressors) and the lighting system (PID and ANN lamps). In this figure, the PID and ANN controllers control the DC motor compressor speed and the lighting system's lux value, respectively. In the Simulink diagram, the types of DC motors, compressors, and lamps are the same for both controllers. This consistency ensures that the output results, specifically the temperature and lux values, are accurate.

Based on Eqn. (1) (ramp behaviour temperature), Eqn. (2) (speed function) and Eqn. (3) (ramp behaviour lux value), the system measures the difference between the reference and actual room temperature and illuminance levels. This is done to simulate real environmental conditions in an office setting. The S-Function (speed function) is used to determine the required speed (in RPM) of the DC motor compressor, based on input data from the reference temperature (Temp.1) and the actual room temperature (Temp.2).

Based on the measured differences, the speed function will provide the required speed for the DC motor compressor. The greater the differences, the faster the motor runs. This study will compare the performance of PID and ANN controllers in three aspects: rise time, settling time, and overshoot percentage.

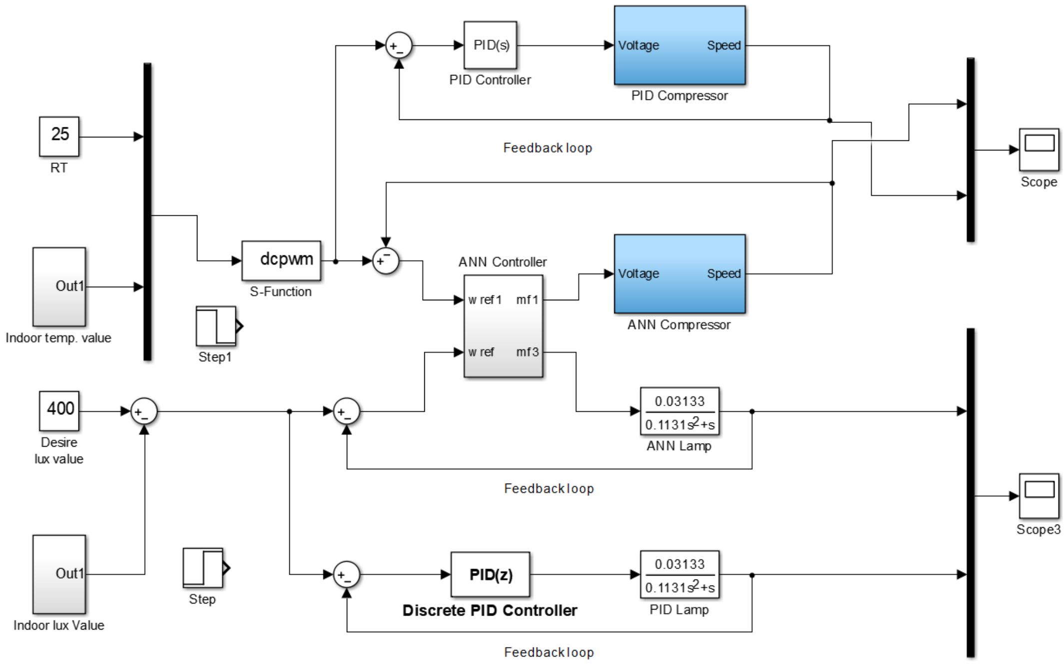


Fig. 4 *Simulink diagram of HVAC and lighting system*

4. Results and Discussion

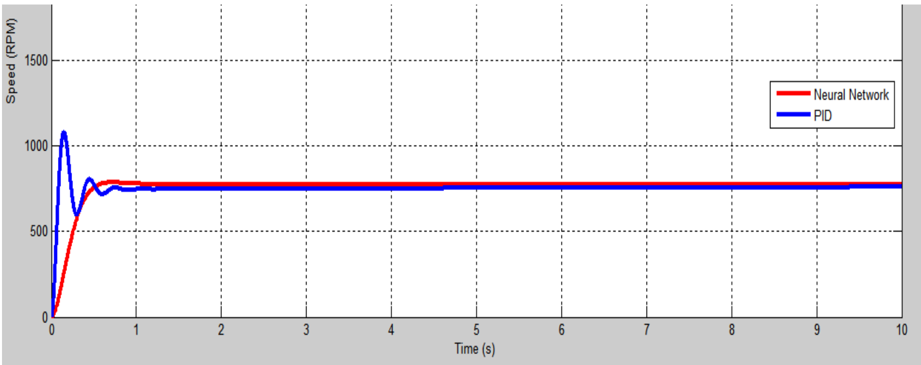
4.1 HVAC System

Two testing conditions were implemented to evaluate the HVAC system. In the first case, the room temperature (Temp.2) was set at a constant value to ensure both controllers reached the same steady-state conditions. This approach allows for a direct comparison, provided that the steady-state results align with theoretical expectations and accurately reflect performance differences. In the second case, the room temperature will ramp up to the desired temperature over time to better reflect the actual office environment. The reference temperature (Temp.1) will be set to 24°C for both cases. To verify the proposed ANN controller towards the energy management system, both controllers, the PID and the ANN controller, will be tested simultaneously under the same testing conditions to ensure the results of both controllers to compare are clear.

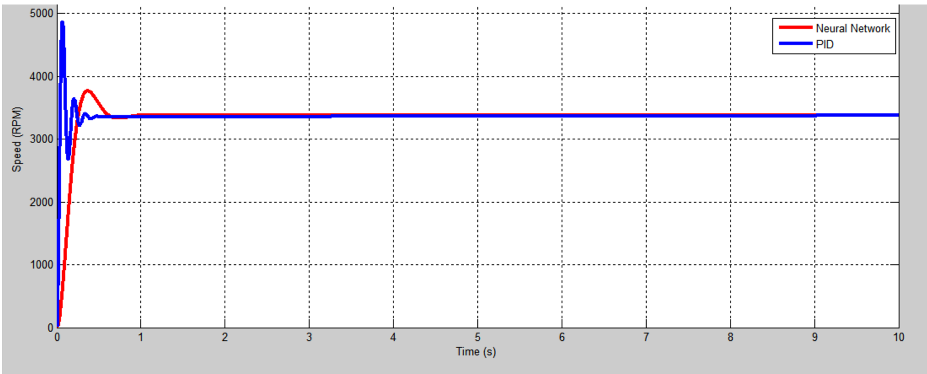
Fig. 5 shows the results for the first case. Fig. 5(a) shows the output speed of the DC motor compressor at a low room temperature of 15°C, with the reference temperature fixed at 24°C. The resulting motor speed is 780 RPM. The same testing condition is repeated by changing the low room temperature to a high room temperature of 30°C, while maintaining the reference temperature. The output speed of the DC motor compressor has increased to 3480 RPM, as shown in Fig. 5(b).

Based on the graph in Fig. 5(a), the motor accelerated from 0 RPM to 780 RPM within 1 second. This will cause an overshoot in motor speed [18]. When comparing the overshoot percentage and rise time of the ANN and PID controllers, the ANN controller's overshoot is nearly 0%, lower than the PID controller's. The ANN controller is 0.25s slower than the PID controller for a rise time of 0.05s. The ANN controller has a settling time of about 0.8s, which is lower than the PID controller's 1.1s. Based on the graph in Fig. 5(b), the motor accelerated from 0 RPM to 3480 RPM within 0.5 seconds. This caused an overshoot problem in motor speed [18]. When comparing the overshoot percentage and rise time of the ANN and PID controllers, the ANN controller's overshoot is 6.32%, lower than that of the PID controller. For the rise time, the ANN controller is 0.1s, which is higher than the PID controller of 0.05s. For the settling time, the ANN controller is about 0.6s, slightly higher than the PID controller of 0.5s.

For the second condition, the corresponding DC motor speed (RPM) for the ramp behaviour as the room temperature changes is shown in Table 1. The room-temperature graph is shown in Fig. 6, and the output DC motor speed (RPM) as a function of room temperature under ramp behaviour, with the reference temperature set to 24°C, is shown in Fig. 7. In Fig. 6, the room temperature in time (t) between 0s and 2s is shown to increase. This increase is illustrated by the time of day. The sun rises, and the workers in the office will experience an increase in the room temperature. For the time (t) between 2.1s and 5s, the temperature is held constant at 31°C, representing the optimum temperature observed in the afternoon. When the time is 5.1s to 6s, the decrease in the room temperature is defined by the time from afternoon to evening. During that time, the sunset and the workers back home will cause the temperature to decrease. The range of 6.1s to 10s represents nighttime. During that time, the absence of sun and fewer workers will cause the temperature to remain constant at 28°C. The graph shows rapid increases or decreases in temperature from 2.0s to 2.1s, 5.0s to 5.1s, and 6.0s to 6.1s. This measure aims to accelerate the direct current (DC) motor compressor to achieve a specified overshoot percentage.



(a)



(b)

Fig. 5 *The output speed of the DC motor compressor in RPM at a constant room temperature of (a) 15 ℃; and (b) 30 ℃ with the reference temperature fixed at 24 ℃*

Table 1 *The corresponding DC motor speed (RPM) with the changes in room temperatures in ramp behaviour*

Formula	Time (s)	Reference Temperature (°C)	Room Temperature (°C)	DC Motor Speed (RPM)
Y=3t+22	0	24	22	2040
	1	24	25	2580
	2	24	28	3120
Y=31	2.1	24	31	3660
	3	24	31	3660
	4	24	31	3660
	5	24	31	3660
Y=-2t+41	5.1	24	30.8	3624
	6	24	29	3300
Y=28	6.1	24	28	3120
	7	24	28	3120

Formula	Time (s)	Reference Temperature (°C)	Room Temperature (°C)	DC Motor Speed (RPM)
	8	24	28	3120
	9	24	28	3120
	10	24	28	3120

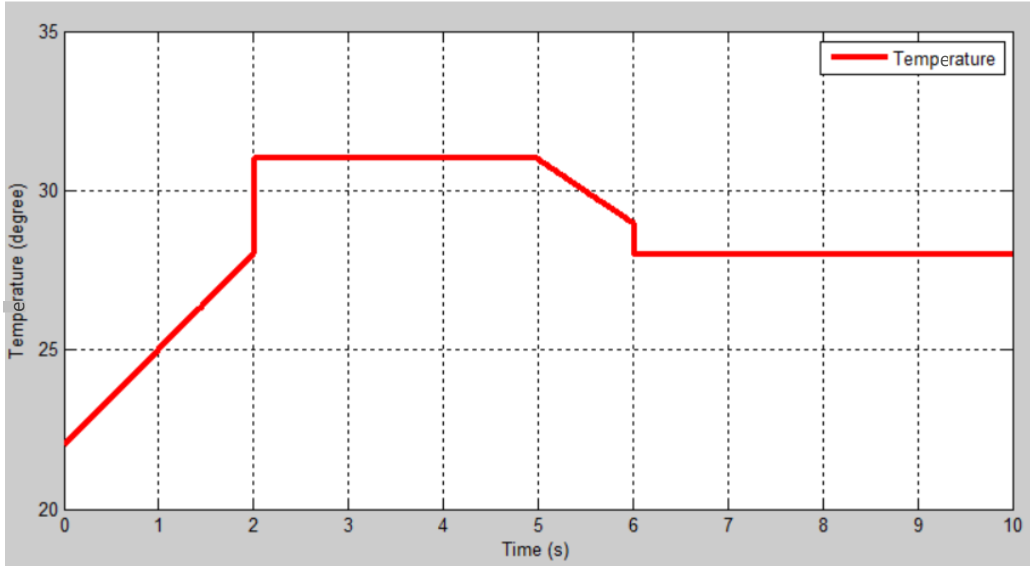


Fig. 6 *The room temperature change in the office*

In Fig. 7, the overshoot problem of the DC Motor Compressor only occurred at 0s, 2s and 6s. This is because rapidly increasing or decreasing the room temperature accelerates the DC Motor Compressor, leading to overshoot [18]. Since the reference temperature is fixed at 24°C, the motor speed depends on the room temperature, as shown in Fig. 6. The higher the room temperature, the faster the motor speed increases. When comparing the performance, the percentage overshoot of the ANN controller in 2s and 6s is lower than that of the PID controller. This shows that the ANN controller can reduce the percentage overshoot more than the PID controller. However, the rise time and settling time of the ANN controller are higher than those of the PID controller. This is the weakness of the ANN controller.

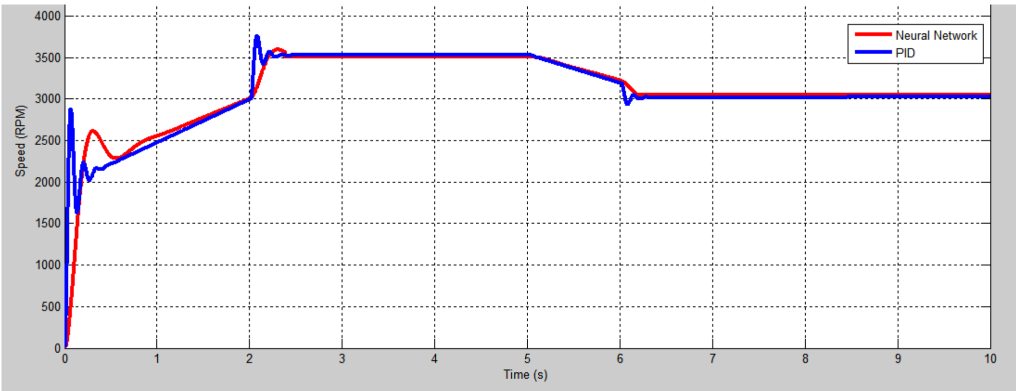


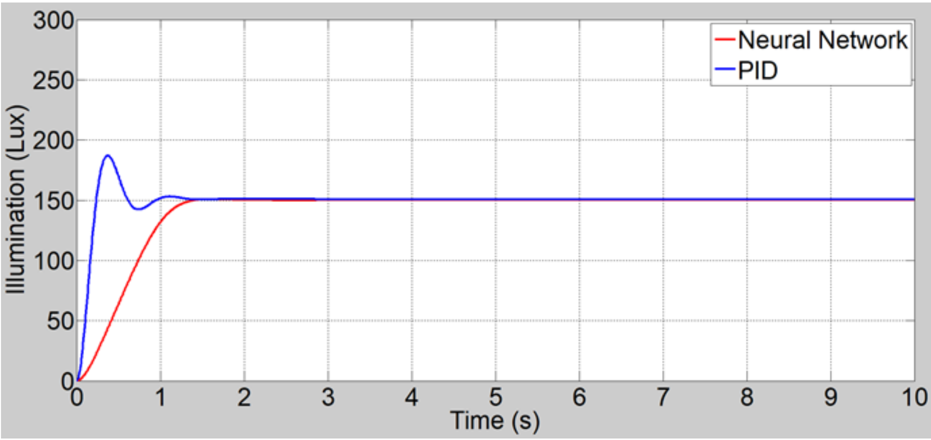
Fig. 7 *The output speed of the DC motor compressor in RPM when the room temperature is set as a ramp behaviour temperature, and the reference temperature is fixed at 24 ℃*

4.2 Lighting System

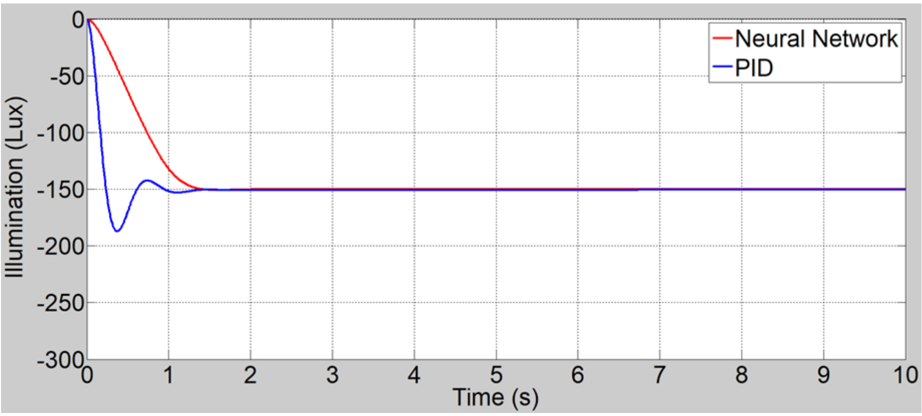
For the lighting system, the test has been conducted in two conditions to verify the proposed controller. First, the office lux is fixed at a constant value, and second, the office lux value is set to a ramp-behaviour illumination. The first test condition evaluates the lighting system's performance in steady state, where the office lux level is held constant. In the second test condition, the lux level follows a ramp behaviour, simulating natural sunlight variations throughout the day. Initially, lux levels increase as sunlight brightens in the morning, peaking in the afternoon before gradually decreasing as daylight fades. To ensure a clear and fair comparison, the proposed ANN controller and the conventional PID controller are tested simultaneously under identical conditions in each scenario.

Fig. 8 shows the output illumination of the lighting system at office lux values of 250 Lux (Fig. 8(a)) and 550 Lux (Fig. 8(b)). For Fig. 8(a), the output illumination of the lighting system is 150 Lux, and the output illumination of Fig. 8(b) is -150 Lux. The positive lux value indicates that the illumination is insufficient. So, some of the fluorescent lamps in the office will be switched on. However, if the illumination is negative, some fluorescent lamps will switch OFF due to the high illumination.

In Fig. 8, the ANN control method does not exhibit overshoot, whereas the PID controller shows an overshoot of 26.67%. In terms of rise time, the PID controller is faster than the ANN controller; however, the settling times for both controllers are identical.



(a)



(b)

Fig. 8 *The output illumination of the lighting system when the office lux value is at (a) 550 Lux; and (b) 880 Lux with the desired lux value fixed at 400 Lux*

The office illumination values in Table 2 were calculated using Eqn. (3) and were designed to vary over time. This variation reflects typical changes in an office environment, ensuring the Lighting System operates under realistic conditions as previously discussed in the Lighting System section of the Methodology. For the desired illumination, the data is received from [10]. For the Lighting System's output illumination, the result is the difference between the desired illumination and the office illumination. The data for office illumination in Table 2 is plotted in Fig. 9, and the output illumination in Table 2 is used to plot the graph in Fig. 10.

Table 2 *The relationship between office illumination (Lux) and time and output illumination of the lighting system (Lux)*

Formula	Time (s)	Desire Illumination (Lux)	Office Illumination (Lux)	Output Illumination (Lux)
Y=65t+220	1	400	285	115
	2	400	350	50
Y=350	3	400	350	50
	4	400	350	50
	5	400	350	50
Y=-76.67t+733.35	6	400	273.33	126.67
	7	400	196.66	203.34
Y=197	8	400	197	203
	9	400	197	203
	10	400	197	203

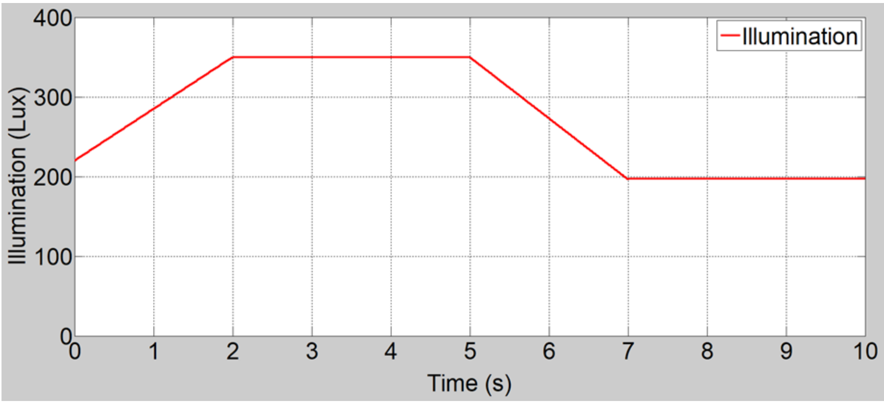


Fig. 9 *Office illumination profile under ramp variation*

From Fig. 10, the graph shows that the result is influenced by the office lux value, as the desired lux value is fixed at 400 Lux [10]. In terms of performance, the PID controller exhibited overshoot at 0s, 2s, and 7s, whereas the ANN controller did not. For the rise-time condition, the ANN controller is slower than the PID controller at 0s, 2s, and 7s. However, the settling times of the ANN and PID controllers are the same.

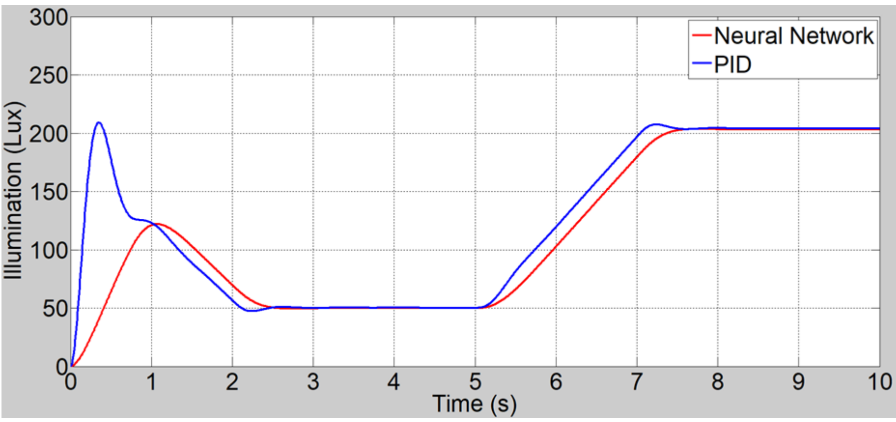


Fig. 9 *The output illumination of the lighting system when the office lux value was in a ramp behaviour of illumination, and the desired lux value was fixed at 400 Lux*

Table 3 and Table 4 compare the PID and ANN controllers for HVAC and lighting systems, showing that the ANN controller significantly reduces overshoot, leading to greater stability and energy efficiency. The highest overshoot for the ANN controller is 6.32% at 30°C, whereas the PID controller reaches 41.00% at 15°C, demonstrating the ANN's superior ability to minimise fluctuations. In the lighting system, the ANN controller maintains zero overshoot across all illumination levels, while the PID controller peaks at 26.67%, highlighting its instability. Lower overshoot translates to reduced energy consumption, as it prevents excessive power fluctuations. However, the ANN controller has a longer rise time than the PID controller, meaning it takes more time to reach the desired temperature or illumination level after a setpoint change. For instance, in the HVAC system at 15°C, the ANN controller's rise time is 0.25s, while the PID controller achieves the same in 0.05s. Similarly, in the lighting system at 250 Lux, the ANN controller takes 1.00s, whereas the PID controller responds in 0.20s, making the ANN slower but more stable. Despite this limitation, the settling time of both controllers is similar, ensuring the system reaches a steady state within a comparable timeframe. This suggests that while the ANN controller adapts more gradually, it ultimately stabilises efficiently. In conclusion, the ANN controller offers better energy efficiency by minimising overshoot and energy fluctuations, making it a more stable alternative to the PID controller, despite its slower response time. Future improvements could focus on optimising its response speed while maintaining its stability benefits, making it an even more effective energy management solution for commercial buildings.

Table 3 *The summaries of the performances of the PID and ANN controllers of the HVAC system from the experiment*

HVAC System						
Temperature (°C)	PID Controller			ANN Controller		
	Overshoot Percentage	Time Settling	Rise Time	Overshoot Percentage	Time Settling	Rise Time
15	41.00%	1.10s	0.05s	0%	0.80s	0.25s
30	37.93%	0.50s	0.05s	6.32%	0.60s	0.10s
Ramp behaviour	2s: 6.58%	0.45s	0.05s	2s: 2.40%	0.45s	0.10s
	6s: 5.93%	0.13s	0.05s	6s: 0%	0.13s	0.05s

Table 4 *The summaries of the performances of the PID and ANN controllers of the lighting system from the experiment*

Lighting System						
Illumination (Lux)	PID Controller			ANN Controller		
	Overshoot Percentage	Time Settling	Rise Time	Overshoot Percentage	Time Settling	Rise Time
250	26.67%	1.15s	0.20s	0%	1.15s	1.00s
550	26.67%	1.15s	0.20s	0%	1.15s	1.00s
Ramp behaviour	2s: 5.20%	0.20s	0.10s	0%	0.20s	0.15s
	7s: 1.97%	0.20s	0.10s	0%	0.20s	0.20s

5. Conclusions

In this study, an artificial neural network (ANN) controller was proposed for the energy management system to optimise HVAC and lighting systems. These systems were selected due to their substantial daily energy consumption in commercial buildings. The performance of the HVAC and lighting systems under the proposed ANN controller was compared with that of the conventional PID controller to validate the proposed ANN control system. It is evident that the ANN controller exhibits a much lower overshoot than the PID controller across all conditions. The highest overshoot observed for the ANN controller is 6.32% at 30°C, while the PID controller reaches 41.00% at 15°C. This difference highlights the ANN controller's ability to effectively regulate temperature fluctuations, reducing sudden changes and ensuring smoother system behaviour. Similarly, in the lighting system, the ANN controller maintains zero overshoot across all tested illumination levels, whereas the PID controller exhibits up to 26.67% overshoot, indicating instability. These improvements indicate that the ANN controller significantly outperforms the PID controller in energy efficiency and control stability. The study confirms that the ANN controller can reduce overshoot and energy consumption, addressing the study's objectives. By integrating ANN technology into Building Energy Management Systems, this approach not only addresses current energy challenges but also supports smarter, more resilient energy solutions for future commercial buildings. The findings highlight the potential of neural networks to enhance energy efficiency and achieve sustainable energy use in modern building systems.

Acknowledgements

This research is supported by the Ministry of Higher Education (MOHE) through the Fundamental Research Grant Scheme (FRGS/1/2024/TK08/UTHM/03/9).

Conflict of Interest

The authors declare that the work reported in this study was not affected by any conflicts of interest or personal connections.

Author Contribution

*The authors confirm their contribution to the paper as follows: **Study conception and design**: Sim Sy Yi, Neo Qi Yuan, Loh Wei Kiat. **Data collection:** Neo Qi Yuan, Loh Wei Kiat Siti Nur Afifah Mohd Suhaimi. **Analysis and interpretation of results:** Sim Sy Yi, Neo Qi Yuan, Loh Wei Kiat, Kah Haw Law, Husam S. Samkari. **Draft manuscript preparation:** Loh Wei Kiat, Kah Haw Law. **Industry insights and validation:** Ammar Alamshah. All authors reviewed the results and approved the final version of the manuscript*

References

[1] National Instruments (2019). PID Theory Explained. https://www.ni.com/en-my/innovations/white-papers /06/pid-theory-explained.html

[2] Al-Ghasem, A., & Ussaleh, N. (2012). Air conditioner control using neural network and PID controller. Proceeding of the 8th International Symposium on Mechatronics and its Applications, pp. 1–5.

[3] Janavicius, A., Morkevicius, N., Janaviciute, A., & Liutkevicius, A. (2015). The usage of artificial neural networks for intelligent lighting control based on resident's behavioural pattern. Journal of Civil Engineering and Management, 21, 72–79. https://doi.org/10.3846/13923730.2013.802710.

[4] Ahmed, M. S., Mohamed, A., Shareef, H., Homod, R. Z., & Ali, J. A. (2017). Artificial neural network-based controller for home energy management considering demand response events. Proceeding of the 2016 International Conference on Advanced Electrical and Electronic Systems Engineering, pp. 506–509.

[5] Jingyun, L., & Ping, L. (2017). Temperature and humidity control with a model predictive control method in the air conditioning system. Procedia Engineering, 205, 408–412. https://doi.org/10.1016/j.proeng.2017. 10.281

[6] EECA Business (2019). Benefits of Energy Management. https://www.eecabusiness.govt.nz/start-saving-energy/develop-an-energy-plan/benefits-of-energy-management/

[7] Petro (2019). HVAC Basics: What is HVAC and What Does It Stand For? https://www.petro.com/resource-center/what-is-hvac

[8] Copeland Corporation. (2018). Copeland Scroll™ Variable Speed Compressors XHV0181P to XHV0382P* Application Guidelines*. Emerson Climate Technologies.

[9] Park, S., Seo, S., Lee, B., & Byun, J. (2014). An energy-efficient smart LED lighting system for building energy management. Proceeding of the 18th IEEE International Symposium on Consumer Electronics, pp. 1–2.

[10] CIBSE (1992). Guide to Workplace Lighting. The Chartered Institution of Building Services Engineers.

[11] Elprocus (2019). How Does A PID Controller Work? Structure & Tuning Methods. https://www.elprocus. com/the-working-of-a-pid-controller/

[12] Weather Spark. (2019). The Typical Weather Anywhere on Earth. https://weatherspark.com/

[13] Mahanta, J. (2017). Introduction To Neural Networks, Advantages and Applications. Towards Data Science. https://towardsdatascience.com/introduction-to-neural-networks-advantages-and-applications-96851bd 1 a207

[14] Akram, A., Abbas, S., Khan, M., Athar, A., Ghazal, T., & Al Hamadi, H. (2024). Smart energy management system using machine learning. Computers, Materials & Continua, 78, 1175–1194. https://doi.org/10.32604/cmc. 2024.046128

[15] Al-Ghaili, A. M., Kasim, H., Al-Hada, N. M., Jørgensen, B. N., Othman, M., & Wang, J. (2021). Energy management systems and strategies in buildings sector: A scoping review. IEEE Access, 9, 63790-813.

[16] Abdullah, A., Syed Fadzil, S. F., & Al-Tamimi, N. A. (2009). Daylight illumination levels in varied room configurations at The View Condominium, Penang, Malaysia. Proceeding of the 3rd International Conference on Built Environment in Developing Countries, pp. 434–447.

[17] Reimann, G. (2010). Managing Light & Daylight Efficiently for Tropical Office Buildings: A Review of Daylighting. International Journal of Sustainable Building Technology and Urban Development, 1, 99–110.

[18] Basak, B. (2002). Transient behaviour of three-phase induction motor. IEE Proceedings – Electric Power Applications, 149, 259–262. https://doi.org/10.1049/ip-epa:20020217