# Classroom Cooling System with Neural Networks Based on Model Predictive Control

Muhammad Ihsan Al Hafiz, Dita Anggraini

**Abstract**— One of the big energy consumption of a building is in the field of HVAC (Heating, Ventilating, Air conditioning). In tropical area such as Indonesia , the air conditioning is extremely needed to achieve the thermal comfort in the room. Kwok, 1990 formulated in his dissertation, thermal comfort for tropical area is about 22 ℃ while the average temperature in tropical area such as Indonesia is 25 ℃ -27 ℃. Thermal comfort in the room must be considered to obtain high productivity in carrying out activities in the room. One of the commercial buildings which require room conditioning is school classroom building. To get the comfortable learning condition, the room temperature must be set up comfortably. One problem is that the room air cooling energy consumption is high and tend to be inefficient because of the unnecessary utilization. This paper designed the system based on neural networks predictive control for control the classroom temperature based on the ambient temperature and the presence of students in the class. The control purpose was to control the room temperature with a corresponding optimal temperature inputs and the environment accordance with the standards of thermal comfort. In this paper the authors were designing and simulating the control process using the Matlab R2013a software. The obtained result from the design of neural networks predictive control was that the room temperature was fluctuating but still closed to the set point that was 22 ℃. The average controlled room temperature was 22.36 ℃, that result closed to the set point and suitable with the standards of thermal comfort. From these result it can be concluded that the neural networks predictive control can be used for classrooms cooling control by considering the fluctuating environment temperature input.

***Index Terms*** — Cooling System, HVAC, Predictive Controller, Neural Networks.

## I. Introduction

A building energy consumption can be divided into many priorities. Data from the Australian Government's energy use in office buildings, energy consumption is divided into 39% HVAC, 25% light, 22% of the machine equipment, 4% lift, 1% of hot water, 9% other [1]. According to data from the Australian Government: Department of Industry, Innovation and Science, the average greatest energy utilization for commercial buildings is for the necessity of HVAC (Heating, Ventilating, Air Conditioning). It is also happened in Indonesia as one of the tropical areas which do not need room heating process, but still need room cooling process with high energy necessity [1].

Now, modern architecture is also directed to energy-efficient design, especially to shorten the process of heating and cooling, as performed by Moslehi which modified the ceiling panels in residential buildings that could generate energy savings reach out 11.3% for heating and 9.1% energy for cooling. One of the commercial buildings that require continuous room refrigeration system is the school building. As a place of education and learning, the school building is expected to have a comfortable air condition [2]. Kwok, in his dissertation research concluded that comfortable air conditions for tropical countries is in the range of temperature of 22 ℃ [3]. The air condition in tropical countries such as Indonesia actually fluctuate with average temperatures reach 25 to 27 ℃. For example, in Yogyakarta, Indonesia, the average environment is 25 ℃.

To get comfortable room temperature, the air conditioning system is required to decrease the room temperature suitable with thermal comfort. The problems of classroom cooling system are students presence in the room and non linear environmental temperature fluctuation. In this paper the design of predictive controller system algorithm based on Neural Networks (NN) to control the classrooms cooling system is discussed. The classroom refrigeration system using neural networks consider the outdoor temperatures and the presence of students in the classroom.

## II. Method

### A. Modelling of Classroom Cooling System

The simple model that could represent the thermal transfer that occured in classroom while the cooling process was needed for the simulation. The first equation is the equation of the used cooler. Cooler was based on the negative value of the heat flow that indicated the coming out heat flow which give the cooling effect. The equation can be shown as follows [4] :

$$\frac{dQ}{dt} = (T_{Cooler} - T_{room}).Mdot.c \quad (1)$$

$\frac{dQ}{dt} = heat\ flow\ from\ the\ room\ because\ cooler$

$c = heat\ capacitu\ of\ air\ at\ constant\ pressure$

$Mdot = air\ mass\ flow\ rate\ though\ cooler\ \left(\frac{kg}{hr}\right)$

$T_{Cooler} = Temperature\ of\ cool\ air\ from\ cooler$

$T_{room} = current\ room\ air\ temperature$

The second equation is the equation of the classroom modelling. In this equation the missing heat flow as function of the room temperature, outdoor temperature, and the equivalent resistance from used classroom modelling is obtained. Then the third equation represent the room temperature change per unit time dependent with the flow rate of the cooling process and the own air characteristics [4].

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$$\left(\frac{dQ}{dt}\right)_{losses} = \frac{T_{room} - T_{out}}{R_{eq}} \quad (2)$$

$$\frac{dT_{room}}{dt} = \frac{1}{M_{air} \cdot c} \cdot \left(\frac{dQ_{cooler}}{dt} - \frac{dQ_{losses}}{dt}\right) \quad (3)$$

$M_{air}$ = *mass of air inside the house*

$R_{eq}$ = *equivalent thermal resistance of the house*

The references value for the parameters variables in modeling are restricted to do not analyzed because of in this design the application of control algorithm with effect of outdoor air conditions and condition of the presence of students in the classroom are more emphasized. From the obtained equations, the modeling of entire cooling system of the classroom can be built. The classroom modelling is built based on the equations of the cooling system and thermal system of the classroom. This model will be used to be the training reference system for the neural networks system. This cooling system is purely obtained from the previous equations and when the input is given, therefore the output as system natural response will be appear. The classroom cooling system modelling can be shown in the figure as follows :

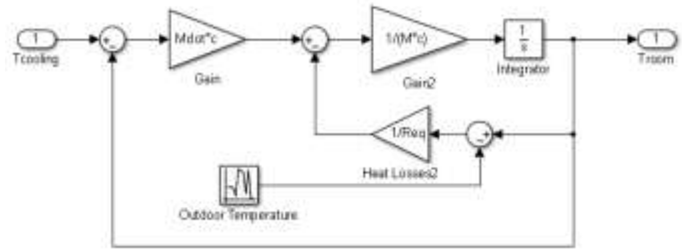


Fig. 1. Modelling of classroom cooling system for the control reference [4]

## B. Neural Networks Predictive Control

In the control system using neural networks predictive algorithms, Artificial Neural Networks (ANN) initialization based on training data from the system reference is done. Then the ANN model will become the basis of the star-stop optimization algorithm for the cooling control. The ANN block diagram can be shown as follows :

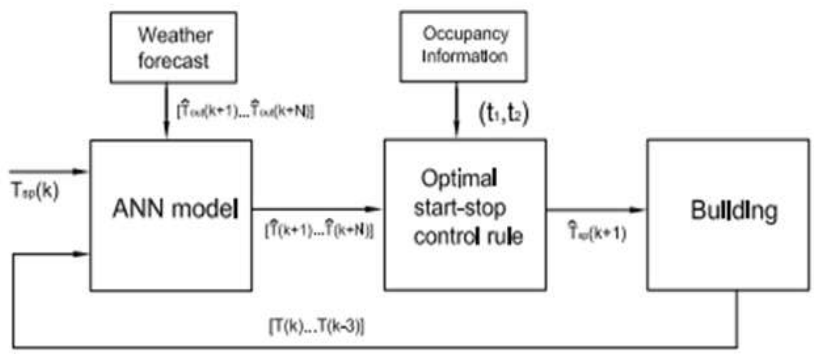


Fig.2. ANN block diagram [5]

With the algorithm of neural networks model predictive controller, system will learn to adjust the existing input that is outdoor temperature. In a study conducted by Huang, Chen, & Hu, neural networks was trained with the basic system which will be controlled, then training data is conducted to train the control systems. The control system will control the system with a given set point added with the needed supporting data. In this case the input is the environment temperature. The neural networks predictive control system will receive a feedback-controlled output of the system as a comparison with a given set point input [5].

The design of predictive control system based on neural networks for classroom cooling system in this paper will be created and simulated using Matlab R2013a Software. Simulations is conducted with simulink diagram based on classroom system modelling and desired conditions. The neural networks control system block library is derived from neural networks model NN Predictive Controller library from Matlab R2013a Software. In this simulation the influence of the system toward the building's financial will be shown to. The cost is obtained from the derivative of absolute value of the cooling flow which is multiplied with a cost constant. The cost value in this case will be limited to only consider the graphs trend of rising and falling without consider the detail cost value per unit performed cooling. By combining the previous classroom cooling system design with the system NN predictive controller the following modelling is obtained as follows :

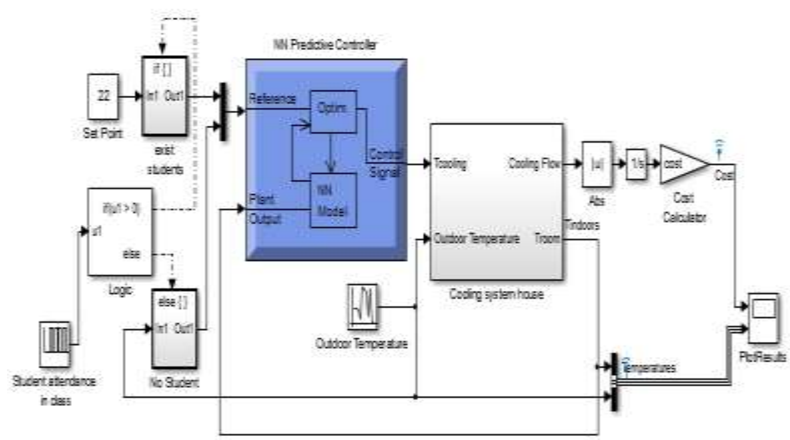


Fig.3. Block diagram of classroom cooling neural networks control system

In the conducted simulation, the environment temperature is modeled by generating random numbers that average value and its variants have been arranged. The value of average ambient temperature is 25 ℃ with 1 ℃ variant according to data from NASA RetScreen [6]. The ambient temperature is simulated with fluctuation changes in every half hour. While the students presence in the classroom is simulated by using the if steatment rules. The students is assumed to attend the class in 7 AM during 2 hours and then break outside the classroom for 1 hour and continue like that until 6 PM. The expected simulation time is for 12 hours, but for compensate the system initial response which is started from point 0, therefore in the beginning an extra 2 hours is given and make the total time is 15 hours. In this simulation division algorithm using random data is used, type of training data using Levenberg-Marquardt, and the performance is measured based on the square root error. The Levenberg-Marquardt algorithm is an algorithm which specifically created to minimize the amount of square root error [7]. In many researches, neural networks can be used for predictive system, as practiced by Ferlito that uses neural networks for predictive models of energy in buildings [8].

## I. RESULT AND DISCUSSION

The neural networks model predictive control system requires data training for optimize the control. Data training is obtained from system natural response which will be controlled that is room modeling and cooling airflow. In the Matlab simulation, data training is obtained from the reference model given by maximum input 26 ℃ and minimum input 22 ℃. The maximum and minimum temperature are set for reach the entire included temperatures that are the maximum ambient temperature 26 ℃ and the temperature set point value 22 ℃. The data training which is obtained from the system natural response without control can be shown as follows :

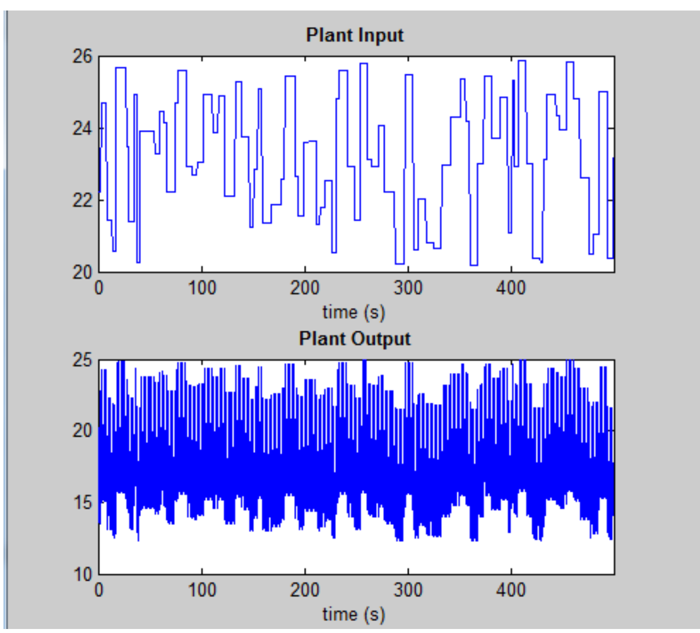


Fig.4. Result of data training of the neural networks model predictive control system

The data training output highly fluctuates from 25 ℃ to about 13 ℃. The amount of generated data training reach out 1000 samples which are produced within 500 s. The amount of data training will affects the performance of the neural networks control. This occurs because the basis algorithm of neural networks is learning process to be able to adjust the conditions with their original state. With the more data training will make make neural networks system be better. In this paper, the data training is limited to only 1000 data.

The aim of the neural networks predictive control on this paper is to control the room temperature. The room temperature will depend on the ambient temperature fluctuation or outdoor temperature. Therefore the control techniques for optimal indoor temperature control is needed based on the cost reduction that can be achieved for create thermal comfort in classroom.The results of neural networks model predictive control can be shown as follows :

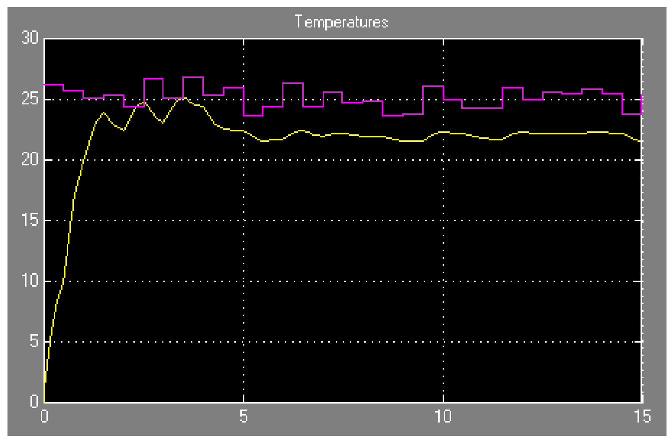


Fig.5. Correlation between indoor and outdoor temperature.

In the figure 5, the yellow line represent the room temperature and the purple line represent the outdoor temperature. Graph of outdoor temperatures fluctuates according to the generated random data with average value of the temperature is 25 ℃ and variants is 1 ℃. For room temperature graph, the initialization time interval is given in the beginning cause yellow graph start from 0 ℃, therefore the excess of 2 units time is given for compensation. The room temperature is also fluctuating at the beginning, it can be caused due to students presence in classroom. There are students in class at 4th time for 2 units time and no students in the classroom for 1 unit time after that, then the condition is repeated. It can be shown in the graphs before 5th unit time that the system is trying to reduce the temperature in order to meet the desired set point. After 5 units time the system already can adapt the temperature set point that is 22 ℃. The algorithm of considering the students presence give significant effect in the beginning but in the end the system still based on the set point due to the factor of students presence just 1 unit time, so it will be more efficient to keep the temperature does not rise too much. When the temperature rises further and need to be decreased quickly, it will reduce the system efficiency and increase the energy consumption. This neural networks control system can improve efficiency of energy consumption [9], Model Predictive Controller (MPC) neural networks can save 5% - 18% of energy consumption. The graph of control neural networks process cost can be shown as follows :

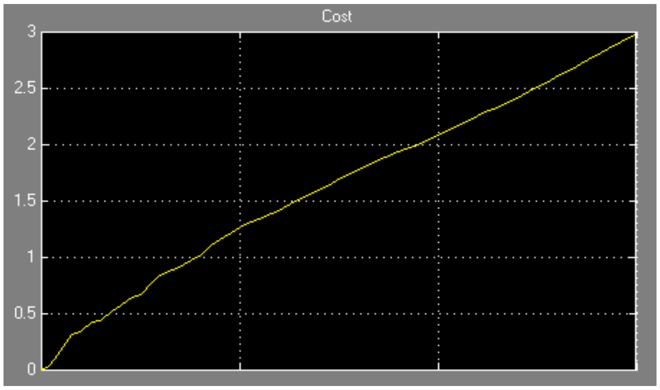


Fig.6. Trend of cost flow from cooling system neural networks

From the graph it can be shown that the cost of cooling is almost linear. The linier results of the cost accordance with the optimization algorithm performed by neural networks in estimating the thermal comfort and the cost incurred.. From the results of the entire system, the average temperature controlled room ( 22.36 ℃ ) is closes to the desired set point which is 22 ℃. For more good control process the more data or many other external inputs are needed to support the simulation. The neural networks model predictive control can become an option for control process in classroom thermal comfort because it able to adapt with linear and non linear systems. To validate and compare the neural networks control system between the simulation to the real conditions , research results from Javed of smart random neural networks controller can be adopted and it given accuracy reached 83.08% [10]. The accuracy value are good enough to prove that the neural networks control can be used well in real application. For the next research, the combination between the hardware designs process by directly observing the nonlinear system environment can be tried using neural networks model predictive control.

## II. Conclusion

From results of the neural networks model predictive control,it can be obtained that value of the small indoor temperature fluctuates around the set point which is determined as 22 ℃. The average controlled room temperature is 22.36 ℃ and it closes to the specified setpoint that is 22 ℃. Therefore, it can be concluded that the neural networks control technique can be used to control the classroom cooling system. This control technique can considering the external inputs and other rules that can support the optimization control process. In addition, the neural networks control can adjust the external inputs and adapt to any parameters changes. For get the well control, neural networks need to be trained with sufficient training data. With the more data, the trained system will be better to adapt and learn for the purposes of the control system

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