Development of Internet of Things (IoT) Technology and Its Applications on Room Cooling System

Joshua Dwi Prasetyo1,a, Husein1,b, Maman Budiman1,c

1Internet of Things Laboratory, Physics Department, Institut Teknologi Bandung, Jl. Ganesha 10, Bandung 40132, Indonesia
E-mail: aartjo26@gmail.com, bhuseinhsn95@yahoo.com, cmaman@fi.itb.ac.id

Abstract. This paper proposes a physical model that includes the outdoor temperature to determine thermal characteristics of the room by using IoT technology. The physical model is used in the computation in the cloud. The thermal characteristics obtained is used to minimize the energy consumption in room cooling system. The temperature in the room can be also controlled by processing the thermal characteristics in real-time. This paper only show the compatibility of the model with the real experiments data. The physical model is obtained by using thermodynamics and transport phenomena concepts, which are heat capacity and thermal resistance. This model is tested by using 4 real room temperature data set and the thermal characteristics values obtained is analysed with plotting them to outdoor-indoor temperature difference. The physical model is compatible with the real temperature data. The thermal characteristics doesn’t vary much with the outdoor-indoor temperature difference. The thermal characteristics value when the compressor is on is higher.

1. Introduction
Room Cooling system has been vital to daily aspects nowadays. Almost every houses, schools, and other building has room cooling system in their rooms. Over the recent years, the control of room cooling system has been developed to maintain the thermal comfort of the residents and to minimize the cost.

The problem in general room cooling system is that it only considers the indoor temperature in determining when the system goes on/off. The other aspect in the environment (outdoor temperature) isn’t included into consideration so the room cooling system can overwork. For example, if the outdoor temperature are low enough (in 21°C), while the indoor temperature are in 27°C, the system can overwork to maintain the temperature low enough. It can be shown, with physical model (in section 3), that system can work less harder to maintain the temperature.

The other problem in general room cooling system is that the temperature sensor in general room cooling system is usually located in the top of the room cooling system. In [1], the temperature is higher when the point to measure the temperature is located higher in the room. It can be concluded that the room cooling system works with "false temperature", meaning that the temperature used to determine the system goes on/off is not the "true temperature" or the
temperature that the residents feel in the room so the system can overwork too. Overworking system causes the cost becomes high. The solution to these problem is to determine the thermal characteristics of the room, which are, heat capacity and thermal resistance. The informations obtained can be used by the system to determine when the system goes on/off. This means that the system can adjust to the environment outside the room so that it doesn’t go on all the time, meaning there will be cost saving. The thermal characteristics can be obtained by using some physical model [2]. It can be done by computing (fitting) the indoor temperature data obtained by the sensor. The computation can be done in the cloud to make things easier. The technology which can be used for this task is Internet of Things (IoT). IoT is a smart system which uses time-series data (big data) and data processing, so that the system can manage sensors, actuators, and other features using the data inputted to the system and the communication network between tools, processes, tools-processes can be made.

We propose a physical model that includes the outdoor temperature to determine thermal characteristics of the room by using IoT technology. The physical model is used in the computation in the cloud. The thermal characteristics obtained is used to minimize the energy consumption in room cooling system. The temperature in the room can be also controlled by processing the thermal characteristics in real-time. This papers only show the compatibility of the model with the real experiments data.

2. Literature Review

2.1. Related Works

In [3], the HVAC (Heating, Ventilating, and Air Conditioning) control systems were made to adapt dynamically to the user and the building environment using Ambient Intelligence paradigm. Gopika used many sensors to measure the occupancy like CO$_2$ sensors, Passive Infrared Sensors, Acoustic Sensors, Magnetic Reed Sensors, etc [4]. Feldmeier and Paradiso used many nodes, in fixed place and user, to make personalized HVAC control system [5].

In [2], study about physical model of thermal characteristics of a building had been conducted by using experimental case in a closed wooden structure with one heated side. In [6] and [7], the thermal resistance is evaluated in the parts of the wall. Although the focuses are different, the physical models in those three papers used the same concept: RC circuit analogy.

2.2. Novelty

The novelty of this paper is that the concept used the thermodynamics and transport phenomena concepts. The model is obtained through simple mathematics manipulation, but the results obtained have similar form as in [2], [6], and [7]. The thermal characteristics obtained are also aggregate constant, so we don’t have to evaluate each part’s thermal characteristics.
3. Problems Modelling
Let the heat exchange in the room behave like this:

![Figure 1: Sistem](image)

with $Q_{in}$ is the heat entering the room and $Q_{out}$ is the heat exiting the room. We have the heat difference:

$$\Delta Q = Q_{in} - Q_{out} \quad (1)$$

$Q_{out}$ only exists when the room cooling system goes on. The room usually has so many components, so we have:

$$\Delta Q = \int \Sigma m_i c_i \,dT = \int C \,dT \quad (2)$$

with $m_i$ is the mass of each component, $c_i$ is the specific heat capacity of each component, and $C = \Sigma m_i c_i$ is total heat capacity of the room. In the differential form, it becomes:

$$dQ = CdT \quad (3)$$

With the analogy of Ohm’s Law, let the heat exchange between indoor and outdoor behave like [8]:

![Figure 2: Heat Exchange](image)

Mathematically, it has the form:

$$\frac{dQ}{dt} = \frac{T_o - T_i}{R} \quad (4)$$

with $\frac{dQ}{dt}$ is the speed of heat entering/exiting the room, $T_o$ is outdoor temperature, $T_i$ is indoor temperature, and R is thermal resistance.
Using equation (3) and (4), assuming that $T_o$ doesn’t vary much more than $T_i$ and doing simple mathematics manipulation, we have:

\[ T(t) = T_o + (T_0 - T_o)e^{-\frac{t-t_0}{RC}} \]  

(5)

with $T_0$ and $t_0$ are the initial temperature and time respectively. We can simplify equation (5) to:

\[ T(t) = a + ce^{-\frac{t-t_0}{b}} \]  

(6)

with $a$, $b$, and $c$ are constants.

4. Control Mechanism

We propose control mechanism for room cooling system:

![Diagram of control mechanism](image)

Temperature and humidity sensor records the temperature inside and outside the room. Energy meter records the electrical quantity of the load (Room Cooling System). The sensor then sends the temperature and humidity data to the server to be fitted to the physical model obtained in section 3. Equation (2) can be modified to:

\[ R\Delta Q = RC\Delta T \]  

(7)

The heat difference (multiplied by $R$) can be obtained by multiplying the thermal characteristics with the temperature difference.

Let we define that one cycle is when the compressor is off and on successively. With the assumption that $\Delta Q = Q_{in}$ when the compressor is off and for one cycle the $Q_{in}$ obtained is the same when the compressor is on (when $\Delta Q = Q_{in} - Q_{out}$), we can obtain $Q_{out}$.

Assuming that $Q_{out}$ is proportional to duty cycle, we can then evaluate the ”proper duty cycle”, that is:

\[ \text{Proper Duty Cycle} = \frac{Q_{out}}{Q_{out, max}} \]  

(8)

The $Q_{out, max}$ is the $Q_{out}$ when the duty cycle is 100%. When we get the ”proper duty cycle”, it is sent to compressor controlling unit to determine when the compressor goes on/off (and thus the room cooling system).
5. Results and Discussions

5.1. Results

In this paper, we have 4 real temperature data set in different configuration and condition. The general form of temperature data we obtained is

![Figure 4: General Form of Temperature Data](image)

The process fitting begins when the compressor goes off for the first time. The fitting is done with equation (6). The average temperature of the room is also evaluated from the time when the compressor is off for the first time. The fitting is done by determining the time when the compressor goes on/off. The R-square obtained, in average, is $R^2 \approx 0.99$.

In this subsection, we plot the RC value we obtained to the (average) outdoor-indoor temperature difference when the compressor is on/off.

![Figure 5: Temperature data set used (from top left, clockwise) (a) Data set 1 (b) Data set 2 (c) Data set 3 (d) Data set 4](image)

By doing the fitting process, we get:
Figure 6: RC Values Obtained When Compressor is On Vs Outdoor-Indoor Temperature Difference for (from top left, clockwise) (a) Data set 1 (b) Data set 2 (c) Data set 3 (d) Data set 4

Figure 7: RC Values Obtained When Compressor is Off Vs Outdoor-Indoor Temperature Difference (from top left, clockwise) (a) Data set 1 (b) Data set 2 (c) Data set 3 (d) Data set 4
5.2. Average RC Value Vs Average Outdoor-Indoor Temperature Difference Plot
We plot the average RC value to Average Outdoor-Indoor Temperature Difference in each data set. We get:

![Graphs showing RC Values Obtained When The Compressor is (a) On (b) Off Vs Outdoor-Indoor Temperature Difference](image)

Figure 8: RC Values Obtained When The Compressor is (a) On (b) Off Vs Outdoor-Indoor Temperature Difference

5.3. Discussion
By looking at the average R-square in the fitting, one can say that this model is compatible with the real temperature data. By looking at the RC value to outdoor-indoor temperature difference graph, we can see that the value doesn’t vary much with the temperature difference, especially when the compressor is off. It means that the RC value is the thermal characteristics of the room, therefore is a constant.
The RC value when the compressor is on is higher because the speed of heat entering the room is lower. The thermal resistance is bigger because it is inversely related with the speed of heat, hence the RC value is bigger.

6. Conclusion
The physical model is compatible with the real temperature data. The thermal characteristics doesn’t vary much with the outdoor-indoor temperature difference. The thermal characteristics value when the compressor is on is higher.
For future works, the performance of the room cooling system using the thermal characteristics will be studied.

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