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The Influence of External Cooling Load on the Distribution of Temperature and Humidity in Conditioned Spaces

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Abstract

Air conditioning is not only important for the comfort of occupants in a building but also for various industrial processes. In the air conditioning process, a device called an Air Conditioner (AC) is required. The AC load can originate from inside the room and from outside the room. This study aims to determine the influence of increased cooling load from outside the room on the distribution of temperature and air humidity inside the conditioned room. The method used in this study involved conditioning four rooms. Two rooms of almost the same size were equipped with two AC units each, while the other two rooms used one AC unit each. Temperature and air humidity data inside the rooms were recorded every 20 minutes, as well as the outside air temperature. Dry bulb thermometer (Tdb) and wet bulb thermometer (Twb) were used to record temperature and humidity data, along with an environmeter. The research data were processed using available equations and with the assistance of a psychrometric chart. The research findings revealed that the average distribution of temperature and air humidity in the meeting room and office headroom of the Pertamina DP-LPG Office in Binjai was 20°C-23°C and 59%-65%. For the distribution office and sales service room of the Pertamina Fuel Filling Terminal in Kisaran, the distribution of temperature and air humidity was 25°C-29°C and 62%-66%. From the test results, it can be concluded that the distribution of temperature and air humidity is highly influenced by the capacity of the AC units and the cooling load entering the room.

Keywords: Air conditioning, air conditioner, cooling load, distribution, temperature.

INTRODUCTION

Air conditioning is not only important for the comfort of occupants in a building but also for various industrial processes such as chemical industries, pharmaceuticals, and various electronic equipment that are highly sensitive to high temperatures [1],[2] Specifically for occupants' needs, air conditioning is required to provide comfort to those who are active inside the building. Comfort conditions indoors refer to a state where the thermodynamic properties of air meet the predetermined comfort criteria. Meanwhile, comfort criteria are conditions tailored to the activities of the room occupants [3]. If the thermodynamic properties of the air meet the predetermined criteria, the expected comfort can be achieved. Factors that can affect an individual's comfort criteria in a room include temperature, humidity, air velocity in the room, and activities performed [4]. In daily activities such as working in an office or at home, the ideal room temperature ranges from 20 to 26°C, with relative humidity between 45% and 70%, and air velocity less than 0.25 m/s [5]. According to Minister of Health Decree No. 261 of 1998 regarding the requirements for the health of office environmental work, the desired room temperature comfort ranges from 18 to 26°C, with relative humidity between 40% and 60%. For industrial processes, air conditioning is expected to provide indoor air at a thermodynamic state that meets specific requirements so that industrial processes can be well fulfilled [4]. In fact, there are still many applications of air conditioning systems in other life activities such as in the pharmaceutical, agricultural, and medical fields. Although the applications are very broad, the principle goal of air conditioning remains the same, which is to create a condition where the thermodynamic properties of the air in a room meet the desired criteria. In order to achieve the desired level of condition according to the criteria mentioned above, equipment called air conditioning machines or Air Conditioners (AC) are required [6].

The use of air conditioning (AC) in a room is expected to provide comfort for its occupants. To assess the performance of an AC in a room, measurements of temperature, humidity, and airflow velocity within the room, discharged from the air conditioning unit, are necessary. These three thermodynamic properties are crucial factors in determining the comfort level experienced by occupants in a room, along with other factors such as air pressure, noise, occupant activity, clothing, and room color [7]. The performance of an AC in a room is determined by various factors that generate heat sources within the room, known as cooling load. The heat acquired, which becomes a load for the AC, is termed as heat gain [8]. Effective design in air conditioning systems for a room should consider a balance between the capacity of the AC unit used and the magnitude of heat gain entering the room. If the capacity of the AC unit is lower than the heat gain acquired, the room will feel hot, leading to discomfort for occupants. Conversely, if the AC capacity is too high, the room will become excessively cold. An oversized AC capacity results in excessive electricity consumption, leading to increased institutional expenses [9]

The research aims to investigate the influence of external cooling load (cooling load from outside the room) on the distribution of temperature and humidity inside the conditioned space. The most significant external cooling load is the increase in outdoor air temperature caused by solar heat, in addition to direct solar heat received by the room. Air conditioning is an effort to regulate, process, and maintain the thermodynamic properties of air in a room, such as temperature, humidity, and airflow velocity, to meet comfort criteria. Air conditioning also involves managing noise and air quality within a room.

RESEARCH METHODS

This research evaluates the impact of increased external cooling load on the distribution of temperature and humidity inside conditioned spaces. The method employed involved conditioning four rooms, two of which were nearly identical in size and equipped with two air conditioning units (AC), while the other two rooms utilized a single AC unit. Temperature and humidity data inside the rooms, as well as outdoor air temperature, were recorded every 20 minutes. Recordings were conducted using dry bulb thermometers (Tdb), wet bulb thermometers (Twb), and an environmeter. The data were then analyzed using equations and psychrometric diagrams. Measurements of various thermodynamic properties of air in Pertamina office workspaces were conducted from June 22 to 28, 2012, at the LPG Filling Depot Tandem in Binjai and the Fuel Filling Terminal Kisaran in North Sumatra. Measurements were taken during peak daily cooling loads, ranging from 10:00 AM to 3:00 PM in each room under clear weather conditions. **Fig. 1** illustrates a schematic model of temperature, humidity, and airflow velocity measurements within a room.

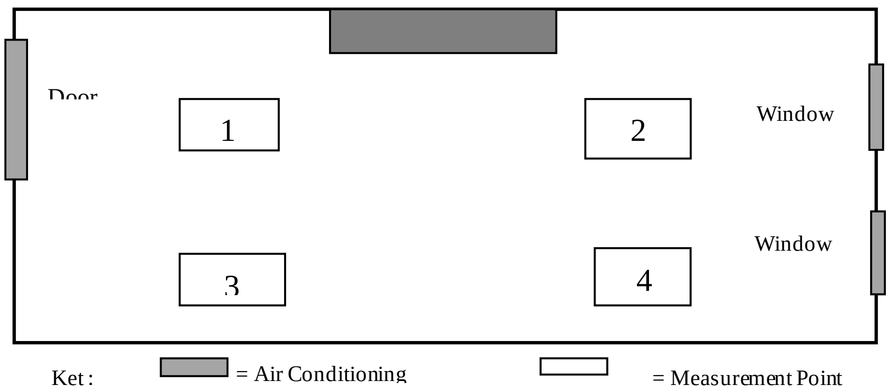

Fig. 1. Layout of the temperature, humidity, and airflow velocity distribution measurement process within the room.

The instruments used to measure absolute humidity (ω) and relative humidity (φ) of the air within the conditioned room include wet bulb (Twb) and dry bulb (Tdb) thermometers. From these two data points, other thermodynamic properties of the air, such as absolute humidity (ω) and relative humidity (φ), can be determined using a psychrometric diagram. Additionally, for comparison purposes, the multifunction Environment Meter Model KW06-291 is utilized. This multifunctional device can measure temperature, humidity, and airflow velocity within a room. An Anemometer Digital instrument is also employed to measure airflow velocity, capable of measuring airflow speeds up to 0.1 m/s.

The steps for measuring temperature, humidity, and airflow velocity within the room are conducted meticulously according to the following procedure. Firstly, the AC is set to a standard temperature of approximately ±21°C to achieve the desired level of comfort. Then, wait for 15 minutes after the AC is turned on to stabilize the temperature, humidity, and airflow velocity within the room. Next, install the Tdb and Twb measuring devices at four points in each room at a height of approximately ± 1.2 m from the floor. The data obtained from the measurements are recorded every 20 minutes in a provided tabulation. Measurements are taken when the cooling load reaches its peak, usually between 10:00 AM to 3:00 PM, under clear weather conditions. Lastly, use the digital anemometer or multifunction Environment Meter Model KW06-291 to measure airflow velocity within the room at four points, with measuring points approximately 1.2 m above the floor. The aim of these measurements is to accurately and efficiently evaluate the air circulation system within the room.

Due to Indonesia's geographical location near the equator, the country is classified as having a tropical climate. The average air temperature in almost all regions of Indonesia is above comfortable conditions. **Table 1** indicates the comfortable condition limitations for several room functions. Meanwhile, the cooling load originating from occupants is divided into sensible and latent loads. The magnitude of each load depends greatly on the individual's body size, type of activity, clothing color, and so on. However, the average values for each activity, as researched by air conditioning engineering experts, can be seen in **Table 2** [10]**.**

Table 1. Design condition limitations of several recommended room functions [11]

No	**Room Function**	**Recommended temperature (°C)**	**Relative Humidity (%)**
1	Apartments, Residential Houses, Offices, Schools	25 – 26	45 – 60
2	Shops, Banks and Super markets	25,5 - 26,6	45 – 50
3	Auditorium, Restaurant, Bar	25,5 - 26,6	50 – 60
4	Assembling Room (industry) and Workshop	26,6 - 29,4	50 – 60

Table 2. Heat gain from room occupants

Activity	**Heat gain at room temperature 78°F**	
	Latent	Sensible
Office workers	235	215
Bank employees	280	220
Shopping center security guards	235	215
Dancers	275	375
Workshop workers	370	670
Laborers	485	965

RESULTS AND DISCUSSION

The data obtained from measurements were processed to obtain the average distribution of dry bulb temperature (Tdb) and wet bulb temperature (Twb) in each room at the Pertamina Liquid Petroleum Gas (LPG) Filling Depot Tandem in Binjai and the Fuel Filling Terminal Kisaran. Utilizing the psychrometric diagram, the average relative humidity (φ) of the air within the rooms was also determined.

1. Pertamina Liquid Petroleum Gas (LPG) Filling Depot Tandem, Binjai
   At the Pertamina Liquid Petroleum Gas (LPG) Filling Depot Tandem in Binjai, the spaces chosen for testing in this study were the meeting room and the office headroom. Both of these rooms were deemed crucial in supporting the smooth operation of the office system.
   a. Meeting Room
      The dimensions of the meeting room are 6m x 4m. During testing, it was assumed that the room was empty, and the number of lights and electronic devices was carefully considered. This room did not receive direct sunlight, and there were no glass walls or windows through which direct sunlight could enter. Therefore, the external cooling load solely consisted of the outdoor air temperature. The distribution of temperature during approximately 5 hours from 10:00 AM to 3:00 PM yielded the distribution of temperature and humidity in the meeting room at the Pertamina Liquid Petroleum Gas (LPG) Filling Depot Tandem in Binjai. **Fig. 2** illustrates the temperature distribution in the meeting room at the Pertamina Liquid Petroleum Gas (LPG) Filling Depot Tandem.

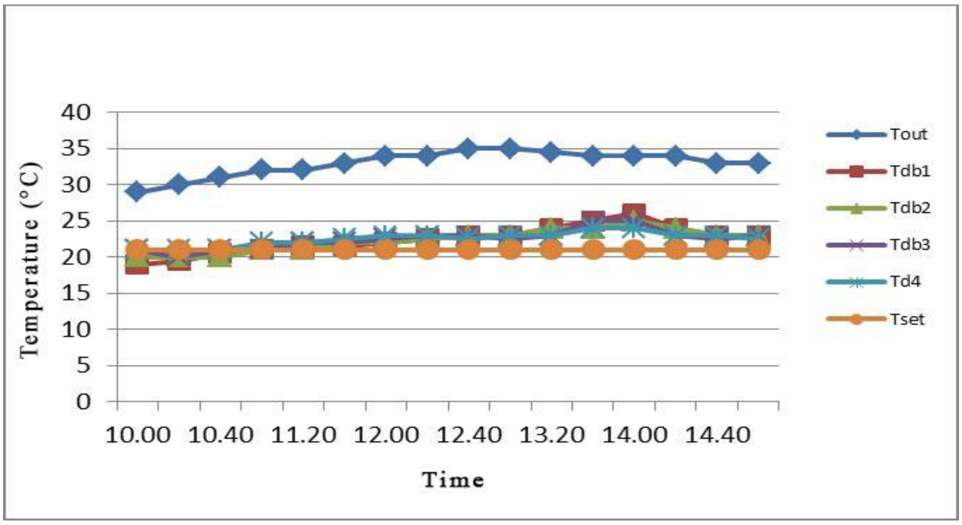

Fig. 2. Graph showing the relationship between temperature distribution within the room over the testing time in the meeting room of Pertamina DP-LPG, Tandem office.

Based on Figure 6, it can be observed that in the morning before reaching the peak load, the room temperature that the cooling machine can achieve is around 19 to 21°C. This temperature is relatively uniform across almost all points in the meeting room. There is no significant temperature difference between the air layers within the meeting room (air stratification). However, as the outdoor air temperature increases due to the heat from sunlight, it consequently raises the conditioned room temperature to reach up to 35°C. The hotter the outdoor air, the higher the room temperature becomes. According to the measurement data, the increase in room temperature due to the influence of hot outdoor air can still be managed by the two air conditioners located within the meeting room. The rise in room temperature remains within the recommended range provided by **Table 1** or Minister of Health Regulation No. 261 of 1998 in this article, which is approximately 18 to 26°C.

In the meeting room of Pertamina Tandem office, there are two Panasonic Split AC units (CU-PS9KKP) with a capacity of 1 HP each. The installation positions of the AC units are quite good, with one unit placed on the left wall of the room, blowing air lengthwise across the meeting room, and the other unit located on the front wall, spreading air flow throughout the room. This installation configuration of the Split AC units ensures a relatively uniform distribution of temperature and humidity within the meeting room across almost all areas. **Fig. 3** is a graph illustrating the distribution of relative humidity (RH) within the meeting room of Pertamina Tandem office. Based **on Fig. 3,** it can be seen that the air humidity in the meeting room ranges from 55% to 68%. This condition essentially meets the comfort criteria for occupants in an office environment, which is typically between 45% and 70%.

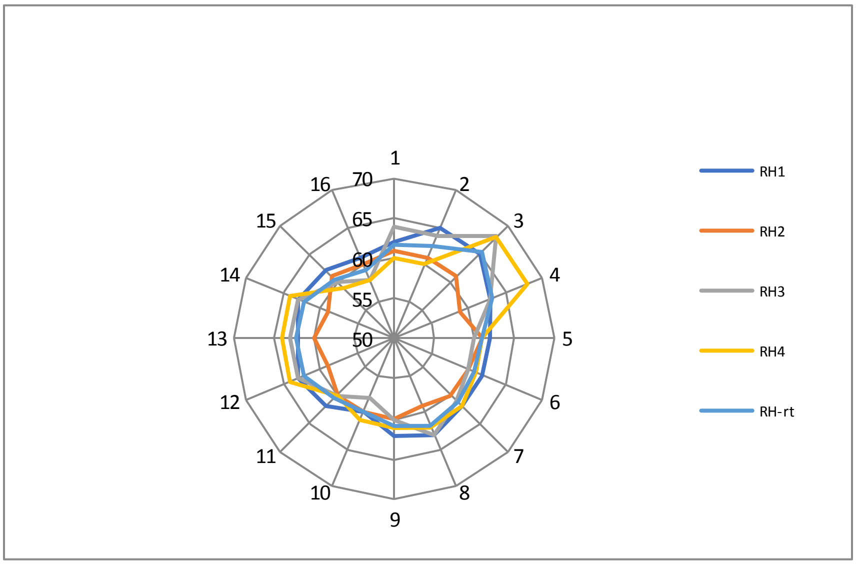

Fig. 3. Graph showing the relationship between relative air humidity and testing time in the meeting room of Pertamina DP-LPG, Tandem office

b. Office Headroom

The office headroom at Pertamina Liquid Petroleum Gas (LPG) Filling Depot Tandem in Binjai has dimensions of approximately 5m x 3.5m. The presence of lights and electronic devices was carefully accounted for in measurements. The measured distribution of air temperature within the office headroom ranged from 23-26°C. At the beginning of the measurements in this room, the temperature decrease by the Split AC was quite effective, reaching temperatures of 23°C. However, as the sunlight became more intense and the outdoor air temperature increased, it indirectly affected the indoor air temperature of the office headroom. In this office headroom, the left side wall is predominantly made of glass. The glass type is ordinary dark-colored glass with a thickness of 5 mm and without a plastic film. However, vertical blind curtains are installed on this wall, which effectively block direct sunlight from entering the room. Therefore, only the temperature difference between the indoor and outdoor temperatures is assumed to be the external load. However, theoretically, due to the thin glass wall, it would have low thermal resistance, facilitating heat transfer into the room through conduction [12], [13]. In the morning when the temperature measurement started, the room temperature remained relatively stable, approaching the set temperature. However, between 11:00 AM and 1:00 PM, the temperature within the office headroom increased, reaching over 26°C. **Fig. 4** illustrates the distribution of air temperature within the office headroom.

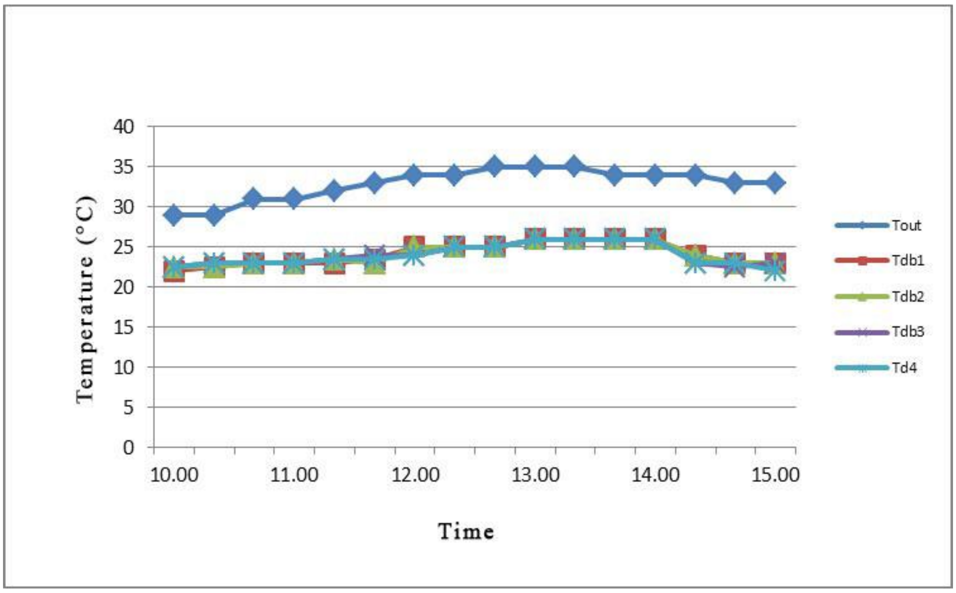

Fig. 4. Graph depicting the relationship between temperature distribution during cooling time in the Head Office Room of Pertamina DP-LPG, Tandem

In the head office room, there is only one Panasonic AC unit (CU-PS9KKP) with a power of 2 HP located on the right side wall of the room. Essentially, this AC functions quite well. However, due to the relatively large size of the head office room and its elongated profile, as well as the non-symmetrical placement of the AC unit not at the center of the room, it results in uneven distribution of temperature and air velocity [14]. This, of course, is one of the reasons why the comfortable temperature setting of 21°C is not achieved in the room. Nevertheless, with an average measured temperature ranging from 23-26°C, it can be considered slightly above the recommended temperature range of 20-25°C for comfortable office working conditions.
To address this issue, it is advisable to add another 2 HP capacity AC unit to the head office room. The 2 HP capacity AC is expected to balance the rate of heat entering from outside (external cooling load). Furthermore, it is also recommended to apply a protective sunlight plastic film to the glass wall. The plastic film is expected to effectively prevent direct sunlight radiation from entering the room. A darker-colored plastic film can help to reduce the amount of sunlight entering the room, and if necessary, it can be complemented with protective curtains to ensure that the desired comfort conditions are achieved. **Fig. 5** illustrates the distribution of relative humidity (RH) in the Pertamina Tandem head office room. The measured relative humidity (φ) in the head office room ranges from 55% to 68%. The indoor air humidity essentially meets the comfort criteria; however, due to the spacious room and external cooling load, the capacity of the 1 HP AC unit is deemed insufficient.

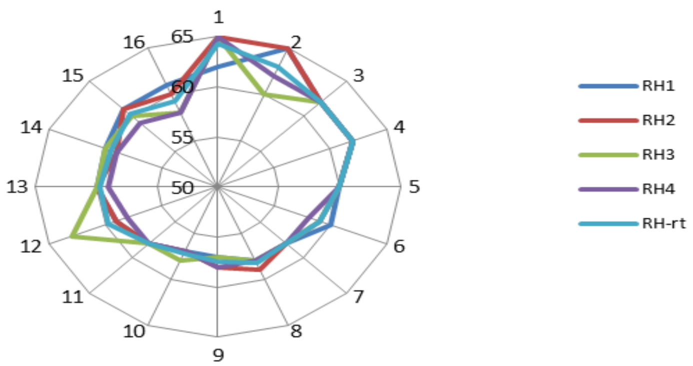

Fig. 5. Distribution of measured air humidity in the head office room of Pertamina, DP-LPG, Tandem.

2. Kisaran Fuel Filling Terminal

   At the Pertamina Kisaran Fuel Filling Terminal, the Head Office Room and the Sales Service Room are the focus of discussion in this draft report. Both of these rooms are also considered crucial in supporting the smooth operation of the Kisaran Fuel Filling Terminal office system.

   a. Office Headroom

      The Pertamina Kisaran Fuel Filling Terminal's office headroom measures approximately 4m x 3m. In the Office Headroom, the average temperature ranges from 25 to 26°C. In principle, this still falls within the comfortable conditions recommended by **Table 1** (Ministry of Health Decree No. 261 of 1998). However, this condition is at the threshold of the recommended temperature, so it may feel less comfortable if staying in the room for an extended period. This discomfort may become more noticeable when the room is occupied by several people simultaneously (for example, during meetings). **Fig. 6** below illustrates the distribution of air temperature in the Office Headroom at the Kisaran Fuel Filling Terminal.

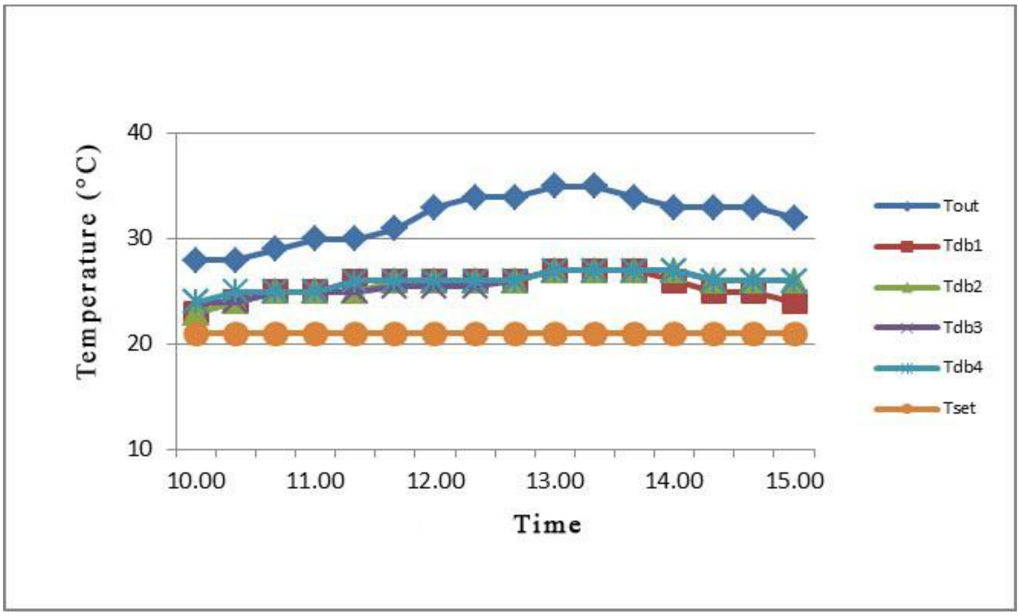

Fig. 6. Graph depicting the relationship between temperature distribution during cooling time in the Pertamina Office Headroom, Kisaran Fuel Filling Terminal (TPBB).

In the Pertamina head office room at the Kisaran Fuel Filling Terminal (TPBB), there is also one LG ME230138810 AC unit with a capacity of 1 HP (9000 Btu/hr). Considering the room size and the capacity of the split AC unit used, this AC power is deemed sufficient to achieve the recommended comfortable temperature range (18-26°C) (refer to Table 1). However, the average lowest temperature distribution achieved by the cooling unit remains relatively high. The likely cause of this condition is the continued presence of cold air escaping or warm air entering the room through ventilation gaps, frequently opened doors, and small gaps near windows [4], [15]. The measured air humidity distribution in the head office room ranges from 62% to 66%. Although slightly above the recommended relative humidity range of 40-60% by **Table 1** or Ministry of Health Decree No. 261 of 1998, it still falls within the range recommended by **Table 2**. This indicates that technically, this condition is still suitable for occupants in the head office room.

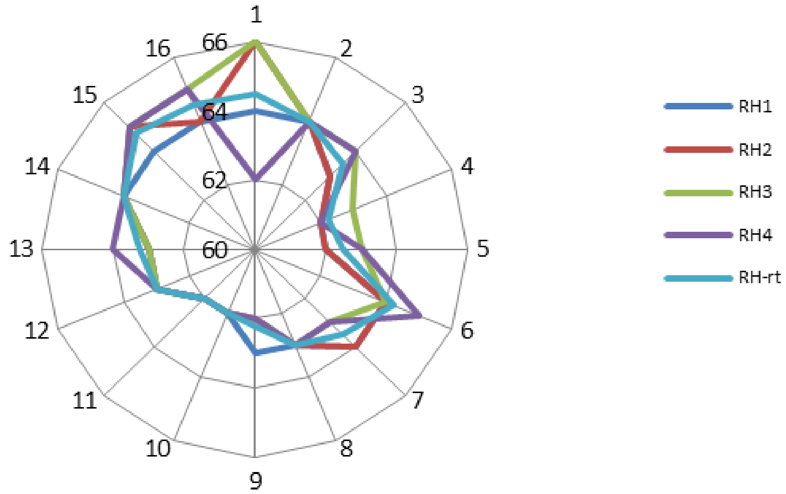

Fig. 7. Distribution of measured air humidity in the Pertamina head office room, TPBB - Kisaran.

b. Sales Service Room

The sales service room at the Pertamina Fuel Filling Terminal in Kisaran, Medan, plays a significant role in the smooth operation of this Pertamina office. Therefore, this room requires a comfortable air temperature for the occupants, who are office workers. This sales service room in the office is quite spacious, measuring 5m x 3m. There is one LG ME230138810 AC unit with a capacity of 1 HP installed in this room. The test results revealed that the air temperature measured during the testing ranged from 25-29°C. In the morning, before 11:00 AM, the temperature remains around 25 or 26°C, which is still within the comfortable range recommended by the Ministry of Health Regulation No. 261 of 1998, which is 18-26°C. However, as the day progresses and the outside air temperature rises due to the intense heat of the sun, the temperature in this room increases significantly beyond the threshold recommended by Ministry of Health Regulation No. 261 of 1998, reaching up to 29°C. **Fig. 8** illustrates the relationship between the distribution of air temperature in the room and the testing time.

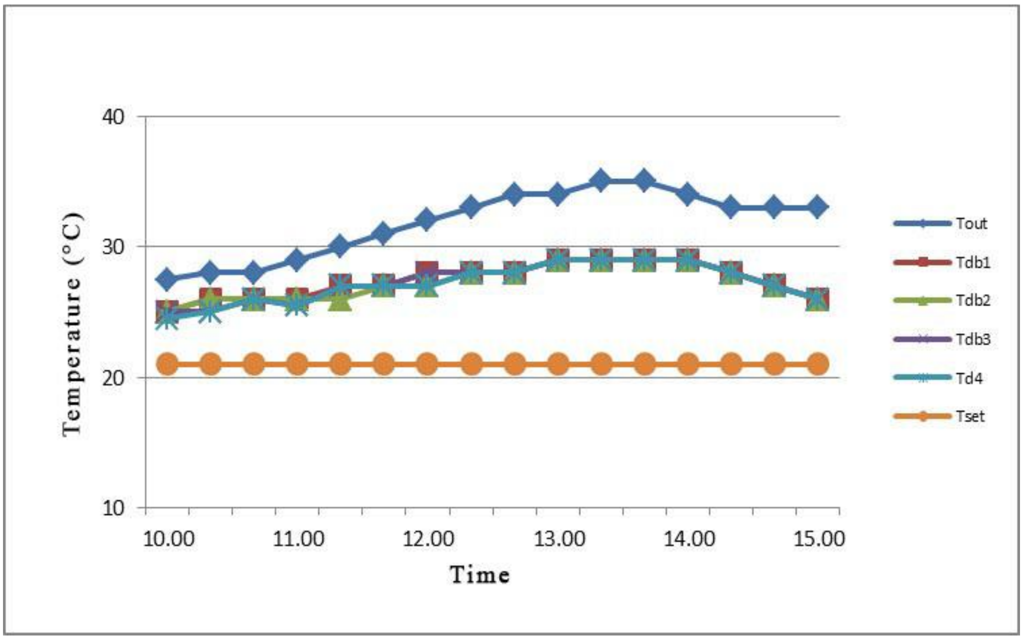

Fig. 8. Graph depicting the relationship between temperature distribution during cooling time in the Sales Service Room at the Pertamina Fuel Filling Terminal, Kisaran.

This condition is caused by the frequent opening of the entrance door to the sales service room and numerous gaps for the cold air to escape from the room. The windows in the room are made of glass facing the sun. Additionally, the height of the room is relatively low, resulting in poor air circulation inside. It is recommended that when the AC is turned on, the door should be kept closed, air leaks near the windows should be sealed, and as a final step, the capacity of the split AC should be increased to minimize the loss of cold air from the gaps and open doors. The distribution of air humidity in the sales service room appears to be relatively uniform, ranging from 62-66%, which is within the recommended tolerance range by the Ministry of Health Regulation No. 261 of 1998, i.e., 40-60%, and within the guidelines from the Refrigeration Dictate (1991), which is 45-70%. Figure 8 illustrates the graph depicting the relationship between air humidity distribution in the sales service room at the Pertamina Fuel Filling Terminal, Kisaran, Medan.

CONCLUSION

Based on the results of the Distribution of Temperature and Air Humidity in Conditioned Rooms in the Pertamina Office at the LPG (Liquid Petroleum Gas) Filling Depot, Tandem, Binjai, and the Fuel Filling Terminal, Kisaran, North Sumatra, it can be concluded that all air conditioning units function effectively. This is evident from the achievement of the lowest temperature, air humidity, and air velocity within the rooms. The measured air humidity in each room at the Pertamina office, as mentioned above, is relatively slightly higher than the normal limit, but technically, these conditions are still suitable for use and do not have a significant impact on the occupants of the rooms. The distribution velocity of air flow within the rooms measured is already approaching normal conditions (<0.25 m/s for office workers), although there are still certain points where the air flow velocity is below 0.1 m/s. To achieve lower room temperatures, the AC settings can be adjusted to the minimum, and the AC units can be operated simultaneously (if there are two AC units in the room).

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