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การทำความเย็นโดยใช้ระบบแปรงหมุนเพื่อผลิตการระเหยของน้ำ

จิรประภา กิมสุนทร

บทคัดย่อ

งานวิจัยนี้เป็นงานวิจัยเกี่ยวกับการนำแปรงหมุนมาทำงานเดี่ยวๆ ซึ่งเมื่อนำละอองน้ำมาสเปรย์ลงบนแปรงหมุนในขณะที่แปรงหมุนนำหมุนอยู่ ก็จะทำให้ระบบนี้กลายเป็นระบบการทำความเย็นแบบระเหย ระบบการทำงานนี้จะให้อุณหภูมิของอากาศที่ต่ำลง การทดลองจะมีการเปลี่ยนค่าของตัวแปรต่างๆ คือ ค่าความเร็วของการหมุนแปงง อัตราการไหลของน้ำที่มาสเปรย์ลงบนแปรง และอุณหภูมิของอากาศก่อนเข้าระบบ ผลที่ได้จากการทดลอง พบว่าอุณหภูมิของอากาศที่ขาออกนั้นจะลดลงเนื่องจากการสเปรย์น้ำลงบนแปรง อย่างไรก็ตามการที่จะปรับค่าของตัวแปรงต่างๆ นั้น (ความเร็วของแปรงและอัตราการไหลของน้ำ) จะต้องขึ้นอยู่กับปริมาณความต้องการอากาศในการที่จะนำไปลดอุณหภูมิภายในห้อง

คำสำคัญ: ระบบการทำความเย็นแบบระเหย แปรงหมุน

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To use a Rotating Brush Evaporative Cooling to Produce Cooling System

Jiraprabha Kimsunthorn

Abstract

This paper investigates the rotating brush's performance when used in isolation. The rotating brush system (with water sprayed on top of the rotating brush) was designed to work as an evaporative cooling system. This system provides cool air. The experiment involved varying the speed of the rotating brush, the water spray flow rate and the air inlet water temperature of each test case. The results of this experiment show that the air outlet temperature was reduced by water spray temperature influence. However, the degrees to which the water flow rate and speed of the rotating brush need to be adjusted are dependent on the amount of cooling air required to effectively cool a room.

Keywords: Evaporative cooling, Rotating brush

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INTRODUCTION

This paper investigates the rotating brush's performance when used in isolation. The rotating brush system was designed to work as an evaporative cooling system, to provide cool air and comfortable surroundings, with the additional function of modifying relative humidity, approprizeness for areas with low relative humidity and hot, dry climates (Moien Farmahini – Farahani, Ghassem Heidarinejad, 2012). Relative humidity is important to people inside the room/building, because it could cause disease such as if the relative humidity is too high, or create discomfort if relative humidity is too low (Manoj Kumar Singh, Sadhan Mahapatra, Atreya S.K., 2011).

The rotating brush's description and the results of the experimental investigation under different operating conditions are discussed in this paper. Figure 1 shows the concept of a rotating brush evaporative cooling system connected to the room/ building.

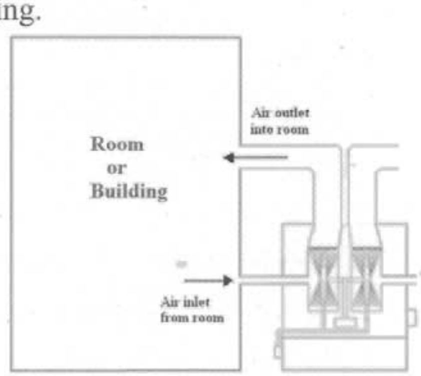

Figure 1. Rotating brush Evaporative Cooling System

Description of the evaporative cooling rotating brush system

The system is comprised of a rotating brush and a water spray system, as shown in Figure 2. The rotation of the brush pulls air into itself. The air then passes over a large surface area of flexible fibres and is exhausted via centrifugal force; at the same time, water is sprayed onto the rotating brush. After striking the flexible fibres, water turns into tiny droplets, or mist, increasing the humidity and affecting the air temperature (resulting in a temperature which is nearer to the water temperature) (Xiaoli Ma, Birnie Michael, Riffat S.B., Gilott Mark, 2008). The air is then blown by the rotating brush into the conditioned room.

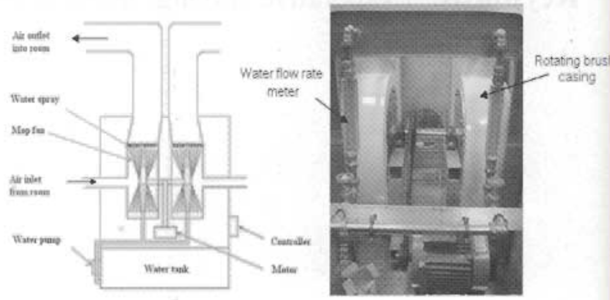

Figure 2. Schematic Diagram of Rotating brush Evaporative Cooling System

Figure 3. (Riffat S.B., Zhao X., 2007) shows the components/system of the rotating brush. The fibre brush is mounted on a shaft in a centrifugal fan casing. It rotates by direct drive with a high efficiency motor. The brush impeller is similar to a chimney sweep's

brush. This system can also be used as an air impeller for removal of particular pollutants (Y.M. Xuan, F.Xiao, X.F. Niu, X. Huang, S.W. Wang, 2012). The brush's fibres are constructed from flexible polymer fibres. Water is sprayed onto the rotating brush (Figure 4), and during the rotating brush's operation the system will mix air with water.

Figure 3. Schematic Diagram of Rotating brush Components

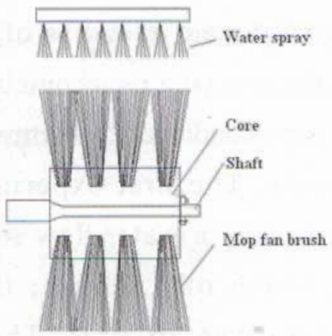

Figure 4. Schematic Diagram of Rotating brush Water Spray Configuration

Some of the water will be absorbed by the air as it passes over it. More water is absorbed by hotter air. When water is in contact with the air, it evaporates to become moisture in the air. How much more moisture airflow it can hold depends on the current relative humidity (Xuan Y.M., Xiao F., Niu X.F., Huang X., Wang S.W., 2012).

This rotating brush gave a good result in terms of cost efficiency (Zhang Wenbin, Liu Hao, Hai Irfan Ul, Neubauer York, Schroder Philipp, Oldenburg Holger, Seilkopf Alexander and Kolling Axel, 2011). The rotating brush specifications are as follows: fibre diameter, 1.5 mm; number of fibres, 2700; total brush surface area, 1.21 m^2; length of the mop, 95 mm; diameter of core, 65 mm; and diameter of brush wheel, 260 mm. The rotating brush was driven by a 0.37 kW, 1.15 A, 3 Phase Brook Crompton motor. The evaporative cooling rotating brush casing is made of fibre glass.

The water that is sprayed onto the top of the rotating brushes can be run to the system by a pump. The water pump is a Gruan pump, type UPS15-50 B130, I(A) = 0.23, p(w) = 50, 230 V and a water flow meter was used to measure the water flow rate. The water pipe has a diameter of 22 mm and is made of brass.

The experiment controlled air inlet from room temperature by duct heater 2 kW. A computer was connected to the data taker (DT500) to monitor the temperature of the process and to collect data. The temperature and relative humidity (%RH) were measured at different positions: air inlet from the room, and air outlet into the room. K-types of thermocouples were used to measure the temperature and a humidity sensor was used to measure relative humidity.

Materials and Methods

The main components of the experiment appear in Figure 5.

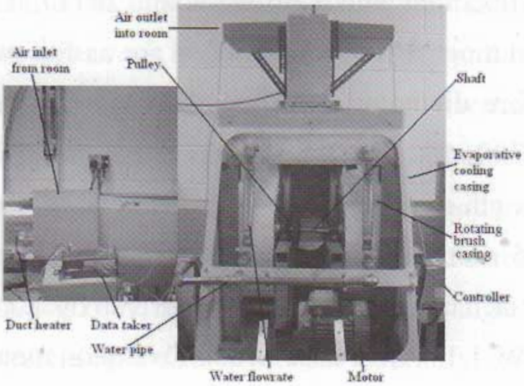

Figure 5. Components of the experiment

The experiments involved varying the following conditions:

1. Air inlet temperature (by duct heater): 26 °C, 28 °C, 30 °C, 32°C and 35 °C
2. Water flow rate: varied at 1l/s, 3l/s and 4l/s

Rotating brush speed (by motor): 0.025 m^3/s, 0.03 m^3/s and 0.035 m^3/s

Air inlet temperature was studied by fixing the water flow rate and brush speed. The experiment varied the air inlet temperature and recorded the resultant air outlet temperature. The water flow rate was studied by fixing the air inlet temperature and brush speed. The experiment varied the water flow rate and recorded the resultant air outlet temperature.

The rotating brush speed was studied by fixing the air inlet temperature and water flow rate. The experiment varied the brush speed and recorded the resultant air outlet temperature.

Comparison of the effect of water flow rate and water temperature

The experiment investigated the effect of the quantity of water and the water temperature on the air outlet temperature, by spraying water on top of the rotating brush at different water flow rates and water temperatures. The standard conditions consisted of an air inlet temperature of 26 °C and an airflow rate of 0.03m^3/s. The relative humidity of the air inlet was of a similar value in the test (see psychometric chart). The tests were conducted by comparing three experiments. The first experiment was conducted using a water flow rate on the rotating brush of 1.5l/min; the water temperature was 20.2 °C. The second experiment was conducted using a water flow rate on the rotating brush of 3l/min; the water temperature was 16 °C. The last experiment was conducted using a water flow rate on the rotating brush of 4l/min; the water temperature was 20.4 °C. The experiment is outlined in Table 1.

Table 1. Test conditions of Tests 1-3

Test no.	Water flow rate (l/mins)	Water temp. (°C)
1	1.5	20.2
2	3	20.5
3	4	20.4

The effect of water temperature

The experiments investigated how water temperature affected the air outlet temperature and the COP. The fixed conditions were an air inlet temperature of 26 °C, and an airflow rate of 0.03m³/s and a water spray flow rate of 3l/min. Water with different temperatures was sprayed on top of the rotating brush.

The cooling coefficient of performance (COP) of the system can be evaluated by calculating the ratio of the cooling capacity ($Q_{cooling}$) provided by the system to the electricity energy (Q_E) consumed by the rotating brushes.

$$COP = Q_{cooling} / Q_E \qquad (1)$$

where

$$Q_{cooling} = m_a C_p \Delta T \qquad (2)$$

The effect of air inlet from room temperature

Standard conditions were used to operate the system; the airflow rate was chosen at 0.03m³/s and the water flow rate for spraying was 3 l/min to supply sufficient mist when the air passed through it. To investigate the effect of air inlet temperature on relative humidity, air outlet temperature, $Q_{cooling}$ and COP, tests were carried out with different air inlet temperatures: 26 °C, 28 °C, 30 °C, 32 °C and 35 °C, respectively. The experiment is outlined in Table 2.

Table 2. Test conditions of Tests 4-8

Test no.	Air inlet from room temp. (°C)
4	26
5	28
6	30
7	32
8	35

The effect of airflow rate

These tests were carried out under the following conditions: the rate of water sprayed on the rotating brush was 3l/min while the room inlet temperature was approximately 20.5 °C. To investigate air outlet temperature, $Q_{cooling}$ and COP, tests were repeated with similar conditions, except airflow rate was altered to 0.025 m³/s, 0.03 m³/s and 0.035 m³/s, respectively. The results were then compared and analyzed. The experiments are outlined in Table 3.

Table 3. Test conditions of Tests 9-11

Test number	Air flow rate (m³/s)
9	0.025
10	0.03
11	0.035

Results

Comparison of the effect of water flow rate and water temperature

The test conditions were referred to in Table 1. Figure 6 shows that the test was conducted by comparing three experiments. The second experiment (3l/min, 20.5 °C) gave the lowest outlet temperature, beating the results of the third experiment, which had a higher water flow rate at 4l/min. Hence, we can conclude that the temperature of water has a greater cooling effect on air temperature than the water flow rate. The colder water temperature is, the better it absorbs heat from the air.

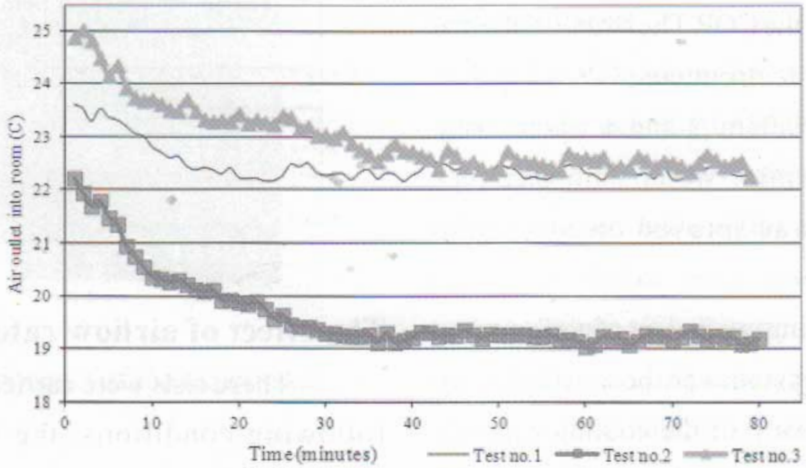

Figure 6. Air Outlet Temperature against Time Duration

The operation of the system can be assessed using the psychometric chart in Figure 7. Process 1-2 is Test no. 2 and Processes 1-3 and 1-4 are Test no. 1 and Test no. 3. The conditions at those points can be controlled separately by supplying water with different temperatures and different water flow rates. The details of the points on the psychometric chart are given in Table 4.

Table 4. Location points to measure the effect of water quantity and water temperature

Point number	Location points
1	Air inlet from room
2	Air outlet into room (Test no. 2)
3	Air outlet into room (Test no. 1)
4	Air outlet into room (Test no. 3)

The results from Figure 7 show that:

Process 1-2: The greater temperature drop is due to the lower water temperature. Colder air has a lower capacity to hold moisture. Together with a lower water flow rate, it resulted in less evaporation in this experiment.

Processes 1-3 and 1-4: When compared with results from Test no. 2, it is noted that there is more evaporation, but with a smaller drop in temperature. This is due to higher water temperature resulting in a lower drop in temperature. The airflow with a higher temperature enables the air to hold more moisture, thus encouraging more evaporation to take place. Furthermore, the water flow rate is higher in this experiment.

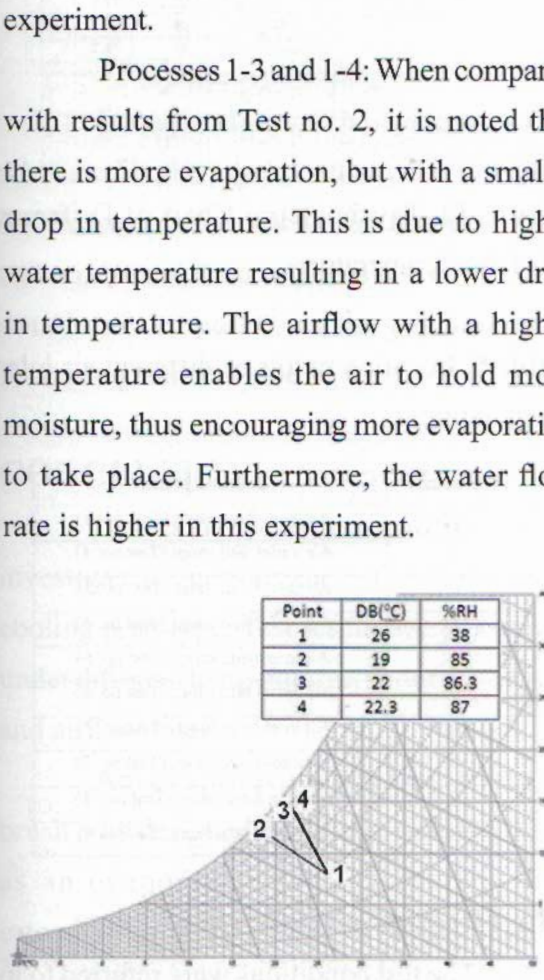

Figure 7. Psychometric Chart of Different Water Flow Rates

The effect of water temperature

The test conditions were referred to in Section 3 Figure 8 shows the effect of water temperature on the air outlet temperature and relative humidity. Figure 9 shows the COP of the whole system. As we can see, water inlet temperature has a direct linear influence on the air outlet temperature. Low water temperature also functions to moisten air and to reduce the airflow temperature to a lower one than the target (comfortable) temperature. Air outlet temperature increases, with a decreasing COP, when water temperature increases. Hence, we can conclude that water temperature has a direct linear influence on air outlet temperature. However, as we can see from the graph, changes in water temperature have little influence on relative humidity.

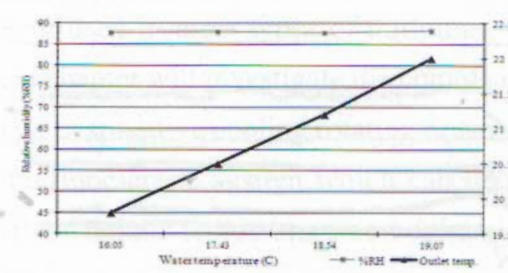

Figure 8. The Effect of Water Spray Temperature against RH and Air Outlet Temperature

The effect of temperature of air inlet from room

The test conditions were referred to in Table 2. Figure 10 and Figure 11 show how the $Q_{cooling}$ and the COP increase with increasing air inlet temperature. From the experiments, we note that lower air inlet temperatures obtain a lower air outlet temperature, but also a lower COP. As water (mist) comes into contact with the airflow, mass and heat transfer take place. Cold water, supplied at a lower temperature, absorbs heat from the airflow, cooling down the airflow until it nears the water temperature.

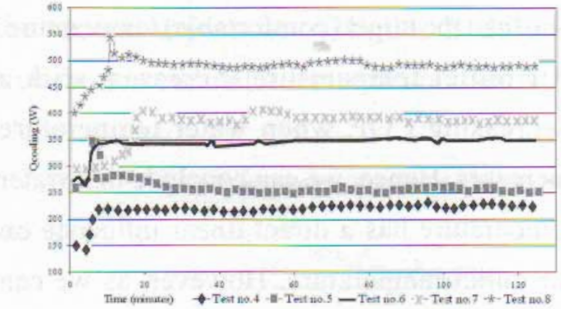

Figure 10. $Q_{cooling}$ against Time Duration in Different Air Inlet Room Temperatures

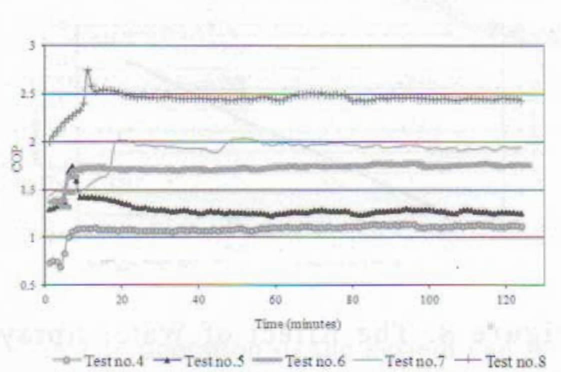

Figure 11. COP against Time Duration in Different Room Air Inlet Temperatures

The operation of the system can be assessed using the psychometric chart in Figure 12. Process 1-2 is test no. 4; Process 3-4 is test no. 5; Process 5-6 is test no. 6; Process 7-8 is test no. 7; Process 9-10 is test no. 8. Air outlet temperature (T_c) increases when air inlet temperature ($T_{in,c}$) increases. The details of the points on the psychometric chart are given in Table 5.

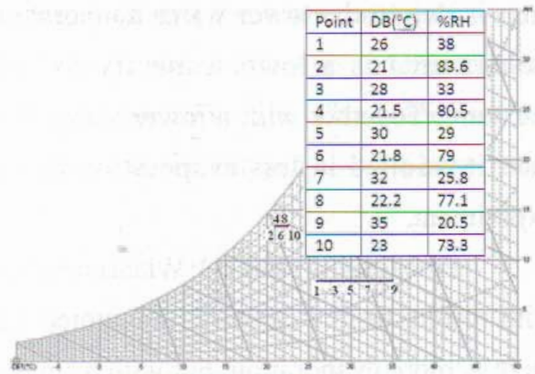

Figure 12. Psychometric Chart of Different Air Inlet Temperatures

Table 5. Location points of different air inlet temperatures

Point number	Location points
1	Air inlet from room (Test no. 4)
2	Air outlet into room (Test no. 4)
3	Air inlet from room (Test no. 5)
4	Air outlet into room (Test no. 5)
5	Air inlet from room (Test no. 6)
6	Air outlet into room (Test no. 6)
7	Air inlet from room (Test no. 7)
8	Air outlet into room (Test no. 7)
9	Air inlet from room (Test no. 8)
10	Air outlet into room (Test no.8)

The effect of airflow rate

The test conditions were referred to in Table 3. Figure 13 and Figure 14 show that a higher airflow rate gave a higher $Q_{cooling}$ and COP. When choosing a suitable airflow rate for a building/room, one has to take into account the cooling load of the room and check that the $Q_{cooling}$ of the evaporative cooling rotating brush is sufficient to remove heat from the room and achieve the desired room temperature.

Table 6. Psychometric chart points at different airflow rates

Point number	Location points
1	Warm air inlet (Test no. 9 to Test no. 11)
2	Warm air outlet (Test no. 9)
3	Warm air outlet (Test no. 10)
4	Warm air outlet (Test no. 11)

The operation of the system can be addressed in the psychometric chart in Figure 15. Process 1-2 is test no. 9; Process 1-3 is test no. 10 and Process 1-4 is test no. 11. The details of the points on the psychometric chart are given in Table 6.

CONCLUSION

Laboratory tests were carried out to investigate the performance of an evaporative cooling prototype. Test results were obtained under different temperatures, water conditions and airflow rates.

An evaporative cooling rotating brush was designed and constructed to work as an evaporative cooling system. The evaporative cooling rotating brush incorporated a number of ideas in its design structure to produce a compact unit.

Water was sprayed onto the rotating brush fibres; the evaporation process (change of liquid state to gaseous) was encouraged by providing a large contact area. The molecules absorb energy (latent heat) in the evaporation process. The energy is absorbed by the evaporation system. Water temperature had a significant effect on air outlet temperature, while water flow rate was less of an influence. A higher airflow rate gave a higher air outlet temperature. However, it gave a better $Q_{cooling}$ and COP, due to the fact that the airflow rate improved the fins' heat transfer performance. Also, water from the rotating brush reduced airflow temperature.

Water spray on the rotating brush results in an airflow with a high relative humidity; this needs to be controlled, when being used in most types of buildings. The next chapter will investigate the combination of an evaporative cooling rotating brush with a thermoelectric system which can help to further reduce temperature and dehumidify the air.

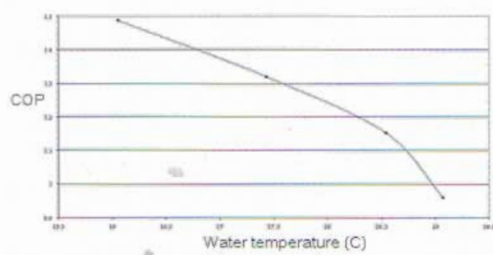

Figure 9. The Effect Of Water Spray Temperature against COP

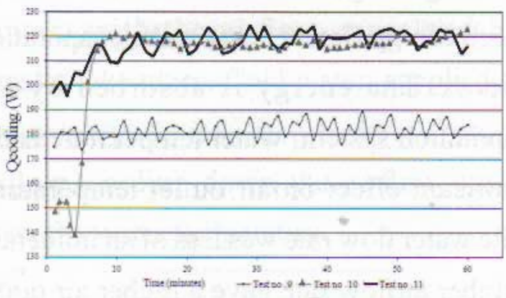

Figure 13. Time Duration against $Q_{cooling}$ in Different Airflow Rates

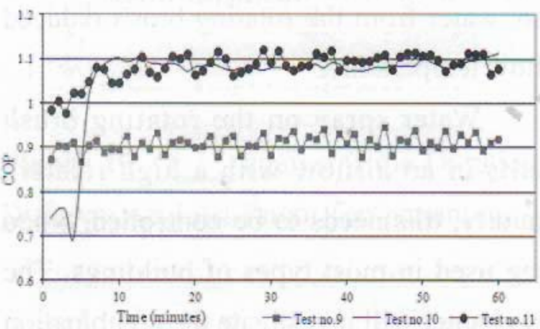

Figure 14. Time Duration against COP in Different Airflow Rates

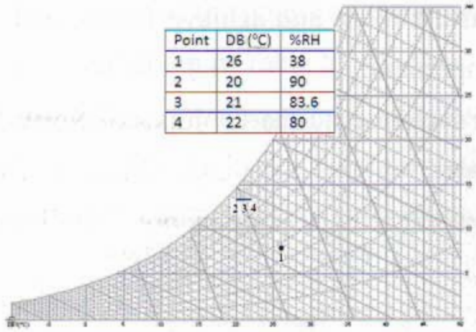

Figure 15. Psychometric Chart at Different Airflow Rates

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