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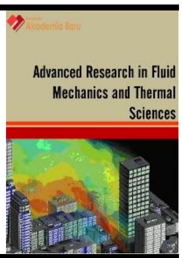


# Experimental Study of the Effect of Piccolo Tube Pipe on the Air-Conditioning Experimental Rig

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**ABSTRACT**

Air-Conditioning system plays vital role in Indoor Air Quality. Low humidity in atmosphere cost crucial consequence to human skin and nasal passages. Installing ultrasonic humidifier to air conditioning system is one of the options to make up lost humidity. An experimental HVAC rig is combined with ultrasonic humidifier to humidify the system by using a piccolo tube. This paper presents experimental study of humidity profile in an experimental rig at different air velocity and piccolo holes diameter. Experiment results show that, under fixed inlet air velocity and mist flow rate, relative humidity (RH) increased with piccolo holes diameter. RH of 12mm holes diameter piccolo tube is 7.4% higher than 5 mm holes diameter piccolo tube for 3ms$^{-1}$ air velocity. Similarly, under fixed piccolo holes diameter and mist flow rate, RH is decreased with increasing air velocity. RH of 5ms$^{-1}$ velocity is 13.4% lower than 1ms$^{-1}$ velocity for RH change. Rate of humidity added to the HVAC system by ultrasonic humidifier also increased with respect to holes diameter size and air velocity. 3ms$^{-1}$ and 12 mm piccolo holes diameter shows highest gradient humidity mixing rate.



## 1. Introduction

The main challenge of the building industry in Malaysia is, Heating Ventilating and Air-Conditioning (HVAC) systems are consuming most of the energy in commercial buildings [1] and creating HVAC solutions that are able to provide comfortable and healthy indoor environment while consuming low energy. This challenge happens due to modern society people spend about 90% of their lives in-doors [2] and contributing more than 60% of the energy consumed by buildings and this numbers are likely to grow in near future [3].

However, it is crucial to maintain healthy and comfortable as per ASHRAE Indoor Air Quality (IAQ) standard 62.1-2007 even though thermal comfort satisfaction is an expression of the individuals' mind. Present day studies reveal that if IAQ improved by a factor of 2 to 7 compared to existing

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standards. It decreases the risk of asthma in homes, while significantly increasing school learning and office productivity [4]. Similarly, the precise control of temperature and humidity is vital in hot-humid hospitals as these affect diseases, infections and allergies etc. [5] and more precisely in operation theatres [6].

Madhavi *et al.,* [7] identified that thermal comfort as a six-dimensional topological solid, having at least six parameters that give dimensions to any unique thermal condition. Two of these, activity and clothing are specific to an individual while air temperature, humidity, air velocity and radiation are the properties of the environment. Humidity level drop drastically during winter which leads to dry skin, irritated eyes, nose, and throat, nose bleeds and nasal congestion to humans [8] and causes Electro-Static-Discharge (ESD) to electronics [9]. For an example, North China has Relative Humidity (RH) value below 20%, most of their residences equipped with indoor heating system in winter season [10-13]. Adding humidifier is an effective way to provide humid climate to achieve thermal comfort zone as per ASHARE 55-2010 standard and reduce the risk of ESD.

Ultrasonic humidifier becomes more popular for indoor application due to safety, economy and convenience compared to traditional steam humidification system [14-17]. Steam humidification system only injecting water vapor as a mechanism, while ultrasonic humidifier simultaneously generating water droplet and mist. Ultrasonic humidifier is utilized as assembled with air-conditioning systems [14,15], or directly to the indoor environment as portable humidification system [16]. In air-conditioning system, dry air humidified in ventilation ducts before being force to supply into indoor space [14]. Unlike first, portable humidifier placed in indoor environment could humidify air directly and create local humidity comfort [17].

Pu *et al.,* [15] conducted numerical simulations to study the steady state air temperature and relative humidity distributions in a ventilated room with ultrasonic humidification system installed in ventilation ducts. During the indoor humidification process, water droplets and water vapor were generated by ultrasonic humidifier simultaneously [17], resulting in complex and non-uniform thermal environment (temperature and humidity).

Air Flow Distribution (AFD) is a vital part in HVAC systems. Recently, effectiveness of perforated pipe has been recognized and included into the AFD, even though characteristics such as pipe material, holes sizes, pipe diameter and fan speed could lead to the variation of air flow characteristics [18]. Perforated fluid distribution pipes is a typical type of dispensing equipment can ensure that the main stream flows uniformly from the sidewall keyhole along the axial channel. Flow distribution in a perforated fluid distribution pipe has been studied by a number of researchers using the energy equation method. Wang *et al.,* [19] introduced a general theoretical model to calculate the flow distribution and pressure drop in a channel with porous walls. However, using ultrasonic humidifier to inject mist through perforated pipe is initiated as a combination of this study.

This research is to investigate the influence of indoor portable ultrasonic humidification system by Piccolo Tube Pipe (continuous humidification process induced by water droplet and vapor) while setting a particular relative humidity and temperature as inlet condition. Size of piccolo tube pipe holes diameter and air velocity were varied to determine the influence on rate of water vapor added to the HVAC system and relative humidity state of outlet air stream.

## 2. Methodology

An air-conditioning experimental rig in Heat Transfer Laboratory, Universiti of Sains Malaysia, as shown in Figure 1, was modified to conduct the experiment. Figure 2 shows the fabricated Perspex material box dimensioning approximately 45.72 x 40.64 x 43.32 cm. This box was used as mist container for this experiment. All six Perspex surface were glued together by using chloroform which softens the surfaces of the Perspex. Chemical bonding between two pieces welds them together by Capillary action which draw the glue into the joint. After 24–48 hours, the joint between two Perspex surfaces were cured together and achieve full strength. After that, four holes were drilled on the bottom side of the box with size of 12mm to connect with rubber piping, which act as a channel to bring the water vapor into HVAC duct. Subsequently, the box shaped container is done with fabricating and combining processes, the ultrasonic humidifier is put into the container.

**Fig. 1.** HVAC experimental rig in Heat Transfer Laboratory

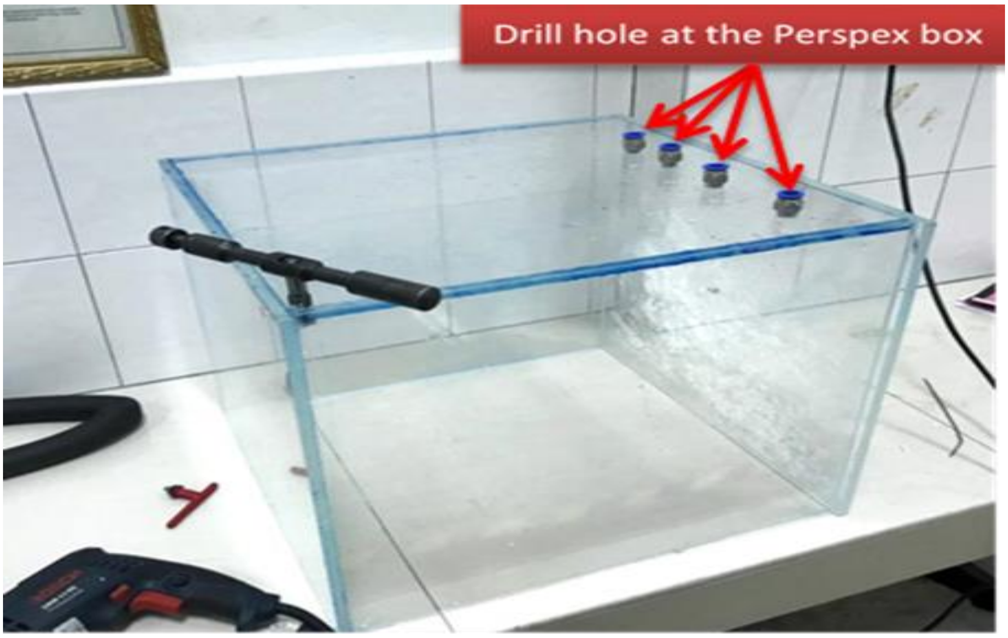


**Fig. 2.** Perspex box drilled with four hole at the bottom

Then, PVC pipes were drilled by utilizing cordless hand driller and piccolo tubes were made. Piccolo tube consist of different holes diameter such as 5mm, 7mm, 10mm and 12mm as shown in Figure 3 and piccolo tube connected with the rubber tube.

**Fig. 3.** Different diameter holes sizes of piccolo tube

The ultrasonic humidifier was kept in an enclosed container in order to make the humidifier produce more water vapor (Figure 4). After the enclosed space fully fulfilled by the water vapor or mist produced by the ultrasonic humidifier, water vapor forced through the rubber piping by a compressor into HVAC experimental rig duct because amount of induced pressure inside the Perspex box was not enough.


**Fig. 4.** Perspex box packed by water vapor

The velocity of air produced by axial fan in the HVAC experimental rig and measured by airflow meter. The air flow velocity set as 1ms$^{-1}$, 3ms$^{-1}$ and 5ms$^{-1}$ to conduct the experiments. Relative Humidity measured by using Cole-Parmer humidity sensor. The humidity sensor accuracy limited in-between 25% to 99% with 0.1% error margin.

## 3. Results

### *3.1 Humidity Distribution*

This section discusses the results obtained from RH measurement study. The effects with time variable, diameter of piccolo holes and air velocities are discussed in the next sections.

### *3.1.1 The effect of diameter of piccolo holes respect to Relative Humidity (RH)*

The test is configured as, Piccolo holes diameter is changed throughout the experiment and relative humidity is measured and results for this experiment is in Figure 5. Velocity of air is maintained as $1ms^{-1}$, $3ms^{-1}$ and $5ms^{-1}$ for three different experimental attempts. Relative humidity for all diameters almost constant with time. That means the data were obtained in steady state condition.

Figure 5 (a), (b), (c) all illustrate that larger the diameter size of the holes, larger the hole area, lower mist pressure loss and higher the amount of water vapor can enter into HVAC duct, thus increases the relative humidity level in the test section. However, Figure 5(a) demonstrate that relative humidity increased quite higher for piccolo tube holes diameter changed from 5mm diameter hole to 7 mm hole comparing with 10mm and 12 mm changes for $1ms^{-1}$ air velocity. This trend changed in Figure 5(b) for 7 mm diameter to 10 mm diameter in between 6 to 15 minute time interval for $3ms^{-1}$ air velocity. The effect of piccolo tube seems not significant for $5ms^{-1}$ air velocity with the experiment time interval as shown in Figure 5(c), because of low mixing ratio of vapor volume flow rate to air-conditioning volume flow rate.

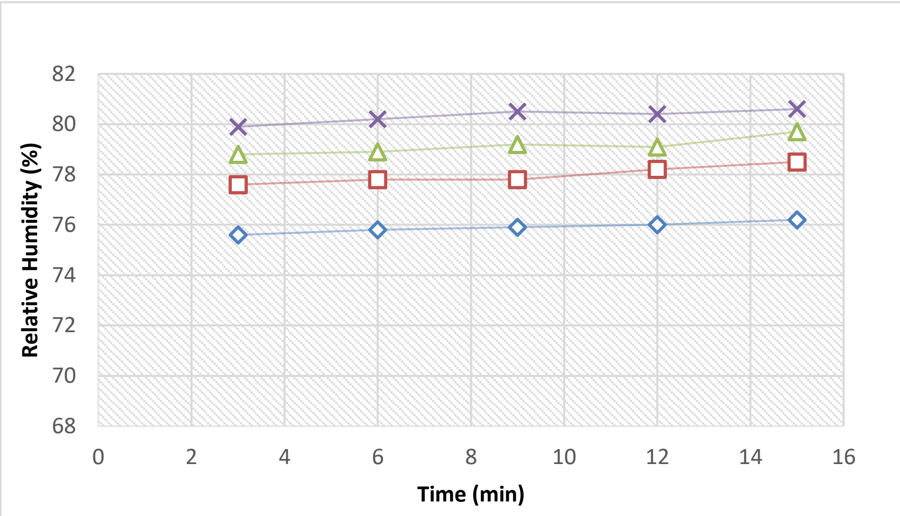


**Fig. 5(a).** RH for $1ms^{-1}$

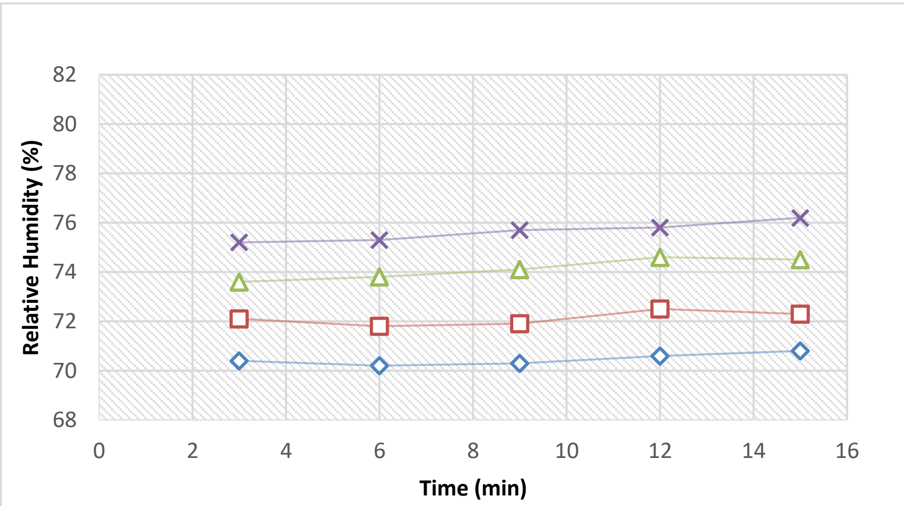


**Fig. 5(b).** RH for $3ms^{-1}$

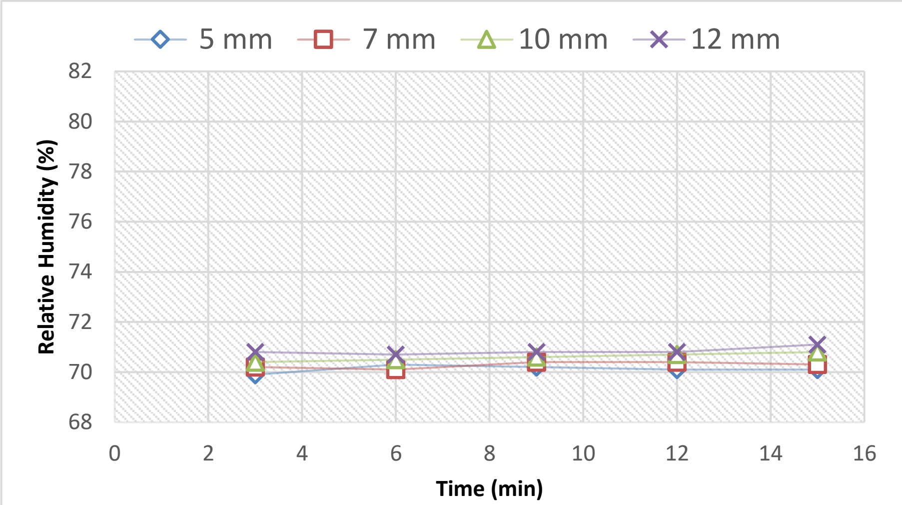


**Fig. 5(c).** RH for 5ms$^{-1}$

### *3.1.2 The effect of air velocity respect to Relative Humidity (RH)*

In this attempt, piccolo holes diameter maintained constant in each attempt and air velocity is changed throughout the test and RH is measured.

Increasing air velocity led to low mixing ratio between water vapor and air-conditioning air inside HVAC system as shown in all figures below. Figure 6(a) clearly illustrates that there is not much significant difference between 3ms$^{-1}$ and 5 ms$^{-1}$ line in the graph for 5 mm piccolo holes diameter because of there is not much mist flow rate difference between these two instances, however this trend gradually changed when piccolo hole diameters got increased and significant gap shown between 3ms$^{-1}$ and 5ms$^{-1}$ air velocities as demonstrated in Figure 6 (b), (c), (d).

### *3.2 Average Relative Humidity Distribution respect to Air Velocity and Piccolo Holes Diameter*

The average relative humidity value respect to air velocities illustrated in Figure 7 and Figure 8 represent, respect to piccolo holes diameters. Figure 7 summing that there is a significant decrease in average relative humidity values for 12 mm piccolo holes diameter respect to air velocities. However, 5 mm and 7 mm diameter piccolo tube shows abrupt decrease in values between 1ms$^{-1}$ and 3ms$^{-1}$ and the rate of decrease is diminishing from 3ms$^{-1}$ to 5ms$^{-1}$ velocities. 10 mm diameter holes showed average relative humidity trend graph similar to 12 mm holes.

Figure 8 illustrating that 1ms$^{-1}$ velocity is the best choice to increase relative humidity compared to other velocities. 3ms$^{-1}$ air velocity shows gradual increase with increasing piccolo holes diameter and 5 ms$^{-1}$ shows the lowest. This led to a conclusion that air velocity rise diminish the RH value in the flowing air stream. The reason behind this phenomenon is the amount of water vapor getting into HVAC system by piccolo holes not much significantly changing for particular diameter, however, the amount of flow rate is increasing while the velocity increases dominating the RH distribution. This could led to lower RH values for increasing velocity. Similar results were encountered by Crozo *et al.,* Krokida *et al.,* and Motevali *et al.,* [20-22] in driers.

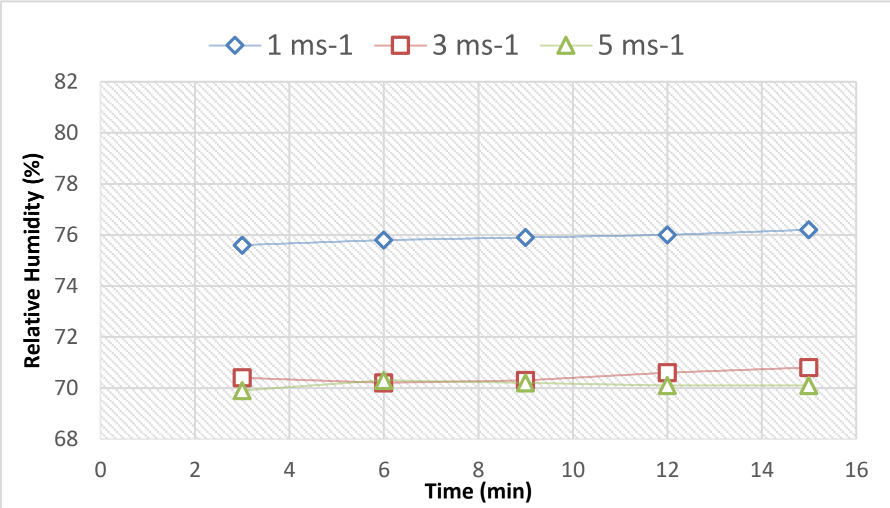


**Fig. 6(a).** RH for 5 mm hole

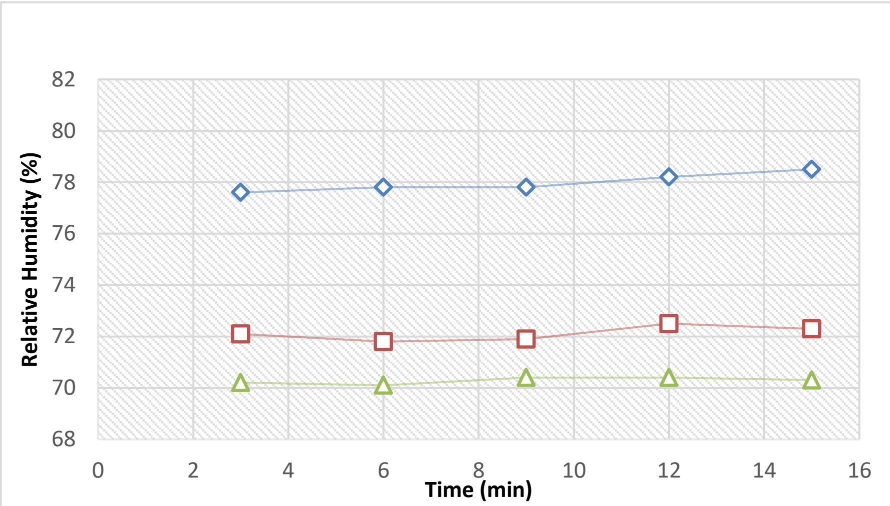


**Fig. 6(b).** RH for 7 mm hole

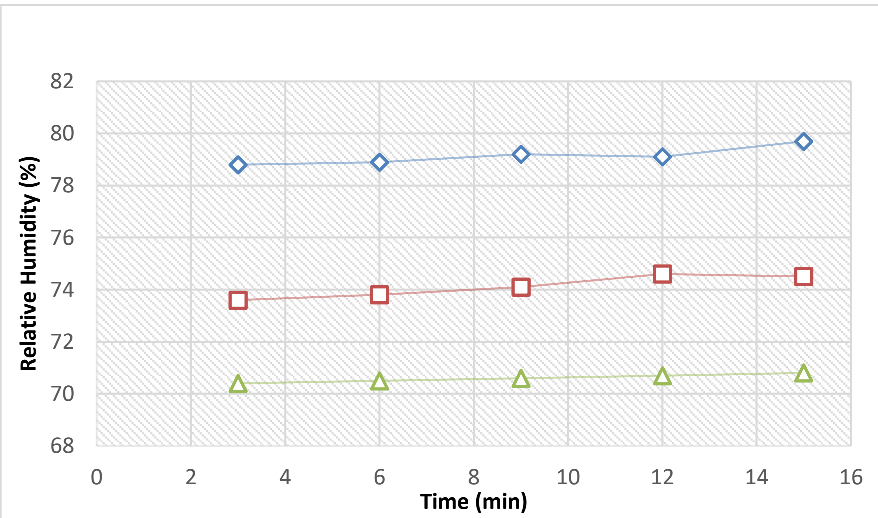


**Fig. 6(c).** RH for 10 mm hole

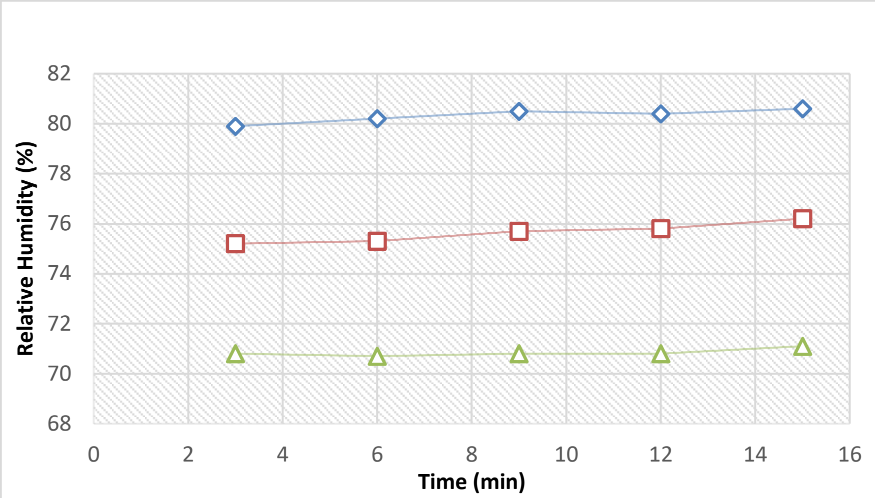


**Fig. 6(d).** RH for 12 mm hole

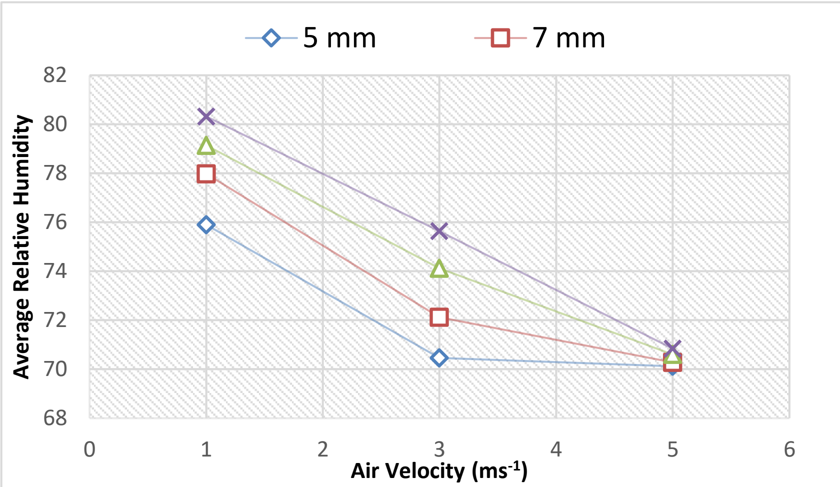


**Fig. 7.** Variation with Average Relative Humidity Value and Air Velocity

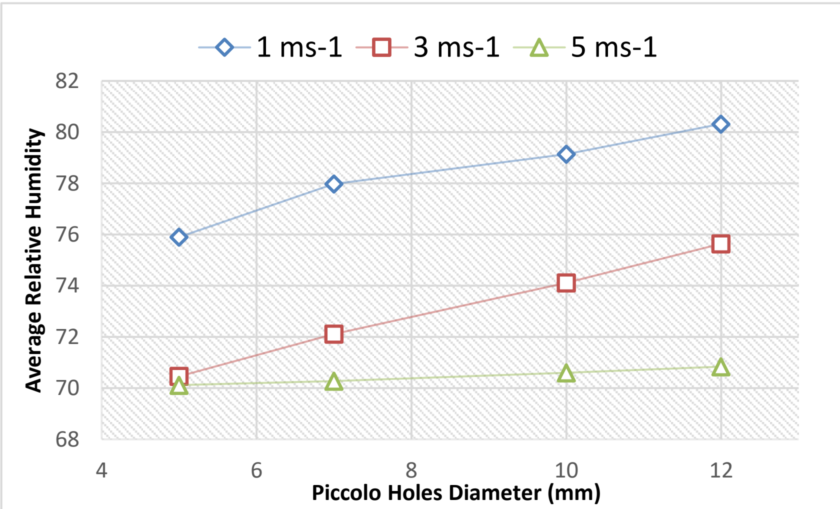


**Fig. 8.** Variation with Average Relative Humidity Value and Piccolo Holes Diameter

### *3.3 Rate of Humidity Added to HVAC System respect to Air Velocity and Piccolo Holes Diameter*

Rate of mass humidity added to the system calculated by help of psychometric chart by assuming moisture addition to the HVAC system is adiabatic. The inlet atmospheric air condition for this study is 32.5$^{o}$C dry air and 26$^{o}$C wet bulb temperature. The variation with rate of vapor added for fifteen minutes by ultrasonic humidifier into HVAC system reference to Piccolo holes diameter for particular air velocity constituted by Figure 9. Rate of water vapor addition increased with velocity increase, which is expected. However, interesting fact from the figure is the gradient of water vapor (between 3 to 15 minutes) added to the system is higher for 3ms$^{-1}$ compared to other two velocities of 1 ms$^{-1}$ and 5 ms$^{-1}$ respect to piccolo holes diameter change. This means, 3ms$^{-1}$ air velocity is the most suitable velocity to increase the rate of water vapor to the system.

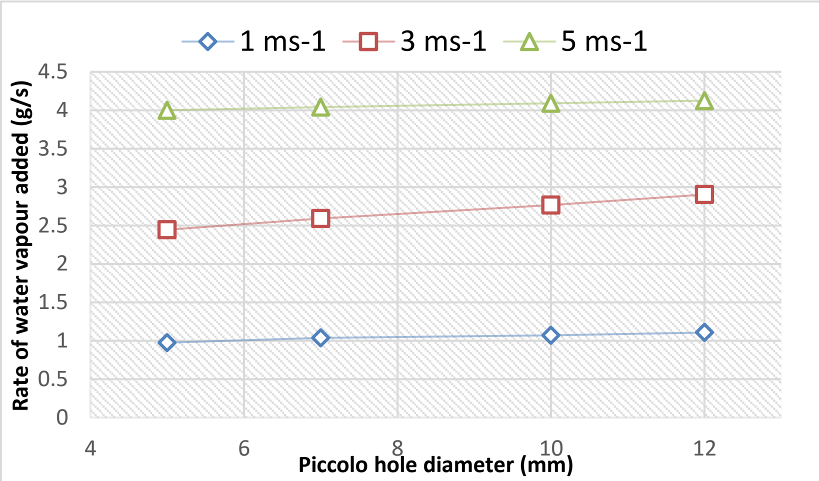


**Fig. 9.** Variation with Rate of water vapor added to HVAC system and Air Velocity

Figure 10 demonstrates that rate of vapor mass per-second is added increases with the holes diameter size. However, this increase is moderate to manifest the difference, regardless thermal comfort will expected to achieve in shorter time is predicted that lead to amount of energy supplied to compressor will be reduce and COP of the total system will be increased. Substantiate this prediction further research is needed in close loop system.

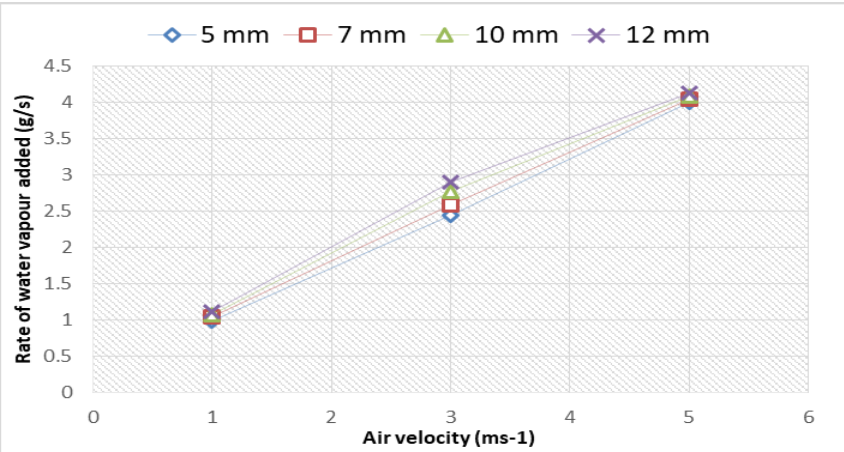


**Fig. 10.** Variation with Rate of water vapor added to HVAC system and Piccolo holes diameter

## 4. Conclusions

In this research, the effect of relative humidity on the diameter size of piccolo holes and air velocities were studied. Relative humidity is increased with the holes sizes and decreased with air velocities. Holes diameter 12 mm are 5.8%, 7.4% and 1% respectively better than 5 mm holes diameter for $1ms^{-1}$, $3ms^{-1}$ and $5ms^{-1}$ air velocity. Subsequently, the Piccolo diameter increases amount of vapour got into system condensed that lead to increase in relative humidity. Air velocity of $5ms^{-1}$ are 8.2%, 11%, 12.1% and 13.4% poor than $1ms^{-1}$ velocity for change in relative humidity. Even though relative humidity is decreased with the air velocity, the rate of water vapour added to the system is increased with air velocities. Increased piccolo holes sizes may result in higher COP performance to the HVAC system.

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