SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Performance of Calcium Chloride and Silica Gel as Solid Desiccant Dehumidifiers for Indoor Air Quality

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ARTICLE INFO

Article history:
Received 29 June 2021
Received in revised form 30 August 2021
Accepted 9 September 2021
Available online 7 November 2021

Keywords:
Calcium chloride; silica gel; solid desiccant; performance analysis; dehumidification

ABSTRACT

Desiccant materials are recently discovered as a viable alternative in dehumidification technology due to their naturally hygroscopic qualities and minimal energy requirement. This paper discusses the performance of four brand samples of selected desiccants used for dehumidification. In this study, dehumidification ability and indoor air quality (IAQ) tests were carried out. The dehumidification ability test was conducted in a controlled environmental chamber at a temperature of 25°C, relative humidity of 70%, and air velocity of 2 m/s for 45-minute session. Meanwhile, the IAQ test was carried out in a naturally ventilated test room, and six IAQ parameters (relative humidity, air velocity, air temperature, particulate matter (PM_{10}), airborne bacteria and carbon dioxide (CO_2) were studied. The IAQ test was performed for five different conditions: control, application of brand samples A, B, C and D in the test room. From this study, it was found, brand A (0.6823 g/kg) and brand B (0.6849 g/kg) had a relatively good dehumidification ability during the 45-minute dehumidification ability test compared to brand C (0.3108 g/kg) and brand D (0.3982 g/kg). The IAQ test revealed that brand A had the biggest variation in indoor-outdoor relative humidity of 13.12%, while brand D had the smallest difference of 11.83%. Brand B had the highest average PM_{10} concentration of 0.037 μg/m^3. The airborne bacterial count for all conditions had no statistical significance, indicating the application of desiccants were not effective in reducing airborne bacteria. From this study, it can be concluded that calcium chloride (brand A and B) samples performed better than silica gel (brand C and D) samples in terms of dehumidification ability and IAQ profile.

1. Introduction

Humidity is a major concern in the hot and humid environment. Controlling humidity and mold growth are essential for human comfort as well as ensuring the quality of air used in indoor spaces or buildings. In the hot and humid environment, these factors also contribute in defining the energy load for thermal comforts towards net-zero energy building (NZEB). Thus, the challenges in providing

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https://doi.org/10.37934/arfmts.88.3.5770

good thermal comfort and indoor air quality (IAQ) for daily living in hot and humid conditions while consuming less energy must be overcome [1]. In the hot and humid environment, one of the strategies to reduce the humidity level in the air is through dehumidification [2].

Dehumidification can be described as a process of removing or reducing the water vapor from humid air to produced dried air. There are three types of methods in general for this process. The first type involves the process of cooling and dehumidification, where the humid air is cooled down and condensed to form a liquid phase. The media that have cooling properties with a lower temperature than the dew point is used to run this process. Another type involves the usage of material with strong hygroscopic property of water-soluble solutions. The materials that possess such property can be found as calcium chloride, lithium chloride, lithium bromide, and diethylene glycol used in the dehumidification system, which is called as liquid desiccant. The third type is the application of solid desiccant with strong hygroscopic effect. The common solid desiccant materials are activated carbon, molecular sieve, alumina gel and silica gel. These materials are versatile and may be incorporated into sachets, canisters, cards, and even bottle closures. In the literature, different types of desiccants and their moisture sorption capabilities can be identified [1]. Molecular sieve has been beneficial in cheaply accessible desiccant materials due to its reduced hygroscopic limit, and activated alumina has brought down sorption confine almost half that of silica gel. These materials can absorb moisture in large capacity, which is about 50 to 1200% range of their dry weight [3]. They can also be regenerated between the temperature of 50 to 120°C, depending on their forms.

In improving the quality of indoor air and thermal comfort and saving energy through a sustainable approach, the application of dehumidification technology based on desiccant materials is now becoming technically feasible [4]. Desiccant materials or dehumidifiers are used to reduce the relative humidity of moist air and convert it to dry air. After absorbing moisture, the desiccant material becomes saturated, which may be eliminated by blowing hot air on the desiccant material. Apart from buildings, these materials are also used in many applications such as crop drying, food industries, pharmaceutical and refrigeration [5,6]. The operational standard of desiccant dehumidification is based on the exchange of moisture between the air and the desiccant, owing to their vapor pressure differences [7].

The most common solid desiccant materials used for the dehumidification process to absorb moisture in the indoor air are silica gel and calcium chloride. Calcium chloride is a deliquescent and very hygroscopic substance. These properties are beneficial as a dust suppressant [8]. Calcium chloride in solid form may be converted to a liquid by collecting moisture from the air. Meanwhile, silica gel is a highly porous amorphous form of silica and is most commonly produced into beads. Its porosity exceeds 70% of its surface area and may reach 650 m^2/g with pores ranging in size from 0.7 to 3 nm, and it has a heat absorption capability of around 2800 kJ/kg [9]. Silica gels are classified into two types: macroporous and microporous. Macroporous silica gel rapidly saturates with its environment, but microporous silica gel retains water for an extended period. Silica gel is typically regenerated at temperatures ranging from 90° to 150°C [10]. Silica gel particles have a huge surface area because they are made up of an interconnected network of capillaries. Surface adsorption and capillary condensation in the porous network are two processes for moisture adsorption by silica gel [1]. At room temperature, silica gel functions effectively, but the adsorption rate and equilibrium moisture content may be reduced at higher temperatures.

To dehumidify a space based on the desiccant dehumidification approach, the determination of the space's size and humidity level are crucial, which would affect the performance of the desiccant. Nowadays, desiccant material is utilized in building ventilation such as air-conditioning systems to conserve energy. It is discovered that the performance of the desiccant material, which is the absorption capacity, varies with the relative humidity [11]. Certain desiccant materials have a high absorption capacity at greater relative humidity, while others have a reduced absorption capacity at increasing relative humidity, and their performance is dependent on the pore size of the desiccant material. To date, limited reports are available in the literature on the performance of desiccants as dehumidifiers for IAQ. Therefore, this study focused on the analysis of calcium chloride and silica gel as a dehumidifier by discussing their dehumidification ability and indoor air quality performance. The findings can be used to provide baseline data for future research and development in the desiccant dehumidification and air-conditioning technology fields in controlling the humidity level in an indoor space.

2. Methodology

2.1 Dehumidification Performance Test

In this study, four different brand samples of solid desiccants were used, representing calcium chloride and silica gel. The anhydrous calcium chloride desiccant was named brand A and B, while the silica gel desiccant was marked as C and D. An experimental setup of the dehumidification performance test is illustrated in Figure 1. A control chamber was prepared with an air temperature of 25°C. The ambient air with 70% humidity at a constant air velocity of 2 m/s was circulated through a duct from a connected humidifier and a fan inside it. A data recorder was connected to the temperature and humidity transmitter to monitor the difference in air conditions with the usage of desiccant samples. Measurement of relative humidity was carried out using temperature and relative humidity transmitter HD9817T1R (Delta Ohm, Italy) with an accuracy value of ± 2% (10 to 90% RH). Then, a data logger DT80 was used to collect data for each test with five seconds of interval for a span of 45 minutes. Eq. (1) was used to calculate the transient dehumidification ability in gram/kilogram, where Δd is the moisture removal ability; d_{in} is the inlet absolute humidity, and d_{out} is the outlet absolute humidity. Both inlet and outlet absolute humidities are in the unit of g/kg [12].

$$\Delta d = d_{in} - d_{out} \quad (1)$$

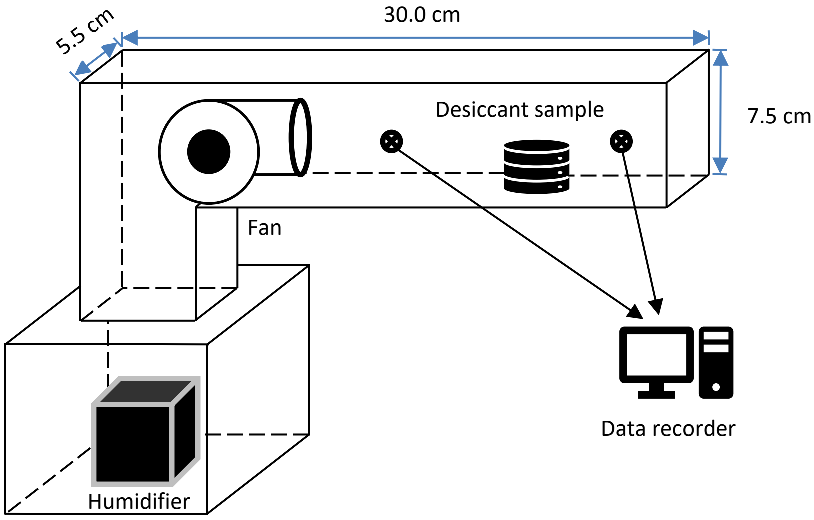

Fig. 1. Dehumidification test experimental setup

2.2 Indoor Air Quality Test

A test room with the characteristics as specified in Table 1 and dimensions in Figure 2 was set up. The IAQ test was done for 8 hours twice a day, with morning and afternoon sessions excluded the microbiological air sampling. Five different conditions were prepared for the IAQ test, which were named as control, brand A, B, C, and D.

Table 1
Test room characteristics

Characteristics	Description
Type of ventilation	Natural ventilation with three windows and a door
Furniture	Two desks, two office chairs and one shelf
Volume of room (m^3)	27.6

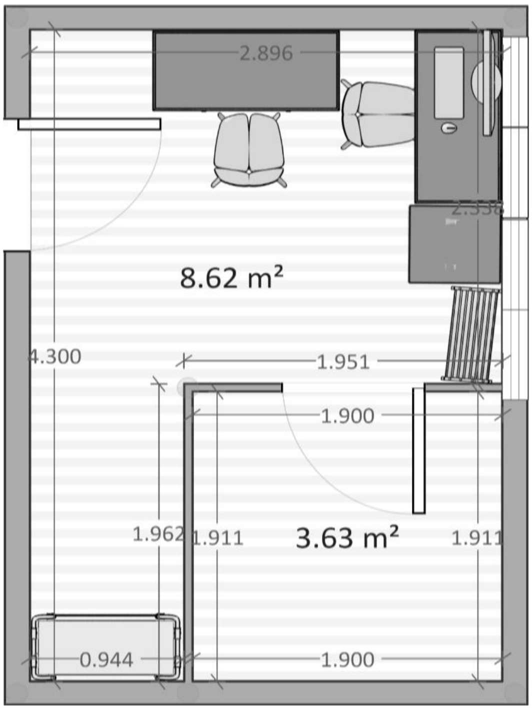

Fig. 2. The floorplan of the test room

2.2.1 Measurement of physical parameters

The physical parameters involved were air velocity, relative humidity, and temperature, measured and monitored using a data logging instrument. The relative humidity and temperature were recorded using a portable meter (EVM-7 Environmental Monitor Kit 3M^{TM}, United States) while a wire probe (HD 32.3) connected to a portable data logger (AP3203 Omnidirectional Delta Ohm, Italy) was used for measuring the air velocity. The values of 0 to 100% were the measurement range of relative humidity with the accuracy value of ±5%, while the values of 0.0°C to 60.0°C were the range of temperature sensor with an accuracy value of ±1.1°C. The values of 0.05 to 5.00 m/s were the range for air velocity with the accuracy value of 0.05 to 1.00 m/s.

2.2.2 Measurement of particulate matter (PM_{10}) concentration

A portable meter of PM_{10} (EVM-7 Environmental Monitor Kit, 3M^{TM}, United States) was used in this analysis which had a particulate sensor with a measurement range value from 0.0 to 200.0 mg/m^3 and the value of accuracy about ±15%.

2.2.3 Measurement of carbon dioxide (CO_2) concentration

A portable meter of CO_2 (EVM-7 Environmental Monitor Kit, 3M^{TM}, United States) was used to measure the CO_2 concentration. The values of 0 to 5000 ppm were the measurement range for CO_2sensor with an accuracy value of ±100 ppm.

2.2.4 Sampling of airborne bacteria

The sampling of airborne bacteria was carried out using a portable air sampler (MAS-100, Merck, Germany) with a flow rate of 100 l/min and 500 l/min. Tryptic soy agar (TSA) was used as a medium in a petri dish size 90 mm [13]. The preparation of TSA media involved 5.0 g sodium chloride, 15.0 g of agar powder, 15.0 g peptone from casein and 5.0 g peptone from soybean. The sampling was implemented two times with triplicates for each condition, where the morning slot at 9.00 am and the afternoon slot at 4.00 pm. The 37±1°C presented as the incubation temperature with a period of 48±3 hours [14]. The positive hole conversion table of the air sampler (MAS-100) adjusted the quantification of the bacteria by the number of colonies.

3. Results and Discussion

3.1 Analysis of Data

The obtained data were organized using Microsoft Excel 2017 for descriptive statistics, while Minitab 17 was used for inferential statistics such as one-way ANOVA and Two-sample T-test. The significance levels for both inferential statistics were obtained as $p<0.05$.

3.1.1 Dehumidification ability

Figure 3 and Table 2 show the rate of average dehumidification for selected desiccant materials at a relative humidity of 70%, 25°C of temperature and 2 m/s of air velocity. The dehumidification rate for desiccant brand A was 0.6823 g/kg/min, and B was 0.6849 g/kg/min. Meanwhile, the dehumidification rate for desiccant brand C was 0.3108 g/kg/min, and brand D was 0.3982 g/kg/min. Duration of 45 minutes for dehumidification test discovered that calcium chloride had a better dehumidification ability than silica gel. Brand A and B showed similar dehumidification ability, while brand D had a better ability as a dehumidifier than brand C. This phenomenon is caused by the larger surface area and smaller pore size possessed by brand D compared to brand C.

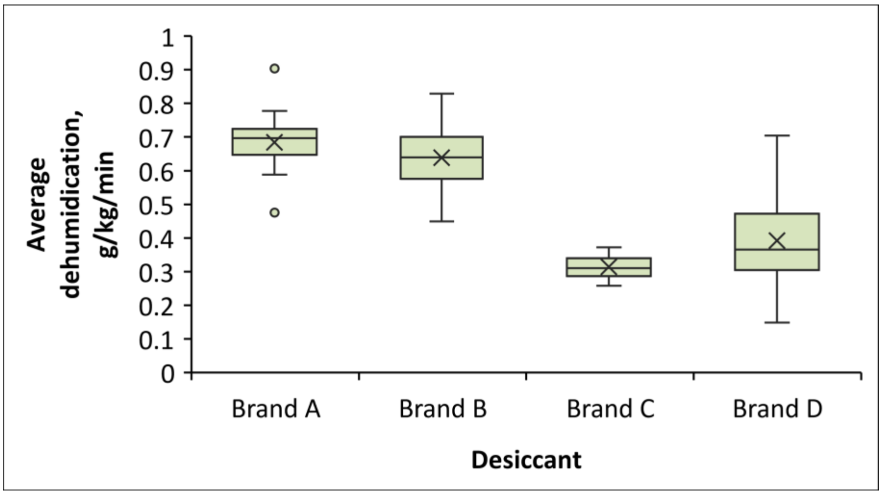

Fig. 3. The average rate of dehumidification per minute at a temperature of 25°C, relative humidity of 70% and air velocity of 2 m/s for each sample

Table 2
Average dehumidification rate data for IAQ test, (g/kg) per minute

Variable	Brand A	Brand B	Brand C	Brand D
Mean	0.6845	0.6381	0.3137	0.3920
Std. Dev	0.0717	0.0810	0.0323	0.1281
Minimum	0.4751	0.4487	0.2580	0.1485
Median	0.6967	0.6395	0.3101	0.3653
Maximum	0.9040	0.8295	0.3723	0.7041

3.1.2 Indoor air quality test analysis

i. Relative Humidity Profile

The relative humidity levels of the test room under various conditions are shown in Figure 4 and Table 3. The average relative humidity of the room from the lowest to the highest for their respective conditions are brand B (63.9%), brand C (66.5%), brand A (67.8%), control (69.0%) and brand D (69.8%). Although the average relative humidity did not reflect brand A as the lowest, the application of brand A in the room gave the highest interquartile range of 21.2%, of which it had a maximum RH of 79.7% among the other conditions. During the application of brand A, the outdoor relative humidity was higher, than during the application of brand B, resulting in higher relative humidity. Brand B had an interquartile range of 20.1%, while brand C had an interquartile range of 14.4%. Furthermore, the application of brand D gave the lowest interquartile range of 13.0%. This can infer that brand D was not as effective in dehumidifying the room.

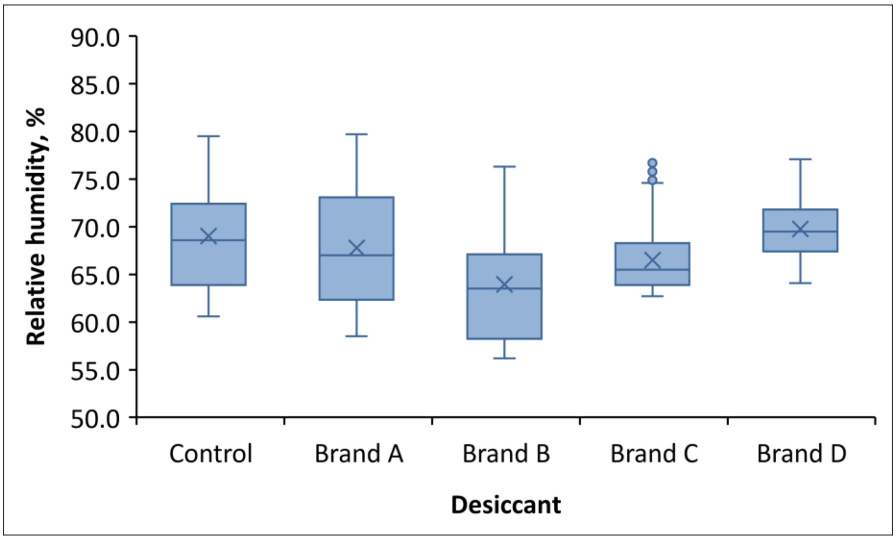

Fig. 4. Relative humidity in the test room during the application of samples

Table 3
Relative humidity data for IAQ test (%)

Variable	Control	Brand A	Brand B	Brand C	Brand D
Mean	69.01	67.78	63.96	66.50	69.77
Std. Dev	5.38	5.10	5.23	3.10	3.18
Minimum	60.60	58.50	56.20	62.70	64.10
Median	68.60	67.00	63.50	65.50	69.50
Maximum	79.50	79.70	76.30	77.10	77.10

ii. Temperature Profile

Figure 5 and Table 4 denote the average temperature of the test room for the five conditions. The control condition recorded 30.9°C, brand A and B were 31.3°C and 32.1°C respectively, while brand C and D were 32.3°C and 31.1°C, respectively. The control condition recorded the lowest average temperature while brand C recorded the highest. The highest fluctuation was owned by Brand A at 5.6°C, while the lowest was brand D at the fluctuation of 3.4°C.

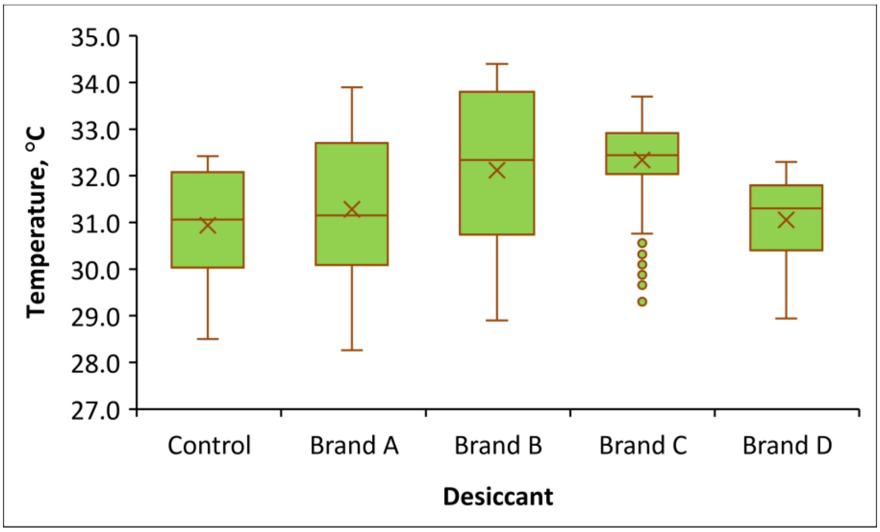

Fig. 5. Air temperature in the test room during the application of samples

Table 4
Temperature data for IAQ test (°C)

Variable	Control	Brand A	Brand B	Brand C	Brand D
Mean	30.9	31.3	32.1	32.3	31.1
Std. Dev	1.1	1.6	1.7	0.9	0.9
Minimum	28.5	28.3	28.9	29.3	28.9
Median	31.1	31.1	32.3	32.4	31.3
Maximum	32.4	33.9	34.4	33.7	32.3

iii. Air Velocity Profile

The air velocity of the test room under the control condition had an average of 0.07 m/s. In Figure 6 and Table 5, the air velocity for brand A was recorded at 0.06 m/s, brand B was 0.002 m/s, brand C was 0.01 m/s, and brand D was 0.03 m/s. Under the test conditions, the fluctuation of air velocity was varied with the highest interquartile of 0.39 m/s recording during the application of Brand A.

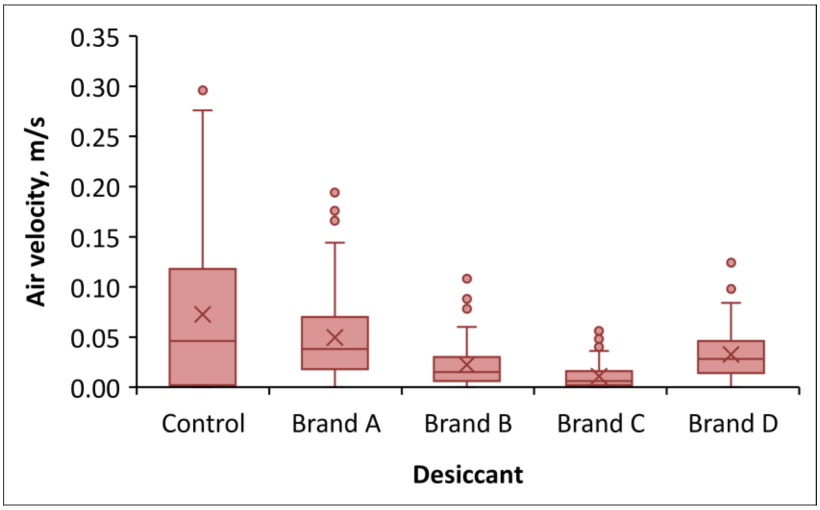

Fig. 6. Air velocity in the test room during the application of samples

Table 5
Air velocity data for IAQ test (m/s)

Variable	Control	Brand A	Brand B	Brand C	Brand D
Mean	0.07	0.06	0.02	0.01	0.03
Std. Dev	0.08	0.08	0.02	0.01	0.02
Minimum	0.00	0.00	0.00	0.00	0.00
Median	0.05	0.03	0.02	0.01	0.03
Maximum	0.30	0.39	0.11	0.06	0.12

iv. Particulate Matter (PM_{10}) Profile

Figure 7 and Table 6 show the mean concentration of PM_{10}. The PM_{10} value of the control condition was found at 0.011 µg/m^3. Brand A and B were 0.005 µg/m^3 and 0.037 µg/m^3, respectively while brands C and D were recorded 0.010 µg/m^3 and 0.005 µg/m^3, respectively. Brand B showed the highest average of PM_{10} at the value of 0.037 µg/m^3. This phenomenon could be due to the road maintenance outside the building that may have contributed to the PM_{10} concentration indoors during the sampling period. A substantial amount of particulate matter was possibly produced by the tar road that contains asphalt [15]. It was reported that indoors could be significantly affected by the outdoor particulate matter [16]. Nevertheless, the hike in PM_{10} could be due to the preparation of calcium chloride pre-packaging in powder form for brand B.

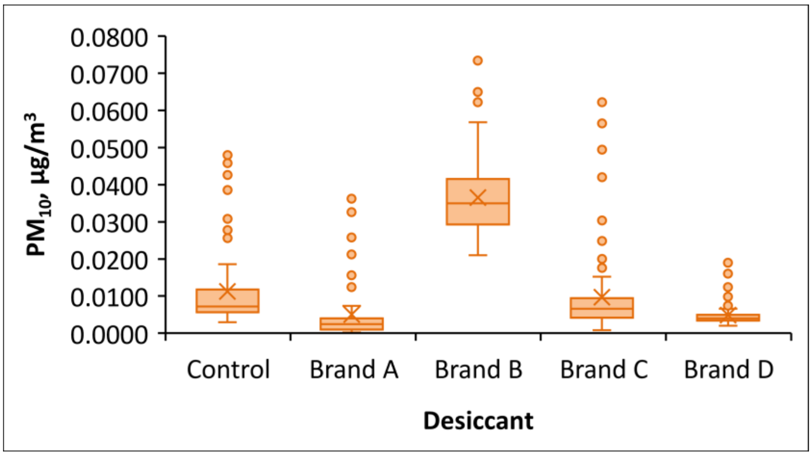

Fig. 7. Particulate matter concentration (PM_{10}) in the test room during the application of samples

Table 6
Particulate matter (PM_{10}) data for IAQ test (µg/m^3)

Variable	Control	Brand A	Brand B	Brand C	Brand D
Mean	0.011	0.005	0.037	0.010	0.005
Std. Dev	0.010	0.008	0.010	0.012	0.003
Minimum	0.003	0.000	0.021	0.001	0.002
Median	0.007	0.002	0.035	0.007	0.004
Maximum	0.048	0.038	0.075	0.064	0.020

v. Carbon Dioxide (CO_2) Concentration Profile

Figure 8 and Table 7 show the concentration of CO_2 measured for each sample. The control condition was recorded at 347.40 ppm of CO_2 concentration. Brand A and B were 347.12 ppm and 377.18 ppm, respectively, while brand C and D were 339.76 ppm and 336.84 ppm, respectively. The test room was naturally ventilated with three opened windows. It was unoccupied during the period of sampling except for the sampling of airborne bacterial and occasional entry. All samples were recorded below the limit value of 5000 ppm and 1000 ppm for CO_2 concentration [17,18].

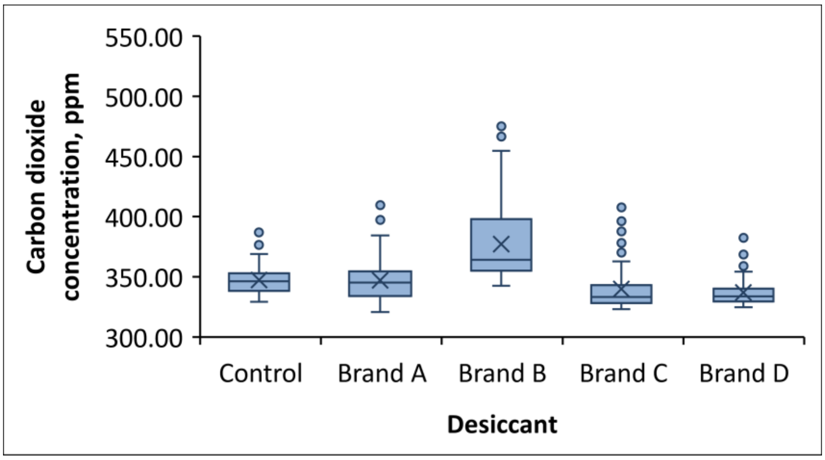

Fig. 8. Carbon dioxide concentration (ppm) in the test room during the application of samples

Table 7
CO_2 concentration data for IAQ test (ppm)

Variable	Control	Brand A	Brand B	Brand C	Brand D
Mean	347.40	347.12	377.18	339.76	336.84
Std. Dev	12.32	16.99	32.23	17.60	11.13
Minimum	329.20	320.80	342.60	323.00	324.60
Median	346.20	345.20	364.10	333.20	333.60
Maximum	389.40	409.60	475.20	407.60	382.40

vi. Airborne Bacteria Profile

The total airborne bacteria counted higher in the afternoon slot compared to the morning slot. The bacterial loading was higher in the afternoon, possibly due to the higher temperature and humidity during that time. A previous study discovered that high bacterial load was affected by factors such as temperature, humidity, and poor ventilation system of an indoor space [19]. Figure 9 shows the average airborne bacteria count for all samples during the morning and afternoon slot. The morning slot for the control condition was recorded as 19±5 cfu/m^3. Meanwhile, morning slots recorded for brands A and B were 18±3 cfu/m^3 and 10±6 cfu/m^3, respectively, while brands C and D were 9±4 cfu/m^3 and 16±4 cfu/m^3, respectively. The afternoon slot for the control condition was recorded as 41±16 cfu/m^3. Brand A and B were 27±20 cfu/m^3 and 24±14 cfu/m^3, respectively, while brand C and D were 37±22 cfu/m^3 and 33±18 cfu/m^3, respectively. Figure 10 illustrates the lowest airborne bacteria count by desiccant brand B. This was caused by the low value of relative humidity present in the test room compared to the other samples during the afternoon slot. Dannemiller *et al.,* [20] discovered that sustained elevated relative humidity gave a significant impact on the growth of the airborne microbial concentration. Hence, the lower relative humidity could decrease the number of moisture-associated bacteria.

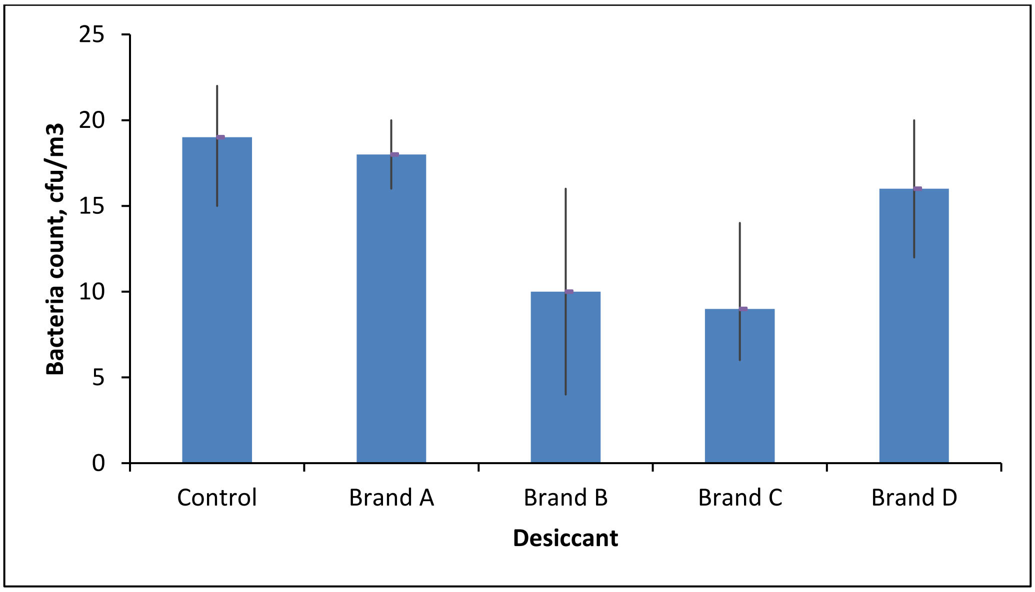

Fig. 9. Airborne bacteria count in the test room during the application of samples for the morning slot

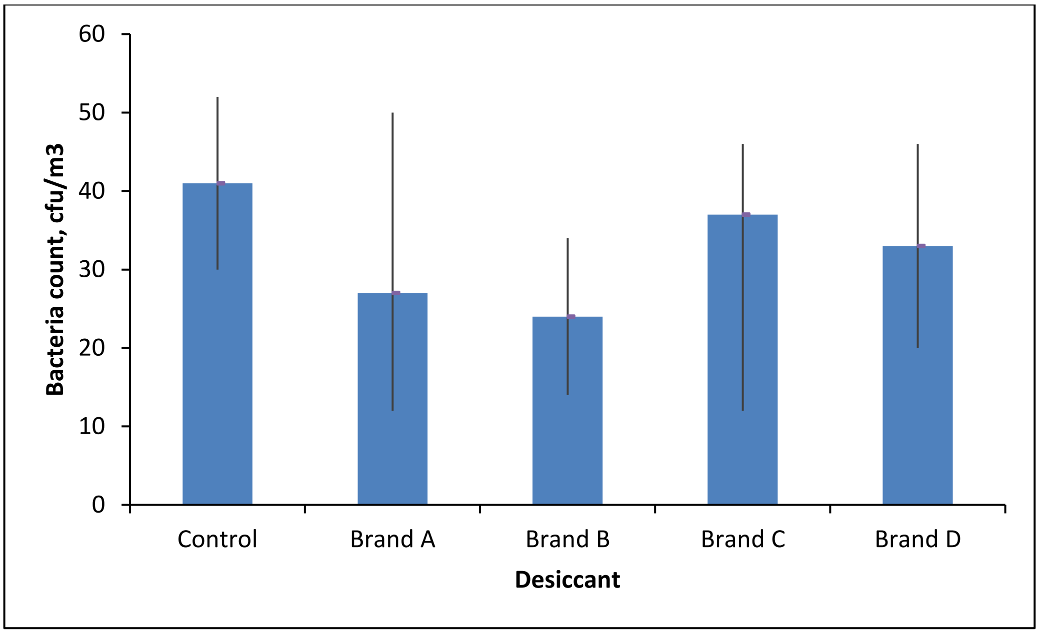

Fig. 10. Airborne bacteria count in the test room during the application of samples for the afternoon slot

3.1.3 Indoor and outdoor relative humidity analysis

The relative humidity for indoor and outdoor profiles are illustrated in Figure 11. Data were collected from Bayan Lepas station (ID: 48601), which was obtained from the website of Malaysian Meteorological Department (MET). The indoor relative humidity profile for all conditions is presented by the line graph in Figure 11. The significant difference of means by two-sample t-test for indoor and outdoor relative humidity was carried out for all samples. The p-value of < 0.05 was obtained, showing that the means value for all samples was significantly different. The difference in relative humidity for brand A was the highest with the value of 13.12%, while the control, brand B, C and D were estimated as 6.54%, 12.54%, 12.05% and 11.83%, respectively.

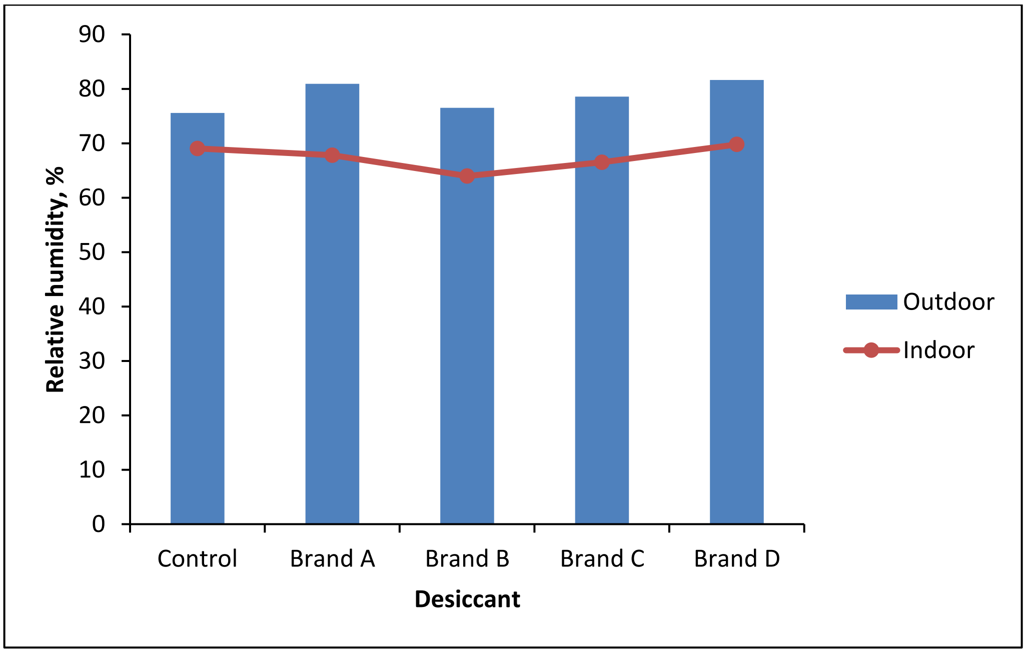

Fig. 11. Indoor and outdoor relative humidity of samples

i. ANOVA Analysis of Indoor Relative Humidity

To determine the significant difference in indoor relative humidity for all samples, one-way ANOVA was carried out. All samples showed significant differences with a p-value was equal to 0.00; thus, the null hypothesis was rejected. Dunnett method was used for post-hoc testing with an interval of 95% confidence. It was concluded that the mean values for all samples were significantly different since the p-value was less than 0.05. This proved that the application of desiccant had a statistical significance towards the dehumidification process in the test room.

Table 8
ANOVA analysis on the indoor relative humidity condition

Factor	N	Mean	Std. Dev	95% CI	
Control	480	69.011	5.399	(68.588, 69.434)	
Brand A	480	67.777	5.948	(67.391, 68.162)	
Brand B	480	63.964	5.285	(63.540, 64.387)	
Brand C	480	66.500	3.459	(66.081, 66.920)	
Brand D	480	69.771	3.224	(69.352, 70.190)	
Source	*DF*	*Adj. SS*	*Adj. MS*	*F-Value*	*P-Value*
Factor	4	10595	2648.7	113.36	0.000
Error	2626	61356	23.36		
Total	2630	71951			

Null hypothesis : All means are equal
Alternative hypothesis : At least one mean is different
Significance level : α = 0.05
Equal variances were assumed for the analysis

ii. ANOVA Analysis of Indoor Airborne Bacterial Count

The analysis for all samples showed that the p-value was equal to 0.873; thus, the null hypothesis was failed to be rejected where it assumes that all the means are equal. The post-hoc test by Dunnett method obtained the p-value was more than 0.05. Hence, all samples in five different conditions were not significantly different, which concluded that the airborne bacterial count was not affected by the application of desiccant materials during the dehumidification process.

Table 9
ANOVA analysis on the indoor airborne bacterial count

Factor	N	Mean	Std. Dev	95% CI	
Control	2	41	15.6	(9.3, 72.7)	
Brand A	3	27.3	20	(1.5, 53.2)	
Brand B	2	24	14.1	(-7.7, 55.7)	
Brand C	3	36.7	21.6	(10.8, 62.5)	
Brand D	2	33	18.4	(1.3, 64.7)	
Source	*DF*	*Adj. SS*	*Adj. MS*	*F-Value*	*P-Value*
Factor	4	421.3	105.3	0.29	0.873
Error	7	2513.3	359		
Total	11	2934.7			

Null hypothesis : All means are equal
Alternative hypothesis : At least one mean is different
Significance level : α = 0.05
Equal variances were assumed for the analysis

4. Conclusions

In this study, the performance in terms of dehumidification ability and IAQ profile of four different brand samples of solid desiccant was carried out. For the dehumidification ability test, a controlled environmental chamber with a relative humidity of 70%, an air velocity of 2 m/s, and a temperature of 25°C was set up. A 45-minute session was applied for all brand samples of desiccant in terms of calcium chloride and silica gel to obtain the average rate of dehumidification ability. The values recorded for that session were 0.6823 g/kg per minute for brand A and 0.6849 g/kg per minute for brand B. Meanwhile, brand C was 0.3108 g/kg per minute and brand D was 0.3982 g/kg per minute. From the IAQ test, brand A showed good dehumidification ability compared to the rest, with the highest indoor-outdoor relative humidity difference of 13.12%. Brand B showed to highest average PM_{10} concentration of 0.037 μg/m^{3,} which may be explicitly due to its powder form. The application of solid desiccants to the test room for the afternoon slot had no statistical significance of means for the indoor airborne bacterial count. In a nutshell, it can be concluded that samples consisted of calcium chloride (brand A and B) possessed better performance compared to silica gel (brand C and D) in terms of dehumidification ability and IAQ profile.

Acknowledgement
This research was funded by the Fundamental Research Grant Scheme (FRGS), Ministry of Education Malaysia, with the account number of 203/PTEKIND/6711574.

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