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The Effect of Hand Dryers on Restroom Indoor Air Quality

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***Abstract*— The widespread use of hand-dryers in public restrooms raises concerns about hygiene and indoor air quality. Hand-dryers facilitate microbial proliferation and aerosolization, increasing infection risk and degrading indoor air quality by dispersing pathogens and allergens. This study investigates microbial growth and air contamination, advancing the field by exploring factors such as humidity, airflow mechanics, and particle count concerning various hand-dryer types. Different models of 8 warm air dryers and 2 jet dryers in ten restrooms were sampled (4 female, 4 male and 2 accessible) in an academic institution. The study involved air sampling from the hand-dryer outlet for 30 seconds directly onto agar plates and surrounding air sampling using the "SAS SUPER ISO 180" device. Microbiological samples were then cultivated on different media, manually counted and identified. Fungi were identified by native smears and safranin staining, bacteria using VITEK. Particle count was measured before and during hand dryer use with "TSI P-TRAK", while other variables such as room temperature, humidity, CO_2 levels, hand dryer air flow velocity, temperature were also recorded. The data was processed using IBM SPSS. Statistically significant correlations were found: airflow temperature negatively correlated with fungal dispersal on Sabouraud agar ($r=-0.747$, $p<0.05$), CO_2 positively correlated with bacterial dispersal on Trypticase soy agar (TSA) ($r=0.661$, $p<0.05$), and humidity showed a significant positive correlation with TSA CFU/min ($r=0.636$, $p<0.05$). Microbial contamination was detected in all restrooms. Warm air dryers consistently emitted higher bacterial loads than jet dryers across all tested media. Hand-dryer air ranged from 0 to 1360 CFU/min, while restroom air ranged from 0 to 1424 CFU/m3. Most fungi identified were molds (*Mucor spp., Penicillium spp., Aspergillus spp.*), with 22 yeast colonies. Analysis identified various opportunistic and pathogenic bacteria, including *Acinetobacter baumannii, Escherichia coli, Staphylococcus* and other species. Average particles count before use was 7831, while during use 11668. The findings indicate that while hand dryers may contribute to bacterial and fungal dispersal, factors such as airflow temperature, humidity, and CO2 levels also play significant roles in microbial behavior.**

Keywords*— *Indoor Air Quality, Hand Dryers, Microbiological contamination, Particles.

I. Introduction

Hand hygiene plays a crucial role in preventing the spread of infections, particularly in public restrooms, where microbial contamination is a concern. While proper hand drying is essential, the method of drying can significantly influence microbial dispersion. Studies have shown that warm air dryers contribute to bacterial aerosolization, potentially increasing contamination levels in restroom environments [1]. - [4.]. Jet dryers, despite their faster drying times, may also pose hygiene risks by dispersing microbes over a larger area due to their high-velocity air streams [5.], [6.].

Research indicates that hand dryers can spread various opportunistic and pathogenic bacterial species, including *Staphylococcus spp., Escherichia coli*, and *Acinetobacter baumannii,* raising concerns about their impact on indoor air quality [7.]- [9.]. Some studies suggest that jet dryers

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result in lower microbial contamination than warm air dryers, while others report greater bacterial dispersion with their use [10.], [11.]. However, comparative studies assessing different hand dryer models under real-world conditions remain limited.

A key finding in previous research is the significant role that air velocity plays in the dispersion of microorganisms [12.]. Notably, this study examined both bacterial and fungal presence while incorporating important environmental parameters such as CO_2 concentration and airflow velocity, which were often overlooked in earlier studies. Understanding how these factors influence microbial transmission is crucial, as room conditions like humidity, temperature, and air exchange rates have a direct impact on the proliferation of both bacteria and fungi [13.], [14.]. These environmental factors are critical in assessing the hygiene risks associated with hand dryers, as they help explain how microbial contamination is spread in enclosed spaces like restrooms.

This study investigates microbial growth and air contamination, advancing the field by exploring factors such as humidity, airflow mechanics, and particle count concerning various hand-dryer types. The aim of this study is to assess the impact of different hand dryers on microbial dispersion and air quality in public restrooms. By analyzing air samples from various hand dryer models in an academic setting, the relationship between airflow mechanics, microbial proliferation, and particle dispersion will be evaluated. The findings will provide insights into the hygiene risks associated with different hand drying methods and their implications for public health.

II. MATERIALS AND METHODS

This study was conducted to assess the microbiological and environmental impact of different types of hand dryers in restrooms within an academic institution, with a particular focus on indoor air quality. Indoor air quality is a critical factor influencing health and hygiene, especially in shared spaces like restrooms where microbial dispersion can occur.

TABLE 1 RESTROOM DESCRIPTION

Room Nr.	Gender and accesibility	Restroom area, m^2	Hand dryer room, m^2
1.	Female	31.9	16.5
2.	Male	30.2	
3.	Accessible	3.1	
4.	Female	12.2	6.5
5.	Male	11.1	2.7
6.	Female	11.9	4.7
7.	Accessible	3	
8.	Male	11.8	4.1
9.	Female	6.8	2.2
10.	Male	6.9	2.2

A total of ten restrooms were included in the study, comprising four female restrooms, four male restrooms, and two accessible restrooms. (Table 1.) The hand-drying devices sampled consisted of eight warm air dryers and two jet dryers, representing various models.

A. Preliminary Data Collection

Prior to the experiment, floor plans including square meter measurements and information on disinfectants and soap used in the restrooms were obtained. The disinfectants used were ethanol 70% and benzalkonium chloride 0.06%. Ethanol is effective against a broad range of bacteria, viruses, and fungi, making it a widely used disinfectant.

TABLE 2 HAND DRYER TYPES

Room Nr.	Hand dryer Type	Hand dryer model
1.	Jet	Faneco Monsun 1900W, DA1900PFW
2.	Jet	Faneco Monsun 1650W, DA1650PFS
3.	Warm air	P+L Systems Automatic Hand Dryer Value DV2100P
4.	Warm air	P+L Systems Automatic Hand Dryer Value DV2100P
5.	Warm air	P+L Systems Automatic Hand Dryer Value DV2100P
6.	Warm air	Mediflow Intelligent sensor operated hand dryer, M02A
7.	Warm air	Machflow sensor operated hand dryer M09A
8.	Warm air	Mediflow Intelligent sensor operated hand dryer, M02A
9.	Warm air	Mediflow sensor operated hand dryer, M03A
10.	Warm air	Mediflow sensor operated hand dryer, M03A

TABLE 3 HAND DRYER DESCRIPTION

Room Nr.	Manufacturer-specified hand dryer velocity, m/s	Manufacturer-specified airflow temperature, C°	Measured airflow temperature, C°
1.	95	35	31.5
2.	95	35	35
3.	20	65	30.8
4.	20	65	Exceeded limit
5.	20	65	Exceeded limit
6.	26	50	23.9
7.	55-90	45	30.4
8.	26	50	41.2
9.	26	50	45.9
10.	26	50	49.3

Benzalkonium chloride provides residual antimicrobial activity and is effective against bacteria and some viruses, but has limited efficacy against fungal spores, which may allow certain fungi to persist in the environment. Additionally, the types of hand-drying models present in the restrooms were identified. The study included two

models of jet dryers and four types of warm air hand dryers. None of the models had UV features, but both jet dryers had an antimicrobial coating. (Table 2., 3.)

B. Microbiological Sampling

Microbiological sampling involved two primary approaches: direct air sampling from the hand dryer outlets and ambient air sampling within the restroom environment. Airborne microbial contaminants emitted by the hand dryers were collected by exposing agar plates directly to the dryer's airflow for 30 seconds (representing average hand drying time) 5-15 cm from the outlet. Concurrently, the surrounding air was sampled using the SAS SUPER ISO 180 air sampler, which was placed near hand-washing stations and dryers, to assess airborne microbial load beyond the immediate dryer vicinity. Plates for fungi and bacteria were filtered through 500L of air from the restroom environment using this system. (Fig.1.)

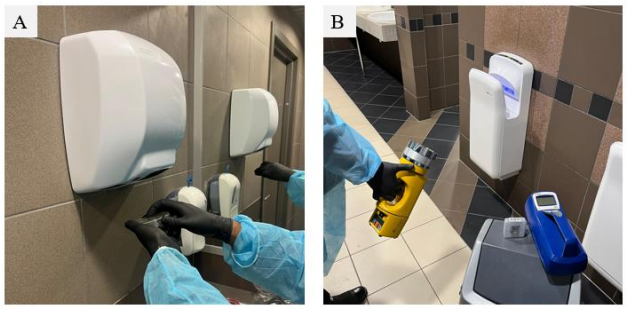

Fig.1 Microbiological sampling
A Hand dryer air sampling B. Restroom air sampling

Following collection, microbiological samples were cultivated in various culture media to facilitate the growth and identification of bacterial and fungal species. Bacterial species were cultivated on Trypticase Soy Agar (TSA) for general bacterial growth, Mannitol Salt Agar (MSA) for the selective growth of Staphylococcus species, and MacConkey Agar (MA) for the isolation of Gram-negative bacteria. Incubation was conducted for 24 hours at 37°C. Fungal species were incubated for 48 hours at 22°C on Sabouraud Agar (SA), which is designed for the selective growth of fungi and yeast. Colony-forming units (CFUs) were manually counted, and microbial identification was performed. Fungal identification was conducted using native smears and safranin staining, while bacterial identification was performed using Gram staining and the VITEK automated identification system. A total of 28 samples were analyzed using the VITEK system, identifying 21 Gram-positive (Gr+) and 7 Gram-negative (Gr-) bacterial species. However, there were limitations in the analysis, as only 28 bacteria could be identified due to technical issues.

C. Environmental and Particle Analysis

In addition to microbiological assessments, particle counts were measured both before and during hand dryer operation using the TSI P-TRAK device (particles size <1 um). This allowed for the evaluation of airborne particle concentration variations in response to dryer use. To evaluate the restroom environment, several parameters were recorded before the experiment (Table 4.) Air temperature and humidity levels were measured using the Aranet4Home monitoring system (Ltd SAF Tehnika), as these factors can influence microbial survival and dispersion. Additionally, airflow velocity and temperature of each hand dryer were measured using the Testo 400 Multimeter (Ltd Testo), as these factors could influence bacterial dispersal patterns. Carbon dioxide (CO_2) levels within the restroom environment were also monitored using the Aranet4Home system to assess ventilation efficiency, which can impact microbial persistence in the air. These measurements provided insight into the potential impact of hand dryers on indoor air quality by examining variations in airborne particle levels before and during their use. Since the restrooms remained open to users during the study, user traffic was recorded to account for potential variations in microbial load due to occupancy levels.

TABLE 4 RESTROOM ENVIRONMENT DESCRIPTION

Room Nr.	Average room airflow, m/s	Average room humidity %	Average room CO_2 levels, ppm	Average room temperature, C^o
1.	0.0183	27.2	824.8	22.8
2.	0.0100	24.8	723.4	24.3
3.	0.0050	26.8	799.6	24.5
4.	0.0017	28.1	955.5	24.4
5.	0.0033	30.2	940.3	23.7
6.	0.0033	32.2	1201.6	23.1
7.	0.0083	31.7	995.1	22.5
8.	0.0067	32.8	1125.9	22.8
9.	0.0167	31.8	963.6	24.2
10.	0.0200	41.8	1033.6	23.5

D. Data Processing and Statistical Analysis

All collected data were processed and analyzed using Excel and IBM SPSS statistical software. The correlations were assessed by Spearman's correlation test. A p value < 0.05 was considered statistically significant. For air sampling, microbial concentrations were calculated as CFU/m³, while for hand dryer air, CFU/min values were determined by doubling the observed counts, as testing was conducted for 30 seconds.

III. RESULTS AND DISCUSSION

A. Microbiology

Microbial contamination was detected in all restrooms. Hand-dryer air ranged from 0 to 1360 CFU/min, while restroom air ranged from 0 to 1424 CFU/m³. Warm air dryers consistently emitted higher bacterial loads than jet

dryers across all tested media. (Fig.2, Fig 3.) Direct air sampling showed Trypticase Soy Agar (TSA) with an average of 531 CFU/min for warm air dryers compared to 66 CFU/min for jet dryers, and similar trends were observed in MacConkey agar (15 CFU/min vs 7 CFU/min) and Mannitol Salt Agar (MSA) (195 CFU/min vs 69 CFU/min). Room air sampling also revealed higher bacterial concentrations in restrooms with warm air dryers, with TSA averaging 671 CFU/m³ and MSA averaging 300 CFU/m³, compared to 520 CFU/m³ and 159 CFU/m³ for jet dryers, respectively. MacConkey agar in room air showed 30 CFU/m³ in restrooms with warm air dryers versus 2 CFU/m³ for jet dryers, highlighting the greater bacterial dispersion associated with warm air dryers. Warm air dryers were often located in smaller and less crowded restrooms, which could limit air circulation and allow bacteria to accumulate over time. Additionally, these dryers appeared less clean, which may have contributed to the higher microbial loads observed. In contrast, jet dryers had an antimicrobial coating, which could have played a role in their lower bacterial emissions.

Gender differences were observed, particularly in MacConkey agar, where jet dryers in female restrooms showed 0 CFU/min, while male restrooms had 14 CFU/min. Conversely, warm air dryers in female restrooms had higher bacterial levels than in male restrooms, with TSA results showing 596

CFU/min in female restrooms versus 342 CFU/min in

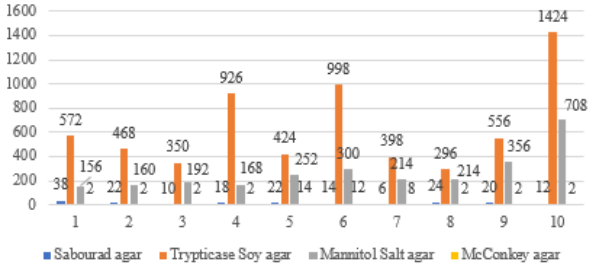

Fig.2 Microorganism concentration in restroom air, CFU/m3

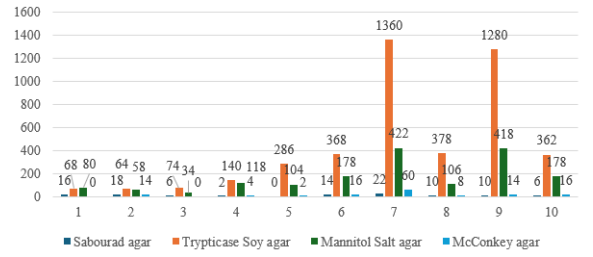

Fig.3 Microorganism concentration in hand dryer air, CFU/min

male restrooms, and MSA results at 238 CFU/min in female restrooms versus 129 CFU/min in male restrooms. These differences could be explained by user traffic patterns, as the average number of users was 6.25 for female restrooms and 2.75 for male restrooms, with peak usage reaching 10 in female restrooms and 5 in male restrooms.

A total of 28 samples were analyzed using the VITEK system, identifying 21 Gram-positive (Gr+) and 7 Gram-negative (Gr-) bacterial species. (Table 5) Among the identified species, *Staphylococcus haemolyticus, Staphylococcus saprophyticus*, and *Acinetobacter baumannii* are considered opportunistic pathogens, potentially posing a risk in vulnerable individuals. Other opportunistic bacteria such as *Escherichia coli* and *Pseudomonas fluorescens* were also identified. Notably, *Escherichia coli* was detected in a male restroom with jet dryers from direct hand dryer air, suggesting possible contamination or bacterial dispersion via the dryers. Additionally, species like *Leuconostoc mesenteroides* and *Kocuria kristinae,* while generally less harmful, can still cause infections under certain conditions. The presence of these bacteria underscores the potential health risks, particularly in environments with high microbial exposure. These findings are in line with other researches which highlighted the presence of *Staphylococcus spp*. in restroom environments [7.].

TABLE 5 IDENTIFIED BACTERIA

Identified bacteria	Count
Leuco.mesen.cremonis	2
Staph.hom.hominis	1
Koc. varians	2
Ps.oryzihabitans	1
Koc. kristinae	3
Staph.lentus	1
Staph. warneri	1
Leuco.mes.dext.	1
Staph. haemolyticus	3
Staph.saprophyticus	1
Staph.vitulinus	1
Sphomon.paucimobilis	2
Parac.yeel	1
Esch.coli	1
Ps.fluorescens	1
Aci.beumanii	1
Unidentified	6
Non/Low reac.biop.	1

Fungi were present in the air of all sampled restrooms, while only 9 out of 10 hand dryer air sampled fungal growth was detected. Regarding fungal diversity, three mold species were identified, with Aspergillus spp. being the most prevalent (40.2%), followed by Penicillium spp. (36.6%) and Mucor spp. (23.2%). Additionally, 22 yeast colonies were detected. The results indicate that the average fungal concentration in room air was 18.6 CFU/m³, while the average fungal count in hand dryer air was 10.4 CFU/min. Among the hand dryers, the jet dryers showed slightly higher average fungal levels (11 CFU/min, 24 CFU/m³) compared to the warm air dryers (8.5 CFU/min, 19.7 CFU/m³). This difference may be attributed to the moisture retention in the air from jet dryers, which could provide a more favorable environment for fungal growth and dispersal.

B. Particles

Hand dryers increase the number of airborne particles during use, with warm air dryers showing a greater impact than jet dryers. On average, the particle count in the room before dryer use was 7,831, rising to 11,668 particles/cm^3 during dryer operation. Warm air dryers had a higher average particle increase (from 8,251 to 12,806 pt/cm3) compared to jet dryers (from 6,150 to 7,115 pt/cm3), suggesting that warm air dryers contribute more to airborne particle dispersion. Additionally, dryer airflow temperature was positively correlated with particle count ($r = 0.714$, $p < 0.05$), further emphasizing that higher temperatures may increase the dispersal of particles. However, the particle count did not show a statistically significant correlation with microbial concentrations in the air, indicating that while hand dryers may increase overall particulate matter, this does not necessarily translate to higher microbial loads.

C. Other variables

There was a positive correlation between humidity and bacterial counts, particularly for MacConkey agar (MA) and Trypticase Soy Agar (TSA). The correlation was significant for TSA CFU/min ($r = 0.636$, $p<0.05$), MA CFU/min ($r = 0.699$, $p<0.05$), and MA CFU/m³ ($r = 0.815$, $p<0.05$), indicating that higher humidity levels may contribute to increased bacterial presence. The recorded humidity levels ranged from 25% to 42%, with an average of 31%. These findings suggest that variations in humidity could influence microbial survival and dispersion in restroom environments, potentially affecting indoor air quality and hygiene conditions.

Positive correlation between CO2 levels and bacterial dispersal was observed. A moderate correlation was found between CO2 and bacterial dispersal on TSA ($r = 0.661$, $p < 0.05$), and a stronger correlation was observed on Mannitol Salt Agar ($r = 0.736$, $p < 0.05$). This correlation between CO2 and bacterial dispersal could be attributed to several factors. Higher CO2 concentrations in enclosed spaces can lead to changes in air circulation patterns, potentially promoting the movement and spread of airborne particles, including bacteria. Additionally, higher CO2 levels may affect microbial metabolic activity, which could also influence bacterial proliferation and dispersion. These findings suggest that environmental factors such as CO2 levels could play a role in bacterial distribution, warranting further investigation to better understand the underlying mechanisms.

Room temperature did not show statistically significant results in relation to bacterial dispersal, but airflow temperature had a negative correlation with fungal dispersal on Sabouraud agar ($r = -0.747$, $p< 0.05$) and bacterial concentration on MacConkey agar ($r = -0.764$, $p<0.05$). These findings suggest higher airflow temperatures may reduce bacterial dispersal. However, there were issues measuring the temperatures of hand dryers, with some exceeding the maximum temperature range of the device.

IV. CONCLUSIONS

Both bacterial and fungal dispersal were observed, with warm air dryers consistently showing higher bacterial concentrations compared to jet dryers. The presence of opportunistic pathogens such as *Staphylococcus haemolyticus, Escherichia coli,* and *Acinetobacter baumannii* in hand dryer air indicates potential health risks, particularly in environments with frequent microbial exposure. Additionally, fungi were detected in all restrooms, with Aspergillus spp. being the most prevalent. Jet dryers exhibited slightly higher fungal counts, possibly due to moisture retention, which creates a more favorable environment for fungal growth.

Airborne particles were also affected by the use of hand dryers, with warm air dryers leading to a greater increase in particle concentration compared to jet dryers. The increase in airborne particles was positively correlated with airflow temperature, which may contribute to the dispersion of particulate matter. However, no statistically significant correlation was found between particle concentration and microbial counts in the air.

Environmental factors such as humidity and CO2 levels played a role in microbial dispersal. A positive correlation between humidity and bacterial counts was observed, particularly on MacConkey and Trypticase Soy agars. CO2 levels also showed a moderate to strong correlation with bacterial dispersal, suggesting that changes in air circulation and microbial metabolic activity could be influencing bacterial movement in enclosed spaces. In contrast, room temperature did not have a significant effect on microbial dispersion.

Overall, this study underscores the importance of considering both microbial and environmental factors when evaluating the impact of hand dryers on indoor air quality. The findings indicate that while hand dryers may contribute to bacterial and fungal dispersal, factors such as airflow temperature, humidity, and CO2 levels also play significant roles in microbial behavior. Further research is needed to explore the underlying mechanisms of microbial dispersal and the influence of environmental factors on air quality in public restrooms to organize appropriate hand dryers' maintenance and air quality exchange.

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