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John Voccio
School of Engineering,
Wentworth Institute of Technology,
Boston, MA 02115
e-mail: voccioj@wit.edu

Valeria Vivas Merino
School of Engineering,
Wentworth Institute of Technology,
Boston, MA 02115
e-mail: vivasv@wit.edu

Mansour Zenouzi[1]
School of Engineering,
Wentworth Institute of Technology,
Boston, MA 02115
e-mail: zenouzim@wit.edu

Andrew Seredinski
School of Science and Humanities,
Wentworth Institute of Technology,
Boston, MA 02115
e-mail: seredinskia@wit.edu

William Burgess
School of Science and Humanities,
Wentworth Institute of Technology,
Boston, MA 02115
e-mail: burgessw@wit.edu

Nicholas Daly
School of Science and Humanities,
Wentworth Institute of Technology,
Boston, MA 02115
e-mail: dalyn@wit.edu

Electrostatic Charge on Smartphone Surfaces

Mobile phones, tablets, and capacitive touchscreens, in general, are ubiquitous in modern society. In this study, the electrostatic charge present near the capacitive touchscreen surfaces was investigated. Results from a Faraday pail experiment indicate that smartphones present an electrostatic charge due to charging and that the magnitude of this charge can vary due to adding additional materials, such as those used as common screen protectors, or by triboelectric events, such as rubbing against another material, as is the case when removing a phone from a pants pocket, for example. Furthermore, this charge increases with lower ambient relative humidity. Understanding these electrostatic charge behaviors may prove useful in minimizing the possibility of either attracting or dispersing unwanted electrically charged particles, such as dust, viruses, or contaminated aerosols, especially in indoor environments with low relative humidity ($RH < 40\%$). [DOI: 10.1115/1.4063982]

Keywords: electrostatic charge, relative humidity, aerosols, Faraday pail, mobile phones, capacitive touchscreens, screen protectors

1 Introduction

Both DC and AC electric fields are endemic to smartphone devices. Most capacitive touchscreens[2] [1–3] utilize projected DC electric fields to detect the presence of a human finger, which has a higher electrical conductivity than air due to its water content, causing a change in the local capacitance. AC electric fields in the hundreds of MHz to GHz are associated with cellular uplink (emitted from the phone) and downlink (received by the phone) signals [4].

The electrostatic charge of airborne particles, such as aerosols, dust, and viruses, also depends on the ambient relative humidity (RH). Aerosols, including those possibly laden with viral particles, generally, as aqueous solutions with dissolved salts, are known to carry electrostatic charge [5]. Therefore, the electrostatic fields near phone surfaces may impact the accumulation via the Coulombic attraction of these aerosolized particles on the phone, which, in turn, make contact with the user.

Relative humidity, which is the ratio of the mole fraction of the water vapor in moist air to the mole fraction of the water vapor in saturated moist air at the same pressure and temperature, directly and indirectly influences several mechanisms that facilitate the transmission of respiratory infections. Most adverse health effects caused by low relative humidity would be minimized by maintaining indoor RH levels between 40% and 60% [6]. Dry air with low RH, as encountered, e.g., indoors during winter due to heating or summer due to air conditioning and inside aircraft, accelerates the evaporation of respiratory droplets exhaled in the air so that they become smaller and lighter, remaining in the air longer, leaving potential pathogens embedded in the droplet suspended in the air [7]. Also, experimental studies have found that RH influences viral stability and that viruses responsible for winter outbreaks are more stable at low RH (20–50%) [8].

Additionally, at low relative humidity, typically $RH < 55\%$ [9], the combination of higher surface resistivities [10] and lower air

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[1] Corresponding author.

[2] https://www.nxp.com/docs/en/white-paper/PROXIMITYWP.pdf

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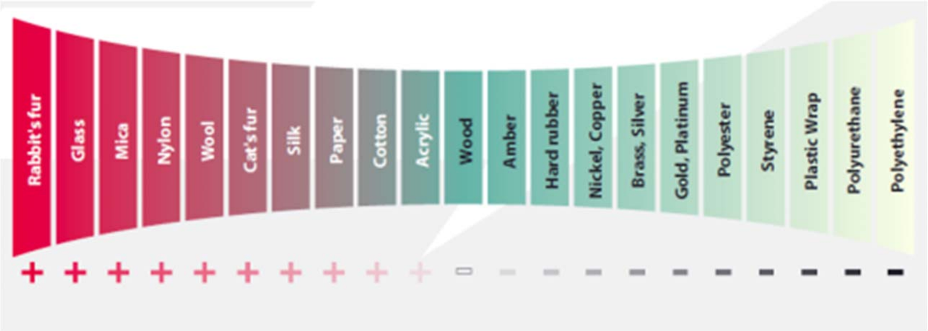

Fig. 1 Typical triboelectric scale: materials on the left side tend to be positively charged, whereas materials on the right side tend to be more negatively charged[6] (with permission from EXAIR LLC, 11510 Goldcoast Drive, Cincinnati, Ohio 45249-1621)

electrical conductivity, due to lower moisture content, gives rise to stronger electrostatic interactions between these electrically charged aerosols and charged surfaces. On the other hand, at high relative humidity, the surface resistivity of airborne particles is reduced by the moisture in the air, thereby lowering any possible electrostatic effect. Therefore, the electrostatic behavior between electrically charged aerosols and capacitive touchscreens could be another important avenue for future study.

In this preliminary experimental study, the effect of relative humidity on the electrostatic charge at phone surfaces after charging is investigated since the surface electrostatic charge is held more strongly at lower relative humidity values [11,12]. As screen protectors are commonly used with smartphones, the impact of different protective layers on charge accumulation is also investigated using different materials across the triboelectric scale [13]. A typical triboelectric scale[3] is shown in Fig. 1, indicating how materials such as rabbit fur and glass (left side of the scale) have a tendency to be positively charged, whereas materials like plastic wrap, polyurethane, and polystyrene (right side of the scale) tend to be negatively charged.

The charge buildup due to a triboelectric charging event depends on the ambient relative humidity. At high relative humidity (RH > 40%), a surface will reach an equilibrium point where the triboelectric current equals the return current, thereby minimizing the electrostatic charge buildup[4]. At low relative humidity levels (RH < 40%), the buildup of electrostatic charge on materials may cause electrostatic discharge (ESD)[5]. Some typical charging events are provided in Table 1, showing the significant difference between charging voltage at 20% RH and 80% RH [14]. Note that charging voltages can be an order-of-magnitude higher at 20% RH as compared to those at 80% RH.

Additionally, the lesser-known effect of contact electrification [15–17] is briefly investigated in this study, as it may help to explain some of the observed experimental data. Contact electrification pertains to the electrostatic charge generation due to contact between materials and subsequent triboelectric events. Furthermore, charge buildup due to contact electrification also depends on relative humidity [18].

Table 1 Triboelectric charging voltages (kV) at low (20%) and high (80%) relative humidity [14]

Charging event (at 20 °C)	20% RH	80% RH
Walking across vinyl floor	12	0.25
Walking across synthetic carpet	35	1.5
Arising from foam cushion	18	1.5
Picking up polyethylene bag	20	0.6
Sliding styrene box on carpet	18	1.5

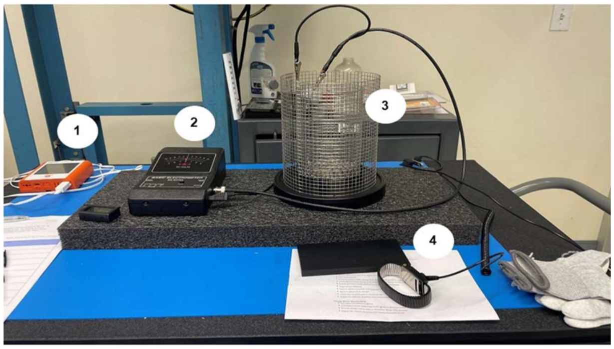

Fig. 2 Faraday ice pail experiment: (1) hygrometer, (2) electrometer, (3) Faraday pail, and (4) grounding strap

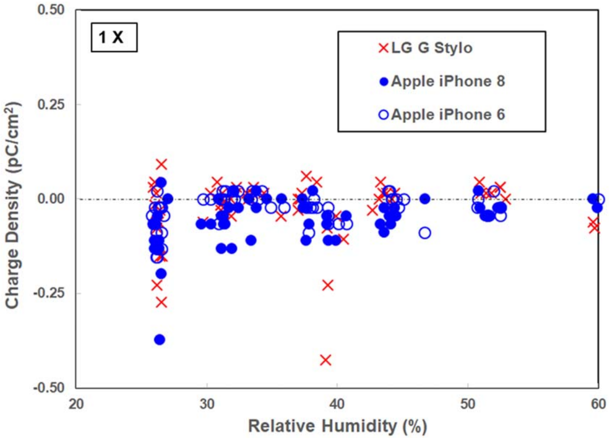

Fig. 3 Bare phone charge density

2 Materials and Methods

In these electrostatic experiments, an Apple iPhone 6, an Apple iPhone 8, and an LG G Stylo phone were employed. The relative humidity was varied in the study by using two dehumidifiers (Haier model HDN655E, Qingdao, China and Toshiba model TDDPP5013ES2, Parsippany, NJ) and measured with a hygrometer (Elitech model GSP-8, San Jose, CA). Additionally, a number of different candidate materials that could be used as screen protectors were studied from across the triboelectric scale. In addition, two commercially available screen protectors—laminate glass and

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[3] https://blog.exair.com/tag/triboelectric-series/

[4] http://esdsystems.descoindustries.com/whitepapers/wp_humidity.html

[5] https://airtecsolutions.com/blog/airtec-blog/airtec-blog/static-electricity

[6] See Note 2.

hydrogel—were tested, and it is important to note that commercially available screen protectors like these typically have an adhesive backing, such as silicone (which is highly negative on the triboelectric scale), which affects the triboelectric behavior of the overall composite material.

For the experiments performed for this study, electrostatic charge accumulation on the phone was measured using a Pasco model ES-9042A Faraday Ice Pail (Roseville, CA) apparatus shown in Fig. 2. In his original experiment, Michael Faraday used a metal pail made to hold ice, which gave the experiment its name [19]. That experiment showed that an electric charge enclosed inside, but not touching, a conducting shell induces an equal charge on the shell and that, in an electrically conducting body, the charge resides entirely on the outer surface [20,21].

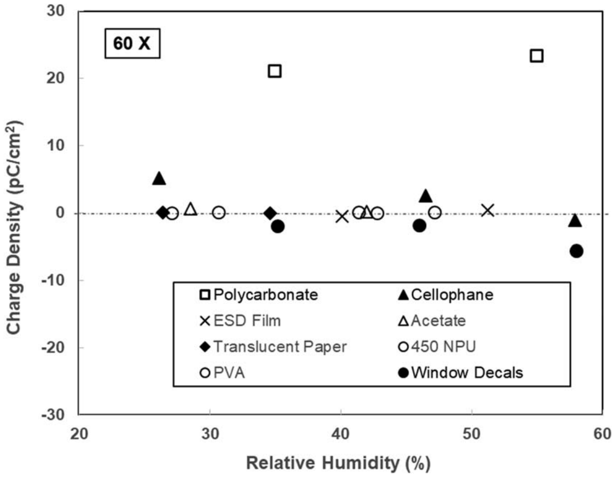

Fig. 4 Candidate screen protector material charge density

For each measurement, the experimenter was initially discharged with a grounding wrist strap. Then, the phones were discharged through the experimenter by clasping in their hands, and the subsequent charge neutrality (prior to phone charging) was confirmed by lowering the phone into the Faraday pail.

Next, the phones were charged for 15 min. Prior to measuring the phone's electrostatic charge, both the inner and outer cages of the Faraday pail were discharged through the experimenter while holding the "zero" function button on the electrometer for 15 s. In order to record the charge measurement, the phones were lowered into the Faraday pail via handling tabs made from anti-static electrostatic discharge (ESD) tape attached to the top of each phone. The conversion factor between charge and measured voltage is approximately 35 picocoulombs per volt (pC/V). The charge density values (pC/cm^2) were calculated by dividing the charge values by the surface area of the phone or the test strips.

3 Results

3.1 Bare Phone Study. The impact of relative humidity on the accumulation of surface static charge during charging of a bare phone (i.e., no screen protector) was explored. For this initial bare phone study, the phones were not removed from the humidity-controlled lab. Each phone was charged with a USB wall charger adaptor for 15 min. The charge was measured after unplugging the phone from its charger. These data are provided in Fig. 3. The 1X label is used to denote this baseline level of charge, and subsequent data were compared to this baseline value and labeled

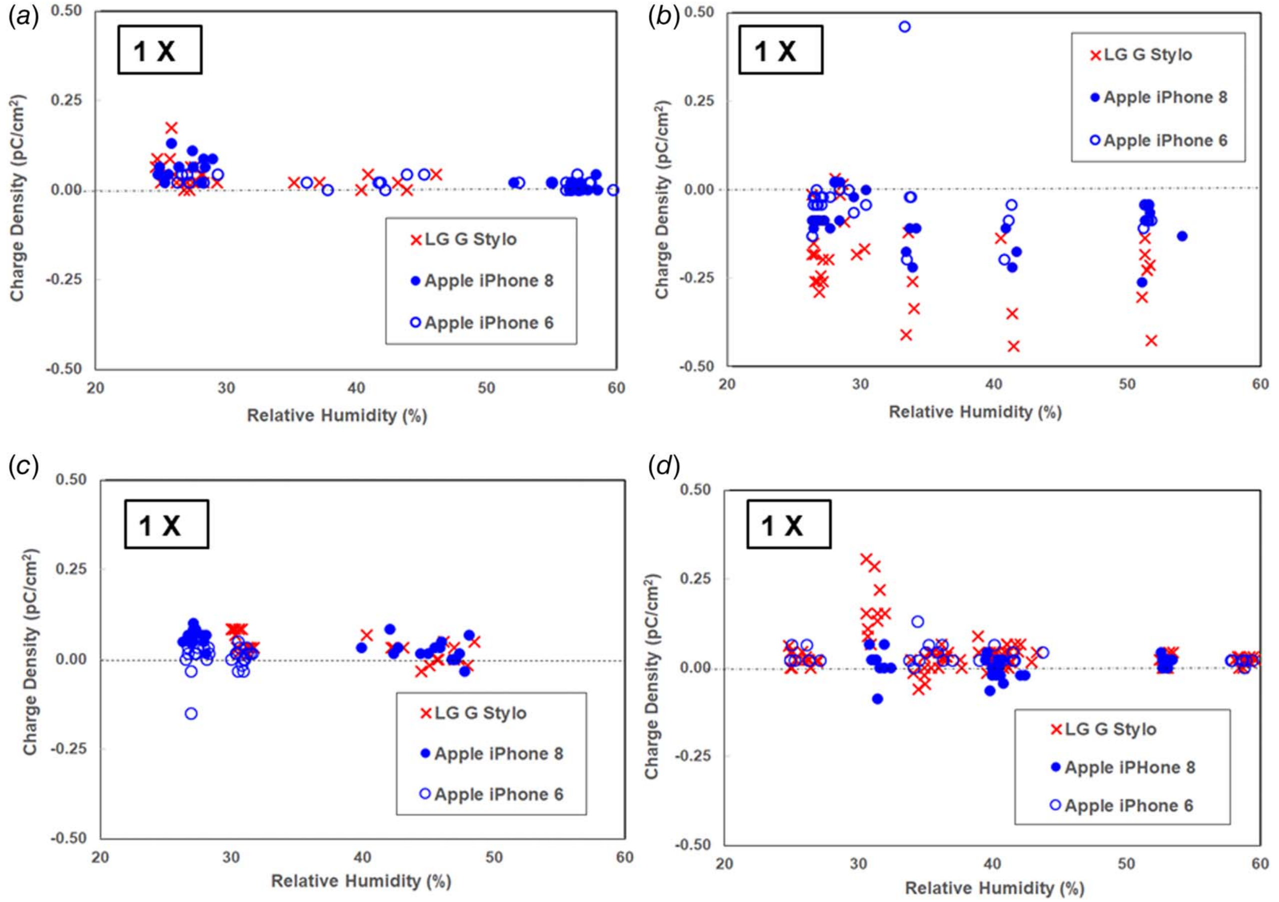

Fig. 5 Charge density with screen protectors: (*a*) PVA film, (*b*) ESD film, (*c*) Futamura 450 NPU paper, and (*d*) translucent paper

accordingly. These data show that bare phones held little charge for RH > 40%, whereas some higher negative charge values were observed at low humidity where RH < 40%.

3.2 Screen Protector Material Study.

Next, electrostatic charge buildup on various materials that *could* be used as screen protectors was investigated. Small samples (15 cm long × 2.5 cm wide) of each candidate material, not attached to any phone, were tested in the Faraday pail. The data in Fig. 4 show that the polycarbonate sample held a significant positive charge (~20 pC/cm^2). Materials located near the center of the triboelectric scale were also tested; these included ESD film, acetate, translucent paper, Futamura 450 NPU paper, which is an uncoated cellulose-based paper, and polyvinyl acetate (PVA). As expected, all of these materials behaved well in terms of showing little or no charge as a function of relative humidity, as shown in Fig. 4.

3.3 Screen Protector Material–Phone Interaction Study.

After separately testing the phones and some of the candidate screen protector materials individually, the candidate screen protector materials were used to cover the phones on both the front and back sides and secured with ESD tape, and the electrostatic charge buildup was measured as a function of relative humidity. The results using candidate screen protector materials selected from the center of the triboelectric scale are shown in Figs. 5(*a*)–5(*d*) for PVA film, ESD film, Futamura 450 NPU paper, and translucent paper, respectively. Phones protected by these materials showed little or no accumulated charge even at low relative humidity, and the overall charge level in the range of −0.5 to +0.5 pC/cm^2 is similar to that of the bare phone data provided previously in Fig. 3.

Since the only candidate material to show a significant charge density in Fig. 4 was the polycarbonate material, this material was also used to cover the phones, and the electrostatic charge was measured as a function of relative humidity, as shown in Fig. 6. While there was a wide range of scatter in these data, the phones with the polycarbonate screen protectors did show positive charge, as expected, in the range of 0–20 pC/cm^2, and these values are similar to those obtained from the individual polycarbonate material data of Fig. 4.

Upon seeing the variation of Fig. 6, additional testing was performed on individual polycarbonate strips as tested in Fig. 4. When suspended in the air (i.e., not touching other surfaces), the polycarbonate strips were able to absorb moisture from the air, thereby partially neutralizing the surface charge. However, polycarbonate strips initially in contact with other materials picked up a significant charge, similar to that of Fig. 4 (~20 pC/cm^2), after contact separation. This observation helped to explain the variation observed when applying the polycarbonate film to the phone in Fig. 6.

3.4 Test Phone Verification Study.

In addition to these lab-condition studies, the accumulated charge on two Apple iPhone 8 phones—one using a commercially available laminate glass screen protector and one having no screen protector—were tested after they were taken outside the lab and manipulated in a typical fashion for smartphones. The phones were randomly tested in the period of September to December 2022, with the experimenter immediately checking the static charge of these two phones upon re-entering the humidity-controlled lab. The results are summarized in Fig. 7. These data mimic phone charge that may accumulate due to triboelectric events such as walking and removing phones from pants pockets. Here, it is important to note that the RH value corresponds to that of the lab and not the environment outside the humidity-controlled lab, which could have either been higher or lower.

In general, these data show that the bare phones with no screen protector (open circles in Fig. 7) had very little charge even at low relative humidity. However, the phone with the laminate glass screen protector (solid circles in Fig. 7) developed an increasing charge at relative humidity RH < 40%. Each data point corresponds to a singular measurement.

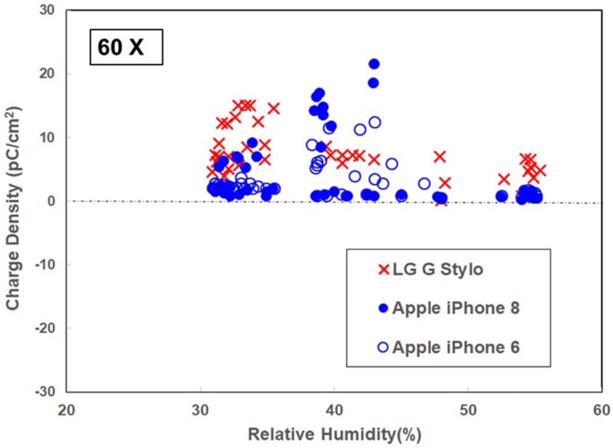

Fig. 6 Charge density with polycarbonate screen protector

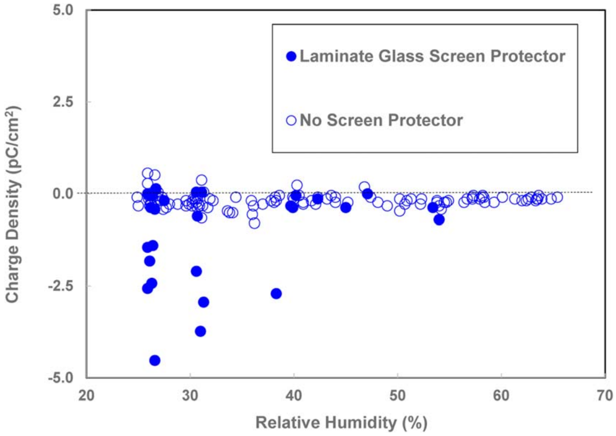

Fig. 7 Verification trial data

3.5 Controlled Screen Protector–Phone Study.

Finally, a couple of different commercially available screen protectors—laminate glass (JETech) and hydrogel (Iiseon)—were tested in a controlled manner, whereby the phones were not removed from the humidity-controlled lab during the study, as opposed to the previous test of Fig. 7 where phones were allowed to leave the lab.

Each of the data points shown in Fig. 8 represents the average of 10 samples taken for each value of relative humidity on two

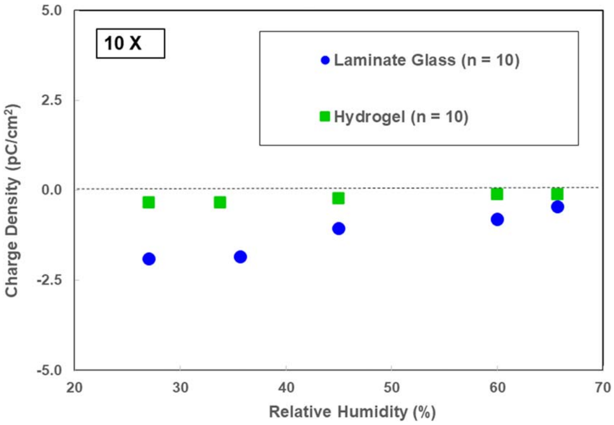

Fig. 8 Screen protector comparison

different Apple iPhone 8 phones. In each case, the phone was also subjected to a triboelectric event, whereby the phone was inserted and removed from a pants pocket and subjected to ten random finger swipes to simulate actual use.

These data indicate that the laminate glass screen protector seems to behave similarly to the previous data from the phone with a laminate glass screen protector in Fig. 7. However, the phone with the hydrogel screen protector shows very little charge even at low relative humidity. Therefore, it is possible that the hydrogel material behaves similarly to the neutral triboelectric materials in Fig. 5 and also the phone with no screen protector in Fig. 7.

4 Conclusions

An electrostatic charge may possibly influence the accumulation via Coulombic electrostatic attraction of electrically charged particles, such as dust, viruses, and aerosols, onto the surface of the phone. Therefore, it is recommended to either use materials that are neutral on the triboelectric scale for screen protectors or perhaps not use a screen protector altogether—i.e., bare phone.

Commercially available hydrogel appears to be a good candidate material since it minimizes electrostatic charge. Also, since hydrogel is a porous, hydrophilic material, it may limit the surface survivability of viruses, as opposed to nonporous surfaces, such as glass, since studies have shown better viral survivability up to several days on flat nonporous surfaces, like glass, than on porous surfaces [22,23].

Also worth noting is that, in these experiments, the experimenter was grounded via a grounding wrist strap. However, in everyday use, people are not grounded while they hold their phones. Therefore, the actual electrostatic charge buildup could be considerably higher depending on the triboelectric history of that person. Future research should investigate the influence of phone case materials too, as they could be a contributing factor to the overall surface charge both due to their triboelectric properties and electrical insulating behavior.

While various risk mitigation strategies, such as social distancing [24], mask wearing [25], and handwashing [26], had varying measures of effectiveness during the SARS-CoV-2 pandemic, other researchers [7,27,28] have noted that low indoor relative humidity seems to influence airborne transmission. In this paper, Faraday pail experiments showed that electrostatic charge on smartphone surfaces is also strongly influenced by indoor relative humidity. Therefore, stronger consideration to raising indoor relative humidity to at least 40% RH should be considered to mitigate risk of these electrostatic interactions, especially in heavily trafficked areas such as airports, and additional research into the electrostatic interactions of airborne particles with capacitive touchscreens may be warranted.

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Conflict of Interest

There are no conflicts of interest. This article does not include research in which human participants were involved. Informed consent not applicable. This article does not include any research in which animal participants were involved.

Data Availability Statement

The authors attest that all data for this study are included in the paper.

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