buildings

Editorial

# Toward Immune Buildings: Lessons Learned from the COVID-19 Pandemic and Its Aftermath

**Tengfei (Tim) Zhang [1] and Zhiqiang (John) Zhai [2,*]**

[1] School of Civil Engineering, Dalian University of Technology (DUT), Dalian 116024, China
[2] Department of Civil, Environmental and Architectural Engineering, University of Colorado at Boulder, Boulder, CO 80309-0428, USA
* Correspondence: john.zhai@colorado.edu

The COVID-19 (SARS-CoV-2) pandemic has not yet ended. The COVID-19 pandemic has been the worst human health crisis after the Second World War [1]. Over 90% of SARS-CoV-2 cross-infections occur in confined spaces (e.g., buildings and transportation cabins), which reveals that confined environments and their associated air systems are vulnerable to infectious disease transmission. Evidence of SARS-CoV-2 indoor transmission has been documented, such as in residential buildings [2], hospitals [3], restaurants [4], offices [5], airport terminals [6], aircraft cabins [7], high-speed trains [8], buses [9], and ships [10], etc. Vaccination has played a crucial role in dampening the SARS-CoV-2 risk; however, it still may not be able to terminate the pandemic in the near future due to the possibility of continuous virus variation. In addition to improving the vaccination rate and vaccine effectiveness, strategies that can reduce the human exposure to various infectious pathogens are pressingly needed, both during and after the pandemic. The experience obtained and lessons learned from one event will always provide great insights into the handling of similar ones in the future.

Buildings are where people spend most of their time, especially during the pandemic. If designed and operated properly, they could slow down or even prevent the transmissions of respiratory infectious diseases. During COVID-19, a variety of control strategies for buildings have been proven to be very useful [11], including wearing masks, washing hands, maintaining social distancing, increasing ventilation and air filtration, managing waste disposal, disinfecting surfaces, etc. After three years of the pandemic, this may be the time to review some of the lessons learned and experiences accumulated from representative COVID-19 events in indoor spaces. This effort may be able to not only guide the current practices for indoor infectious disease control, but also enlighten us on the development and operation of future buildings and environmental systems.

In light of the above aims, we proposed this Special Issue entitled, "Toward Immune Buildings: Lessons Learned from the COVID-19 Pandemic and Its Aftermath", with a call for broad submissions related to COVID-19 transmission, exposure, infection, and control in buildings and public transportation vehicle cabins. It was anticipated that pioneering research and practices could provide new evidence of COVID-19 transmission routes, methods for infection risk evaluation, and novel strategies to reduce indoor SARS-CoV-2 transmission and exposure by means of building design, environmental system operation, human behavior management, etc. This Special Issue includes eight cutting-edge research articles that covered these topics.

These eight papers address two main perspectives: identifying the mechanisms of disease transmission in various indoor spaces and proposing strategies/technologies to reduce indoor pathogen exposure. Minimizing indoor particle exposure can provide a broad protection to indoor occupants by not only reducing the transmission of SARS-CoV-2, but also reducing the transmission of other unknown pathogens for diseases. Several articles investigated both the mechanisms of indoor aerosol transport and the corresponding controls. In exploring the fundamentals of virus transmission, aerosol transport and



**Citation:** Zhang, T.; Zhai, Z. Toward Immune Buildings: Lessons Learned from the COVID-19 Pandemic and Its Aftermath. *Buildings* **2022**, *12*, 1440. https://doi.org/10.3390/buildings12091440

Received: 7 September 2022
Accepted: 9 September 2022
Published: 13 September 2022

exposure risk were analyzed in a restaurant [12], ballroom [12], nasopharyngeal swab sampling cabin [13], lavatory [14], and farmer's market [15]. Some interesting findings deserve attention, such as that the current central air-conditioning systems in commercial buildings may exhaust only a very small fraction (less than 5%) of the pathogen particles released from an infector [12], which reveals the vulnerability of most buildings to infectious disease transmission. Additionally, infectious virus transmission due to human close contact behavior [16] surely merits more concern. Different population groups, e.g., students, workers, and non-workers/non-students, presented different infection risks when they were in close contact with an infector [16].

A few exposure risk mitigation strategies/technologies were analyzed and discussed in great detail in this Special Issue, such as implementing ventilation [17]: by adopting the stratum ventilation, zone ventilation, displacement ventilation, etc., by using force ventilation along with partition boards [13], and by applying portable air filtration and optimizing the filtration deployment locations [12]; and developing personal protection equipment (PPE): by improving face masks with a lower leakage rate but a better comfort feeling [18]. Furthermore, social-psychological responses to infection control and the effectiveness of human behavior management were also addressed [19]—an often neglected aspect in the technical analysis-dominated studies.

As a large amount of uncertainty remains around future pandemics, developing buildings that are resilient and immune to infectious disease transmission is of great interest and is beneficial to human beings and the whole of society. This Special Issue may, as one stepping stone, stimulate more interest and discussion, and provoke more concerns and efforts to investigate human-centered, cost-effective solutions to mitigate health risks before, during, and after any potential pandemics. This Special Issue could not have been published without the great efforts of the authors and our invited reviewers. We are grateful to the editorial team of *Buildings*, including Ms. Haley Shi and Ms. Astoria Yao. Their hard work assured wide distribution of this Special Issue, and quick and professional management of the review of all of the submitted manuscripts.

**Author Contributions:** Writing—original draft preparation, T.Z.; writing—review and editing. Z.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** National Natural Science Foundation of China through Grant No. 51978450.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Li, Y.; Nazaroff, W.W.; Bahnfleth, W.; Wargocki, P.; Zhang, Y. The COVID-19 pandemic is a global indoor air crisis that should lead to change: A message commemorating 30 years of Indoor Air. *Indoor Air* **2021**, *31*, 1683–1686. [CrossRef] [PubMed]
2. Kang, M.; Wei, J.; Yuan, J.; Guo, J.; Zhang, Y.; Hang, J.; Qu, Y.; Qian, H.; Zhuang, Y.; Chen, X.; et al. Probable Evidence of Fecal Aerosol Transmission of SARS-CoV-2 in a High-Rise Building. *Ann. Intern. Med.* **2020**, *173*, 974. [CrossRef] [PubMed]
3. Liu, Y.; Ning, Z.; Chen, Y.; Guo, M.; Liu, Y.; Gali, N.K.; Sun, L.; Duan, Y.; Cai, J.; Westerdahl, D.; et al. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. *Nature* **2020**, *582*, 557–560. [CrossRef] [PubMed]
4. Lu, J.; Gu, J.; Li, K.; Xu, C.; Su, W.; Lai, Z.; Zhou, D.; Yu, C.; Xu, B.; Yang, Z. COVID-19 Outbreak Associated with Air Conditioning in Restaurant, Guangzhou, China, 2020. *Emerg. Infect. Dis.* **2020**, *26*, 1628–1631. [CrossRef] [PubMed]
5. Froum, S.H.; Froum, S.J. Incidence of COVID-19 Virus Transmission in Three Dental Offices: A 6-Month Retrospective Study. *Int. J. Periodontics Restor. Dent.* **2020**, *40*, 853–860. [CrossRef] [PubMed]
6. Chokshi, A.; DallaPiazza, M.; Zhang, W.W.; Sifri, Z. Proximity to international airports and early transmission of COVID-19 in the United States-An epidemiological assessment of the geographic distribution of 490,000 cases. *Travel Med. Infect. Dis.* **2021**, *40*, 102004. [CrossRef] [PubMed]
7. Wang, F.; You, R.; Zhang, T.; Chen, Q. Recent progress on studies of airborne infectious disease transmission, air quality, and thermal comfort in the airliner cabin air environment. *Indoor Air* **2022**, *32*, e13032. [CrossRef] [PubMed]
8. Li, T.; Rong, L.; Zhang, A. Assessing regional risk of COVID-19 infection from Wuhan via high-speed rail. *Transp. Policy* **2021**, *106*, 226–238. [CrossRef] [PubMed]
9. Shen, Y.; Li, C.; Dong, H.; Wang, Z.; Martinez, L.; Sun, Z.; Handel, A.; Chen, Z.; Chen, E.; Ebell, M.H.; et al. Community Outbreak Investigation of SARS-CoV-2 Transmission Among Bus Riders in Eastern China. *JAMA Intern. Med.* **2021**, *180*, 1665–1671. [CrossRef] [PubMed]

10. Mizumoto, K.; Kagaya, K.; Zarebski, A.; Chowell, G. Chowell, GEstimating the asymptomatic proportion of coronavirus disease 2019 (COVID-19) cases on board the Diamond Princess cruise ship, Yokohama, Japan, 2020. *Eurosurveillance* **2020**, *25*, 2000180. [CrossRef]
11. WHO. Transmission of SARS-CoV-2: Implications for Infection Prevention Precautions, Scientific Brief. 2020. Available online: https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions (accessed on 6 September 2022).
12. Zhai, Z.; Li, H.; Bahl, R.; Trace, K. Application of Portable Air Purifiers for Mitigating COVID-19 in Large Public Spaces. *Buildings* **2021**, *11*, 329. [CrossRef]
13. Ma, J.; Qian, H.; Liu, F.; Sui, G.; Zheng, X. Exposure Risk to Medical Staff in a Nasopharyngeal Swab Sampling Cabin under Four Different Ventilation Strategies. *Buildings* **2022**, *12*, 353. [CrossRef]
14. Wan, J.; Wei, J.; Lin, Y.; Zhang, T. Numerical Investigation of Bioaerosol Transport in a Compact Lavatory. *Buildings* **2021**, *11*, 526. [CrossRef]
15. Deng, J.; Yao, F. Sneezing Aerosol Transport in an Indoor Farmers' Market. *Buildings* **2022**, *12*, 355. [CrossRef]
16. Miao, D.; Zhang, N. Human Close Contact Behavior-Based Interventions for COVID-19 Transmission. *Buildings* **2022**, *12*, 365. [CrossRef]
17. Ren, C.; Zhu, H.-C.; Cao, S.-J. Ventilation Strategies for Mitigation of Infection Disease Transmission in an Indoor Environment: A Case Study in Office. *Buildings* **2022**, *12*, 180. [CrossRef]
18. Zhang, T.; Zhang, T.; Liu, S. A Modified Surgical Face Mask to Improve Protection and Wearing Comfort. *Buildings* **2022**, *12*, 663. [CrossRef]
19. Zatta, E.; Condotta, M.; Tatano, V.; Bettelli, A.; Zanella, E.; La Magna, N.; Gamberini, L. Improving the Effectiveness of Anti-COVID Measures in Buildings: Learning from Users' Perception. *Buildings* **2022**, *12*, 1161. [CrossRef]