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EDITORIAL

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Introduction to the indoor environment themed issue

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In the past decade, indoor-air science has shifted from a primary focus on pollutant concentrations to a deeper exploration of how chemical and physical processes unfold on indoor surfaces and in confined air volumes. This editorial previews the advances and open questions captured in this themed issue of *Environmental Science: Processes & Impacts*. Building parameters like ventilation and heating, the types of materials used in construction and decoration, and the behaviors of the occupants all have very large impacts on air quality in the built environment. Thus, a comprehensive view of indoor air quality will need to bridge across fundamental processes and engineering principles to social and behavioral analysis and decisions. This makes it a dynamic and engaging interdisciplinary field. The goal of this themed issue is to showcase recent advances in understanding the indoor environment. The articles range across measurement and modeling studies and bridge between chemistry and engineering perspectives of indoor environments.

Poor indoor air quality is not a new phenomenon. In some locations, it is due to polluted outdoor air infiltrating indoors. Other major sources come from indoor emissions through combustion, cleaning, cooking, spraying, or outgassing. The challenge of pollution coming from indoor emissions dates back centuries. In ancient Rome there is evidence for lung damage in skeletons which is thought to be due to indoor combustion of fats and solid fuels for lighting and cooking.[1] Today indoor combustion for heating and cooking is used by communities across the world, causing indoor air pollution to be the second highest environmental risk factor for premature deaths.[2] In western society fewer people burn solid fuels indoors and more focus is placed on chemicals introduced or created during cooking and cleaning. Overall, the specific challenges in terms of the types and sources of indoor pollutants have changed with time and differ across cultures and across climate zones.

Humans typically spend up to 90% of their time indoors.[3] Indoors can mean different types of enclosed spaces including transportation vehicles, shops, schools, work, and home. Given our time spent in these various built environments, it would make sense to have as much information about the chemicals and pollutants in those spaces as possible. However, this is very challenging due to the wide variety of different pollutants and the breadth of differences across these spaces. Recent advances in measurement techniques have expanded our ability to measure small amounts of chemicals or aerosol particles rapidly.[4] This allows us to probe not only exposures, but also look at the behavior of those pollutants as a function of activities in an indoor environment. The application of advances in analytical techniques opens new doors in our understanding for the types of pollutants we should be concerned with.

The variations observed across different indoor environments is a big challenge in the field. For example, indoor spaces have different types of ventilation and this can vary based on the time of year or even the time of day. We can also add the humans themselves to these variables and the types of clothing, products, and activities they are engaging in. Tackling this variability has been approached in a few different ways. One method is to study a large number of different indoor environments. A field campaign at the turn of the century called RIOPA (Relationships of Indoor, Outdoor, and Personal Air) did this by sampling homes in Los Angeles CA, in Houston TX, and in Elizabeth NJ.[5] These types of field studies provide rich data sets on a relatively small number of measured parameters and they help us understand indoor air quality, especially in comparison to outdoor air. Another experimental approach is to work on understanding fundamental chemical and physical processes so that we can extrapolate to a wide range of different indoor spaces. This approach bridges

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between laboratory studies and 'field' studies in test houses. All of these experimental approaches can support and are supported by models which can provide insights into the fundamental processes and help extrapolate the results to other indoor spaces. The combination of measurements and models is a very powerful tool in this field.

The collection addresses three cross-cutting themes: (i) human influence and mitigation, including pollutant bursts from cooking and cleaning and the rise of low-cost air-cleaning interventions; (ii) novel measurement and analytic methods, from high-resolution time-of-flight mass spectrometry to new approaches for PFAS detection; and (iii) surface-driven processes, examining how high surface-area-to-volume ratios govern indoor chemistry and exposure. The first area is related to the role of humans with studies either looking at the impacts of their actions or studies that help us understand actions people can take to improve their indoor air quality. Activities that generate large amounts of indoor pollutants like cooking and cleaning are important, as can be seen in multiple papers in the issue. For actions people can take, air cleaning methods underwent a large growth due to the Pandemic and multiple articles focus on methods for either aerosol removal or the removal of the infectious portion of respiratory aerosol. Another area that this collection centers on is improvements in measurement techniques and the application of these to better understand both emerging contaminants like PFAS and underappreciated or unexplored chemistry occurring in indoor environments. Finally, the role of surfaces is incredibly important indoors because of the very high surface area to volume ratio. Many articles either probe this directly, or evaluate the effects or characteristics of the indoor surfaces. These articles highlight a wide range of questions in the field, all of which will provide guidance to improve indoor air quality in homes, offices, and schools.

We hope these contributions spark new collaborations and inspire the next wave of inquiries, spanning disciplines, continents, and scales, needed to safeguard the air in the places we live, learn, and work. The built environment has direct impacts on our lives, so we are happy to see all of this research focusing on indoor environments. We would like to thank the RSC and the *Environmental Science: Processes & Impacts* editorial board for giving us the opportunity to work on this collection. We are especially thankful for all the authors who contributed excellent articles and we are grateful for the assistance of the associate editors and the editorial office who helped handle all the papers in this collection.

References

1 L. Capasso, Indoor Pollution and Respiratory Diseases in Ancient Rome, *Lancet*, 2000, **356**(9243), 1774, DOI: 10.1016/S0140-6736(05)71971-1.
2 Institute for Health Metrics and Evaluation (IHME), *Global Burden of Disease 2021: Findings from the GBD 2021 Study; IHME: Sattle*, WA, 2024.
3 N. E. Klepeis, W. C. Nelson, W. R. Ott, J. P. Robinson, A. M. Tsang, P. Switzer, J. V. Behar, S. C. Hern and W. H. Engelmann, The National Human Activity Pattern Survey (NHAPS): A Resource for Assessing Exposure to Environmental Pollutants, *J. Exposure Sci. Environ. Epidemiol.*, 2001, **11**(3), 231–252, DOI: 10.1038/sj.jea.7500165.
4 D. K. Farmer, Analytical Challenges and Opportunities For Indoor Air Chemistry Field Studies, *Anal. Chem.*, 2019, **91**(6), 3761–3767, DOI: 10.1021/acs.analchem.9b00277.
5 C. P. Weisel, J. Zhang, B. J. Turpin, M. T. Morandi, S. Colome, T. H. Stock, D. M. Spektor, L. Korn, A. Winer, S. Alimokhtari, J. Kwon, K. Mohan, R. Harrington, R. Giovanetti, W. Cui, M. Afshar, S. Maberti and D. Shendell, Relationship of Indoor, Outdoor and Personal Air (RIOPA) Study: Study Design, Methods and Quality Assurance/Control Results, *J. Exposure Sci. Environ. Epidemiol.*, 2005, **15**(2), 123–137, DOI: 10.1038/sj.jea.7500379.

