Stale and Still: The Importance of Air Quality and Ventilation in Prisons.

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The air we breathe affects us all. It influences our health, our behaviour, and our life course.[3] However, it is an underappreciated aspect of imprisonment, contributing to violence and shaping behaviour.[4] As an interdisciplinary authorship team spanning public health, criminology, architecture and fluid dynamics, we address the importance of air quality and ventilation in prisons with a bottom-up zemiological approach,[5 6] contending that poor air quality is a structural harm with social and health consequences. We propose recommendations and novel opportunities for improving air quality in prisons that can improve prison safety and public health.

Air quality is an underexplored issue in prisons. Whilst it is widely accepted that prison ventilation is inadequate,[7] literature generally overlooks why it is important and what can be done to address it. Even the Certified Prisoner Accommodation Framework (2023) is vague in its definition of 'adequate' ventilation and the 'likely' risk to health.[8] There is only one mention of 'air' and one brief section on ventilation. However, awareness of its importance has recently increased.

COVID-19 refocused attention and awareness of indoor air quality. The pandemic presented as one of the most impactful and global public health challenges in recent history. By May 2023, COVID-19 accounted for more than 7 million deaths worldwide,[9 10] with over 225,000 in the UK.[11] Many of the highest death rates were found in enclosed settings, particularly indoor residential and care spaces, where people mix frequently and closely.[12] Influenced by environmental, demographic, and pre-existing vulnerability factors, there were 3.33 times more deaths among people in prisons than expected given the age and sex of the population.[13] These settings present a unique health risk to those living and working inside but are interdependent with wider social settings. Addressing the environmental harms associated with these settings will provide a public health dividend for all. In this article, we focus on prison settings, where security measures restrict the opportunities for mitigations, but monitoring and responding to inadequate air quality and ventilation are critical for prison and public safety.

The Value of Air Quality in Prisons

Prisoners can spend more than 95 per cent of their time indoors.[14] Yet, indoor air quality is a relatively understudied subject matter in prison literature. Of the

1. Corresponding author: o.omara@essex.ac.uk
2. The authors acknowledge support and funding from the PROTECT COVID-19 National Core Study on transmission and environment.
3. Whitty, C. (2022). *Chief Medical Officer's annual report 2022: Air pollution.* HM Government.
4. Bondy, M., Roth, S., & Sager, L. (2020). Crime is in the air: The contemporaneous relationship between air pollution and crime. *Journal of the Association of Environmental and Resource Economists, 7*(3), 555-585.
5. Ventilation is the process of bringing in fresh air from outside and removing stale indoor air, which may contain pollutants including chemicals, particulates, bacteria and virus particles. Ventilation is central to reducing indoor air pollution and enabling good indoor air quality.
6. Canning, V., & Tombs, S. (2021). *From social harm to zemiology: A critical introduction.* Routledge.
7. Jewkes, Y., & Moran, D. (2015). The paradox of the 'green' prison: Sustaining the environment or sustaining the penal complex? *Theoretical Criminology, 19*(4), 451-469.
8. Ministry of Justice (2023). *Certified Prisoner Accommodation Framework.* Ministry of Justice.
9. The WHO Director General suggested the true total may be as high as 20 million deaths.
10. World Health Organization (2023). *Weekly epidemiological update on COVID-19* - 4 May. WHO
11. UK Government (2023). *Deaths in the UK; Coronavirus in the UK (30 Jul).* HM Government.
12. Office for National Statistics (2023). *Number of deaths in care homes notified to the Care Quality Commission, England.* Office for National Statistics.
13. Braithwaite, I., Lewer, D., & Edge, C. (2021). I*ndirect age- and sex-standardisation of COVID-19-related mortality rates for the prison population of England and Wales.* UCL Collaborative Centre for Inclusion Health.
14. HM Inspectorate of Prisons (2022). *HM Chief Inspector of Prisons annual report: 2021 to 2022.* HMIP

few known studies on indoor air quality, these suggest a pervasive problem. In Canada, prison staff revealed that prison spaces that were poorly ventilated or contaminated by mould created a perceived risk to physical health and exposure to airborne pathogens.[15] In a Bahamanian prison, the 'stale, contaminated air',[16] combined with overcrowding, was associated with exposure to respiratory tract infections. In a study of nine Italian prisons,[17] prison spaces represent a crucial setting for tuberculosis (TB) — a disease spread through the inhalation of expelled Mycobacterium tuberculosis bacteria. Data from 32 wing landings across four England prisons in 2016 indicated that air quality improved significantly with the introduction of a smoke-free policy. However, air pollution remained an issue and further work was required.[18] More recently, the prevalence of vaping has increased the level of particulates in the air with possible adverse respiratory and cardiovascular effects.[19] These studies suggest that inadequate air quality is systemic across prisons and prison services are failing to address this issue.

These issues exacerbate ongoing delivery challenges as prisons experience high levels of sickness and disproportionate health outcomes among staff and residents. Approximately 10 per cent of annual staff sickness absences are due to respiratory conditions.[20] In the two years to April 2022, 'epidemic/ pandemic' sickness was the leading cause of absence, exceeding mental health issues. Among residents, respiratory infections are twice as common than the wider community,[21] with a long history of experiencing outbreaks, such as tuberculosis,[22] diarrhoea/vomiting, and influenza.[23] Enclosed by walls, doors and windows, those working and living in these settings find themselves sharing the experience: sharing air, respiratory aerosols, bodily fluids, and often physical contact. The high connectivity within these settings and with the wider community poses a public health risk to residents, staff, and wider society.[24]

Part of the problem (and solution) is identifying what to do. Prisons are part of a vast social ecosystem and cannot be epidemiologically isolated. Through inter-prison transfers, staff movements, prisoner release, court appearances, hospitalisation, Release on Temporary License (ROTL), social visits, and new receptions, prisons are interconnected with wider society. Due to this connectivity, the crowded prisoner population, and the proximity of interactions, prisons act as 'amplifiers' and 'reservoirs' of infection, increasing infections and stimulating variants and mutations.[25] In February 2020, a COVID-19 outbreak in a prison 450 miles away from Wuhan, China, was seeded by staff who had visited the Wuhan area, resulting in over 200 infections.[26] Between March and April 2020, there were 135 outbreaks of COVID-19 across prisons in England and Wales. By February 2023, there were over 49,000 known positive cases of infections among prisoners across 130 settings with over 300 confirmed

> The air we breathe affects us all. It influences our health, our behaviour, and our life course.

15. Turner, J., Ricciardelli, R., & Gacek, J. (2023). The "Pains of Employment"? Connecting Air and Sound Quality to Correctional Officer Experiences of Health and Wellness in Prison Space. T*he Prison Journal, 103*(5), 610-632.
16. Moxey-Adderley T., Williams E., Gibson-Mobley I., Sands S. (2016). Prison conditions and the health and well-being of inmates. In W. Fielding, V. Balance, P. Smith, A. Veyrat-Pontet, & H. Sutton (Eds.), *Our prisoners: A collection of papers arising from a 2016 Survey at The Bahamas Department of Correctional Services Facility at Fox Hill* (pp. 161–170). Inter-American Development Bank.
17. Carbonara S., Babudieri S., Longo B., Starnini G., Monarca R., Brunetti B., Andreoni M., Pastore G., De Marco V., Rezza G., & Gruppo di Lavoro Infettivologi Penitenziari (GLIP) (2005). Correlates of *Mycobacterium Tuberculosis* infection in a prison population. European Respiratory Journal, 25(6), 1070–1076
18. Jayes, L. R., Murray, R. L., Breton, M. O., Hill, C., Ratschen, E., & Britton, J. (2019) Smoke-free prisons in England: indoor air quality before and after implementation of a comprehensive smoke-free policy. BMJ open, 9(6), e025782.
19. Li, L., Lin, Y., Xia, T. & Zhu, Y. (2020). Effects of Electronic Cigarettes on Indoor Air Quality and Health. *Annual Review of Public Health, 41*, 363–380
20. HM Prison and Probation Service (2024). *Workforce quarterly: June 2024.* Ministry of Justice.
21. House of Commons Health and Social Care Committee (2018). P*rison Health. Twelfth Report of Session 2017–19, HC 963*. House of Commons.
22. Smith, C. M., Trienekens, S. C., Anderson, C., ... & Maguire, H. (2017). Twenty years and counting: epidemiology of an outbreak of isoniazid-resistant tuberculosis in England and Wales, 1995 to 2014. *Eurosurveillance, 22*(8), 30467.
23. Kinner, S. A., Young, J. T., Snow, K., Southalan, L., Lopez-Acuña, D., Ferreira-Borges, C., & O'Moore, É. (2020). Prisons and custodial settings are part of a comprehensive response to COVID-19. *The Lancet Public Health, 5*(4), e188-e189.
24. SAGE (2021). *EMG: COVID-19 risk by occupation and workplace - 11 Feb.* HM Government.
25. SAGE (2021). *COVID-19 Transmission in Prison settings.* HM Government.
26. Barnert, E., Ahalt, C., & Williams, B. (2020). Prisons: Amplifiers of the COVID-19 Pandemic Hiding in Plain Sight. *American Journal of Public Health, 110*(7), 964–966
27. HMPPS (2023). Official Statistics, *HMPPS COVID-19 statistics – February 2023.* Ministry of Justice.

deaths.[27] As Farmer wrote, 'better habitats for epidemics of airborne disease could hardly be found than overcrowded prisons'.[28] However, improving ventilation and air quality in these settings is challenging, especially as prisons are intended to be physically secure and operational.

In parts of the world that have been urbanised for longer, prisons are frequently older buildings, built either to older standards or before standards were introduced. Some older prison buildings, particularly those built during the nineteenth century, had clear ventilation strategies and provisions. Ventilation was considered important due to the need to exhaust combustion products from lighting and heating systems (such as open fires).[29] However, adaptions over the years, particularly those aimed at improving physical security and energy efficiency, may have reduced the effectiveness of these systems. With limited access to outdoor spaces and restrictions on window openings and free movement, prisons are populous but confining spaces with low ceilings and generally poor air circulation. Although it is unclear how 'new' prisons (built in the previous twenty years) perform, during research in prisons across England during the pandemic as part of the National Core Study (NCS) PROTECT project,[30] the (poor) air quality was immediately apparent in a diverse range of spaces and building types, even without instrumentation. Air in the cells and on the wings felt still and dense with 'security' measures, such as reinforced concrete cells and limited window openings, hindering circulation. This has resulted in high occupancy buildings in-use today that do not meet current guidelines or what was considered good practice when they were built.

Understandably, the attention looking forward is on how to 'build better', but existing buildings remain the bulk of the stock. Our focus on prisons emerges from these risks and the related challenges of interventions. Whilst monitoring air quality was hampered by physical restrictions, affecting many of the privileges we take for granted in wider society (such as remote internet access) we found that prisons have significant potential for mitigations and improvements in public health. Our working assumption is that, with regular environmental monitoring and servicing of natural and mechanical systems, many of the public health risks associated with prisons can be mitigated at low economic cost for high social value.

The relationship between air quality, ventilation, and health outcomes

Inadequate air quality is systemic across prisons and prison services are failing to address this issue.

Poor air quality and inadequate ventilation may impact the behaviour and health of occupants. In addition to deaths from communicable diseases, air pollution contributes to an estimated mortality burden of between 26,000 and 38,000 a year in England.[31] Air quality has been linked to adverse birth outcomes, diabetes, impaired cognitive performance, violence, and susceptibility to more severe health outcomes,[32] with the most deprived experiencing the most adverse effects of poor air quality and the worst health outcomes.[33] [34] There is an interdependent relationship between air quality and ventilation, health, and social outcomes.

With many infectious diseases spread via the respiratory tract,[35] inadequate ventilation and poor air quality pose a well-established risk of aerosol transmission and infection. Aerosol or 'airborne' transmission depends on the interaction between viral emission, ventilation, duration of exposure, environmental conditions, and the number and susceptibility of occupants in an area. In spaces where activities generate high levels of aerosols (e.g. singing, shouting, or aerobic activity) or where people mix in

28. Farmer, P. (2005) *Pathologies of power.* University of California Press
29. Jacob, E. (1894). *Notes on the Ventilation and Warming of Houses, Churches, Schools and Other Buildings.* Society for Promoting Christian Knowledge.
30. Other publications are in development
31. See footnote 3: Whitty (2022).
32. Lu, J.G. (2020). Air pollution: A systematic review of its psychological, economic, and social effects. *Current Opinion in Psychology, 32*, 52–65.
33. Bell, M., Zanobetti, A. & Dominici, F. (2013). Evidence on Vulnerability and Susceptibility to Health Risks Associated With Short-Term Exposure to Particulate Matter: A Systematic Review and Meta-Analysis. *American Journal of Epidemiology, 178(*6), 865–876
34. Marmot, M., Allen, J., Boyce, T., Goldblatt, P. & Morrison, J. (2020). *Health Equity in England: The Marmot Review 10 Years On.* The Health Foundation.
35. Dasaraju, P. & Liu, C. (1996). Infections of the Respiratory System. In S. Baron (Ed.), *Medical Microbiology* (4th ed) (chapter 93). University of Texas.

densely populated spaces (e.g. prisons), adequate ventilation is critical to mitigating infection and illness. Ventilation rates (the amount of outdoor air brought into an indoor space over a given time) below 8-10 litres per second (L/s) per person increase the risk of infections, asthma, allergies, short-term sick leave and decreased perceptions of productivity.[36] The higher the ventilation rate, the more fresh air for occupants and the removal of airborne contaminants.

Addressing indoor air quality may also affect criminality. Studies have shown that air pollution and inadequate air quality are part of a complex social ecology linked to violent crime.[37] In a study of London, Bondy and colleagues (2020) identified that air pollution was linked to higher crime rates and affects crimes that are more likely to be spontaneous (interpersonal violence, criminal damage), concluding that exposure to air pollution may be associated with aggressive or impulsive reactions in people.[38] Air quality is a critical environmental factor contributing to harm.[39] As such, addressing inadequate indoor air quality can contribute to safety and security efforts in prisons and wider society.

Ventilation and good air quality can further mitigate exposure to Volatile Organic Compounds (VOCs). These are emitted as gases from certain solids or liquids and are widely found as ingredients in household products such as floorings, paints and many cleaning, disinfecting, and cosmetic products. Many of these are benign, but some VOCs are associated with short- and long-term health issues, such as cancers.[40] VOCs are ubiquitous indoors and concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors.[41] Residents and staff in prisons, particularly older buildings, are at increased risk of exposure and health issues due to the physical restrictions of their (total) function and delivery, with residents and staff in frequent and close contact in an environment with inadequate ventilation. Monitoring and responding to these risks protects public health and reduces the socioeconomic burden on prison and health services.

Where a building or setting is situated is also an important consideration. It should be noted that where simple ad hoc measures such as opening windows are possible, the ingress of external pollutants from road and rail networks or industrial operations may increase greatly. Air from external smoking areas may infiltrate the buildings, imposing passive smoking on people inside. Similarly, combustion products from site boilers or kitchen extractors may re-enter indoor spaces. A complicating factor here is the dependence on external wind patterns that may shift and alter the risk. At its core, indoor air is outdoor air and as such, certain buildings and sites in urban areas are at more risk than others. Prisons pose a public health risk according to their design and location.

> As Farmer wrote, 'better habitats for epidemics of airborne disease could hardly be found than overcrowded prisons'.

How can air quality and ventilation be improved?

In settings, like prisons, where individuals have little control over their environment and the air they breathe, it is critical to maximise ventilation while keeping buildings thermally comfortable and efficient. Building designs may differ but the first step is to inform policymakers about the relationship between air quality and health. In a report on air pollution in 2022, the Chief Medical Officer for the UK reiterated the importance of air quality and the duty of society to respond:

> *[Air quality] is associated with impacts on lung development in children, heart disease, stroke, cancer, exacerbation of asthma and increased mortality, among other health effects. Except for air quality in our own homes, we have little control as individuals over the level of pollution that we and our*

36. Wargocki, P., et al. (2002). Ventilation and health in non-industrial indoor environments: report from a European multidisciplinary scientific consensus meeting (EUROVEN). *Indoor Air, 12*(2), 113–128
37. Berman, J. D., Burkhardt, J., Bayham, J., Carter, E., & Wilson, A. (2019). Acute air pollution exposure and the risk of violent behavior in the United States. *Epidemiology, 30*(6), 799-806.
38. Bondy, M., Roth, S., & Sager, L. (2020). Crime is in the air: The contemporaneous relationship between air pollution and crime. *Journal of the Association of Environmental and Resource Economists, 7*(3), 555-585.
39. Cruz, E., D'alessio, S. & Stolzenberg, L. (2021). Air Pollution and Violent Criminal Behaviour. *British Journal of Criminology, 62,* 450-467.
40. Rumchev, K., Brown, H., & Spickett, J. (2007). Volatile organic compounds: do they present a risk to our health? *Reviews on Environmental Health, 22*(1), 39-56.
41. De Gennaro, G., Farella, G., Marzocca, A,. Mazzone, A., & Tutino, M. (2013). Indoor and Outdoor Monitoring of Volatile Organic Compounds in School Buildings: Indicators Based on Health Risk Assessment to Single out Critical Issues. *International Journal of Environmental Research and Public Health, 10*(12), 6273-6291.
42. See footnote 3: Whitty (2022). p. i

families breathe — this must be seen as a societal problem to solve.[42]

However, prisons are not required to routinely monitor indoor air quality and ventilation.

Prison design and construction are assessed against and should comply with accepted standards. In the UK these are provided by the Building Regulations (2021), The Health and Safety Executive (HSE) Workplace Health, Safety and Welfare Regulations (1992), and Chartered Institution of Building Services Engineers (CIBSE) standards (Guide A). The recommended standard for workplaces (including law courts, offices, conference rooms, education areas, recreation rooms, and changing rooms) is a fresh air supply/ ventilation rate of at least 10 L/s/person, reflecting how a space is used and occupied. However, many UK prisons were designed and built long before these guidelines, and compliance with these regulations is not adequately assessed, with relatively few buildings retrofitted for ventilation purposes in recent times. Moreover, some aspects of the regulations (e.g., the Workplace Health, Safety and Welfare regulations) apply to prison staff but not to prisoners, while for others the exposure limits are no longer considered acceptable. Critically, our research undertaken as part of the NCS PROTECT project in 2022 across four prisons indicates that the volume, occupancy and behaviours of a space may be more significant than the age of the building.[43] This highlights that 'build better' does not necessarily mean 'build new'. So, what can be done about existing buildings and those prisons that cannot be easily modified or rebuilt?

Those working and living in these settings find themselves sharing the experience: sharing air, respiratory aerosols, bodily fluids, and often physical contact.

Educate and Empower

A prerequisite to improving indoor air quality and the associated health outcomes is increasing knowledge about the importance and value of indoor air quality and ventilation among policymakers and building users. This is particularly important in prisons which are often 'forgotten about' or purposefully neglected to represent and reflect the punitive agenda of imprisonment.[44]

This punitive agenda disregards the impact of the environment on health outcomes and affects everyone in society. For example, between 1844 and 1865 some prisons in England had in-cell sanitation. This was introduced to improve public health and hygiene, however, due to political pressure, in-cell sanitation was removed following the Prison Act of 1865 and was not reinstated in prisons such as Reading until 1990.[45] Prisons have since remained reservoirs and amplifiers of infectious disease, sustaining epidemics such as tuberculosis and streptococcus, affecting public health outcomes for prisoners, staff, and the wider public.[46] As such, education for policymakers and politicians is vital to avoid the mistakes of the past and protect us in the future.

Educating people about what good air quality and ventilation means allows for interventions to be adequately executed. Information for, and the education of, both facilities managers and the occupants are vital. Having buy-in from both those in control of systems and users of the systems is an essential ingredient of implementing improvements, particularly one where there may be a perception of an increase in cost or a reduction in thermal comfort. There needs to be a focus on occupancy and the introduction of clean air, e.g., ventilation and monitoring systems. Alone, each intervention may have minimal effect, but collectively these technologies can contribute significantly to addressing the social harms of inadequate air quality.

These interventions range from controlling room occupancy to improving ventilation by using windows and doors efficiently. Conveying of interventions could range from simple guidance for all or most users of a space to more detailed guidance to those in charge of managing the space (prison officers, teachers, etc.) and thorough guidance and/or training to those controlling ventilation settings to a larger extent (such as those in facilities teams, especially when mechanical ventilation, hybrid ventilation or automated building management

43. National Core Studies programme (2022). https://www.gov.uk/guidance/national-core-studies-programme
44. D. Moran and Y. Jewkes (2015). Linking the carceral and the punitive state: A review of research on prison architecture, design, technology and the lived experience of carceral space. *Annals of Géographie, 124,* 163–184
45. Berkshire Record Office Collections. http://ww2.berkshirenclosure.org.uk/CalmView/Record.aspx?src=CalmView.Catalog&id=PRP1
46. Tavoschi, L., O'Moore, È. & Hedrich, D. (2019). Challenges and opportunities for the management of infectious diseases in Europes' prisons: evidence-based guidance. *Lancet Infections Diseases, 19*(7), e253–e258.

systems are in place). Guidance can be shared through simple messages during inductions or newsletters, or training activities that cover straightforward interventions about when and how to use vents or control room occupancy to a detailed explanation of ventilation strategies. However, this information is predicated on effective and serviceable ventilation systems.

The use of vents — windows, doors and trickle vents — generally increases the ventilation rate,[47] and their use should be recommended (where they are functioning), particularly when relying solely on natural ventilation. The location and opening position of the windows in the space also affect the flow and information on how to best use them should be considered.[48] These measures could lead to changes in temperature, acoustics or even an increase of other pollutants (such as particulate matter from outdoors), so a degree of guidance and personal control about which vents could be left open more generally (such as trickle vents) and which should be used on a more temporal basis (large area vents) would make a positive difference. Using filtering systems may also be recommended when openings cannot be used (because of a lack of them or detriment to other air quality conditions) or if they provide insufficient mitigation.[49] Improving air quality is not impossible, even in enclosed settings, but it starts with education, willpower, and investment.

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Monitor CO2 in 'High-risk, high-contact' spaces

Building and accommodation policies should reflect the changing use and conditions of prison spaces, not just the initial design and building standards. Consequently, prisons require investment in longitudinal monitoring and research of ventilation and air quality. This should start in high-risk, high-contact spaces.

Air quality monitoring can quantitatively assess ventilation in occupied spaces and elicit an appropriate mitigation. Longitudinal monitoring and immediately visible measurements of the air conditions (or gases and aerosols) in a room can be used to identify air quality and the adequacy of or need for ventilation. One of the most used indicators of air quality is the concentration of CO2. As advocated by the HSE, this came to the fore during the COVID-19 pandemic because, in many settings, CO2 can be used as a proxy for the relationship between occupancy and ventilation, therefore informing the risk of exposure and transmission from an infected case. CO2 — along with water vapour, aerosolised droplets from the respiratory tracts and a variety of volatile compounds — is exhaled in the occupants' breath. In the absence of other significant sources of CO2, its measurement can indicate how the air circulates and exchanges, from which the risk of exposure to pathogens or pollutants can be measured. The precise concentration varies depending on the activity performed (e.g., aerobic activity can increase CO2 levels), but for a given level of activity and occupancy, higher CO2 concentrations mean poorer ventilation and a higher risk of exposure.[50]

While the UK's workplace exposure limit for CO2 is currently set at 5000 ppm for eight hours, this is no longer considered acceptable. The recommendation for schools has been 1500 ppm since 2018. More recently, the HSE has issued guidelines stating, 'CO2 levels consistently higher than 1500 ppm in an occupied room indicate poor ventilation and you should take action to improve it'. [51 52] In prisons, there are no standards for monitoring or responding to CO2 levels.

Knowing how a space is designed and used is important to understand air quality and ventilation. The design of the space — its windows, doors, walls, vents and other infrastructure differences — will affect the ventilation, and the levels of occupancy and activity will affect the concentration of CO2, potentially infectious aerosols and other pollutants. Including the requirement to monitor CO2 as part of a Building policy provides a valuable quantitative proxy, indicating when

47. Kolokotroni, M., White, M. & Perera, M. (1997). Trickle ventilators: Field measurements in refurbished offices. *Building Services Engineering Research and Technology, 18*(4) 193–199.
48. N. Khan, Y. Su, and S. B. Riffat (2008). A review on wind driven ventilation techniques. *Energy & Buildings, 40(*8), 1586–1604.
49. Faulkner, C.A., Castellini, J.E., Zuo, W., Lorenzetti, D. & Sohn, M. (2022). Investigation of HVAC operation strategies for office buildings during COVID-19 pandemic. *Building and Environment, 207*, p.108519
50. Chartered Institution of Building Services Engineers (2021). *Covid-19 Guidance: Ventilation* (*v4).* CIBSE
51. UK Government (2018). BB 101: *Ventilation, thermal comfort and indoor air quality 2018*. HM Government.
52. Health and Safety Executive (2023). *Using CO2 monitors - Ventilation in the workplace.* HSE.

a space is being used, providing an idea of occupancy and an assessment of the adequacy of the ventilation rates, hence an indication of other aspects of air quality.[5354] Monitoring spaces and evaluating interventions against guidelines can ensure safe use.

The focus should be on high-risk and high-contact spaces with the poorest ventilation and the greatest risk. Prisons may have different floor plans, number and volume of rooms, orientation to environmental elements, and how the spaces are used/redesigned or adapted from their original purpose. Still, they share high-risk, high-contact spaces, where people behave predictably and follow a formally administered schedule encompassing location and timing.[55] In our aforementioned 2022 study, we identified high levels of CO2 in most shared spaces in prisons, including healthcare settings, gyms, classrooms, staff rooms and offices. The average effective ventilation rate (Litres per second per person) across four prison gyms was around 6 for adjudication rooms, below six for prison gyms, and around four for healthcare spaces.[56] These spaces are significantly below the recommended 10 litres per second per person.[57] CO2 levels in these spaces in each prison also reached maximums of over 2000ppm during occupancy, with a steady state of over 1000ppm, again not meeting recommendations.[58] From spaces with short durations of occupancy to residential accommodation, from workplaces and faith spaces to visitation spaces, ventilation rates were consistently identified as failing to meet guidelines. Monitoring these shared spaces to facilitate air quality improvements will provide a public health dividend, a benefit for all of society.

However, we acknowledge that improving ventilation is not the panacea to reducing the burden of health issues in prisons. As Goyes noted, 'it is impossible to enumerate exhaustively all the situations that impair the health of humans, non-humans and the eco-system'.[59] For example, when infectious and susceptible individuals interact in close proximity (typically less than 2 metres), ventilation alone may have little impact if large respiratory droplets can cross the distance without needing air movements to carry the droplet over a larger distance. Overcrowding, prisoner health profiles, temperature, humidity, and building design are some of the critical considerations in improving prison safety and reducing social harm. Therefore, it is important to take a holistic approach to indoor air quality, addressing how people behave and how the air moves in their environment and interacts with external conditions. Critics may argue that this is a niche issue and priority investments lie elsewhere, but not addressing air quality disregards the role that physical spaces play in our daily lives and fails to address some of the fundamental challenges faced during the COVID-19 pandemic in reducing the risk of aerosol transmission, minimising sickness and staff absences, and protecting the most vulnerable people in our society. With the consequences of climate change, such as extreme temperatures and air pollution, already emerging, these environmental issues will intensify. Air quality and ventilation are not niche issues, they are a public health issue.

Conclusion

Clean air is fundamental to public health and vital for prison safety. We have indicated the interdependent relationship between air quality and ventilation, health, and social outcomes, but the effects are amplified by the social and physical design of prisons. Therefore, users and managers must be educated on how to optimise the safe use of these spaces. It is equally imperative to monitor shared spaces and invest in installing and maintaining adequate ventilation systems (natural or mechanical). Where fresh air cannot be easily provided, services should explore design strategies and new technologies. It is possible to improve indoor air quality and address its social harm, but it takes concerted effort and investment. Any changes are likely to incur a short-term cost, but failing to meet the challenge will inevitably increase the long-term financial and social consequences.

53. Sherman, M. (1990). Tracer-gas techniques for measuring ventilation in a single zone. *Building and Environment, 25*(4), 365–374.
54. Ha, W. et al. (2022). Use of carbon dioxide measurements to assess ventilation in an acute care hospital. *American Journal of Infection Control, 50*(2) 229–232
55. Su, C. et al. (2019). Case Investigations of Infectious Diseases Occurring in Workplaces, United States, 2006–2015. *Emerging Infectious Diseases, 25(*3), 397–405
56. The 'true' ventilation rate is based on room occupancy and calculated by the co2 degradation from peak occupancy to the co2 level at the end of the experiment (ambient or occupancy).
57. CIBSE (2014). Module 69: *Delivering ventilation to occupied spaces.* CIBSE.
58. SAGE (2021). EMG and SPI-B: *Application of CO2 monitoring as an approach to managing ventilation to mitigate SARS-CoV-2 transmission,* 27 May. HM Government.
59. Goyes, D. R. (2019). *Southern green criminology: A science to end ecological discrimination.* Emerald Publishing.