Breathing City: Challenges and Opportunities for Future Urban Ventilation

Scoping document, June 2021

The Breathing City network is one of six networks in the Clean Air Programme. The network hosted a launch event in January 2021 and several subsequent Theme working group meetings to define the network's scope and priorities. Below is a short summary of these discussions up to spring 2021 setting out the key challenges and opportunities that can shape the future of ventilation in urban settings.

Planned activities for the next 12 months of the network include:

- Open call for small research projects (4 x £5,000) that align with the network's aims and objectives and this scoping document. Funded by the network grant.
- Directed call for student internships. Funded by network grant, project partners or a combination of both.
- Survey of public attitudes and understanding of ventilation and indoor air quality.
- Mapping the policy and regulatory responsibilities for air quality in urban environments.
- Workshop for policymakers and legislators to identify challenges and opportunities.
- Seminar series to facilitate knowledge exchange.
- Theme led workshops.

The need for a holistic approach.

A reoccurring theme across all discussion topics is the need for a holistic approach to consider air quality improvement schemes alongside other factors associated with the built environment. These include but are not limited to: ventilation design and operation, energy consumption, operational running costs, sustainability, occupant health, fire safety, thermal comfort, noise, weather protection, building use and crime. Studies show a high percentage of ventilation systems are disabled or have reduced effectiveness due to some of these factors, and that this may be more likely in more deprived communities[1–4].

To simplify a holistic approach, it has been proposed that the network take a four-point methodology focusing on health, species, location, and source, and consider these aspects with respect to the physical environment, regulation and guidance and human behaviour. A systems type approach has already been identified as a useful strategy to explore how these aspects interact.

The need for health-evidence led change.

The causal relationships between indoor air quality and health are difficult to determine. There is quantitative evidence that relates outdoor air pollution to health, but this is more challenging indoors and data on indoor conditions is sparse. To evidence the links between indoor air quality and health, intervention studies, cohort studies and citizen science approaches could build a database of ill-health triggers by monitoring pollutant species and sources (inside and outside), occupants' behaviours, occupants' pre-existing health conditions, peak pollutant/air flow variability and hospital/care-home acquired infections. Some studies show low ventilation rates may be associated with Sick Building Syndrome (SBS) symptoms, perceived air quality, health effects (inflammation, infections, asthma, allergy) and productivity, with more data available for office environments. Few conclusive studies exist regarding residential ventilation and its direct association to health effects of vulnerable groups (e.g. children and elderly people[5]). Lessons can be leant from health-evidence case studies[6–9] and attempts to characterize the health burden associated with outdoor air quality[10].

While the network cannot undertake these studies directly it can identify gaps in knowledge, facilitate collation and sharing of existing information, and bring together teams to tackle larger follow-on research studies. This aspect is critical as a stronger evidence base is needed to influence policy and regulation.

The need to adapt approaches based on pandemic experiences.

Since the inception of the Breathing City network, the COVID-19 pandemic has resulted in a greater understanding of the connection between ventilation and infectious disease, recommendations to increase ventilation rates in many UK buildings and increased public understanding more broadly of indoor air quality (IAQ).

To bring together the latest information on the connections between ventilation and health, a review of academic and grey literature is required along with a series of expert interviews. It is proposed that this work will be led by Theme 2 within the Breathing City network.

The need for monitoring, testing and data.

The need for monitoring was a reoccurring theme in discussions. Monitoring is needed to provide an evidence-based foundation for indoor air quality improvement schemes and help the network identify sources and transport of pollution. The indoor species suggested to be monitored include PM1s, PM2.5s, NO_2, CO, O_3, VOCs and reaction partners (OH, NO_3, Cl radicals), and moisture. Studies can also include monitoring CO_2 along with temperature and relative humidity as one of the simplest indictors of ventilation levels in occupied rooms. For outdoor monitoring, short term episodes of poor air quality vs. longer term pollution must be considered[11]. Ideally these data sets can be paired. Discussions also highlighted the need to consider overlooked or emerging air pollution sources, including construction emissions, non-standardized scented products' emissions, COVID-19 and other microbial exposures, smaller and more toxic urban pollutants, relative humidity from laundry drying, and solid fuel burning. There is also a need to connect air pollution monitoring to measurements of other parameters that may be determinants of exposure, including the physical environment (ventilation, weather, noise) as well as societal data such as population demographics, healthcare data, traffic, crime etc.

Several monitoring approaches have been suggested:

- Using low resolution indoor air quality monitors to identify trends, patterns and "hotspots" followed by high resolution static monitors and wearable devices to extrapolate results and provide data for modelled systems. Use of live monitoring to engage stakeholders/building occupants via traffic light monitors.
- Detailed monitoring of rooms in controlled environment pilot studies to assess spatial variability in data and the relationship with outdoor environments.
- Combine pollutant monitoring with occupant questionnaires to determine both acute and chronic exposures.

It is feasible for the network to draw together existing knowledge, including through the planned air quality studies database, and to collect new pilot data using some of these monitoring and modelling approaches through the network research seed-corn funds. This may also include data-linkage studies to relate air quality data with other data sets.

The need for effective approaches to modelling air flows and pollutants.

Modelling coupled indoor-outdoor air flows is challenging due to the difference in scales and the need to capture physical as well as environmental aspects of the flows. Discussions have suggested a need to model some of the settings where physical measurements are carried out and to combine laboratory-based studies and parameterized models with real-world data collection, to extrapolate relationships and understand the role of airflow. There is a need to source physical data for validation, or undertake field measurements if this is not readily available. Discussions also highlighted a need to look at coupling between different tools to model indoor and outdoor flows to consider the accuracies of the various techniques to effectively model the indoor-outdoor exchange processes.

While the network is unlikely to undertake large scale simulation studies it will be able to carry out analysis to compare modelling approaches and capabilities and to identify key knowledge gaps for future modelling.

The use of artificial intelligence (AI), internet of things (IoT) and big data to respond to temporal variations in environments.

The variation of the environment (air quality, noise, crime risk, temperature, weather etc.) over time is often overlooked. As such, the concept of responsive ventilation/filtration systems using sensors to change air flow depending on indoor/outdoor environment was a popular discussion topic. Deployment of such systems* would improve understanding of building operations (energy consumption, ventilation, IAQ) and enable energy-efficient and health-driven ventilation. This would require increased use of air monitoring to measure delivery of existing indoor air quality schemes. For a long-term successful roll out of responsive monitoring systems, it was suggested that greater standardization is needed across the AI/IoT market.

A summary review paper on how indoor environments may become more responsive in real time considering combined research and practitioner perspectives, including relationships to flow models, would be a useful output from the network.

The need to couple indoor-outdoor environments for different building types and urban locations.

To address the challenges associated with coupling indoor-outdoor environments, the network and its members identified the most important unknowns in pollutant exchange, selected the key pollutant species involved and discussed the practical barriers that cause poor indoor air quality. The diversity of building stock, building use, layout within, and occupant behaviour were also discussed.

Urban residential, SME workplaces, community buildings and hospitality and retail settings were deemed the network's primary building categories of interest as these are likely to be places where more vulnerable occupants may be exposed to air pollutants on a regular basis, and are overlooked. Addressing exposure over the life course particularly for those who are more vulnerable is a key ethos of the SPF Clean Air programme[12]. Larger office spaces are already being studied and were therefore considered beyond the scope of the Breathing City project. Schools were also not considered a focus point due to this being covered by a partner network, TAPAS. Hospitals already have more specific ventilation requirements and have a range of other factors that influence their indoor air quality and will therefore not be in the central scope. However, any overlap into these secondary building categories will of course be taken advantage of and we will collaborate with partners where appropriate.

Of the primary building categories, the physical indoor spaces can be compared and categorised via factors such as building age, ceiling height and room size. Variation between them includes occupancy period and occupant behaviour, the types of ventilation systems within different buildings and the ability for occupants to control the environment. The buildings' ever changing outdoor environment is also an area requiring attention.

These factors can be addressed through data collection (ventilation and behaviour questionnaires, citizen science projects, air quality monitoring and commercial building maps[13]) and computational modelling (to include outside microclimate, flow at indoor/outdoor interface and effect of surround buildings). A typical British high street has been suggested as a preliminary data collection site for pilot scale research studies as it will usually include all the primary building categories.

The need to advance ventilation technologies and energy efficiency.

Some ventilation solutions have the potential to increase energy consumption if not considered in line with net zero targets and the UK's domestic retrofit roll-out. This has been highlighted as an opportunity to be involved with building modifications and approaches, such as Passivhaus design,

* Example pilot study from West Midlands Air Quality Improvement Programme[15]: Real-time air quality data is being collected from IoT modular sensors, which can send data over Wi-Fi and made available via a data hub for analysis to help monitor air pollution in the area[16].

to ensure ventilation is considered in the toolbox of energy efficient technologies[14]. The use of AI and IoT was suggested to measure the energy consumption associated with good indoor air quality. This information can be used to manage when/how to ventilate while maintaining low energy consumption and inform design guidance. External factors which change requirements were also highlighted, such as increased demand for air conditioning on hotter summers or changes in exposures to air pollution due to working from home. Studies that may be relevant for this work include those that focus on school ventilation, use of intermittent ventilation considering indoor and outdoor environments, passive mitigation of PM from outdoor sources, and low-carbon and breathable homes. Considerations might include ingress of outdoor pollutants, heating demand, cooling demand, mechanical ventilation with heat recovery (MVHR), air filtration, natural ventilation, air tightness, cost, noise and risk of crime.

The network has the opportunity to explore the suitability of various ventilation strategies and indoor environment requirements in the context of a net zero built environment in a variety of building types. This could be through seed-corn funding to enable new data on the measured or modelling performance of systems or collation and analysis of existing data across multiple studies.

The need for wide stakeholder engagement.

To successfully deliver better urban ventilation to reduce air pollution exposure, stakeholder engagement is essential at all stages. However, the policy and regulatory responsibilities for indoor and outdoor air may include a wide range of agencies, with some overlaps, but also some significant gaps. The need for a Breathing City advocator was discussed. Stakeholders were separated into several categories:

- Building and urban environment users and occupants and citizens, in particular those vulnerable to poor air quality: children, elderly, urban residents/workers, those with underlying health conditions, and the third sector organisations that represent these groups.
- Those involved in shaping regulation: policy makers, local authorities, professional institutes, MPs and Peers, health trusts, industry standards bodies (e.g., for clean air delivery rate (CADR)).
- Those involved in the entire build process: architects, town planners, developers, engineers, contractors, regulators, building control officers, and clients.
- Those involved in maintaining buildings: building owners, landlords, facilities managers, maintenance engineers, suppliers and contractors.

Successful collaboration and communication with any stakeholder requires a holistic approach as detailed above. It was recognised this may involve collaboration between the stakeholders themselves (e.g., owners and occupiers) to identify their shared responsibilities. It is also this area where there are significant overlaps between technical solutions and behavioural responses.

A successful stakeholder engagement program requires improved understanding/awareness of the importance of good indoor air quality, how this can be visualised and understood, and how this may be achieved. This was highlighted as a challenge in all stakeholder groups. This can be addressed through appropriate engagement on several levels:

1. How to communicate the numbers. For example: traffic light monitors as a ‘health thermometer’ of fresh air in indoor spaces and to improve understanding of what constitutes good air quality, greater standardization across the IoT market and encouraging medical and public health professionals to support this public awareness programme.
2. How to separate the numbers. IAQ is a catch-all phrase for a variety of conditions that makes it difficult to communicate and address (need separating to (e.g.,) PM in kitchen, relative humidity, CO_2 in bedroom).
3. How to respond to the numbers. To identify causes and mitigations; external pollutant sources entering the indoor environment (e.g., traffic pollution), internal pollutant sources remaining

indoors (e.g., open flame appliances), mitigation through source control, mitigation through improved ventilation.

4. How regulatory frameworks can support awareness. This may include considering environments where it is appropriate to recommend monitoring, how this should be utilised in practice and how compliance can be demonstrated.

Priorities for the network include collecting and/or collating data on stakeholder knowledge and understanding of these aspects and establishing the most effective ways of communicating strategies to improve indoor air quality that consider the complex interactions between indoor and outdoor factors.

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