Airflow in Supermarkets and Similar Retail Stores: a rapid survey on infection transmission

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Purpose: to assess the literature relating to ventilation in supermarkets and similar retail premises and whether or how to alter ventilation (HVAC system) operation to minimise the risk of cross-infection in the light of the size of aerosols exhaled by customers from normal activity.

Objectives: 1) ascertain the typical size range of particles and droplets exhaled; 2) examine current system design and operation guidelines; 3) report on advice from professional bodies about feasible changes to current practice.

Summary:
1) Breathing expels a wide range of droplet sizes with some studies showing 80–90% of particles are smaller than 1 μm (non-settling particles).
2) Typical HVAC configuration gives a well-mixed air flow through most of a store.
3) Air flow rates in supermarkets are large compared with exhalation volumes from customers; exhaled non-settling particles will be carried in the airflow.
4) Increased air changes per hour further reduces the risk of cross-infection.

Assumptions:
1) UK stores of mainstream food and other retailers.
2) Customers are not displaying obvious symptoms of SARS-Cov2 (i.e. not coughing) as they are already instructed to self-isolate. Customers are either free from the virus or are asymptomatic.
3) People breathe normally and speak at normal conversation levels.

Nomenclature:

ACH	Air Changes per Hour
CFD	Computational Fluid Dynamics
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality

1. Supermarket Characteristics

1.1 The total volume of the public space is large compared with customers and shelving. Ceilings are typically 3m or higher.
1.2 Customers are moving with short dwell-times at any particular location.
1.3 Each regional or national retailer operates similar systems and configurations across their portfolio of properties. A measure of uniformity improves operational efficiency.

1.4 Regional or national retailers employ energy/environment and/or estate managers with good knowledge of system operation to ensure regulatory compliance and to reduce energy use across the portfolio.
1.5 HVAC systems are sized to cope with the maximum thermal and ventilation loads in summer and winter.
1.6 Typically air is supplied from the ceiling into aisles and is normally returned through the ceiling to the air handling plant.
1.7 These points may fairly describe other ‘big-box’ and large-scale high street retailers.

2. Typical Size-range of Particles and Droplets Exhaled

2.1 Droplets exist in a continuum of sizes, but particles below 5 μm are ‘non-settling’ i.e. will not fall under gravity to the floor (even in no-airflow conditions). A review of CFD and experimental studies (Bahl et al., 2020) suggests that larger droplets also can be carried much further by air momentum or turbulent currents and be suspended for many minutes.
2.2 Morawska (2006) (building on careful experimental work by Duguid (1946)) summarises these aerosol production activities (Table 1). Morawska notes that modern measuring techniques show that 80–90% of particles from human respiratory activities are smaller than 1 μm with most droplet sizes of order of 0.1 μm. Morawska also notes that sufficient studies have not been conducted on this complex area.
2.3 The spread of SARS-CoV-2 by aerosols is a controversial question (Lewis, 2020). van Doremalen et al. (2020) found that SARS-CoV-2 can aerosolise and survive for up to three hours in aerosolised form. SARS-CoV-2 RNA has been found in hospital ventilation systems indicating that viral particles are small enough to be suspended (Liu et al., 2020; Santarpia et al., 2020).
2.4 This transmission mechanism is assumed small (WHO guidelines) as breathing and coughing creates a small number of aerosols, only some of which will contain virus particles, and of these, the number with viable virus particles will be even smaller still.

Activity	Number of droplets generated (range)	Region of origin	Presence of droplet 1–2 μm (droplet residue)
Normal breathing (for 5 min)	0–few	Nose	Some in this range
Single strong nasal expiration	Few–few hundred		Some in this range
Laughing (for 1 min)	0–few	Facial region	
Counting softly (1–100)	Few–few dozen		
Counting loudly	Few dozen–few hundred	Front of the mouth	Most in this range
A single cough (mouth open)	0–few hundred	Facial region	Some in this range
A single cough (mouth initially closed)	Few hundred–many thousand	Front of the mouth	Most in this range
Single sneeze	Few hundred thousand–few million Few–few thousand	Front of the mouth Both from the nose and the facial region	Most in this range Some in this range

Table 1. Droplet generation from various activities (Morawska, 2006).

3. Ventilation

3.1 Usually, supermarket ventilation systems are studied for energy efficiency, thermal comfort, and IAQ. Ventilation systems are normally set to provide minimum ventilation rates to maintain good IAQ using carbon dioxide levels as an indicator. There are very few studies of ventilation in supermarkets (or other retail) relevant to pathogen transmission, or even CFD simulations related to supermarket ventilation.

3.2 Engineering design principles and practice has led to different configurations of ventilation system being used in hospitals, offices, and retail. As expected, most work relating to airborne pathogen transmission has been conducted in medical settings. We summarise the knowledge which can be considered transferable to supermarket-type spaces.

3.3 The movement of people creates localised turbulence thus mixing air (Brohus et al., 2008), but too few experiments have been conducted to be conclusive about the effects. Additional ventilation airflows should also improve mixing. Cool and warm air is relatively well mixed by a height of 2m (Foster and Quarini, 2005). Therefore, we expect a relatively uniform concentration of small particles which are renewed by people and removed by bulk extraction. This simplifies the problem leaving the primary consideration of extraction rate. Secondary considerations are airflow patterns which will be unique to each store layout and HVAC systems and fixed sources within the indoor environment (Ai and Melikov, 2018).

3.4 For experiments using (unmasked) stationary manikins i.e. not simulating people moving around a space, Ai and Melikov (2018) reviewed the work of Bolashikov et al. (2012; Liu et al. {2017; Olmedo et al. (2012, 2013; Villafruela et al. (2016) and is shown in Figure 1. Note that the data labeled '**x**' (Bolashikov et al., 2012) was testing 3 ACH or greater. Although mimicking a small two bed hospital room, it suggests the air exchange rate may have a more significant effect than the other variables (see caption).

3.5 The relative spatial orientation of people (in a hospital setting) has an effect on the risk of cross-infection (Olmedo et al., 2012). Direct face-to-face (analogous to standing at the till) carries an elevated likelihood of cross-infection, whilst angled faces, offset (analogous to walking along aisles), and side-by-side (analogous to standing at a shelf), face-to-back (analogous to queuing at the till) are approximately one twelfth of the risk. The direct face-to-face situation at the till is already mitigated by the use of screens. This has been incorporated into Figure 1 (labeled '+') (Ai and Melikov, 2018) .

3.6 Large air circulation patterns are normally set up within the volume which provide consistent transport routes to carry away pathogens. Some accumulation of pathogens could be possible in large (floor-wall-ceiling) and small recirculations (such as corners) or stagnant flow regions, however continuous exchange of air and movement of people may help prevent this in the majority of the space.

3.7 Menzies et al. (2000) observe (for healthcare settings) that < 2 ACH is too few. Modeling by Gao et al. (2016) suggested that increasing ventilation in multiple types of setting (homes, offices, shops, classes, restaurants, transportation and other public places) significantly reduces overall infections. They suggested that doubling all ventilation approximately halved infection rate, though further additional benefits diminished above 5 ACH.

3.8 Ventilation rates in homes, classrooms, and offices (and assumed similar spaces such as pubs and restaurants) can reach up to 5 ACH simply by opening windows and doors (Escombe et al., 2007).

3.9 Supermarket ventilation rate capacity is usually high, up to 6 ACH. HVAC systems can be divided into two categories (Mylona et al., 2018):

1. Coupled systems (the most common) where heating, ventilation and AC are provided by the same system, delivering air through overhead distribution ductwork to different parts of the store. The systems can provide uniform air distribution in large areas with similar cooling requirements. They could be constant or variable air flow ventilation systems.

2. Decoupled system – heating and AC is separated from the ventilation system. The decoupled system is a non-duct air conditioner where heat is transferred to or from the space directly by circulating refrigerant to evaporators. They are usually multi-split systems with many evaporators, refrigerant management and control systems. As they do not provide ventilation, a separate ventilation system is necessary. The separate ventilation system could be similar (but scaled down and without heating/cooling requirements) as for the coupled systems or it could be an extract system only with make-up air through openings (mainly the entrance area).

3.10 Normal breathing (tidal) volume is 0.5–1 litre per breath with approximately 12-20 breaths per minute i.e. 6-20 lmin^{-1} (Tortora and Derrickson, 2018). Nominal IAQ design airflow rates (CIBSE and ASHRAE Guidelines) of 10 litres/s/person i.e. 600 lmin^{-1} are approximately 30 times the likely maximum exhalation rate per person.

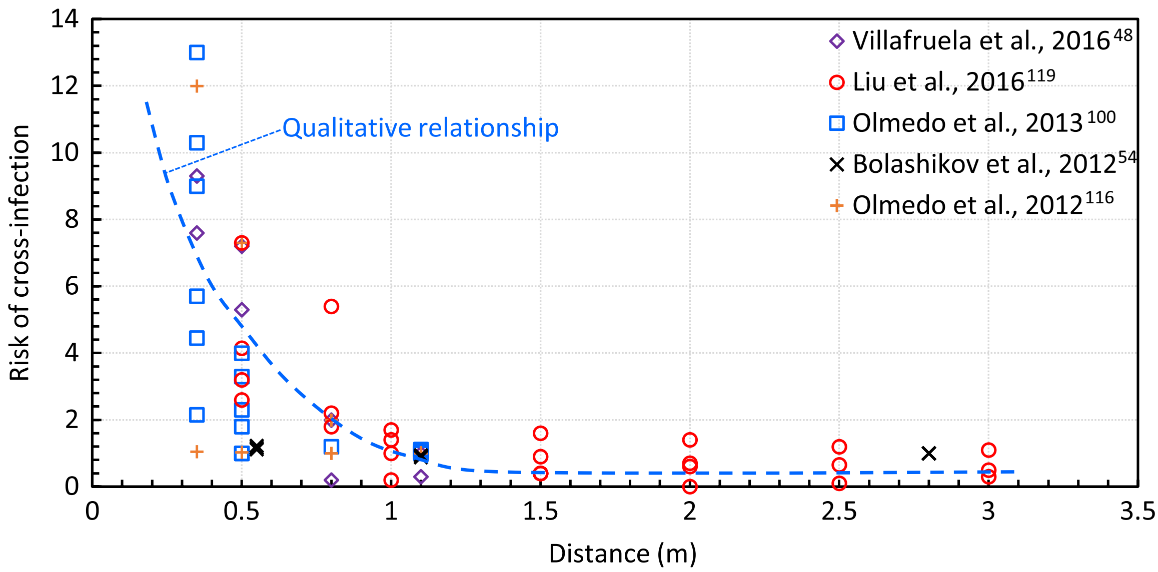

Figure 1. Analysis by Ai and Melikov (2018) of the risk with separation distance between an infected and a non-infection manikin. The risk of cross infection is calculated as a dimensionless number from the ratio of the concentration exposure (inhalation) to the concentration measured in the return (Olmedo et al., 2013). All results are for enclosed test laboratories (volumes smaller that supermarkets) usually mimicking hospital settings or offices. The vertical spread of points is due to ventilation method, relative location to the supply diffuser and exhaust grille, relative orientation of the manikins, number of air changes per hour, and breathing mode. Graph: © 2018 John Wiley & Sons. Caption: authors.

4. Current Guidance from Ventilation Professional Associations

There are three relevant organisation: the UK's Chartered Institution of Building Services Engineers (CIBSE), European Federation of Heating and Ventilation Engineers (REHVA, for which CIBSE is the UK representative), and the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). We summarise their guidance most relevant to supermarkets on how to operate and use building services to minimise the spread of the virus through HVAC or plumbing systems (REHVA, 2020; Schoen, 2020):

4.1 Increase air supply and exhaust ventilation. Supply as much outside air as reasonably possible (use caution in highly polluted areas) as this increases the effective dilution ventilation per person.

4.2 Operate systems 24 hours a day. Start ventilation at nominal speed at least 2 hours before opening time and switch to lower speed 2 hours after closing.

4.3 Do not change heating, cooling and possible humidification setpoints.

4.4 If heat recovery devices are used, they may carry over virus attached to particles from the exhaust air side to the supply air side via leaks. Inspect the heat recovery equipment, including the pressure difference measurement. Maintenance personnel should follow standard safety procedures of dusty work, including wearing gloves and respiratory protection. Virus particle transmission via heat recovery devices is NOT an issue when a HVAC system is equipped with a twin coil unit or another heat recovery device that guarantees 100% air separation between return and supply side.

4.5 No use of recirculation. Virus particles in return ducts might re-enter a building when centralized air handling units are equipped with recirculation sectors.

4.6 Do not plan duct cleaning for this period. Duct cleaning has no practical effect.

4.7 Change of outdoor air filters is NOT necessary. But replace central outdoor air and extract air filters as usually, according to maintenance schedule. Regular filter replacement and maintenance works should be performed with common protective measures including respiratory protection.

4.8 Improve central air filtration to F7 (EU classification) or the higher compatible with the filter rack, and seal edges of the filter to limit bypass.

5. Conclusions

5.1 For supermarkets and other retail spaces, there has been relatively few research studies (experimental or theoretical). This lack is in part due to 1) the most important setting for infection control is hospitals, 2) as large complex spaces, supermarkets are difficult to model meaningfully and calculations are computationally expensive, 3) due to potential disruption, retailers have been reluctant to allow measurements in the public areas, 4) supermarkets have not been considered as high risk sites in previous disease outbreaks such as influenza epidemics.

5.2 Normal breathing produces droplet nuclei in the size range of 0.1–1 μm and therefore are considered to be non-settling particles.

5.3 Airflow rates in supermarkets (≈600 $\mathrm{lmin^{-1}person^{-1}}$) are large compared with exhalation rates from customers (6-20 $\mathrm{lmin^{-1}person^{-1}}$).

5.4 Current ventilation regimes in supermarkets remove the non-settling particles. The typical HVAC supply and extraction portal configuration gives a well-mixed air flow through most parts of a store; exhaled non-settling particles will be carried in the airflow.

5.5 Guidance provided by the principal professional organisations accounts for the risk of cross-infection in stores operating well-maintained HVAC systems.

5.6 We suggest that our review is applicable to other retailers with similar in-store aisle arrangements.

5.7 We call for reviews of other types of public space such as cinemas, gyms, pubs, restaurants, small shops, libraries, etc. The variety of operational situations is greater, even though they may share some characteristics with supermarkets.

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