9-18-2018

Reducing Exposures Traffic-Related Air Pollution And Urban Building Design

Elliott Gall
Portland State University

Linda George
Portland State University, georgel@pdx.edu

Citation Details

Gall, E. T., & George, L. (2018). Traffic-Related Air Pollution And Urban Building Design. ASHRAE Journal, 60(9).

Traffic-Related Air Pollution and Urban Building Design

ASHRAE Journal, IEQ applications column, Submission date: Aug. 2nd, 2018

Elliott T. Gall, Ph.D.[1,*], Member ASHRAE; Linda George, Ph.D.[2]

[1]*Assistant Professor, Mechanical and Materials Engineering, Portland State University*

[2]*Professor, Environmental Science and Management, Portland State University*

**corresponding author, gall@pdx.edu*

Rapid growth of cities along with increased demand for motor vehicle transport has resulted in a large fraction of the world's population working or residing in proximity to major roadways. The Health Effects Institute estimates that living within 500 meters of a highway or major roadway constitutes an area "highly affected" by traffic-related air pollution (TRAP). Currently 30-45% of individuals in North America live within this distance.[1] In some cities, policies to promote high density housing to support public transportation and other sustainability goals have the potential to significantly increase the number of residences within this TRAP zone. Since we spend the vast majority of our time indoors, exposure to these air pollutants will largely occur indoors. This presents an opportunity for the building services sector to reduce indoor exposures to TRAP and in so doing, help realize substantial public health benefits.

Many of our most critical built environments are sited near highways. Schools, hospitals, office buildings, and residences line major roadways. Traffic-related air pollution is a complex mixture of particle and gas-phase air pollutants. The levels and type of air pollutants in this mixture will vary with proximity to roadway, vehicle type, speed, local meteorology, and fuel composition. Some of these factors vary diurnally, weekly, or seasonally. As a result, major roadways produce a significant source of air pollution that is both spatially and temporally variant.

The science is settled that TRAP poses a threat to human health. Since TRAP is a complex mixture, epidemiological studies of the impact of roadways on health may use measures of traffic intensity (e.g., vehicle count, distance from roadway) or select proxy pollutants as indicators of exposure. This study approach is used because it is not yet certain what components of TRAP, in isolation or in combination, produce observed decrements in health. Yet, extensive reviews exist that summarize the body of literature demonstrating the adverse health effects of exposure to vehicle emissions.[2] These studies demonstrate that TRAP adversely affects cardiovascular health and lung function, exacerbates asthma, and possibly increases incidence of cancer.

An emerging body of research also indicates that TRAP impacts human cognition, including increases in early developmental disorders such as autism and gestational and fetal growth[3,4] and impacts on cognition in older adults.[5] It also appears that TRAP impacts cognition by stunting development in working memory and attention. A recent study of over 2,700 students showed decrements in students' tests of cognition correspond with higher exposures to elemental carbon, nitrogen dioxide, and ultrafine particle number.[6]

As our understanding of the health and cognitive impacts of TRAP evolves, so should the state of practice regarding building operation and filtration and air cleaning for buildings located near major roadways. ASHRAE Standard 62.1 stipulates cleaning outdoor ventilation air if national standards are exceeded for PM_{10}, $PM_{2.5}$, or O_3. While this approach is a reasonable first step, it should be understood that the EPA National Ambient Air Quality Standards are designed to control regional scale, persistent pollutants; they do not address highly localized or episodic sources or mixtures of pollutants. ASHRAE Standard 62.2 "assumes that the outdoor air quality is acceptable" and the designer is "encouraged to ensure this assumption is correct" (ASHRAE Guideline 24-2015). Managing built environments near roadways should more fully consider three key aspects of traffic related air pollution: time and spatial variation of the source, the complexity of multicomponent mixtures, and the path of air entering a building.

First, traffic related air pollution is spatially and temporally variant across an urban environment. While vehicles do contribute to the air pollution burden at the regional scale (10s of *kilometers*), buildings in proximity to major roadways experience TRAP emissions at much shorter length scales (10s to 100s of *meters*). Buildings near roadways can experience air pollution levels far greater than the regional background, especially during rush hours, even while the region maintains regulatory compliance. This scenario is only acknowledged in ASHRAE 62.1 if TRAP is identified as a source impacting the outdoor air quality acceptability via a required observational survey of outdoor contaminant sources (ASHRAE 62.1-2016, Section 4.2-4.3).

Second, TRAP is a toxic mixture of gas and particle pollutants, many of which are not measured by regulatory monitoring stations. There exists a temptation to evaluate outdoor air quality by comparison of individual air pollutants to corresponding national standards, but this approach is problematic. Regulatory standards are not promulgated for each component of TRAP and, even if available, health impacts can occur at levels below the standard. For example, black carbon is a particle-phase TRAP component that contributes to $PM_{2.5}$ but is known to cause adverse health effects far below the U.S. EPA NAAQS primary standards for $PM_{2.5}$.[7] Furthermore, there is a lack of knowledge regarding the additive effects of exposures to components of TRAP. Even if one or multiple regulated components of TRAP are below thresholds, there may still exist a hazard due to the presence of many toxic compounds.

Third, the path by which TRAP enters a building must be considered. Outdoor air enters a building via natural ventilation, infiltration, and mechanical ventilation. Each path requires distinct considerations if a building is sited near a major roadway. Natural ventilation is inadvisable for buildings in proximity to major roadways since pollutants in outdoor air are difficult to remove in naturally ventilated buildings. Infiltration through unintentional leaks in the building enclosure, while offering some protection via penetrative losses,[8,9] is still undesirable in locations impacted by TRAP as it bypasses filtration and air cleaning in the HVAC system. Mechanical ventilation systems offer the best opportunity to clean outdoor air entering the building. However, greater awareness of particle and gas-phase air pollutants present in TRAP, and effectiveness of treatment options for addressing those pollutants, are needed to ensure a protective built environment.

At Portland State University, we are currently working with a local school district to conduct measurements and make recommendations for a middle school renovation in close proximity to a major freeway. Our experiences to date have informed the design and renovation of the school with the intent of reducing student and staff exposures to TRAP and can be generalized into three strategies for controlling indoor exposures to TRAP: administrative, passive, and active control measures.

Administrative controls can reduce exposures to TRAP through informed scheduling of activities. This encompasses, e.g., activities of people in and around the building as well as the operation of the building. Developing administrative controls requires consideration of the dynamics of the source (e.g., traffic and meteorology trends) in conjunction with usage and design of the building. Thus, for example, higher exertion or outdoor human activities could be scheduled for hours when traffic intensity is low. The HVAC system operation could also be scheduled accordingly, such as performing a night-purge in advance of morning rush hour.

Passive measures can involve site layout and design to leverage spatial trends in TRAP concentrations for a low or zero-energy control strategy. The concentration of TRAP decrease with distance from the freeway. While distances >500 meters are necessary to reduce some compounds to urban background, there exist steep gradients in the first several hundred meters for carbon monoxide, metals, ultrafine particles, and benzene.[10] Such gradients exist for other TRAP, but with lower drop-off rates. The building shell and ventilation systems should be designed accordingly. For example, outdoor air intakes should be sited as far as is feasible from the roadway. Note that Standard 62.1-2016 requires intakes to be sited only 7.5 m from high traffic thoroughfares (Table 5.5.1). Outdoor air infiltration should be minimized through air balancing and tight building enclosure design and construction, especially where the building is impacted by outdoor airflow coming from the freeway. Tree walls and other barriers could be considered, but must be designed carefully to reduce downwind contaminant levels.[11]

Reductions downwind of tree walls and other barriers vary by site and pollutant considered, but are generally not greater than ~40%. Based on our monitoring, this magnitude of reduction is not sufficient to reduce near freeway pollutant levels to urban background levels.

Active measures require higher energy, material and maintenance costs to remove TRAP from ventilation or recirculation air. Much is known about TRAP composition, but systems should be designed with site specific knowledge to assess source strength. Critically, both particle- and gas-phase TRAP should be addressed. Particle-phase filtration is generally standard practice, although Standards 62.1 and 62.2 stipulate MERV 6 or 8 filtration, with low removal efficiencies in the ultrafine size range (< 100 nm) that will be elevated in TRAP. Only when regional $PM_{2.5}$ is elevated above U.S. standards are MERV 11 filters stipulated in 62.1. However, higher efficiencies are necessary to achieve substantial removal across the ultrafine size range; >90% removal of all ultrafines requires MERV 16 filtration. Control for gas-phase pollutants is less common in typical buildings. For many buildings, a properly designed combination of particle filters and physical and/or chemical sorbents can substantially reduce levels of most TRAP. ASHRAE publications provide an excellent summary of the state of air-cleaning technologies for particle- and gas-phase contaminants.[12,13]

There exists sufficient evidence that proximity to sources of TRAP is detrimental to the health and cognitive function of building occupants. In order to address these concerns, municipalities can require higher levels of building performance. For example, building codes in San Francisco and Los Angeles now require MERV 13 filtration in housing near high-traffic roadways, though concerns remain regarding the lack of treatment of gas-phase pollutants.[14] As public awareness of the health effects of TRAP grows, demand for building designs that mitigate the full suite of TRAP will become the norm. The effort is worthwhile given the enormous added value in health and cognition from lowering indoor exposures to TRAP.

References

(1) Health Effects Institute. *Understanding the Health Effects of Ambient Ultrafine Particles*; 2013.

(2) HEI. *Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects*; A Special Report of the Institute's Panel on the Health Effects of Traffic-Related Air Pollution; Health Effects Institute, 2010.

(3) Volk, H. E.; Lurmann, F.; Penfold, B.; Hertz-Picciotto, I.; McConnell, R. Traffic-Related Air Pollution, Particulate Matter, and Autism. *JAMA Psychiatry* **2013**, *70* (1), 71–77.

(4) Woodward, N.; Finch, C. E.; Morgan, T. E. Traffic-Related Air Pollution and Brain Development. *AIMS Environ Sci* **2015**, *2* (2), 353–373.

(5) Power, M. C.; Weisskopf, M. G.; Alexeeff, S. E.; Coull, B. A.; Spiro, A.; Schwartz, J. Traffic-Related Air Pollution and Cognitive Function in a Cohort of Older Men. *Environ. Health Perspect.* **2011**, *119* (5), 682–687.

(6) Sunyer, J.; Esnaola, M.; Alvarez-Pedrerol, M.; Forns, J.; Rivas, I.; López-Vicente, M.; Suades-González, E.; Foraster, M.; Garcia-Esteban, R.; Basagaña, X.; et al. Association between Traffic-

Related Air Pollution in Schools and Cognitive Development in Primary School Children: A Prospective Cohort Study. *PLOS Medicine* **2015**, *12* (3), e1001792.
(7) Janssen, N. A.; Hoek, G.; Simic-Lawson, M.; Fischer, P.; Van, L. B.; Ten, H. B.; Keuken, M.; Atkinson, R. W.; Anderson, H. R.; Brunekreef, B.; et al. Black Carbon as an Additional Indicator of the Adverse Health Effects of Airborne Particles Compared with PM10 and PM2.5., Black Carbon as an Additional Indicator of the Adverse Health Effects of Airborne Particles Compared with PM10 and PM2.5. *Environ Health Perspect* **2011**, *119*, *119* (12, 12), 1691, 1691–1699.
(8) Liu, D.-L.; Nazaroff, W. W. Modeling Pollutant Penetration across Building Envelopes. *Atmospheric Environment* **2001**, *35* (26), 4451–4462.
(9) Stephens, B.; Gall, E. T.; Siegel, J. A. Measuring the Penetration of Ambient Ozone into Residential Buildings. *Environ. Sci. Technol.* **2012**, *46* (2), 929–936.
(10) Karner, A. A.; Eisinger, D. S.; Niemeier, D. A. Near-Roadway Air Quality: Synthesizing the Findings from Real-World Data. *Environ. Sci. Technol.* **2010**, *44* (14), 5334–5344.
(11) Baldauf, R. Roadside Vegetation Design Characteristics That Can Improve Local, near-Road Air Quality. *Transportation Research Part D: Transport and Environment* **2017**, *52*, 354–361.
(12) ASHRAE. *ASHRAE Position Document on Filtration and Air Cleaning*; ASHRAE Position Document, 2015.
(13) ASHRAE. *Control of Gaseous Indoor Air Contaminants*; ASHRAE Handbook - HVAC Applications; ASHRAE, 2015.
(14) Barboza, T. L.A. requires air filters to protect residents near freeways. Are they doing the job? http://www.latimes.com/local/lanow/la-me-ln-freeway-pollution-filters-20170709-story.html (accessed Jun 26, 2018).