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## Reducing Exposures Traffic-Related Air Pollution And Urban Building Design

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1 **Traffic-Related Air Pollution and Urban Building Design**

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

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

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

30           An emerging body of research also indicates that TRAP impacts human cognition, including  
31 increases in early developmental disorders such as autism and gestational and fetal growth<sup>3,4</sup> and impacts  
32 on cognition in older adults.<sup>5</sup> It also appears that TRAP impacts cognition by stunting development in

33 working memory and attention. A recent study of over 2,700 students showed decrements in students’  
34 tests of cognition correspond with higher exposures to elemental carbon, nitrogen dioxide, and ultrafine  
35 particle number.<sup>6</sup>

36 As our understanding of the health and cognitive impacts of TRAP evolves, so should the state of  
37 practice regarding building operation and filtration and air cleaning for buildings located near major  
38 roadways. ASHRAE Standard 62.1 stipulates cleaning outdoor ventilation air if national standards are  
39 exceeded for PM<sub>10</sub>, PM<sub>2.5</sub>, or O<sub>3</sub>. While this approach is a reasonable first step, it should be understood  
40 that the EPA National Ambient Air Quality Standards are designed to control regional scale, persistent  
41 pollutants; they do not address highly localized or episodic sources or mixtures of pollutants. ASHRAE  
42 Standard 62.2 “assumes that the outdoor air quality is acceptable” and the designer is “encouraged to  
43 ensure this assumption is correct” (ASHRAE Guideline 24-2015). Managing built environments near  
44 roadways should more fully consider three key aspects of traffic related air pollution: time and spatial  
45 variation of the source, the complexity of multicomponent mixtures, and the path of air entering a  
46 building.

47 First, traffic related air pollution is spatially and temporally variant across an urban environment.  
48 While vehicles do contribute to the air pollution burden at the regional scale (10s of *kilometers*), buildings  
49 in proximity to major roadways experience TRAP emissions at much shorter length scales (10s to 100s of  
50 *meters*). Buildings near roadways can experience air pollution levels far greater than the regional  
51 background, especially during rush hours, even while the region maintains regulatory compliance. This  
52 scenario is only acknowledged in ASHRAE 62.1 if TRAP is identified as a source impacting the outdoor  
53 air quality acceptability via a required observational survey of outdoor contaminant sources (ASHRAE  
54 62.1-2016, Section 4.2-4.3).

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

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

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

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

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

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

101 Active measures require higher energy, material and maintenance costs to remove TRAP from  
102 ventilation or recirculation air. Much is known about TRAP composition, but systems should be designed  
103 with site specific knowledge to assess source strength. Critically, both particle- and gas-phase TRAP  
104 should be addressed. Particle-phase filtration is generally standard practice, although Standards 62.1 and  
105 62.2 stipulate MERV 6 or 8 filtration, with low removal efficiencies in the ultrafine size range (< 100 nm)  
106 that will be elevated in TRAP. Only when regional PM<sub>2.5</sub> is elevated above U.S. standards are MERV 11  
107 filters stipulated in 62.1. However, higher efficiencies are necessary to achieve substantial removal across  
108 the ultrafine size range; >90% removal of all ultrafines requires MERV 16 filtration. Control for gas-  
109 phase pollutants is less common in typical buildings. For many buildings, a properly designed  
110 combination of particle filters and physical and/or chemical sorbents can substantially reduce levels of  
111 most TRAP. ASHRAE publications provide an excellent summary of the state of air-cleaning  
112 technologies for particle- and gas-phase contaminants.<sup>12,13</sup>

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

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