Needham Board of Health

Prevent. Promote. Protect.

AGENDA

Thursday, November 10, 2016
4:00 p.m. – 6:15 p.m.

Charles River Room – Public Services Administration Building
500 Dedham Avenue, Needham MA 02492

- **4:00 to 4:05 - Welcome & Review of Minutes (October 21st)**
- **4:05 to 4:30 - Discussion re: Modera Needham Housing**
  - **Lars Unhjem, Vice President, Mill Creek Development**
  - **Doug Brugge, Professor, Tufts School of Medicine**
- **4:30 to 5:00 - Discussion of Marijuana Dispensaries & Residential Parcels**
  - **Matt Borrelli and Marianne Cooley, Board of Selectmen**

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Board of Health Public Presentation/Hearing

- **5:00 to 5:30 - Eversource West Roxbury to Needham Reliability Project and Associated Health Impacts**
  - **Jack Lopes, Community Relations Specialist, Eversource**
- **5:30 to 5:40 - Initial Review of Draft Regulations**
  - **Tobacco Regulations (proposed revisions)**
  - **Marijuana (proposed new regulations)**

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- **5:40 to 5:50 - Board Discussion of Policy Positions, Goals**
- **5:50 to 6:00 - Overview of Public Health Accreditation**
- **6:00 to 6:15 - Director and Staff Reports**
- **Other Items**
- **Next Meeting … Friday December 16th? Friday December 2nd?**
- **Adjournment**

(Please note that all times are approximate)

1471 Highland Avenue, Needham, MA 02492
E-mail: healthdepartment@needhamma.gov
781-455-7500 ext 511 (tel); 781-455-0892 (fax)
Web: www.needhamma.gov/health

Memorandum

To: Board of Health
From: Timothy Muir McDonald, Director of Public Health
Date: November 10, 2016
Re: Feedback on Modera Needham Housing Development and the Health Effects of Traffic Emissions

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At today's Board of Health meeting, both Professor Doug Brugge from Tufts Medical School and Lars Unhjem, the Vice President of Development for Mill Creek Residential Trust will engage in discussion with the Board of Health about the proposed action steps to mitigate the health effects caused by traffic emissions on the future residents of the Modera Needham housing development.

In a draft Memorandum of Understanding (MOU) which I sent to your attention yesterday, Mill Creek Residential Trust outlined the following action steps to respond to the Board of Health's concerns.

- **Site Layout**—to the extent possible given the size and location of the parcel owned, the developer responded with small modifications to the layout of the building closest to the highway and to the recreational amenities (pool, children's play area) attached to that building.

- **Air Filtration**—this is the area where the developer has made the most significant modifications in response to the Board of Health's concerns. The developer has moved the air-intakes from the Route 128 side of the building to the Greendale Avenue side of the building, which allows the air intakes to be shielded from traffic emissions and ultrafine particles (UFP) by the mass of the building. The developer has also committed to upgrade the level of filtration on the building's HVAC system from MERV-4 to MERV-8. In its letter, Mill Creek Residential commits to both the capital cost of upgrading to MERV-8 filters as well as the ongoing operational costs to appropriately maintain higher grade filters which require a more frequent replacement schedule. Improperly maintained filters have substantially reduced effectiveness, so a well-maintained air filter is essential to achieving the highest level of filtration. It is important to note that the Board of Health, in its correspondence with the Zoning Board of Appeals in 2013, 2015, and 2016, recommended filtration levels at MERV-16 level, but in this building that would involve a substantial redesign of the project and would negate the benefit achieved by having the air intakes shielded from the highway by the building's mass.

- **Vegetative and Physical Barriers**—in addition to its previous commitment to other Town departments and Boards that it will preserve the existing vegetative barrier between the development parcel and the highway and its commitment to install additional plantings and physical barriers in that space, Mill Creek Residential has revised the layout and planting specifications around the recreational amenities (children's playground and pool) to incorporate the Board of Health's feedback on the research that shows evergreen plantings are more effective than deciduous plantings at screening traffic emissions and ultrafine particles in most circumstances.

In the supplementary materials from October's Board of Health meeting and the same materials for this month's meeting, I included a number of scientific studies and peer-reviewed journal articles. The one with the most direct relevance to this subject is the 2015 publication in *Environmental Justice*, of which Professor Brugge is the lead author.[1] That article includes a review of the efficacy of different measures to reduce traffic-related air pollutants (TRAP), and concludes that the most effective measures (categorized as "Good", up to a 40% reduction) include filtration, air intake location, and sound proofing. Mill Creek Residential has taken steps on two of three of those fronts.

The second tier of measures (categorized as "Moderate", up to a 40% reduction) include the healthy placement of buildings and parking structures, trees and planting, built or vegetative barriers, active travel locations, and decking over highways. In this tier of interventions, Mill Creek Residential has partially placed the buildings and parking structures in a healthy way, has committed to both preserving existing trees and to an extensive post-construction re-planting program, and will install built and vegetative barriers. The other interventions—active travel locations and decking over highways—are not realistically within Mill Creek Residential's span of control.

Of note, Mill Creek Residential did not make a commitment to reduce the size of the porch balconies along the highway side of the building. Currently the balconies are the minimum size to comply with federal and state accessibility requirements, so there was never a choice to reduce the size of the balconies, only the choice of keeping them or eliminating them entirely. The company did seriously consider the Board of Health's request, but felt that for both architectural style and for the perceived value of the units, that removing the balconies would provide a serious financial hit.

In my opinion, the Board of Health's commitment to this issue has resulted in **a number of positive modifications and revisions by Mill Creek Residential, which will have a significant impact and will improve the health and wellness of future residents** of the Modera Needham housing development. This is not a perfect agreement; it does not

[1] Brugge, D. et al. "Developing Community-Level Policy and Practice to Reduce Traffic-Related Air Pollution Exposure." *Environmental Justice*. 8 (2015) 3: 95-104.

achieve all of the recommendations outlined in the Board of Health's letter to the Zoning Board of Appeals in 2013, 2015, and 2016. But it is a significant and positive step forward, and I hope the Board of Health will consider endorsing this agreement.

Thank you for your consideration of this memorandum. I look forward to discussing with you later today at the next Board of Health meeting.

Sincerely,

Timothy Muir McDonald

Timothy Muir McDonald
Director of Public Health, Town of Needham

Attachments:

1. *Memorandum of Understanding between Board of Health and Mill Creek Residential Trust—Redlined by TMM, Revised Slightly by Developer, and Reviewed and Approved by Town Counsel*
2. *Modera Needham Project Overview Packet (as previously distributed)*
3. *Health Effects of Traffic Emissions Packet (as previously distributed)*

MILL CREEK
RESIDENTIAL

November 8, 2016

Needham Board of Health
1471 Highland Avenue
Needham, MA 02492

Re: Modera Needham, Greendale Avenue

Dear Members of the Board,

Thank you to the Board and to Tim McDonald for the discussions over the last weeks. We appreciate the hard work and consideration given by the Board to the Modera Needham project on Greendale Avenue (the "Project"). On behalf of MCREF Needham LLC (the "Developer"), I write to follow up on these discussions.

This purposes of this letter are (i) to follow up on the Board of Health's letter dated August 11, 2016 and addressed to the Needham Zoning Board of Appeals (the "BOH Letter"); (ii) memorialize certain Project aspects and changes that respond to the BOH Letter; and (iii) document these changes as commitments by the Developer. We understand that the BOH wants the Project changes and commitments to be memorialized in a memorandum of understanding format. Accordingly, please have this letter countersigned on behalf of the BOH and returned to my attention. By their mutual execution of this letter, the Developer and BOH agree that this letter is considered to be a binding memorandum of understanding.

In summary, the BOH Letter identified three major areas for potential changes to the Project including (i) Site Layout, (ii) Air Filtration, and (iii) Vegetative and Physical Barriers. As described below, the Developer has incorporated the following into the Project:

Site Layout. The final site layout of the Project reflects a number of changes that address the BOH Letter. This includes locating the two-level garage closest to the highway, which, in combination with the residential structure above, physically screens a significant amount of the Project from Route 128. Outdoor intermittent-use amenities including the pool, grills, and playground area are located adjacent to this building and are oriented so as to optimize distances from the highway, while also addressing the concerns and comments of emergency response and safety officials and other considerations such as grading and accessibility concerns.

Air Filtration. As discussed over recent weeks, one attribute of the Project that may not have been evident from the initial permit drawings is that each individual apartment does not have external HVAC fresh-air intakes. Each apartment has an individual HVAC system that recirculates conditioned air within the home. The common areas are supplied by systems that do include fresh-air intakes. This arrangement creates positive pressure in the corridors that, in turn, helps circulate fresh air to the units.

At the recommendation of the BOH, the Developer agrees to relocate the fresh-air intakes for the common areas to the side of the midrise building facing Greendale Avenue and furthest away from the highway. This will substantially increase the linear distance from the highway to the fresh-air intakes. In addition, as described below, the air intakes are further separated from the highway by the existing vegetative barrier.

The current Project design contemplates the use of Mill Creek's (and the industry's) standard specification of MERV-4 filters within each individual apartment HVAC system, as well as within each common area HVAC system. As a result of discussions with the BOH, the Developer agrees to upgrade the HVAC equipment and the HVAC-filter-maintenance program, as necessary, to maintain MERV-8 filters in all HVAC equipment. These changes to equipment, filters, and the maintenance program represent a significant financial commitment by the Developer, well in excess of half a million dollars, plus increased maintenance obligations and costs.

Vegetative and Physical Barriers. As discussed over recent weeks, the final site layout aims to maximize preservation of the existing vegetative barrier between the highway and the occupied portions of the site. This existing vegetative barrier is augmented by a comprehensive and lush landscaping plan designed to incorporate a significant number of deciduous and evergreen trees, bushes, shrubs, and other plantings. In addition, retaining walls and stockade fences have been incorporated into the project design and provide additional physical barriers to the site from the highway.

These vegetative and physical barriers are further enhanced by the topography of the project site, whereby the apartments and intermittent-use outdoor amenity areas nearest to the highway are located above and screened from the highway. Closer to Greendale Avenue, the topography and significant grade difference between the project site and the highway further separates project uses from the highway.

During recent discussions, the BOH requested that the playground area be redesigned to include fewer deciduous and more evergreen plantings in order to account for the likely three-season use of the playground area. As a result, the Developer agrees to increase the type and number of evergreen plantings between the playground area and the highway.

In consideration of these Project changes, which are conditioned on the Developer obtaining all necessary permits and approvals necessary to implement the same, the BOH agrees (i) that the above changes respond to the BOH's concerns and represent a significant effort by the Developer to incorporate changes to the Project to address the concerns in the BOH letter and otherwise; (ii) to withdraw its objections to the Modera Needham development in an open letter to the Zoning Board of Appeals and the Board of Selectmen for the Town of Needham and to support issuance of the Project's building permit(s), certificates of occupancy(ies) and other permits necessary for the Project; and (iii) to assist the developer with the any Board of Health/Public Health permits necessary for the Project, such as a pool permit or irrigation permit, without additional Project changes except as necessary to comply with all applicable state and local regulations or by-laws pertaining to such permits.

If the above is satisfactory, please have this letter executed on behalf of the BOH and returned to my attention.

Sincerely,

MCREF NEEDHAM LLC

By: __________________________
Lars Unhjem
Vice President of Development
Mill Creek Residential Trust

AGREED AND ACCEPTED:

NEEDHAM BOARD OF HEALTH

By:

____________________	____________________	____________________
Name:	Name:	Name:
Hereunto duly authorized	Hereunto duly authorized	Hereunto duly authorized
Date:	Date:	Date:

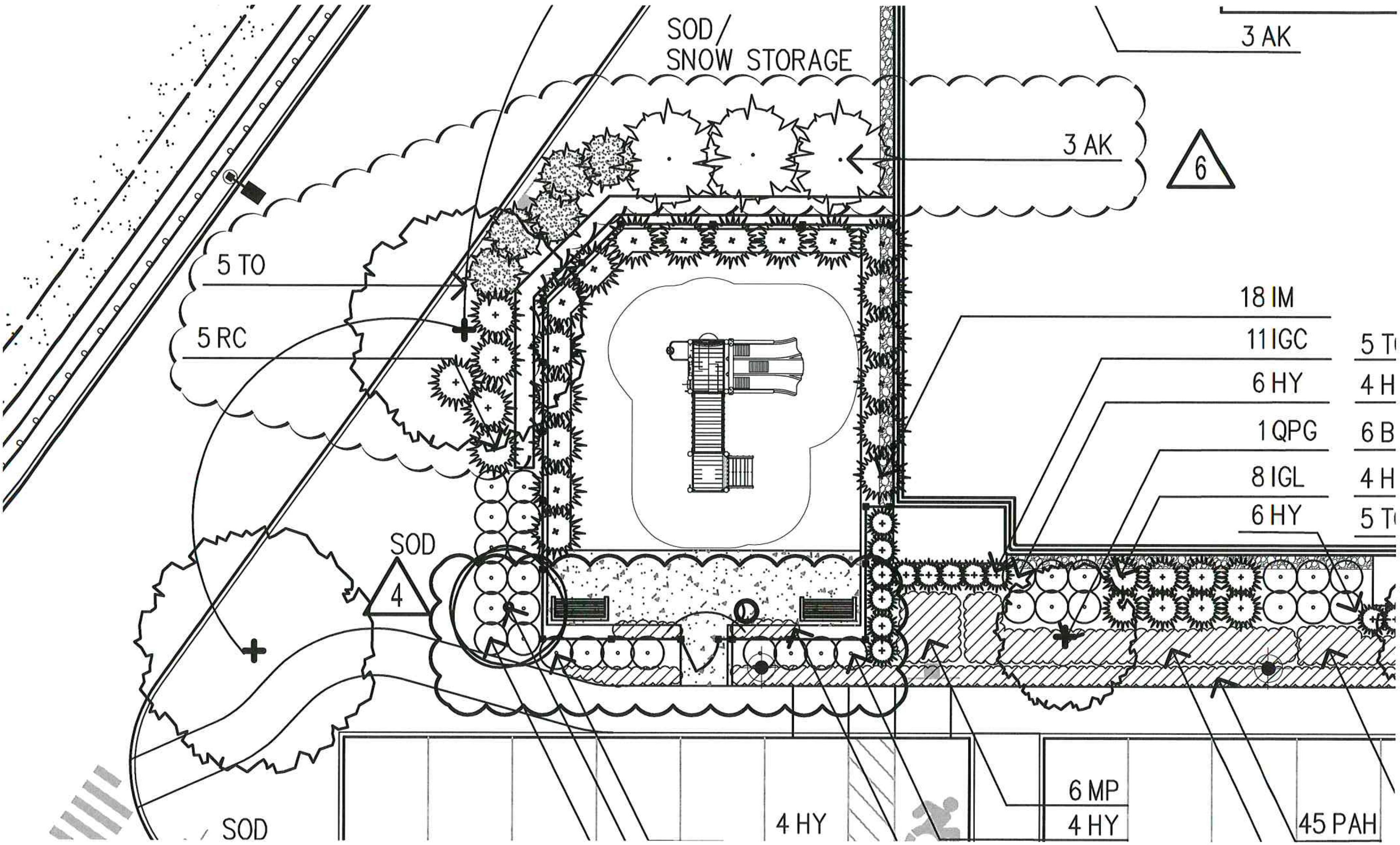
CC: Timothy Muir McDonald, Director, Public Health Division, Health & Human Services Dept.
Robb Hewitt, Senior Managing Director, Mill Creek Residential Trust

10 SITE SECTION
Scale : 1/16" = 1'-0"

I-95/
+128

121' or
122' elevation

Greendale
Ave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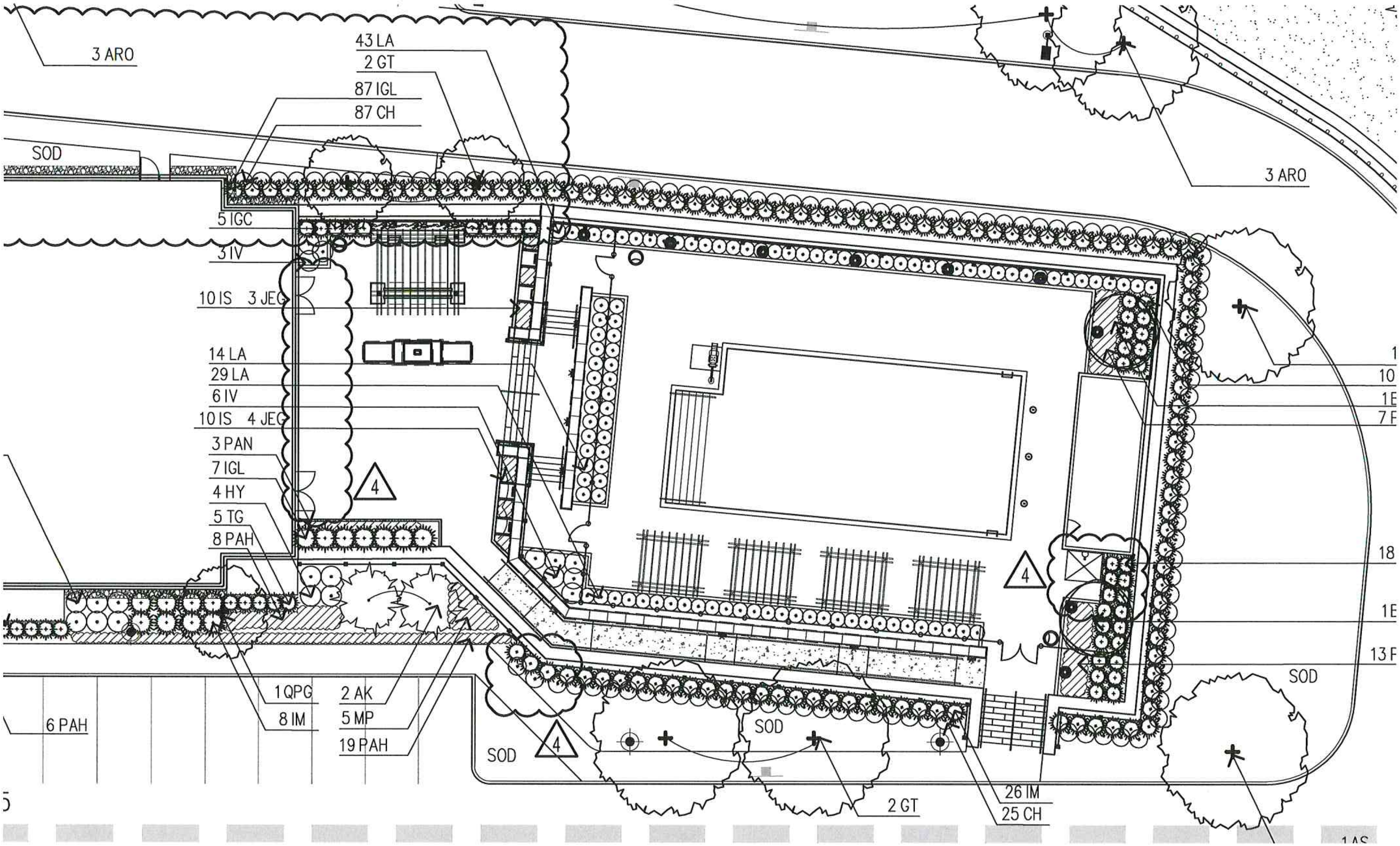
45 PAH

Pool: *Quercus palustris* 'Green Pilar' Columnar Pin Oak - deciduous but retains leaves till spring (marcescence). Height: 50.00 to 60.00 feet Spread: 12.00 to 15.00 feet	
Playground: *Abies koreana* Korean Fir - evergreen Height: 20.00 to 30.00 feet Spread: 10.00 to 18.00 feet *Thuja occidentalis* American Arborvitae – evergreen Height: 20.00 to 40.00 feet Spread: 10.00 to 15.00 feet	 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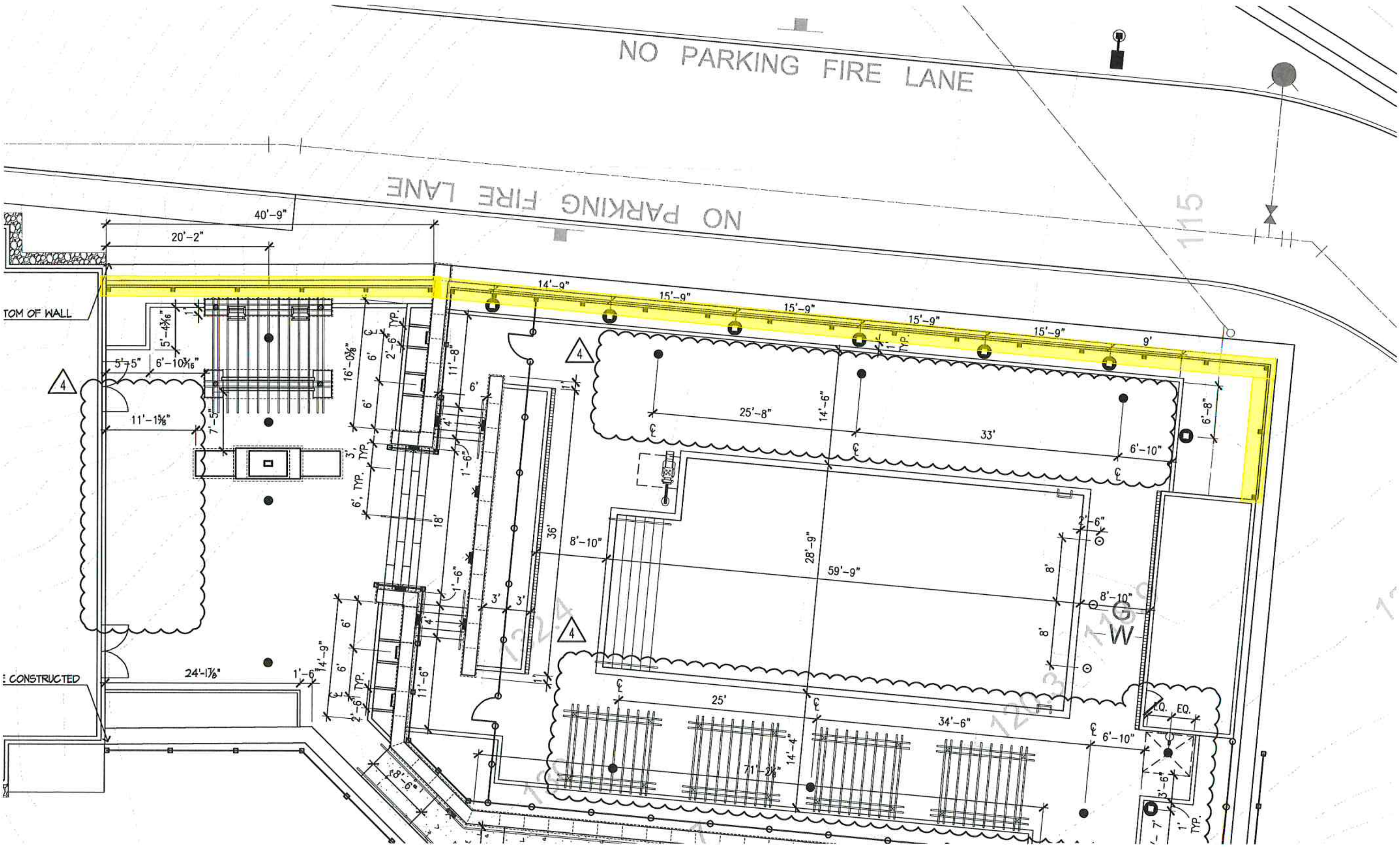

NO PARKING FIRE LANE
NO PARKING FIRE LANE
115
40'-9"
20'-2"
14'-9"
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15'-9"
9'
TOM OF WALL
E CONSTRUCTED
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33'
14'-6"
6'-8"
6'-10"
59'-9"
28'-9"
8'-10"
36'
18'
11'-1⅝"
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25'
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14'-4"
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EQ.
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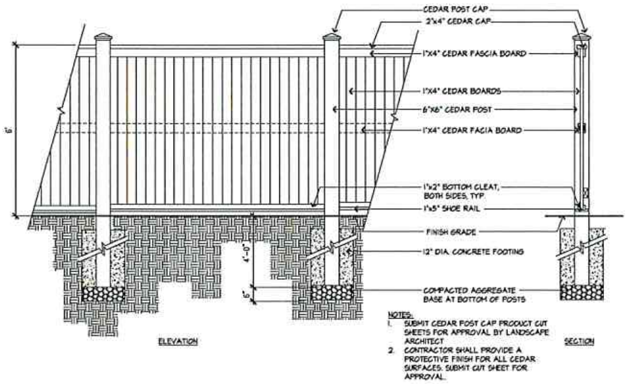
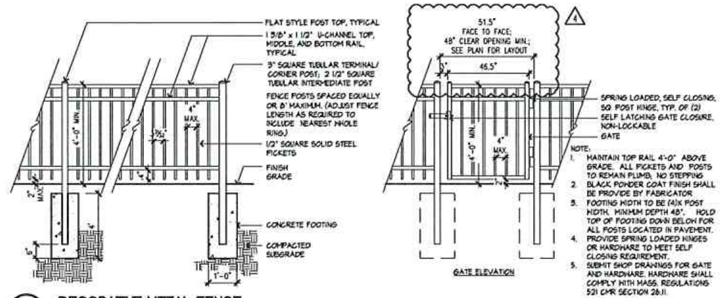
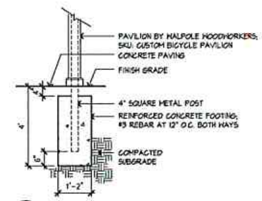


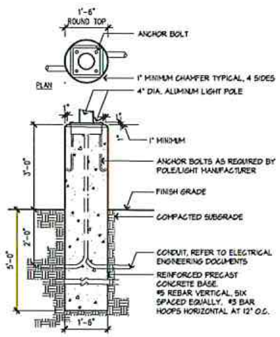
1 CEDAR BOARD FENCE
SCALE: 1/2"=1'-0"



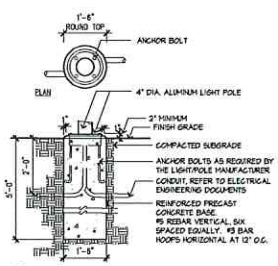
2 DECORATIVE METAL FENCE
SCALE: 1/2"=1'-0"



3 MAIL SHELTER
SCALE: 1/2"=1'-0"



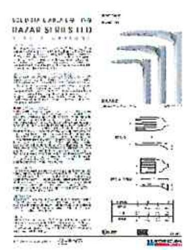
4 LIGHT POLE BASE - VEHICULAR
SCALE: 1/2"=1'-0"



5 LIGHT POLE BASE - LANDSCAPE
SCALE: 1/2"=1'-0"

6 SITE LIGHT - TRELLIS FIXTURE
SCALE: NTS

7 SITE LIGHT - WALKWAY FIXTURE
SCALE: NTS



8 SITE LIGHT - PARKING LOT FIXTURE
SCALE: NTS

9 SITE LIGHT - BOLLARD LIGHT
SCALE: NTS

10 SITE LIGHT - SIGN UP-LIGHT
SCALE: NTS

11 SITE LIGHT - WALL LIGHT
SCALE: NTS

Friday, August 19, 2016 1:17:07 PM
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tat
the architectural team

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Consultant:
Stantec

Revision:

2016.08.12	Addendum #4

Architect of Record:

Drawn: BN
Checked: MN
Scale: AS NOTED
Key Plan:

Project Name:
Modera Needham

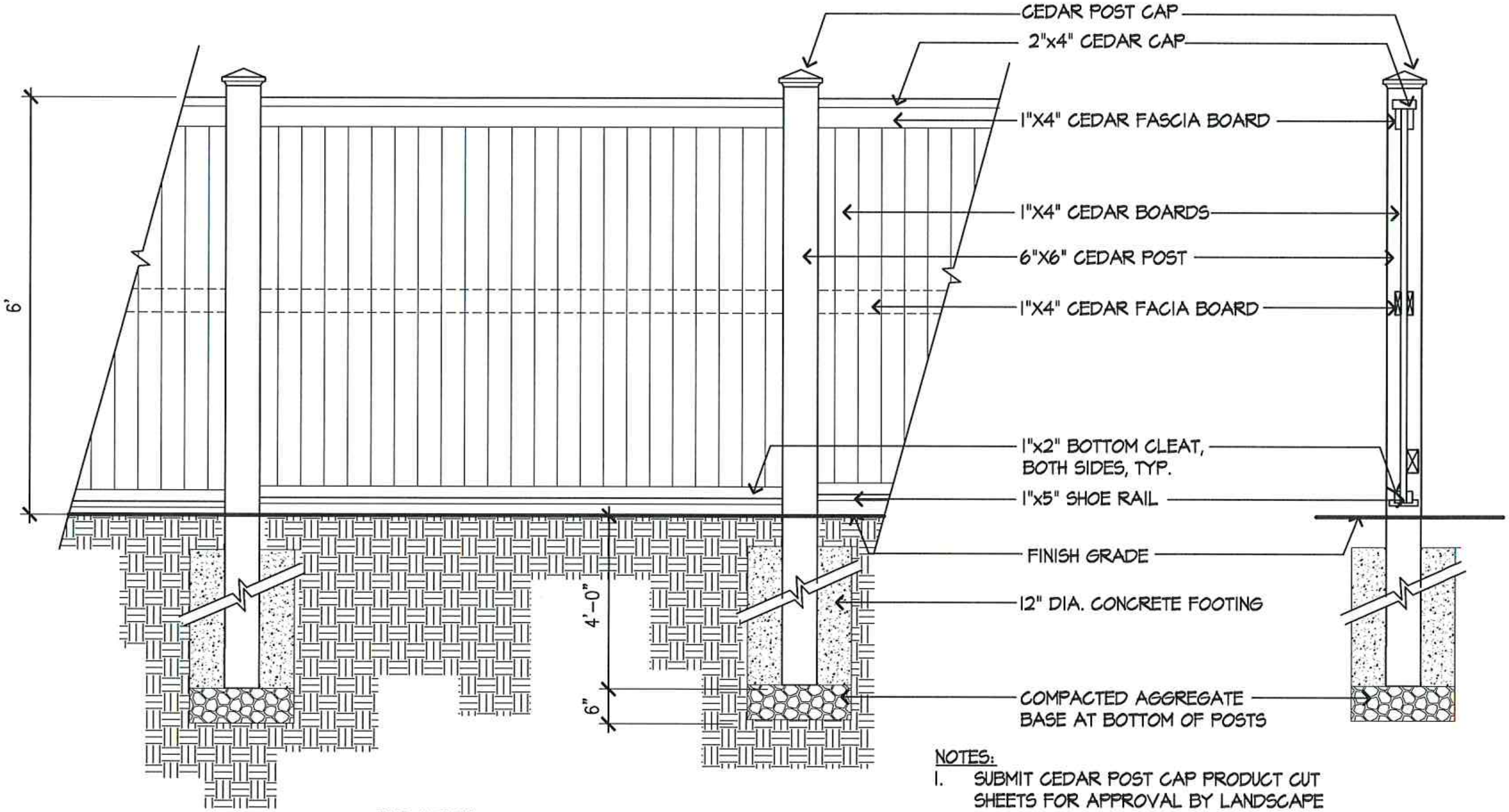
Greendale Avenue
Needham, MA

Sheet Name:
LANDSCAPE PLANS - SITE DETAILS

Project Number:
210801027

Issue Date:
May 13, 2016

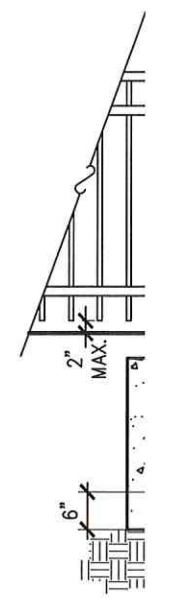
Sheet Number:
L-403



NOTES:
1. SUBMIT CEDAR POST CAP PRODUCT CUT SHEETS FOR APPROVAL BY LANDSCAPE ARCHITECT
2. CONTRACTOR SHALL PROVIDE A PROTECTIVE FINISH FOR ALL CEDAR SURFACES. SUBMIT CUT SHEET FOR APPROVAL.

1 CEDAR BOARD FENCE

SCALE: 1/2"=1'-0"



2

NEEDHAM BOARD OF HEALTH

Prevent. Promote. Protect.

August 11, 2016

Ms. Sheila Page, Administrative Specialist
Town of Needham, Zoning Board of Appeals
Planning and Community Development Department
Public Service Administration Building
500 Dedham Avenue
Needham, MA 02492

Dear Ms. Page,

Thank you for the correspondence of August 2nd sent to the Needham Public Health Division requesting comments on the Final Approved Plan Set for the Greendale Mews / Modera Needham housing development at 692-774 Greendale Avenue.

We appreciate the opportunity to once again provide feedback to the Zoning Board of Appeals (and by extension the developer Mill Creek Residential, LLC), but were genuinely disappointed to learn that the Final Approved Plan Set provided to the Public Health Division for its review did not reflect any of the Board of Health's strong recommendations and suggestions from correspondence with the ZBA and its staff in November 2013, October 2015, and November 2015.[1]

As the elected members of the Needham Board of Health, we reiterate the Board of Health's official position about the likely health risks[2,3,4] associated with housing located in close proximity to major roadways. Since the initial data review in 2013 when the Needham Board of Health stated its official position, additional findings from scientific studies have documented the hazards to human health which result from vehicle pollution which occurs to sensitive land uses (i.e. housing, recreation) located within close proximity (300-500ft) to major roadways.[5,6]

Therefore it remains the Board of Health's position that any developer proposing to construct housing in close proximity to a major interstate highway should undertake specific and targeted interventions to protect the health and well-being of the future residents of that development.

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[1] Please review the attachments which include copies of the correspondence from those months.
[2] Centers for Disease Control and Prevention. "Residential Proximity to Major Highways—United States, 2010." *Morbidity and Mortality Weekly Report (MMWR)* 2013;62(Suppl 3): 46-50.
[3] Brugge D, Lane K, Padró-Martínez LT, Stewart A, Hoesterey K, Weiss D, Wang DD, Levy JI, Patton AP, Zamore W, Mwamburi M. "Highway proximity associated with cardiovascular disease risk: the influence of individual-level confounders and exposure misclassification." *Environmental Health* 2013, 12:84
[4] Brugge D, Durant JL, Rioux C. "Near-highway pollutants in motor vehicle exhaust: A review of epidemiologic evidence of cardiac and pulmonary health risks." *Environmental Health* 2007, 6:23
[5] Zhu Y, Hinds WC, Kim S, Shen S, Sioutas C, 2002. "Study of ultrafine particles near a major highway with heavy-duty diesel traffic." *Atmospheric Environment* 36: 4323-4335.
[6] Brugge D, Patton A.P., Bob A, Reisner E, Lowe L, Bright OJ.M., Durant J, Newman J, Zamore W. "Developing community-level policy and practice to reduce traffic-related air pollution exposure." *Environ. Justice*. 2015.

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Web: www.needhamma.gov/health

The Board of Health strongly encourages the developer, Mill Creek Residential LLC, to schedule time to talk to the Public Health Department about its building plans and about options for specific and targeted interventions to protect the health and wellness of the inhabitants of housing located in close proximity to major roadways. These interventions might include:

Site layout: Land use buffers can be effective in separating sensitive land uses from traffic and highway air pollution.

- Air intakes should be placed on rooftops or on the sides of buildings that do not face major roadways.[7,6]
- Building(s) should be oriented with doors and outdoor living areas on the side of the building away from the highway to provide physical screening by the building.[8]
- Orient low use structures (i.e. parking garages) closer to the highway creating a functional barrier between the highway and the sensitive land use.[3] In a similar vein, place outdoor recreation areas (playground, swimming pool) at the furthest possible point from the source of highway air pollution.

Vegetative and Physical Barriers: High walls and mature plantings of trees or large evergreen shrubs (arborvitae, for example) may serve to mitigate the impact of highway air pollution.

- Sound walls have been found to reduce pollutant concentrations near roadways by up to 50%.[9]
- Vegetation along the side of the highway can reduce air pollution behind the vegetation barrier by as much as 40%.[3,10] "Dense vegetation performs similarly to a solid barrier by both blocking and filtering air pollution with effectiveness depending on wind direction and whether the roadside trees are decidua or evergreen." [3,5] The federal Environmental Protection Agency's guidance for constructing vegetation barriers to improve near-road air quality[7] should be consulted.
- Combinations of sound walls and vegetation barriers are most effective and have been shown to disperse air pollutants more consistently and at a greater distance, with up to 60% air pollution reduction.[6]

Air Filtration: Mechanical systems have also demonstrated a significant impact on the ability of major roadway air pollution to impact indoor air quality in sensitive uses like housing built in proximity to major roadways.

- MERV 9-12 filters begin to remove particles smaller than PM2.5.[6] And MERV 13-16 filters have been shown to be capable of removing ultrafine and submicron particles such as those emitted from vehicles.[6] Santa Barbara, CA recommends MERV 13 or better[5] and school studies have demonstrated that MERV 16 filters are capable of reducing particles (including super fine particles) up to 96%.[11] The Needham Board of Health's recommendation in November 2013 called for the use of MERV-16

[7] Green NE, Etheridge DW, Riffat SB, Location of air intakes to avoid contamination of indoor air: A wind tunnel investigation. *Building and Environment*. 2001.
[8] City of Santa Barbara. City wide recommendation to city council on air quality design standards for development near Highway 101. Resolution NO. 005-14. 2014.
[9] ARB. Status of Research on potential mitigation concepts to reduce exposure to nearby traffic pollution. California Air Resources Board. 2012.
[10] EPA. Recommendations for construction roadside vegetation barriers to improve near-road air quality. Environmental Protection Agency. 2016.
[11] SCAQMD. Pilot study of high performance air filtration for classrooms applications. Final report to the South Coast air Quality Management District. South Coast Air Quality Management District and IQAir North America. 2012.

electrostatic filters in the HVAC system of any new housing constructed in close proximity to major roadways.
- A study comparing outcomes from individuals exposed to unfiltered air and HEPA filtered air showed inconclusive results,[12] which means that air filtration best practices call only for MERV-rated filters rather than HEPA air filtration.

If, in the opinion of the Board of Health, the developer Mill Creek Residential, LLC does not implement targeted interventions to protect the health and well-being of the future residents of its proposed Modera Needham housing development located in close proximity to a major roadway (Interstate 95), then the Board of Health reserves the right to act to protect the public's health under its authority to make reasonable health regulations[13] and to "examine all nuisances, sources of filth and causes of sickness".[14] These actions may include, but are not necessarily limited to, the following:

- restrictions on the placement or use of outdoor recreation areas (pool, playground);
- restrictions on the use or placement of balconies, decks, and patios if not sufficiently screened from the source of air pollution; and
- a written disclosure of the impact of health effects of air pollution before the developer enters into any lease or sale agreement for any housing units located on the property.

Thank you for your attention.

Sincerely,

Edward Cosgrove, PhD Chair	Stephen Epstein, MD, MPP	Jane Fogg, MD, MPH Vice Chair

CC: *Timothy Muir McDonald, Director of Public Health*
Tara Gurge, Environmental Health Agent
Town of Needham Zoning Board of Appeals
Town of Needham Planning Board
Town of Needham Board of Selectmen
Kate Fitzpatrick, Town Manager
Christopher Coleman, Assistant Town Manager/Director of Operations
Lee Newman, Director of Planning and Community Development
David Roche, Building Commissioner
Jason R. Talerman, Esq., Blatman, Bobrowski, Mead & Talerman, LLC
Mill Creek Residential, LLC

Attachments: *BOH Letter to Zoning Board of Appeals, dated November 9, 2015*
Tara Gurge Email Correspondence, dated October 28, 2015
BOH Memo to Zoning Board of Appeals, dated November 14, 2013

[12] Padro-Martinez L, Owusu E, Reisner E, Zamore W, Simon M, Mwambur M, Brown C, Chung M, Brugge D, Durant J. A randomized cross-over air filtration intervention trial for reducing cardiovascular health risks in residents of public housing near a highway. *Int. J. Environ. Res. Public Health.* 2015.
[13] M.G.L. ch. 111, s.31, available at: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXVI/Chapter111/Section31
[14] M.G.L. ch. 111, s.122, available at: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXVI/Chapter111/Section122

Needham Board of Health

November 9, 2015

Town of Needham, Zoning Board of Appeals
Public Service Administration Building
500 Dedham Avenue
Needham, MA 02492

Dear Chair Jonathan Schneider and Zoning Board of Appeals Members,

As the elected members of the Needham Board of Health, we reiterate the Board of Health's official position about the likely health risks[1,2,3] associated with housing located in close proximity to major roadways. The Board of Health's position was conveyed to the Zoning Board of Appeals in writing on November 14, 2013 (following a Board of Health meeting that morning), and was provided at the specific request of the Zoning Board of Appeals and the Board of Selectmen. That memorandum is included as an attachment to this letter. Last week, the Public Health Director Timothy McDonald and the Environmental Health Agent Tara Gurge were able to review the revised site plan negotiated between the Town and the developer, Mill Creek Residential LLC. The Board of Health was extremely disappointed to see that none of its recommendations were addressed.

In the nearly two years since the Board of Health's position was recorded, additional scientific studies have supported the finding of health risks associated with housing located in close proximity to major roadways and additional research is underway that may definitively confirm those risks. Therefore it remains the Board of Health's position that any developer proposing to construct housing in close proximity (defined as less than 100 meters) to a major

[1] Centers for Disease Control and Prevention. *Residential Proximity to Major Highways—United States, 2010*. MMWR 2013;62(Suppl 3): 46-50.
[2] Brugge D, Lane K, Padró-Martínez LT, Stewart A, Hoesterey K, Weiss D, Wang DD, Levy JI, Patton AP, Zamore W, Mwamburi M. *Highway proximity associated with cardiovascular disease risk: the influence of individual-level confounders and exposure misclassification*. Environmental Health 2013, 12:84
[3] Brugge D, Durant JL, Rioux C. *Near-highway pollutants in motor vehicle exhaust: A review of epidemiologic evidence of cardiac and pulmonary health risks*. Environmental Health 2007, 6:23

interstate highway should undertake specific and targeted interventions to protect the health and well-being of the future residents of that development.

The Board of Health strongly encourages the developer, Mill Creek Residential LLC, to schedule time to talk to the Public Health Department before plans are finalized about options for specific and targeted interventions to protect the health and wellness of the inhabitants of housing located in close proximity to major roadways.

If, in the opinion of the Board of Health, compelling evidence of the health risks associated with housing located in close proximity to major roadways is supported with additional scientific evidence in the future and if specific and targeted interventions to protect the health and well-being of the future residents of housing located in close proximity to major roadways are not undertaken, then the Board of Health reserves the right to act to protect the public's health under its authority to make reasonable health regulations[4] and to "examine all nuisances, sources of filth and causes of sickness"[5].

Thank you for your attention.

Sincerely,

Edward Cosgrove, PhD | Stephen Epstein, MD, MPP | Jane Fogg, MD, MPH

CC: *Timothy Muir McDonald, Director of Public Health*
Board of Selectmen
Kate Fitzpatrick, Town Manager
Christopher Coleman, Assistant Town Manager/Director of Operations
Sheila Page, Administrative Specialist, Zoning Board of Appeals
Lee Newman, Director of Planning and Community Development
Jason R. Talerman, Esq., Blatman, Bobrowski, Mead & Talerman, LLC
Mill Creek Residential, LLC

[4] M.G.L. ch. 111, s.31, available at: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXVI/Chapter111/Section31
[5] M.G.L. ch. 111, s.122, available at: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXVI/Chapter111/Section122

From:	Tara Gurge
Sent:	Wednesday, October 28, 2015 4:24 PM
To:	Sheila Page
Cc:	Timothy McDonald; Dawn Stiller
Subject:	RE: Greendale Mews October 20th Hearing Memo

Sheila –

Here are the requirements that were set by the Board of Health, at our meeting that was held on Nov. 14, 2013, directed to the Zoning Board of Appeals re: this proposed project (see below). We received your previous email with the 2 proposed conditions, after looking at the proposed plans, we also have the following additional conditions –

- According to these proposed plans, the pool is located 154 feet from the highway. We will not allow the permitting of this pool in this location. In order to allow this pool, as stated in our Board of Health meeting minutes, all recreational facilities need to be at least 100 meters from highway and shielded. As a result, this pool would need to be centrally located (in courtyard area), closer to Greendale Ave., and have a buffer (or be shielded).
- The Playground would also need to be located in a centrally located courtyard area and be located at least 100 meters from the highway, and have a buffer (or be shielded). Please confirm.
- The BOH also noted that 'any new residential construction should be greater than 100 meters away from the highway'. Please confirm, since these setback distances were not clearly noted on the proposed plans.
- The BOH also required that windows facing the highway shall be fixed/sealed. Please confirm.
- Forced central air filtration systems must meet or exceed filtration with properly maintained MERV-16 electrostatic filters. Please confirm.
- Are any proposed open balconies located within 100 meters of the highway? Please confirm.
- Since these proposed garages are located within the building, and are located next to living spaces (i.e. Dens), you need to ensure that there will be no risk of indoor air contaminants (i.e. VOCs) from flowing into the abutting living spaces. (NOTE: Supply-side leaks can cause problems by pressurizing the garage and inducing flow into the abutting living space.) Please confirm.
- The Board of Health stated that a written disclosure to residents may need to be required as part of this approval (due to the potential effects of micro particulates, since these residences are located so close to the highway.)
- Need to ensure that as many trees as possible remain in order to provide a natural barrier. Please confirm.

Please let me know if you need any clarifications on these requirements.

Thanks,
Tara

From: Sheila Page
Sent: Wednesday, October 28, 2015 2:15 PM
To: Dawn Stiller
Cc: Tara Gurge; Timothy McDonald
Subject: RE: Greendale Mews October 20th Hearing Memo

Hi all, Thanks for your input regarding the comments. I will pass them on to the Board, since this is a negotiated deal and the hearing opened and closed already, I am not sure how much they will take into account your comments. They still want know of potential issues and the applicant will still need to follow the laws and regulations. I am sorry for the confusion.

Below are two conditions being proposed -

4. In order to mitigate the effects of air pollution from the nearby highway, the owner of the building shall be responsible for maintenance of air filters in any air conditioning or filtration system and shall change or clean the filters on a regular basis, no less frequently than as recommended by the manufacturer.

5. The project shall comply with any HUD noise guidelines set forth in 24 CFR 51; or any other applicable requirements for noise mitigation. Prior to the issuance of a building permit, the applicant shall submit a plan for noise abatement that is approved by the Building Commissioner. Prior to the issuance of an occupancy permit, the applicant shall demonstrate compliance with HUD noise guidelines and any applicable noise mitigation requirements or regulations.

Sheila Page

Administrative Specialist
Zoning Board of Appeals
Planning and Community Development
781-455-7550 ext 261
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Town of Needham
500 Dedham Avenue
Needham, Massachusetts
www.needhamma.gov

From: Dawn Stiller
Sent: Wednesday, October 28, 2015 10:34 AM
To: Sheila Page
Cc: Tara Gurge; Timothy McDonald
Subject: RE: Greendale Mews October 20th Hearing Memo

Hi Sheila,

Tara has the plans (which she just received Monday for some reason and we do check the mail daily). She said that THERE ARE SOME DISCREPANCIES that she needs to review with Tim. He is in meetings for most of the day. She will try to get back to you today with the issues in the plans.

~Dawn

Dawn Stiller | Administrative Coordinator

Needham Public Health
781-455-7500 ext. 258 | (fax) 781-455-0892

From: Sheila Page
Sent: Tuesday, October 27, 2015 3:41 PM
To: Dawn Stiller

Cc: Tara Gurge; Timothy McDonald
Subject: RE: Greendale Mews October 20th Hearing Memo

Hi Dawn, Tara should have received the architectural plans for the 136 unit plan, but I am concerned because I mailed both Tim's memo and the plans on the same day - October 19 - via interoffice mail. If I mailed it after the PSAB pick-up time then it went out October 20. I did not confirm whether folks had received the plans. Thank you for the heads up.

The plans can be viewed on the website: http://needhamma.gov/index.aspx?NID=3298
I will send a paper copy again. I am expecting the engineering plans, I hope, today from the applicant. Tony already has a copy.

That October 28 deadline was embedded in the Greendale Mews Settlement. But we are still missing plans from the applicant so I am not sure how that deadline will pan out. I have received comments from Tara regarding other projects but not Greendale Mews. (that should a been a red flag to me because she always gets comment to me quickly!) At her earliest convenience is best. The hearing is November 10 but the applicant will need to fix any concerns by the hearing date.

I will change Tim's name - thanks.

Sheila

Sheila Page

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From: Dawn Stiller
Sent: Tuesday, October 27, 2015 2:06 PM
To: Sheila Page
Cc: Tara Gurge; Timothy McDonald
Subject: Greendale Mews October 20th Hearing Memo

Hi Sheila,

Tim received the memo regarding the revised plans that went out for review and comments or concerns. We have a couple of issues with this memo:

1. Has Tara received the revised plans for the 136 units to review?
2. Why are we just receiving the memo today with a deadline of tomorrow?
3. Tara is out unexpectedly today, so if she hasn't received the revised plans (and there weren't any with the memo), she will not be able to respond with any safety/drainage/circulation concerns in a timely manner.

If she has already responded with comments that's great, but where she's out we aren't really sure.

P.S. Please note Tim's last name is McDonald not MacDonald

Thank you,
~Dawn

Dawn Stiller | Administrative Coordinator

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Prevent. Promote. Protect.

To: Zoning Board of Appeals

From: Needham Board of Health

Date: November 14, 2013

Subject: Recommendations from the Needham Board of Health on Proposed Greendale Mews Project

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The Needham Board of Health has carefully considered a large body of recent health related research including that conducted by Dr. Douglas Brugge of Tufts University and that based upon that data and the potential for future work supporting the data already collected we (the BOH) make the following recommendations:

New residential construction should be greater than 100 meters (328 feet) from major highways, ideally > 150 meters (about 500 feet).

Mitigating risk closer to highways

- Windows directly facing highways should be fixed/sealed. Other windows should be designed so as not to direct particulate matter into living spaces.
- Forced central air filtration systems to meet or exceed filtration standards, with properly maintained MERV-16 electrostatic filters.
- Recreational facilities (bike paths, pools, etc.) should be >100 meters from the highway and shielded from highway.
- Leave as many trees as possible and submit a landscape design, particularly including evergreens which will not shed leaves in the winter.

Consider particulate particle study of site

- Testing performed by company that can test to the micro particulate level.
- Perform testing to assess the risk involved with building design and allow for modification of design, if needed.
- Aim to have testing samples performed over 4 seasons, to detect seasonal variations.

As the evidence of health risks becomes stronger, the Board may consider requiring a written disclosure to residents (similar to current lead paint disclosures for residential home sales).

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Developing Community-Level Policy and Practice to Reduce Traffic-Related Air Pollution Exposure

Doug Brugge[1], **Allison P. Patton**[2], **Alex Bob**[3], **Ellin Reisner**[4], **Lydia Lowe**[5], **Oliver-John M. Bright**[1], **John L. Durant**[2], **Jim Newman**[6], and **Wig Zamore**[4]

[1]Tufts University School of Medicine, Department of Public Health and Community Medicine

[2]Tufts University, Department of Civil and Environmental Engineering

[3]City of Somerville, Office of Strategic Planning and Community Development

[4]Somerville Transportation Equity Partnership

[5]Chinese Progressive Association

[6]Linnean Solutions

Abstract

The literature consistently shows associations of adverse cardiovascular and pulmonary outcomes with residential proximity to highways and major roadways. Air monitoring shows that traffic-related pollutants (TRAP) are elevated within 200–400 m of these roads. Community-level tactics for reducing exposure include the following: 1) HEPA filtration; 2) Appropriate air-intake locations; 3) Sound proofing, insulation and other features; 4) Land-use buffers; 5) Vegetation or wall barriers; 6) Street-side trees, hedges and vegetation; 7) Decking over highways; 8) Urban design including placement of buildings; 9) Garden and park locations; and 10) Active travel locations, including bicycling and walking paths. A multidisciplinary design charrette was held to test the feasibility of incorporating these tactics into near-highway housing and school developments that were in the planning stages. The resulting designs successfully utilized many of the protective tactics and also led to engagement with the designers and developers of the sites. There is a need to increase awareness of TRAP in terms of building design and urban planning.

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Highway proximity and health

Concentrations of traffic-related air pollutants (TRAP) are frequently elevated next to highways and major roadways. The mixture of gasses and particles in fresh motor vehicle exhaust emissions are distinct from other air pollutants that are spread more evenly over large metropolitan areas. Key pollutants in TRAP include ultrafine particles (UFP, particles <0.1 microns in diameter), black carbon, PM_{10} (particles <10 microns in diameter), nitrogen oxides (including nitrogen dioxide and nitrogen oxide, NO), carbon monoxide, and volatile organic compounds[1,2,3]. Thus, people who live or spend time in locations adjacent to busy roadways are more highly exposed to these pollutants.

Many studies have looked at where people live relative to major roadways and investigated whether closer proximity puts them at greater risk of adverse health outcomes. These "proximity studies" have consistently found that living closer to heavy traffic is associated with childhood asthma and reduced lung function[4,5], cardiovascular health and mortality[6,7], biomarkers of cardiovascular health[8], and development of autism[9,10].

We have been conducting community-based participatory research projects under the umbrella of the Community Assessment of Freeway Exposure and Health (CAFEH; http://sites.tufts.edu/cafeh/) study to look at the possible role of UFP on the health of residents living near heavy traffic. Other research suggests that UFP might be a causal agent of near highway health effects. Animal studies have reported that UFP can penetrate deep into the lungs and translocate into the blood. UFP promote inflammation, oxidative stress and atherosclerosis in animals[11,12,13]. Both controlled human exposure studies and studies of short term association with UFP add evidence that UFP affect inflammation and coagulation[14,15,16,17,18,19].

In CAFEH, we monitored UFP in both near highway (<400 m from highways) and urban background (>1 km from highways) neighborhoods[20] and collected blood biomarker samples and lifestyle information from participants living in these locations. Resulting data were used to build land use regression models of UFP for the study areas[21]. These models predict hourly UFP levels at participants' residences for every hour for a year. Subsequently, we modified participant exposure by their time activity patterns and use of air conditioning. The resulting individualized exposures were used to test associations with blood biomarkers of inflammation and coagulation, which are predictors of cardiovascular disease risk. We have not published our main findings for association of UFP with the biomarkers and cannot report them here.

Environmental Justice

TRAP is an environmental justice issue because low-income and minority populations are disproportionately concentrated near high traffic volume roadways. A U.S.-wide study that linked National Health and Nutrition Examination Survey data to the National Highway Planning Network found that Non-Hispanic blacks, Mexican Americans and people living just above or below the poverty line were more likely to have higher TRAP exposure[22]. Two other studies recently conducted similar investigations of traffic exposure in the U.S. Both

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studies had similar findings. The first used census track level data and found that residential location of non-Hispanic blacks and Hispanics had positive Spearman correlation coefficients with road density. They also found a similar association for poverty[23]. The second study analyzed national data at a finer grain, using census blocks. This study also found that being non-Hispanic black, Hispanic and low-income were associated with higher traffic volume and density. They also found that greater racial and income disparity were associated with increased traffic density[24].

Principles for reducing or avoiding UFP exposure

Development of protective tactics for near-highway locations requires knowledge of atmospheric processes and TRAP emission rates. It is important to note that UFP concentrations change rapidly in time and space, which makes understanding exposure complex. However, because highway traffic patterns and UFP emission rates are predictable, we can build fairly reliable models to predict UFP concentrations at different locations and times[25,26]. General principles for reducing or avoiding exposure should consider: 1) wind direction; 2) wind speed; 3) distance from busy roadways; 4) time of day; and 5) time of year. For example, based on the CAFEH study we found that the highest UFP concentrations occurred in Somerville within 0-50 m of Interstate 93 (I-93) with distance-decay gradients varying depending on traffic and meteorology[27].

The annual median particle number concentration (PNC, a proxy for UFP) 0-50 m from I-93 was two-fold higher compared to the background area (>1 km from I-93). PNC was generally highest in winter and lowest in summer and fall, higher on weekdays compared to weekends, and higher during morning rush hour compared to later in the day. For winds out of the southwest and northwest, PN concentrations were elevated on the northeast side of I-93 relative to the southwest side, and when winds were out of the northeast the opposite occurred, indicating that I-93 is the dominant source of PNC to neighborhoods immediately downwind of the highway. PNC was also greatly impacted by wind speed: median PN concentrations were highest for calm winds (<0.3 m/s) and lowest for wind speeds >1.6 m/s.

Tactics for Reducing Community Exposure

Evidence for efficacy of different tactics to reduce near-highway communities' TRAP exposure was reviewed. These tactics derive from empirical research and are intended for consideration in building and community design. They comprise methods to reduce TRAP generation, prevent pollution from reaching locations people frequent, and moving people away from pollution. We searched for studies specifically measuring air pollutant concentration differences as a result of each tactic in PubMed and in the urban planning and environmental science literature. Although many papers claim that these tactics reduce TRAP exposure and improve health, there were limited measurements demonstrating these effects. Therefore, effectiveness of the different tactics based on the literature was classified as good (>40% potential reduction), moderate (<40% potential reduction), or inconclusive (insufficient evidence) for both on-site and off-site tactics (Table 1).

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Land use buffers can often be used to separate sensitive land uses (e.g., residences, schools) from traffic and other sources of air pollution. TRAP exposure zones with concentrations 40% to 90% higher than concentrations in urban backgrounds extend about 50 m to 1500 m from highways and major roads, with most pollutants decreasing to background levels within 300 m to 500 m and at shorter distances upwind than downwind[28,29,30,31,32].

Siting parks requires consideration of competing factors. Although poor siting (e.g., in TRAP exposure zones) can expose children to air pollution, parks also provide benefits and services that might outweigh pollutant health risks, especially for communities without alternative park space[33,34,35].

Reducing pollution entry into buildings is the most effective on-site method to reduce TRAP exposure indoors. Multiple guidelines support moving air inlets to locations with cleaner air[36,37,38]. Research suggests placing air intakes on rooftops or on sides of buildings that do not face roads can decrease pollutant concentrations indoors.[39,40] Infiltration of TRAP can also be reduced by tightening buildings, frequently achieved using soundproofing or energy efficiency measures.[41,42,43,44,45]

Filtration is an effective method for improving indoor air quality. In the U.S., filters are rated based on the Minimum Efficiency Reporting Value (MERV, higher is more efficient) for particles in the 0.3–1 μm, 1–3 μm, and 3–10 μm size ranges[46,47,48]. Although minimum efficiencies are not reported for UFP, pilot studies have shown that at least some high-MERV filters can remove UFP.[49,50] Challenges with filtration include improper filter replacement and long term maintenance.[51]

Moderate effectiveness can also be achieved through urban design. For example, avoiding wind flow through open areas of raised highways or orienting street canyons so that wind flows through them instead of stagnating could reduce pollutant concentrations by one third to one half.[52,53,54,55] In addition, garages and street parking could be distributed so as to decrease driving or low emissions zones could substitute some of the vehicle fleet with electric vehicles.[56,57].

Urban vegetation including green roofs or walls can also decrease air pollution by slightly, particularly in highly polluted cities (e.g., Mexico City) through deposition on leaf surfaces and reduced need for air conditioning due to the cooling effect provided by the soil layer and building shade[58,59,60,61,62]. Vegetation along the side of a busy road can reduce air pollution behind the vegetative barrier by less than 40%, although results vary greatly by wind direction and study[63,64]. When planning urban vegetation, it is important to note that vegetation in street canyons can increase pollutant concentrations by as much as 33% due to decreasing wind flow and ventilation[65,66,67,68,69]. Off-site, solid or vegetative noise barriers along highways can decrease the amount of air pollution reaching neighborhoods[70,71]. Factors such as the effects of barrier height and road width require further study[72,73]. The limited evidence for vegetative barriers suggests that dense vegetation performs similarly to a solid barrier by both blocking and filtering air pollution, with effectiveness depending on wind direction and whether the roadside trees are deciduous or evergreen[74,75,76].

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Bicycle or other active travel lanes can be separated from traffic to reduce TRAP exposure for people breathing heavily during exercise.[77,78,79]. Larger-scale projects like capping highways with decking has been shown to reduce concentrations near one major project[80,81,82]. However, elevated air pollution levels have been measured in highway tunnels and near vents/exits to decked areas, leading to potentially higher exposures for commuters and people living near vents/exits[83,84,85,86].

There is increased interest in urban agriculture to improve access to fresh, healthy, affordable food and reduce transportation costs while lowering carbon emissions is popular[87], but has led to questions of how garden location affects exposure. In fact, some vegetables can accumulate pollutants from the air, resulting in a dietary exposure pathway[88,89].

Charrette Methods

In May 2014, the CAFEH team used lessons from their research to organize a charrette that brought together environmental scientists, health researchers, architects, planners, community members and designers in a creative problem-solving session focused on near-highway projects in Somerville and Boston Chinatown[90].

Somerville Case Example

The City of Somerville, MA, just north of Boston, is highly burdened with TRAP. The city is the most densely populated in New England with 78,000 residents living within 11.6 km^2. The city is crossed by I-93, Boston's main North-South highway (about 170,000 vehicles/day)[91]; Rt. 28, (about 38,000 vehicles/day)[92]; Route 38 (about 34,000 vehicles/day)[93]; and other high volume roadways. This results in high UFP levels in residential areas near the roadways[94]. The Somerville population is economically and ethnically diverse with many low income and immigrant residents living near major roadways. Demand for housing and commercial space combined with little developable land has resulted in pressure to develop near highways.

A vacant site in the city was selected to be a test case in our charrette to consider pollutant exposure mitigation strategies. The site is located <200 m from both Interstate 93 (I-93) and McGrath Highway (Rt. 28), and is next to a Stop & Shop supermarket. Surrounding the site is a small abandoned park and a neighborhood of two and three family homes. The nearby area includes several commercial buildings and Foss Park, the largest park in Somerville (Figure 1). The site is zoned for commercial use, but a residential developer aims to amend the zoning to allow residential development. The vacant parcel, located near so many TRAP sources, is similar to much of the remaining developable land in the city.

Concepts that emerged in the charrette ranged from design elements for the proposed housing to neighborhood-wide plans. Multiple types of barriers were considered. There are currently no sound walls along I-93 or McGrath near the site. Rather than traditional walls, charrette participants opted for more functional barriers such as minimally occupied structures including parking garages and commercial buildings (with high efficiency filtration) situated between the highway and the proposed new housing. Participants also

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considered vegetation buffers to be planted in the abandoned playground next to I-93. The goal was to reserve areas farther from the highway for more sensitive, residential uses, while also blocking flow of pollutants into residential areas (Figure 2).

Concepts designed to reduce exposure at the nearby and heavily utilized Foss Park included creating earthen berms around the edges and a shell performance stage as functional barriers. In addition, participants recommended siting more active park elements, such as sports fields, farthest from the highways. While the focus of the charrette was on new development or redevelopment, addressing the pollution exposure of current residents was also considered. One recommendation was to provide residents near the highway with weatherization and filtering options, potentially through a city loan program.

Following the charrette, our work in Somerville with respect to this site has continued. We presented some of the charrette ideas to developers and are exploring ways to enhance the air filtration systems they propose to use in the housing, should it be approved for construction.

Boston Chinatown Case Example

Boston Chinatown is an historic neighborhood near the heart of downtown that lies at the junction of the Massachusetts Turnpike (I-90) and the I-93 expressway; most of the community's housing lies within 400 m of the highway. Its surface streets are major access points to and from the highways. Chinatown is also Boston's densest neighborhood, with only 5.1% tree canopy coverage, compared to 28% for the city overall.

On the east side of Boston Chinatown lies a 20-acre tangle of highway ramps and empty land, owned by the Massachusetts Department of Transportation and designated as an important area for economic development. It was labelled the “Chinatown Gateway Special Study Area” in the 1990s. In 2013, as luxury downtown development made available parcels scarcer and even more valuable, Boston's outgoing mayor proposed to build a new $261 million two-school facility for the Josiah Quincy Upper School and the Boston Arts Academy on one of the Chinatown Gateway sites known as Parcel 25. The project would place more than one thousand public school students into a school that straddles an I-93 on-ramp and tunnel exit (Figure 3). Despite vocal concerns about the children's safety and health, the community has been largely supportive of the project, with no other suitable development location available in Chinatown.

The charrette produced a host of mitigation ideas. One of the central concepts was to incorporate high-quality air filtration into the HVAC system of the school, paying attention to the siting of air intake units as far from the highways as possible. Other ideas included physical or vegetative barriers between the highway and the building and a large atrium with filtered air and plantings within the building interior (Figure 4). A broader recommendation was to call upon the state Department of Transportation to deck over the highways and provide large-scale air filtering of tunnel exhaust. Chinatown community members expressed that mitigation was both an environmental justice issue and a form of reparations to a community that was destroyed to make way for the highways over fifty years ago.

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Post-charrette, the architectural team for the school project altered its building design to relocate air intake units on the rooftop as far from traffic pollution sources as possible, combined with 100% replacement air, and incorporated high-MERV air filters into its HVAC system design. Since then, plans for the school have been put on hold by Boston's new mayor, but one of the project's architects has become a vocal advocate of this type of healthy building design and will hopefully bring this knowledge into future near-highway schools.

Municipal Strategies

Municipalities have a range of tools at their disposal for enhancing the health and well-being of residents living near highways. While fine particulate matter is regulated at both the federal and state levels, the lack of federal and state standards on UFP has hampered municipal efforts to mitigate the negative health effects of UFP exposure. Since TRAP concentrations are highly variable and challenging to predict, many municipal responses have included air quality testing requirements. Monitoring is also crucial to further research on the health impacts from UFP[95].

The most effective regulatory model, either through zoning or a standalone law, is to restrict what can be built within a defined buffer zone around high pollution roadways. For example, regulation might include restrictions on the location of residences, schools, and active parkland. Non-restricted building types could be permitted within a buffer zone, subject to indoor air quality standards. In California, law restricts siting schools within 500 ft. of urban highways (more than 100,000 vpd) and rural highways (more than 50,000 vpd) unless prescribed conditions are met[96]. This restriction, while not codified by federal standards, sets the stage for municipalities to define high pollution exposure zones and land use guidelines for near highway locations. However, in many urban settings this is not sufficient as urban building densities, including schools and housing, around highways and other high-traffic roadways are already established.

Communities may be able to require protective air filtration for residential or school buildings within a buffer zone of highly traveled roadways through ordinances or conditions put on new developments. In California, the community of Jurupa Valley focused on very specific pollution conditions and forced a legal settlement with companies and municipalities that mandates and pays for filtration in residences and schools within a specified buffer zone[97]. New construction of multi-family affordable housing near highways may offer an opportunity for other municipalities to take similar measures.

Conclusion

The growth of interest in “green buildings” and “healthy homes” has mostly focused on addressing indoor sources of air pollution. We show here that there is an equally important need to consider and prevent exposure to ambient pollutants that infiltrate into homes and schools. While there is a need for more research on the tactics described in this paper, we feel that it is possible, with the evidence available now, to better protect people from TRAP emanating from high traffic roadways.

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Acknowledgements

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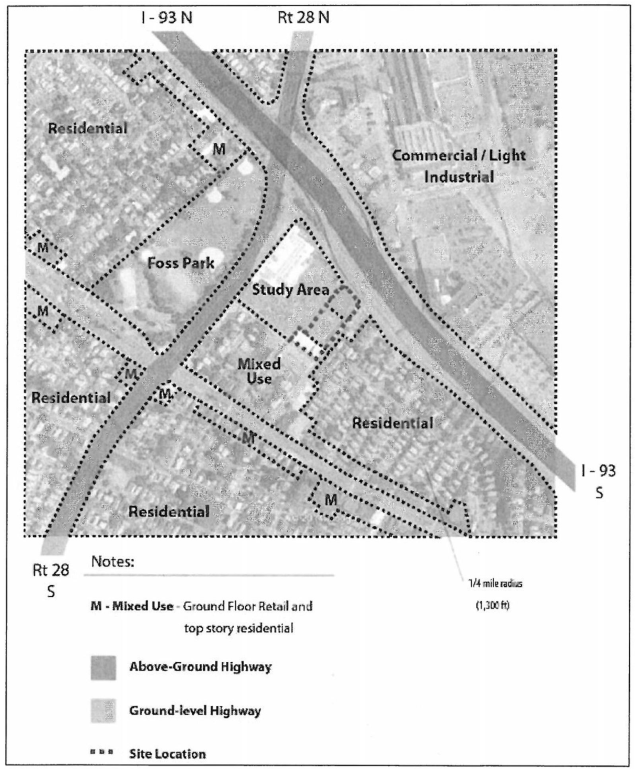

Figure 1.

The Cross Street East site in Somerville. The site is located near both I-93 and Route 28. *Credit: Linnean Solutions*.

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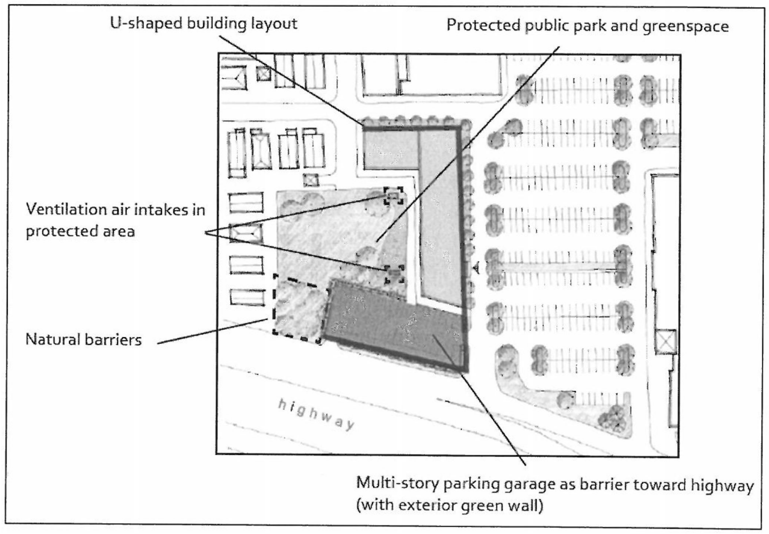

Figure 2.

A design to reduce exposure to TRAP at the site in Somerville. *Credit: Giamportone Design, Linnean Solutions*.

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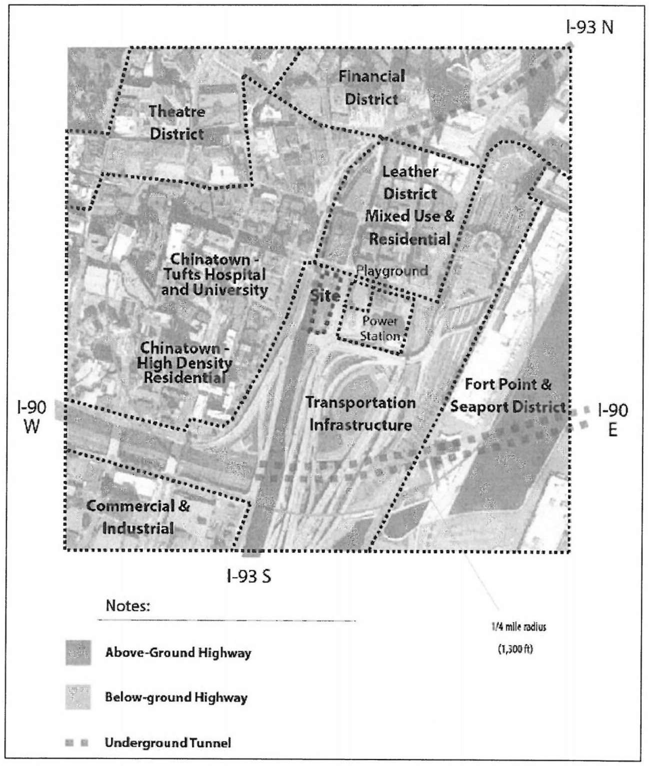

Figure 3.
The Parcel 25 site in Chinatown. The site is located directly above I-93 at a tunnel exit.
Credit: Linnean Solutions.

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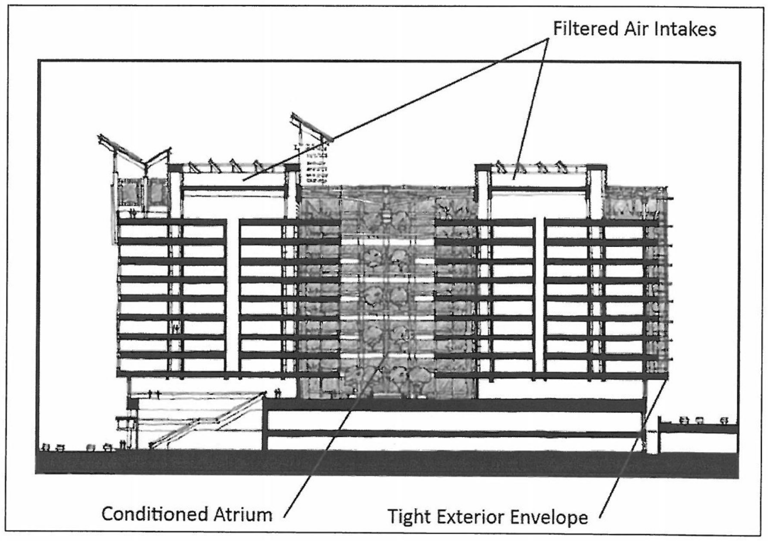

Figure 4.

A proposed building design for the Chinatown site with two enclosed HVAC zones, joined in the middle by a plant-filled atrium *Credit: Giamportone Design*

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Table 1

Summary of expected effectiveness of different tactics.

	Effectiveness		
Location	**Good**	**Moderate**	**Inconclusive**
On-Site	• Filtration • Air intake location • Sound proofing	• Healthy placement of buildings and parking structures • Trees and Plantings	• Healthy vegetables
Off-Site	• Park locations • Land use buffers	• Built or vegetative barriers • Active travel locations • Decking over highways	

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Residential Proximity to Major Highways — United States, 2010

Supplements

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Introduction

Traffic-related air pollution is a main contributor to unhealthy ambient air quality, particularly in urban areas with high traffic volume. Within urban areas, traffic is a major source of local variability in air pollution levels, with the highest concentrations and risk of exposure occurring near roads. Motor vehicle emissions represent a complex mixture of criteria air pollutants, including carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM), as well as hydrocarbons that react with NOx and sunlight to form ground-level ozone. Individually, each of these pollutants is a known or suspected cause of adverse health effects (*1–4*). Taking into consideration the entire body of evidence on primary traffic emissions, a recent review determined that there is sufficient evidence of a causal association between exposure to traffic-related air pollution and asthma exacerbation and suggestive evidence of a causal association for onset of childhood asthma, nonasthma respiratory symptoms, impaired lung function, all-cause mortality, cardiovascular mortality, and cardiovascular morbidity (*5*).

The mixture of traffic-related air pollutants can be difficult to measure and model. For this reason, many epidemiologic studies rely on measures of traffic (e.g., proximity to major roads, traffic density on nearest road, and cumulative traffic density within a buffer) as surrogates of exposure (*6–8*). These traffic measures typically account for both traffic volume (i.e., number of vehicles per day), which is a marker of the type and concentration of vehicle emissions, and distance, which addresses air pollution gradients near roads. Traffic emissions are highest at the point of release and typically diminish to near background levels within 150 to 300 meters of the roadway (*7,9,10*); however, the potential exposure zone around roads can vary considerably depending on the pollutant, traffic volume, ambient pollution concentrations, meteorologic conditions, topography, and land use (*5*). Traffic exposure metrics in the published literature have used a variety of different density and distance cut-points (*6*). Nevertheless, numerous epidemiologic studies have consistently demonstrated that living close to major roads or in areas of high traffic density is associated with adverse health effects, including asthma, chronic obstructive pulmonary disease, and other respiratory symptoms (*11–15*); cardiovascular disease risk and outcomes (*16–20*); adverse reproductive outcomes (*21,22*); and mortality (*23–25*). Some studies have observed a dose-response gradient such that living closer to major roads is associated with increased risk (*13,14,16–18*). In terms of traffic density, several studies have reported adverse health effects associated with residential proximity to roads with average daily traffic volume as low as 10,000 vehicles per day (*6,11,15–17*).

In the United States, it is widely accepted that economically disadvantaged and minority populations share a disproportionate burden of air pollution exposure and risk (*26,27*). A growing body of evidence demonstrates that minority populations and persons of lower socioeconomic status experience higher residential exposure to traffic and traffic-related air pollution than nonminorities and persons of higher socioeconomic status (*5,28–31*). Two recent studies have confirmed that these racial/ethnic and socioeconomic disparities also exist on a national scale (*32,33*).

This report is part of the second CDC Health Disparities and Inequalities Report (CHDIR). The 2011 CHDIR (*34*) was the first CDC report to assess disparities across a wide range of diseases, behavior risk factors, environmental exposures, social determinants, and health-care access. The topic presented in this report is based on criteria that are described in the 2013 CHDIR Introduction (*35*). This report provides descriptive data on residential proximity to major highways, a topic that was not discussed in the 2011 CHDIR. The purposes of this report are to discuss and raise awareness of the characteristics of persons exposed to traffic-related air pollution and to prompt actions to reduce disparities.

Methods

To characterize the U.S. population living close to major highways, CDC examined data from several sources using Geographical Information Systems (GIS). Three data sources were used for this assessment: 1) the 2010 U.S. census (available at http://www.census.gov/2010census), 2) 2006–2010 American Community Survey (ACS) 5-year estimates (available at http://www.census.gov/acs), and 3) 2010 (Quarter 3) road network data from NAVTEQ, a commercial data source that provides comprehensive road information for the United States (available at http://www.navteq.com). Seven sociodemographic variables were examined. Data on age, sex, and race/ethnicity were obtained from the 2010 census; data on nativity, language spoken at home, educational attainment, and poverty status were obtained from the ACS.

The U.S. Census Bureau collects data on race and ethnicity (i.e., Hispanic origin) as two separate questions. For this analysis, persons of non-Hispanic ethnicity were classified as white, black, Asian/Pacific Islander, American Indian/Alaska Native, other race, and multiple races. Persons of Hispanic ethnicity, who might be of any race or combination of races, were grouped together as a single category. Educational attainment was defined as less than high school, high school graduate or equivalent, some college, or college graduate. For the variable nativity, "native born" includes U.S. citizens born abroad (one or both of whose parents were citizens at the time of birth) and anyone born in the United States or a U.S. territory; "foreign-born" denotes persons who were not U.S. citizens at birth. Poverty status was categorized by using the ratio of income to the federal poverty level (FPL), in which "poor" is <1.0 times FPL, "near poor" is 1.0–2.9 times FPL, and "nonpoor" is ≥3.0 times FPL.

Major highways were defined as interstates (Class 1) or as other freeways and expressways (Class 2) based on the Federal Highway Administration (FHWA) Functional Classification system. These road types represent the most heavily-trafficked, controlled-access highways in the United States. Although traffic volume is not factored directly into the Functional Classification system, FHWA statistics indicate that the majority of major highways have average daily traffic volumes exceeding 10,000 vehicles per day (i.e., 77% of rural interstates have >10,000 vehicles per day and >72% of urban interstates and other freeways and expressways have >30,000 vehicles per day) (*36*).

The census tract is the smallest geographic unit of analysis available for the variables of interest in the ACS data. ESRI ArcGIS v10 GIS software was used to create circular buffers of 150 meters around all major highways, and the proportion of each census tract included within the buffer area was calculated. This area proportion was then applied to the census tract-level data from the 2010 census and ACS to estimate the number of persons living within 150 meters of a major highway for the total population and by sociodemographic characteristics. Census tract count estimates were summed to obtain state and national estimates. The proportion of the population living within 150 meters of a major highway was calculated for each category of the seven sociodemographic variables, using category-specific denominators derived from the 2010 census and ACS. No sampling error is associated with the 100% population counts obtained from the 2010 census. Standard errors were not calculated for the estimated population counts derived from the ACS because of the complexity of the GIS analysis used to generate these data. Therefore, for this descriptive analysis, no statistical testing or calculation of 95% confidence intervals was conducted, and it was not possible to determine if the observed differences across population subgroups are statistically significant.

Results

Approximately 11.3 million persons (or 3.7% of the 308.7 million U.S. population) live within 150 meters of a major highway. State-level estimates ranged from 1.8% in Maine to 5.6% in New York (Figure). Regional patterns, based on U.S. Census Bureau groupings, indicate that the estimated proportion of the population living within 150 meters of a major highway ranged from 3.1% in the Midwest and 3.3% in the South to 4.3% in the Northeast and 4.4% in the West. The proportion of the population living near a major highway did not differ by sex (Table). By age group, the estimated proportion of persons living close to a major highway varied from 3.4% among those aged 45–79 years to ≥4.0% among those aged 18–34 years.

The greatest disparities were observed for race/ethnicity, nativity, and language spoken at home; the populations with the highest estimated percentage living within 150 meters of a major highway included members of racial and ethnic minority communities, foreign-born persons, and persons who speak a language other than English at home (Table). The estimated percentage of the population living within 150 meters of a major highway ranged from a low of 2.6% for American Indians/Alaska Natives and 3.1% for non-Hispanic whites to a high of 5.0% for Hispanics and 5.4% for Asians/Pacific Islanders. Likewise, the estimated proportion of the population living near a major highway was 5.1% for foreign-born persons, 5.1% for persons who speak Spanish at home, and 4.9% for persons who speak another non-English language at home.

Disparities by educational attainment and poverty status were less pronounced (Table). The estimated percentage of the population living near a major highway varied from 3.4% for high school graduates to 4.1% for those with less than a high school diploma. A more consistent pattern was observed for poverty status; the estimated proportion of the population living near a major highway was 4.2% for those in the poor category, 3.7% for those in the near-poor category, and 3.5% for those in the nonpoor category.

Discussion

Overall, approximately 4% of the total U.S. population lives within 150 meters of a major highway, suggesting increased exposure to traffic-related air pollution and elevated risk for adverse health outcomes. Estimates of residential proximity to major roads are influenced by the number and type of roads and the distance or buffer size used. In terms of quantifying the total U.S. population exposed to traffic-related air pollution, the estimate of 11.3 million people derived from this analysis should be considered conservative because only interstates, freeways, and expressways were included and a relatively small buffer distance of 150 meters was used. These conditions were selected to capture persons who are at the highest risk for exposure to traffic-related air pollution. In addition, this estimate is based on distance to a single road and does not account for cumulative exposure to traffic from multiple roads.

The percentage of the population exposed to traffic-related air pollution is expected to be larger in urban areas because of higher population density, more roads, and higher traffic volume. A case study of two North American cities (Los Angeles County and Toronto, Canada) estimated that 30%–45% of the population in these urban areas lives within 500 meters of a highway or 50–100 meters of a major road (*5*). Although this report does not address urban/rural differences directly, an additional state-level analysis of these data indicated that the percentage of the population living within 150 meters of a major highway was correlated positively ($R = 0.65$) with the percentage of the population living in urban areas. Additional studies are needed to understand potential sociodemographic disparities among populations living near major highways across levels of urbanization.

This analysis suggests that social and demographic disparities exist with respect to residential proximity to major highways. Larger disparities were observed for indicators of minority status (i.e., race/ethnicity, nativity, and language spoken at home) than for traditional indicators of socioeconomic status (i.e., poverty and educational attainment). Two other national studies have reported similar findings using alternative approaches. A study that examined the distribution of sociodemographic variables across various traffic exposure metrics assessed at the residential address found that race, ethnicity, poverty status, and education all were associated with one or more traffic exposure metrics (*32*). Another study demonstrated that the correlation between traffic exposure metrics and sociodemographic variables across all U.S. census tracts was stronger for race and ethnicity than it was for poverty, income, and education and that the magnitude of the correlations varied spatially by region and state (*33*).

The environmental justice literature suggests that socially disadvantaged groups might experience a phenomenon known as "triple jeopardy" (*37*). First, poor and minority groups are known to suffer negative health effects from social and behavioral determinants of health (e.g., psychosocial stress, poor nutrition, and inadequate access to health care). Second, as suggested in this analysis, certain populations (e.g., members of minority communities, foreign-born persons, and persons who speak a non-English language at home) might be at higher risk for exposure to traffic-related air pollution as a result of residential proximity to major highways. Third, there is evidence suggesting a multiplicative interaction between the first two factors, such that socially disadvantaged groups experience disproportionately larger adverse health effects from exposure to air pollution (*37–39*).

Limitations

The findings in this report are subject to at least three limitations. First, the area-proportion technique used assumes a homogeneous population density and population distribution by sociodemographic characteristics within each census tract, which might result in erroneous count estimates. The direction of the bias (overestimate or underestimate) could differ across population subgroups. For example, if socioeconomic disparities associated with residential proximity to major highways exist within census tracts, then the calculated percentages for minority subgroups might be underestimated and those for nonminority subgroups might be overestimated. Second, living within 150 meters of a major highway is only a surrogate for exposure to traffic-related air pollution. This study did not address the following factors that could affect exposure to traffic-related air pollution: number and type of vehicles traveling on major highways, cumulative effect of living near multiple roads, individual time-activity patterns (e.g., time spent at home vs. away, time spent inside vs. outside), meteorologic conditions, topography, and land-use patterns. Finally, it was not possible to perform testing to determine if the differences in the estimated percentages across population subgroups were statistically significant. However, the findings are consistent with other published research (*32,33*).

Conclusion

Primary prevention strategies to reduce traffic emissions include improving access to alternative transportation options (e.g., transit, rideshare programs, walking, and cycling), financial incentives to reduce vehicle miles traveled and congestion, diesel retrofitting, and promoting the use of electric and low emission vehicles. In addition, secondary prevention strategies to reduce exposure to traffic emissions include mitigation techniques for existing homes and buildings (e.g., roadside barriers and improved ventilation systems) and land-use policies that limit new development close to heavily-trafficked roads. For example, a recent study of roadside barriers suggests that solid barriers (i.e., noise barriers) might be more effective at mitigating traffic-related air pollution than vegetative barriers (i.e., tree stands) (*41*). In California, public health law has been used to restrict siting of new schools near major highways and busy traffic corridors (California Education Code §7213.c.2.C). Implementation of these strategies can help reduce exposures to traffic-related air pollution and health risks associated with these exposures.

Focusing prevention and mitigation interventions in urban areas, where there is a higher concentration of traffic-related air pollution and a greater proportion of the population residing near major roads, and in areas with the most socially disadvantaged populations will likely result in larger health benefits (*37*). Future and ongoing efforts to address disparities in residential proximity to major highways and traffic-related air pollution exposures will require an interdisciplinary collaboration between transportation, urban planning, and public health specialists.

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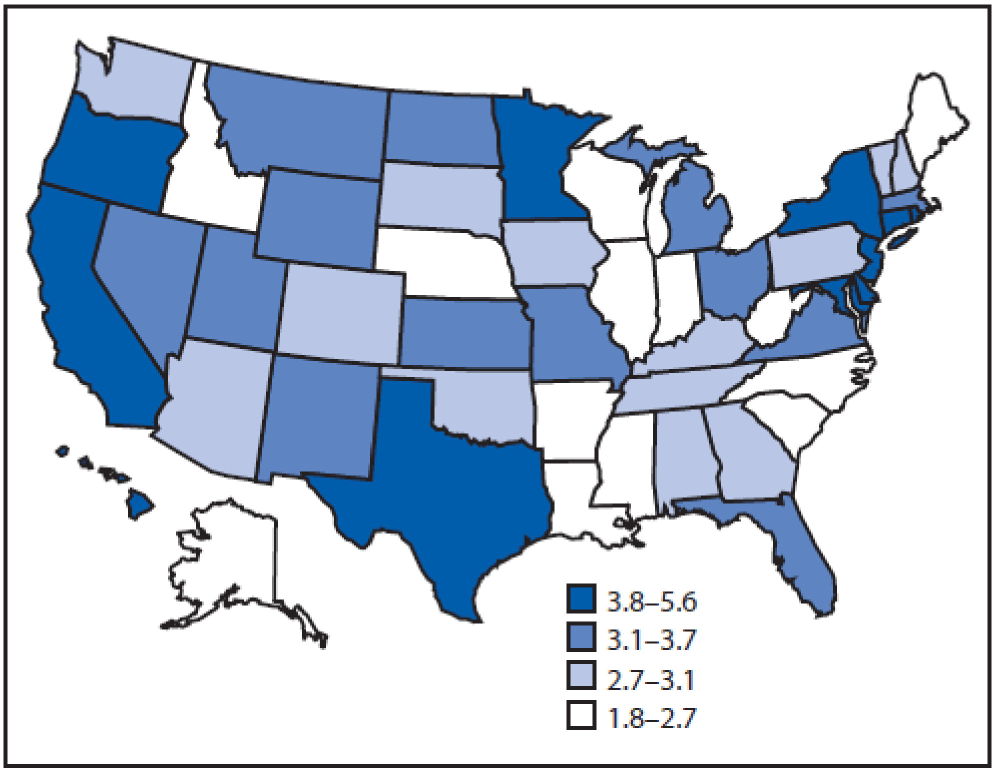
FIGURE. Percentage* of population living within 150 meters of a major highway, by state — United States, 2010



* Calculated by dividing the population within 150 meters of a major highway by the total population per state and multiplying by 100. The percentages are displayed using quartiles.

Alternate Text: The figure shows the percentage of the U.S. population living within 150 meters of a major highway, by state in 2010. The percentage was calculated by dividing the total population within 150 meters of a major highway by the total population per state and multiplying by 100. The percentages are displayed using quartiles.

TABLE. Number and percentage of population living within 150 meters of a major highway, by selected characteristics — United States, 2010

Characteristic	**No.**	**(%)***
Total†	**11,337,933**	**(3.7)**
Sex†		
Male	5,547,223	(3.7)

Female	5,790,844	(3.7)
Age group (yrs)†		
0–4	766,603	(3.8)
5–9	727,279	(3.6)
10–17	1,168,995	(3.5)
18–24	1,219,887	(4.0)
25–34	1,714,903	(4.2)
35–44	1,523,607	(3.7)
45–64	2,808,121	(3.4)
65–79	977,948	(3.4)
≥80	412,215	(3.7)
Race/Ethnicity†		
Non-Hispanic		
White	6,030,811	(3.1)
Black	1,676,225	(4.4)
Asian/Pacific Islander	800,723	(5.4)
American Indian/Alaska Native	59,378	(2.6)
Other	27,239	(4.5)
Multiple race	235,995	(4.0)
Hispanic§	2,502,616	(5.0)
Nativity¶		
Native born**	9,172,481	(3.5)
Foreign born††	1,966,763	(5.1)
Language spoken at home (≥5 yrs)¶		
English only	7,513,304	(3.3)
Spanish	1,805,261	(5.1)
Other	1,059,572	(4.9)
Educational attainment (≥25 years)¶		

Less than high school	1,225,735	(4.1)
High school graduate or equivalent	1,988,228	(3.4)
Some college	1,977,261	(3.5)
College graduate	2,092,232	(3.8)
Poverty status¶,§§		
Poor (<1.0 times FPL)	1,733,031	(4.2)
Near-poor (1.0–2.9 times FPL)	3,882,694	(3.7)
Nonpoor (≥3.0 times FPL)	5,227,274	(3.5)

Abbreviation: FPL = federal poverty level.

* Denominator for overall population is 308,745,348. Percentages for all other rows were calculated by using category-specific denominators.

† **Source:** U.S. Census Bureau, 2010 census (available at http://www.census.gov/2010census).

§ Persons of Hispanic ethnicity might be of any race or combination of races.

¶ **Source:** U.S. Census Bureau, 2006–2010 American Community Survey (available at http://www.census.gov/acs).

** Includes U.S. citizens born abroad (one or both of whose parents were citizens at the time of birth) and anyone born in the United States or a U.S. territory.

†† Persons who were not U.S. citizens at birth.

§§ Additional information is available at http://aspe.hhs.gov/poverty/figures-fed-reg.cfm .

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Highway proximity associated with cardiovascular disease risk: the influence of individual-level confounders and exposure misclassification

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Abstract

Background

Elevated cardiovascular disease risk has been reported with proximity to highways or busy roadways, but proximity measures can be challenging to interpret given potential confounders and exposure error.

Methods

We conducted a cross sectional analysis of plasma levels of C-Reactive Protein (hsCRP), Interleukin-6 (IL-6), Tumor Necrosis Factor alpha receptor II (TNF-RII) and fibrinogen with distance of residence to a highway in and around Boston, Massachusetts. Distance was assigned using ortho-photo corrected parcel matching, as well as less precise approaches such as simple parcel matching and geocoding addresses to street networks. We used a combined random and convenience sample of 260 adults

>40 years old. We screened a large number of individual-level variables including some infrequently collected for assessment of highway proximity, and included a subset in our final regression models. We monitored ultrafine particle (UFP) levels in the study areas to help interpret proximity measures.

Results

Using the orthophoto corrected geocoding, in a fully adjusted model, hsCRP and IL-6 differed by distance category relative to urban background: 43% (-16%,141%) and 49% (6%,110%) increase for 0-50 m; 7% (-39%,45%) and 41% (6%,86%) for 50-150 m; 54% (-2%,142%) and 18% (-11%,57%) for 150-250 m, and 49% (-4%, 131%) and 42% (6%, 89%) for 250-450 m. There was little evidence for association for TNF-RII or fibrinogen. Ortho-photo corrected geocoding resulted in stronger associations than traditional methods which introduced differential misclassification. Restricted analysis found the effect of proximity on biomarkers was mostly downwind from the highway or upwind where there was considerable local street traffic, consistent with patterns of monitored UFP levels.

Conclusion

We found associations between highway proximity and both hsCRP and IL-6, with non-monotonic patterns explained partly by individual-level factors and differences between proximity and UFP concentrations. Our analyses emphasize the importance of controlling for the risk of differential exposure misclassification from geocoding error.

Keywords

Highway proximity Air pollution Traffic Geocoding Inflammation

Background

Residential proximity to major roadways and highways has been found to be associated with numerous adverse health outcomes, including cardiovascular diseases [1, 2, 3]. These studies suggest that prior conditions, diabetes and obesity for example, make individuals more vulnerable to traffic exposure [4, 5]. Only a few studies have reported levels of blood markers–C-Reactive Protein (hsCRP), Interleukin-6 (IL-6), and fibrinogen–relative to distance to highways or roadways [5, 6, 7].

A primary hypothesis for near roadway health effects has been traffic-related air pollutants, many of which are elevated next to high traffic roadways [8]. A recent meta-analysis of near highway air monitoring studies found that there was consistent evidence for steep gradients of UFP, elemental carbon, volatile organic compounds, CO, NO and NO_x[9]. These pollutants tend to decline to urban background levels within 200-400 m, vary considerably with changes in meteorology, and have most often been measured over short time periods, typically individual days [10]. While health studies have reported exposure to various pollutants as well as distance to roadways [2, 7], none have yet assigned exposure to UFP in the near highway environment. With or without pollutant exposure measures, proximity could represent traffic noise, a factor we could not address in this analysis [11], or gradients of socioeconomic status (SES) near heavy traffic, raising the need to carefully address potential confounders.

Prior traffic proximity studies have often used exposure metrics with potentially significant misclassification. Many studies that use proximity as an exposure proxy have assigned residential locations by geocoding addresses to street networks, which introduces positional error that could bias results of fine-scale proximity analysis [12, 13, 14]. Previous analysis of this study population found a mean positional error of 39 m and 49 m when geocoding to a commercially and publicly available street network address dataset, respectively [15]. Given steep pollution gradients within 200 m of a highway, this degree of error could be significant.

The Community Assessment of Freeway Exposure and Health study (CAFEH) is a community-based participatory research cross sectional study of near highway air pollutants, primarily UFP, and blood markers of cardiovascular risk [16]. Here we report an analysis of proximity to a major highway and association with blood markers of cardiovascular risk. We focus on state of the art geopositioning of residential addresses and consideration of a large number of potential confounders. We also use UFP concentration patterns to inform stratified analyses that better reflect spatial distributions of pollutants.

Methods

Recruitment

The analysis presented here includes data from two near-highway areas and two paired urban background areas, located in Somerville and in the Dorchester and South Boston neighborhoods of Boston, MA [Somerville and Dorchester hereafter; Figure 1[16]. A third neighborhood from which we recruited, Chinatown in downtown Boston, was excluded because the highway geometries and street canyons complicated assignment of simple proximity values. Recruitment proceeded in approximately one year blocks. In each neighborhood we stratified recruitment for <100 m, 100-400 m and >1000 m from the edge of Interstate-93 (I-93) in order to maximize local exposure contrast. We ended up with a small number of residences outside of 400 m so we extended the study to 450 m. On the basis of location of our recruited sample, we excluded from analysis the 450-1000 m areas. All participants in the study areas resided in buildings that were no more than 6 stories high and most were in buildings of 3 stories or less. Random samples were generated for all addresses within our study areas and every address in the random sample was approached. We had complete sets of documents available in English, Spanish, Portuguese, Haitian Creole, Vietnamese and Chinese and field members fluent in these languages to ensure broad inclusion of non-English speaking residents. Recruitment was door-to-door by surveyors who received extensive training and supervision. To bolster numbers, we recruited additional convenience samples. The convenience samples largely consisted of residents in 4 elderly housing developments, 2 each in Somerville and Dorchester. The study protocol and consent forms were approved by the Tufts Health Sciences IRB.

Within 50 m	50 m-150 m	150-250 m	250-450 m	>1000 m
(N = 30)	(N = 58)	(N = 65)	(N = 54)	(N = 53)

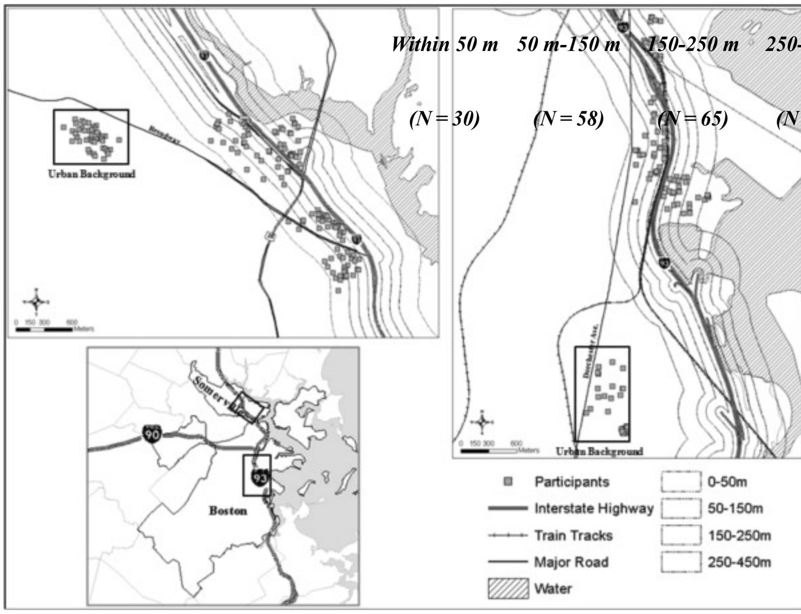

Figure 1

The near highway and urban background study areas in (a) Somerville and (b) Dorchester with participant residential addresses.

Human data

Participants who enrolled in the study completed a survey in their home which included questions about demographic information (Table 1). Time activity was collected for 2 recent days and included time spent inside and outside at home, at work/school, at other locations, and on highways for each hour for a recent workday/weekday and non-workday/weekend. Time activity data displayed significant differences in micro-environment time allocation when stratified by demographic variables, but low within participant variability between the first and second questionnaire [15]. We asked questions that assessed exposure to highway pollutants in other microenvironments (residential, occupational, commuting, etc.). We also gathered information on possible confounders with cardiovascular disease (diet, physical activity, stress, etc.) and inquired about relevant diagnosed comorbidities (diabetes, hypertension, etc.). Medications were recorded from labels of all prescriptions that were available in the home and were classified into broad categories by a physician: statins, oral hypoglycemic agents (OHAs), insulin, anti-hypertensives, antacids, anti-inflammatories and hormones. Data were double entered into MS Access, checked for errors and corrected (verified and validated) by reference to the original survey hard copy. Most variables included in the regression models had 1% or less missing. BMI and smoking status had 8% and 4% missing, respectively. Income had the largest percent missing at 11%. Those with missing income were categorized into a separate group and retained in the analysis.

Table 1

Characteristics of the study population stratified by categories of distance to the highway

	Within 50 m	*50 m-150 m*	*150-250 m*	*250-450 m*	*>1000 m*
	(N = 30)	*(N = 58)*	*(N = 65)*	*(N = 54)*	*(N = 53)*
Demographic variables					
Age, mean (SD)	56.1 (11)	55.9 (11.36)#	61.9 (10.6)*#	58.6 (10.97)	56.7 (13.65)
BMI	31.9 (7.42)*#	27.7 (5.75)#	31.9 (7.85)*#	29.5 (7.65)	28.2 (7.58)
Female	57%	52%	58%	63%	68%
Born in USA					
Yes	53%	71%	72%	57%	68%
Missing	10%	1%	3%	2%	4%
Race					
White	67%	70%	65%	63%	64%

	Within 50 m	***50 m-150 m***	***150-250 m***	***250-450 m***	***>1000 m***
	(N = 30)	***(N = 58)***	***(N = 65)***	***(N = 54)***	***(N = 53)***
Non-white	30%	28%	34%	37%	36%
Missing	3%	2%	1%	0%	0%
Annual household income					
Less than $24,999	27%#	26%#	61%*#	35%#	28%
$25,000-$74,999	43%#	40%#	25%#	31%	25%
$75,000 or more	10%	22%#	8%*#	22%#	38%
Don't know/ refused	20%#	12%	6%#	11%	9%
Terminal degree					
Less than high school	27%	14%	31%	24%	13%
High school	46%*#	33%	26%#	37%	21%
Undergraduate	27%	39%*#	25%#	20%	32%
Graduate	0%	14%	18%	19%	34%
Employment					
Working full or part time	53%#	45%#	28%*#	43%	53%
Retired, disabled, unemployed	37%#	52%#	69%*#	57%	45%
Missing	10%	3%	3%	0%	2%
Study area					
Somerville	67%#	38%*#	53%	69%*#	49%
Exposure variables					
Workday time spent inside home (hrs)	14.6 (5.41)	17.1 (4.62)	17.4 (4.16)	16.7 (5.85)	16.8 (4.39)
Non-workday time spent inside home (hrs)	17.2 (5.37)	18.5 (4.23)	19.5 (4.12)	18.7 (5.27)	17.7 (5.20)
Previous week combustion exposure score	3.1 (2.35)	3.9 (1.92)	3.8 (2.03)	3.9 (2.38)	3.2 (1.98)
Job combustion score	3.27 (1.62)	3.21 (1.64)	3.70 (1.65)	3.20 (1.69)	3.17 (1.61)
Open windows in winter					

	Within 50 m	*50 m-150 m*	*150-250 m*	*250-450 m*	*>1000 m*
	(N = 30)	*(N = 58)*	*(N = 65)*	*(N = 54)*	*(N = 53)*
Yes	59%	59%	63%	52%	49%
Missing	3%	3%	2%	0%	0%
Open windows in summer					
Yes	96%	96%	91%	91%	94%
Missing	3%	2%	5%	0	2%
Travel on highway					
Yes	17%#	4%*#	15%#	17%#	11%
Missing	3%	2%	0%	0%	0%
Health & medications					
Statin medication	13%	33%	21%	33%	23%
Previous heart attack	3%	5%	9%	5%	6%
Diabetes	13%	14%	15%	15%	15%

*Indicates a significant mean or proportional difference from the urban background (>1000 m).

#Indicates a significant mean or proportional difference from any other group.

We derived variables for race as white or non-white, based on the small numbers in other racial minority categories. An occupational combustion exposure was based on a qualitative assessment of each participant's current and past occupation(s) along with self-reported exposure on the job. Pack years of smoking was calculated for current and past smokers. Vigorous leisure time physical activity was calculated based on frequency and duration. Upon completing the in-home survey, participants were invited to attend field clinics (typically within weeks of the home visit) after fasting through the night. Clinics were held in the morning in the study areas. At the clinics, we administered a second brief survey that included illnesses in the past week, alcohol consumption, when they last ate, whether they had recent stressful life events (open ended) and exposure to 18 sources of combustion in the previous week. A combustion exposure score was derived by adding up the number of reported combustion exposures in the week preceding their blood draw.

Height and weight were recorded using a standard scale (SECA, Model #8761321009) and stadiometer (Shorr Productions LLC, Model #905055). Diastolic and systolic blood pressure were measured in the right, then left, then right arms with the participant seated using an automatic blood pressure machine (Model #HEM711ACN2, Omron Healthcare, Kyoto, Japan). Hypertension was defined as either measured elevated blood pressure or taking antihypertensive medications. Blood lipid profile was measured on site from a finger stick using a CardioChek PA device (Polymer Technology Systems, Inc. CardioChek, Indianapolis, IN). A venous blood sample was taken, processed to plasma and stored at minus 80 degrees centigrade. Stored plasma was analyzed in 3 batches. Each sample was assayed using immunoassay kits for hsCRP (SPQ High Sensitivity CRP Reagent Set; DiaSorin, Stillwater, MN); fibrinogen (κ-Assay, Kamiya Biomedical, Seattle, WA); Tumor Necrosis Factor alpha receptor II (TNF-RII; Quantitative, R & D Systems, Minneapolis, MN); and IL-6 (Quantitative HS, R & D Systems, Minneapolis, MN).

Participants with hsCRP levels greater than 10 mg/L (N = 23) were examined for individual/group mean differences for BMI, current smoking, recent illness, serious chronic illness, and recent combustion exposure. We found no trends in individuals or significant group differences in means that could justify removing them from the analysis.

Geographic data

Residential address and apartment numbers were verified during recruitment. Parcel address geo-databases were obtained from the Somerville and Boston GIS and city planning departments and used to geocode residential addresses of study participants within ESRI ArcGIS 10.1. Aerial photography with 15-30 cm resolution and horizontal error less than 1 m from a 2008–2009 flyover of Massachusetts was downloaded from the Massachusetts Office of Geographic Information and used to manually locate each residence from the parcel centroid to the center of residential buildings (N = 235) [17]. Parcel building and floor plans were obtained for parcels with multiple or larger buildings. Floor plans were scanned and georeferenced to the aerial photos in ArcGIS to assign the apartment within each building. Parcel geocoding with aerial photography has been considered a gold standard methodology for address assignment [14]. To the best of our knowledge this study is the first near highway health study to employ this level of precision.

We defined highways to include entrance and exit ramps as well as feeder roads running parallel to the highway. The state road network contains a surface width variable that was used to create an edge of roadway buffer, which was visually verified for accuracy using the aerial photography layer. Distance to highway was calculated for each residence within ArcGIS by conducting a spatial join to the edge of highway polygon, providing a Euclidian distance. These values were then used to categorize study participants into categories of 0–50 m, 50-150 m, 150-250 m, 250-450 m, and ≥ 1000 m (urban background) from the highway. Distance to highway was explored as a continuous variable, but was found to not be appropriate since there is a gap between 450 m and 1000 m where participants were intentionally not recruited as part of the CAFEH study in order to maximize exposure contrast in the study population. Proximity cut points were determined based upon previous literature identifying strongest association with 0-50 m from a major roadway and cardiovascular health outcomes [6, 7]. Subsequent exposure groupings were determined based upon maximizing number of cut points while maintaining sufficient sample size to conduct a multiple linear regression. A dichotomous exposed/unexposed cut point (categories of 0-450 m and 1000 m+) was found to not be significantly associated with hsCRP and IL-6. Other cut points that mixed the 0-50 m category (categories of 0-100 m, 100-450 m and 1000 m+; and categories of 0-50 m, 51-450 m and 1000 m+) also did not show significant associations.

Air pollution data

Mobile monitoring of particle number concentration which is dominated by UFP was conducted with the Tufts Mobile Air Pollution Laboratory (TAPL), a converted recreational vehicle equipped with a condensation particle counter (TSI Model 3775). The TAPL was driven on the same route which encompassed the areas with study participants for 283 hours in Somerville and 141 hours in Dorchester/South Boston [15, 18]. Particle number concentrations, are presented for the distance categories given above. The instrument time stamp was used to correct for measurement lag times (3 seconds). Other details of quality control are reported elsewhere [18]. All the data collected in each distance category listed above is presented. We excluded data collected between 450 m and 1000 m because there were no study participant residences in this range of distances from the edge of I-93.

Statistical methods

Analyses were performed using SAS® (Statistical Analysis Software, Cary, North Carolina) version 9.12 and SPSS® (SPSS, Inc., Chicago, IL) version 20.0. Bivariate analyses were conducted using t-tests and Wilcoxon tests to compare means and medians for normally and non-normally distributed continuous variables respectively between two categories. Analysis of variance (ANOVA) with a post-hoc Tukey multiple comparisons test were used to compare means of normally distributed continuous variables between the exposed and urban background groups. Differences in medians for non-normally distributed continuous variables for each exposed group and urban background were calculated using Wilcoxon tests with a post-hoc Bonferroni correction for multiple comparisons. Chi-square analysis and Fisher's exact test, when appropriate, were used to compare differences in proportions. All hypothesis tests were two-sided.

Multivariate regression consisted of examining the association between proximity to highway and lognormal-transformed levels of hsCRP, IL-6 and TNF-RII. The lognormal-transformed regression ß-estimates and 95%CIs were exponentiated to obtain the percent difference between each exposed group and urban background for each outcome. Fibrinogen was normally distributed and was examined for absolute differences.

Model-building involved consideration of variables, using a series of bivariate analyses to identify potential confounders. Age, sex, and smoking status were forced into the models. Variables associated with both the outcome and main predictor which had p-values less than 0.15 were considered potential confounders and included in the multivariate linear regression model building process. Adjusted linear regression model building was performed using a forward stepwise selection approach with a p-value of 0.15 as both entry and exit criteria. We performed an additional manual selection process where variables were retained if they had an impact on the beta coefficients of the distance variables. Effect modification was explored as part of the multivariate model building process and did not yield any significant interactions. In addition to the unadjusted model two other models were developed, a model adjusted for variables that could influence exposure to air pollution ("exposure adjusted") and a fully adjusted model that included the exposure variables. Residuals were checked and found to be normally distributed. We also fit generalized additive models (GAM) which allowed for a smooth effect of the continuous distance variables and generated corresponding spline plots for the 0-450 m study areas.

Results

Participants were recruited between July 2009 and June 2011. Out of a random sample of 1,247 addresses, 587 were determined to be eligible and, of these, 327 (56%) completed surveys and 174 gave blood samples with one participant's blood sample not viable for analysis (final N = 173). Ninety-four convenience participants are also included. In total we had blood samples from 267 people and used 260 of these for this analysis, eliminating 7 who lived outside the distance categories.

The mean age of participants was 58.2 years, 155 (58%) were women and most (66%) were White. The proportion of those who completed high school was 78%, most had incomes below $75,000 (69%) and mean BMI was 29.7. There was little difference with distance for near-highway population subgroups 0-50 m, 150-250 m and 250-450 m for age, BMI, household income, education, employment, study area, or traveling on highways (Table 1). It is important to note that the 50-150 m distance group was younger, had lower BMI, higher SES, and traveled less on highways, resembling the urban background population.

In the Somerville study area both hsCRP and IL-6 were higher in near highway areas than in the urban background (>1000 m), although a dose response relationship with distance was not apparent. Mean and median biomarker data by distance to highway for the total sample and by neighborhood (Additional file 1: Table S1). Fibrinogen and TNF-RII were not elevated near the highway in Somerville. Near highway levels were not elevated for any of the blood markers for the Dorchester area. There was little evidence of associations with distance in regression models for TNF-RII or fibrinogen (Additional file 2: Table S2).

In the unadjusted model hsCRP was higher near the highway compared to urban background except in the 50-150 m distance category (Table 2 and Figure 2). Adjustment for exposure modifiers resulted in a gradient from closer to farther from the highway, with the exception of 50-150 m residences. The fully adjusted model included age, smoking status, gender, income, BMI, born in the USA, vigorous physical activity, travel on highway, cooked with oil, non-workday time spent inside home, insulin medication, statin medication, heart attack. This model no longer had a distance-dependent gradient, although hsCRP remained elevated relative to urban background for all distance categories except 50-150 m.

Table 2

Regression models comparing hsCRP and IL-6 with distance from the highway

Highway distance	Unadjusted model		Exposure adjusted		Adjusted model	
	(N = 260)		(N = 252)		(N = 225)	
hsCRP	%Diff	95%CI	%Diff	95%CI	%Diff	95%CI
	Adj. $R^2 = 0.05$		Adj. $R^2 = 0.14$		Adj $R^2 = 0.38$	
0-50 m	67%	(-8%,197%)	99%	(12%,254%)	43%	(-16%,141%)

Highway distance	Unadjusted model		Exposure adjusted		Adjusted model	
	(N = 260)		(N = 252)		(N = 225)	
hsCRP	%Diff	95%CI	%Diff	95%CI	%Diff	95%CI
	Adj. $R^2 = 0.05$		Adj. $R^2 = 0.14$		Adj $R^2 = 0.38$	
50-150 m	-15%	(-48%,38%)	-24%	(-53%,22%)	7%	(-39%,45%)
150-250 m	75%	(9%,180%)	70%	(7%,169%)	54%	(-2%, 142%)
250-450 m	31%	(-20%,116%)	29%	(-27%,107%)	49%	(-4%,131%)
≥1000 m	ref	ref	ref			
IL-6	Adj. $R^2 = 0.04$		Adj. $R^2 = 0.17$		Adj $R^2 = 0.29$	
0-50 m	51%	(4%,119%)	72%	(20%,146%)	49%	(6%,110%)
50-150 m	28%	(-6%,75%)	29%	(-4%,73%)	41%	(6%,86%)
150-250 m	54%	(13%,108%)	43%	(7%,90%)	18%	(-11%, 57%)
250-450 m	46%	(-5%,101%)	50%	(11%,101%)	42%	(6%,89%)
≥1000 m	ref	ref	ref			

Values represent percent difference between distance category and urban background population.

Exposure adjusted models.

hsCRP adjusted for time spent at home, windows opened in winter and summer, smoking pack years and driving on highway.

IL 6 adjusted for time spent at home, windows opened in winter, work combustion exposures and air conditioner type.

Fully adjusted models.

hsCRP adjusted for age, smoking status, gender, income, BMI, born in the USA, vigorous physical activity, travel on highway, cooked with oil, non-workday time spent inside home, insulin medication, statin medication, heart attack.

IL6 adjusted for age, gender, smoking status, BMI, workday time spent at home, windows opened in winter and air conditioner type.

Ortho Corrected Parcel StreetMap TIGERLine
Distance
% Diff (95%CI) % Diff (95%CI) % Diff (95%CI) % Diff (95%CI)

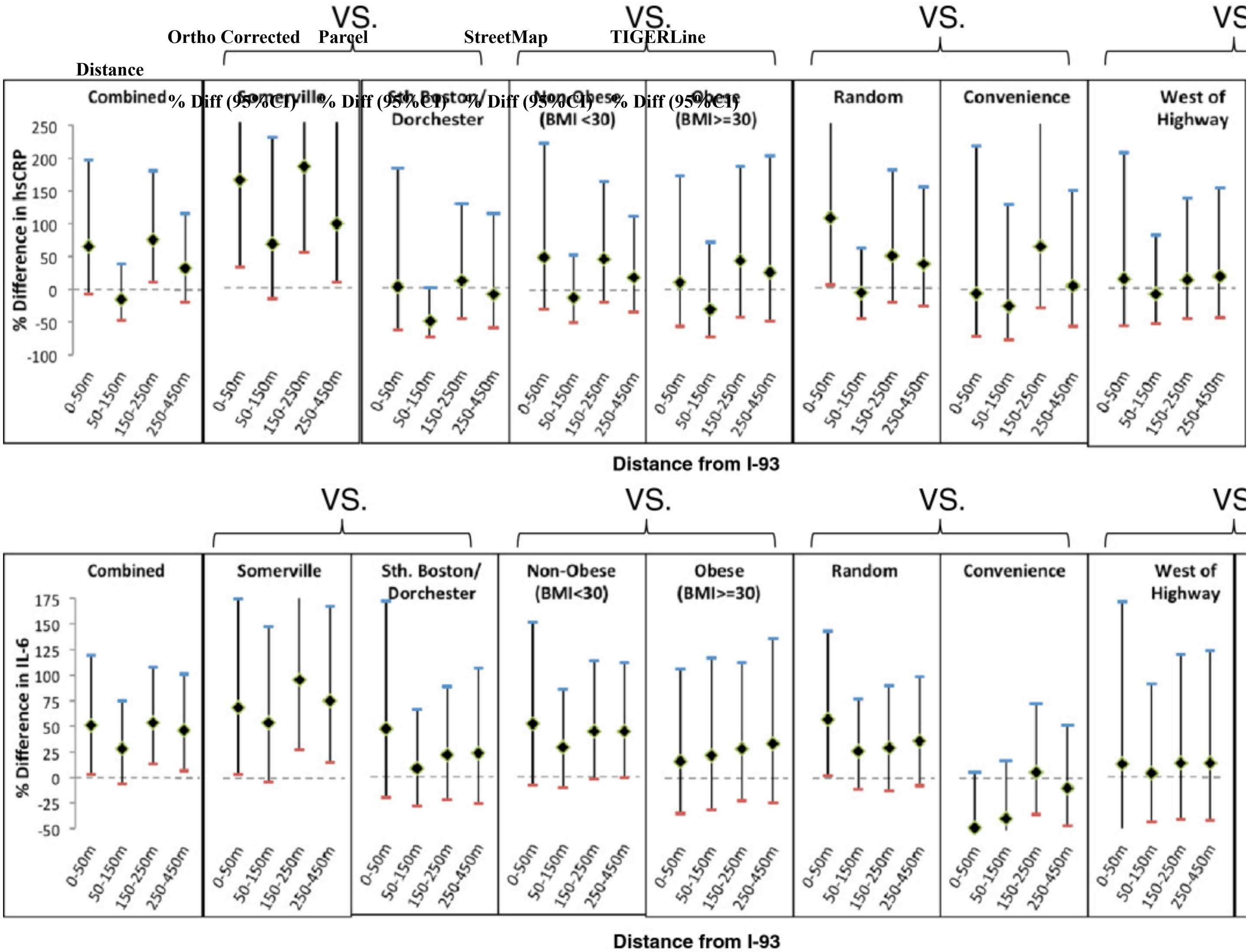

Figure 2

Unadjusted analysis of associations between distance and hsCRP and IL-6 levels, for various subpopulations compared to background.

In the unadjusted model for IL-6, all of the near highway distance categories had positive associations relative to urban background (Table 2 and Figure 2). As with hsCRP, the exposure adjusted model increased the estimate for the < 50 m distance category. The fully adjusted model adjusted for age, gender, smoking status, BMI, workday time spent at home, windows opened in winter and air conditioner type. In this model all population groups had elevated IL-6 relative to urban background, though notably less for the 150-250 m population. In the fully adjusted models for hsCRP and IL-6 BMI was found to contribute the greatest amount to the adjusted R^2 and was shown to be significantly associated with proximity to highway (results not shown).

Adjusted GAM models for the relationship between LN IL-6 and LN hsCRP and distance to highway in the 0-450 m study population (Additional file 3: Figure S1.) displayed a similar trend to the independent variable categorical distance. Stratification of adjusted GAM models by study area displayed markedly different patterns for LN hsCRP. Distance to highway was also examined as a continuous linear variable in adjusted models and while not significant had an inverse relationship with LN IL-6 and LN hsCRP (data not present here).

We also restricted the analysis for Table 2 to include only those participants with complete data for both hsCRP and IL-6 in the fully adjusted models (Additional file 4: Table S3, Additional file 5: Table S4). Percent differences in Additional file 4: Table S3 increased in the unadjusted models, but remained relatively similar to Table 2 in the exposure adjusted and fully adjusted models while standard errors widened in all models. Using the same restriction as for Table 3, Additional file 5: Table S4 compares geocoding methodologies adjusting for covariates, which reduced sample size further. Adjustment of variables revealed a quantitative shift in percent differences within each of the geocoding methods but the qualitative comparison between methods remained similar.

Table 3

Fully adjusted percent difference of biomarkers by geocoding methodology

	Distance	Ortho Corrected	Parcel	StreetMap	TIGERLine
		% Diff (95%CI)	% Diff (95%CI)	% Diff (95%CI)	% Diff (95%CI)
	0-50 m	44% (-18%,151%)	49% (-12%,149%)	79% (-11%,258%)	51% (-25%,197%)

	Distance	Ortho Corrected	Parcel	StreetMap	TIGERLine
		% Diff (95%CI)	% Diff (95%CI)	% Diff (95%CI)	% Diff (95%CI)
HsCRP	51-150 m	-2% (-37%,53%)	2% (-34%,57%)	13% (-27%,73%)	22% (-21%,88%)
	151-250 m	40% (-11%,122%)	53% (-4%,143%)	22% (-25%,99%)	16% (-27%,85%)
	251-450 m	46% (-7%,128%)	46% (-7%,130%)	39% (-12%,119%)	57% (-33%,119%)
	>= 1000 m	Ref	Ref	Ref	Ref
IL-6	0-50 m	59% (2%,147%)	41% (-9%,119%)	27% (-37%,158%)	34% (-21%,128%)
	51-150 m	41% (-0.2%,100%)	45% (3%,105%)	18% (-21%,77%)	53% (10%,112%)
	151-250 m	4% (-27%,48%)	12% (-21%,60%)	-13% (-45%,38%)	3% (-27%,47%)
	251-450 m	60% (12%,128%)	55% (8%,123%)	8% (-31%,68%)	54% (5%,126%)
	>= 1000 m	Ref	Ref	Ref	Ref

The sample has been restricted to include those participants geocoded to all three methodologies and containing complete data for variables for each multi-variable regression model (Orthophoto and Parcel N = 223; TIGER N = 210).

We reran the unadjusted and adjusted hsCRP and IL-6 models using the parcel matched, StreetMap USA and TIGER address geocoding and found predominantly that there were changes in associations toward the null for the StreetMap USA and TIGER addresses. The effect of geocoding error on directionality of effect for model ß-estimates was not systematic. The confidence intervals (95%) changed in non-uniform ways, resulting in some spurious results (Table 3 & Additional file 5: Table S4). Distance bin misclassification was examined for the TIGER and Parcel geocoding methodologies by comparing to the ortho-photo corrected residential locations. TIGER geocoding had more false negatives and less sensitivity than parcel geocoding in all distance bins (Additional file 6: Table S5).

We examined medications in detail. Statins, OHAs, and antihypertensives were associated with higher levels of all biomarkers in crude associations. Antacid use was associated with higher levels of hsCRP, IL-6 and TNF-RII. Anti-inflammatory medications and hormones were not associated with differences in biomarkers. In regression models, inclusion of BMI often resulted in medications losing significance. When BMI was excluded from models, some medications could be included; however, this was usually antihypertensive treatment, acting in the same direction as BMI, and likely collinear with BMI in the models (Additional file 7: Table S6). Overall, we found that medications had nominal impact on associations and were included in only two of the models in Table 2.

We also examined reported combustion exposures in the week preceding the blood draw. In adjusted regression models several exposures were associated with cooking with oil for hsCRP and IL-6; spending time on a city street for 20 minutes for IL-6 (in the opposite direction from expected; Additional file 8: Table S7), and smoke exposure at work for TNF-RII (results not shown). Of these, only cooking with oil made it into our fully adjusted model for hsCRP (Table 2). Cooking with oils generates UFP, but we were not able to distinguish effects of food consumption from inhalation of aerosolized oil and found no literature that addressed this issue [19].

To inform subgroup analyses and interpret proximity measures, we compared proximity associations to box plots of UFP concentrations from mobile monitoring in Somerville and Dorchester (Figure 3). UFP were elevated on both sides of the highway in Somerville and for the east side (right side of figure) in Dorchester. The west side (left side of figure, predominantly upwind and with higher local traffic loads) of the highway in Dorchester had a flatter pattern with less evidence of elevation next to the highway (Figure 3b). A prominent sound wall along the east edge of I-93 in Somerville may also have affected concentrations. Concentrations were skewed to the right (approximately lognormal, outliers not shown). For each study area, mean and median UFP concentrations <450 m from the highway were higher than the same statistics in the urban background.

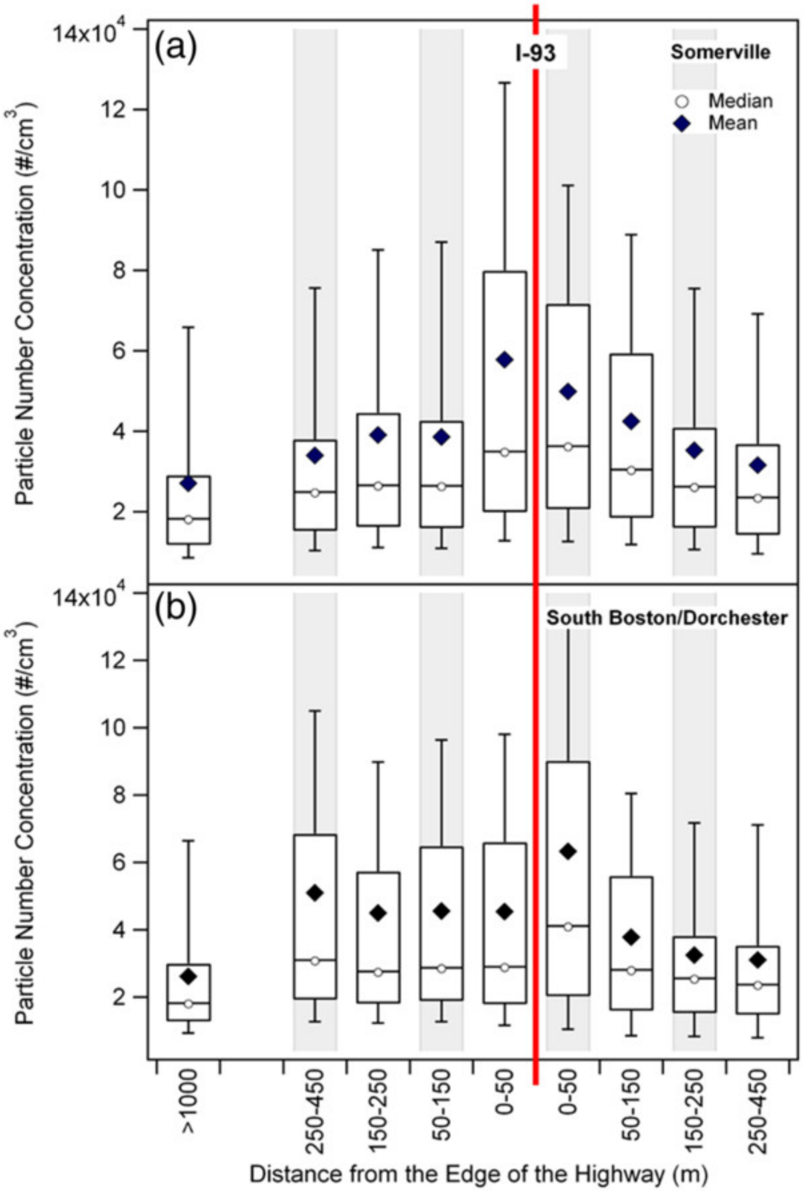

Figure 3

Box plots of 1-second PNC measurements as a function of distance from I-93 for Somerville (a) and Dorchester/South Boston (b). The boxes represent the 25^{th} and 75^{th} percentiles of the data, the whiskers represent the 10^{th} and 90^{th} percentiles. The horizontal solid line in each box represents the median PNC; the black diamond represents the average PNC. The right side of the red line indicates distance to the east of I-93 (generally downwind), and the left side indicates distance to the west of I-93 (generally upwind).

In subgroup analyses of unadjusted hsCRP and IL-6 (Figure 2) we found that associations were stronger in Somerville, in non-obese participants (particularly for IL-6) and in the random sample compared to the convenience sample. Associations were also stronger (especially for hsCRP) on the east side of the highway, which is predominantly downwind. We found less consistent differences in associations by native vs. foreign born, age, gender and smoking or diabetes status (Additional file 9: Figure S2 and Figure S3).

Discussion

Using precise geo-positioning for residential addresses and screening a large number of potential confounders we found associations of distance to highway with hsCRP and IL-6. However, we found little evidence for associations for TNF-RII or fibrinogen with proximity. Associations of hsCRP and IL-6 with each other and with cardiovascular disease (CVD) are well established in the literature. The risk ratio for coronary heart disease for a 3-fold higher hsCRP level in a large meta analysis was 1.63, suggesting that if our associations were shown to be causal they could have an impact on morbidity and mortality for near highway residents [20].

Previous research has shown that geocoding addresses to street networks results in substantial misclassification for proximity studies requiring a high degree of spatial accuracy [13, 15, 21]. Our results expand upon these findings and indicate that misclassification can result in biased regression models (Table 3 and Additional file 5: Table S4). Misclassification was differential in our data set, as those closest to the highway had the greatest classification error, attributable in part to street network geocoding [15]. Studies that require fine-scale spatial resolution such as a near highway analysis should, at a minimum, use local parcel data for geocoding in order to limit the effects of positional error and should consider ortho-photo matching.

Geocoding to tax parcel databases has been used less frequently, but has been shown in this study and others to introduce less positional error than geocoding to street networks [12, 14]. Parcel datasets are primarily created at the city or county planning level. It requires collaboration with city planners to gain access to these geo-databases. Ortho-photo imagery is readily available through ESRI ArcGIS, but temporal accuracy and spatial resolution may vary across different areas. We were fortunate that MassGIS has compiled statewide parcel and ortho-photo datsets and made them freely available to download from a single website easing the process of obtaining these datsets in Massachusetts. Researchers working with large cohorts will need to weigh the benefits of reducing positional error against the additional computational resources and time requirements of ortho-photo correction. However, the increase in exposure accuracy can be considerable.

We back calculated expected effect sizes from the literature to test the consistency of our findings with those of others. Because none of the studies comparing highway proximity and hsCRP had data that could be compared to ours, we started with Panasevich et al. who found a statistically significant correlation between long-term exposure to elevated residential NO_2 and higher hsCRP and IL-6 (5-year exposure values from Table 2 of their publication) [22]. Since NO_2 concentrations decay next to highways, we used the NO_2 distance-decay slope for a highway similar to that of our study area, calculated by Gilbert et al. (linear regression model with the highest R^2), to convert NO_2 levels from Panasevich to distance [23]. Using these two studies, we estimated that hsCRP and IL-6 levels within 100 m of the highway might be expected to be 11% and 24% higher, respectively, than for those living further than 1000 m away. The actual effect sizes we found were mostly 2–5 times higher (Table 2). One possible source of difference, other than study methodology and differences in location, could be that NO_2 gradients decay more gradually than do UFP gradients next to highways, and that UFP is more likely to be the causal agent [8]. Another possibility is that we had a vulnerable population with high prevalence of obesity and diabetes relative to the comparison study. Still, our estimates of effect appear higher than previous estimates in general, especially for the random sample and for the Somerville subset.

UFP decay patterns were similar to the relationship between hsCRP and IL-6 using categorical distance to highway. The biomarker associations we found for distance from the highway were relatively flat across distance categories, except for the 50-150 m category for hsCRP. Associations of hsCRP and IL-6 with distance were lower on the west side of the highway (Figure 2), where UFP concentrations were lower and gradients were less pronounced (Figure 3). UFP gradients in both neighborhoods were steeper east of the highway (usually downwind; right side of Figure 3) than west, perhaps due to busy local roadways and wind direction. In a detailed analysis reported elsewhere, this UFP difference between west (upwind) and east (downwind) highway sides held for analysis by categories including season, time of day, day of week, wind speed and wind direction [18]. These factors may account in part for the substantial differences in distance associations for hsCRP and IL-6 between Somerville and Dorchester. In particular local street traffic may contribute to UFP exposures especially in the urban background area in Dorchester where participants resided much closer to a major roadway.

In our analysis of hsCRP, the 50-150 m distance category was anomalous and did not have elevated levels relative to background, even in the fully adjusted models. The population living 50-150 m from the highway was demographically similar to the population in the comparison group (urban background). As Table 1 clearly shows, there are appreciable individual level socioeconomic differences between populations in different distance categories. While there was an indication of a smaller but similar pattern in IL-6 models, the fully adjusted model brought the 50-150 m category in line with other near highway categories, suggesting confounding. IL-6 promotes the release of hsCRP, so it is not surprising that we found similar responses. But we cannot explain why controlling for confounding did not adjust the 50-150 m hsCRP associations as it did for IL-6. Adjusting for potential confounders failed to eliminate the possibility of residual confounding based on the results for hsCRP in the 50-150 m group.

Limitations and strengths

Our sample size was modest and there was considerable heterogeneity of the populations in distance categories (Additional file 2: Table S2), which increased the risk of residual confounding. Despite our random sample, our analysis may have limited generalizability. Indications of limitation include the difference in findings between our study areas, the exclusion of one study area due to geographic complexity and between the random and convenience samples. If such variability in response exists within our sample, it is likely that our sample and other populations also will vary. Additionally, we would expect our population to be better matched with populations in the Northeastern US than in other parts of the country or the world.

Our primary exposure metric, distance from the highway, likely introduced exposure misclassification relative to what might be seen with individually-assigned exposures to UFP. We also did not test associations with traffic or topographic metrics other than distance to the highway. We have shown elsewhere [15] that for near highway residents misclassification was differential for time spent away from home, which could reduce exposure. Controlling for time activity and other exposure modifiers enhanced near-highway associations.

A particular strength of this analysis was the use of precise geocoding for residential addresses, achieving the “gold standard” in the field. We recruited in 6 languages, increasing our sampling of hard to reach residents. Our sample was stratified by distance from the highway to maximize exposure contrast. We screened for a large number of potential confounders which included many variables not usually assessed in highway proximity studies, however, we could not assess the impact of traffic or other ambient noise. We explored in full regression models the role of medications and other sources of exposure to combustion. We also had measurements of UFP from the study areas from the same year in which we recruited participants and made a separate qualitative comparison of UFP gradients with associations of distance with hsCRP and IL-6. Finally, we had objective measures of both distance and health.

Conclusion

Our results suggest that highway proximity affects blood markers of inflammation which are, in turn, associated with increased cardiovascular disease risk. Highway proximity is associated with UFP and other pollutants, but also SES and traffic noise. We point to three main lessons from this analysis: 1) Attention to high standards in geocoding is valuable, as less rigorous approaches led to different results; 2) Individual level confounding is a threat to valid associations; and 3) Side of highway and predominant wind direction affected associations, emphasizing limitations in proximity measures. By addressing these issues, we feel that we have improved confidence that traffic pollution next to highways is a risk factor for cardiovascular disease. Future research will need to go beyond using proximity and, instead, assign individual exposures to residents, ideally moving toward personal exposure measures that would decrease potential confounding due to other distance-dependent factors.

Abbreviations

ArcGIS:

Geographic Information System Software

CAFEH:

Community Assessment of Freeway Exposure and Health

CO:

Carbon Monoxide

CVD:

Cardiovascular Disease

GIS:

Geographic Information System

hsCRP:

High-Sensitivity C-reactive Protein

IL-6:

Interleukin-6

NO:

Nitric oxide

NOx:

Nitrogen oxides

NO2:

Nitrogen Dioxide

Orthoimage:

Aerial photograph that is geometrically corrected

SES:

Socioeconomic Status

TAPL:

Tufts Mobile Air Pollution Laboratory

TIGER:

Topologically Integrated Geographic Encoding and Referencing

TNF-RII:

Tumor necrosis factor receptor type 2

UFP:

Ultrafine Particles.

Declarations

Acknowledgements

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Electronic supplementary material

12940_2013_700_MOESM1_ESM.pdf Additional file 1: Table S1: Mean and median values for blood biomarkers stratified by distance to the highway. (PDF 80 KB)
12940_2013_700_MOESM2_ESM.pdf Additional file 2: Table S2: Regression models comparing fibrinogen and TNF-RII with distance from the highway. Values for fibrinogen represent absolute differences (mg/dl) between distance category and urban background population, and values for TNF-RII represent percent differences between distance category and urban background population. (PDF 237 KB)
12940_2013_700_MOESM3_ESM.pdf Additional file 3: Figure S1: LOESS smooth plots of predicted LN IL-6 and LN hsCRP from Fully Adjusted Generalized Additive Models. (PDF 213 KB)
12940_2013_700_MOESM4_ESM.pdf Additional file 4: Table S3: Regression models comparing hsCRP and IL-6 with distance from the highway for orthophoto corrected geocoded residential positions. Values represent percent difference between distance category and urban background population restricted to include those participants containing complete data for all variables in the fully adjusted multi-variable regression models for LN of hsCRP and IL-6 (N = 223). (PDF 77 KB)
12940_2013_700_MOESM5_ESM.pdf Additional file 5: Table S4: Unadjusted percent difference of biomarkers by geocoding methodology. This table has different sample sizes from Table 1 due to participants in the 450-1000 m groups being removed from the analysis. (PDF 33 KB)
12940_2013_700_MOESM6_ESM.pdf Additional file 6: Table S5: Distance bin misclassification by geocoding methodology. The analysis includes individuals in the 450-1000 m distance group to provide exhaustive distance coverage but omits those not successfully geocoded to both the TIGERline and Parcel datasets (n = 262). Confirmed match represents the number of residences classified in the distance group by each geocoding method and orthophoto corrected location assignment.% False negatives indicate the number of residences that should have been in the distance bin but were geocoded to an incorrect bin divided by the total sample size (n = 262).% False positives indicate the number of residences that were incorrectly geocoded to the distance bin divided by the total sample size (n = 262). Sensitivity is the percentage of confirmed positive residences for each distance bin (confirmed match divided by orthophoto corrected). Specificity is the percentage of correctly identified negative residences for each distance bin. (PDF 62 KB)
12940_2013_700_MOESM7_ESM.pdf Additional file 7: Table S6: Regression models of medication usage by group. Values represent percent differences between individuals taking versus not taking the listed medications. (PDF 66 KB)
12940_2013_700_MOESM8_ESM.pdf Additional file 8: Table S7: Regression models of combustion exposure in the 2 weeks preceding the blood draw by group. Values represent percent differences between individuals with and without the exposure. (PDF 90 KB)
12940_2013_700_MOESM9_ESM.zip Additional file 9: Figure S2: Unadjusted analysis of associations between distance and hsCRP and IL-6 levels by age, Born USA and Smoking. Figure S3 Unadjusted analysis of associations between distance and hsCRP and IL-6 levels by gender and diabetic. (ZIP 446 KB)
Below are the links to the authors' original submitted files for images.
12940_2013_700_MOESM10_ESM.tif Authors' original file for figure 1

12940_2013_700_MOESM11_ESM.pdf Authors' original file for figure 2
12940_2013_700_MOESM12_ESM.tif Authors' original file for figure 3

Competing interests

Brugge has received travel support to make presentations about uranium mining from Friends of the Earth and International Physicians for the Prevention of Nuclear War. Funding was provided by the National Institute of Environmental Health Sciences (ES015462). Padró-Martínez and Brugge were also supported by HUD grant MALHH0194-09. Support for Lane and Patton was provided by EPA STAR Fellowships (FP-917349-01-0; FP-91720301-0).

Authors' contributions

DB led and directed the study, provided oversight to the analysis and was the lead writer. KL was the lead analyst and contributed to writing, LTP-M led the analysis of the air monitoring data, AS contributed to the literature review and did the analysis presented in the discussion, KH did the medication analysis, DW did the combustion exposure analysis, DDW contributed to the analysis, JIL contributed meaningful intellectual ideas during the writing that affected the interpretation of our data, APP contributed to the air pollution analysis, WZ helped initiate and design the overall study and contributed intellectually to its interpretation, MM oversaw the statistical analysis and wrote that section of the paper. All authors read the manuscript multiple times, provided input and approved the version as submitted.

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Near-highway pollutants in motor vehicle exhaust: A review of epidemiologic evidence of cardiac and pulmonary health risks

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Abstract

Go to:

There is growing evidence of a distinct set of freshly-emitted air pollutants downwind from major highways, motorways, and freeways that include elevated levels of ultrafine particulates (UFP), black carbon (BC), oxides of nitrogen (NOx), and carbon monoxide (CO). People living or otherwise spending substantial time within about 200 m of highways are exposed to these pollutants more so than persons living at a greater distance, even compared to living on busy urban streets. Evidence of the health hazards of these pollutants arises from studies that assess proximity to highways, actual exposure to the pollutants, or both. Taken as a whole, the health studies show elevated risk for development of asthma and reduced lung function in children who live near major highways. Studies of particulate matter (PM) that show associations with cardiac and pulmonary mortality also appear to indicate increasing risk as smaller geographic areas are studied, suggesting localized sources that likely include major highways. Although less work has tested the association between lung cancer and highways, the existing studies suggest an association as well. While the evidence is substantial for a link between near-highway exposures and adverse health outcomes, considerable work remains to understand the exact nature and magnitude of the risks.

Background

Go to:

Approximately 11% of US households are located within 100 meters of 4-lane highways [estimated using: [1,2]]. While it is clear that automobiles are significant sources of air pollution, the exposure of near-highway residents to pollutants in automobile exhaust has only recently begun to be characterized. There are two main reasons for this: (A) federal and state air monitoring programs are typically set up to measure pollutants at the regional, not local scale; and (B) regional monitoring stations typically do not measure all of the types of pollutants that are elevated next to highways. It is, therefore, critical to ask what is known about near-highway exposures and their possible health consequences.

Here we review studies describing measurement of near-highway air pollutants, and epidemiologic studies of cardiac and pulmonary outcomes as they relate to exposure to these pollutants and/or proximity to highways. Although some studies suggest that other health impacts are also important (e.g., birth outcomes), we feel that the case for these health effects are less well developed scientifically and do not have the same potential to drive public policy at this time. We did not seek to fully integrate the relevant cellular biology and toxicological literature, except for a few key references, because they are so vast by themselves.

We started with studies that we knew well and also searched the engineering and health literature on Medline. We were able to find some earlier epidemiologic studies based on citations in more recent articles. We include some studies that assessed motor vehicle-related pollutants at central site monitors (i.e., that did not measure highway proximity or traffic) because we feel that they add to the plausibility of the associations seen in other studies. The relative emphasis given to studies was based on our appraisal of the rigor of their methodology and the significance of their findings. We conclude with a summary and with recommendations for policy and further research.

Motor vehicle pollution

It is well known that motor vehicle exhaust is a significant source of air pollution. The most widely reported pollutants in vehicular exhaust include carbon monoxide, nitrogen and sulfur oxides, unburned hydrocarbons (from fuel and crankcase oil), particulate matter, polycyclic aromatic hydrocarbons, and other organic compounds that derive from combustion [3-5]. While much attention has focused on the transport and transformation of these pollutants in ambient air – particularly in areas where both ambient pollutant concentrations and human exposures are elevated (e.g., congested city centers, tunnels, and urban canyons created by tall buildings), less attention has been given to measuring pollutants and exposures near heavily-trafficked highways. Several lines of evidence now suggest that steep gradients of certain pollutants exist next to heavily traveled highways and that living within these elevated pollution zones can have detrimental effects on human health.

It should be noted that many different types of highways have been studied, ranging from California "freeways" (defined as multi-lane, high-speed roadways with restricted access) to four-lane (two in each direction), variable-speed roadways with unrestricted access. There is considerable variation in the literature in defining highways and we choose to include studies in our review that used a broad range of definitions (see Table 1).

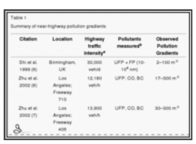
Table 1

Summary of near-highway pollution gradients

Citation	Location	Highway traffic intensity[a]	Pollutants measured[b]	Observed Pollution Gradients
Shi et al. 1999 (6)	Birmingham, UK	30,000 veh/d	UFP + FP (10-10^4 nm)	2–100 m
Zhu et al. 2002 (8)	Los Angeles; Freeway 710	12,180 veh/h	UFP, CO, BC	17–300 m
Zhu et al. 2002 (7)	Los Angeles; Freeway 405	13,900 veh/h	UFP, CO, BC	30–300 m

Table 1

Summary of near-highway pollution gradients

It should also be noted that there may be significant heterogeneity in the types and amounts of vehicles using highways. The typical vehicle fleet in the US is composed of passenger cars, sports utility vehicles, motorcycles, pickup trucks, vans, buses, and small, medium, and large trucks. The composition and size of a fleet on a given highway may vary depending on the time of day, day of the week, and use restrictions for certain classes of vehicles. Fleets may also vary in the average age and state of repair of vehicles, the fractions of vehicles that burn diesel and gasoline, and the fraction of vehicles that have catalytic converters. These factors will influence the kinds and amounts of pollutants in tailpipe emissions. Similarly, driving conditions, fuel chemistry, and meteorology can also significantly impact emissions rates as well as the kinds and concentrations of pollutants present in the near-highway environment. These factors have rarely been taken into consideration in health outcome studies of near-highway exposure.

Based on our review of the literature, the pollutants that have most consistently been reported at elevated levels near highways include ultrafine particles (UFP), black carbon (BC), nitrogen oxides (NOx), and carbon monoxide (CO). In addition, $PM_{2.5}$, and PM_{10} were measured in many of the epidemiologic studies we reviewed. UFP are defined as particles having an aerodynamic diameter in the range of 0.005 to 0.1 microns (um). UFP form by condensation of hot vapors in tailpipe emissions, and can grow in size by coagulation. $PM_{2.5}$ and PM_{10} refer to particulate matter with aerodynamic diameters of 2.5 and 10 um, respectively. BC (or "soot carbon") is an impure form of elemental carbon that has a graphite-like structure. It is the major light-absorbing component of combustion aerosols. These various constituents can be measured in real time or near-real time using particle counters (UFP) and analyzers that measure light absorption (BC and CO), chemiluminescence (NOx), and weight ($PM_{2.5}$ and PM_{10}). Because UFP, NO_x, BC, and CO derive from a common source – vehicular emissions – they are typically highly inter-correlated.

Air pollutant gradients near highways

Several recent studies have shown that sharp pollutant gradients exist near highways. Shi et al. [6] measured UFP number concentration and size distribution along a roadway-to-urban-background transect in Birmingham (UK), and found that particle number concentrations decreased nearly 5-fold within 30 m of a major roadway (>30,000 veh/d). Similar observations were made by Zhu et al. [7,8] in Los Angeles. Zhu et al. measured wind speed and direction, traffic volume, UFP number concentration and size distribution as well as BC and CO along transects downwind of a highway that is dominated by gasoline vehicles (Freeway 405; 13,900 vehicles per hour; veh/h) and a highway that carries a high percentage of diesel vehicles (Freeway 710; 12,180 veh/h). Relative concentrations of CO, BC, and total particle number concentration decreased exponentially between 17 and 150 m downwind from the highways, while at 300 m UFP number concentrations were the same as at upwind sites. An increase in the relative concentrations of larger particles and concomitant decrease in smaller particles was also observed along the transects (see Figure 1). Similar observations were made by Zhang et al. [9] who demonstrated "road-to-ambient" evolution of particle number distributions near highways 405 and 710 in both winter and summer. Zhang et al. observed that between 30–90 m downwind of the highways, particles grew larger than 0.01 um due to condensation, while at distances >90 m, there was both continued particle growth (to >0.1 um) as well as particle shrinkage to <0.01 um due to evaporation. Because condensation, evaporation, and dilution alter size distribution and particle composition, freshly-emitted UFP near highways may differ in chemical composition from UFP that has undergone atmospheric transformation during transport to downwind locations [10].

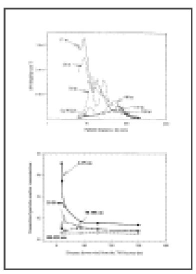

Figure 1
Ultrafine particle size distribution (top panel) and normalized particle number concentration for different size ranges (bottom panel) as a function of distance from a highway in Los Angeles. From Zhu et al. (8). Reprinted with permission from Elsevier. **...**

Two studies in Brisbane (Australia) highlight the importance of wind speed and direction as well as contributions of pollutants from nearby roadways in tracking highway-generated pollutant gradients. Hitchins et al. [11] measured the mass concentrations of 0.1–10 um particles as well as total particle number concentration and size distribution for 0.015–0.7 um particles near highways (2,130–3,400 veh/h). Hitchens et al. observed that the distance from highways at which number and mass concentrations decreased by 50% varied from 100 to 375 m depending on the wind speed and direction. Morawska et al. [12] measured the changes in UFP number concentrations along horizontal and vertical transects near highways to distinguish highway and normal street traffic contributions. It was observed that UFP number concentrations were highest <15 m from highways, while 15–200 m from highways there was no significant difference in UFP number concentrations along either horizontal or vertical transects – presumably due to mixing of highway pollutants with emissions from traffic on nearby, local roadways.

In addition to UFP, other pollutants – such as $PM_{2.5}$, PM_{10}, NO_2 (nitrogen dioxide), VOCs (volatile organic compounds), and particle-bound polycyclic aromatic hydrocarbons (PPAH) – have been studied in relation to heavily-trafficked roadways. Fischer et al. [13] measured $PM_{2.5}$, PM_{10}, PPAH, and VOC concentrations outside and inside homes on streets with high and low traffic volumes in Amsterdam (<3,000–30,974 veh/d). In this study, PPAH and VOCs were measured using methods based on gas chromatography. Fischer et al. found that while $PM_{2.5}$ and PM_{10} mass concentrations were not specific indicators of traffic-related air pollution, PPAH and VOC levels were ~2-fold higher both indoor and outdoor in high traffic areas compared to low traffic areas. Roorda-Knape et al [14] measured $PM_{2.5}$, PM_{10}, black smoke (which is similar to BC), NO_2, and benzene in residential areas <300 m from highways (80,000–152,000 veh/d) in the Netherlands. Black smoke was measured by a reflectance-based method using filtered particles; benzene was measured using a method based on gas chromatography. Roorda-Knape et al reported that outdoor concentrations of black smoke and NO_2 decreased with distance from highways, while $PM_{2.5}$, PM_{10}, and benzene concentrations did not change with distance. In addition, Roorda-Knape et al. found that indoor black smoke concentrations were correlated with truck traffic, and NO_2 was correlated with both traffic volume and distance from highways. Janssen et al. [15] studied $PM_{2.5}$, PM_{10}, benzene, and black smoke in 24 schools in the Netherlands and found that $PM_{2.5}$ and black smoke increased with truck traffic and decreased with distance from highways (40,000–170,000 veh/d).

In summary, the literature shows that UFP, BC, CO and NOx are elevated near highways (>30,000 veh/d), and that other pollutants including VOCs and PPAHs may also be elevated. Thus, people living within about 30 m of highways are likely to receive much higher exposure to traffic-related air pollutants compared to residents living >200 m (+/- 50 m) from highways.

Cardiovascular health and traffic-related pollution

Results from clinical, epidemiological, and animal studies are converging to indicate that short-term and long-term exposures to traffic-related pollution, especially particulates, have adverse cardiovascular effects [16-18]. Most of these studies have focused on, and/or demonstrated the strongest associations between cardiovascular health outcomes and particulates by weight or number concentrations [19-21] though CO, SO_2, NO_2, and BC have also been examined. BC has been shown to be associated with decreases in heart rate variability (HRV) [22,23] and black smoke and NO_2 shown to be associated with cardiopulmonary mortality [24].

Short-term exposure to fine particulate pollution exacerbates existing pulmonary and cardiovascular disease and long-term repeated exposures increases the risk of cardiovascular disease and death [25,26].

Though not focused on near-highway pollution, two large prospective cohort studies, the Six-Cities Study [27] and the American Cancer Society (ACS) Study [28] provided the groundwork for later research on fine particulates and cardiovascular disease. Both of these studies found associations between increased levels of exposure to ambient PM and sulfate air pollution recorded at central city monitors and annual average mortality from cardiopulmonary disease, which at the time combined cardiovascular and pulmonary disease other than lung cancer. The Six-Cities Study examined $PM_{2.5}$ and $PM_{10/15}$. The ACS study examined $PM_{2.5}$. Relative risk ratios of mortality from cardiopulmonary disease comparing locations with the highest and lowest fine particle concentrations (which had differences of 24.5 and 18.6 ug/m^3 respectively) were 1.37 (1.11, 1.68) and 1.31 (1.17, 1.46) in the Six Cities and ACS studies, respectively. These analyses controlled for many confounders, including smoking and gas stoves but not other housing conditions or time spent at home. The studies were subject to intensive replication, validation, and reanalysis that confirmed the original findings. $PM_{2.5}$ generally declined following implementation of new US Environmental Protection Agency standards in 1997 [17,29], yet since that time studies have shown elevated health risks due to long-term exposures to the 1997 PM threshold concentrations [29,30].

Much of the epidemiological research has focused on assessing the early physiological responses to short-term fluctuations in air pollution in order to understand how these exposures may alter cardiovascular risk profiles and exacerbate cardiovascular disease [31]. Heart rate variability, a risk factor for future cardiovascular outcomes, is altered by traffic-related pollutants particularly in older people and people with heart disease [22,23,32]. With decreased heart rate variability as the adverse outcome, negative associations between HRV and particulates were strongest for the smallest size fraction studied [33] (PM0.3–1.0); [34] (PM0.02–1). In two studies that included other pollutants, black carbon, an indicator of traffic particles, also elicited a strong association with both time and frequency domain HRV variables; associations were also strong for PM2.5 for both time and frequency HRV variables in the Adar et al study [[23]; this and subsequent near highway studies are summarized in Table 2], however, PM2.5 was not associated with frequency domain variables in the Schwartz et al. study [22].

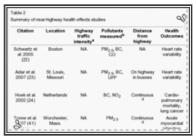

Table 2

Summary of near-highway health effects studies

Several studies show that exposure to PM varies spatially within a city [35-37], and finer spatial analyses show higher risks to individuals living in close proximity to heavily trafficked roads [18,37]. A 2007 paper from the Woman's' Health Initiative used data from 573 $PM_{2.5}$ monitors to follow over 65,000 women prospectively. They reported very high hazard ratios for cardiovascular events (1.76; 95% CI, 1.25 to 2.47) possibly due to the fine grain of exposure monitoring [18]. In contrast, studies that relied on central monitors [27,28] or interpolations from central monitors to highways are prone to exposure misclassification because individuals living close to highways will have a higher exposure than the general area. A possible concern with this interpretation is that social gradients may also situate poorer neighborhoods with potentially more susceptible populations closer to highways [38-40].

At a finer grain, Hoek et al. [24] estimated home exposure to nitrogen dioxide (NO_2) and black smoke for about 5,000 participants in the Netherlands Cohort Study on Diet and Cancer. Modeled exposure took into consideration proximity to freeways and main roads (100 m and 50 m, respectively). Cardiopulmonary mortality was associated with both modeled levels of pollutants and living near a major road with associations less strong for background levels of both pollutants. A case-control study [41], found a 5% increase in acute myocardial infarction associated with living within 100 m of major roadways. A recent analysis of cohort data found that traffic density was a predictor of mortality more so than was ambient air pollution [42]. There is a need for studies that assess exposure at these scales, e.g., immediate vicinity of highways, to test whether cardiac risk increases still more at even smaller scales.

Although we cannot review it in full here, we note that evidence beyond the epidemiological literature support the contention that $PM_{2.5}$ and UFP (a sub-fraction of $PM_{2.5}$) have adverse cardiovascular effects [16,17]. $PM_{2.5}$ appears to be a risk factor for cardiovascular disease via mechanisms that likely include pulmonary and systemic inflammation, accelerated atherosclerosis and altered cardiac autonomic function [17,22,43-46]. Uptake of particles or particle constituents in the blood can affect the autonomic control of the heart and circulatory system. Black smoke, a large proportion of which is derived from mobile source emissions [30], has a high pulmonary deposition efficiency, and due to their surface area-to-volume ratios can carry relatively more adsorbed and condensed toxic air pollutants (e.g., PPAH) compared to larger particles [17,47,48]. Based on high particle numbers, high lung deposition efficiency and surface chemistry, UFP may provide a greater potential than $PM_{2.5}$ for inducing inflammation [10]. UFPs have high cytotoxic reactive oxygen species (ROS) activity, through which numerous inflammatory responses are induced, compared to other particles [10]. Chronically elevated UFP levels such as those to which residents living near heavily trafficked roadways are likely exposed can lead to long-term or repeated increases in systemic inflammation that promote arteriosclerosis [18,29,34,37].

Asthma and highway exposures

Evidence that near highway exposures present elevated risk is relatively well developed with respect to child asthma studies. These studies have evolved over time with the use of different methodologies. Studies that used larger geographic frames and/or overall traffic in the vicinity of the home or school [49-52] or that used self-report of traffic intensity [53] found no association with asthma prevalence. Most recent child asthma studies have, instead, used increasingly narrow definitions of proximity to traffic, including air monitoring or modeling) and have focused on major highways instead of street traffic [54-59]. All of these studies have found statistically significant associations between the prevalence of asthma or wheezing and living very close to high volume vehicle roadways. Confounders considered included housing conditions (pests, pets, gas stoves, water damage), exposure to tobacco smoke, various measures of socioeconomic status (SES), age, sex, and atopy, albeit self-reported and not all in a single study.

Multiple studies have found girls to be at greater risk than boys for asthma resulting from highway exposure [55,57,60]. A recent study also reports elevated risk only for children who moved next to the highway before they were 2 years of age, suggesting that early childhood exposure may be key [57]. The combined evidence suggests that living within 100 meters of major highways is a risk factor, although smaller distances may also result in graded increases in risk. The neglect of wind direction and the absence of air monitoring from some studies are notable missing factors. Additionally, recent concerns have been raised that geocoding (attaching a physical location to addresses) could introduce bias due to inaccuracy in locations [61].

Studies that rely on general area monitoring of ambient pollution and assess regional pollution on a scale orders of magnitude greater than the near-roadway gradients have also found associations between traffic generated pollution (CO and NOx) and prevalence of asthma [62] or hospital admission for asthma [63]. Lweguga-Mukasa et al. [64] monitored air up and down wind of a major motor vehicle bridge complex in Buffalo, NY and found that UFP were higher downwind, dropping off with distance. Their statistical models did not, however, support an association of UFP with asthma. A study in the San Francisco Bay Area measured $PM_{2.5}$, BC and NO_X over several months next to schools and found both higher pollution levels downwind from highways and a linear association of BC with asthma in long-term residents [60].

Gauderman et al. [65] measured NO_2 next to homes of 208 children. They found an odds ratio (OR) of 1.83 (confidence interval (CI): 1.04–3.22) for outdoor NO_2 (probably a surrogate for total highway pollution) and lifetime diagnosis of asthma. They also found a similar association with distance from residence to freeway. Self-report was used to control for numerous confounders, including tobacco smoke, SES, gas stoves, mildew, water damage, cockroaches and pets which did not substantially affect the association. Gauderman's study suggests that ambient air monitoring at the residence substantially increases statistical power to detect association of asthma with highway exposures.

Modeling of elemental carbon attributable to traffic near roadways based on ambient air monitoring of $PM_{2.5}$ has recently emerged as a viable approach and a study using this method found an association with infant wheezing. The modeled values appear to be better predictors than proximity. Elevation of the residence relative to traffic was also an important factor in this study [66]. A 2007 paper reported on modeled NO_2, $PM_{2.5}$ and soot and the association of these values with asthma and various respiratory symptoms in the Netherlands [67]. While finding modest statistically significant associations for asthma and symptoms, it is somewhat surprising that they found stronger associations for development of sensitization to food allergens.

Pediatric lung function and traffic-related air pollution

Studies of association of children's lung function with traffic pollutants have used a variety of measures of exposure, including: traffic density, distance to roadways, area (city) monitors, monitoring at the home or school and personal monitoring. Studies have assessed both chronic effects on lung development and acute effects and have been both cross-sectional and longitudinal. The wide range of approaches somewhat complicates evaluation of the literature.

Traffic density in school districts in Munich was associated with decreases in forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), FEV1/FVC and other measures, although the 2-kilometer (km) areas, the use of sitting position for spirometry and problems with translation for non-German children were limitations [68]. Brunekreef et al. [69] used distance from major roadways, considered wind direction and measured black smoke and NO2 inside schools. They found the largest decrements in lung function in girls living within 300 m of the roadways.

A longitudinal study of children (average age at start = 10 years) in Southern California reported results at 4 [70] and 8 years [71]. Multiple air pollutants were measured at sites in 12 communities. Due to substantial attrition, only 42% of children enrolled at the start were available for the 8-year follow-up. Substantially lower growth in FEV_1 was associated with PM_{10}, NO_2, $PM_{2.5}$, acid vapor and elemental carbon at 4 and at 8 years. The analysis could not indicate whether the effects seen were reversible or not [72]. In 2007, it was reported from this same cohort that living within 500 m of a freeway was reported to be associated with reduced lung function [73].

A Dutch study [74] measured $PM_{2.5}$, NO_2, benzene and EC for one year at 24 schools located within 400 m of major roadways. While associations were seen between symptoms and truck traffic and measured pollutants, there was no significant association between any of the environmental measures and FVC < 85% or FEV_1 < 85%. Restricting the analysis to children living within 500 m of highways generally increased ORs.

Personal exposure monitoring of NO_2 as a surrogate for total traffic pollutants with 298 Korean college students found statistically significant associations with FEV_1, FEV_1/FVC, and forced expiratory volume between 25 and 75% ($FEV_{25–75}$), but not with FVC. The multivariate regression model presented suggests that $FEV_{25–75}$ was the outcome measure that most clearly showed an effect [75]. Cross-sectional studies of children in Korea [76] and France [77] also indicate that lung function is diminished in association with area pollutants that largely derive from traffic.

Time series studies suggest there are also acute effects. A study of 19 asthmatic children measured PM via personally carried monitors, at homes and at central site monitors. The study found deficits in FEV_1 that were associated with PM, although many sources besides traffic contributed to exposure. In addition, the results suggest that ability to see associations with health outcomes improves at finer scale of monitoring [78]. PM was associated with reduced FEV_1 and FVC in only the asthmatic subset of children in a Seattle study [79]. Studies have also seen associations between PM and self reported peak flow measurements [80,81] and asthmatic symptoms [82].

Cancer and near highway exposures

As noted above, both the Six-Cities Study [27] and the American Cancer Society (ACS) Study [28] found associations between PM and lung cancer. Follow-up studies using the ACS cohort [29,37] and the Six-Studies cohort [83] that controlled for smoking and other risk factors also demonstrated significant associations between PM and lung cancer. The original studies were subject to intensive replication, validation, and re-analysis which confirmed the original findings [84].

The ASHMOG study [85] was designed to look specifically at lung cancer and air pollution among Seventh-day Adventists in California, taking advantage of their low smoking rates. Air pollution was interpolated to centroids of zip codes from ambient air monitoring stations. Highway proximity was not considered. The study found associations with ozone (its primary pollutant of consideration), PM10 and SO2. Notably, these are not the pollutants that would be expected to be substantially elevated immediately adjacent to highways.

A case control study of residents of Stockholm, Sweden modeled traffic-related NO2 levels at their homes over 30 years and found that the strongest association involved a 20 year latency period [86]. Another case control study drawn from the European Prospective Investigation on Cancer and Nutrition found statistically significantly elevated ORs for lung cancer with proximity to heavy traffic (>10,000 cars per day) as well as for NO_2 and PM_{10} at nearby ambient monitoring stations [87]. Nafstad et al. [88] used modeled NO_2 and SO_2 concentrations at the homes of over 16,000 men in Oslo to test associations with lung cancer incidence. The models included traffic and point sources. The study found small, but statistically significant associations between NO_2 and lung cancer. Problems that run through all these studies are weak measures of exposure to secondhand tobacco smoke, the use of main roads rather than highways as the exposure group and modeled rather than measured air pollutants.

A study of regional pollution in Japan and a case control study of more localized pollution in a town in Italy also found associations between NO_2 and lung cancer and PM and lung cancer [89,90]. On the other hand, a study that calculated SIRs for specific cancers across lower and higher traffic intensity found little evidence of an association with a range of cancers [91].

The plausibility of near-highway pollution causing lung cancer is bolstered by the presence of known carcinogens in diesel PM. The US EPA has concluded after reviewing the literature that diesel exhaust is "likely to be carcinogenic to humans by inhalation" [92]. An interesting study of UFP and DNA damage adds credibility to an association with cancer [93]. This study had participants bicycle in traffic in Copenhagen and measured personal exposure to UFP and DNA oxidation and strand breaks in mononuclear blood cells. Bicycling in traffic increased UFP exposure and oxidative damage to DNA, thus demonstrating an association between DNA damage and UFP exposure *in vivo*.

Policy and research recommendations

Based on the literature reviewed above it is plausible that gradients of pollutants next to highways carry elevated health risks that may be larger than the risks of general area ambient pollutants. While the evidence is considerable, it is not overwhelming and is weak in some areas. The strongest evidence comes from studies of development of asthma and reduction of lung function during childhood, while the studies of cardiac health risk require extrapolation from area studies of smaller and larger geographic scales and inference from toxicology laboratory investigations. The lung cancer studies, because they include pollutants such as O_3 that are not locally concentrated, are not particularly strong in terms of the case for near-highway risk. There is a need for lung cancer research that uses major highways rather than heavily trafficked roads as the environmental exposure.

While more studies of asthma and lung function in children are needed to confirm existing findings, especially studies that integrate exposure at school, home and during commuting, to refine our knowledge about the association, we would point to the greater need for studies of cardiac health and lung cancer and their association with near highway exposures as the primary research areas needing to be developed. Many of the studies of PM and cardiac or pulmonary health have focused on mortality. Near highway mortality studies may be possible, but would be lengthy if they were initiated as prospective cohorts. Other possibilities include retrospective case control studies of mortality, cross sectional studies or prospective studies that have end points short of mortality, such as biological markers of disease. For all health end points there is a need for studies that adequately address the possible confounding of SES with proximity to highways. There is good reason to think that property values decline near highways and that control for SES by, for example, income, may be inadequate.

Because of the incomplete development of the science regarding the health risks of near highway exposures and the high cost and implication of at least some possible changes in planning and development, policy decisions are complicated. The State of California has largely prohibited siting of schools within 500 feet of freeways (SB 352; approved by the governor October 2, 2003). Perhaps this is a viable model for other states or for national-level response. As it is the only such law of which we are aware, there may be other approaches that will be and should be tried. One limitation of the California approach is that it does nothing to address the population already exposed at schools currently cited near freeways and does not address residence near freeways.

Conclusion

Go to:

The most susceptible (and overlooked) population in the US subject to serious health effects from air pollution may be those who live very near major regional transportation route, especially highways. Policies that have been technology based and regional in orientation do not efficiently address the very large exposure and health gradients suffered by these populations. This is problematic because even regions that EPA has deemed to be in regional PM "attainment" still include very large numbers of near highway residents who currently are not protected. There is a need for more research, but also a need to begin to explore policy options that would protect the exposed population.

Abbreviations

Go to:

UFP = ultra fine particles

BC = black carbon

NO_2 = nitrogen dioxide

NOx = oxides of nitrogen

CO = carbon monoxide

PM = particulate matter

$PM_{2.5}$ = particulate matter less than 2.5 um

PM_{10} = particulate matter less than 10 um

PPAH = particle bound polyaromatic hydrocarbons

EC = elemental carbon

VOC = volatile organic compounds

SO_2 = sulfur dioxide

ACS = American Cancer Society

SES = socioeconomic status

EPA = Environmental Protection Agency

OR = odds ratio

FEV_1 = forced expiratory volume in 1 second

FEV_1/FVC = ratio of FEV_1 and forced vital capacity

FEV_{25-75} = forced expiratory volume between 25 and 75

FVC = forced vital capacity

ug/m^3 = micrograms per cubic meter of air

m = meters

um = micrometers

veh/d = vehicles per day

veh/h = vehicles per hour

Competing interests

Go to:

The author(s) declare that they have no competing interests.

Authors' contributions

Go to:

DB took the lead on the manuscript. He co-wrote the background and wrote the sections on asthma, lung function and cancer and the conclusions. JLD wrote the section on air pollutants near roadways and contributed substantially to the background. CR wrote the section on cardiovascular health. All authors participated in editing and refining the manuscript and all read it multiple times, including the final version.

Acknowledgements

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Study of ultrafine particles near a major highway with heavy-duty diesel traffic

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Abstract

Motor vehicle emissions usually constitute the most significant source of ultrafine particles (diameter $<0.1\,\mu m$) in an urban environment. Zhu et al. (J. Air Waste Manage. Assoc., 2002, accepted for publication) conducted systematic measurements of the concentration and size distribution of ultrafine particles in the vicinity of a highway dominated by gasoline vehicle. The present study compares these previous measurements with those made on Interstate 710 freeway in Los Angeles. The 710 freeway was selected because more than 25% of the vehicles are heavy-duty diesel trucks. Particle number concentration and size distribution in the size range from 6 to 220 nm were measured by a condensation particle counter and a scanning mobility particle sizer, respectively. Measurements were taken at 17, 20, 30, 90, 150, and 300 m downwind and 200 m upwind from the center of the freeway. At each sampling location, concentrations of carbon monoxide (CO) and black carbon (BC) were also measured by a Dasibi CO monitor and an Aethalometer, respectively. The range of average concentration of CO, BC and total particle number concentration at 17 m was 1.9–2.6 ppm, 20.3–24.8 $\mu g/m^3$, 1.8×10^5–$3.5\times10^5/cm^3$, respectively. Relative concentration of CO, BC and particle number decreased exponentially and tracked each other well as one moves away from the freeway. Both atmospheric dispersion and coagulation appears to contribute to the rapid decrease in particle number concentration and change in particle size distribution with increasing distance from the freeway. Average traffic flow during the sampling periods was 12,180 vehicles/h with more than 25% of vehicles being heavy-duty diesel trucks. Ultrafine particle number concentration measured at 300 m downwind from the freeway was indistinguishable from upwind background concentration. These data may be used to estimate exposure to ultrafine particles in the vicinity of major highways.
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Keywords: Ultrafine particles; Freeways; Diesel; Carbon monoxide; Black carbon

1. Introduction

Epidemiological data from air pollution studies have shown a consistent relationship between increases in particulate matter (PM) exposure and contemporary increases in mortality and morbidity (Schwartz, 1991; Dockery et al., 1993; Pope et al., 1995; Vedal, 1997). However, the underlying biological causes of the health effects of PM exposure and the correct measurement metric are unclear. For example, it is not clear whether the mass concentration (Osunsanya et al., 2001) or the number concentration (Peters et al., 1997; Penttinen et al., 2001) is most important in causing these adverse

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PM health effects. Currently, there are several hypotheses used to explain the association of PM and observed adverse health effect. One argues that particle surface contaminants, such as transition metals, contribute towards ill health (Fubini et al., 1995; Gilmour et al., 1996), wherein the ultrafine particles are thought to act as vehicles for those contaminants, initiating local lung damage when the particles deposit on the epithelial surfaces. Another hypothesis is that the physical characteristics (e.g. number, size, shape, aggregation properties) are important in producing health effects (Bérubé et al., 1999). Particle shape and size are critical factor controlling where the inhaled particles deposit in the various regions of human respiratory system by the complex action of aerosol deposition mechanisms (Hinds, 1999).

Recent toxicological studies have concluded that ultrafine particles (diameter <100 nm) are more toxic than larger particles with the same chemical composition and at the same mass concentration (Ferin et al., 1990; Oberdörster, 1996, 2001; Donaldson et al., 1998, 2001; Churg et al., 1999; Brown et al., 2000). Currently, however, only the mass concentration of PM $<10\,\mu$m in aerodynamic diameter (PM_{10}) and $<2.5\,\mu$m ($PM_{2.5}$) are regulated. Information about ultrafine particles is usually not available. In fact, even though ultrafine particles represent over 80% of particles in terms of number concentration in an urban environment (Morawska et al., 1998a, b), the less numerous but much heavier particles of the accumulation (0.1–2 μm) and coarse (2.5–10 μm) modes dominate mass concentration measurements. Thus, number concentration, together with the size distribution of ultrafine particles, is needed to better assess ambient air quality and its potential health effects.

Emission inventories suggest that motor vehicles are the primary direct emission sources of fine and ultrafine particles to the atmosphere in urban areas (Schauer et al., 1996; Shi et al., 1999; Hitchins et al., 2000). Although traffic-related air pollution in urban environments has been of increasing concern, most studies have focused on gaseous pollutants, total mass concentration, or chemical composition of particulate pollutants (Kuhler et al., 1994; Clairborn et al., 1995; Williams and McCrae, 1995; Janssen et al., 1997; Roorda-Knape et al., 1998a, b; Wrobel et al., 2000). Booker (1997) found that particle number concentration was strongly correlated with vehicle traffic while PM_{10} was essentially uncorrelated with traffic. Since the majority of particle number from vehicle exhaust are in the size range 20–130 nm for diesel engines (Morawska et al., 1998a, b) and 20–60 nm for gasoline engines (Ristovski et al., 1998), it is important and necessary to quantify ultrafine particle emission levels, and to determine ultrafine particle behavior after emission as they are transported away from the emission source—busy roads and freeways.

Morawska et al. (1999) measured the horizontal and vertical profiles of submicrometer particulates (16–626 nm) near a major arterial route in the urban area of Brisbane, Australia. They found, with the exception of measurements in close proximity to the road (about 15 m), that the horizontal ground-level profile measurements did not show statistically significant differences in fine particle number concentration for up to 200 m distances away from the road. Hitchins et al. (2000) examined the particle size distribution and concentration in the size range from 15 nm to 20 μm at distances from a road ranging from 15 to 375 m at two sites in Australia. They conducted measurements under different wind conditions and found that when the wind is blowing directly from the road, the concentration of the fine and ultrafine particles decayed to about half of their maximum at a distance of 100–150 m from the road. Shi et al. (1999) measured ultrafine particle number concentrations and size distributions at a busy roadside and at nearby urban background sites in Birmingham, United Kingdom. They observed a faster decline of particle number concentration than mass concentration. In a recent study, Shi et al. (2001) reported that the fraction of particles <10 nm represents more than about 40% of the total particle number concentrations at 4 and 25 m from the roadside curb.

While there have been recent studies of ultrafine particles from traffic in other countries, except for Zhu et al. (2002), no comparable work has been done in the Los Angeles basin, a home to more than 15 million individuals and 10 million vehicles contributing to daily traffic. Previous studies have shown that meteorological conditions may affect substantially the characteristics of PM emitted from vehicles. Kittelson et al. (2001) found in their on-road PM measurements that the concentration of particles in the nuclei mode increases by nearly a factor of 10 as the (air) temperature is reduced from 25°C to 15°C. This observation suggests that there could be significant differences in the tendency to form semi-volatile nanoparticles between, for example, northern Europe and Southern California.

Zhu et al. (2002) conducted a systematic ultrafine particle study near one of the busiest freeways in the Los Angeles basin, Interstate 405. Traffic on that freeway was dominated by gasoline-powered cars and light trucks, with $<5\%$ of vehicles being heavy-duty diesel trucks. In the US, spark ignition vehicles usually account for most of the vehicles operating on highways. However, since diesel vehicles emit more PM on a fleet averaged, gram-per-vehicle mile mass basis (Kittelson et al., 2001), and that diesel engine exhaust has been proposed as carcinogen in animals and probably carcinogenic for humans (IARC, 1989), it is necessary and timely to conduct a comprehensive study of ultrafine particles in the vicinity of a diesel vehicle dominated freeway. Thus, the aim of the present paper is to systematically evaluate ultrafine particles in the vicinity of the 710 freeway in the Los Angeles basin, a freeway where more than 25% of vehicles are heavy-duty diesel trucks. Particle number concentration and size distribution in the size range from 6 to 220 nm are measured along with CO and black carbon (BC) as a function of distances upwind and downwind the 710 freeway. The results from the current study are compared to these by Zhu et al. (2002) which were obtained near the 405 freeway.

2. Experimental

2.1. Description of sampling site

This study was conducted in the City of Downey along Southern Avenue between 30 August and 27 October 2001. The location was chosen for its proximity to the freeway and the lack of other nearby ultrafine particle emission sources. Southern Avenue is located perpendicular to Interstate 710 Freeway and Garfield Avenue near the Los Amigos Country Club. Freeway 710 runs generally north and south near the sampling site and parallels the Los Angeles River.

This location is ideal for this study for several reasons. First, there are no other major roadways near the sampling sites along Southern Avenue. Second, businesses along Southern Avenue generally have large open land areas with little activities during the day. Thus, there is minimal local traffic influence at the sampling locations. Third, the freeway is at the same elevation as Southern Avenue. The only separation between the freeway and Southern Avenue is a metal chain link fence along the freeway. This allowed measurements as close as 3 m from the edge of the freeway. Fourth, a nearby residential area approximately 200 m upwind from the freeway was easily accessible for sampling.

During the sampling period, a fairly consistent eastward wind developed each day starting at approximately 11:00 AM. This wind carried the freeway vehicular emissions directly to the sampling location. The 710 freeway has eight lanes, four north bound and four south bound. It is approximately 26 m wide including a 1-m-wide median strip. Measurement site locations for this study were designated by their distance from the center of the median strip. Thus, the distance from each sampling location to the nearest traffic lane is 13 m less than the indicated distance.

Freeway 710 is a major truck route in Southern California with a large percent of the traffic consisting of heavy-duty diesel trucks. During the sampling period, traffic density ranged from 180 to 230 vehicles/min passing the sampling site, total for both directions, with approximately 25% of the vehicles being heavy diesel trucks.

2.2. Sampling and instrumentation

Wind speed and direction were measured at a fixed site 6 m above the ground level 20 m downwind of 710 freeway, which also served as a particle number concentration control site. Wind data were averaged over 1 min intervals and logged into a computerized weather station (Wizard III, Weather Systems Company, San Jose, CA). Throughout each measurement period, the traffic strength on the freeway, defined as number of vehicles passing per minute, was continuously monitored by a video recorder (camcorder), which captures all eight lanes of the freeway. After each sampling session, the videotapes were replayed and traffic density counted manually. Three 1-min samples were randomly selected from each 10-min interval. Cars, light trucks, and heavy-duty trucks were counted separately to estimate the traffic density by type of vehicle.

Particle number concentration and size distribution in the size range from 6 to 220 nm were measured by a condensation particle counter (CPC 3022A; TSI Inc., St. Paul, MN) and a scanning mobility particle sizer (SMPS 3936, TSI Inc., St. Paul, MN). The sampling flow rate of the SMPS was adjusted to 1.5 lpm in order to measure particles as low as 6 nm as well as to minimize the diffusion losses of ultrafine particles during sampling. Flexible, conductive tubing (Part 3001940, TSI Inc., St. Paul, MN) was used for sampling to avoid particle losses due to electrostatic forces. The sizing accuracy of the SMPS was verified in the laboratory by means of monodisperse polystyrene latex spheres (PSL, Polysciences Inc., Warrington, PA). Data reduction and analysis of the SMPS output was done by the Aerosol Instrument Manager software (version 4.0, TSI Inc., St. Paul, MN). Measurements were taken at 17, 20, 30, 90, 150, and 300 m downwind and 200 m upwind from the center of the freeway 710. At each location, three size distribution samples were taken in sequence with the SMPS. Scanning time for each was 180 s.

In addition to size distribution and the total number concentration, the concentrations of BC and carbon monoxide (CO), were monitored simultaneously at each sampling location. Before each measurement session, all instruments were time synchronized. Data were averaged after collection over the time periods corresponding to the scanning intervals of the SMPS. A Dual Beam Aethalometer (Model AE-20, Andersen Model RTAA-900, Andersen Instruments Inc., Smyrna, GA) was used to measure the BC concentrations every 5 min. Concentrations of CO were measured by a near-continuous CO monitor (Dasibi Model 3008, Environmental Corp., Glendale, CA) every minute. The CO monitor was calibrated by means of standard CO gas (RAE systems Inc., Sunnyvale, CA) in the laboratory and automatically zeroed each time the power was turned on.

Electric power for the control site CPC and Weather Station was obtained by an extension cord to a nearby office. Electric power for other sampling instruments at the sampling locations was supplied by a 1.2 kW gasoline-powered portable power generator (Model EU 1000i, Honda Motor Co., LTD., Tokyo, Japan). The generator was placed approximately 50 m downwind of each sampling location. Both total particle number and CO concentrations were measured at the control site with the generator turned on and with it turned off. No detectable difference was observed.

Table 1 gives the sampling dates and times and summarizes the instruments that were used on each date. The weather station and control CPC were placed at the 20 m downwind control site and sampled throughout the sampling period each day. All other applicable instruments were moved together and sampled simultaneously at each sampling location. It takes about 10 min to complete sampling at each location and 120 min to complete a set, all six locations. Three to four sets were performed on each sampling date.

3. Results and discussion

The results presented below include measurements of total particle number concentrations by a control CPC, wind velocity by a Weather Wizard III, both positioned at a fixed location 20 m downwind of the freeway; and CO, BC concentration, and ultrafine particles size distributions upwind and at six downwind distances from freeway 710.

3.1. *Wind effects*

Changes in wind conditions have been reported to modify dramatically the pattern of total particle number concentration versus distances from a major road (Hitchins et al., 2000). Consistency in wind speed and direction allows data from different days to be averaged together (Zhu et al., 2002). Wind speed and direction were measured, averaged and logged over every 1-min interval throughout each sampling period. One hundred wind data points were randomly selected out of more than 5000 observations from all the sampling dates and plotted in Fig. 1. The orientation of freeway 710 and the sampling road, Southern Avenue, are also shown in the Fig. 1. The Weather Wizard III instrument recorded wind direction at a 22.5° interval (e.g. 11.25° on either side of N, NNE, etc.) and wind speed at 0.4 or 0.5 m/s intervals. In the figure, duplicate observations were spread out slightly in both directions to better illustrate how strong the wind was and how often the wind came from certain directions. Based on all 5000 observations, the percent of sampling time that the wind came from each 22.5° segment is also shown in Fig. 1. As shown in Fig. 1, about 80% of the time, the wind was coming directly from the freeway towards the sampling road with a speed <3 m/s. The consistency of observed wind direction and speed is a result of a generally low synoptic wind velocities and a consistent sea breeze in the sampling area.

In this study, we found that not only wind direction, but also wind speed, played an important role in determining the characteristics of ultrafine particles near the 710 freeway, similar to the observations made by Zhu et al. (2002) near the 405 freeway. However the pattern of total particle number concentrations as a function of wind speed is somewhat different for the two studies. Fig. 2 shows total particle number concentrations measured by the control CPC, located 20 m downwind of the 710 freeway versus wind speed. Averaged data for the 405 freeway from Zhu et al. (2002) are also plotted for comparison. The CPC was programmed to archive averaged total particle number concentrations at 1-min interval in synchronization with the averaging time of the meteorological data. Only wind data within $\pm 22.5°$ of normal to the freeway was used in this figure which accounts for more than 60% of the total observations. The difference between the absolute value of total particle number concentration is due in part to the difference in the sampling distance. The control CPC was located 20 m downwind from the 710 freeway but 30 m from the 405 freeway. Assuming the fitted exponential decay characteristics of ultrafine particles holds right to the edge of the freeway, it is thus

Table 1
Sampling dates, time and instruments used

Date	Time	Weather Wizard III	Control CPC	SMPS	CO monitor	Aethalometer
08/30/01	10:00–15:30	×	×	×	×	×
09/05/01	10:30–16:00	×	×	×		
09/21/01	10:00–15:00	×	×	×	×	×
09/25/01	10:30–16:00	×	×	×	×	×
10/05/01	10:30–16:00	×	×	×	×	×
10/24/01	10:00–15:30	×	×		×	×
10/30/01	10:00–15:30	×	×	×		

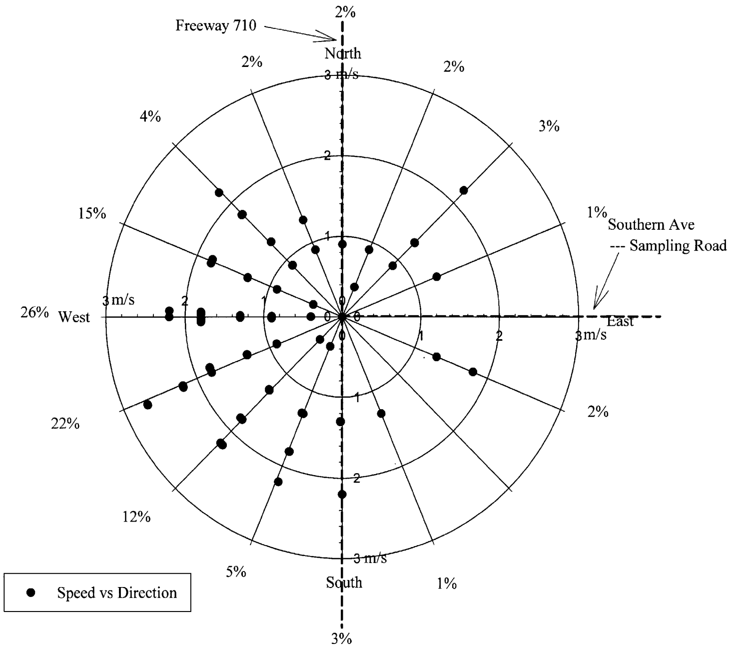

Fig. 1. Wind direction and speed at sampling site.

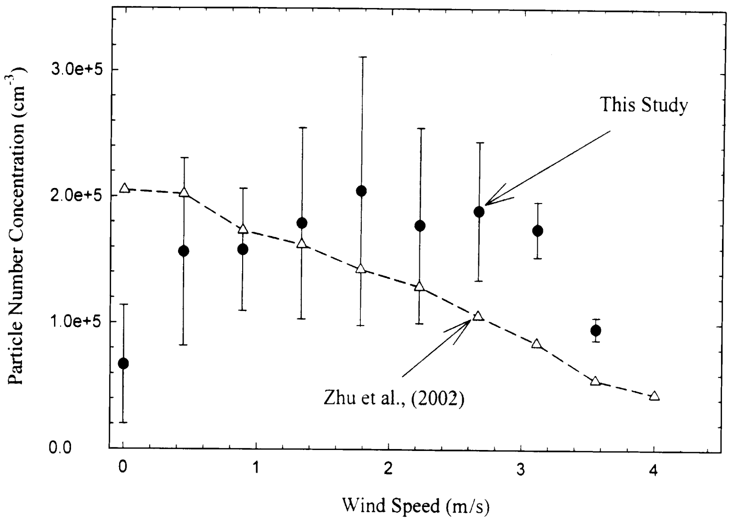

Fig. 2. Total particle number concentration measured by CPC located at 20 m downwind from freeway 710 versus wind speed. Bars indicate one standard deviation.

not surprising, as discussed below, that the CPC will read a greater total particle number concentration at 20 m in the present study than at 30 m in that by Zhu et al. (2002), given similar traffic load on both freeways. However, the relative particle number concentration as function of wind speed are somewhat different in these two studies. The relative particle number concentration decreased as the wind speed increased near the 405 freeway. In contrast, particle number concentration in the 710 freeway first increases, reaches a maximum around 1.5 m/s, and then decreases. There is no obvious explanation for the observed difference. In both studies, data showed large error bars, and the data of low wind speed (<1 m/s) were very limited. In addition, the 405 freeway is elevated approximately 4.5 m above the surrounding terrain, while, the 710 freeway is at ground level, the same as the sampling location. Lower speed wind would be expected to cause less atmospheric dilution, and thus lead to greater particle number concentrations, as Zhu et al. (2002) reported. However, at extremely low wind speeds, it would take a considerably longer time for the wind to carry particles to the sampling port of the CPC, which gives ultrafine particles more time to coagulate with either themselves or with larger particles, a phenomenon that would decrease the total particle number concentration. This may partially explain the observed "n" shape curve in the current study.

3.2. Traffic effects

The portion of freeway 710 passing through the City of Downey is a major truck shipping route. The average traffic volume per hour during the measurement period was: 8730 cars, 870 light trucks, 2580 heavy trucks, and 12180 total vehicles. It is apparent from these numbers that diesel emission vehicles on the 710 freeway represent about 30% of vehicles while on the 405 freeway they represent <5% (Zhu et al., 2002). Fig. 3 compares the traffic volume on both the 405 and the 710 freeways. Error bars represent one standard deviation. It is seen that the 710 freeway has about 7 times as many diesel vehicles and 70% of gasoline vehicles as the 405 freeway. The total vehicle numbers on both freeways are quite similar 12,180 versus 13,900/h for the 405 freeway.

Zhu et al. (2002) reported that a traffic slowdown on freeway 405 was associated with a drop in total particle number concentration indicating that fewer ultrafine particles are emitted during such events. In this study, the traffic speed on the 710 freeway stayed constant through out the sampling period. No traffic slow down was observed. The difference in the variability of traffic volume on both freeways is indicated by the error bars in Fig. 3.

Zhu et al. (2002) reported that both wind speed and traffic density affected the characteristics of ultrafine particles near the 405 freeway, and the control CPC responded to these effects reasonably well. Thus, subsequent data for ultrafine particle analysis at increasing distances from the freeway were all normalized to the control CPC's reading. An average CPC reading, $\overline{C_N}$, was obtained based on all the measurements. In Figs. 4–6, number concentration and size distribution data were scaled to $\overline{C_N}$ by dividing each measurement by the ratio of CPC reading for the period of measurement to $\overline{C_N}$.

3.3. Change in ultrafine particle size distribution with increasing distance

Fig. 4 depicts ultrafine particle size distributions at 17, 20, 30, 90, 150 and 300 m downwind and 300 m upwind of freeway 710. The size distributions are smoothed and shown together with common scales for both axes. The horizontal axis represents particle size on a logarithmic scale, while the vertical axis represents normalized particle number concentration in the size range of 6–220 nm as measured by the SMPS. Data were averaged for all applicable sampling dates for each distance from the freeway. As shown in Fig. 4, ultrafine particle size

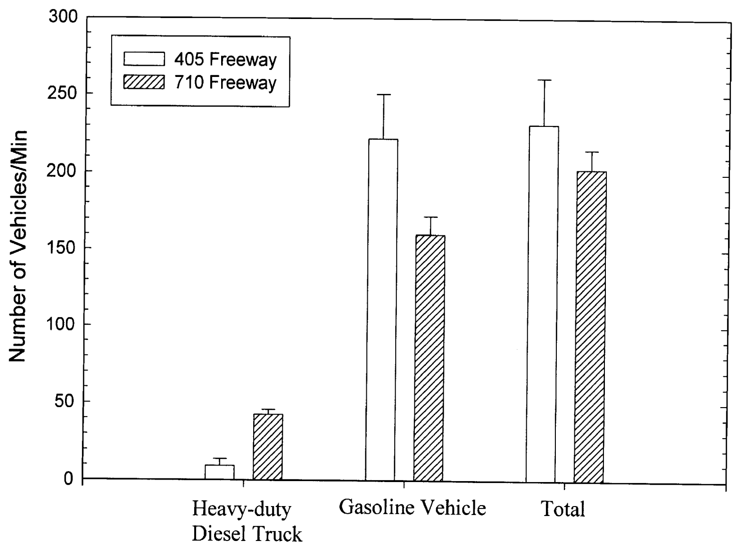

Fig. 3. Traffic volume comparison for the 405 and 710 freeway. Bars indicate one standard deviation.

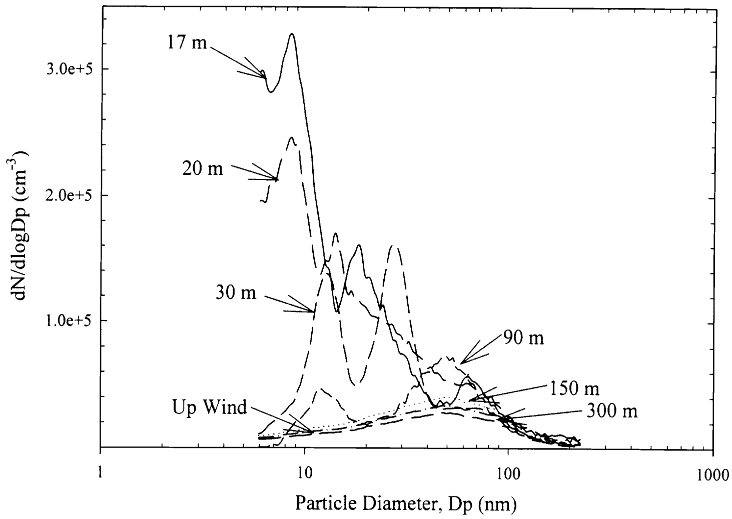

Fig. 4. Ultrafine particle size distribution at different sampling locations near the 710 freeway.

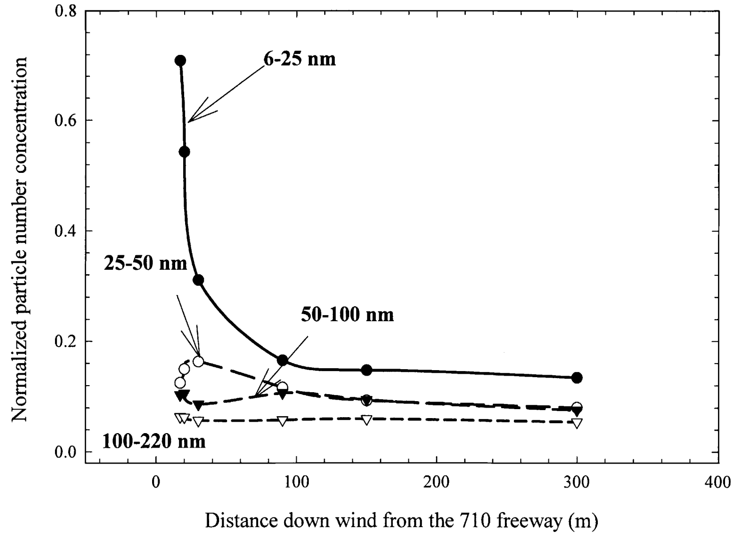

Fig. 5. Normalized particle number concentration for different size ranges as a function of distance from the 710 freeway.

distribution changed markedly and its number concentration dropped dramatically with increasing distance. At the nearest sampling location, 17 m downwind from the center of the freeway, the dominant mode was around 10 nm with a modal concentration of more than $3.2 \times 10^5/cm^3$. This mode remained at 10 nm for the second sampling location, 20 m downwind from the freeway, but its concentration dropped to $2.4 \times 10^5/cm^3$. It shifted to larger size range and its concentration kept decreasing for farther sampling locations. This mode was not observed at distance >150 m downwind from the freeway. The dramatic decrease of particle number concentration in the size range around 10 nm was likely due to atmospheric dilution and several atmospheric aerosol particle loss mechanisms that favor small particles, diffusion to surfaces, evaporation, and coagulation. The smaller the particle, the greater its diffusion coefficient and its Brownian motion. Particles of 10 nm diffuse about 80 times faster than particles of 100 nm (Hinds, 1999). As particle size gets smaller, the Kelvin effect becomes more important, making it easier for molecules to leave the particle's surface by evaporation. In addition, when two small particles collide due to their Brownian motion (coagulate), they form a bigger particle. Thus, coagulation reduces number concentrations and shifts the size distribution to larger sizes.

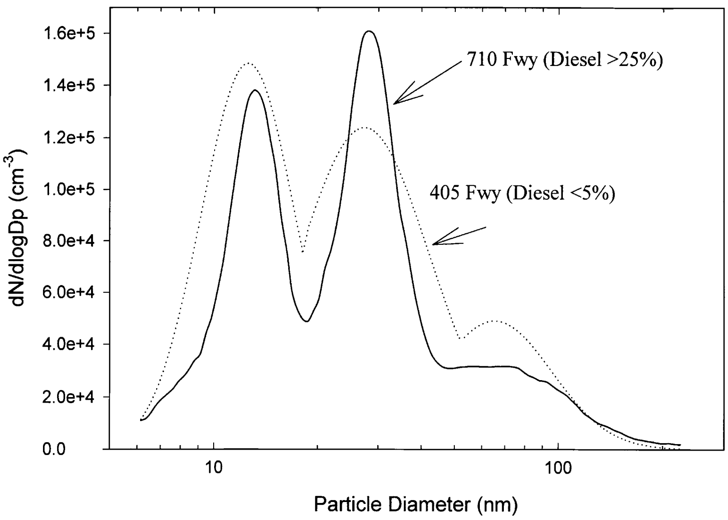

Fig. 6. Comparison of ultrafine particle number concentration at 30 m downwind from 405 and 710 freeway.

In Fig. 4, the second mode at 17 m downwind from the freeway was around 20 nm with a concentration of $1.5 \times 10^5/cm^3$. This mode remained at similar size range and concentration for the next sampling location, 20 m, but shifted to 30 nm at 30 m downwind from the freeway. It is of particular note that, while the concentration for the primary mode, 10 nm mode, decreased about 60% of its maximum value from 17 to 30 m with a slight shift in its mode, the 20 nm mode concentration did not change significantly but the modal size shifted noticeably. This second mode continued to shift to larger sizes with increasing distance from the freeway. In general number concentrations for smaller particles, $d_p < 50$ nm, dropped significantly with increasing distances from the freeway, but for larger ones, $d_p > 100$ nm, number concentrations decreased only slightly. These results are in excellent agreement with what Zhu et al. (2002) reported for freeways impacted mostly by gasoline vehicles, which suggests that coagulation is more important than atmospheric dilution for the smallest ultrafine particles and vice versa for large particles. Ultrafine particle concentrations measured at 150 and 300 m downwind of the 710 freeway were statistically within the variation of the 300 m upwind background concentration. The maximum number concentration that was observed next to the freeway was about 30 times greater than that for the background location. This suggests that people who live or work within 100 m downwind of major traffic sources, or spend a substantial amount of time commuting on such highways, will have a much higher ultrafine particle exposure than those who do not. This result can be used in epidemiological studies to estimate exposure to ultrafine particles.

Based on Fig. 4, it is clear that vehicle-emitted ultrafine particles of different size ranges behave quite differently in the atmosphere. Zhu et al. (2002) showed the decay of ultrafine particle number concentrations in four size ranges 6–25, 25–50, 50–100 and 100–220 nm. They found coagulation played a significant role in modifying the particle size distribution of vehicle-emitted ultrafine particle downwind of a freeway. Fig. 5 was prepared in the same ways as Zhu et al. (2002). The measured particle number concentrations in each SMPS size bin were combined in the corresponding size range, and the result was normalize to averaged wind speed. The general trends of sub-grouped ultrafine particle decay curves are quite comparable to those given by Zhu et al. (2002), Figs. 7a and b. Total particle number concentration in the size range of 6 to 25 nm accounted for about 70% of total ultrafine particle number concentration and dropped sharply, by about 80%, at 100 m, and leveled off after 150 m. Overall, it decayed exponentially through out the whole measured distance. Number concentrations in the next two size ranges 25–50 and 50–100 nm, all experienced a shoulder between 17 and 150 m. These results are in excellent agreement with what Zhu et al. (2002) observed and can be explained by particles, in smaller size ranges, coagulating with these particles to increase their size.

Fig. 6 compares the ultrafine particle size distributions at 30 m downwind from the 710 and the 405 freeways. Three-mode lognormal fitting was used for 405 freeway. Raw data were smoothed by averaging for 710 freeway. Heavy-duty diesel trucks on the 710 freeway represent more than 25% of traffic while on the 405 freeway they represent $< 5\%$ (Zhu et al., 2002). Average PM emission rate for heavy-duty diesel trucks is about 0.4 g/mi (California ARB, 2000) while for passenger cars is

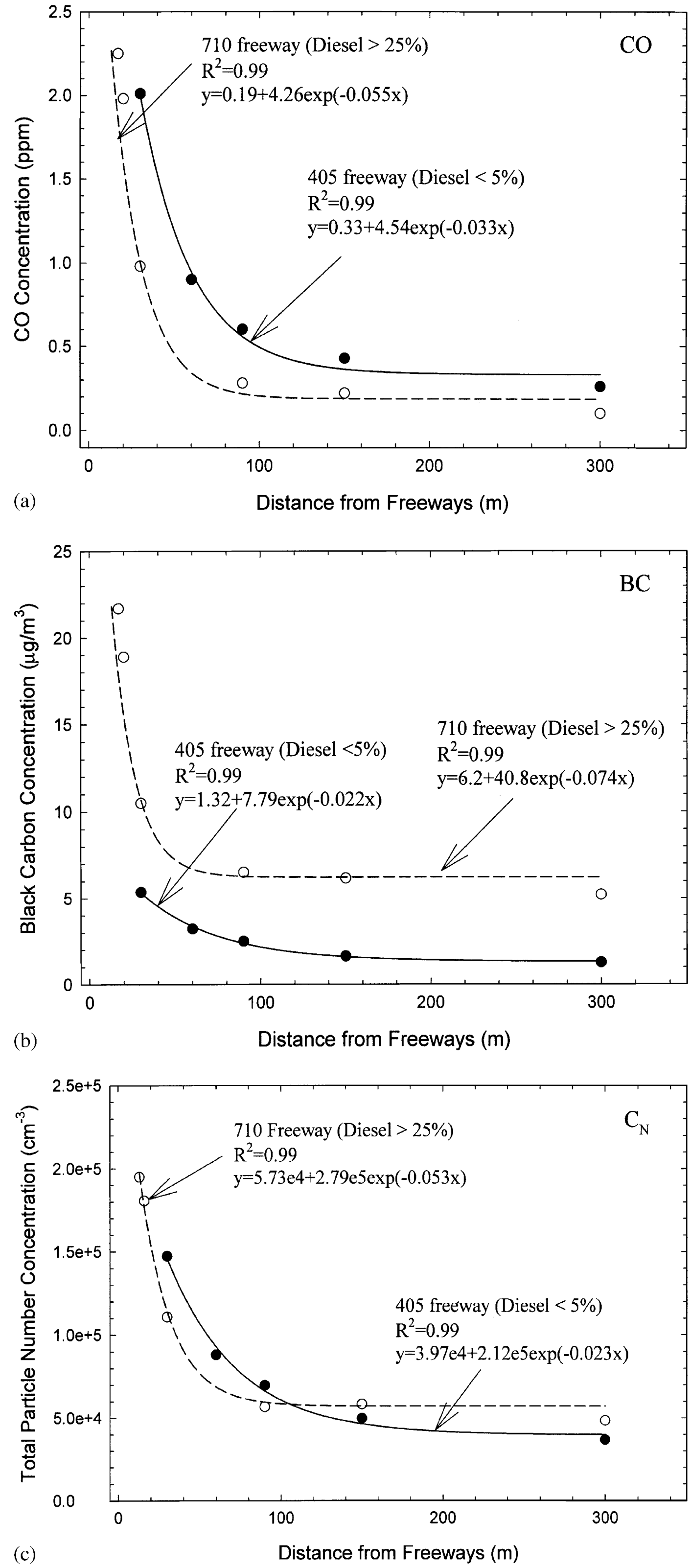

Fig. 7. Decay curves of: (a) CO, (b) BC and (c) particle number concentration near the 405 and 710 freeway.

about 0.08 g/mi (EPA, 2000). Thus, on the 710 freeway, about 60% of PM emission is due to heavy-duty diesel trucks $((0.25\times0.4)/(0.25\times0.4+0.75\times0.08)=62.5\%)$. In Fig. 6, both size distributions have three distinct modes. The concentration for the first mode, between 10 to 20 nm, is slightly higher near the 405 freeway. This mode is likely to arise from homogeneous nucleation of semi-volatile materials and is similar to that previously reported for direct laboratory measurement of gasoline vehicle emissions (Ristovski et al., 1998). The concentration for the second mode, around 30 nm, is about 30% higher near the 710 freeway than that near the 405 freeway. This mode probably comprises mainly of BC and is likely due to the much higher diesel emissions on the 710 freeway. The last mode, around 70 nm, represents an insignificant contribution to number concentrations for these two freeways and in both cases are comparable to the background concentrations.

3.4. Decay of carbon monoxide, black carbon and particle number concentration

To make this freeway study more comprehensive, the concentrations of CO, BC, and particle number were also measured at increasing distance from the freeway on selected dates, as shown in Table 1. CO and BC were intentionally selected because their ambient concentrations are closely related to vehicular emissions. Averaged concentration and range of values at different distances from the freeway of each measured property are summarized in Table 2. CO and BC concentrations decreased noticeably when moving away from the traffic sources, similar to the findings of the study by Zhu et al. (2002).

Figs. 7a–c were prepared by comparing the decay characteristic of CO, BC and particle number concentrations near the 405, gasoline vehicle dominated, and the 710, diesel vehicle dominated, freeways. Exponential decay was found to be a good estimator for predicting total particle number concentrations at different locations (Zhu et al., 2002). Each data point in the figure represents an averaged value for all measurements with similar wind directions. The solid line was the best fitting exponential decay curve, determined using SigmaPlot 2000 nonlinear curve fitting procedure. The best fitting exponential decay equations and R^2 values are also given in the figure. It can be seen, in general, all three pollutants decay at a similar rate near both freeways. This implies that atmospheric dilution plays a comparable role in both studies. As discussed previously, the average wind speed for these two studies are all close to 1.5 m/s. The discrepancies of the curves were mainly due to the different traffic fleet compositions on these two freeways. The 710 freeway has more than 25% heavy diesel trucks while the 405 freeway has $<5\%$. It is well known that diesel engines emit less CO and more BC comparing to spark ignition engines (Kittelson et al., 2001). Fig. 7a shows that the concentration of CO near the 710 freeway is generally half of that near the 405 freeway. By comparison, Fig. 7b shows the BC concentration near a diesel vehicle dominated freeway is more than three times greater than that near a gasoline vehicle dominated freeway. As shown in Fig. 7c, the total particle number concentration close to the 405 freeway is somewhat higher than that near the 710 freeway, but drops faster with downwind distance. Since the rate of coagulation increases with decreasing particle size down to 20 nm (Hinds, 1999), the observed result suggests more of the smallest ultrafine particles, mostly in nano-size range, were emitted from the 405 freeway. This may be explained by a total of 20% more vehicles on the 405 freeway. It was previously reported that number emission rates from the spark-ignition vehicles were much lower than from the diesel vehicles under most operating conditions, but were similar under high-speed highway cruise conditions (Rickeard et al., 1996; Kittelson, 1998). It should also be noted that the exponential decay characteristic appears to extend to about 3 m downwind from the edge of the freeway for all three pollutants. Based on our results we conclude that atmospheric dilution is so rapid that average concentration decays continuously after leaving the tailpipe.

Table 2
Measured averaged concentrations at increasing distances from the freeway[a]

Measurement	Upwind (m)	Downwind distance (m)					
	200	17	20	30	90	150	300
CO	0.1	2.3	2.0	1.7	0.5	0.4	0.2
(ppm)	(0.0–0.2)	(1.9–2.6)	(1.5–2.4)	(1.1–1.9)	(0.2–0.7)	(0.1–0.5)	(0.1–0.3)
Black carbon	4.6	21.7	19.4	17.1	7.8	6.5	5.5
($\mu g/m^3$)	(3.1–5.9)	(20.3–24.8)	(16.5–21.6)	(12.6–19.3)	(4.5–9.3)	(3.9–9.2)	(3.5–7.7)
Number concentration	0.48	2.0	1.8	1.6	0.72	0.61	0.49
($\times 10^{-5}/cm^3$)	(0.36–0.57)	(1.8–2.5)	(1.5–2.5)	(1.2–1.9)	(0.42–1.1)	(0.35–0.98)	(0.30–0.59)

[a] Range given in parenthesis.

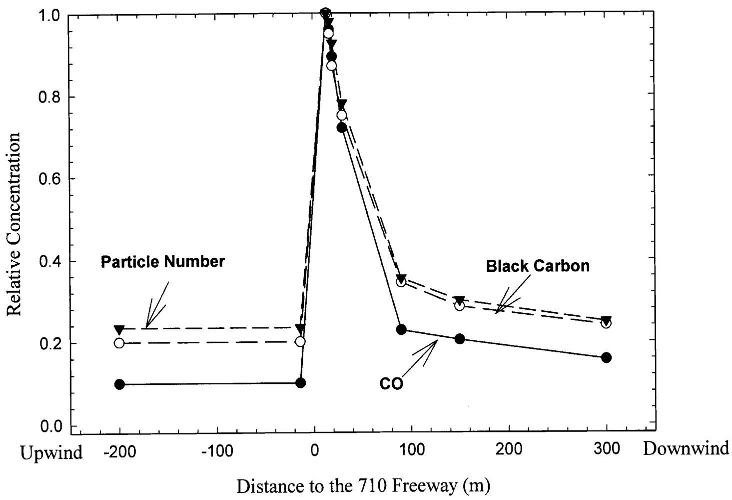

Fig. 8. Relative particle number, BC, CO concentrations versus distance from the 710 freeway.

Fig. 8 shows the decay curves for relative concentrations of CO, BC and total particle number. The curves are normalized and extended to reach 1.0 at the downwind edge of the 710 freeway. Background concentrations are also shown in the figure. It is seen that CO, BC and particle number concentration decreased about 60–80% in the first 100 m and then leveled off somewhat after 150 m, similar to what Zhu et al. (2002) reported. Background CO has a much lower relative concentration while background BC and particle number concentrations are comparable. Thus, CO was diluted more quickly and significantly than BC and particle number concentration. In general, CO, BC and particle number concentrations tracked each other very well. These results confirm the common assumption that vehicular exhaust is the major source for CO, BC and ultrafine particles near a busy freeway. They also support the conclusion made by Zhu et al. (2002) that for the conditions of these measurements the decreasing characteristics of any of these three pollutants could be used interchangeably to estimate the relative concentration of the other two pollutants near freeways.

4. Conclusions and summary

Wind speed and direction are important in determining the characteristic of ultrafine particles near freeways. The average concentrations of CO, BC and particle number concentration at 17 m was 1.9–2.6 ppm, 20.3–24.8 $\mu g/m^3$, 1.8×10^5–$3.5 \times 10^5/cm^3$, respectively. Relative concentration of CO, BC and particle number tracked each other well as one moves away from the freeway. Exponential decay was found to be a good estimator for the decrease of these three pollutants' concentration with distance along the wind direction starting from the edge of the freeway. Measurements show that both atmospheric dilution and coagulation play important roles in the rapid decrease of particle number concentration and the change in particle size distribution with distance away from a freeway.

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Developing Community-Level Policy and Practice to Reduce Traffic-Related Air Pollution Exposure

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ABSTRACT

The literature consistently shows associations of adverse cardiovascular and pulmonary outcomes with residential proximity to highways and major roadways. Air monitoring shows that traffic-related air pollutants (TRAP) are elevated within 200–400 meters of these roads. Community-level tactics for reducing exposure include the following: 1) high-efficiency particulate arrestance (HEPA) filtration; 2) appropriate air-intake locations; 3) sound proofing, insulation; 4) land-use buffers; 5) vegetation or wall barriers; 6) street-side trees, hedges and vegetation; 7) decking over highways; 8) urban design including placement of buildings; 9) garden and park locations; and 10) active-travel locations, including bicycling and walking paths. A multidisciplinary design charrette was held to test the feasibility of incorporating these tactics into near-highway housing and school developments that were in the planning stages. The resulting designs successfully utilized many of the protective tactics and also led to engagement with the designers and developers of the sites. There is a need to increase awareness of TRAP in terms of building design and urban planning.

HIGHWAY PROXIMITY AND HEALTH

Concentrations of traffic-related air pollutants (TRAP) are frequently elevated next to highways and major roadways. The mixture of gasses and particles in fresh motor vehicle exhaust emissions are distinct from other air pollutants that are spread more evenly over large metropolitan areas. Key pollutants in TRAP include ultrafine particles (UFP, particles <0.1 microns in diameter), black carbon, PM_{10} (particles <10 microns in diameter), nitrogen oxides (including nitrogen dioxide and nitrogen oxide, NO), carbon monoxide, and volatile organic compounds.[1,2,3] Thus, people who live or spend time in locations adjacent to busy roadways are more highly exposed to these pollutants.

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[1] Alex A. Karner, Douglas S. Eisinger, and Deb A. Niemeier, ‘‘Near-Roadway Air Quality: Synthesizing the Findings from Real-World Data,’’ *Environmental Science and Technology* 44 (July 15, 2010): 5334–44, doi:10.1021/es100008x.

[2] Allison P. Patton et al., ‘‘Spatial and Temporal Differences in Traffic-Related Air Pollution in Three Urban Neighborhoods near an Interstate Highway,’’ *Atmospheric Environment* 99 (Dec. 2014): 309–21, doi:10.1016/j.atmosenv.2014.09.072.

[3] Luz T. Padró-Martínez et al., ‘‘Mobile Monitoring of Particle Number Concentration and Other Traffic-Related Air Pollutants in a near-Highway Neighborhood over the Course of a Year,’’ *Atmospheric Environment* 61 (Dec. 2012): 253–64, doi:10.1016/j.atmosenv.2012.06.088.

Many studies have looked at where people live relative to major roadways and investigated whether closer proximity puts them at greater risk of adverse health outcomes. These ''proximity studies'' have consistently found that living closer to heavy traffic is associated with childhood asthma and reduced lung function,[4,5] cardiovascular health and mortality,[6,7] biomarkers of cardiovascular health,[8] and development of autism.[9,10]

We have been conducting community-based participatory research projects under the umbrella of the Community Assessment of Freeway Exposure and Health (CAFEH; <http://sites.tufts.edu/cafeh/>) study to look at the possible role of UFP on the health of residents living near heavy traffic. Other research suggests that UFP might be a causal agent of near highway health effects. Animal studies have reported that UFP can penetrate deep into the lungs and translocate into the blood. UFP promote inflammation, oxidative stress, and atherosclerosis in animals.[11,12,13] Both controlled human exposure studies and studies of short term association with UFP add evidence that UFP affect inflammation and coagulation.[14,15,16,17,18,19]

In CAFEH, we monitored UFP in both near highway (<400 meters from highways) and urban background (>1 kilometer from highways) neighborhoods[20] and collected blood biomarker samples and lifestyle information from participants living in these locations. Resulting data were used to build land use regression models of UFP for the study areas.[21] These models predict hourly UFP levels at participants' residences for every hour for a year. Subsequently, we modified participant exposure by their time activity patterns and use of air conditioning. The resulting individualized exposures were used to test associations with blood biomarkers of inflammation and coagulation, which are predictors of cardiovascular disease risk. We have not published our main findings for association of UFP with the biomarkers and cannot report them here.

ENVIRONMENTAL JUSTICE

TRAP is an environmental justice issue because low-income and minority populations are disproportionately concentrated near high traffic volume roadways. A U.S. -wide study that linked National Health and Nutrition Examination Survey data to the National Highway Planning Network found that non-Hispanic blacks, Mexican Americans, and people living just above or below the poverty line were more likely to have higher

[4] Rob McConnell et al., ''Childhood Incident Asthma and Traffic-Related Air Pollution at Home and School,'' *Environmental Health Perspectives* 118 (July 2010): 1021–26, doi:10.1289/ehp.0901232.

[5] W. James Gauderman et al., ''Childhood Asthma and Exposure to Traffic and Nitrogen Dioxide,'' *Epidemiology* 16 (Nov. 2005): 737–43.

[6] Michael Jerrett et al., ''A Cohort Study of Traffic-Related Air Pollution and Mortality in Toronto, Ontario, Canada,'' *Environmental Health Perspectives* 117 (May 2009): 772–77, doi:10.1289/ehp.11533.

[7] Wen Qi Gan et al., ''Changes in Residential Proximity to Road Traffic and the Risk of Death from Coronary Heart Disease,'' *Epidemiology* 21 (Sept. 2010): 642–49, doi:10.1097/EDE.0b013e3181e89f19.

[8] Doug Brugge et al., ''Highway Proximity Associated with Cardiovascular Disease Risk: The Influence of Individual-Level Confounders and Exposure Misclassification,'' *Environmental Health* 12 (Oct. 3, 2013): 84, doi:10.1186/1476-069X-12-84.

[9] Heather E. Volk et al., ''Traffic-Related Air Pollution, Particulate Matter, and Autism,'' *JAMA Psychiatry* 70 (Jan. 2013): 71–77, doi:10.1001/jamapsychiatry.2013.266.

[10] Andrea L. Roberts et al., ''Perinatal Air Pollutant Exposures and Autism Spectrum Disorder in the Children of Nurses' Health Study II Participants,'' *Environmental Health Perspectives* 121 (Aug. 2013): 978–84, doi:10.1289/ehp.1206187.

[11] Jesus A. Araujo et al., ''Ambient Particulate Pollutants in the Ultrafine Range Promote Early Atherosclerosis and Systemic Oxidative Stress,'' *Circulation Research* 102 (Mar. 14, 2008): 589–96, doi:10.1161/CIRCRESAHA.107.164970.

[12] Jesus A. Araujo and Andre E. Nel, ''Particulate Matter and Atherosclerosis: Role of Particle Size, Composition and Oxidative Stress,'' *Particle and Fibre Toxicology* 6 (Sept. 18, 2009): 24, doi:10.1186/1743-8977-6-24.

[13] Marianne Geiser et al., ''Ultrafine Particles Cross Cellular Membranes by Nonphagocytic Mechanisms in Lungs and in Cultured Cells,'' *Environmental Health Perspectives* 113 (Nov. 2005): 1555–60.

[14] Robert B. Devlin et al., ''Controlled Exposure of Humans with Metabolic Syndrome to Concentrated Ultrafine Ambient Particulate Matter Causes Cardiovascular Effects,'' *Toxicological Sciences: An Official Journal of the Society of Toxicology* 140 (July 2014): 61–72, doi:10.1093/toxsci/kfu063.

[15] A. Nemmar et al., ''Passage of Inhaled Particles into the Blood Circulation in Humans,'' *Circulation* 105 (Jan. 29, 2002): 411–14.

[16] James M. Samet et al., ''Concentrated Ambient Ultrafine Particle Exposure Induces Cardiac Changes in Young Healthy Volunteers,'' *American Journal of Respiratory and Critical Care Medicine* 179 (June 1, 2009): 1034–42, doi:10.1164/rccm.200807-1043OC.

[17] Ralph J. Delfino et al., ''Circulating Biomarkers of Inflammation, Antioxidant Activity, and Platelet Activation Are Associated with Primary Combustion Aerosols in Subjects with Coronary Artery Disease,'' *Environmental Health Perspectives* 116 (July 2008): 898–906, doi:10.1289/ehp.11189.

[18] Ralph J. Delfino et al., ''Association of Biomarkers of Systemic Inflammation with Organic Components and Source Tracers in Quasi-Ultrafine Particles,'' *Environmental Health Perspectives* 118 (June 2010): 756–62, doi:10.1289/ehp.0901407.

[19] Sabine Hertel et al., ''Influence of Short-Term Exposure to Ultrafine and Fine Particles on Systemic Inflammation,'' *European Journal of Epidemiology* 25 (Aug. 2010): 581–92, doi:10.1007/s10654-010-9477-x.

[20] Christina H Fuller et al., ''A Community Participatory Study of Cardiovascular Health and Exposure to near-Highway Air Pollution: Study Design and Methods,'' *Reviews on Environmental Health* 28 (2013): 21–35, doi:10.1515/reveh-2012-0029.

[21] Allison P. Patton et al., ''An Hourly Regression Model for Ultrafine Particles in a Near-Highway Urban Area,'' *Environmental Science and Technology* 48 (Mar. 18, 2014): 3272–80, doi:10.1021/es404838k.

TRAP exposure.[22] Two other studies recently conducted similar investigations of traffic exposure in the U.S. Both studies had similar findings. The first used census track level data and found that residential location of non-Hispanic blacks and Hispanics had positive Spearman correlation coefficients with road density. They also found a similar association for poverty.[23] The second study analyzed national data at a finer grain, using census blocks. This study also found that being non-Hispanic black, Hispanic, and low-income were associated with higher traffic volume and density. They also found that greater racial and income disparity were associated with increased traffic density.[24]

PRINCIPLES FOR REDUCING OR AVOIDING UFP EXPOSURE

Development of protective tactics for near-highway locations requires knowledge of atmospheric processes and TRAP emission rates. It is important to note that UFP concentrations change rapidly in time and space, which makes understanding exposure complex. However, because highway traffic patterns and UFP emission rates are predictable, we can build fairly reliable models to predict UFP concentrations at different locations and times.[25,26] General principles for reducing or avoiding exposure should consider: 1) wind direction; 2) wind speed; 3) distance from busy roadways; 4) time of day; and 5) time of year. For example, based on the CAFEH study we found that the highest UFP concentrations occurred in Somerville within 0–50 meters of Interstate 93 (I-93) with distance-decay gradients varying depending on traffic and meteorology.[27]

The annual median particle number concentration (PNC, a proxy for UFP) 0–50 meters from I-93 was two-fold higher compared to the background area (>1 kilometer from I-93). PNC was generally highest in winter and lowest in summer and fall, higher on weekdays compared to weekends, and higher during morning rush hour compared to later in the day. For winds out of the southwest and northwest, PN concentrations were elevated on the northeast side of I-93 relative to the southwest side, and when winds were out of the northeast the opposite occurred, indicating that I-93 is the dominant source of PNC to neighborhoods immediately downwind of the highway. PNC was also greatly impacted by wind speed: median PN concentrations were highest for calm winds (<0.3 meters per second) and lowest for wind speeds >1.6 meters per second.

TACTICS FOR REDUCING COMMUNITY EXPOSURE

Evidence for efficacy of different tactics to reduce near-highway communities' TRAP exposure was reviewed. These tactics derive from empirical research and are intended for consideration in building and community design. They comprise methods to reduce TRAP generation, prevent pollution from reaching locations people frequent, and move people away from pollution. We searched for studies specifically measuring air pollutant concentration differences as a result of each tactic in PubMed and in the urban planning and environmental science literature. Although many papers claim that these tactics reduce TRAP exposure and improve health, there were limited measurements demonstrating these effects. Therefore, effectiveness of the different tactics based on the literature was classified as good (>40% potential reduction), moderate (<40% potential reduction), or inconclusive (insufficient evidence) for both on-site and off-site tactics (Table 1).

Land use buffers can often be used to separate sensitive land uses (e.g., residences, schools) from traffic and other sources of air pollution. TRAP exposure zones with concentrations 40% to 90% higher than concentrations in urban backgrounds extend about 50 meters to 1,500 meters from highways and major roads, with most pollutants decreasing to background levels within 300

TABLE 1. SUMMARY OF EXPECTED EFFECTIVENESS OF DIFFERENT TACTICS

	Effectiveness		
Location	*Good*	*Moderate*	*Inconclusive*
On-Site	• Filtration • Air intake location • Sound proofing	• Healthy placement of buildings and parking structures • Trees and Plantings	• Healthy vegetables
Off-Site	• Park locations • Land use buffers	• Built or vegetative barriers • Active travel locations • Decking over highways	

[22] Jennifer Parker et al., *Linkage of the 1999–2008 National Health and Nutrition Examination Surveys to Traffic Indicators From the National Highway Planning Network*, National Health Statistics Report (U.S. Department of Health and Human Services, Apr. 2, 2012).

[23] Nancy Tian, Jianping Xue, and Timothy M. Barzyk, "Evaluating Socioeconomic and Racial Differences in Traffic-Related Metrics in the United States Using a GIS Approach," *Journal of Exposure Science and Environmental Epidemiology* 23 (Mar. 2013): 215–22, doi:10.1038/jes.2012.83.

[24] Gregory M. Rowangould, "A Census of the US near-Roadway Population: Public Health and Environmental Justice Considerations," *Transportation Research Part D Transport and Environment* 25 (2013): 59–67, doi:10.1016/j.trd.2013.08.003.

[25] Allison P. Patton et al., "An Hourly Regression Model for Ultrafine Particles in a Near-Highway Urban Area," *Environmental Science and Technology* 48 (Mar. 18, 2014): 3272–80, doi:10.1021/es404838k.

[26] Leonard M. Zwack et al., "Modeling Spatial Patterns of Traffic-Related Air Pollutants in Complex Urban Terrain," *Environmental Health Perspectives* 119 (June 2011): 852–59, doi:10.1289/ehp.1002519.

[27] Luz T. Padró-Martínez et al., "Mobile Monitoring of Particle Number Concentration and Other Traffic-Related Air Pollutants in a near-Highway Neighborhood over the Course of a Year," *Atmospheric Environment* 61 (Dec. 2012): 253–64, doi:10.1016/j.atmosenv.2012.06.088.

meters to 500 meters and at shorter distances upwind than downwind.[28,29,30,31,32]

Siting parks requires consideration of competing factors. Although poor siting (e.g., in TRAP exposure zones) can expose children to air pollution, parks also provide benefits and services that might outweigh pollutant health risks, especially for communities without alternative park space.[33,34,35]

Reducing pollution entry into buildings is the most effective on-site method to reduce TRAP exposure indoors. Multiple guidelines support moving air inlets to locations with cleaner air.[36,37,38] Research suggests placing air intakes on rooftops or on sides of buildings that do not face roads can decrease pollutant concentrations indoors.[39,40] Infiltration of TRAP can also be reduced by tightening buildings, frequently achieved using soundproofing or energy efficiency measures.[41,42,43,44,45]

Filtration is an effective method for improving indoor air quality. In the U.S., filters are rated based on the minimum efficiency reporting value (MERV, higher is more efficient) for particles in the 0.3–1 μm, 1–3 μm, and 3–10 μm size ranges.[46,47,48] Although minimum efficiencies are not reported for UFP, pilot studies have shown that at least some high-MERV filters can remove UFP.[49,50] Challenges with filtration include improper filter replacement and long term maintenance.[51]

Moderate effectiveness can also be achieved through urban design. For example, avoiding wind flow through open areas below raised highways or orienting street canyons so that wind flows through them instead of stagnating could reduce pollutant concentrations by one third to one half.[52,53,54,55] In addition, garages and street parking could be distributed so as to decrease driving or low emissions zones

[28]HEI panel on the health effects of traffic-related air pollution, *Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects*, HEI Special Report 17 (Boston, MA: Health Effects Institute, 2010), <http://cdm16064.contentdm.oclc.org/cdm/ref/collection/p266901coll4/id/2584>.

[29]Alex A. Karner, Douglas S. Eisinger, and Deb A. Niemeier, ''Near-Roadway Air Quality: Synthesizing the Findings from Real-World Data,'' *Environmental Science and Technology* 44 (July 15, 2010): 5334–44, doi:10.1021/es100008x.

[30]Allison P. Patton et al., ''Spatial and Temporal Differences in Traffic-Related Air Pollution in Three Urban Neighborhoods near an Interstate Highway,'' *Atmospheric Environment* 99 (Dec. 2014): 309–21, doi:10.1016/j.atmosenv.2014.09.072.

[31]Luz T. Padró-Martínez et al., ''Mobile Monitoring of Particle Number Concentration and Other Traffic-Related Air Pollutants in a near-Highway Neighborhood over the Course of a Year,'' *Atmospheric Environment* 61 (Dec. 2012): 253–64, doi:10.1016/j.atmosenv.2012.06.088.

[32]J. L. Durant et al., ''Short-Term Variation in near-Highway Air Pollutant Gradients on a Winter Morning,'' *Atmospheric Chemistry and Physics (Print)* 10 (2010): 5599–5626.

[33]Anna Chiesura, ''The Role of Urban Parks for the Sustainable City,'' *Landscape and Urban Planning* 68 (May 15, 2004): 129–38, doi:10.1016/j.landurbplan.2003.08.003.

[34]Zhou Yuan, Shi Tiemao, and Gao Chang, ''Multi-Objective Optimal Location Planning of Urban Parks,'' in *2011 International Conference on Electronics, Communications and Control (ICECC)*, 2011, 918–21, doi:10.1109/ICECC.2011.6066364.

[35]M. N. Neema and A. Ohgai, ''Multi-Objective Location Modeling of Urban Parks and Open Spaces: Continuous Optimization,'' *Computers, Environment and Urban Systems* 34 (Aug. 2010): 359–76, doi:10.1016/j.compenvurbsys.2010.03.001.

[36]*Standards 62.1 and 62.2: The Standards for Ventilation and Indoor Air Quality* (ASHRAE, 2013), 1, <https://www.ashrae.org/resources–publications/bookstore/standards-62-1–62-2> (last accessed on Dec. 15, 2014).

[37]American Lung Association of the Upper Midwest, ''Health House,'' n.d., <http://www.healthhouse.org/> (last accessed on Dec. 15, 2014).

[38]''Air Quality Standards and Area Designations,'' *California Environmental Protection Agency Air Resources Board*, Apr. 17, 2014, <http://www.arb.ca.gov/homepage.htm> (last accessed on Dec. 15, 2014).

[39]N. E Green, D. W Etheridge, and S. B Riffat, ''Location of Air Intakes to Avoid Contamination of Indoor Air: A Wind Tunnel Investigation,'' *Building and Environment* 36 (Jan. 1, 2001): 1–14, doi:10.1016/S0360-1323(99)00056-6.

[40]Tsang-Jung Chang, Hong-Ming Kao, and Yi-Fang Hsieh, ''Numerical Study of the Effect of Ventilation Pattern on Coarse, Fine, and Very Fine Particulate Matter Removal in Partitioned Indoor Environment,'' *Journal of the Air and Waste Management Association (1995)* 57 (Feb. 2007): 179–89.

[41]Birgitta Berglund, Thomas Lindvall, and Dietrich H. Schwela, *Guidelines for Community Noise* (Geneva: World Health Organization, 1999).

[42]U.S. Department of Transportation Federal Highway Administration, *Highway Traffic Noise: Analysis and Abatement Guidance* (2011).

[43]Berglund, Lindvall, and Schwela, *Guidelines for Community Noise*.

[44]Lars Jarup et al., ''Hypertension and Exposure to Noise Near Airports: The HYENA Study,'' *Environmental Health Perspectives* 116 (Mar. 2008): 329–33, doi:10.1289/ehp.10775.

[45]Thomas Münzel et al., ''Cardiovascular Effects of Environmental Noise Exposure,'' *European Heart Journal* (Mar. 8, 2014), ehu030, doi:10.1093/eurheartj/ehu030.

[46]United States Environmental Protection Agency, *Residential Air Cleaners: A Summary of Available Information* (2009).

[47]B. Stephens and J. A. Siegel, ''Ultrafine Particle Removal by Residential Heating, Ventilating, and Air-Conditioning Filters,'' *Indoor Air* 23 (Dec. 1, 2013): 488–97, doi:10.1111/ina.12045.

[48]Bin Zhou and Jinming Shen, ''Comparison of General Ventilation Air Filter Test Standards between America and Europe'' (The 6th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings IAQVEC, Sendai, Japan, 2007).

[49]A. Polidori et al., ''Pilot Study of High-Performance Air Filtration for Classroom Applications,'' *Indoor Air* 23 (June 2013): 185–95, doi:10.1111/ina.12013.

[50]Stephens and Siegel, ''Ultrafine Particle Removal by Residential Heating, Ventilating, and Air-Conditioning Filters.''

[51]S. Batterman et al., ''Particulate Matter Concentrations in Residences: An Intervention Study Evaluating Stand-Alone Filters and Air Conditioners,'' *Indoor Air* 22 (June 2012): 235–52, doi:10.1111/j.1600-0668.2011.00761.x.

[52]J. H. Amorim et al., ''CFD Modelling of the Aerodynamic Effect of Trees on Urban Air Pollution Dispersion,'' *Science of The Total Environment* 461–462 (Sept. 1, 2013): 541–51, doi:10.1016/j.scitotenv.2013.05.031.

[53]Peter E. J. Vos et al., ''Improving Local Air Quality in Cities: To Tree or Not to Tree?,'' *Environmental Pollution* 183 (Dec. 2013): 113–22, doi:10.1016/j.envpol.2012.10.021.

[54]Amorim et al., ''CFD Modelling of the Aerodynamic Effect of Trees on Urban Air Pollution Dispersion.''

[55]Zheming Tong et al., ''Modeling Spatial Variations of Black Carbon Particles in an Urban Highway-Buildings Environment,'' *Environmental Science and Technology* 46 (Jan. 3, 2012): 312–19, doi:10.1021/es201938v.

could substitute some of the vehicle fleet with electric vehicles.[56,57]

Urban vegetation including green roofs or walls can also decrease air pollution slightly, particularly in highly polluted cities (e.g., Mexico City), through deposition on leaf surfaces and reduced need for air conditioning due to the cooling effect provided by the soil layer and building shade.[58,59,60,61,62] Vegetation along the side of a busy road can reduce air pollution behind the vegetative barrier by less than 40%, although results vary greatly by wind direction and study.[63,64] When planning urban vegetation, it is important to note that vegetation in street canyons can increase pollutant concentrations by as much as 33% due to decreasing wind flow and ventilation.[65,66,67,68,69] Off-site, solid or vegetative noise barriers along highways can decrease the amount of air pollution reaching neighborhoods.[70,71] Factors such as the effects of barrier height and road width require further study.[72,73] The limited evidence for vegetative barriers suggests that dense vegetation performs similarly to a solid barrier by both blocking and filtering air pollution, with effectiveness depending on wind direction and whether the roadside trees are deciduous or evergreen.[74,75,76]

Bicycle or other active travel lanes can be separated from traffic to reduce TRAP exposure for people breathing heavily during exercise.[77,78,79] Larger-scale projects like capping highways with decking has been shown to reduce concentrations near one major project.[80,81,82] However, elevated air pollution levels have been measured in highway tunnels and near vents/exits to

[56]Paul G. Höglund, ''Parking, Energy Consumption and Air Pollution,'' *Science of the Total Environment* 334–335 (Dec. 1, 2004): 39–45, doi:10.1016/j.scitotenv.2004.04.028.

[57]J. A. Acero et al., ''Impact of Local Urban Design and Traffic Restrictions on Air Quality in a Medium-Sized Town,'' *Environmental Technology* 33 (Nov. 2012): 2467–77, doi:10.1080/09593330.2012.672472.

[58]Rich Baldauf et al., ''The Role of Vegetation in Mitigating Air Quality Impacts from Traffic Emissions'' (U.S. Environmental Protection Agency, 2011).

[59]David J. Nowak et al., ''Modeled PM2.5 Removal by Trees in Ten U.S. Cities and Associated Health Effects,'' *Environmental Pollution* 178 (July 2013): 395–402, doi:10.1016/j.envpol.2013.03.050.

[60]Darrel Baumgardner et al., ''The Role of a Peri-Urban Forest on Air Quality Improvement in the Mexico City Megalopolis,'' *Environmental Pollution* 163 (Apr. 2012): 174–83, doi:10.1016/j.envpol.2011.12.016.

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[62]Thomas A. M. Pugh et al., ''Effectiveness of Green Infrastructure for Improvement of Air Quality in Urban Street Canyons,'' *Environmental Science and Technology* 46 (July 17, 2012): 7692–99, doi:10.1021/es300826w.

[63]D. Bradley Rowe, ''Green Roofs as a Means of Pollution Abatement,'' *Environmental Pollution* 159, (Sept. 2011): 2100–2110, doi:10.1016/j.envpol.2010.10.029.

[64]Riccardo Buccolieri et al., ''Aerodynamic Effects of Trees on Pollutant Concentration in Street Canyons,'' *Science of the Total Environment* 407 (Sept. 15, 2009): 5247–56, doi:10.1016/j.scitotenv.2009.06.016.

[65]Annett Wania et al., ''Analysing the Influence of Different Street Vegetation on Traffic-Induced Particle Dispersion Using Microscale Simulations,'' *Journal of Environmental Management* 94 (Feb. 2012): 91–101, doi:10.1016/j.jenvman.2011.06.036.

[66]J. A. Salmond et al., ''The Influence of Vegetation on the Horizontal and Vertical Distribution of Pollutants in a Street Canyon,'' *Science of the Total Environment* 443 (Jan. 15, 2013): 287–98, doi:10.1016/j.scitotenv.2012.10.101.

[67]Vos et al., ''Improving Local Air Quality in Cities.''

[68]Heikki Setälä et al., ''Does Urban Vegetation Mitigate Air Pollution in Northern Conditions?,'' *Environmental Pollution* 183 (Dec. 2013): 104–12, doi:10.1016/j.envpol.2012.11.010.

[69]Acero et al., ''Impact of Local Urban Design and Traffic Restrictions on Air Quality in a Medium-Sized Town.''

[70]N. Schulte and A. Venkatram, ''Effects of Sound Barriers on Dispersion from Roadways,'' *DRAFT* (2013).

[71]Halley L. Brantley et al., ''Field Assessment of the Effects of Roadside Vegetation on near-Road Black Carbon and Particulate Matter,'' *Science of the Total Environment* 468–469 (Jan. 15, 2014): 120–29, doi:10.1016/j.scitotenv.2013.08.001.

[72]Schulte and Venkatram, ''Effects of Sound Barriers on Dispersion from Roadways.''

[73]Brantley et al., ''Field Assessment of the Effects of Roadside Vegetation on near-Road Black Carbon and Particulate Matter.''

[74]Baldauf et al., ''The Role of Vegetation in Mitigating Air Quality Impacts from Traffic Emissions.''

[75]Abdullah N. Al-Dabbous and Prashant Kumar, ''The Influence of Roadside Vegetation Barriers on Airborne Nanoparticles and Pedestrians Exposure under Varying Wind Conditions,'' *Atmospheric Environment* 90 (June 2014): 113–24, doi:10.1016/j.atmosenv.2014.03.040.

[76]Gayle S. W. Hagler et al., ''Field Investigation of Roadside Vegetative and Structural Barrier Impact on near-Road Ultrafine Particle Concentrations under a Variety of Wind Conditions,'' *Science of the Total Environment* 419 (Mar. 1, 2012): 7–15, doi:10.1016/j.scitotenv.2011.12.002.

[77]Sarah Jarjour et al., ''Cyclist Route Choice, Traffic-Related Air Pollution, and Lung Function: A Scripted Exposure Study,'' *Environmental Health* 12 (Feb. 7, 2013): 14, doi:10.1186/1476-069X-12-14.

[78]Marianne Hatzopoulou et al., ''The Impact of Traffic Volume, Composition, and Road Geometry on Personal Air Pollution Exposures among Cyclists in Montreal, Canada,'' *Journal of Exposure Science and Environmental Epidemiology* 23 (Feb. 2013): 46–51, doi:10.1038/jes.2012.85.

[79]Luc Int Panis et al., ''Exposure to Particulate Matter in Traffic: A Comparison of Cyclists and Car Passengers,'' *Atmospheric Environment* 44 (June 2010): 2263–70, doi:10.1016/j.atmosenv.2010.04.028.

[80]Peter Harnik and Mayor Michael Bloomberg, *Urban Green: Innovative Parks for Resurgent Cities*, 2nd edition (Washington, DC: Island Press, 2010).

[81]Jonathan Reich, *Factors Affecting the Feasibility of Urban Infill Development Over Freeways Another Shade of Green: Implementing Complex Multidisciplinary Work* (n.d.).

[82]Robert Cervero, ''Transport Infrastructure and Global Competitiveness: Balancing Mobility and Livability,'' *ANNALS of the American Academy of Political and Social Science* 626 (Nov. 1, 2009): 210–25, doi:10.1177/0002716209344171.

decked areas, leading to potentially higher exposures for commuters and people living near vents/exits.[83,84,85,86]

There is increased interest in urban agriculture to improve access to fresh, healthy, affordable food and reduce transportation costs while lowering carbon emissions,[87] but it has led to questions of how garden location affects exposure. In fact, some vegetables can accumulate pollutants from the air, resulting in a dietary exposure pathway.[88,89]

CHARRETTE METHODS

In May 2014, the CAFEH team used lessons from their research to organize a charrette that brought together environmental scientists, health researchers, architects, planners, community members, and designers in a creative problem-solving session focused on near-highway projects in Somerville and Boston Chinatown.[90]

Somerville case example

The City of Somerville, MA, just north of Boston, is highly burdened with TRAP. The city is the most densely populated in New England with 78,000 residents living within 11.6 km^2. The city is crossed by I-93, Boston's main North-South highway (about 170,000 vehicles/day);[91] Rt. 28, (about 38,000 vehicles/day);[92] Route 38 (about 34,000 vehicles/day);[93] and other high volume roadways. This results in high UFP levels in residential areas near the roadways.[94] The Somerville population is economically and ethnically diverse with many low income and immigrant residents living near major roadways. Demand for housing and commercial space combined with little developable land has resulted in pressure to develop near highways.

A vacant site in the city was selected to be a test case in our charrette to consider pollutant exposure mitigation strategies. The site is located <200 meters from both Interstate 93 (I-93) and McGrath Highway (Rt. 28), and is next to a Stop and Shop supermarket. Surrounding the site is a small abandoned park and a neighborhood of two and three family homes. The nearby area includes several commercial buildings and Foss Park, the largest park in Somerville (Figure 1). The site is zoned for commercial use, but a residential developer aims to amend the zoning to allow residential development. The vacant parcel, located near so many TRAP sources, is similar to much of the remaining developable land in the city.

Concepts that emerged in the charrette ranged from design elements for the proposed housing to neighborhood-wide plans. Multiple types of barriers were considered. There are currently no sound walls along I-93 or McGrath near the site. Rather than traditional walls, charrette participants opted for more functional barriers such as minimally occupied structures including parking garages and commercial buildings (with high efficiency filtration) situated between the highway and the proposed new housing. Participants also considered vegetation buffers to be planted in the abandoned playground next to I-93. The goal was to reserve areas farther from the highway for more sensitive, residential uses, while also blocking flow of pollutants into residential areas (Figure 2).[95]

Concepts designed to reduce exposure at the nearby and heavily utilized Foss Park included creating earthen berms around the edges and a shell performance stage as functional barriers. In addition, participants recommended siting more active park elements, such as sports fields, farthest from the highways. While the focus of the charrette was on new development or redevelopment, addressing the pollution exposure of current residents was also considered. One recommendation was to provide

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[88] Agnes B. Lobscheid, Randy L. Maddalena, and Thomas E. McKone, "Contribution of Locally Grown Foods in Cumulative Exposure Assessments," *Journal of Exposure Analysis and Environmental Epidemiology* 14 (Jan. 2004): 60–73, doi:10.1038/sj.jea.7500306.

[89] Jie Hong et al., "Evidence of Translocation and Physiological Impacts of Foliar Applied CeO_2 Nanoparticles on Cucumber (Cucumis Sativus) Plants," *Environmental Science and Technology* 48, (Apr. 15, 2014): 4376–85, doi:10.1021/es404931g.

[90] The Community Assessment of Freeway Exposure and Health, *Improving Health in Communities Near Highways: Design Solutions from a Charrette (DRAFT)* (Boston, MA, n.d.).

[91] "I-93 North Between Route 28, Charlestown, and the New Hampshire State Line," <ftp://ctps.org/pub/Express_Highway_Volumes/21_I93_North.pdf> (last accessed Dec. 10, 2014).

[92] "Grounding McGrath Report," <http://www.massdot.state.ma.us/portals/23/docs/02bchapter2bexistingconditions.pdf> (last accessed Dec. 10, 2014).

[93] "Road Safety Audit: Mystic Avenue (Route 38)/Temple Street/Temple Road City of Somerville," <http://www.massdot.state.ma.us/Portals/8/docs/traffic/SafetyAudit/District4/Somerville_MysticAve_TempleSt_061614.pdf> (last accessed Dec. 10, 2014).

[94] Padró-Martínez et al., "Mobile Monitoring of Particle Number Concentration and Other Traffic-Related Air Pollutants in a near-Highway Neighborhood over the Course of a Year," Dec. 2012.

[95] Doug Brugge et al., *Improving Health in Communities Near Highways: Design Ideas from a Charrette.* Community Assessment of Freeway Exposure and Health (Nov. 2014), <https://sites.tufts.edu/cafeh/files/2011/10/CAFEH-Report-Final-2-26-15-hi-res.pdf>.

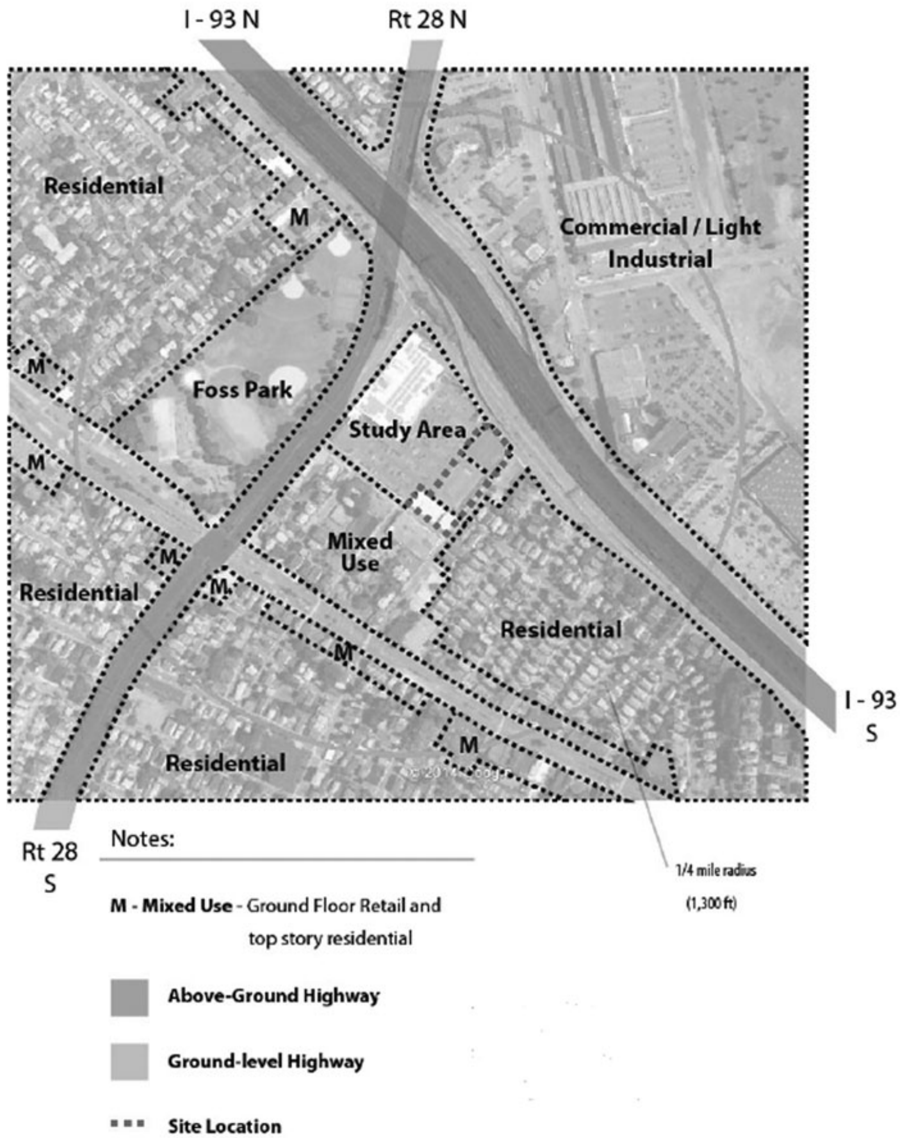


FIG. 1. The Cross Street East site in Somerville. The site is located near both I-93 and Route 28. *Credit:* D. Brugge, J. Durant, A. Patton, J. Newman, and W. Zamore. *Improving Health in Communities Near Highways: Design Ideas from a Charrette*. Community Assessment of Freeway Exposure and Health. Nov, 2014. *Available at:* <https://sites.tufts.edu/cafeh/files/2011/10/CAFEH-Report-Final-2-26-15-hi-res.pdf>.

residents near the highway with weatherization and filtering options, potentially through a city loan program.

Following the charrette, our work in Somerville with respect to this site has continued. We presented some of the charrette ideas to developers and are exploring ways to enhance the air filtration systems they propose to use in the housing, should it be approved for construction.

Boston Chinatown case example

Boston Chinatown is an historic neighborhood near the heart of downtown that lies at the junction of the Massachusetts Turnpike (I-90) and the I-93 expressway; most of the community's housing lies within 400 meters of the highway. Its surface streets are major access points to and from the highways. Chinatown is also Boston's densest neighborhood, with only 5.1% tree canopy coverage, compared to 28% for the city overall.

On the east side of Boston Chinatown lies a 20-acre tangle of highway ramps and empty land, owned by the Massachusetts Department of Transportation and designated as an important area for economic development. It was labelled the ''Chinatown Gateway Special Study Area'' in the 1990s. In 2013, as luxury downtown development made available parcels scarcer and even more valuable, Boston's outgoing mayor proposed to build a new \$261 million two-school facility for the Josiah Quincy Upper School and the Boston Arts Academy on one of the Chinatown Gateway sites known as Parcel 25. The project would place more than one thousand public school students into a school that straddles an I-93 on-ramp and tunnel exit (Figure 3). Despite vocal concerns about the children's safety and health, the community has been largely supportive of the project, with no other suitable development location available in Chinatown.

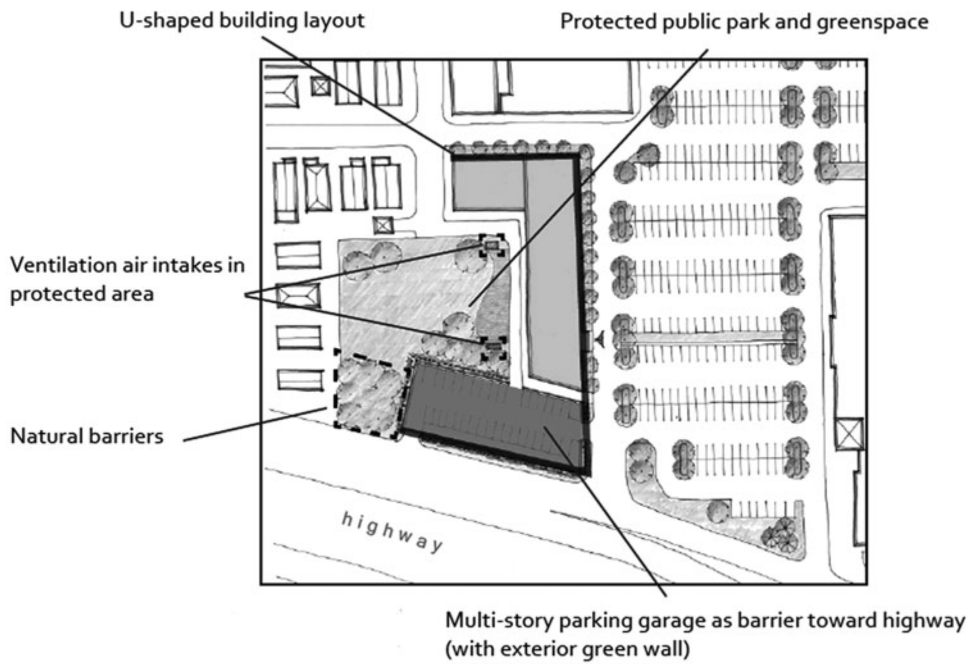


FIG. 2. A design to reduce exposure to traffic-related air pollutants (TRAP) at the site in Somerville. *Credit:* D. Brugge, J. Durant, A. Patton, J. Newman, and W. Zamore. *Improving Health in Communities Near Highways: Design Ideas from a Charrette*. Community Assessment of Freeway Exposure and Health. Nov, 2014. *Available at:* <https://sites.tufts.edu/cafeh/files/2011/10/CAFEH-Report-Final-2-26-15-hi-res.pdf>.

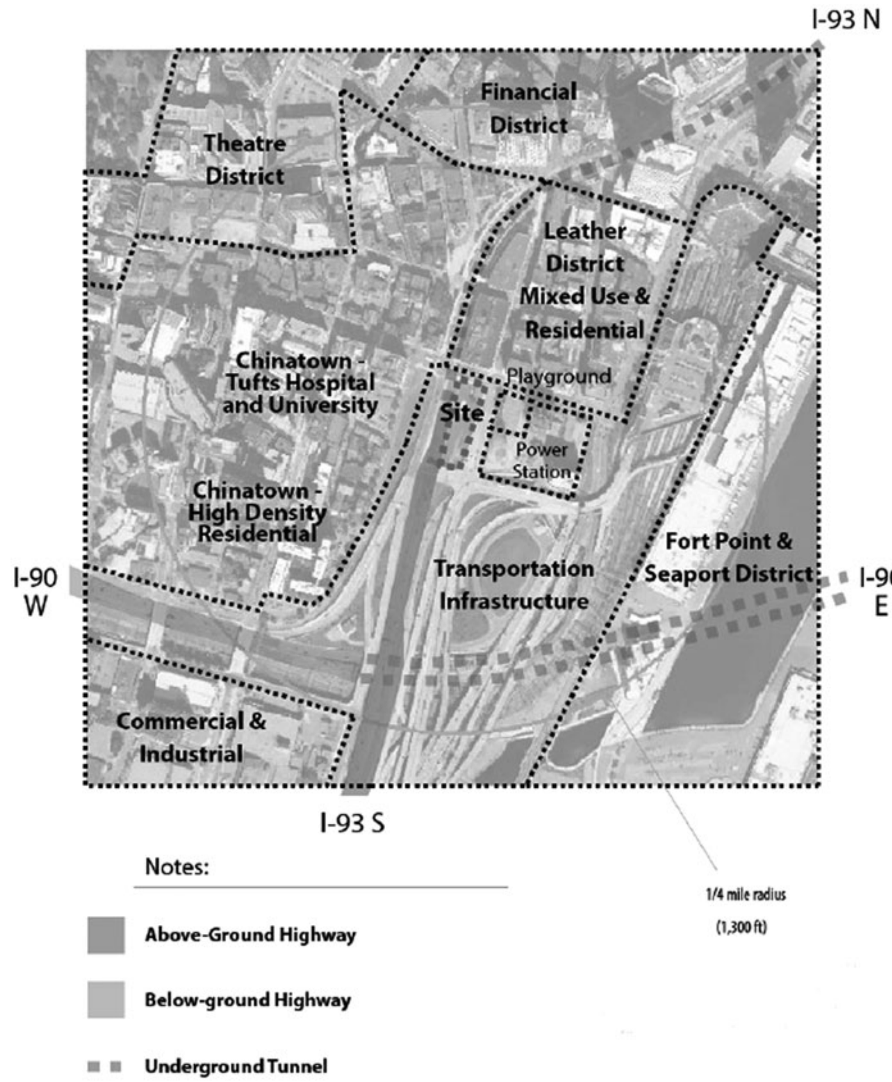
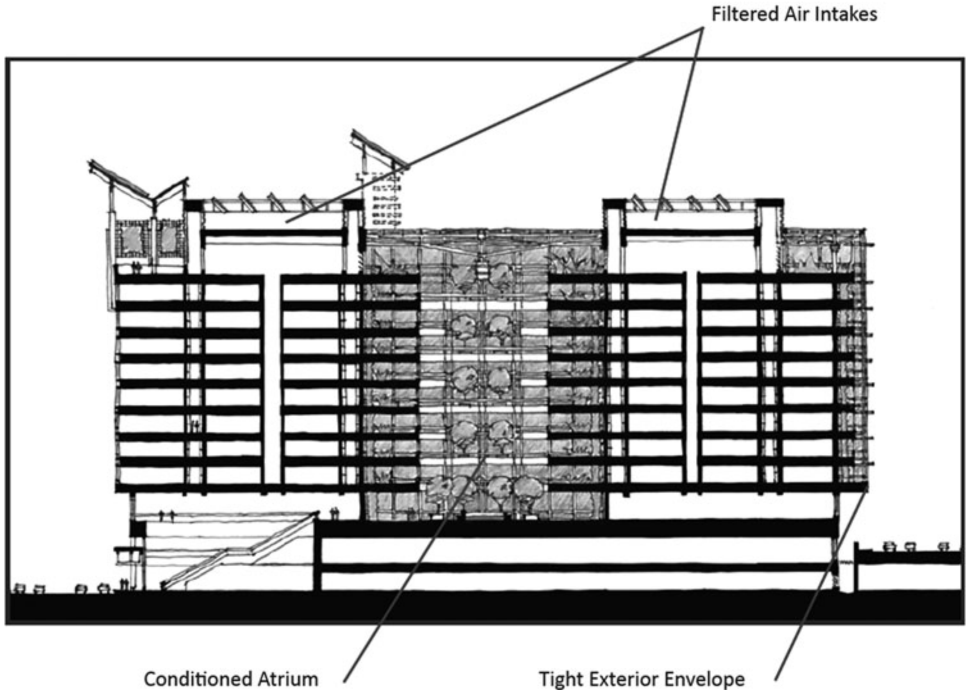


FIG. 3. The Parcel 25 site in Chinatown. The site is located directly above I-93 at a tunnel exit. *Credit:* D. Brugge, J. Durant, A. Patton, J. Newman, and W. Zamore. *Improving Health in Communities Near Highways: Design Ideas from a Charrette*. Community Assessment of Freeway Exposure and Health. Nov, 2014. *Available at:* <https://sites.tufts.edu/cafeh/files/2011/10/CAFEH-Report-Final-2-26-15-hi-res.pdf>.

FIG. 4. A proposed building design for the Chinatown site with two enclosed heating, ventilating, and air conditioning (HVAC) zones, joined in the middle by a plant-filled atrium *Credit:* D. Brugge, J. Durant, A. Patton, J. Newman, and W. Zamore. *Improving Health in Communities Near Highways: Design Ideas from a Charrette*. Community Assessment of Freeway Exposure and Health. Nov, 2014. *Available at:* <https://sites.tufts.edu/cafeh/files/2011/10/CAFEH-Report-Final-2-26-15-hi-res.pdf>.



The charrette produced a host of mitigation ideas. One of the central concepts was to incorporate high-quality air filtration into the heating, ventilating, and air conditioning (HVAC) system of the school, paying attention to the siting of air intake units as far from the highways as possible. Other ideas included physical or vegetative barriers between the highway and the building and a large atrium with filtered air and plantings within the building interior (Figure 4). A broader recommendation was to call upon the state Department of Transportation to deck over the highways and provide large-scale air filtering of tunnel exhaust. Chinatown community members expressed that mitigation was both an environmental justice issue and a form of reparations to a community that was destroyed to make way for the highways over fifty years ago.

Post-charrette, the architectural team for the school project altered its building design to relocate air intake units on the rooftop as far from traffic pollution sources as possible, combined with 100% replacement air, and incorporated high-MERV air filters into its HVAC system design. Since then, plans for the school have been put on hold by Boston's new mayor, but one of the project's architects has become a vocal advocate of this type of healthy building design and will hopefully bring this knowledge into future near-highway schools.

Municipal strategies

Municipalities have a range of tools at their disposal for enhancing the health and well-being of residents living near highways. While fine particulate matter is regulated at both the federal and state levels, the lack of federal and state standards on UFP has hampered municipal efforts to mitigate the negative health effects of UFP exposure. Since TRAP concentrations are highly variable and challenging to predict, many municipal responses have included air quality testing requirements. Monitoring is also crucial to further research on the health impacts from UFP.[96]

The most effective regulatory model, either through zoning or a standalone law, is to restrict what can be built within a defined buffer zone around high pollution roadways. For example, regulation might include restrictions on the location of residences, schools, and active parkland. Non-restricted building types could be permitted within a buffer zone, subject to indoor air quality standards. California restricts siting schools within 500 feet of urban highways (more than 100,000 vehicles per day [vpd]) and rural highways (more than 50,000 vpd) unless prescribed conditions are met.[97] This restriction, while not codified by federal standards, sets the stage for municipalities to define high pollution exposure zones and land use guidelines for near highway locations. However, in many urban settings this is not sufficient as urban building densities, including schools and housing, around highways and other high-traffic roadways are already established.

Communities may be able to require protective air filtration for residential or school buildings within a

[96]Environmental Protection Agency. *Near Roadway Air Pollution and Health* (Aug. 2014), <http://www.epa.gov/otaq/nearroadway.htm>.

[97]California Legislative Information. Senate Bill No. 352, Chapter 668. ''An act to amend Section 17213 of the Education Code, and to amend Section 21151.8 of the Public Resources Code, relating to public schools.''

buffer zone of highly traveled roadways through ordinances or conditions put on new developments. In California, the community of Jurupa Valley focused on very specific pollution conditions and forced a legal settlement with companies and municipalities that mandates and pays for filtration in residences and schools within a specified buffer zone.[98] New construction of multi-family affordable housing near highways may offer an opportunity for other municipalities to take similar measures.

CONCLUSION

The growth of interest in ''green buildings'' and ''healthy homes'' has mostly focused on addressing indoor sources of air pollution. We show here that there is an equally important need to consider and prevent exposure to ambient pollutants that infiltrate into homes and schools. While there is a need for more research on the tactics described in this article, we feel that it is possible, with the evidence available now, to better protect people from TRAP emanating from high traffic roadways.

ACKNOWLEDGMENTS

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Location of air intakes to avoid contamination of indoor air: a wind tunnel investigation

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Abstract

The location of air intakes is of prime importance in buildings that are situated in close proximity to busy urban roads. If intakes are placed where the concentration of traffic pollution is high then indoor air concentrations can reach similarly high levels. This paper presents the findings from a wind tunnel investigation into the dispersion of a simulated traffic pollutant in a 1:100 scale model. The concentrations at different points on a building in the model are measured and a comparison with full-scale data is made. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Traffic pollution is of increasing concern in many of the world's cities. Occupants in buildings situated close to busy roads can expect to be exposed to a range of pollutants emitted by the motor vehicle such as oxides of nitrogen, volatile organic compounds and carbon monoxide (CO). Although the health effects of these pollutants are not yet fully understood, asthma, other respiratory diseases and some cancers have all been linked to traffic emissions [1,2]. On an urban scale, 89% of all the carbon monoxide in the atmosphere is due to the motor vehicle [3] and the concentration of CO in the atmosphere has been shown to be a good indicator of the concentration of other traffic related contaminants [4].

Wind tunnel modelling of the atmospheric boundary layer has been extensively used in the past to predict pollutant concentrations around buildings as a result of a pollution incident — such as the discharge of effluent from an adjacent stack or the exhaust from motor vehicles at a nearby road junction. Wind tunnels allow the complex airflow patterns that develop around structures to be modelled and are an important tool in the study of the dispersion and transport of traffic pollutants in the urban environment. When concentration measurements are taken in the field there is no control of parameters such as wind speed, wind direction and ambient temperature and as a consequence the interpretation of data is often difficult. A wind tunnel not only offers control over these parameters but also facilitates a more efficient and economical testing regime.

Previous studies of pollutant dispersion around scale models in wind tunnels can to a large extent be categorised into one of three forms: (i) an idealised city; (ii) a single building with simplified geometry; and (iii) a site specific problem. In most studies, an inert tracer gas such as sulphur hexafluoride (SF_6), ethane or krypton 85 is injected at specific points in the model to simulate the pollutant source (i.e. traffic exhaust) and concentration measurements are then taken at different points on the model for a range of wind directions. Dispersion studies of idealised city forms have illustrated the interaction of the geometry of the urban environment and wind conditions in determining the dilution of traffic pollution. In these studies the simplified city is typically modelled as an orthogonal grid of streets and avenues with a stationary traffic queue modelled as a line of discreet emission points [5–7].

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Nomenclature

C_1	concentration at location 1 (ppm)
C_2	concentration at location 2 (ppm)
d	displacement height (m)
K	concentration coefficient
K_L	model length scale
k	von Karman's constant (0.4)
M	emission rate (g/s)
Q	volume flow rate of air (m^3/s)
U^*	friction velocity (m/s)
$U_{(z)}$	mean velocity at height z (m/s)
z	height above datum (m)
$z_{(0)}$	roughness length (m)
Re	building Reynolds number

subscripts p and m denote model and prototype and concentrations are expressed in volumetric parts per million (ppm)

Model studies of pollutant dispersal around single buildings have highlighted the significance of flows in the wake of buildings in determining the pollution concentration [8,9]. Wake flows were found to be heavily dependent on the building shape and orientation and on the scale of the approaching boundary layer.

If the correct scaling conditions are applied to a model, then wind tunnel measurements of pollutants around even complex buildings can be representative of those found in the field. This was illustrated in a site-specific study in which the dispersion of gases in a built up area were investigated to assess the impact of an accidental release of a toxic gas at an industrial plant [10]. Wind tunnel results were compared to measurements obtained in the field and in general the data indicated excellent agreement. In a further validation of field and wind tunnel measurements, it was shown that the dispersion of exhausts from motorways could be adequately simulated in a wind tunnel since the wind turbulence causing the dispersion depended primarily on the geometry of the surroundings [11].

When considering the ventilation of a building in the urban environment, either by natural or mechanical methods, the position of openings/air inlets is of great importance if the contamination of the indoor air is to be avoided [12,13]. Studies have shown that if openings are placed where the pollutant concentration is high then indoor concentrations can reach similarly high levels [14,15]. Wind tunnel studies can therefore be very useful in providing information on where best to locate air inlets. Previously, few studies have used wind tunnel measurements in this way to assess the impact of different vent locations. A notable exception to this was a study used to evaluate odour problems associated with diesel trucks at loading docks. In this study the effects of different air intake locations and building configurations were investigated [16].

The current study is concerned with the concentration of traffic pollutants at the facade of a naturally ventilated building situated in close proximity to a busy urban ring road. Tracer gas concentrations were measured on a 1:100 scale model and compared to carbon monoxide levels obtained in a previous field study [17]. The results are then used to evaluate different air intake positions.

2. Wind tunnel testing

2.1. Low velocity atmospheric wind tunnel

The wind tunnel used in the tests was a small open-jet wind tunnel capable of delivering a maximum air speed of 4.5 m/s. The working section has a width of 1 m, height 0.75 m and length 2.25 m [18]. The wind tunnel is relatively simple, and its use may be criticised on the grounds that is does not allow appropriate simulation of the turbulence structure. The mean velocity can be reasonably well simulated, but there is no real control over the generation of turbulence. In particular, the small upstream fetch and the relatively large size of the model (compared to the tunnel dimensions) do not allow for artificial generation of large-scale turbulence in the outer boundary layer, nor small-scale turbulence close to the ground.

The choice of model scale factor ($K_L = 100$) is based on practical convenience rather than the scales of turbulence, although as noted in Section 2.2, there is evidence from the mean velocity profile that the small-scale turbulence is reasonably simulated; this may be misleading because the mean velocity and the turbulence are unlikely to be in equilibrium with such a small fetch. On the positive side, there is some evidence that the importance of turbulence generated in the proximity of the building has been underrated in the past [19].

There are also other arguments for at least attempting to use such a simple tunnel for the present purpose. First, it is an inexpensive facility in terms of capital and running costs. This can be an important factor when dealing with the design of buildings for which the development budgets are often likely to be small.

On a more technical level, for ventilation design purposes it is not absolute values that are of prime interest, but relative values. The objective here is to determine the best positions for air inlets. The absolute values will depend on the emission rates that are outside the control of the designer. Furthermore, it is mean values that are of interest, rather than instantaneous values or levels of fluctuation. This is simply due to the fact that indoor concentrations take a finite time to build up. If the mean concentration at an opening is simulated, but the fluctuations are not, the resulting error in indoor concentrations is likely to be small unless there is a strong correlation between the concentration and the flow rate at the opening [20]. On this basis the simulation of turbulence structure is less important than it is, say, for the design of structures where instantaneous gust loading is of prime concern. Of course turbulence levels do affect the mean values, such as mean concentrations in the dispersion of plumes. However such effects will be reduced in the present tests by the virtue of the fact that we are not dealing with a point emission source, but one which approximates to a two-dimensional line source.

2.2. Non-uniform velocity profile

At the end of the settling chamber, a grid of horizontal slats is used to generate a non-uniform velocity profile in the tunnel. A staggered arrangement of 70 mm cubes was placed 450 mm downwind of the slats to represent the low urban environment in the immediate vicinity of the modelled area. The variation of mean longitudinal velocity with height in the tunnel is represented by the logarithmic velocity profile for a thermally neutral atmosphere, i.e.:

$$U_{(z)} = \frac{U^*}{k} \ln\left[\frac{z-d}{z_0}\right] \tag{1}$$

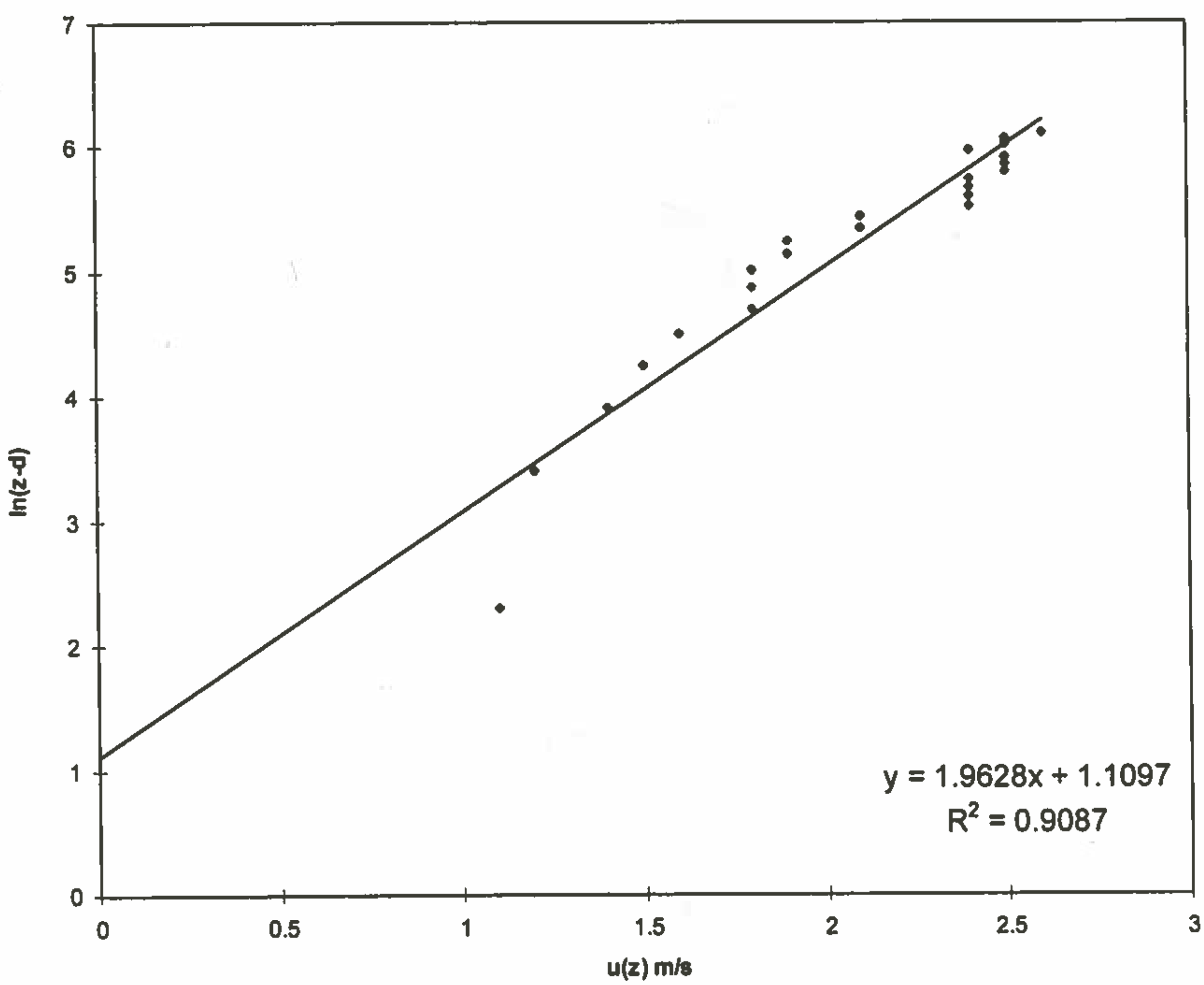

Fig. 1. Wind tunnel logarithmic velocity profile.

rearranging Eq. (1) gives:

$$\ln(z-d) = \left(\frac{k}{U^*}\right)U_{(z)} + \ln(z_0) \tag{2}$$

Fig. 1 shows a plot of $U_{(z)}$ vs $\ln(z-d)$ for a reference wind velocity in the tunnel of 2 m/s and displacement height of 70 mm (i.e. the height of the cubes). The velocity profile was measured using a Pitot tube placed at the edge of the model. From Fig. 1 the y-intercept, $\ln(z_0)$, is equal to 1.11 giving a value for z_0 of 3.0 mm. Although the measurements are relatively crude, the equivalent full-scale value of z_0 is 0.3 m, which is reasonably representative of the area under consideration. Typically a value for z_0 of between 0.3 and 0.4 m would indicate terrain similar to the outskirts of town, a few kilometres upwind of the site, whilst a value

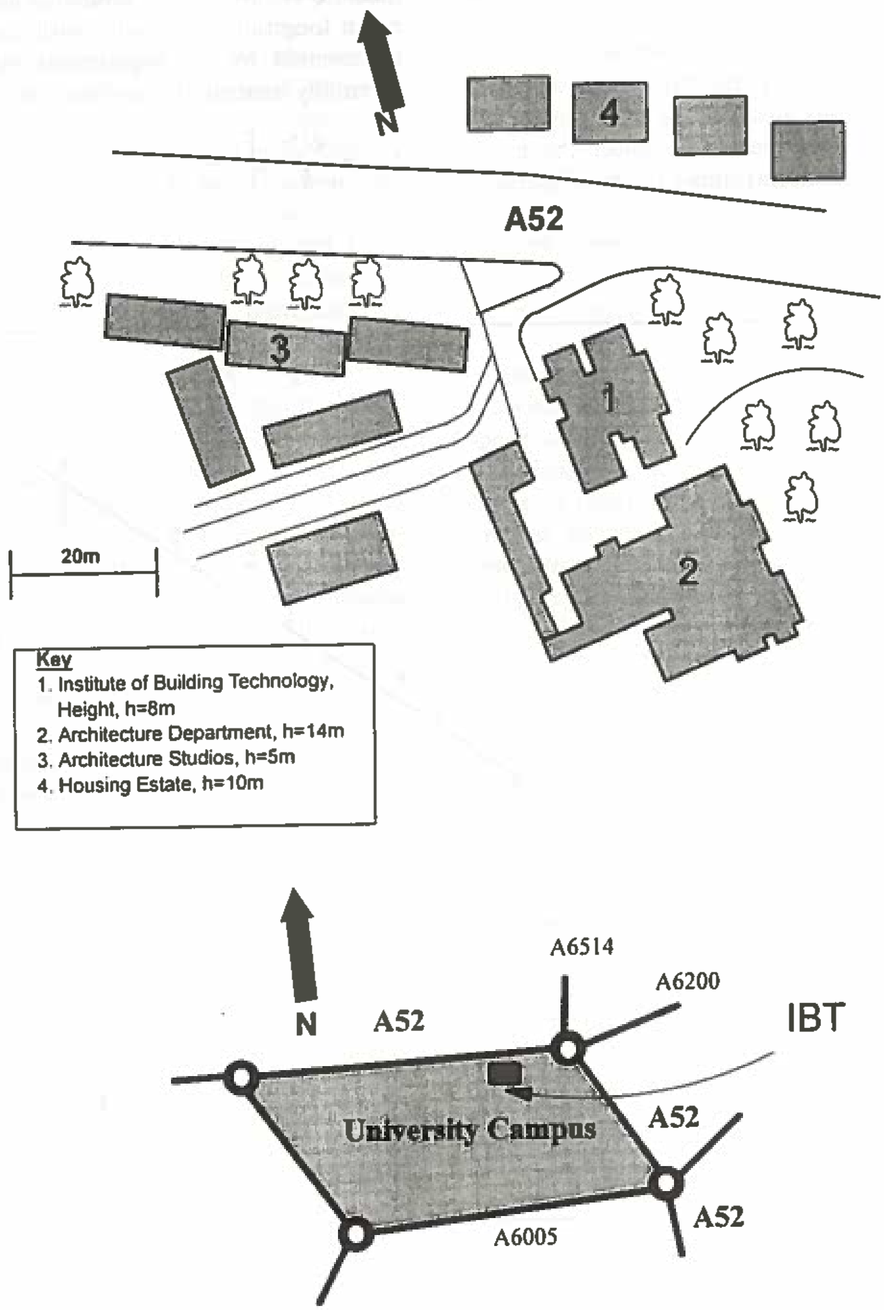

Fig. 2. Area modelled in the wind tunnel and the position of the IBT relative to the local road network.

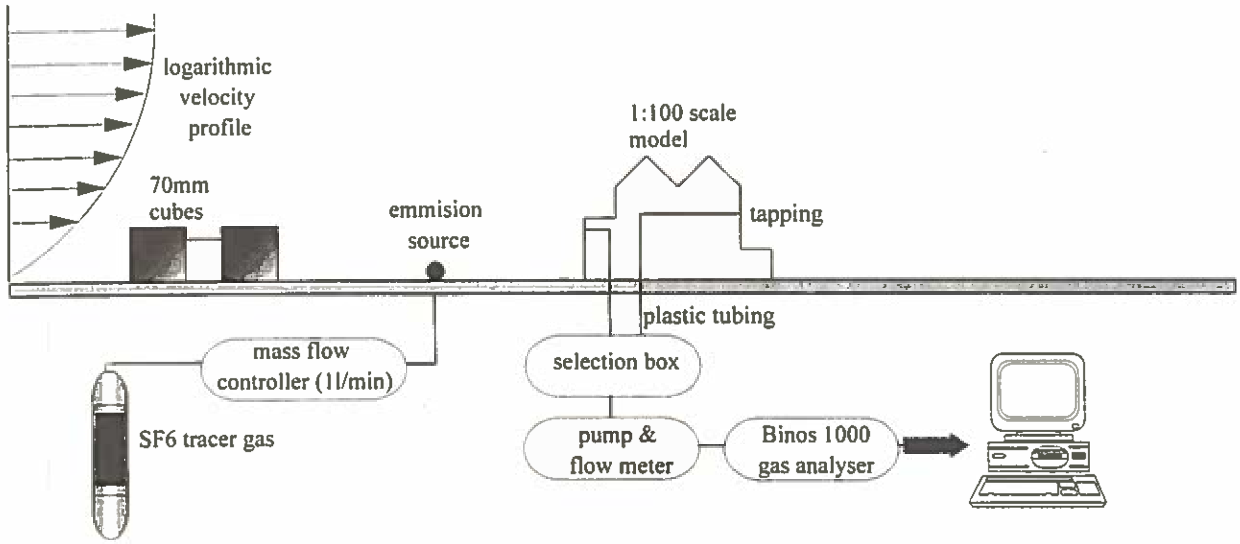

Fig. 3. Wind tunnel set up and apparatus.

between 0.4 and 1.0 m would represent the centre of a small town [21].

2.3. *Reynolds number (Re)*

For sharp-edged (bluff-body) buildings, the flow field should be independent of the approach velocity if the Reynolds number, Re, is greater than a critical value (typically quoted as 11,000). With a reference tunnel speed of 2 m/s and a characteristic model length of 8 cm (building height), the value of Re is 1.3×10^4 — i.e. greater than the critical value.

3. Scale model construction

A 1:100 scale model was constructed of the area shown in Fig. 2. The Institute of Building Technology (IBT) is housed in a naturally ventilated building situated in close proximity to a busy urban ring road (A52). Traffic flow figures supplied by Nottinghamshire County Council for this section of the A52 show that rush-hour peak flows are typically in the region of 2500 vehicles per hour in each direction. During these peak periods traffic can be stationary for short periods, whilst at other times the traffic is to a large extent free flowing. Total daily flows are in the region of 25,000 vehicles in each direction.

The model of the IBT building was constructed from 3 mm perspex and the surrounding buildings and features constructed from medium-density fibreboard. Prior to making the model, a surveying exercise was performed to determine the gradient of the road and the relative height of the IBT with respect to the road; this detail was incorporated into the model. It was necessary to simplify some of the finer architectural detail on the buildings due to the scale of the model and no attempt was made to model any surface roughness.

To simulate the exhaust emitted from a queue of stationary traffic, 40 × 1 mm diameter holes were drilled in a 800 mm length of 9 mm internal diameter copper tubing. The holes were separated by 20 mm to represent an average spacing of 2 m full scale between successive vehicle exhausts in congested traffic. The tube was then positioned on the model at the centre line of the roadway. SF_6 tracer gas was delivered to the tube at a controlled rate of 1 l/min via a Bronkhurst mass flow controller.

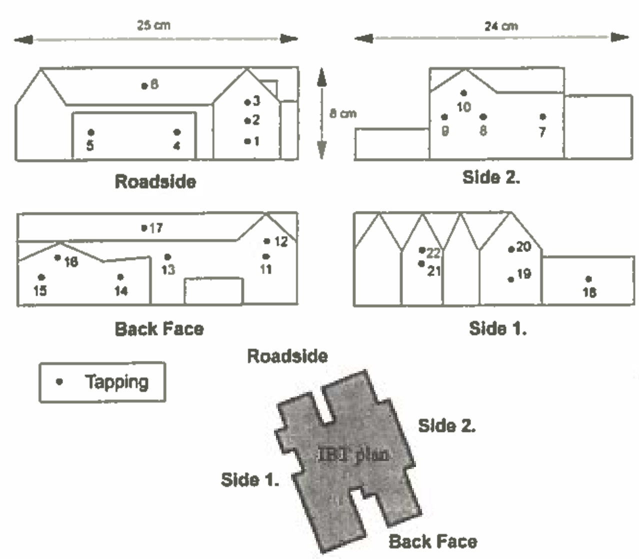

Fig. 4. Location of the tappings on the 1:100 scale model.

The IBT model was fitted with several tappings (0.8 ID mm brass tubing) flush on its surface to allow measurement of tracer gas concentration at different locations. Plastic tubing was attached to each of the tappings via a hole in the wind tunnel table and connected to the instrumentation as shown in Fig. 3.

In total, 20 different sampling locations were selected on four of the building faces and, in addition, two tappings were placed on the roof (Fig. 4). Table 1 shows the heights of each tapping on the model. Analysis of the gas samples was carried out using a Binos 1000 gas analyser connected to the tappings via a selection box and the concentrations recorded directly onto a personnel computer running a simple logging programme. On a weekly basis the span and zero point of the gas analyser were calibrated using a standard gas. Drift was found to be within ±5%.

4. Experimental procedure

The concentration of SF_6 was measured at each tapping for nine different wind angles and a constant reference velocity of 2 m/s measured at 0.6 m above the wind tunnel table. Due to limitations in the logging program it was only possible to log concentrations every second, so for each location readings were taken over a period of 1 min (i.e. 60 readings) and an average calculated. The selection box was manually adjusted between successive locations and since this involved entering the tunnel a 2-min period was

Table 1
Tapping heights on 1:100 scale model

Tapping	Height (cm)
1	1.5
2	3.5
3	5.5
4	3.5
5	3.5
6	7.0
7	3.5
8	3.5
9	3.5
10	5.5
11	3.5
12	5.5
13	3.5
14	2.0
15	2.0
16	3.5
17	7.0
18	2.0
19	2.0
20	5.5
21	3.5
22	5.5

Table 2
Maximum concentrations of tracer gas measured in the wind tunnel at the roadside and back face for different wind directions

Wind direction	Maximum tracer gas concentration roadside face		Maximum tracer gas concentration back face		Percentage reduction between roadside and back face
	ppm	tapping	ppm	tapping	
West	< 5	All	< 5	All	Nil
N West	< 5	All	< 5	All	Nil
NN West	180	5	45	5,12	75
North	340	1	170	16	50
NN East	220	4	65	15	70
N East	160	4	120	12	25
EN East	185	5	170	14	10
East	215	4	65	12	70
S East	< 5	All	< 5	All	Nil

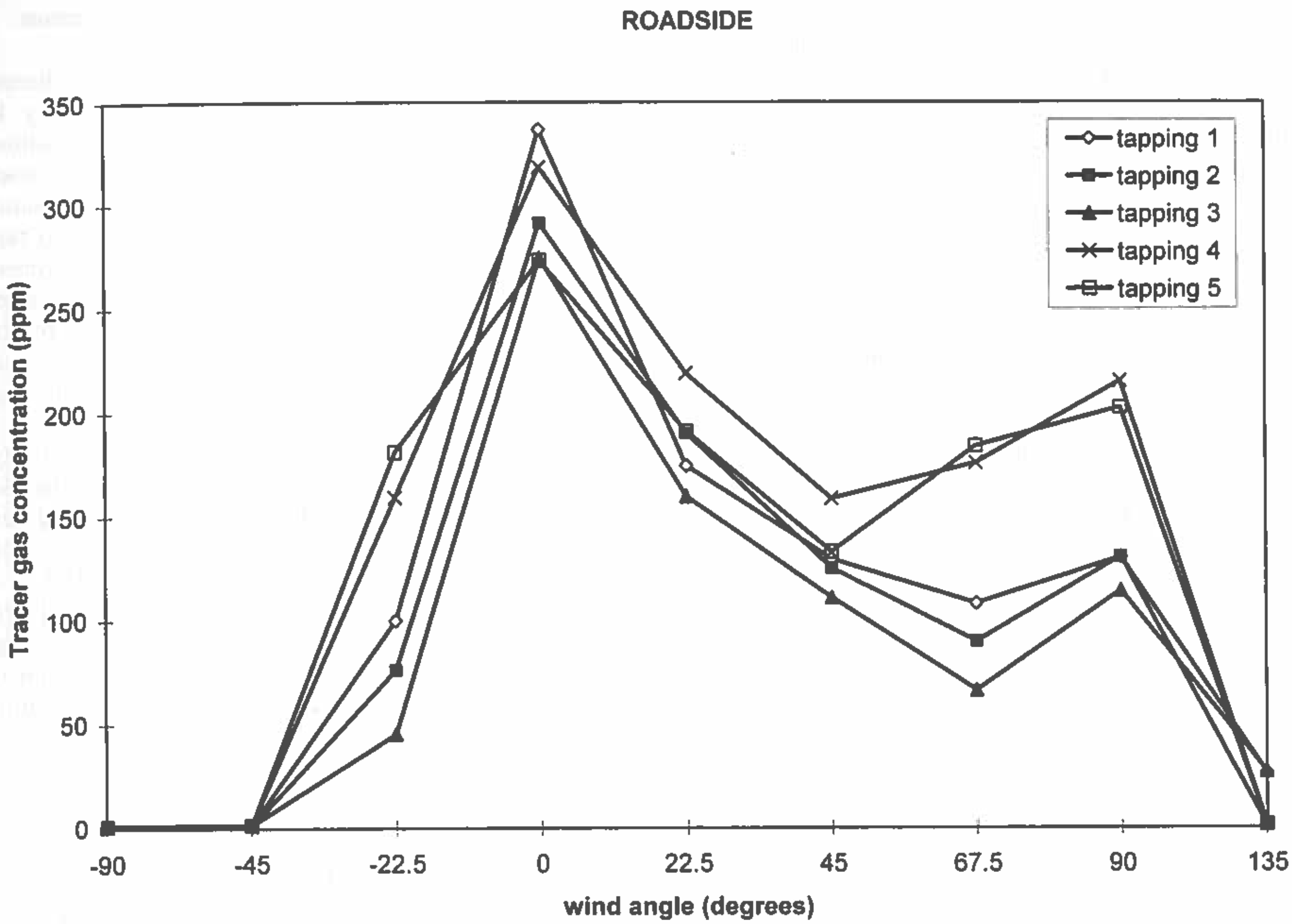

Fig. 5. Tracer gas concentrations (ppm SF_6) recorded at the roadside tappings in the windtunnel. 0 deg = North wind.

allowed between runs to enable the flow field to stabilise.

5. Wind tunnel test results

The average concentration recorded at each location for the different wind directions is shown in Figs. 5–8. It is evident that for most of the tappings the highest concentration occurs when the wind is from a northerly direction (i.e. the building is downwind of the pollutant source) and that the concentrations are greatest on the roadside face. The maximum concentrations on Side 1 are comparable to those on the roadside face and those on Side 2 similar to the back face.

5.1. Concentrations at the roadside and back face

Table 2 shows the maximum concentrations recorded at the roadside and back face for different wind directions. The maximum concentrations on the roadside and back face occur when the wind is from the north, i.e. 340 ppm at tapping 1 and 170 ppm at tapping 16. This represents a reduction of 50% between the maximum at the roadside and back face. With different wind directions, reductions of up to 75% were observed between the roadside and back face maxima.

5.2. Variation in concentration with height

The variation in tracer gas concentration with height was also considered. Taking the north wind case, Table 3 shows the difference in concentration with

Table 3
Variation in measured tracer gas concentration with height on the roadside face

Tapping	Height (cm)	Average tracer gas concentration (ppm)
1	1.5	340
2	3.5	290
3	5.5	270
4	3.0	320
5	3.0	270
6 (roof)	7.0	110

height on the roadside face. Tappings 2 and 3 on the model represent the position of the ground and first-floor windows on the full-scale building. Under steady state conditions there is a reduction of 7% between the concentration recorded at the ground floor window and that recorded at the first floor.

5.3. Concentrations at roof level

A tapping was placed on the roof of the model at a height of 7 cm, on both the roadside and back face. From Fig. 9 it can be seen that the tracer gas concentration at both roof top tappings was highest when the wind was from the north. In this case, a maximum concentration of 110 ppm was recorded at the roadside roof tapping, which represents a reduction of almost 70% in the maximum concentration recorded on the roadside wall (340 ppm at tapping 1), and a reduction of 60% from the concentration recorded at tapping 2 (ground floor window). Slightly greater reductions were found at the back face roof tapping, 75% and 70% respectively.

6. Comparison of wind tunnel and field measurements

In two separate experiments field-data was collected around the area modelled in the wind tunnel study. In the first experiment (Experiment 1), CO concentrations were recorded at 15 min intervals over a two-week period at the kerbside of the A52, and at a ground-floor window on the IBT building (equivalent to tapping 2 on the model). In the second experiment (Experiment 2), an additional sample point was added at a first floor window (equivalent to tapping 3 on the model). Local wind direction and velocity were recorded in Experiment 1 by means of a wind vane mounted on the roof of the IBT building.

Table 4 summarises the results from the field study. The lower average concentrations recorded in the second week of Experiment 1 were a result of the different wind conditions experienced. In the first week the average wind direction was such that the IBT was downwind of the traffic source (i.e. between northerly and southerly), whilst in the second week the average wind direction was such that the IBT was upwind of the traffic source. The dilution in CO concentration

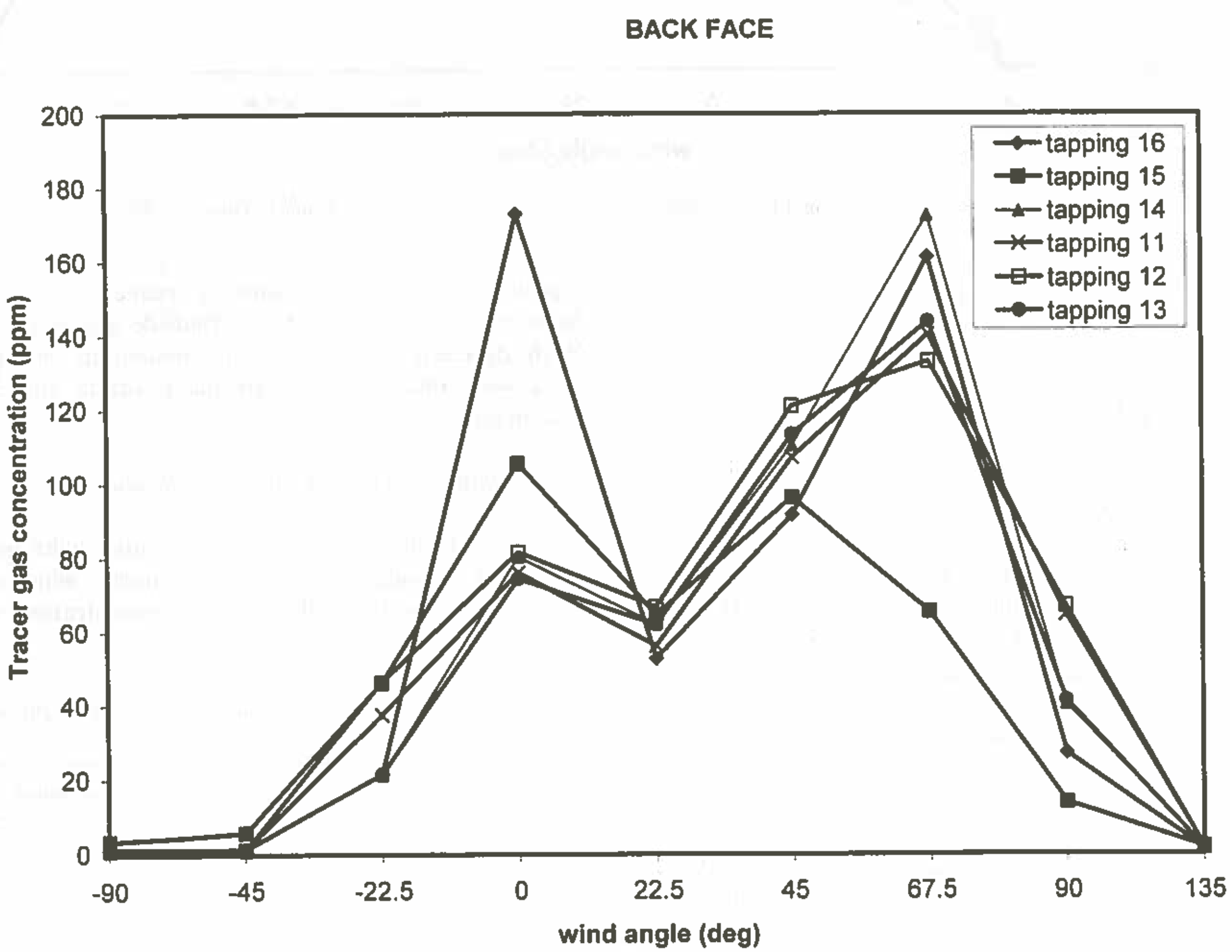

Fig. 6. Tracer gas concentrations (ppm SF_6) recorded at the backface tappings in the windtunnel. 0 deg = North wind.

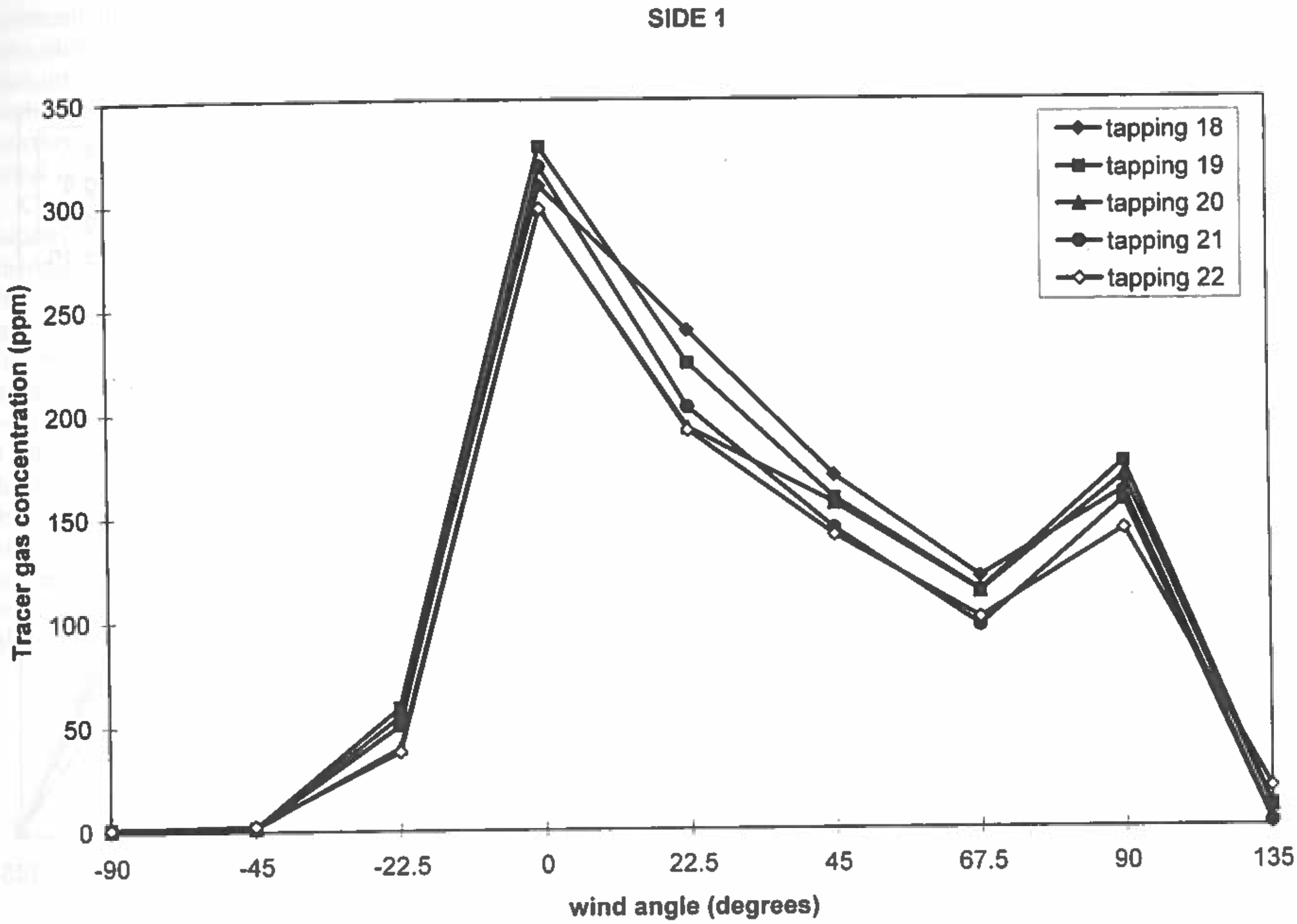

Fig. 7. Tracer gas concentrations (ppm SF_6) recorded at the side 1 tappings in the windtunnel. 0 deg = North wind.

between the kerbside sampling point and the ground floor window showed little variation in the experiments, suggesting that when averaged, the wind direction had little influence on the dilution between the points.

There are several ways of comparing the concentration readings obtained in the wind tunnel (model) and data recorded in the field (prototype) — the underlying problems are that the actual emission from the prototype vehicles in the field is unknown, and the wind direction and speed are constantly changing.

6.1. Comparison of dilutions between kerb and building

This is potentially the best comparison, because measurements at corresponding points have been made on both the prototype and the model. If we assume similarity of the velocity fields and emission characteristics, then the concentration fields should be similar, i.e.:

$$\left[\frac{C_1}{C_2}\right]_m = \left[\frac{C_1}{C_2}\right]_p \tag{3}$$

Table 4
Summary of the carbon monoxide concentrations recorded in the field study. (1) = ground floor window, (2) = first floor window

Expt	Average CO concentration (ppm)			98-percentile CO concentration (ppm)			Dilutions	
	Kerbside	Window (1)	Window (2)	Kerbside	Window (1)	Window (2)	Kerbside/Window (1)	Kerbside/Window (2)
Expt 1								
Week 1	3.91	2.32	–	14	8	–	1.75	–
Week 2	1.61	0.64	–	8	4.5	–	1.77	–
Expt 2	1.2	0.60	0.5	6.6	4.3	3.5	1.53	1.88

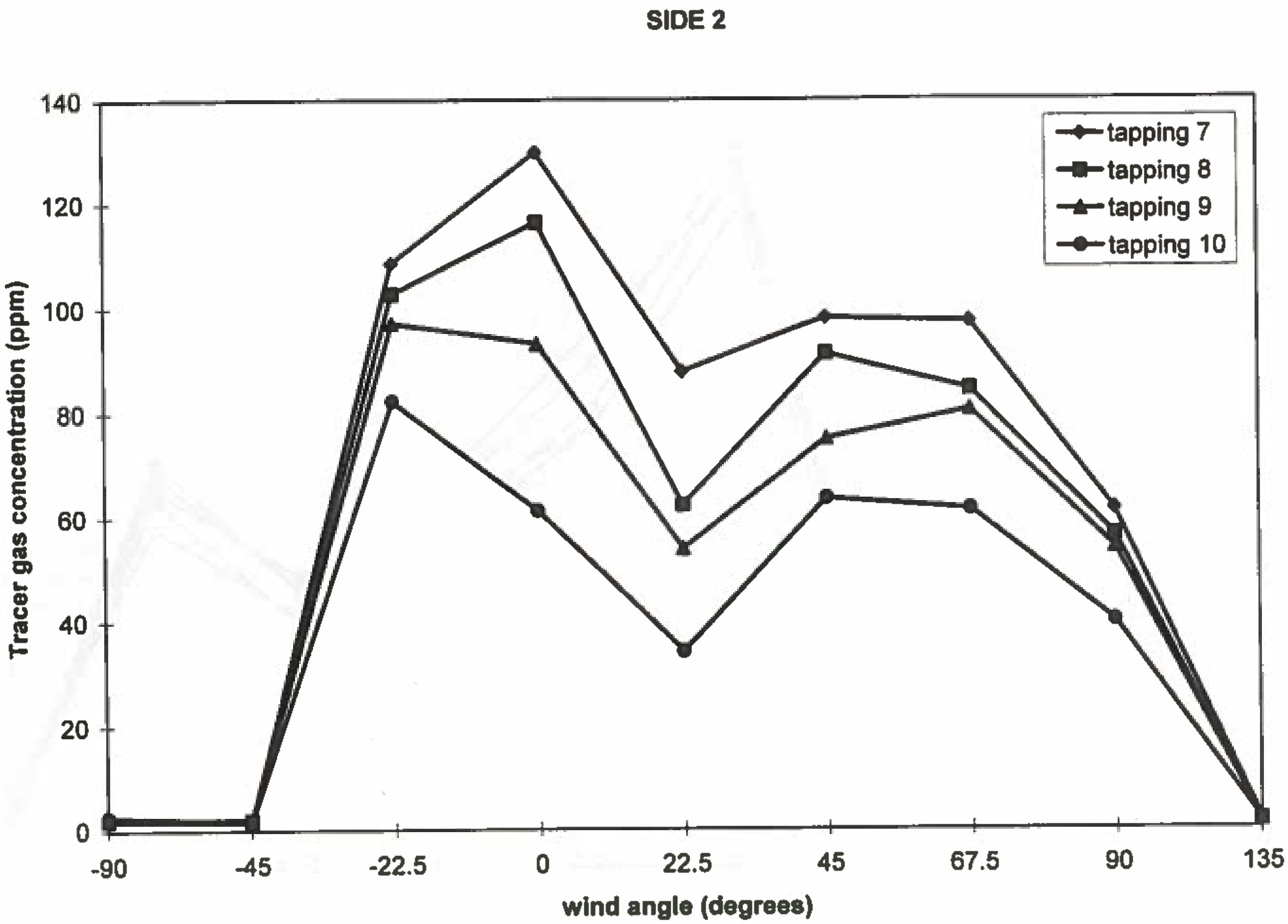

Fig. 8. Tracer gas concentrations (ppm SF_6) recorded at the side 2 tappings in the windtunnel. 0 deg = North wind.

where the subscript m and p denote model and prototype, and C_1 and C_2 are concentrations at two specified points.

Taking $C_1 \equiv$ kerb concentration and $C_2 \equiv$ building concentration, Table 5 shows the dilutions obtained in the model for the range of wind directions measured during week 1 of Experiment 1 in the field study. During this period, the dilution between the kerbside and the ground floor window was found to be between 1.53 and 1.78, based on the 98-percentile concentrations (Table 4). The 98-percentile was used as the basis for comparing the field and wind tunnel data in an attempt to overcome inherent difficulties in comparing the data from the two sources. By making the following assumptions, the concentrations measured in the wind tunnel can be demonstrated to be reasonably representative of those in the field.

An initial assumption, presumes that in the field study the maximum concentrations were recorded at times when the actual traffic conditions during the peak traffic periods most closely resembled the modelled queue of stationary emission points. It was also

Table 5
Dilutions measured in the wind tunnel between (i) the kerbside and tapping 2; and (ii) the kerbside and tapping 3

Wind direction	Tracer gas concentration at kerbside (ppm) [A]	Tracer gas concentration at tapping 2 (ppm) [B]	Tracer gas concentration at tapping 3 (ppm) [C]	Dilution [A]/[B]	Dilution [A]/[C]
North	1069	292	275	3.66	3.88
NN East	1643	190	160	8.67	10.26
N East	1014	125	111	8.11	9.14
EN East	967	90	66	10.74	14.65
East	783	131	114	5.93	6.89
S East	–	–	–	–	–

assumed that the maximum readings in the field were recorded when the traffic was downwind of the predominant wind direction. Hence the 98-percentile concentrations from week 1, when the wind was from a northerly to easterly direction, were compared to the wind tunnel data for the same range of wind angles.

Comparison of Tables 4 and 5 shows that the dilutions found in the wind tunnel are higher than recorded in the field, although when the wind was from the north the dilution in the wind tunnel is only greater by a factor of two. In the wind tunnel, the dilution from the kerbside to tapping 3 is marginally greater than that between the kerbside and tapping 2 — this is in accordance with observations at full scale. Considering the difference in concentration with height, Table 3 shows a 7% decrease in concentration between tappings 2 and 3. This is notably smaller than the difference in the 98-percentile concentrations observed in the field of 18%, however it is comparable to a relationship observed during rush-hour traffic. In this case it was observed that the average first floor concentration was at times only 5% lower than that at the ground floor [17].

It is clear that the dilutions between the kerb and building are significantly larger in the wind tunnel than those observed in the field. This is unexpected to the extent that the wind tunnel does not reproduce the larger scales of turbulence which one might expect to lead to lower dilutions in the model. However, there are several factors that could account for the larger dilutions. For example, the boundary conditions at the side of the flow are not well simulated in the model; this will lead to higher dilutions in the model. However, the most likely reason lies in the simulation of the emission, which is clearly only approximate. The closer one approaches the emission line, the poorer the simulation is likely to be. Thus there could be significant errors in the kerbside values and these could have a large effect on the dilution value. One way round this problem is to compare the field and model concentrations directly, although it is necessary to make an assumption about the field emissions. This is done in

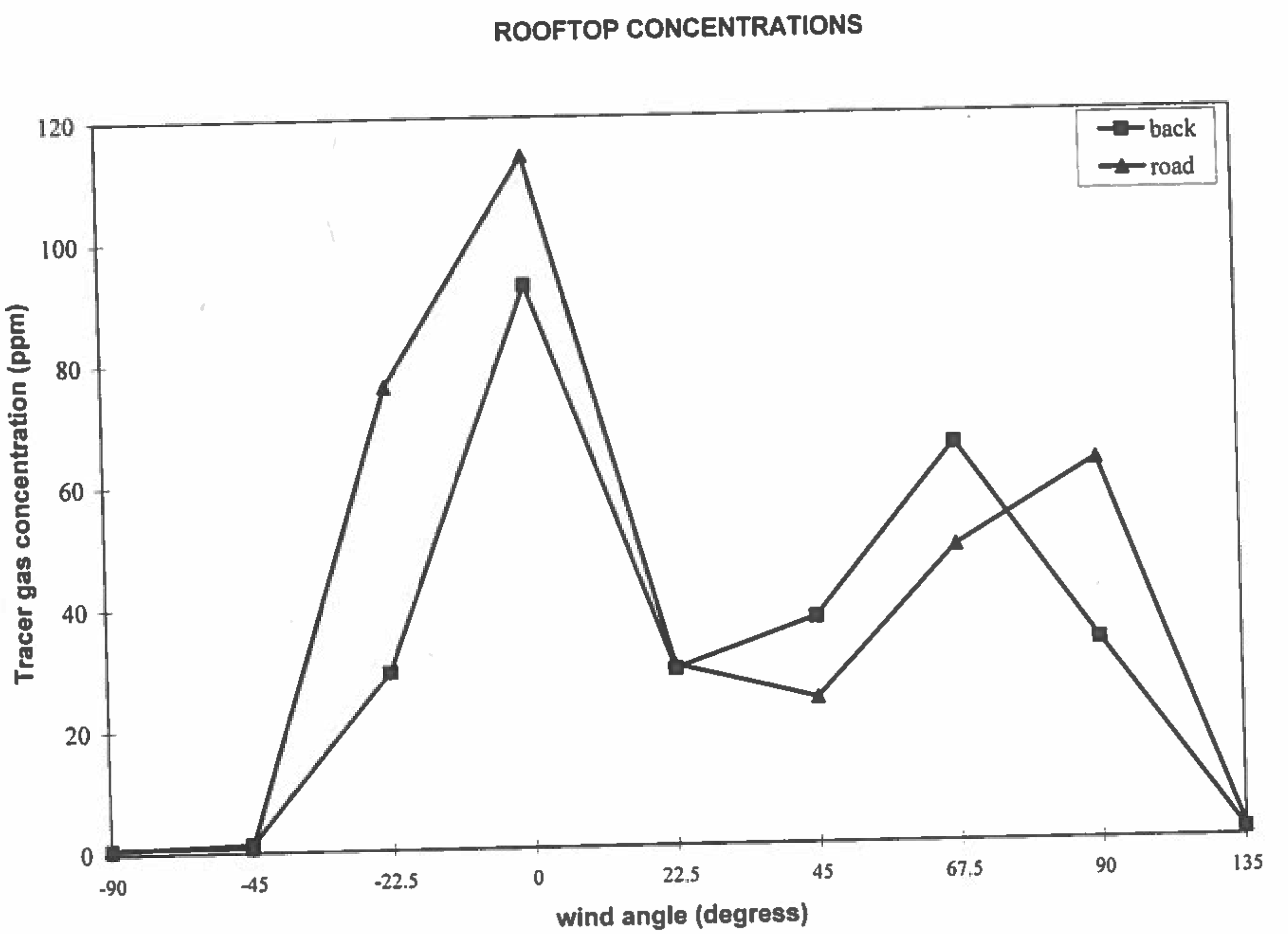

Fig. 9. Tracer gas concentrations (ppm SF6) measured at the rooftop tappings in the windtunnel. 0 deg = North wind; back = tapping 6; road = tapping 17.

Table 6
Calculated prototype concentrations (C_p) obtained from wind tunnel data (C_m) at tappings 2 and 3

Tapping	Tracer concentration C_m (ppm SF_6)	Concentration coefficient K_m (dimensionless)	Prototype concentration C_p (ppm CO)
2	292	2.325	7.22
3	274	2.182	6.77

the following and it will be seen that much better agreement can be obtained.

6.2. Assuming an emission value for the prototype

If similarity conditions have been adequately met then it is possible to equate the dimensionless concentration coefficients K_m and K_p., i.e.:

$$K_m = K_p \tag{4}$$

hence

$$\left[Q\frac{C}{M}\right]_m = \left[Q\frac{C}{M}\right]_p \tag{5}$$

where Q denotes a measure of the volume flow rate of air (m^3/s), C is the sampled concentration (kg/m^3) and M is the mass flow rate of the emitted gas (kg/s). K_m can be directly calculated from the wind tunnel data and if we assume a prototype emission rate and equality of K_m with K_p, then C_p can be determined. The value of C_p can then be compared to actual field results to provide a means of validating the wind tunnel data.

In the model, a line of queuing vehicles was simulated with a constant wind direction and model concentrations were compared to the 98-percentile (maximum) readings obtained in the field. It is assumed that these maximum values were recorded at periods when the traffic was at its busiest — characterised by congestion, long and short stoppages and low speeds. It is therefore difficult to assign a single emission rate (M_p) to the traffic in the prototype as the emission rate is a function of driving cycle, which is not constant over the queue length. A reasonable assumption was made that at any one time an equal proportion of the traffic would be accelerating, decelerating and idling. Thereby, using data from a similar study [22], an emission rate for CO (g/min per vehicle) was assigned to each of these driving cycles thus: accelerating 10, decelerating 8.34 and idling 3; this led to an average emission rate of 7.11 g/min per vehicle. The Appendix shows the procedure for calculating the prototype concentrations of CO in ppm from the concentration of SF_6 recorded at tappings 2 and 3 on the model for the north wind case.

The calculated prototype concentrations at tappings 2 and 3 for a northerly wind are shown in Table 6. There is good agreement between the 98-percentile concentration at the ground floor window of 8 ppm measured in the field study (Table 4) and the prototype concentration of 7.2 ppm determined from the window tunnel data at tapping 2. The calculated prototype concentration at the first floor window of 6.8 ppm is somewhat higher than the field measurement of 3.5 ppm, however since no wind data was available for Experiment 2 one cannot make the assumption that similar situations are being compared.

Having validated the wind tunnel data for the northerly wind, it is possible to have a degree of confidence that the relative concentrations observed in the wind tunnel are likely to be representative of those in the field under the same conditions.

7. Conclusions

The wind tunnel results have been shown to be similar to the results obtained in the field study. The comparison based on an assumed emission gives the better agreement between the field data and wind tunnel measurements, and this is most likely due to the inherent difficulties in accurately simulating the emission source. The unsteady conditions experienced in the field make direct comparison difficult, but the general relationship between the points measured in the field is consistent with wind tunnel data if some assumptions are made. Firstly, if we compare the 98-percentiles in the field data with the readings in the tunnel we are assuming that the maximum values in the field were recorded at times when the traffic was slow moving and congested, and similar to the line of static emission points in the model. Secondly, the assumption is also made that these maximum values occurred when the traffic was downwind of the predominant wind direction for the period. Neither of these assumptions is unreasonable.

The wind tunnel data indicates that the maximum concentrations on the back face may be up to 50% lower than the maximum on the roadside face. This suggests that location of air intakes on this face would offer immediate benefits to the indoor air quality. Only small reductions in concentration are found between the ground and first floor windows under traffic conditions similar to the congested flow during rush hours. However, if air intakes were situated on the rooftop, then, irrespective of the wind direction, significantly lower concentrations of contaminants would be found here.

In addition to air intake location, a further reduction in the concentration of contaminants entering the building space could be achieved by means of ventilation control. In a previous theoretical study [23], it was illustrated how control of ventilation rates could reduce the mean indoor contaminant concentration by up to 34%. This was achieved by adjusting the ventilation rate through an opening in response to external and internal contaminant levels. Therefore, it is suggested that a combined strategy of vent location and ventilation control is most likely to yield the largest gains in terms of indoor air quality and this is the topic of current work.

Acknowledgements

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Appendix. Calculation of prototype concentration in parts per million (ppm) of CO from model measurement of SF_6 tracer gas (ppm)

If similarity conditions are satisfied then:

$K_m = K_p$ (where subscripts m and p denote model and prototype).

K is the dimensionless concentration coefficients defined by:

$$K = \frac{QC}{M}$$

where: Q is the reference volume flow rate of air; C is the sampled concentration and M is the emission rate of gas.

Q is defined by Q = wind velocity × cross-sectional flow area where cross-sectional flow area = length of emission source × model height hence, $Q_m = 200 \times (80 \times 10) = 1.6 \times E^5$ cm^3/s.

At tapping 2 on the model, average concentration with north wind = 292 ppm.

Hence, $C_m = 1.453$ μg/cm^3

$$\text{from: C g/cm}^3 \left[\frac{\frac{10^6}{146}}{3.44E^{-5}} \right] = \text{C ppm}$$

where: 146 = molecular weight SF_6; 3.41 E^{-5} = moles of air in 1 cm^3; 1 mole air = 29 l).

In the model the tracer gas SF_6 was emitted at 1 l/min. Density of SF_6 = 6 kg/m^3 hence, $M_m = 1 \times 10^5$ μg/s.

The above values for Q_m, C_m and M_m give $K_m = 2.325$.

An average emission factor for CO from the prototype traffic source is 7.11 g/car per min (see Section 6.2). Therefore for 40 vehicles, $M_p = 4.74$ g/s.

Q_p = wind velocity × length of emission source × building height (where dimensions are full scale) hence, $Q_p = 1.6 \times 10E^9$ cm^3/s.

The above values for M_p and Q_p give a value for C_p of $6.88 \times E^{-9}$ g/cm^3.

This is equivalent to 7.22 ppm CO (with the molecular weight of CO = 28).

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STATUS OF RESEARCH ON POTENTIAL MITIGATION CONCEPTS TO REDUCE EXPOSURE TO NEARBY TRAFFIC POLLUTION

August 23, 2012

California Environmental Protection

Air Resources Board

Introduction

Air Resources Board (ARB) staff has prepared this document to provide information on scientific research that has been conducted on various building-related and site mitigation concepts suggested as potentially effective approaches for reducing the traffic-related exposures of those living near high traffic roadways. While it provides useful information for consideration of potential mitigation approaches, this paper is not intended as guidance for any specific project, and does not provide a methodology for determining appropriate mitigation measures for purposes of compliance with the California Environmental Quality Act. This review looked only at the current status of air pollution research, and does not address other potential community benefits of the concepts, such as the aesthetic and noise reduction benefits of adding vegetation or sound walls.

The State's current set-back requirement for schools (500 feet [ft]; PRC 21151.8) and the ARB's recommendations on siting for housing and other sensitive uses (e.g., 500 ft from major roadways and 1000 ft from busy distribution centers and rail yards; ARB 2005a) are intended to help protect the public from exposure to traffic emissions. Such emissions have been associated with a variety of serious health impacts in epidemiological studies, including exacerbation of respiratory and cardiovascular diseases and conditions, increased asthma and bronchitis in children, and increased risk of premature death. Traffic pollutant concentrations near high traffic roadways have been found to be 2 to 10 times higher than levels at a distance from the roadways. Also, recent studies have shown elevated traffic pollutant levels at greater distances from the roadway than previously measured.

ARB and the U.S. EPA continue to adopt increasingly stringent regulations limiting emissions from vehicles of all types, which have substantially reduced, and will continue to reduce, vehicle emissions. However, recently adopted regulations have compliance dates extending as far as 2025 for full implementation, and fleet turnover to zero or near-zero technologies will take 20 to 30 years. New reductions in vehicle emissions are improving regional air quality throughout California, including near roadways. As the ARB and the air districts work to reduce emissions from diesel PM and other pollutants, the impact of proximity will also be reduced. However, the differential exposure to high air pollution near high traffic roadways compared to other locations makes the siting of housing in those locations a continuing health concern. Recognizing that unhealthful levels of air pollution is a long term problem, ARB is funding research to identify advanced technologies to further reduce vehicle emissions, to better understand traffic related air pollution exposures, and to explore the benefits of high efficiency filtration in California homes.

As communities plan for more compact development, the potential health impacts of infill projects will need to be considered. Infill development can reduce urban sprawl and has other potential health and environmental benefits. It also has the potential to increase exposure to traffic pollution due to the proximity of the infill areas to established traffic routes.

Status of Research on Traffic Exposures and Health Impacts

Measurements of air pollutants near roadways show a consistent finding of elevated levels based on proximity. Black carbon, often used as an indicator of diesel exhaust, and ultrafine particles (particles less than 0.1 microns in size), which are emitted in very high numbers from vehicles, are often 2 to 10 times (or more) higher near roadways and freeways (Zhu et al., 2002a, 2002b, 2006; Kuhn et al., 2005; Westerdahl et al., 2005; Ntziachristos et al., 2007; Kozawa et al., 2009a). Concentrations of PM2.5 (particles 2.5 microns or less in diameter) near busy roadways can be about 20% higher than levels at a distance (Zhu et al., 2002a; Kim et al., 2004; Janssen et al., 2001). Nitrogen oxides also are elevated near roadways, usually about 2 to 3 times the levels measured at a distance from the roadway (Kim et al., 2004; Singer et al., 2004; Kozawa et al., 2009a; Durant et al., 2010).

Previous studies of near roadway pollutant levels showed that concentrations of pollutants emitted from vehicles were highest right at the roadway and decreased substantially in the first 300-500 feet from the roadway (Zhu et al., 2002b; Knape 1999). These results were consistent with health studies that showed a stronger association of health impacts for those living within 300-500 ft of the roadway compared to those living farther than 500 ft from the roadway (Brunekreef et al., 1997; Venn et al., 2001; English et al., 1999). More recent studies have shown a somewhat longer plume of increased pollutant concentrations farther from the roadway. Using data collected mostly during the day and near roadways, a meta-analysis of many studies found that for almost all pollutants, elevated levels of pollutants caused by the increased contributions from roadways returns to background levels at 160 - 570 meters (m; 525 – 1870 ft; Karner et al., 2010). The range of distances needed to reach background is usually a result of local meteorological conditions, which can vary significantly; however, a more constant observation is a steep concentration gradient observed closest to the roadway, within 500 ft, with a more gradual and extended decline at further distances. Another meta-analysis found that the "spatial extent of impact" of motor vehicles can extend up to 400 m (1312 ft) for black carbon and particles and 500 m (1640 ft) for nitrogen dioxide (NO_2; Zhou and Levy 2007). Levels of traffic pollutants near roadways vary due to many factors, including traffic type and density, wind direction and speed, local and roadway topography, and time of day and season (Zhu et al., 2004; Kuhn et al., 2005; Moore et al., 2007; Ning et al., 2007; Hu et al., 2009; Kozawa et al., 2009a, 2009b).

In a major 2008 review of the scientific literature by the Health Effects Institute (HEI), proximity to busy roadways was found to be associated with a variety of adverse health impacts, the strongest association being exacerbation of asthma, with others including asthma onset in children, impaired lung function, and increased heart disease (HEI, 2010). More recent studies have added to the list of effects and heightened concern regarding exposure to traffic emissions. Respiratory and cardiovascular effects seen in these studies include an increased risk of new-onset chronic obstructive pulmonary disease (Andersen et al., 2010), a faster progression of atherosclerosis in those living within 100 m of highways in Los Angeles (Künzli et al., 2010), increased risk of premature death from circulatory disease (Jerrett et al., 2009), and increased incidence of new heart disease (Kan et al., 2008). Other effects include increased risk of low birth weight (Brauer et al., 2008; Llop et al., 2010) and increased risk of pre-term delivery (Wilhelm and Ritz, 2003; Wilhelm et al., 2011) for mothers living very near heavy traffic, lower immune function in post-menopausal women living within 150 m of arterial roads (Williams et al., 2009), and increased risk of Type 2 diabetes in post-menopausal women (Krämer et al., 2010).

Children appear to be particularly vulnerable to the adverse effects of traffic emissions. Epidemiological studies have found significant associations of children living near high traffic areas with decreased lung function (Brunekreef et al., 1997; Gauderman et al., 2007), increased medical visits and hospital admissions for childhood asthma (English et al., 1999; Lin et al., 2002), increased wheezing (Venn et al., 2001), and increased childhood asthma and bronchitis (Kim et al., 2004; Gauderman et al., 2005; McConnell et al., 2006), including development of new asthma cases (McConnell et al., 2010; Gehring et al., 2010). Children living near busy roadways are especially likely to experience elevated exposures because they would also play outdoors in the neighborhood and typically would attend nearby schools. Their higher breathing rates per unit of body mass relative to adults (Adams, 1993) and their developing immune, neurological, and respiratory systems make them especially susceptible to impacts from air pollution.

ARB's recommendation to avoid siting sensitive land uses such as new housing within 500 ft of busy roadways was based on the traffic exposure and health studies completed as of 2005. More recent studies confirm the relationship, and indicate that in some situations an elevated risk extends well past 500 ft. A few studies have measured elevated pollutant levels at distances well beyond 1000 ft (305 m; Karner et al., 2010; Zhou and Levy, 2007). For example, Hu and colleagues (2009) found that in the pre-dawn hours in Los Angeles, elevated ultrafine particle number concentration, nitric oxide, and particle-bound polycyclic aromatic hydrocarbons extended at least 1200 m (3937 ft) downwind of the freeway and did not reach background levels until a distance of 2600 m (8530 ft). More importantly, results from the Southern California Children's Health Study on the association of residential distance to traffic and lung function development, performed in the same general location as the Hu et al. study, found adverse health effects in children living as far as 1500 m (4921 ft) from roads (Gauderman et al., 2007). These are not unique findings; in the HEI (2010) report mentioned above, the authors noted that studies showed that people living up to 500 m (1640 ft) from heavy traffic are most at risk from the health effects of traffic pollution.

Status of Research on Mitigation Concepts

Various building and site mitigation approaches have been suggested as potential means to reduce exposure to traffic pollution near roadways. A review by ARB staff found that there has been limited study of most of these approaches. Building measures examined include high efficiency filtration for residences through either central, in-duct type filtration or portable air cleaners; and external building design measures, such as locating the air intakes for ventilation systems on the opposite side of the building from outdoor sources, reducing the size and number of openable windows on the side of the building nearest the outdoor sources, or housing people in tall buildings. Site mitigation measures examined include the use of sound walls and vegetation as barriers. These measures are all assessed further below. Studies of elevated and below-grade roadways and freeway caps (also called freeway decks, lids or covers), which are covers over a sunken roadway that produce a road tunnel, also were reviewed, but studies were limited and results variable, and these measures are not feasible or are impractical for most new housing developments. Traffic measures such as those to reduce vehicle miles traveled also were considered; most such measures are typically integrated into roadway and community planning for regional benefits.

Building-related Measures: Filtration

No single building-related measure has been identified as adequate to reduce entry of pollutants from nearby roadways to the extent expected from set-back under common conditions. However, the use of high efficiency filtration appears to be relatively effective in most circumstances, as discussed below. It is especially appropriate for new homes because new homes in California must have mechanical ventilation systems [CCR 2008, Title 24, Section 150(o)], and those systems purposely pull outdoor air into the home that often is not filtered at all or is poorly filtered. High efficiency filtration also appears useful in existing homes without mechanical ventilation as discussed below. Mechanical ventilation systems and the Code requirement are discussed further in the Addendum at the end of this paper.

Background for Filtration

Outdoor-generated pollutants enter and leave buildings through three primary mechanisms: mechanical ventilation systems, which actively draw in outdoor air through an intake vent and distribute it throughout the building; natural ventilation (opening of doors or windows), which is the typical ventilation mode for most homes and small commercial buildings in California; and infiltration, which is the passive entry of unfiltered, outdoor air through small cracks and gaps in the building shell. Both natural ventilation and infiltration allow unfiltered air into the building and reduce the effectiveness of any filtration device.

Filter efficiency is rated using several scales, the most common of which is the Minimum Efficiency Reporting Value (MERV) rating system (ASHRAE 52.2-2007 as cited in EPA 2009). Flat fiberglass filters are the most common filters used in residential heating and air systems, and are rated at only MERV 1 to 4; they remove only a portion of the largest particles in the airstream that passes through the filter. MERV 5 to 8 filters are medium efficiency filters that remove some additional types of particles such as mold spores and cat and dog dander, but they still do not remove the finer particles produced on roadways. MERV 9 to 12 filters begin to remove particles smaller than PM2.5. Higher efficiency MERV 13 to 16 filters are rated to remove a portion of the ultrafine and submicron particles emitted from vehicles. True HEPA (high efficiency particle arrestance) filters (equivalent to MERV 17 to 20) remove 99.97% to 99.999% of particles less than 0.3 microns, but these generally have not been available for residential applications. High efficiency filters associated with central heating, ventilating and air conditioning (HVAC) systems must be carefully selected to assure the mechanical system can handle the increased airflow resistance. Additional information on MERV ratings, the size particles they remove, and typical applications are provided in Table 1 in the Addendum at the end of this paper.

High Efficiency Filtration with Mechanical Ventilation

Because mechanical ventilation has not been used in residential buildings until recently, there has been limited assessment of its impact on entry of particles and other pollutants into homes. However, a few recent studies of homes and schools have shown that high efficiency filtration in mechanical ventilation systems can be effective in reducing levels of incoming outdoor particles. In a seven-home study in northern California, Bhangar et al. (2010) found that the two homes with active filtration in a mechanical system had a notably lower portion of indoor particles from outdoors when the systems were on (filtration active) than when they were turned off (no filtration). In a modeling study of Korean residential units with mechanical ventilation, Noh and Hwang (2010) found that filters rated lower than MERV 7 were insufficient for reducing contaminants that enter through the ventilation filter, and concluded that filters should exceed MERV 11. In a school pilot study, a combination of MERV 16 filters used as a replacement for the normal panel filter in the ventilation system and in a separate filtration unit reduced indoor levels of outdoor-generated black carbon, ultrafine particles and PM2.5 by 87% to 96% in three southern California schools (SCAQMD, 2009). Use of the MERV 16 panel filter alone in the HVAC system achieved average particle reductions of nearly 90%. In a study of a single school in Utah, indoor submicron particle counts were reduced to just one-eighth of the outdoor levels in a building with a mechanical system using a MERV 8 filter (Parker et al., 2008). The investigators noted that the building shell and other mechanical system components appeared to play a significant role in the submicron particle removal as well.

These findings are similar to those from earlier studies of mechanically ventilated office buildings (e.g., Jamriska et al., 2000; Fisk et al., 1998). Fisk et al. (2000) concluded that use of higher efficiency filters instead of normal filters can reduce indoor numbers of submicron particles by 90% and that there is evidence of a large rate of removal of submicron indoor particles by processes (e.g., deposition) other than ventilation and filtration.

Because most of the studies discussed above were conducted in buildings with few or no indoor sources of submicron particles, the measured efficiencies of filters for reducing indoor concentrations of submicron particles from all sources may be overestimated. Many other studies have identified activities such as unvented cooking, cigarette smoking, and use of unvented gas appliances as indoor sources of submicron particles (ARB, 2005b, studies cited). These would only be removed by filtration to the extent the indoor air is re-circulated through the filters.

High Efficiency Portable Air Cleaning Devices

Portable or stand-alone air cleaners are generally not as capable as in-duct air cleaners and those associated with mechanical ventilation systems for cleaning large areas such as an entire home (Consumer Reports, 2007). However, when they are appropriately sized for the space to be treated, and when they use high efficiency or HEPA filters, portable air cleaners can significantly reduce particles in the treated area and serve as an adjunct to other pollutant reduction measures (Hacker and Sparrow, 2005; Shaughnessy et al., 1994; Shaughnessy and Sextro, 2006; Skulberg et al., 2005; Ward et al., 2005). In the pilot study conducted in three southern California schools (discussed above), a large stand-alone air cleaner with MERV 16 filters reduced black carbon, ultrafine particles and PM2.5 counts by 90% or more, and PM2.5 mass by 75%, when the HVAC system was not running (SCAQMD, 2009). Barn et al. (2008) found median removal efficiencies of 55% to 65% for PM2.5 from fires and wood burning by a HEPA air cleaner in 21 winter homes and 17 summer homes. In other work, Fisk et al. (2002) estimated an 80% reduction in outdoor fine mode particles with stand-alone air cleaners using filters in the MERV 11 to 13 range.

Because new California homes are now required to have mechanical ventilation, stand-alone air cleaners are less relevant to the assessment of measures for new California home construction. However, highly efficient portable air cleaners may be useful in reducing indoor exposure to pollutants in existing homes that do not have mechanical ventilation, and in homes that use bathroom exhaust type mechanical ventilation systems, which by their design cannot incorporate filtration of the incoming air because the supply air enters through leakage points throughout the building.

Removal of Gaseous Pollutants

There are limited options for effective removal of gaseous pollutants such as volatile organic chemicals, or VOCs, and NO_2 in central systems, and although the number and variety of technologies are increasing, there has been only limited research to date on their effectiveness. However, a few studies have examined the effectiveness of stand-alone filtration technologies intended to remove gaseous pollutants from the airstream (Shaughnessy and Sextro, 2006). The most comprehensive study was conducted by Chen et al. (2005), who tested the initial performance of 15 air cleaners with a mixture of 16 representative VOCs in a chamber study. Sorption filtration (e.g., activated carbon) removed some but not all VOCs (light and very volatile gases such as aldehydes and dichloromethane were not well removed). However, devices that included sorption media such as activated alumina impregnated with potassium permanganate showed better VOC removal efficiencies. In the schools study discussed above, the stand-alone unit used in one of the schools included charcoal sorbent for removal of gaseous pollutants; it removed 52% of the benzene indoors and 15% of total VOCs when operated with the HVAC turned off (SCAQMD, 2009). In a children's daycare center in Finland, Partti-Pellinen et al. (2000) found that up to 50% to 70% of nitrogen oxides could be removed by chemical filtration using a combination of charcoal, aluminum oxide and potassium permanganate, while another study found about 50% NO_2 removal by a HEPA air cleaner with large quantities of carbon in the adsorption bed, but little or no removal by other types of air cleaners (Shaughnessy et al., 1994).

Results from these studies show effectiveness for some technologies but are not conclusive due to their limited number and scope, including a relative lack of real world measurements. Additionally, some investigators have found that some filters re-emit VOCs that have been removed over time, or emit reaction products from the matter collected on the filter (Daisey and Hodgson, 1989; Fisk, 2007; Destaillats et al., 2011; Hyttinen et al., 2006, 2007).

Limitations of High Efficiency Filtration

Although they can substantially reduce indoor concentrations of pollutants, mechanical filtration systems alone are insufficient to fully protect occupants from particles and other emissions from nearby roadways, for several reasons.

- First, most people tend to open their windows or doors at least part of each day (Offermann, 2009; Phillips et al., 1990), and such natural ventilation involves no filtration of incoming air and can diminish any pollutant reductions attained through the use of the mechanical system. The effectiveness of high efficiency filtration in homes whose occupants open their doors and windows regularly has not been quantified.
- Second, as higher MERV filters are used, greater attention must be paid to the increased air flow resistance that occurs with some filter types; mechanical system motors must be sufficiently sized to accommodate the air flow needs.
- Third, studies have shown that homeowners are not provided with sufficient information regarding use and maintenance of their central HVAC systems, or do not read and follow instructions for maintaining their filters (EPA, 2009; Offermann, 2009). Filtration is only effective if filters are well-fitted and are replaced or maintained according to the manufacturer's recommendations, and duct leakage is minimized (Thatcher et al., 2001; Wallace et al., 2004). Older (aged) filters have been associated with increased irritant health symptoms and decreased work performance in studies of filtration maintenance in workplaces (Clausen, 2004; Seppänen and Fisk, 2002; Wargocki et al., 2004).
- Finally, as discussed above, gaseous pollutants are not removed by most particle filters, and the technologies for VOC removal in residential applications are limited and still evolving.

Expected Benefits of High Efficiency Filtration

High efficiency filtration has been used in homes and schools only recently, and there is a range of highly variable building characteristics, filtration technologies, and occupant behaviors that determine the effectiveness of high efficiency filters in reducing the overall levels of pollutants indoors. Accordingly, it is difficult to accurately quantify the actual reduction in particulate matter that would be achieved by introducing high efficiency filtration on a widespread basis across the population of California homes and schools. For example, while filters with a MERV 16 rating remove more than 95% of particles from 0.3 to 3 microns in diameter, only those particles in the airstream actually passing through the filter are removed. Factors that determine the fraction of particles removed from the air in a building include the airflow rate through the unit, the amount of time that the system is “on”, the extent to which windows and doors are opened, and other factors. While results from the studies conducted in homes and schools to date appear promising, those studies usually limited the opening of windows and doors or followed other specific protocols. Thus, although a substantial reduction in particles would be expected, the reduction that would be realized across the wide variety of conditions in California homes and schools cannot be confidently estimated.

Two kinds of programs are currently being implemented that will provide critical information needed to help confirm and quantify the effectiveness of high efficiency filtration. First, ARB is funding two key studies of high efficiency filtration in homes. Second, several local air quality management districts and school districts are implementing programs to install high efficiency filtration devices in a substantial number of schools in California, and collecting data regarding the performance of the filtration units. These are discussed below.

ARB’s Planned High Efficiency Filtration Research

ARB is funding a project entitled “Reducing In-Home Exposure to Air Pollution” to measure the exposure reduction and energy use of combinations of mechanical ventilation and filtration systems in order to identify compatible, low-energy systems that are effective at reducing indoor exposures to indoor, and incoming outdoor, pollutants. The study will be conducted by Drs. Brett Singer and Iain Walker of Lawrence Berkeley National Laboratory. The investigators plan to evaluate 15 current and new systems, and test seven of the most promising systems in a test home near a major roadway in an area with high ambient ozone and PM2.5 levels. They will measure fine and ultrafine particles, ozone, VOCs, NO_2 and black carbon, both indoors and outdoors, along with energy consumption and the performance of systems as filters age. This project is needed because new California homes are now required to have mechanical ventilation as discussed above, and the most widely used, low energy mechanical ventilation systems, bathroom exhaust systems, do not filter the incoming air; hence, the occupants’ indoor exposure to outdoor air pollutants can potentially increase with these systems.

ARB is also funding a second study entitled “Benefits of High Efficiency Filtration to Children with Asthma”. Dr. Deborah Bennett from the University of California at Davis will conduct this 4-year study of 200 children with asthma in Fresno and Riverside to quantify the exposure and asthma reduction benefits of high efficiency filtration in their homes. One intervention group will have high efficiency filters or filtration systems installed in their homes’ central heating and air conditioning systems. The second group will have high efficiency portable air cleaners placed in the child’s bedroom and in the main living area. Filters with a MERV rating of 15 or higher will be used. Improvements in asthma symptoms will be evaluated in a randomized cross-over design, with each participant receiving high efficiency air filtration for a year and no filtration for a year, allowing the investigators to identify the improvements related to the air filtration. During the control periods, “sham” filters with little or no particle removal capability will be used. Half of the homes with portable air cleaners will also have filters that remove ozone and VOCs. The extent to which particulate matter (PM10, PM2.5

and ultrafine particles), ozone, black carbon, and nitrogen oxides are reduced will be measured. Key asthma health endpoints will also be examined, including unplanned utilization of the healthcare system for asthma-related illness, short-term medication use, symptom diaries, peak exhaled flow, spirometry and exhaled nitric oxide.

Current Programs Using High Efficiency Filtration

Several programs have been completed or are underway in the State to install and/or test high efficiency filters, primarily in schools, to reduce exposures to pollutants from heavy traffic and/or port-related emissions. Since 2008, the South Coast Air Quality Management District (SCAQMD) has approved $3 million for installation of high efficiency air filtration devices in a total of 18 schools and one community center in the Long Beach and Los Angeles Unified School Districts, San Bernardino and the Boyle Heights area (Kwon, 2012). SCAQMD also has agreed to oversee implementation of a program to utilize $5.4 million in settlement funds to install and maintain high performance air filtration devices at about 47 schools in Wilmington and San Pedro. Installation of the filtration devices was scheduled to begin in summer 2012. Detailed site assessments of the schools are underway prior to installation in order to determine the best filtration device for each classroom and to facilitate assessment of actual improvements in classroom air.

Also, the Bay Area Air Quality Management District (BAAQMD) is conducting a school air filtration project in five schools for about $300,000 (Smith, 2012). In 2010, a contractor completed installation of high efficiency air filtration equipment at five elementary schools located in the Bay View Hunters Point neighborhood of San Francisco. The filtration equipment is designed to reduce exposure inside the schools to particles from outdoor sources, as well as indoor-based particles such as some allergens. Initial monitoring results indicate that there has been a substantial reduction of particulate matter (up to about 50% to 75% for PM2.5 and higher for very small particles) inside the classrooms as a result of the newly installed high performance filters (IQAir, 2012).

To date, these programs appear successful, but overall cost, changes to the operation of the classrooms' central HVAC systems (such as running the system continuously rather than allowing it to switch on and off based on temperature needs) and other considerations (noise, drafts) may reduce the feasibility of the current technologies for use in all classrooms and require further refinements. However, because of the similarities of schools to homes with mechanical ventilation systems, one would expect comparable reductions in particle levels from high efficiency HVAC filtration in new and retrofitted homes.

Cost of High Efficiency Filtration

About a dozen companies offer high efficiency filtration devices incorporated into, or suitable for, residential mechanical ventilation systems, and most offer just one or two models. The devices are rated from MERV 11 to 16, plus several are true HEPA filters (equivalent to about MERV 17 to 20). Initial costs range from about $200 to $2800 for a very high end system; however, most cost less than $500. This range does not include installation, although in a new home the added cost over the installation of the mechanical system itself would be expected to be minimal. Annual filter replacement and/or maintenance cost ranges from about $25 to $255 per year, depending on MERV rating, number of filter changes needed per year, and whether the system includes a carbon filter for VOCs (which increases the cost of filter replacement, as these typically need to be replaced several times per year).

For existing homes and those that are renovated and do not have a mechanical ventilation system, either higher efficiency filters in the central heating and air system or portable high efficiency filtration devices could be used. High efficiency filters for central systems that can accept them cost about $20. However, the increased airflow resistance may cause the central system to be less efficient. Effective, high efficiency portable units range in purchase cost from about $200 to $1250 depending on the size of the room or space to be treated and the specific technologies included (e.g., MERV rating and charcoal or other VOC removal filters) and would typically not involve any installation costs. Replacement filters and maintenance range from about $75 to $500 per year, again depending on the types of filters included and how dirty the air is, which would determine the frequency of filter changes needed. To adequately treat the living areas of most homes (e.g., bedrooms, family room, living room), two or more portable units may be needed.

External Building Design Measures

Moving Air Intakes

Research focused on assessing external building design measures is generally not readily available. Locating air intakes for mechanical ventilation systems on the opposite side of the building from the nearby outdoor source and prevailing wind direction seems logical. However, the reduction of pollutant entry in such a case would depend on the distance of the intake from the outdoor source, the consistency of the prevailing wind direction, and any local geographical or structural objects that might produce wind turbulence or eddies near the building and the air intake. One particle expert has noted that moving the intake would likely only be beneficial when the outdoor source is very near the intake and the intake is moved fairly far away; otherwise, because particles tend to disperse quickly and particle plumes “flow” around buildings, elevated particle concentrations around the building will be fairly consistent (Thatcher, 2010). This view appears at least partially substantiated by an Australian study that found that the concentration of submicron particles was consistently high and relatively undiluted around a building that was within 15 m of the roadway (Morawska et al., 1999). However, because this option has received little scientific study, and because all new California homes are required to use mechanical ventilation, which will often include a supply air intake, this option warrants further study to determine whether there are conditions under which strategic placement of air intakes might provide some benefits.

Reducing Openable Windows

Reducing the size and number of openable windows on the side of the building nearest the outdoor source would likely do little to reduce entry of particles and other pollutants into homes. Furthermore, this potential measure may not be acceptable to homeowners, who often open windows to take advantage of the breeze, from which the benefit arises primarily from opening windows on the prevailing wind side of the building. Windows opened only on the opposite side may result in little air movement in the home. In regions of the State where window opening currently replaces air conditioning in the summer evening and nighttime periods, there could be substantial energy and cost penalties for the increased use of mechanical air conditioning to cool the home. Additionally, increased indoor air stagnation and condensation may occur, which can result in mold issues. Thus, for all of these reasons, this option does not appear practical for single family dwellings. This measure might be acceptable in multi-family dwellings, depending on the specific building design and the ventilation systems used. However, inclusion of a sufficient number of windows (even if unopenable) would allow more daylight into the building, which would reduce energy use for indoor lighting and provide the satisfaction and efficiency benefits that accompany daylighting (Heschong Mahone Group, 2003a, 2003b).

Taller Buildings

Housing people in taller buildings has also been suggested as a possible exposure reduction measure. However, one of the few relevant studies of multi-story buildings near busy roadways found that vertical differences in fine and ultrafine particle concentrations outside buildings with 9 to 26 stories were not significant and can be highly variable, depending on other local sources and local meteorological conditions (Morawska et al., 1999). A second study, conducted in New York, found significant decreases for outdoor black carbon and non-volatile polycyclic aromatic hydrocarbons for floors 6 to 32 during the non-heating season only (Jung et al., 2011). Additionally, floors 3 to 5 showed the highest median outdoor concentrations for all pollutants measured, although the trend was not statistically significant and the elevated pollutants were believed to come from nearby rooftop exhausts. Thus, multi-story housing may reduce exposure in some situations but requires further research to determine conditions under which tall buildings might provide a reliable approach to reduce exposure near busy roadways.

Site-related Measures

The primary site-related measures reviewed by ARB staff were sound walls and vegetation barriers.

Sound Walls

Sound walls appear to reduce pollutant concentrations near the roadway; near-road concentrations (within 15-20 m [49-66 ft]) have shown reductions up to about 50% (Ning et al., 2010; Baldauf et al., 2008; Bowker et al., 2007; Hagler et al., 2012). However, in some studies higher levels of pollution were seen behind the barrier and at a distance from the sound walls and roadways, although in some of these studies the higher levels appear related to other sources of pollution (Ning et al., 2010; Bowker et al., 2007; Hagler et al., 2010; Baldauf et al., 2008). In one of the few field measurement studies of sound walls, conducted along two southern California freeways, Ning et al. (2010) found that concentrations at farther distances (about 80 to 100 m from the roadway) were typically greater for the portions of the roads with sound walls, and background levels behind sound walls were not reached until 250 to 400 m as compared to 150 to 200 m without sound walls. Modeling and tracer studies (Heist et al., 2009; Finn et al., 2009) showed that barriers reduced air pollution downwind of the barrier, although in some cases trapping of pollution and increased levels on the road would occur (Hagler et al., 2011; Finn et al., 2009). Nearby buildings and structural barriers can also affect the attenuation and dispersion of pollution from roadways, but results vary with different meteorological conditions (Bowker et al., 2007; Hagler et al., 2010; Hagler et al., 2012).

Vegetation Barriers

Results for vegetation alone are more variable than those for sound walls. Vegetation can remove some gaseous pollutants by uptake or absorption, and particles are removed primarily by interception (impaction or physical adherence; Nowak et al., 2006; Fujii et al., 2008; Smith, 1990; Pardyjak et al., 2008; Baldauf et al., 2008). However, particles can be resuspended, apparently even at very low wind speeds (Fujii et al., 2008; Smith, 1990). Vegetation may restrict dispersion and increase concentrations on-road in street canyons with closer spacing of trees, particularly in low wind conditions (Gromke, 2011; Gromke and Ruck, 2007, 2009; Buccolieri et al., 2009). Another study has further shown the complexity of the effects of vegetation; investigators found different results depending on particle size and wind speed, and a non-linear increase of particle removal with increased leaf area density, which varies by tree species and season (Steffens et al., 2012). Gaps in vegetation barriers can have a significant negative impact on their effectiveness (Hagler et al., 2012), which needs to be addressed in future California research because California roadside vegetation tends to be less dense than that in the eastern U.S., where most previous field studies have been conducted. Also, some types of vegetation can trigger asthma and allergy attacks, and some emit reactive VOCs that contribute to the formation of ozone.

Sound Walls and Vegetation Combined

A combination of sound walls and vegetation appears to be more effective than either one alone. The two used together have been shown to disperse pollutants more consistently and to greater distances than either alone, with up to about a 60% reduction in near roadway levels (Baldauf et al., 2008; Bowker et al., 2007). While sound walls alone and sound walls combined with vegetation show promise, the increase in concentrations on-road and at a distance seen in some studies can increase exposures of others in the population and thus redistributes, rather than removes, pollutants. Additionally, the complexity of pollutant movement under varying conditions makes accurate prediction of exposure reduction difficult. Specific conditions under which sound walls and vegetation can reliably and consistently reduce exposures to air pollution have not been identified, especially in California.

Reduction of Indoor-generated Pollutants to Reduce Overall Exposure

Particles, NO_2 and other pollutants emitted by vehicles and other outdoor sources also have indoor sources that can produce higher indoor concentrations at times (ARB, 2005b, Section 2, and sources cited). Therefore, a reduction in indoor emissions and exposures can reduce the overall health impact of exposure to outdoor pollutants because the total exposure (indoor plus outdoor) to those pollutants experienced by the building occupants would be reduced. A number of studies have identified unvented cooking, cigarette smoking, the use of unvented gas appliances, burning of candles and incense, and woodburning as indoor sources of fine and ultrafine particles (Bhangar et al., 2010; ARB, 2005b; Fortmann et al., 2001; Wallace, 1996; Wallace, 2005; Wallace et al., 2008). High fine and ultrafine particle counts have been measured from such indoor sources. In homes with such sources, average indoor concentrations and occupants' personal exposures to fine and ultrafine PM are dominated by those indoor sources. Thus, measures to reduce indoor sources can help to significantly reduce occupants' peak and overall daily exposures to key pollutants emitted from both traffic and indoor sources.

Summary of Research Review

ARB has developed and adopted increasingly stringent regulations limiting emissions from passenger cars, trucks and buses, which have substantially reduced, and will continue to reduce, vehicle emissions. However, recently adopted regulations have compliance dates extending as far as 2025 for full implementation, and fleet turnover to zero or near-zero technologies will take 20 to 30 years. The set-back of buildings from high traffic roadways remains the most certain approach for preventing the residual health risk from traffic pollution exposures for those living closest to the roadways because it distances them from the highest pollutant concentrations. Research conducted since the publication of ARB's recommendations in 2005 further supports the use of set-back.

There are two mitigation measures that can be effective for exposure reduction. Increased filtration of air and reduction of indoor pollution sources potentially can reduce the overall pollution burden in homes. These measures warrant consideration especially in light of recent studies showing that the pollutant plumes at times can extend beyond 1000 ft (305 m) from the roadway. For most residential applications near busy roadways, high efficiency (MERV 13 to 16, or higher) pleated particle filters would generally be considered the most effective approach to filtration because they can remove the very small particles emitted by motor vehicles without emitting ozone, formaldehyde, or other harmful byproducts. Based on a limited number of studies, such high efficiency filtration has been shown to reduce indoor PM2.5 and ultrafine particle levels by up to 90% relative to incoming outdoor levels when doors and windows are kept mostly closed. Purchase costs for high efficiency filtration devices or systems that are compatible with residential mechanical ventilation systems (which are now required in new residential construction in California) range from $200 up to $2800, but most are available for under $500. Because Title 24 now requires mechanical ventilation for new residential construction, enhanced filtration can help avoid increased exposures to outdoor pollutants that may occur. The use of high efficiency air filters in central heating and air systems or stand-alone air cleaning devices can also reduce exposures in existing homes and homes that use certain types of mechanical ventilation systems that cannot accommodate central filtration.

While research shows that high efficiency filtration can be effective, it has several limitations. Filtration cannot remove all incoming outdoor pollutants because of normal building leakage and the fact that most people open windows and doors at least a portion of the day, allowing entry of unfiltered air. Additionally, not all pollutants are filtered by the filter media. Moreover, studies show irregular homeowner maintenance of filters and central systems, and regular maintenance is critical for effective removal of pollutants. ARB is funding two studies that should help further identify the approximate reduction in exposure that high efficiency filtration can provide in homes. High efficiency filtration is already being used or is planned for use in over 70 schools in California; these programs should provide comparable information for high efficiency filtration in classrooms.

The benefits are less clear for most of the other potential mitigation measures examined. Studies have shown that the use of sound walls alone, or sound walls and vegetation together, can reduce near roadway concentrations by about 50% and 60%, respectively. However, the extent of exposure reduction is quite variable under different conditions of meteorology and topography, and increased levels of pollutants can occur on-road and at a distance from the roadway. Thus, unlike the situation with filtration, pollutants are primarily redistributed rather than removed; while individuals living near the roadway would benefit, those traveling on the road or living at a distance could experience elevated exposures at times. The effectiveness of vegetation alone is even more variable, and has not been well-quantified. Furthermore, vegetation with low allergenic potential and low reactive VOC formation needs to be identified and tested, and other limitations of vegetation as a pollution barrier need to be better understood. Research is needed that identifies the specific conditions under which sound walls and vegetation can consistently provide a reliable exposure reduction benefit with limited disbenefits. In particular, California field studies are needed because of the significant differences in California meteorology, building practices, and flora from those of the eastern U.S.

The limited studies conducted to date on other potential mitigation concepts are not promising, although further research may identify situations in which they are generally effective. Placement of air intakes on the side of the building opposite the roadway may make little difference in terms of exposure, due to rapid particle movement around buildings. Locating windows only on the side of the building opposite the roadway reduces indoor daylighting, air circulation and cooling, and may do little to reduce exposure. Finally, taller buildings do not necessarily experience substantially reduced pollutant levels at higher floor levels, depending on local meteorology and other nearby sources of pollution. However, further research on placement of air intakes and housing in taller buildings may identify conditions under which these measures reliably reduce exposures. Research is warranted on these measures and the measures discussed above as effective or showing promise in order to further identify cumulative measures that together can assure sufficient exposure reduction and health protection for those living near busy roadways.

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ADDENDUM

Current California Building Code Requirements

Section 150(o) of Title 24 of the California Code of Regulations (CCR 2008) requires mechanical ventilation in all <u>new</u> residential construction in California built after January 1, 2010. Section 150(o) allows the requirement to be met through a variety of system types (CEC 2010). “Exhaust only” type systems increase the entry of unfiltered outdoor air through leakage points in the building shell and can result in negative pressure indoors, thus increasing the possibility of backdrafting of combustion emissions from gas water heaters, fireplaces and other combustion appliances. These are the most widely used systems in California. “Supply systems” typically use a small motor to bring outdoor air in through a ducted supply and can include high efficiency filters to filter the air as it is brought in, prior to circulation of the air throughout the home. Combination (supply and exhaust) systems are available, with some linked to the central heating and air system; these include filtration of incoming outdoor air. However, the Code requires only a MERV 6 air filter (an increase to MERV 8 is proposed in the 2012 revisions to Title 24), which does not remove the smaller particles emitted by vehicles which are the particles of greatest concern. In future construction, the type of mechanical system used in new homes will have a major impact on the entry of outdoor pollutants indoors − if filtration is not included or is weak, indoor exposures to outdoor pollutants likely will increase.

Table 1. MERV Ratings*

MERV Rating	Average Particle Size Efficiency (PSE), microns – % Removal			Typical Controlled Contaminant or Material Sources (ASHRAE 52.2)	Typical Building Applications
	0.3-1.0	**1.0-3.0**	**3.0-10.0**		
1-4			<20%	**> 10 Microns** Textile Fibers Dust Mites, Dust, Pollen	Window AC units Common Residential Minimal Filtration
5			20-35	**3.0 to 10.0 Microns** Cement Dust, Mold Spores, Dusting Aids	Industrial Workplace Better Residential Commercial
8			>70		
9		<50	>85	**1.0 to 3.0 Microns** Legionella, Some Auto Emissions, Humidifier Dust	Hospital Laboratories Better Commercial Superior Residential
12		>80	>90		
13	<75	>90	>90	**0.3 to 1.0 Microns** Bacteria, Droplet Nuclei (sneeze), Most Tobacco Smoke, Insecticide Dust	Superior Commercial Smoking Lounge Hospital Care General Surgery
16	>95	>95	>95		
17**	≥ 99.97			**<0.3 Microns (HEPA/ULPA filters)**** Viruses, Carbon Dust, Fine Combustion Smoke	Clean Rooms Carcinogenic & Radioactive Matls., Orthopedic Surgery
18**	≥ 99.99				
19, 20**	≥ 99.999				

* Adapted from EPA 2009; originally from ANSI/ASHRAE Standard 52.2-2007.
** Not part of the official ASHRAE Standard 52.2 test, but added by ASHRAE for comparison purposes.

City of Santa Barbara
California

CITY OF SANTA BARBARA PLANNING COMMISSION

RESOLUTION NO. 005-14
CITY WIDE
RECOMMENDATION TO CITY COUNCIL ON
AIR QUALITY DESIGN STANDARDS FOR DEVELOPMENT NEAR HIGHWAY 101
FEBRUARY 13, 2014

AIR QUALITY DESIGN STANDARDS FOR DEVELOPMENT NEAR HIGHWAY 101

The Planning Commission held public hearings on January 16, 2014 and February 13, 2014 on a draft ordinance to establish air quality design standards for new development of sensitive uses within 250 feet of Highway 101, to implement adopted General Plan Policy ER7. The intent of the ordinance is to reduce health risks from highway vehicle exhaust for any future development of residences, nursing or retirement homes, schools, or family day care close to the freeway. Project design criteria involve site layouts, vegetative screening, and interior air filtration. The Planning Commission considered recommendations to City Council regarding ordinance adoption. Public comment was welcomed.

WHEREAS, the Planning Commission has held the required public hearing on the above application, and the City Staff was present.

WHEREAS, no one appeared to speak in favor of the recommendation, and no one appeared to speak in opposition thereto or with concerns at the February 13, 2014 hearing, and the following documents were presented for the record:

1. Staff Report with Attachments, January 9, 2014.
2. Staff Report with Attachments, February 6, 2014.
3. Draft Public Handout to assist understanding of the ordinance.
4. Staff memorandum summarizing phone call from Cynthia Ruano in support of ordinance, February 13, 2014.
5. Correspondence received in opposition to the recommendation or with concerns:
   a. Mary Rose Bryson, via email
   b. Steve Johnson, via emails
   c. Azam Mirtorabi, via emails and hand-delivered letter
   d. Tracy Hernandez, Santa Barbara, CA

NOW, THEREFORE BE IT RESOLVED that the City Planning Commission recommended to City Council the following actions:

I. Adopt the Ordinance establishing Air Quality Design Standards for Development near Highway 101, as provided in Exhibit A of the Staff Report dated February 6, 2014, with the following revisions:

Amend Title 22 of the Santa Barbara Municipal Code by adding Chapter 22.65 titled "Design Standards for Development Near Highway 101" to read as follows:

22.65.010 Purpose and Intent.

It is the purpose of this section to limit and regulate development within close proximity to Highway 101 in a manner that promotes the health, safety, and welfare of the residents of the City of Santa Barbara.

Pursuant to 2011 General Plan Policy ER7, the design standards in this Chapter are intended to limit the number of people, including Sensitive Individuals, who receive Extensive Exposure to potential air pollution hazards from highway vehicle exhaust including diesel particulates by limiting the development of new sensitive land uses within close proximity of Highway 101 or by modifying the design of new sensitive land uses to reduce the amount of air pollution exposure received, until such time as statewide diesel particulate levels are reduced by planned State regulations or other means.

22.65.020 Definitions.

For the purpose of this Chapter, the following words and phrases shall have the following meanings:

A. **Accessory Building.** As defined in Section 28.04.010 of this Code.

B. **Extensive Occupancy or Exposure.** Substantial time periods involving daily occupancy or frequent lengthy visits of many hours occurring repeatedly over many years, as experienced with residential land uses and schools.

C. **Main Building.** As defined in Section 28.04.145 of this Code.

D. **Required Outdoor Living Space.** Outdoor living space or open yard area required in accordance with City residential zoning standards as specified in Title 28 of this Code.

E. **Sensitive Individuals**. Persons most susceptible to adverse affects of poor air quality (including from diesel particulates) including children, the elderly, and people who are ill or have serious chronic respiratory, heart, or other medical conditions that are exacerbated by air pollution.

F. **Sensitive Land Uses.** Land uses that involve Extensive Occupancy or Exposure by Sensitive Individuals, including residences; nursing homes, retirement homes, and other community care facilities; schools; and large family day care facilities. Land uses not considered sensitive land uses include retail, commercial services, and offices.

G. **State Highway Roadside Sound Wall.** A roadside sound wall constructed by the California Department of Transportation.

22.65.030 Applicability and Exemptions.

A. **Applicability.**

1. **Location.** Any property that is located in whole or part within 250 feet of Highway 101 as measured from the outer edge of the nearest highway travel lane (excluding highway on- and off-ramps) is subject to the requirements of this Chapter, unless identified as exempt in Subsection B of this Section 22.65.030.

2. **Types of Development.** The following types of development are subject to the requirements of this Chapter, unless identified as exempt in Subsection B of this Section 22.65.030:

a. The development of one or more new residential units on a lot.

b. An addition to an existing residential unit that increases the net floor area of the residential unit by more than 50% of the net floor area that existed within the residential unit as of December 1, 2011. If multiple additions are made to a residential unit during the time this Chapter is in effect, the amount of the additional floor area shall be measured in the aggregate.

c. The development of a new main building that will be occupied by a Sensitive Land Use.

d. The demolition of an existing building and its replacement with a main building that will be occupied by a Sensitive Land Use.

e. A change of use of an existing main building from a use not defined as a Sensitive Land Use to a Sensitive Land Use.

f. A change of use of an existing Main Building from a Sensitive Land Use that existed on the effective date of the ordinance adopting this Chapter to a different Sensitive Land Use.

B. **Exemptions.** The following projects are exempt from this Chapter:

1. Projects on sites where a State Highway Roadside Sound Wall is located between the highway and project site.
2. Projects with applications submitted to the City before December 1, 2011 for development permits including a Master Application, building permit plan check, or for other development approval, where the application has not expired.
3. Projects that received a final approval from the City prior to December 1, 2011 where the approval remains valid.
4. Projects where the property owner submits a site plan that demonstrates that no new Main Building or required outdoor living area that is to be occupied by a Sensitive Land Use will be located within 250 feet of Highway 101, as measured from the outer edge of the nearest highway travel lane.
5. Projects where the property owner can demonstrate to the satisfaction of the Community Development Director or the Director's designee that site-specific climatic or topographic conditions avoid or address the air quality risks from Highway 101 on the site such that the site specific conditions present a health risk of less than 10 excess cancer cases per one million persons.

Nothing in this Subsection B prevents an applicant from incorporating the design standards specified in Section 22.65.040 to exempt projects on a voluntary basis.

22.65.040 Design Standards for Air Quality.

The following design standards apply to development and occupancy of main buildings to which this Chapter applies. The location, design, and filtration standards specified in this Section are not required for accessory buildings or areas on the lot where Sensitive Individuals would not be subject to Extensive Occupancy or Exposure (e.g., parking).

A. **Proximity to Highway 101 and Project Design Features.** Main buildings that will be occupied by Sensitive Land Uses are prohibited from locating within 250 feet of Highway 101 unless the City

Community Development Director or designee determines that project design features satisfactorily address air quality risks. When determining whether the project design features satisfactorily address air quality risks, the Director shall consider the following factors:

1. **Distance from Highway 101.** Main buildings and outdoor living areas that will be extensively occupied by Sensitive Land Uses should be located as far from Highway 101 as feasible. For projects that have a mixture of Sensitive Land Uses and non-sensitive land uses, Main Buildings and areas expected to have Extensive Occupancy or Exposure by Sensitive Individuals should be located furthest from the highway, while facilities for non-sensitive populations and/or involving short-term use (such as parking facilities) should be placed closer to the highway.
2. **Building Orientation and Outdoor Living Areas.** Main Buildings for occupancy by Sensitive Land Uses should be oriented with doors and outdoor living areas on the side of the building away from the highway in order to provide physical screening by the building.
3. **Vegetative Screening and Physical Barriers.** Project sites to be occupied by Sensitive Land Uses should incorporate dense, tiered vegetative plantings between the highway and the Main buildings and outdoor living areas that are to be occupied by Sensitive Land Uses, which helps to remove air pollutants and reduce diesel particulate concentrations. Vegetation should largely entail trees with complex foliage (leafy vegetation or with needles) that allow substantial in-canopy airflow; preferably in multiple rows, using tree plantings of tall and uniform height that retain foliage year-round and have a long life span. Inclusion of physical barriers such as walls and solid fences between the highway and the project also help to reduce air pollutant exposure levels.
4. **Air Infiltration.** In addition to a filtration system as required in Section 22.65.040 B, Main Buildings occupied by Sensitive Land Uses should be designed to locate air intake vents on the side of building away from the highway and use double-paned windows throughout.
5. **Other Measures.** An applicant proposing a Sensitive Land Use that will be located within 250 feet of Highway 101 may propose other measures that have a demonstrated ability to reduce highway air pollution exposure.

B. **Interior Air Filtration System.** Main Buildings intended for occupation by a Sensitive Land Use that are located within 250 feet of Highway 101 and are not exempt pursuant to Section 22.65.030.B shall incorporate a central ventilation system with air filtration rated at Minimum Efficiency Reporting Value of "MERV13" or better for enhanced particulate removal efficiency. The owner of any development subject to this requirement shall attach a copy of the operator's manual for the central ventilation and filtration system as an exhibit to every lease of the building or any portion of the building.

22.65.050 Maintenance of Design Features.

Design features incorporated into an approved project design pursuant to Section 22.65.040 shall be maintained as long as this Chapter remains in effect.

II. As part of the City General Plan Adaptive Management Program, provide funding to conduct an air quality study of the Highway 101 corridor within 2-3 years and update the study as needed thereafter and, based on the study results or other available air quality information, consider whether to repeal or amend General Plan Policy ER7 and the implementing Ordinance.

This motion was passed and adopted on the13th day of February, 2014 by the Planning Commission of the City of Santa Barbara, by the following vote:

AYES: 6 NOES: 0 ABSTAIN: 0 ABSENT: 1 (Jordan)

I hereby certify that this Resolution correctly reflects the action taken by the city of Santa Barbara Planning Commission at its meeting of the above date.

Julie Rodriguez, Planning Commission Secretary

March 13, 2014
Date

The Case for Public Health Accreditation

October 2016

The Needham Public Health Department is considering seeking national accreditation from the Public Health Accreditation Board (PHAB). The application for accreditation is long and labor intensive but will, in the long run, enhance the performance and quality of services provided by the department. The process of achieving the pre-requisites for accreditation will also ensure that the services offered by Needham Public Health are responsive to existing and emerging health needs in the community.

What does the term "Accreditation" Mean?

> "Accreditation provides a means for public health departments to identify performance improvement opportunities, enhance management, develop leadership and team work, and strengthen relationships with their community. The accreditation process will challenge a health department to think about its roles and responsibilities and how it fulfills them. It will encourage and stimulate quality and performance improvement in the health department. Accreditation demonstrates the capacity of the public health department to deliver the three core functions and the ten Essential Services of Public Health." (PHAB Accreditation Coordinator Handbook, Version 1.0)

Accreditation provides local health departments with the opportunity to adhere to (and to measure their performance against) a set of quality standards with the goal of constantly improving department capacity, quality, and accountability. Achieving accreditation recognizes a public health department's successful completion of an intensive application and assessment process to ensure it meets or exceeds PHAB standards.

Why Pursue Accreditation?

Seeking voluntary accreditation through PHAB will enhance the Needham Public Health Department's ability to:

- Effectively and efficiently meet community needs with high quality essential services;
- Improve operational processes and protocols in the process of meeting requirements;
- Enhance management processes and develop leadership within the health department;
- Adopt quality improvement practices;
- Adopt performance management practices;
- Better understand and build on the health department's strengths and address areas in need of improvement;
- Improve competitiveness for funding;
- Strengthen relationships with community stakeholders and policy makers;
- Enhance the department's status both locally and nationally.

The Challenges to Pursuing Accreditation

Readiness to apply for accreditation requires a great deal of time and effort. Public Health accreditation was designed for much larger health departments (unlike in Massachusetts, most health departments are county based and have significantly greater resources and responsibilities). Most of the 150 health departments that have achieved accreditation did so by fully engaging staff members and by assembling "accreditation teams" to meet the Standards and Measures established by PHAB.

The health departments that are most likely to succeed in this process are those that have already embraced and incorporated Quality Improvement and Performance Management into department operations.

The process can take several years. The accreditation coordinator at Worcester Division of Public Health and Human Services reported that the department worked toward accreditation for five years. Other local health departments in Massachusetts have been involved in the process for longer than that.

Accreditation is costly. The application fee for Needham would be at least $14,000, with a $5,600 annual service fee.

Steps in the Accreditation Process:

The Public Health Accreditation Board outlines the following steps in the accreditation application process:

- <u>Pre-application</u> - Prepare for the application process, including:
    - Assess organizational and community readiness
    - Complete pre-requisites for application
        - Strategic plan
        - Community Health Assessment
        - Community Health Improvement Plan
    - Inform PHAB of the intent to apply and register on the PHAB electronic submission system
- <u>Application</u> – Formal notification of the applicant's commitment to initiate the process. Submit prerequisites and attend PHAB training.
- <u>Documentation Selection and Submission</u> - Gather and submit documentation of the department's achievement of PHAB Standards and Measures.
- <u>Site Visit</u> - A PHAB site visit team reviews documentation, conducts a site visit, and develops a report.
- <u>Accreditation Decision</u> - PHAB Accreditation Committee determines accreditation status: Accredited (accreditation for 5 years) or not accredited.
    - An Action Plan may be required before a final decision is made.

- Reports - Accredited health departments submit yearly reports.
- Reaccreditation – Submit new statement of intent and application.

References

- http://www.phaboard.org/wp-content/uploads/National-Public-Health-Department-Accreditation-December-2014.pdf
- http://www.phaboard.org/news-room/accredited-health-departments/

Needham Public Health Accreditation Work Plan

October 31, 2016
Lynn Schoeff

The Needham Public Health Department intends to seek national accreditation from the Public Health Accreditation Board (PHAB). The application for accreditation is long and labor intensive but will, in the long run, enhance the performance and quality of services provided by the department.

Phase I: Pre-application preparedness

During this initial phase the Needham Director of Public Health and the Accreditation Coordinator will become thoroughly familiar with PHAB, the 12 Domains of Accreditation, application pre-requisites, and the resources necessary to achieve accreditation.

Steps:

- Accreditation Coordinator and Public Health Director review PHAB Standards and Measures
- Orientation for staff and BOH
- Assess Needham's degree of readiness to undertake accreditation
- Prioritize accreditation tasks
- Join state and national accreditation networks
- Establish links with other local health departments for technical assistance and consultation

Phase I Completion date: **December 2016**

Phase II: Self-Assessment

During this phase we will conduct organizational self-assessments:

- Using the PHAB Standards and Measures, to assess the department's degree of readiness for accreditation;
- Using the Turning Point Performance Management Self-Assessment tool to determine strengths and weaknesses of the department's performance management;

Following the self-assessments, Needham will develop a plan to address deficiencies and will start to develop a comprehensive Quality Improvement plan.

Steps:

- Conduct self-assessment against Standards & Measures, identifying areas requiring improvement
    - Identify documentation available for each Domain
    - Identify documentation gaps

- Conduct Performance Management self-assessment
    - Identify strengths and weaknesses

- Work with Human Resources to determine how to address deficiencies

Phase II Completion date: **March 2017**

<u>Phase III: Quality Improvement Plan</u>
During this phase Needham will train staff on QI, will identify initial projects that will benefit from QI, and will develop a comprehensive QI plan.

Steps:
- Identify a QI Team
- Train staff on QI
- Establish a QI tracking system
- Develop QI plan
- Begin QI with identified projects

Phase III Completion date: **May 2017**

<u>Phase IV: Document Organization</u>
During this phase a plan to address gaps will be developed. A documentation management system will organize, track, and facilitate PHAB submission of documents.

Steps:
- Develop document management system including document standards, organization, and tracking
- Develop plan to produce necessary documents
- Assign staff responsible for documentation

Phase IV Completion date: **April 2017**

<u>Phase V: Application Pre-requisites</u>
During this phase Needham identifies or produces the three pre-requisites for accreditation:
- Community Health Assessment (CHA)
- Community Health Improvement Plan (CHIP)
- Department Strategic Plan

Steps:
- Evaluate value of BID-N Community Health Needs Assessment
- Develop plan to augment BID-N assessment
- Engage community support
- Develop and produce Community Health Assessment
- Analyze and write up Community Health Assessment – July 2017

- Develop and produce Community Health Improvement Plan – September 2017
- Develop and produce Department Strategic Plan – November 2017[1]

Phase V Completion date: **November 2017**

Phase VI: Application

During this phase Needham, having accomplished the pre-requisites, will submit the Letter of Intent to PHAB.

Steps:
- Submit Statement of Intent
- Submit accreditation fee
- Submit pre-requisites

Phase VI Completion date: **December 2017**

Phase VII: Meeting Accreditation Requirements

During this phase Needham will provide PHAB with all required documentation and respond to PHAB requests. Needham will also participate in all necessary training and orientation meetings.

Steps:
- Accreditation Coordinator will attend necessary meetings and orientations at PHAB
- Accreditation Coordinator will work with PHAB representative
- Assure that all required documentation meets PHAB requirements
- Submit required documentation

Phase VII Completion date: **July 2018**

Phase VIII: Site-Visit Preparation

During this phase a site-visit team will be established and prepared.

Steps:
- Identify members of the site-visit preparation team including Health Director, Accreditation Coordinator, community partners, BOH members.
- Solicit technical assistance from accredited local health departments.
- Conduct a mock site-visit

Phase VIII Completion date: **December 2018 or as determined by PHAB**

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[1] The Department Strategic Plan will likely happen much earlier than this; perhaps as early as December 2016 – January 2017.

Phase IX: Establish System for Re-Accreditation Readiness

Assuming that PHAB has granted accreditation, Needham will establish systems for assuring that the department maintains systems and standards to allow for annual reporting and re-application.

- Announce accreditation decision
- Celebrate with staff and community partners
- Establish systems for continued QI and document management

Phase IX Completion date: Determined by PHAB

PHAB

Advancing public health performance

Public Health Accreditation Board

STANDARDS: AN OVERVIEW

VERSION 1.5

Adopted December 2013

Public Health Accreditation Board

STANDARDS: AN OVERVIEW

ASSESS

DOMAIN 1:	Conduct and disseminate assessments focused on population health status and public health issues facing the community
Standard 1.1:	Participate in or Lead a Collaborative Process Resulting in a Comprehensive Community Health Assessment
Standard 1.2:	Collect and Maintain Reliable, Comparable, and Valid Data that Provide Information on Conditions of Public Health Importance and On the Health Status of the Population
Standard 1.3:	Analyze Public Health Data to Identify Trends in Health Problems, Environmental Public Health Hazards, and Social and Economic Factors that Affect the Public's Health
Standard 1.4:	Provide and Use the Results of Health Data Analysis to Develop Recommendations Regarding Public Health Policy, Processes, Programs, or Interventions

INVESTIGATE

DOMAIN 2:	Investigate health problems and environmental public health hazards to protect the community
Standard 2.1:	Conduct Timely Investigations of Health Problems and Environmental Public Health Hazards
Standard 2.2:	Contain/Mitigate Health Problems and Environmental Public Health Hazards
Standard 2.3:	Ensure Access to Laboratory and Epidemiologic/Environmental Public Health Expertise and Capacity to Investigate and Contain/Mitigate Public Health Problems and Environmental Public Health Hazards
Standard 2.4:	Maintain a Plan with Policies and Procedures for Urgent and Non-Urgent Communications

INFORM & EDUCATE

DOMAIN 3:	Inform and educate about public health issues and functions
Standard 3.1:	Provide Health Education and Health Promotion Policies, Programs, Processes, and Interventions to Support Prevention and Wellness
Standard 3.2:	Provide Information on Public Health Issues and Public Health Functions Through Multiple Methods to a Variety of Audiences

COMMUNITY ENGAGEMENT

DOMAIN 4:	Engage with the community to identify and address health problems
Standard 4.1:	Engage with the Public Health System and the Community in Identifying and Addressing Health Problems through Collaborative Processes
Standard 4.2:	Promote the Community's Understanding of and Support for Policies and Strategies that will Improve the Public's Health

POLICIES & PLANS

DOMAIN 5:	Develop public health policies and plans
Standard 5.1:	Serve as a Primary and Expert Resource for Establishing and Maintaining Public Health Policies, Practices, and Capacity
Standard 5.2:	Conduct a Comprehensive Planning Process Resulting in a Tribal/State/Community Health Improvement Plan
Standard 5.3:	Develop and Implement a Health Department Organizational Strategic Plan
Standard 5.4:	Maintain an All Hazards Emergency Operations Plan

PUBLIC HEALTH LAWS

DOMAIN 6:	Enforce public health laws
Standard 6.1:	Review Existing Laws and Work with Governing Entities and Elected/Appointed Officials to Update as Needed
Standard 6.2:	Educate Individuals and Organizations on the Meaning, Purpose, and Benefit of Public Health Laws and How to Comply
Standard 6.3:	Conduct and Monitor Public Health Enforcement Activities and Coordinate Notification of Violations among Appropriate Agencies

ACCESS TO CARE

DOMAIN 7:	Promote strategies to improve access to health care
Standard 7.1:	Assess Health Care Service Capacity and Access to Health Care Services
Standard 7.2:	Identify and Implement Strategies to Improve Access to Health Care Services

WORKFORCE

DOMAIN 8:	Maintain a competent public health workforce
Standard 8.1:	Encourage the Development of a Sufficient Number of Qualified Public Health Workers
Standard 8.2:	Ensure a Competent Workforce through Assessment of Staff Competencies, the Provision of Individual Training and Professional Development, and the Provision of a Supportive Work Environment

QUALITY IMPROVMENT

DOMAIN 9:	Evaluate and continuously improve processes, programs, and interventions
Standard 9.1:	Use a Performance Management System to Monitor Achievement of Organizational Objectives
Standard 9.2:	Develop and Implement Quality Improvement Processes Integrated Into Organizational Practice, Programs, Processes, and Interventions

EVIDENCE-BASED PRACTICES

DOMAIN 10:	Contribute to and apply the evidence base of public health
Standard 10.1:	Identify and Use the Best Available Evidence for Making Informed Public Health Practice Decisions
Standard 10.2:	Promote Understanding and Use of the Current Body of Research Results, Evaluations, and Evidence-Based Practices with Appropriate Audiences

ADMINSTRATION & MANAGEMENT

DOMAIN 11:	Maintain administrative and management capacity
Standard 11.1:	Develop and Maintain an Operational Infrastructure to Support the Performance of Public Health Functions
Standard 11.2:	Establish Effective Financial Management Systems

GOVERNANCE

DOMAIN 12:	Maintain capacity to engage the public health governing entity
Standard 12.1:	Maintain Current Operational Definitions and Statements of the Public Health Roles, Responsibilities, and Authorities
Standard 12.2:	Provide Information to the Governing Entity Regarding Public Health and the Official Responsibilities of the Health Department and of the Governing Entity
Standard 12.3:	Encourage the Governing Entity's Engagement In the Public Health Department's Overall Obligations and Responsibilities

PHAB

Advancing public health performance

The **PHAB STANDARDS** apply to all health departments—Tribal, state, local, and territorial. Standards are the required level of achievement that a health department is expected to meet. Domains are groups of standards that pertain to a broad group of public health services. The focus of the PHAB standards is "what" the health department provides in services and activities, irrespective of "how" they are provided or through what organizational structure. Please refer to the **PHAB Standards and Measures** Version 1.5 document, available at **www.phaboard.org**, for the full official standards, measures, required documentation, and guidance.

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