Demolition of High-Rise Public Housing Increases Particulate Matter Air Pollution in Communities of High-Risk Asthmatics

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ABSTRACT

Public housing developments across the United States are being demolished, potentially increasing local concentrations of particulate matter (PM) in communities with high burdens of severe asthma. Little is known about the impact of demolition on local air quality. At three public housing developments in Chicago, IL, PM with an aerodynamic diameter <10 μm (PM_{10}) and <2.5 μm were measured before and during high-rise demolition. Additionally, size-selective sampling and real-time monitoring were concurrently performed upwind and downwind of one demolition site. The concentration of particulates attributable to demolition was estimated after accounting for background urban air pollution. Particle microscopy was performed on a small number of samples. Substantial increases of PM_{10} occurred during demolition, with the magnitude of that increase varying based on sampler distance, wind direction, and averaging time. During structural demolition, local concentrations of PM_{10} 42 m downwind of a demolition site increased 4- to 9-fold above upwind concentrations (6-hr averaging time). After adjusting for background PM_{10}, the presence of dusty conditions was associated with a 74% increase in PM_{10} 100 m downwind of demolition sites (24-hr averaging times). During structural demolition, short-term peaks in real-time PM_{10} (30-sec averaging time) occasionally exceeded 500 μg/m^3. The median particle size downwind of a demolition site (17.3 μm) was significantly larger than background (3 μm). Specific activities are associated with real-time particulate measures. Microscopy did not identify asbestos or high concentrations of mold spores. In conclusion, individuals living near sites of public housing demolition are at risk for exposure to high particulate concentrations. This increase is characterized by relatively large particles and high short-term peaks in PM concentration.

IMPLICATIONS

Demolition of public housing high-rise structures using heavy equipment causes large increases in local concentrations of particulate matter, which, unlike demolition by implosion, may be sustained over weeks. The particulates generated are relatively large, and their temporal distribution is characterized by high but short-lived peaks in concentration. Because public housing demolition is taking place on a national scale in communities with substantial burdens of severe asthma, communication with affected communities and dust suppression measures are advised.

INTRODUCTION

In 1992, the National Expert Panel on Severely Distressed Public Housing advised that thousands of units of public housing be demolished.[1] Subsequently the U.S. Department of Housing and Urban Development (HUD) initiated the HOPE VI program, which allocated more than (U.S.)$395,000,000 between 1996 and 2003 to fund the demolition of 57,593 units of public housing.[2] Thousands of additional HUD units will be demolished, within and outside of the HOPE VI program. The demolition of public housing structures typically occurs in minority, low-income, urban communities, which, in Chicago, IL, tend to have higher prevalence rates of asthma[3] and more severe asthma than the general population.[4,5] A study conducted in public housing developments slated for HOPE VI demolition estimated that 25% of children <6 years of age have asthma, and one in eight children of all ages have had an emergency department visit for asthma in the preceding 12 months.[6] Demolishing public housing structures could result in higher local concentrations of particulate matter (PM) air pollution, which may adversely affect the respiratory health of nearby residents.

Demolition by implosion has been associated with local increases in particulate matter. The demolition of a 22-story residential structure in Baltimore, MD, by implosion resulted in short-term concentrations of PM that were >1000 times higher than pre-implosion levels; averaged over 24 hr, however, U.S. Environmental Protection Agency (EPA) air quality standards were not violated.[7] The implosion of a hospital in Calgary, Alberta, Canada, similarly produced

Table 1. Characteristics of three sites of public housing demolition.

	Demolition Site 1 Robert Taylor Homes	Demolition Site 2 Stateway Gardens	Demolition Site 3 ABLA
Period of observation	7/21/02-10/17/02	10/25/02-11/25/02	10/24/03-1/29/04
Building size	16-story	17-story	15-story
Construction	Brick and steel; dry wall interior	Brick and steel, cinderblock interior	Brick and steel, cinderblock interior
Interior demolition technique	Plow interior walls and push debris down elevator shaft opened to outside	None	Limited plowing activity
Structural demolition technique	Wrecking ball	Excavators fitted with pneumatic jacks	Excavators fitted with pneumatic jacks; torching and cutting for metal salvage
Distance from demolition site to sampler	125.6 meters	95.6 meters	86.6 meters
Direction from center of demolition site to sampler ⟶ **(S=sampler)** **Dominant wind direction during sampling at site** ⋯⋯▶	North Wind↘ S↘	North Wind↗ S↙	North Wind↗ S↗

very high peak concentrations, as well as violations of the 24-hr Canadian standard for total suspended particulates (TSPs).[8]

In Chicago and other urban areas, public housing high-rise demolition is taking place using techniques other than implosion. Mechanical disruption of structures is accomplished using heavy equipment, such as the wrecking ball, pneumatic jack, and excavator. Although this would be expected to produce lower peak exposures, structural demolition takes place over weeks, compared with the near-instantaneous implosion method. This may increase local concentrations of PM over an extended period of time in areas where residents of adjacent buildings continue to reside.

We conducted a series of air quality investigations, which sought to answer the following questions about the locally generated PM during demolition: (1) what is the magnitude of local increases in PM attributable to demolition?; (2) what is the size of particles generated at sites of public housing demolition?; (3) what are the temporal characteristics of local PM concentrations during demolition (i.e., do short-term peaks in particulate concentrations occur)?; (4) what activities at a site of structural demolition are associated with changes in real-time particulate measures?; and (5) would particle microscopy identify asbestos or high concentrations of mold spores in air samples taken adjacent to demolition?

EXPERIMENTAL WORK
Demolition Sites
Three sites of high-rise public housing demolition were studied, all of which were within 100 m of occupied high-rise public housing structures. All three of the sites were within 250 m of a school or community building. Table 1 highlights differences between the sites regarding their structural characteristics and the demolition methods used. Other differences between housing developments include the direction from each demolition site to the dichotomous samplers and the dominant wind direction during sampling at each site.

General Approaches to Identifying PM Generated by Demolition
To differentiate locally generated PM at sites of demolition from background urban air pollution (UAP), two general approaches were used. The first involved fixed-site sampling of local PM at the demolition sites (i.e., the mixture of locally generated and regional PM), obtaining regional PM measures, and then modeling local PM as a function of regional PM and demolition (present or absent). The second approach involved measuring particulates at a demolition site (i.e., the mixture of locally generated and background PM) and concurrently upwind of the site (background UAP). The difference between the two measurements was taken to reflect the contribution of demolition to local PM.

Approach 1: Fixed-Site Dichotomous Sampling at Three Demolition Sites. At each housing development, fixed-site monitoring stations were selected for placement of the dichotomous samplers on the basis of proximity, power supply, security, and access. Based on the above considerations, Graseby-Andersen Series 241 Dichotomous $PM_{10}/PM_{2.5}$ samplers were placed on roofs of 1- to 2-story buildings located ~100 m away from the perimeter fences of the demolition sites. Samplers were operated at flow rates of 16.7 L/min for 24 hr (midnight to midnight) 5 days per week for ~8 consecutive weeks at each of the three sites covering both predemolition and demolition time periods (predemolition sampling occurred during the weeks immediately before demolition). Three or four samplers were present at each site. Every 2–3 days, flow rates and timer

settings of all of the pumps were checked, and filters were changed in the samplers that had run in the preceding 1–2 days. Visual observations of demolition activities and the presence or absence of dusty conditions were recorded at the time of flow check/filter change. PM was collected on 37-mm polytetrafluoroethylene (PTFE) 2-μm pore filters (Gelman Sciences). Before use in the field, filters were placed in Petri dishes, desiccated for a minimum of 48 hr, then weighed on a Sartorius MC-5-μg balance a minimum of three times on each of 2 days. After sampling in the field, desiccation and weighing procedures were repeated. The precision of mass measurement of filters was maintained by reweighing filters if, after three mass measurements, the standard deviation was >5 μg. Quality assurance procedures included the use of field blanks, laboratory blanks, and check weights.

Approach 2: Size Selective, Upwind-Downwind Sampling and Real-Time Monitoring at One Development. During 6 days of structural demolition at the ABLA development between January 15 and February 3, 2004, intensive sampling was performed, including upwind-downwind sampling, size-selective sampling, integrated gravimetric sampling, and real-time particulate monitoring. On each of 6 days, sampling began at ~8:00 a.m. and continued for 6 hr. The prevailing wind direction was determined each day before the initiation of sampling. The average distances from the center of the demolition site to the main, downwind, and upwind stations were 41.8, 77.1, and 192 m, respectively. At each of the three sampling stations, the following instruments were used concurrently: (1) a Marple cascade impactor (Model 298, Thermo Corp.) with glass fiber filter media, operated at 2 L/min; (2) an Institute of Medicine (IOM) sampler with polyvinyl chloride filter operated at 2 L/min; and (3) a Personal Data Ram (pDR), Model 1200 (Thermo Corp.). The cascade impactor allows measurement of concentrations of PM in each of nine size fraction, ranging from <0.52 to >21.3 μm in aerodynamic diameter. The IOM sampler measures PM in the inhalable size range (<100 μm aerodynamic diameter). The pDR measures PM concentration in real time with a 30-sec averaging time by measuring the scattering of light through sampled air. These real-time instruments were operated in active mode without heated inlets or prefiltering with cyclones, and, as calibrated and configured, are most accurate in the 1–10 μm range. When a prefilter is not used, particles above that range are measured with less accuracy. Thus, in our setting, the pDRs were used to monitor relative changes in PM concentrations over short (30-sec) time intervals rather than to provide an absolute measure of concentration for a well-defined size fraction. For each set of cascade impactor samples, log-probability plots of cumulative PM concentrations versus particle size were used to determine mass median aerodynamic diameter. Procedures for gravimetric analyses of filters used in the size-selective sampling were as described for dichotomous sampling. Real-time particulate concentrations were measured continuously at all three stations with the pDRs, which were zeroed with high-efficiency particulate air filters each day before use. During the 6 days of intensive sampling, a log of observations of demolition activities was maintained by members of the research team and industrial hygiene trainees. Every 5 minutes, the following were recorded in a chart: visible dust, water spraying, bulldozer activity on the ground, structural demolition by excavator, fire burning (used by workers to warm their hands), rock crushing, plowing of debris out of the upper floors of the structure, wrecking ball striking building, loading of debris into trucks, trucks entering/leaving site, and excavator sorting/moving debris.

Particle Microscopy

Particulate matter air samples were obtained over 2 consecutive days in January 2003 at the Stateway Gardens development during excavator and jackhammer structural demolition. Samples were obtained simultaneously at the perimeter fence of the demolition site, as well as 102 m upwind and 42 m downwind of the site. Air was sampled using six open-face cassettes (flow rate: 2.2 L/min) and a Respicon sampler (flow rate: 3.3 L/min) for a mean of 391 min through a total of nine glass fiber filters (six open face; three Respicon). Samples were analyzed by an American Industrial Hygiene Association, National Voluntary Laboratory Accreditation Program, and Environmental Laboratory Accreditation Program-accredited laboratory (MACS Labs, Santa Clara, CA). For particle and fiber characterization, phase-contrast and polarized microscope were used. For phase-contrast microcopy of minerals, National Institute of Standards and Technology and/or American Society for Testing and Materials-traceable reference standards were used to identify particles and fibers. Spores and conidiospores were analyzed by transmitted light microscopy and classified by taxon. For each type of particle, fiber, and conidiospore identified, concentrations per meter cubed of air sample were calculated based on examination of 100 optical (Graticule) fields in each of the nine filters.

Regional Measures of Air Quality

Regional measures of air quality were obtained from the Illinois Environmental Protection Agency network of monitoring stations. The nearest stations with daily coarse PM (PM_{10}) and fine PM ($PM_{2.5}$) measurements during the study period are located ~11.7 miles southeast and 7.2 miles southwest of the demolition sites, respectively. Wind speed and direction data were obtained from the National Climatic Data Center Midway Airport monitors 6.6 miles southwest of the demolition sites. We categorized the dominant wind direction on each day of PM collection at the fixed dichotomous sites as being predominantly "upwind," "downwind," or neither. If the dominant wind direction was <75° from the site-to-sampler line, the sampler was considered to be downwind of the site that day. If the dominant wind direction was >105° from the site-to-sampler line, the sampler was considered to be upwind of the site that day. The cutoffs of <75° and >105° for these wind direction categories were chosen as a balance between more restrictive cutoffs (such as <30° and >150°), which produce fewer, but more accurately categorized, data points versus less restrictive cutoffs (such as <90° and >90°), which would provide more, but less accurate data points.

Data Analysis

Impact of Demolition on Local PM, Approach 1. PM concentrations derived from approach 1 (fixed-site dichotomous PM_{10}/$PM_{2.5}$ sampling at three housing developments before

and during demolition with 24-hr averaging times) were log-normally distributed and were log transformed for comparisons of means. Geometric means and standard deviations were calculated for each site, and analysis of variance (ANOVA) and *t* tests were performed to compare means by site, stage of demolition, and whether or not dusty conditions were observed. Locally measured (at the demolition site) and regionally measured (by EPA monitoring stations) were correlated (Pearson correlation coefficient for log-transformed PM_{10} was 0.52 [$P < 0.0001$] and for log-transformed $PM_{2.5}$ was 0.40 [$P = 0.0002$]). Because of that correlation, we attempted to characterize the relationship between local PM and demolition independent of regional air quality. Linear regression modeling was performed to predict local PM measures based on regional PM, the presence of demolition, and average daily wind speed, which is known to be associated with PM[9] as follows:

$$Local\ PM = \beta_0 + \beta_1 * Regional\ PM + \beta_2 * Demolition$$
$$+ \beta_3 * Wind\ speed \quad (1)$$

where *Demolition* is a dichotomous variable, predemolition is 0, and demolition period is 1. The regression coefficient for demolition (β_2) equals the change in local PM associated with demolition, after adjusting for regional PM and wind speed. To estimate the increase in PM during demolition on days when dusty conditions were observed, the following model was applied to the subset of measurements made during the demolition periods:

$$Local\ PM = \beta_0 + \beta_1 * Regional\ PM + \beta_2 * Dusty\ conditions \quad (2)$$

The regression coefficient for dusty conditions (β_2) equals the change in local PM associated with dusty conditions, after adjusting for regional PM. In contrast to eq 1, wind speed was not a significant predictor when added to eq 2. Coefficients for indicator variables for the demolition sites were not significant in the above models, and for that reason, the data from the three sites were pooled for modeling. Log transformation was not performed in regression analyses to simplify interpretation of the regression coefficients (i.e., the change in locally measured PM attributable to demolition). Plots of residuals versus predicted local PM concentrations and the White test did not reveal any heteroscedasticity, supporting the analysis of nontransformed data.

The dichotomous sampler sites were fixed at each of the three housing developments so that some of the time the dominant wind direction was from the demolition site to the sampler, and at other times it was not. The regression equations were applied to the dataset overall and also to subsets of data based on wind direction. To evaluate the relative increase in particulates attributed to demolition, ratios were calculated of the regression coefficients for "demolition" to the respective background concentrations (regional PM geometric mean, same time periods). This was repeated to evaluate the relative increase in particulates during the demolition period when dusty conditions were observed. Relative increases in local PM associated with demolition and dusty conditions were calculated for the dataset overall and also for the subset of days that the samplers were downwind of the demolition sites.

Impact of Demolition on Local PM, Approach 2. The second approach to differentiating local from regional PM made use of the results of upwind/downwind and size-selective sampling for 6 hours per day during structural demolition at the ABLA development. Because of the relatively small sample size (sampling was performed on 6 days), geometric mean concentrations of particulates measured by each type of sampler at each sampling station over the entire 6 days of sampling were calculated.[10] For each sampler type, paired *t* tests were performed for same-day measures of PM comparing stations near the demolition site (main and downwind stations) to that measured at the downwind site. In the case of real-time particulate measures, both daily mean and daily peak values were analyzed. The difference between the main station and the upwind site was used to estimate the concentration of PM attributed to demolition. To evaluate the relative increase in particulates attributed to demolition, ratios were calculated of locally generated PM to background (upwind) concentrations.

Estimates of the impact of specific demolition activities and dust suppression by water spraying on local air quality were calculated using real-time PM measures during 6 days of structural demolition at the ABLA development. PM measurements were not normally distributed, even after excluding values above the 95th and below the 5th percentiles or after log transforming that restricted dataset. For that reason, the Wilcoxon test was used to determine the statistical significance of differences of real-time PM based on the presence or absence of water spraying, during different demolition activities, as well as during ~100 min over the 6 days when no demolition activities were taking place. To determine whether specific demolition activities may be associated with elevated concentrations of PM, a dichotomous variable was created to indicate whether main station 10-min rolling average real-time PM was either above or below the median value. Odds ratios and confidence intervals for association between activities and the dichotomous PM variable were calculated. Statistical analyses were performed using SAS, version 8.12 (SAS Institute) and Microsoft Excel. A 0.05 level of statistical significance was used.

RESULTS
The Magnitude of the Increase in PM Attributable to Demolition

Approach 1. Local PM concentrations (24-hr averaging time) measured at three demolition sites with dichotomous samplers were obtained on 120 days of sampling. Of those 120 days, both local and regional PM_{10} measurements and local $PM_{2.5}$ were available on 116 days, and PM analyses are based on those 116 sets of measurements. PM concentrations were log-normally distributed, and comparisons of concentrations were performed on log-transformed values. For the entire dataset (covering both predemolition and demolition phases at the three housing developments), geometric mean (GM) PM_{10} concentrations in micrograms per cubic meter and (geometric standard deviation) were 20.3 (1.7), $PM_{10-2.5}$ were 7.9 (2.1), and $PM_{2.5}$ were 11.5 (1.7). $PM_{2.5}$ concentrations were not significantly different at the

Table 2. Demolition, dusty conditions, and concentrations of particulate matter at local and regional monitoring stations.

| | All Days of Sampling | | | | | Days Samplers Downwind of Sites | | | | |
| | Predemolition | | Demolition | | | Predemolition | | Demolition | | |
PM Measure	n	Conc.	n	Conc.	Difference	n	Conc.	n	Conc.	Difference
PM_{10} local	50	17.1	66	23.2	6.1**	21	15.2	24	25.4	10.1**
PM_{10} regional	50	17.4	66	19.2	1.8	21	17.3	24	21.4	4.2
$PM_{2.5}$ local	50	10.9	66	11.9	1.0	21	9.6	24	13.2	3.6
$PM_{2.5}$ regional	26	17.4	61	14.6	−2.8	7	13.1	22	14.2	1.1
$PM_{10-2.5}$ local	50	5.4	66	10.2	4.7**	21	4.9	24	10.5	5.6**

| | Demolition, All Days | | | | | Demolition, Days Samplers Downwind | | | | |
| | Not Dusty | | Dusty | | | Not Dusty | | Dusty | | |
PM Measure	n	Conc.	n	Conc.	Difference	n	Conc.	n	Conc.	Difference
PM_{10} local	18	20.1	11	30.4	10.3*	7	19.3	5	32.2	12.9
PM_{10} regional	18	18.1	11	19.7	1.7	7	17.6	5	18.4	0.8
$PM_{2.5}$ local	18	11.6	11	16.6	5.0	7	11.4	5	17.4	6.0
$PM_{2.5}$ regional	16	11.7	10	14.2	2.5	7	12.8	5	13.9	1.1
$PM_{10-2.5}$ local	18	7.4	11	12.9	5.5*	7	6.1	5	14.1	8.0*

Notes: Local PM concentrations are based on dichotomous sampling, 24-hr averaging times, at three housing developments (approach 1). Geometric mean concentrations are reported by subsets of days of sampling, based on the phase of demolition (predemolition vs. demolition), whether the samplers were downwind of the demolition sites, and, during demolition, whether dusty conditions were observed. Results are limited to 116 days for which local and regional PM_{10} data were available; Conc. = concentration, $\mu g/m3$; n = number of observations; *$P < 0.05$; **$P < 0.01$.

three demolition sites, but at one of the developments (Robert Taylor Homes), concentrations of larger particles were significantly higher than at the other two sites (for PM_{10} GM = 25.2 vs. 17.8 and 18.8 at the other two sites, ANOVA $P = 0.008$; for $PM_{10-2.5}$ GM = 11.8 vs. 6.6 and 6.4 at the other two sites, ANOVA $P < 0.0001$).

Local PM_{10} and $PM_{10-2.5}$ were higher during demolition phases compared with the predemolition phases at the developments, whereas $PM_{2.5}$ concentrations were not different (Table 2). During demolition periods, on days that dusty conditions were visually noted at the sites, local PM_{10} and $PM_{10-2.5}$ were considerably higher than when dusty conditions were not noted (Table 2). The differences in local PM concentrations noted above (predemolition vs. demolition and nondusty demolition vs. dusty demolition) were accentuated in analyses restricted to the days that the dominant wind direction was within 75° of the site-to-sampler line. Background PM concentrations measured at regional EPA monitoring stations were not different in the predemolition vs. demolition periods or in the dusty vs. nondusty demolition periods. This suggests that the higher concentrations of PM at the demolition sites during demolition and on dusty days were not because of increases in background regional particulate pollution. Particularly dusty conditions were noted in two main settings. The first was during interior demolition at housing development 1 when drywall and other dry interior debris were plowed from the upper floors into elevators chutes. Debris then fell to the bottom of the chute, which had been opened to the exterior of the building, where the falling materials stuck the ground and created dust plumes (Figure 1). The second period of frequent observations of dusty conditions was during structural demolition at all three of the housing developments.

In multivariate regression models, wind speed, demolition, and regional PM_{10} were all significant independent predictors of local PM_{10} (Table 3). After adjusting for wind speed and regional PM_{10}, demolition was associated with a 4.5-$\mu g/m^3$ increase in local PM_{10}. On days that the samplers were downwind of the demolition sites, the average increase in local PM_{10} during demolition was 9 $\mu g/m^3$. When the samplers were upwind of the demolition sites, regional PM_{10} had a stronger influence, and demolition had a weaker influence on local PM_{10} than when the samplers were downwind of the demolition sites. No point sources of PM_{10} were present in the vicinity of the three sites in the upwind direction (based on the demolition site to sampler line).

Figure 1. Dusty conditions at housing development 1 during interior demolition. Dry interior debris from the upper floors was plowed into an empty elevator chute, which had been opened to the exterior of the building. In the foreground is a dichotomous $PM_{10}/PM_{2.5}$ sampler.

Table 3. Effects of demolition, regional PM_{10}, wind speed, and wind direction on local PM_{10}.

Position of Sampler Relative to Demolition	Number of Samples	Demolition Effect	Regional PM_{10} ($\mu g/m^3$) Effect	Wind Speed (mi/hr) Effect
Downwind	45	9.0*	0.3	−1.0
Upwind	49	1.6	0.7*	−0.8
Intermediate	22	0.6	0.9*	0.2
All	116	4.5*	0.6*	−0.7*

Notes: Data based on approach 1, with local PM measured with dichotomous samplers, 24-hr averaging time, at three demolition sites. Effects are regression coefficients for the unit change in local PM_{10} ($\mu g/m^3$) per unit change in the above predictors. *$P < 0.05$.

Approach 2. The second approach to estimating the concentration of local PM generated by demolition was to compare PM concentrations measured simultaneously at, downwind, and upwind of the demolition at the ABLA development during 6 days of structural demolition. Sampling occurred at three monitoring stations on each of 6 days for a mean of 360 (± 46.6) min per sampler per day. Measurements of the pDR as calibrated and configured are most accurate in the 1–10 μm range; however, the median size of demolition PM was above that range (see below). For that reason, our real-time PM measurements reflect relative changes in PM concentrations over short (30-sec) time intervals, rather than providing an absolute measure of concentration for a well-defined size fraction. Results (Table 4) are, therefore, reported as a size fraction for the IOM sampler (inhalable, <100 μm aerodynamic diameter) and simply as "real-time PM" for pDR data. Geometric mean concentrations of particulates at the main and downwind monitoring stations were higher than those at the upwind station. Paired *t* tests demonstrate substantially higher PM concentrations at and downwind of the demolition site compared with background (measured at the upwind monitoring station). The only PM measure that was higher at the demolition site than at the downwind monitoring station was daily peak real-time PM.

A summary of the increase in PM attributable to demolition is presented in Table 5. Results of approach 1 (dichotomous sampling with a 24-hr averaging time, 100 m from three demolition sites, to model local PM_{10} as

a function of regional PM, demolition, and wind direction) are summarized in Table 5, A and B. Relative increases in local PM associated with dusty conditions during demolition were larger for PM_{10} than for $PM_{2.5}$, which may be explained by the large size of particles generated by demolition (see below). Thus, dusty conditions may reflect substantial local increases in large particles, with demolition producing greater increases in PM_{10} than in $PM_{2.5}$. Estimates of the relative increase in local PM because of demolition were larger on days that the dominant wind direction was from the demolition sites to the samplers. The estimated increases in PM derived from approach 2 (simultaneous upwind-downwind sampling, 6-hr averaging time over 6 days of structural demolition at the ABLA development) are presented in Table 5C. Based on this approach, demolition was associated with higher local geometric mean PM concentrations that, depending on sampler used, represent 384.7–932.2% of background. The increase in peak concentrations of real-time PM is much larger than changes in mean concentration.

Size of Particles Attributable to Demolition

Geometric means of particle size were calculated using cascade impactor (CI) data. Of the 18 sets of CI data (three sites on each of 6 days), three sets were excluded from analysis because ≤3 stages contained nonnegative field blank-adjusted particle concentrations. As displayed in Table 4, at the upwind sampling station, the geometric mean particle size was considerably smaller than at the main and downwind stations (paired *t* test; $P < 0.05$).

Temporal Characteristics of Particulate Matter during Demolition

An example of real-time PM concentrations (30-sec averaging time), along with concurrent observations, is presented in Figure 2. On top of a fluctuating baseline of particulate concentrations, brief short-term peaks are noted, as well as an overall decrease during the lunch break (12:00–12:30 p.m.) of demolition workers. Wind speed (range: 8–11 mph) and direction (range: 120–150° from north) were quite constant that day during the sampling period and for that reason do not account for the higher PM concentrations in the afternoon. Excavator demolition activities (such as knocking down walls) in the afternoon may have resulted in higher concentrations of PM. Figure 2 suggests higher local PM concentrations in

Table 4. Mean daily PM measures, by sampling station during 6 days of demolition.

PM Measure (units)	Sampler	Sampling Station and Distance from Center of Demolition Site		
		Main (42 m)	Downwind (77m)	Upwind (192 m)
Median particle size (μm)	Cascade impactor	16.8 (1.3)**	17.3 (2.8)*	3.0 (1.3)
Inhalable PM conc. ($\mu g/m^3$)	Institute of Medicine	566.7 (1.4)**	283.8 (2.8)*	54.9 (1.3)
Real-time PM-GM ($\mu g/m^3$)	Personal DataRam	139.1 (1.3)*	115.9 (4.0)*	28.7 (1.9)
Real-time PM-peak ($\mu g/m^3$)	Personal DataRam	3967.5 (2.6)**,***	737.9 (2.0)*	142.6 (2.7)

Notes: Sampling performed at the ABLA development (approach 2). Values presented as geometric means and (geometric standard deviation). Daily peak concentration based on 30-sec averaging time; all other measures are based on 6-hr averaging times). Inhalable PM indicates an aerodynamic diameter of <100 μm. Real-time PM size fraction undefined (see text). *P* of paired *t* test for the comparison to same-day, same-sampler type log-transformed PM measure at upwind location; *<0.05 and **<0.01; ***P* of paired *t* test for the comparison to same-day, same-sampler type, log-transformed PM measure at downwind location <0.05.

Table 5. Increases in local PM attributable to demolition, relative to background.

A. Demolition.

Sampling Days	n	Predemolition Background Concentration		Increase Because of Demolition		Percent Increase Because of Demolition	
		PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
All	50	17.1	10.9	4.5	0.9	26.3	8.3
Downwind only	21	15.2	9.6	9	3.9	59.2	40.6

B. Dust.

Sampling Days	n	Demolition Background Nondusty Days		Increase Because of Dusty Conditions		Percent Increase Because of Dusty Conditions	
		PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
All	18	20.1	11.6	10.4	2.5	51.7	21.6
Downwind only	7	19.3	11.4	14.3	4.2	74.1	36.9

C. Upwind-Downwind Sampling.

Sampler	n	Background PM Concentration	Increase Because of Demolition	Percent Increase Because of Demolition
IOM (inhalable)	6	54.9	511.8	932.2
pDR (real-time mean)	6	28.7	110.4	384.7
pDR (peak)	6	142.6	3824.9	2682.2

Notes: Data in A and B are from approach 1 (dichotomous sampling 100 m away at three demolition sites with 24-hr averaging times). Data in C is from approach 2 (size-selective sampling during 6 days of structural demolition 42 m away from one site, with 6-hr averaging times). For A and B, 'Background' refers to predemolition geometric means (from Table 2); 'Increase because of Demolition' is adjusted for regional PM and, for PM_{10}, wind speed, as presented in Table 3. Concentrations in C come from Table 4. Background concentration was measured at the upwind station, whereas increase because of demolition is the difference in concentration between main and upwind stations.

the afternoon than in the morning, although dusty conditions were noted during both periods. This may be because dusty conditions were recorded as being either present or absent, even if, in the afternoon, conditions appeared considerably more dusty than they did in the morning. Over the 6 days of sampling, based on 30-sec averaging times at the main station monitor, 39 short-term peaks occurred in which PM concentrations were 10 times higher than the median value of 57 $\mu g/m^3$ at that station. Figure 3 demonstrates that real-time PM measures were lower at the upwind site than at the main or downwind site and that the averaging time used to characterize real-time PM impacts the variability of the measures. Comparing the 30-sec and 60-min averaging times side by side, it is apparent that although mean and median concentrations are essentially unchanged by averaging times, the longer averaging time results in the loss of information about extremely high short-lived peaks in PM.

Demolition Activities and Real-Time Particulate Concentrations

Table 6 summarizes geometric mean concentrations of real-time PM during 6 days of structural demolition at the ABLA development. Concentrations of PM (10-min averaging time) varied by activity and by the presence or

absence of water spraying. Water spraying was associated with significantly lower PM concentrations during several demolition activities (bulldozer activity, excavator demolition, and rock crushing), although water spraying was associated with substantially higher concentrations of PM when fires were burning. Concentrations of PM were more likely to be above the median when the following specific activities or observations were present: visible dust (odds ratio: 2.9; 95% confidence interval: 2–4.4), excavator moving debris (odds ratio: 2.9; 95% confidence interval: 1.9–4.4), and rock crushing (odds ratio: 1.7; 95% confidence interval: 1–2.9). Water spraying was associated with a decreased odds ratio for real-time PM above the median (odds ratio: 0.16; 95% confidence interval: 0.09–0.28), as were loading debris (odds ratio: 0.28; 95% confidence interval: 0.17–0.48) and excavator demolition (odds ratio: 0.59; 95% confidence interval: 0.38–0.92).

Microscopy of Demolition Particulates

Microscopic analyses of nine samples (six from open-face samplers and three from stages of a Respicon sampler) obtained during structural demolition of the Stateway Gardens development identified no asbestos. Concentrations of mold spores averaged 100–300 spores/m^3 for *Aspergillus/Penicillium, Cladosporium,* and *Basidiospores,*
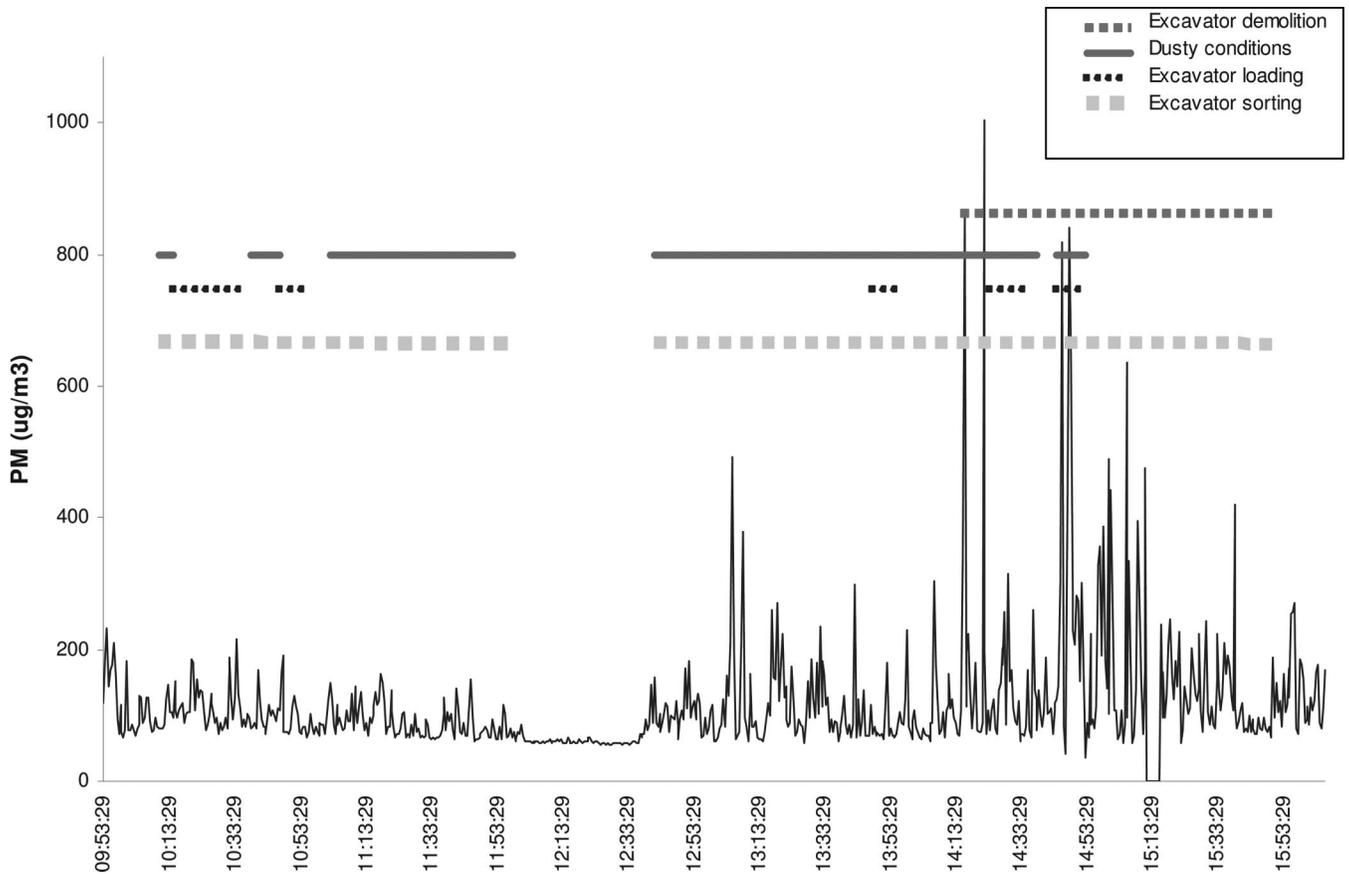
Figure 2. Observations during structural demolition and real-time particulate concentrations (30-sec averaging time) housing the ABLA development, day 6.

and concentrations between the upwind and other sites were not different. At the main and downwind sites, calcium carbonate particles were seen in higher concentration than at the upwind site (9.1 million/m³ vs. 1.1 million/m³; $P = 0.1$). Silicate concentrations were also higher than at the upwind site (138,636 particles/m³ vs. 0), but this difference was not statistically significant either.

DISCUSSION
Our Findings in the Context of Previous Research

By comparing same-day measures of local (from dichotomous samplers) and regional (from EPA monitoring stations), as well as by comparing upwind and downwind samples obtained on the same day by the same type of
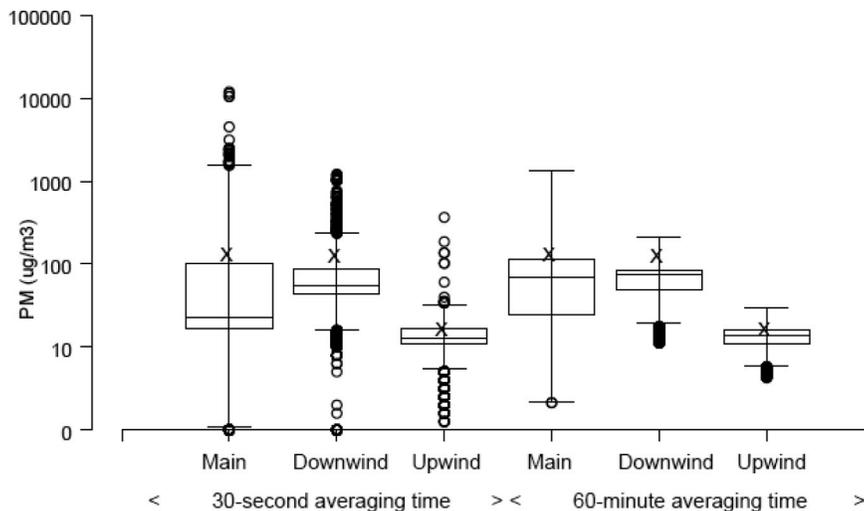

Figure 3. Influence of averaging times (30 sec vs. 60 min) on observations of extreme values of real-time PM at three monitoring stations during 6 days of structural demolition at the ABLA development. Box and whiskers plots: X indicates mean; upper, middle, and lower lines of "boxes" indicate seventy-fifth, fiftieth, and twenty-fifth percentiles. "Whiskers" indicate values 1.5 times the interquartile range. Circles indicate observations beyond the "whiskers."

Table 6. Concentrations of PM with and without water spraying, by activity/observation.

Observation	No Water Spraying		Water Spraying		Difference (no water-water)
	N	Mean (SD)	N	Mean (SD)	
Bulldozer activity	57	82.9 (68.2)	14	56.0 (40.3)	26.9[a]
Excavator demolition	68	103.5 (86.4)	43	54.4 (36.9)	49.1[a]
Excavator loading debris	44	80.2 (68.1)	44	84.1 (258.2)	−3.9[b]
Excavator moving debris	134	175.1 (249.9)	0		
Fire burning	185	150.2 (225.0)	36	321.7 (996.4)	−171.5[b]
Light snow	66	156.0 (221.2)	0		
Plowing debris	66	83.4 (87.5)	19	56.4 (51.8)	27
Rock crushing	51	121.1 (77.2)	9	45.0 (6.3)	76.1[a]
Trucks enter/leave	7	71.4 (26.1)	4	45.6 (6.7)	25.8
Visible dust	156	133.2 (151.9)	27	52.8 (41.8)	80.4[b]
Wrecking ball activity	0		74	139.0 (215.0)	
No demolition activities	10	71.4 (15.4)			

Notes: SD = standard deviation; Data based on arithmetic means of real-time estimates of PM (μg/m^3) with 10-min averaging time, 6 hr/day over 6 days adjacent to structural demolition at the ABLA development. *P*: Wilcoxon two-sided [a]$P < 0.05$; [b]$P < 0.01$.

samplers, we note increases in particulates attributable to public housing demolition. Although EPA lists demolition as a source of PM$_{10}$,[11] limited information currently exists regarding the amounts and physical characteristics of particulates released by such activities, and EPA does not have an emissions factor for demolition.[12] Two studies of demolition by implosion noted extremely high instantaneous TSP concentrations: in one study, a maximum 1-min average was 54,000 μg/m^3,[7] and in the other, a 10-sec average was >99,999 μg/m^3.[8] In both of those studies, peak concentrations dramatically decreased within minutes to hours after implosion, although at some monitoring sites they remained elevated compared with baseline measures. Because structural demolition by mechanical disruption occurs over weeks rather than minutes, the elevated concentrations of particulates are sustained over a much longer time frame than when implosion is used.

We note a range of estimates of the impact of demolition on local PM concentrations, as summarized in Table 5. The wide range of estimates results from differences in the methods of PM monitoring used, as well as differences in the activities at demolition sites during the dichotomous sampling and the intensive sampling. Estimates of the concentrations of PM generated by demolition are lower in analyses of dichotomous sampler data than those based on data for the other sampler types for several reasons. First, the dichotomous samplers operated from midnight to midnight, whereas the other sampler types only operated during hours of active demolition. The dichotomous samplers operated from a mean distance of 103 m from center of the three demolition sites, whereas the samplers at the "main station" during intensive sampling were 42 m away from the center of a demolition site. Additionally, the intensive sampling at that site took place during a phase of active structural demolition, whereas "demolition," as defined during dichotomous sampling, also included days in which activities less likely to generate PM took place (such as site preparation and indoor salvage activities). As would be expected, wind direction impacted the estimates of the contribution of demolition to local PM. The estimated concentration of PM$_{10}$ attributable to demolition was twice as high in the analyses of those days that the wind blew from site to sampler (9 μg/m^3) compared with the average of all days (4.5 μg/m^3). The dichotomous samplers were downwind of the site only on a subset of days, therefore, the average mass of PM collected each day was lower than if the samplers were consistently downwind. The strong influence that wind direction (relative to the demolition sites and sampler locations) had a on the estimate of change in PM attributed to demolition (Table 3) provides support for the validity of our dichotomous monitoring as a means of measuring the impact of demolition. Our observation that the mass median aerodynamic diameter is ~17 μm is consistent with findings in a study of roadway construction that showed that >65% of particles generated were >10 μm in size.[13] Dust samples collected outdoors after the destruction of the World Trade Center were mainly (by mass) >53 μm in diameter,[14] considerably larger than we noted. However, we sampled ambient air, whereas the World Trade Center samples were of settled dust, which one would expect to contain larger particles. Although the mass median aerodynamic diameter of particles near the demolition site was in the inhalable range, we also note that on days in which dusty conditions were observed at the demolition sites, local PM$_{2.5}$ was also higher than baseline (although not at a 0.05 level of statistical significance), possibly because of the operation of diesel-powered heavy equipment. Microscopy was reassuring in that it did not identify asbestos or high concentrations of mold spores. Although the demolished structures had at one point contained asbestos, abatement had been performed in the past, and removal of all asbestos containing materials (friable and nonfriable) was performed before demolition. The fact that the particulates were composed of predominantly calcium carbonate is to be expected, because it is a major component of building materials. This has also been noted in samples from the World Trade Center site.[14] Lead remediation had been performed by the local health department in the past, and an exploratory sampling that we performed of airborne lead adjacent to the demolition of public housing low-rise structures (thought to be at

higher risk for lead contamination than high rises) found concentrations within EPA standards (data not presented).

None of the local PM concentrations measured with dichotomous samplers with a 24-hr averaging time at the three public housing developments (approach 1) exceeded EPA 24-hr standards for PM_{10} (150 $\mu g/m^3$), $PM_{2.5}$ (65 $\mu g/m^3$), or the annual arithmetic mean (AAM) standard for PM_{10} (50 $\mu g/m^3$). Local and regional measures of $PM_{2.5}$ did exceed the AAM standard for $PM_{2.5}$ (15 $\mu g/m^3$) on 31 and 51% of days of sampling, respectively. The PM concentrations obtained during 6 days of upwind-downwind and size-selective sampling at the ABLA development (approach 2) exceeded EPA PM limits by several-fold. However, the basic sampling approach used over those 6 days was quite different than Federal Reference Method to be used for monitoring compliance with the EPA PM standards in terms of sampling equipment and averaging times (we sampled for 6 rather than 24 hr). For that reason, the results obtained using approach 2 are not comparable to the EPA standards. Nevertheless, adverse cardiac effects are known to occur after short-term (2-hr) increases in concentrations of PM_{10}[15] and $PM_{10-2.5}$,[16] and for that reason, increases in local PM in at-risk community are concerning, regardless of averaging time. The fact that demolition-associated increases in PM concentrations did not bring local PM_{10} concentrations above EPA standards does not imply that no increase in adverse health effects would be expected, because health effects of PM_{10} are known to occur at concentrations within regulatory limits.[17]

Many epidemiologic studies of health impacts of air pollutants rely on regional EPA monitoring stations for measures of air quality. Air quality in the local microenvironments of individuals may differ substantially from those measured at regional monitoring stations. Air sampled in such a microenvironment contains a mixture of particulates, some from regional and some from local sources. The placement of samplers at several locations demonstrates that there is substantial spatial variation, and the real-time monitoring demonstrates substantial temporal variation in PM because of demolition, emphasizing the value of local monitoring compared with 24-hr integrated regional monitoring.

Potential for Health Effects

The elevated PM concentrations in relation to demolition represent a potential health hazard. Individuals who work or live near public housing high-rise structures undergoing demolition by mechanical disruption with heavy equipment may be subject to increases in PM exposure in their outdoor environment. Across the United States, thousands of public housing units will be demolished in upcoming years. Given the high prevalence rates of asthma in public housing developments slated for demolition,[6] the potential for adverse health effects among local residents, as well as demolition workers, is concerning. We note that downwind of demolition sites, PM_{10} concentrations increased by 59%, and much larger increases occurred closer to the demolition site itself. Thus, workers at the site are at risk for dramatic increases in PM exposure. Although EPA standards were not violated, local concentrations of PM_{10} during demolition were well within the range observed in studies that found associations between PM_{10} and increased mortality.[18,19] In general, a 50-$\mu g/m^3$ increase in ambient PM_{10} is associated with an estimated increase in emergency department visits for asthma of ~10–15%.[20–22] A study that looked specifically at inner city asthmatic children found that after adjusting for O_3, SO_2, and NO_2, a 20-$\mu g/m^3$ increase in PM_{10} as measured at regional monitoring sites was associated with a 25% increase in the odds of having morning respiratory symptoms.[23] Relatively high concentrations of cockroach[24] and mouse[25] allergens have been documented in inner city homes and could become aerosolized by demolition. Delfino et al.[26] have demonstrated that among a panel of asthmatic children in California, symptom scores were associated more strongly with 1-hr maximum same-day PM_{10} measures than with 8-hr maximums and not significantly associated with the 24-hr same-day mean PM_{10}. Although very high short-term peaks in PM (Figure 3) were noted, particularly using 30-sec averaging times, the size of the particulates during those peaks was unable to be characterized. Nevertheless, the increases in short-term peaks of local PM were much greater than changes in mean concentrations with longer averaging times (Tables 4 and 5). For all of the above reasons, the potential for adverse health effects because of public housing demolition is real. The large size (~17 μm aerodynamic diameter) of demolition particulates may mitigate these effects to some degree. Particles of this size are unlikely to infiltrate indoors[27] or to be inhaled into the lower respiratory tract, although they could cause upper airway symptoms. Significant increases in the coarse fraction of PM_{10} ($PM_{10-2.5}$) did occur during demolition (Table 2), which could reach the lower airways and trigger health effects.[17]

Efforts required to minimize local concentrations of PM generated by demolition are generally "low tech." It was noted that water spraying is associated with lower concentrations of particulate matter. The local authorities were notified about dusty conditions during interior demolition at the Robert Taylor development. This prompted a simple modification of dust suppression efforts: indoor debris was sprayed before it was plowed out of the upper floors of buildings, rather than after it fell to the ground. This revised process was associated with much less visible dust. Activities that were found to be associated with higher PM concentrations (rock crushing, moving of debris by excavators, and other conditions producing visible dust) could be prioritized for maximal dust suppression efforts. Other potential preventive efforts include effective wind barriers, covering debris piles, and hauling rock and other debris away to less populated areas where crushing operations can take place. Based on approach 1 (dichotomous samplers, 24-hr averaging time, three housing developments), the observation of dusty conditions is associated with a 74% increase in PM_{10} (Table 5) 100 m downwind. Consistent with that finding, approach 2 (size-selective upwind and downwind sampling, one development, 6-hr averaging time) also demonstrated that the visual observation of dusty conditions is associated with high (above the median) real-time PM concentrations (odds ratio: 2.9). Thus, the observation by local residents of dusty conditions at demolition sites appears to be a valid indication of a significant increase in local PM. For this

reason, involving local community residents to visually monitor air quality near demolition sites may be a valuable component of an integrated dust-suppression program.

In conclusion, the demolition of high-rise public housing structures is associated with substantial increases in local concentrations of large particulates. For an individual 100 m downwind of the demolition site, demolition is associated with a 59% increase in outdoor PM_{10} concentration, whereas larger increases occur closer to the site. The excess PM concentration attributable to demolition is primarily because of relatively large particles, and it includes brief periods of PM concentrations that are several-fold higher than baseline. These increases in PM are occurring in the midst of communities with substantial burdens of severe asthma and may be compromising the health of at-risk individuals. Simple preventive measures, such as effective water spraying and wind barriers, are recommended.

ACKNOWLEDGMENTS

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