



PERGAMON

AE International – North America

Atmospheric Environment 37 (2003) 2681–2690

ATMOSPHERIC
ENVIRONMENT

www.elsevier.com/locate/atmosenv

Elemental analysis of airborne particulate matter and cooling water in west Texas residences

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Received 27 November 2002; received in revised form 27 February 2003; accepted 7 March 2003

Abstract

Ten residences in El Paso, TX were monitored in the summer of 2001 for concurrent indoor and outdoor PM_{2.5} and PM₁₀ 10-min mass concentrations in an attempt to establish the indoor–outdoor PM correlation for typical west Texas residences equipped with evaporative coolers. Simultaneously, the modified tapered element oscillating microbalance instruments were used to collect 48-h PM_{2.5} and PM₁₀ samples, both indoor and outdoor, for elemental analysis. Water samples were also taken at each home for chemical and PM correlation analysis.

The air and water samples were analyzed by inductively coupled plasma–mass spectrometry, with 30 elements identifiable above detection limits in the outdoor PM₁₀ samples and fewer elements in the PM_{2.5} and indoor PM₁₀. Indoor elemental concentrations in PM₁₀ were found to be approximately 50–70% lower than outdoor concentrations in nine of ten homes, consistent with the PM₁₀ indoor/outdoor (I/O) mass concentrations previously reported. PM_{2.5} I/O ratio correlations were not as strong as for PM₁₀; however, reduced correlations could be attributed to a pattern of recurring outlier data pairs, consisting of the same three or four elements in all ten homes.

Comparison of the elemental concentrations of the evaporative cooler supply water and indoor PM demonstrated little or no correlation, yielding a conclusion that the evaporative cooler was not introducing dissolved solids from the supply water into indoor air. Overall, evaporative cooling appears to provide a cleansing of indoor air.

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Keywords: Air pollution; Evaporative cooler; Particulate matter; Indoor–outdoor ratio; Element composition

1. Introduction

1.1. Background

Prior articles by the authors (Paschold et al., 2003; Li et al., 2003) have described the PM pollution and its health effects in the bi-national area of El Paso, TX and Ciudad Juarez, Chihuahua along with the operation and effect of evaporative coolers on the PM indoor/outdoor

(I/O) ratios within the homes of this region. Evaporative cooling is used in arid regions for summertime cooling, functioning by drawing a high airflow through water-laden pads. An initial laboratory study provided an uncomplicated view, without human activity interference, of the effect of evaporative cooling on PM. Evaporative coolers had a greater overall indoor reduction effect on PM₁₀ (up to 45%) than on PM_{2.5}, based on observation of I/O ratio comparisons for the various operating modes (Paschold et al., 2003). The field experiment in occupied houses produced results suggested by the laboratory experiment, again with a slightly greater indoor PM reduction effect on PM₁₀

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than on $PM_{2.5}$, 40% vs. 35% in actual residences (Li et al., 2003). Correlation coefficients were lower in the field study compared to laboratory results. Indoor-source-generated and human-activity-induced PM presented short-term peaks in mass concentrations that were rapidly dispersed by outdoor air introduced by the evaporative cooler.

Highsmith et al. (1992) investigated the effect of humidifiers, some of which are similar in operation to evaporative coolers, on indoor air quality with regard to the physical and chemical characterization of PM, after previously finding a high correlation between elevated indoor PM levels and the total dissolved solids (TDS) in the humidifier supply water. Chemical analysis of indoor PM where humidifiers were in use, with moderate level TDS tap water supply, showed elevated concentrations of calcium, chlorine, potassium, sulfur, and silicon. This particular combination of elevated elements is also a “fingerprint” for the tap water with the moderate TDS levels, providing evidence that the TDS was aerosolized into the indoor air by the humidifiers in the study.

Only one study found in our literature search specifically investigated the chemical composition of indoor PM in a home with evaporative cooling. Concerns of human exposure to an inhalation carcinogen, hexavalent chromium, delivered by aerosols originating from contaminated tap water prompted an investigation by Finley et al. (1996). A controlled study of indoor air quality associated with the use of contaminated water during a shower and evaporative cooling in a rural residence was conducted in the central California desert region. Four 24-h periods were simultaneously monitored indoors and outdoors for Cr(VI)-contaminated evaporative cooler supply water during evaporative cooler operation. The study found an indoor mean concentration slightly, but not statistically significant, lower than outdoor air. This, combined with the chemical analysis, prompted the conclusion that the evaporative cooler was not a contributor to indoor airborne PM. The evaporative coolers are designed to prevent aerosol formation and transport; physical observation of the evaporative cooler and ductwork yielded no evidence of water condensation or accumulation resulting from water aerosol production.

A study of the homes of non-smokers in Riverside, CA during 1990 investigated the relationship between ambient, indoor and personal PM exposures (Clayton et al., 1993). Of 13 primary elements of interest, eight were generally found in measurable quantities in the samples, especially in personal PM_{10} . The PM_{10} elements found in the highest concentrations were those associated with soils (silicon, aluminum and calcium), along with potassium and sulfur. Elemental concentration level variations by time of day and sample type were similar to the patterns detected for PM mass concentra-

tions. Pellizzari et al. (1999) investigated the relationships of residential PM I/O along with PM from an ambient-monitoring site for mass concentrations and manganese content. Indoor PM manganese was found to be lower and less variable than that measured outside the residence and at fixed-site ambient locations. A low correlation of indoor and personal exposure levels (which were expected to be highly correlated to each other due to the high percentages of time spent indoors) to the outdoor manganese suggested that indoor and outdoor environments produce PM with dissimilar chemical composition. Conner et al. (2001) measured chemical characteristics of PM within an elderly population in Baltimore, MD in 1998. This study showed significant differences between geological attributes and particle classes collected at community, outdoor and indoor sampling sites. Geller et al. (2002) investigated PM I/O mass relationships and chemical composition for residences in the southern Californian deserts. I/O concentrations of trace elements and metals were well correlated for $PM_{2.5}$, with lower correlations found for PM_{10} . This study also suggested that the total residential indoor PM mass was dominated by outdoor $PM_{2.5}$ even though outdoor desert air has traditionally been considered to consist primarily of coarse PM.

1.2. Research objective

The evaporative coolers commonly used in arid regions were found to reduce overall PM mass indoors (Li et al., 2003). However, the association of elemental compositions between indoor PM and outdoor PM in residences equipped with evaporative coolers is not conclusive and the impacts of the accumulative TDS in the water used for evaporative cooling on indoor PM require special attention in the light of the possible role of indoor PM as an asthma exacerbator (US EPA, 2002). According to a recent survey by SN Health (2002), five of the top seven cities in the US ranked as adverse for asthma are located in arid regions (Tucson, AZ; Phoenix, AZ; Fresno, CA; El Paso, TX and Albuquerque, NM), where we have found that evaporative coolers are common. Thus, PM elemental composition analysis was performed to help identify sources of PM inside the homes, exploring the elemental composition of both PM fractions and water from the home's tap system and evaporative cooler pan. Comparisons are evaluated between indoor and outdoor PM; tap and cooler pan water; and cooler pan water and indoor PM to help identify sources of indoor PM through the element concentration “fingerprints” of the PM and water. Identification of the PM sources is intended to define the evaporative cooler's role in PM mass concentrations reduction or increase.

2. Experimental procedures

2.1. Sample collection determination of mass concentrations by gravimetric weighing

Tapered element oscillating microbalance (TEOM) airflow is split into two streams: the “main” flow, 3.0 l/min, through the sensor unit and weighing filter, and the “auxiliary” flow, 13.67 l/min, vented through the controller unit (Rupprecht & Patashnick Co., Inc., 1996). Four rigid plastic filter holders, to hold one 47 mm filter each, were fabricated and inserted into the auxiliary flow lines. Pre-weighed filters were used to collect physical samples of PM_{2.5} and PM₁₀ in accordance with the corresponding PM size undergoing TEOM monitoring. Approximately every 48 h, the indoor and outdoor TEOM air inlets and controller settings were changed to accommodate a different PM fraction, at which time valves were opened and closed to switch from one auxiliary line filter to the other with minimal disturbance of the system. After each run at the houses, the filters were carefully removed, identified, and stored in a transport container. Two 400-ml water samples were collected at each home, one each from the tap water system and the cooler, then stored within a refrigerated room until elemental analysis was performed. The loaded filters from the auxiliary flow lines of the TEOMs were carefully removed from the transport containers in the Air Quality Research Laboratory at the University of Texas at El Paso (UTEP) for gravimetric analysis with a CAHN model C-33 microbalance. Detailed procedures for the gravimetric analysis are described by Orquiz (2001).

2.2. Inductively coupled plasma–mass spectrometry (ICP–MS)

An ICP–MS, Hewlett Packard HP 4500, was used to analyze the samples for elements in water or in particulate matter dissolved from air filters, with determination of the concentrations of these elements at levels typically around 1 ppb (parts per billion) in the solution. More than 30 elements, including toxic elements such as lead, manganese, copper, barium and chromium, were detected and quantifiable in outdoor PM₁₀ air samples. The indoor PM (PM₁₀ and PM_{2.5}) and outdoor PM_{2.5} samples provided smaller sample loads (mass), yielding less favorable detection limits.

Each air filter was divided into halves: one-half of the filter was used for analysis and the other reserved for reference, if needed. Dissolution of the particulate was accomplished by acid digestion with microwave heating in sealed Teflon bombs following the protocols of US Environmental Protection Agency Method 3051 “*Microwave Assisted Acid Digestion of Sediments, Sludges, Soils and Oils*” (US EPA, 1994) for microwave extrac-

tion. Extremely high buildup of dissolved solids within several evaporative cooler pan water samples mandated multiple dilutions before analysis due to high concentrations. For quality control, each carousel of 12 reaction vessels included a laboratory-fortified blank and sample (matrix blank) with US National Institute of Standards and Technology (NIST)-traceable spikes. Two US Environmental Protection Agency methods were used to implement appropriate protocols: *determination of trace elements in waters and wastes by inductively coupled plasma–mass spectrometry* and *determination of metals in ambient particulate matter using inductively coupled plasma mass spectrometry (ICP/MS)*. The first of these is Method 200.8 and the second a preliminary draft Method, EPA/625/R-96/010a (US EPA, 1991, 1997). Corrections were made for interferences from polyatomic ions from gas, air, reagents, and sample matrices using appropriate protocols (US EPA, 1991, 1997). All results presented herein fell within the relevant US Environmental Protection Agency guidelines. Additional analytic details of our routine air analysis techniques are found in Espino (2000). More than 60 elements were detected in the PM air samples, albeit many in extremely low concentrations barely above detection limits.

3. Results and discussion

3.1. PM₁₀ indoor vs. outdoor elemental concentration relationships

Table 1 presents descriptive and comparative statistics, including the I/O average of the means, for PM₁₀ geologic elements (aluminum, calcium, sodium, potassium, manganese, iron, titanium, and magnesium) and selected trace metals (copper, zinc, lead, and barium), chosen according to their frequency of occurrence and minimum mean concentrations of 0.002 μg m⁻³. A calculation of *p*-values from the Student's *t*-test for paired data is presented, followed by the Pearson *r*-value for the paired I/O data points for each house, with a determination of statistical significance at the 0.05 level (MacBerthouex and Brown, 1994). In the case of PM₁₀, only two *p*-values for trace elements are greater than 0.05, showing no significant difference in means between indoor and outdoor data at the 0.05 level of significance. Both geologic elements and trace elements in the ambient PM₁₀ observed during this study are comparable to El Paso observations in 1999 (Li et al., 2001), an indication of stabilized ambient PM levels in the past few years. The mean values for geologic elements as well as trace metals did decrease from outdoor to indoor environment for PM₁₀. The I/O ratio of the means for all geological elements (that characterize the outdoor PM₁₀) fall between 0.33 and 0.52, indicating a reduction of 48–67% of outdoor PM₁₀ to indoor. This agrees with

Table 1
Descriptive and comparative statistics for chemical analysis of indoor and outdoor PM₁₀ for selected element concentrations in $\mu\text{g m}^{-3}$

Element	n	PM ₁₀ indoor concentration ($\mu\text{g m}^{-3}$)				PM ₁₀ outdoor concentration ($\mu\text{g m}^{-3}$)				I/O ratio of means	Student <i>t</i> -test <i>p</i> -value ^a	Pearson <i>r</i> -value ^b
		Mean	Std. dev.	Min.	Max.	Mean	Std. dev.	Min.	Max.			
Geologic material												
Sodium	10	0.189	0.135	0.059	0.468	0.574	0.533	0.052	1.671	0.33	*	(-0.21)
Magnesium	10	0.158	0.181	0.034	0.661	0.372	0.297	0.059	1.099	0.43	***	0.92
Aluminum	10	0.602	0.790	0.091	2.792	1.207	1.070	0.123	3.731	0.50	**	0.91
Potassium	10	0.191	0.250	0.043	0.888	0.397	0.248	0.098	0.821	0.48	**	0.71
Calcium	10	0.368	0.217	0.094	0.898	0.929	0.471	0.325	1.678	0.40	***	(0.57)
Titanium	10	0.025	0.040	0.005	0.138	0.047	0.055	0.003	0.185	0.52	**	0.93
Manganese	10	0.008	0.011	0.002	0.040	0.017	0.018	0.004	0.066	0.48	**	0.97
Iron	10	0.294	0.399	0.087	1.414	0.646	0.629	0.184	2.291	0.46	*	0.96
Trace metal												
Copper	10	0.010	0.011	0.001	0.038	0.014	0.009	0.003	0.032	0.74	<i>p</i> > 0.05	0.64
Zinc	10	0.032	0.018	0.010	0.071	0.062	0.031	0.024	0.110	0.52	*	(-0.34)
Barium	10	0.006	0.006	0.003	0.022	0.012	0.007	0.005	0.026	0.54	***	0.79
Lead	10	0.004	0.003	0.001	0.012	0.005	0.003	0.002	0.010	0.76	<i>p</i> > 0.05	0.70

^a****p* < 0.001, ***p* < 0.01, **p* < 0.05.

^b|*r*| < 0.63 is insignificant at 0.05 level for *n* = 10 (MacBerthouex and Brown, 1994).

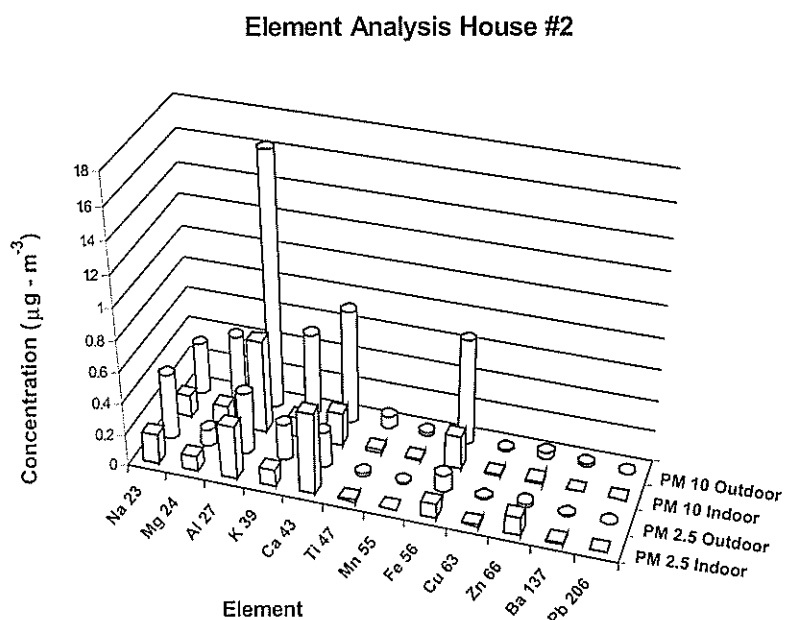


Fig. 1. Chemical composition bar graph for House #2, showing indoor and outdoor PM_{2.5} and PM₁₀, exhibiting spikes in geologic elements.

the findings developed from continuous short time average I/O observations of PM₁₀ mass at the same houses (Li et al., 2003). The Pearson *r*-values for all geological elements (significant at the 0.05 level except for sodium and calcium) fall between 0.57 and 0.97

(except sodium), with the majority above 0.90, consistent with the linear association between indoor and outdoor PM₁₀ and the reported evaporative cooler PM₁₀ removal efficiency of 30–50% (Li et al., 2003). Trace elements with anthropogenic origins are less likely to

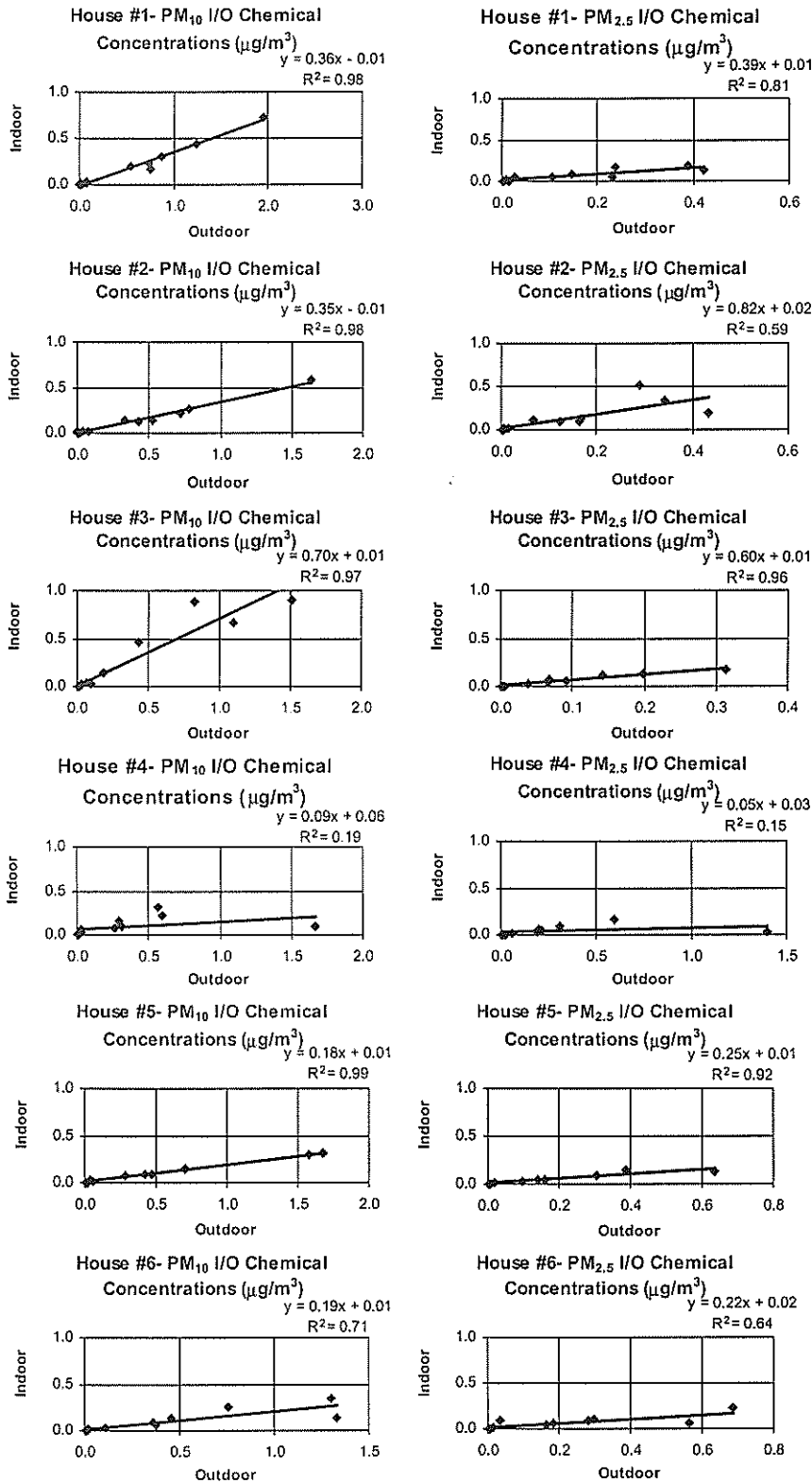


Fig. 2. Graphic presentation of I/O relationship between the total concentration of 12 elements for both PM₁₀ and PM_{2.5} for all ten houses.

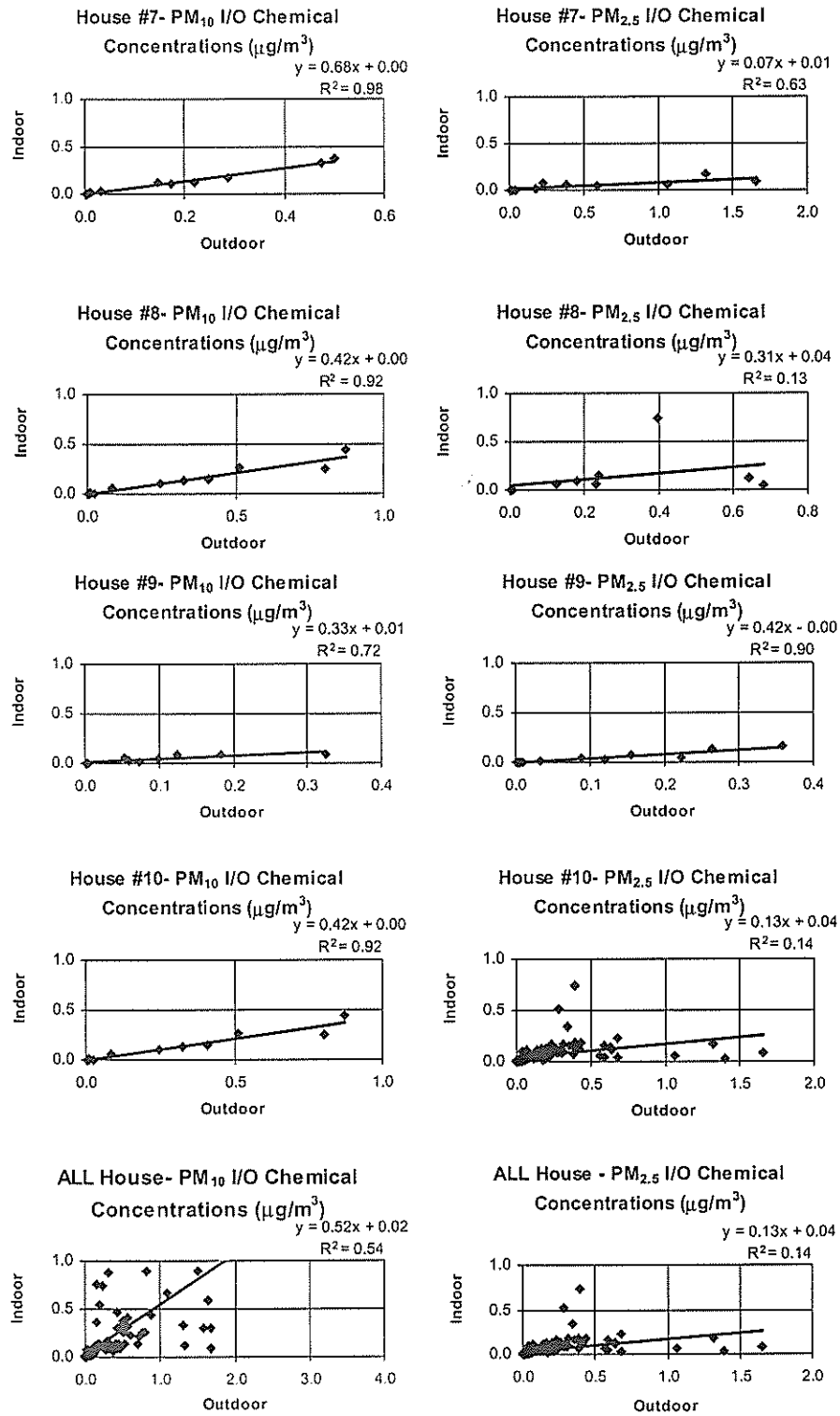


Fig. 2 (continued).

appear in the coarse fraction (PM_{2.5-10}) of PM₁₀ than in the fine fraction (PM_{2.5}) in El Paso (Li et al., 2001). The removal efficiency by evaporative coolers for PM_{2.5} is less pronounced than for PM₁₀. As a result, the I/O ratios of means for the trace elements are generally indistinguishable between indoors and outdoors with weak association (high *p*-values and low *r*-values).

Spikes of aluminum, indicative of geologic material, in either indoor or outdoor PM₁₀ appeared in Houses #1, #2, #3 (west El Paso) and #10 (east “colonia”). Fig. 1 shows these results for House #2. Elevated copper levels were found in two PM₁₀ outdoor samples for Houses #7 and #8, but were very low at all other houses. Fig. 2 presents a series of graphs for each house showing the I/O relationship for 12 elements (sodium, magnesium, aluminum, potassium, calcium, titanium, manganese, iron, copper, zinc, barium, and lead) found in PM₁₀ and PM_{2.5} with the calculated *R*² for each location and PM size. Nine of the houses had high *R*² values, exceeding 0.71, for I/O PM₁₀ concentrations for the aforementioned elements. The remaining home, House #4, had an *R*² value of 0.19. Two “outlier” elements, sodium, and calcium, were observed in the PM₁₀ data set, slightly decreasing the *R*² values. Sodium existed as an outlier in three houses (#4, #6, and #10), two above and one below the linear regression line. Finally, one instance of a calcium I/O relationship outlier was observed in House #9, with a concentration disproportionately greater outdoors. Both sodium and calcium are common naturally occurring elements found in the environment, with relatively high concentrations in the

El Paso water supply (El Paso Water Utilities, 2002). The few instances of elevated indoor sodium may have resulted from occasional “puffs” of particulate that occur upon the startup of the evaporative cooler after the pads have dried (Paschold et al., 2003). Linear trends indicate that overall indoor PM₁₀ elemental concentrations of the 12 elements were lower than outdoor in all houses. The final graph in Fig. 2 for PM₁₀ depicts all houses combined. A relatively good coefficient of correlation, significant at the 0.01 level, exists for this combined data set showing that 54% of the data could be explained by an I/O ratio of 0.52.

3.2. PM_{2.5} indoor vs. outdoor elemental concentration relationships

Table 2 presents descriptive and comparative statistical results for PM_{2.5}. The mean concentration I/O ratios for the geologic elements appear to be lower for PM_{2.5} than that for PM₁₀, ranging from 0.20 to 0.52. All but one of the indoor geologic element concentration means are statistically distinguishable from outdoors (as indicated by Student's *t*-test *p*-values); however, all the Pearson *r*-values are very low (−0.04 to 0.27) and insignificant at the 0.05 level due to the low sample number of ten. The indoor and outdoor means are different, but are not proportional (correlated) to one another, suggesting differing origins for at least part of the indoor and outdoor PM_{2.5}. Data of half the four trace elements of suspected anthropogenic origin showed indistinguishable indoor and outdoor

Table 2
Descriptive and comparative statistics for chemical analysis of indoor and outdoor PM_{2.5} for select element concentrations in µg/m³

Element	<i>n</i>	PM _{2.5} indoor concentration (µg m ⁻³)				PM _{2.5} outdoor concentration (µg m ⁻³)				I/O ratio of means	Student <i>t</i> -test <i>p</i> -value ^a	Pearson <i>r</i> -value ^b
		Mean	Std. dev.	Min.	Max.	Mean	Std. dev.	Min.	Max.			
Geologic material												
Sodium	10	0.082	0.051	0.030	0.188	0.415	0.400	0.055	1.395	0.20	**	(−0.04)
Magnesium	10	0.050	0.016	0.030	0.089	0.171	0.156	0.053	0.592	0.29	*	(−0.13)
Aluminum	10	0.144	0.077	0.063	0.337	0.419	0.442	0.102	1.653	0.34	*	(−0.16)
Potassium	10	0.053	0.023	0.026	0.101	0.176	0.093	0.068	0.383	0.30	***	(0.27)
Calcium	10	0.261	0.204	0.136	0.744	0.506	0.329	0.237	1.316	0.52	*	(−0.21)
Titanium	10	0.004	0.003	0.001	0.011	0.010	0.010	0.003	0.037	0.40	<i>p</i> > 0.05	(−0.15)
Manganese	10	0.002	0.001	0.001	0.004	0.007	0.005	0.002	0.019	0.35	**	(−0.11)
Iron	10	0.082	0.027	0.035	0.132	0.272	0.287	0.079	1.066	0.30	*	(−0.17)
Trace metal												
Copper	10	0.007	0.003	0.001	0.012	0.011	0.006	0.003	0.021	0.67	<i>p</i> > 0.05	(0.13)
Zinc	10	0.040	0.037	0.011	0.114	0.117	0.204	0.018	0.683	0.34	<i>p</i> > 0.05	(−0.02)
Barium	10	0.003	0.001	0.001	0.005	0.005	0.004	0.002	0.016	0.47	*	(−0.04)
Lead	10	0.002	0.001	0.001	0.004	0.005	0.003	0.002	0.011	0.51	*	(0.33)

^a ****p* < 0.001, ***p* < 0.01, **p* < 0.05.

^b |*r*| < 0.63 is insignificant at 0.05 level for *n* = 10 (MacBerthouex and Brown, 1994).

concentration means based upon the p -values exceeding the 0.05 significance level; the other half showed a significant difference of means. Pearson r -values range from -0.04 to 0.33 indicating little or no linear relationship for all $PM_{2.5}$ I/O trace element concentrations. The indistinguishable difference between indoor and outdoor concentration means and very weak Pearson r -values for the listed trace metal element again suggest differing sources for at least part of the $PM_{2.5}$ found indoors and outdoors.

$PM_{2.5}$ I/O relationships for element concentrations for the houses are displayed side by side with the PM_{10} graphs in Fig. 2. Seven houses had an R^2 exceeding 0.50 for $PM_{2.5}$ I/O concentrations for the 12 elements. The remaining three homes had R^2 values ranging from 0.13 to 0.15. Among the $PM_{2.5}$ data was a pattern of three “outlier” elements: sodium, calcium, and zinc. Elevated indoor sodium and calcium levels may be a result of the “puff” effect upon evaporative cooler startup. Zinc outliers were observed in Houses #6 and #8, both below the linear regression line. Zinc is found in very fine particles, less than $0.5\mu m$, originating from fossil fuel combustion (Geller et al., 2002; Seinfeld and Pandis, 1997). Linear trends indicate that overall $PM_{2.5}$ elemental concentrations of the 12 elements were lower indoors than outdoor in all ten houses, although statistically insignificant.

Fig. 3 concludes with a graph depicting the I/O relationship of the selected elements for $PM_{2.5}$ for all houses combined. The composite $PM_{2.5}$ R^2 of 0.14 is lower than eight of the individual house R^2 values and much lower than the R^2 of 0.54 found for the PM_{10} all-house data. The low correlation for the $PM_{2.5}$ is most likely attributable to indoor sources of $PM_{2.5}$.

3.3. Cooler pan vs. tap water elemental concentration relationships

Water samples were collected from each residence’s tap water in the kitchen and the evaporative cooler reservoir pan, with element concentration relationships presented in Table 3. All homes displayed very strong linear relationships with R^2 values in a narrow range between 0.97 and 1.00, indicating that few or no other elements are introduced into the cooler pan water in addition to those contributed by tap water. Extremely high element concentrations, up to 24,700 ppm (mg/l), were detected in the reservoir pan water from houses without bleed-off lines in their evaporative coolers (#5 and #6), compared to those with bleed-off lines. “Bleed-off” refers to a drain line with an external discharge inserted into the pad water supply hose for the purpose of continuously removing particle-laden cooler pan water and increasing fresh water supply. House #10, located in the colonia, has a bleed-off line for the evaporative cooler that probably malfunctioned at the

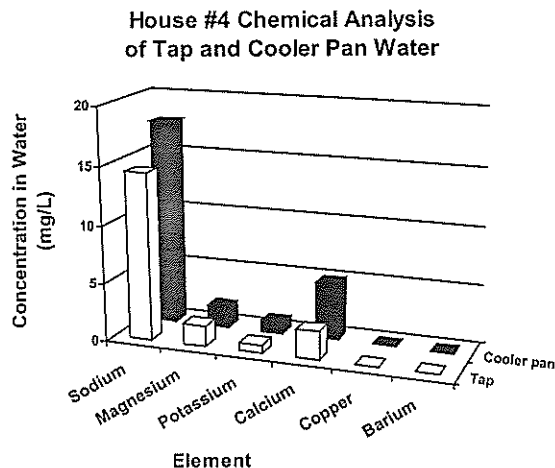


Fig. 3. House #4—chemical concentrations in tap and cooler pan water samples in an evaporative cooler with effective water bleed-off.

Table 3
Relationships between evaporative cooler pan water and tap water element concentrations

House #	Bleed-off	Slope (a) ^a	R^2
1	On	1.37	1.00
2	On	1.29	1.00
3	On	7.07	1.00
4	On	1.26	0.99
5	Off	282.37	0.99
6	Off	1874.03	0.97
7	On	1.11	1.00
8	On	1.47	1.00
9	On	0.92	1.00
10	Off ^b	508.56	0.98

^a From $y = (a)x$, where y = cooler, x = tap.

^b Malfunctioned?

time of testing, as indicated by the high element concentrations in the cooler pan water. A comparison of elemental concentrations for tap and cooler pan water sample pairing in Houses #4 and #5 is shown in Figs. 3 and 4, respectively. The El Paso Water Utilities (EPWU) provides tap water of consistent quality to all homes; none of our tap water samples exceeded the limits found and stated in the EPWU annual public drinking water quality chemical analysis report (El Paso Water Utilities, 2002). Contribution from the geologic and anthropogenic sources near these houses to the element concentrations in the cooler reservoir is still not determined.

3.4. Relationship between evaporative cooler pan water and indoor PM chemical concentrations

Table 4 presents a summary comparison of the R^2 values for the relationships between indoor $PM_{10}/PM_{2.5}$

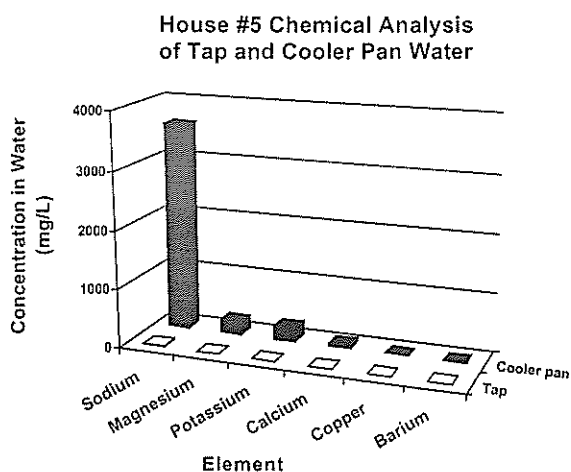


Fig. 4. House #5—chemical concentrations in tap and cooler pan water samples in an evaporative cooler without effective water bleed-off.

element concentrations and the cooler pan water element concentrations. For both PM size fractions, eight of ten houses resulted in extremely low R^2 values under 0.10, which indicate essentially no correlation. The remaining R^2 values were also very low, supportive of a conclusion of no correlation between the elemental mass concentration of the evaporative cooler supply water with the indoor air PM element concentrations. This suggests that the elements in the supply water are not being introduced into the indoor air through the evaporative cooler to any significant extent. This is also supported by the previously referenced residential hexavalent chromium and evaporative cooling study (Finley et al., 1996). The findings of Highsmith et al. (1992) indicated elevated calcium and potassium concentrations in indoor PM resulted from the use of high dissolved solid concentration tap water in the humidifiers. Our study found no instances of elevated potassium within the homes relative to outdoors, with calcium outliers disproportionately higher indoors than outdoors in only four houses. Furthermore, sodium, the element with the highest concentrations in the water samples, was found to have an I/O ratio of mean concentrations of 0.48 for PM_{10} and only 0.20 for $PM_{2.5}$. This leads to a conclusion that the evaporative cooler does not aerosolize the supply water and introduce dissolved solids into the air as occurs with certain types of home humidifiers.

4. Conclusions

Our findings in this study are generally consistent with prior findings for the El Paso region. Our research

Table 4

A comparison of R^2 values for PM_{10} and $PM_{2.5}$ element concentrations compared with evaporative cooler pan water element concentrations

House #	PM_{10} — R^2	$PM_{2.5}$ — R^2
1	0.00	0.13
2	0.00	0.02
3	0.01	0.00
4	0.01	0.02
5	0.00	0.00
6	0.01	0.00
7	0.01	0.10
8	0.18	0.22
9	0.06	0.01
10	0.26	0.04
All houses combined	0.00	0.00

objective was accomplished through the element analysis to help confirm or deny sources of indoor PM in homes with evaporative cooling. Specific findings include:

- I/O ratios for PM_{10} showed a fairly high correlation between indoor and outdoor element concentrations, and with indoor air concentrations generally presenting lower elemental levels than outdoors by approximately 50–70%.
- The relative consistency of PM_{10} I/O element concentrations was caused by the high ventilation rate of evaporative cooling, rapidly replacing indoor with outdoor air.
- $PM_{2.5}$ showed significant differences between the indoor and outdoor element mean concentrations with very low correlations for indoor and outdoor element concentrations, suggesting differing sources for indoor $PM_{2.5}$.
- Evaporative cooler pan water was virtually identical in chemical concentration proportion to tap water; high concentrations were found in the cooler pans of houses without functional bleed-off lines.
- There appeared to be little or no correlation between evaporative cooler pan chemical concentrations and indoor PM chemical concentrations, suggesting that the evaporative coolers are not introducing additional elements into indoor air by aerosolizing the water supply or any other processes.

Acknowledgements

This material is based in part upon work supported by the Texas Advanced Research (Technology) Program under Grant No. ARP 14-6595-99. Special thanks are extended to Joel Mora and Julian Chianelli, who made the implementation of this project possible.

Administrative as well as partial student support received from the Department of Civil Engineering, the Center for Environmental Resource Management, and the Model Institute for Excellence at UTEP is gratefully acknowledged.

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