Supplementary Materials: Volatile Organic Compounds (VOCs) in Conventional and High Performance School Buildings in the U.S.

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Table S1. Studies examining VOCs in schools in the literature.

Papers	No. of Schools	No. of Classrooms	Location	Sampling Method	Analysis Method	Major Remarks
[1]	6	97	Sweden	Active sampling (1 L/min, 2 hr), charcoal tubes	Extracted with CS_2 and GC/MS	Perception of high room temperature and air dryness were related to high VOC concentration.
[2]	7	20	Los Angeles, USA	Passive sampling (5–7 days), charcoal tubes	Extracted with acetone and CS_2, GC/MS	The four most prevalent VOCs measured were toluene, *p*/*m*-xylene, α-pinene, and limonene.
[3]	2	10	Minnesota, USA	Passive sampling (indoor: 31 hr; outdoor: 103 hr), charcoal-based tubes	Extracted with acetone and CS_2 and GC/MS	The school and outdoor environments had similar influence on personal exposure to VOCs.
[4]	2	4	California, USA	Active sampling (5-6 mL/min for VOCs, 150 mL/min for aldehydes, 7–8 h), modified Tenax-TA tubes, DNPH tubes	TD/GC/MS	Indoor minus outdoor VOC concentrations with an advanced HVAC operated were low; only formaldehyde concentrations exceeded 5 ppb.
[5]	9	64	Michigan, USA	Passive sampling (3.5–4.5 days), Tenax GR tubes	Thermal desorption (TD)/cryofocusing system and GC/MS	Art room, science room, and indoor pools are identified VOC sources.
[6]	3	-	Kocaeli, Turkey	Passive sampling (1 day), graphitized charcoal tubes (35–50 mesh)	TD/GC/FID	Indoor concentrations were generally higher than those observed outdoors. Indoor target compound concentrations were more strongly correlated with outdoor concentrations in summer than in winter.
[7]	9	18	Porto, Portugal	Low flow sample pump, Tenax-TA tubes	GC/MS	No statistically significant association between asthma symptoms and VOC concentrations.

Table S1. *Cont.*

Papers	No. of Schools	No. of Classrooms	Location	Sampling Method	Analysis Method	Major Remarks
[8]	-	46–188	11 European cities	Passive sampling (7 days), charcoal tubes, DNPH tubes	Extracted with CS_2 and GC/MS, HPLC	Sources in the indoor environment are prevailing for most VOCs. Aromatics in indoors were almost equal to the outdoors. Terpenes were low during warm seasons.
[9,10]	14	28	Lisbon, Portugal	Passive sampling (14 days), activated charcoal (35–50 mesh) tubes, DNPH tubes	Extracted with CS_2 and GC/FID; HPLC	I/O ratios above unity indicate the impact of indoor sources and building conditions on IAQ. Higher indoor VOC concentrations occur often in the winter, and carbonyl concentrations were higher in the summer.
[11]	109	More than 400	6 French cities	Passive sampling	-	Formaldehyde, acetaldehyde and acrolein showed low to moderate degree of similarity between the classrooms.
[12]	8	24	Italy	Passive sampling (5 days), Carbograph tubes (35–50 mesh)	TD/GC/MS	High terpenes were found in all monitored classroom. Outdoor concentrations were lower than indoors for each monitored school.
[13]	2	6	London, UK	Passive sampling (5 days)	TD/GC/MS	VOC concentrations in the classrooms were much higher than outdoor levels.
[14]	20	73	Portugal	Passive sampling (5 days), Tenax TA (60/80 mesh) tubes	TD/GC/MS	The median TVOC was 140.3 μg/m^3, which was lower than the WHO (2010) values.

VOC: volatile organic compounds; DNPH: 2,4-Dinitrophenylhydrazine; TA: trapping Agent; GR: graphite; GC/MS: gas chromatograph/mass spectrometer; FID: flame ionization detector; HPLC: high performance liquid chromatography; HVAC: heating, ventilation and air conditioning; I/O: indoor/outdoor; IAQ: indoor air quality; TVOC: total target VOC.

Table S2. School building characterization.

Energy Performance	Conventional	Energy Star	LEED	
Count	10	15	12	
Building typology	Single-story	Two-story	Three-story	
Count	17	14	6	
Ventilation system	AHU	UV	AHU + UV	Geothermal pump
Count	26	4	2	5
Filter	MERV-8	MERV-higher level	other	
Count	15	17	5	
Classroom	General classroom	Music room	Art room	Resource room
Count	139	2	1	2

LEED: leadership in energy and environmental design; AHU: air handling units; UV: unit ventilator; MERV: minimum efficiency reporting value.

Table S3. Target compounds and analytical performance.

Compound	Abbreviation	CAS No.	Target Ion	Qualifier Ion	MDL (ug/m³)
Aromatics					
Benzene		71-43-2	78	50	0.08
Toluene		108-88-3	91	92	0.07
Ethylbenzene		100-41-4	91	106	0.14
p,*m*-Xylene		106-42-3, 108-38-3	91	106	0.16
o-Xylene		95-47-6	91	106	0.09
1,2,4-trimethylbenzene	1,2,4-TMB	95-63-6	105	120	0.06
Alkanes					
n-Hexane	C_6	110-54-3	57	86	0.19
n-Heptane	C_7	142-82-5	43	71	0.24
n-Undecane	C_{11}	1120-21-4	57	43	0.11
n-Dodecane	C_{12}	112-40-3	57	43	0.44
n-Tridecane	C_{13}	629-50-5	57	43	0.15
n-Tetradecane	C_{14}	629-62-9	57	43	0.13
n-Pentadecane	C_{15}	544-76-3	57	43	0.08
n-Hexadecane	C_{16}	536-78-7	105	104, 78	0.13
Methyl cyclohexane	MCH	108-87-2	83	55	2.50
Terpenes					
α-Pinene		7785-70-8	93	77, 105	0.17
d-Limonene		5989-27-5	68	93, 136	0.25
Other					
Ethyl acetate		141-78-6	43	45	0.50
Methyl isobutyl ketone	MIBK	108-10-1	43	58, 55, 100	0.08
Naphthalene		91-20-3	128	102	0.24
Methyl chloride	DCM	75-09-2	84	49	0.75
Chloroform		67-66-3	83	47	0.25
1,4-Dichlorobenzene	*p*-DCB	541-73-1	146	111, 75	0.06
Formaldehyde		50-00-0	N/A	N/A	6.00

MDL: Method detection limits.

Table S4. Ninety-four GC/MS calibration compounds and detection frequency (DF).

No.	VOC	DF (%)	No.	VOC	DF (%)
1	1,2-Dichloroethylene (trans, E)	3	48	Tetrachloroethene	8
2	Methylene chloride	20	49	1,1,1,2-Tetrachloroethane	0
3	Hexane	95	50	Chlorobenzene	0
4	Methyl t-butyl ether	0	51	Ethylbenzene	36
5	1,1-Dichloroethane	0	52	*p*-Xylene, *m*-Xylene	81
6	Propanenitrile	0	53	Bromoform	0
7	Butanal	0	54	*n*-Nonane	6
8	2-Butanone	3	55	Heptanal	0
9	Methacrylonitrile	0	56	Styrene	10
10	1,2-Dichloroethylene (Cis, Z)	0	57	1,1,2,2-Tetrachloroethane	1
11	Bromochloromethane	0	58	*o*-Xylene	51
12	Chloroform	31	59	1,2,3-Trichloropropane	0
13	Ethyl acetate	26	60	1,4-Dichlor-2-butene (trans, E)	0
14	2,2-Dichloropropane	0	61	Isopropylbenzene (cumene)	0
15	Methyl acrylate	0	62	a-Pinene (1R) - (+)	47
16	Tetrahydrofuran	1	63	Bromobenzene	0
17	1,2-Dichloroethane	1	64	*n*-Propylbenzene	0
18	1,1,1-Trichloroethane	0	65	2-Chlorotoluene	0
19	Butyl chloride	0	66	4-Chlorotoluene	0
20	1,1-Dichloropropene	0	67	4-Ethyl toluene	2
21	Chloroacetonitrile	0	68	1,3,5-Trimethylbenzene	10
22	Isopropyl acetate	0	69	Pentachloroethane	0
23	Carbontetrachloride	0	70	*n*-Decane	8
24	Benzene	93	71	tert-Butylbenzene	0
25	pentanal	0	72	1,2,4-Trimethylbenzene	59
26	2-nitropropane	0	73	sec-Butylbenzene	0
27	Dibromomethane	0	74	1,3-Dichlorobenzene	0
28	n-Heptane	35	75	1,4-Dichlorobenzene	15
29	1,2-Dichloropropane	0	76	p-Isopropyltoluene	1
30	Trichloroethylene	1	77	Limonene (R) - (+)	94
31	Bromodichloromethane	0	78	o-Cresol	0
32	Methyl methacrylate	0	79	1,2-Dichlorobenzene	0
33	*n*-propyl acetate	0	80	*p,m*-Cresol	0
34	Methyl cyclohexane	28	81	*n*-Butylbenzene	0
35	1,1-Dichloro-2-propanone	0	82	n-Undecane	17
36	1,3-Dichloropropene (Cis, Z)	0	83	1,2-Dibromo-3-chloropropane	0
37	1,3-Dichloropropene (trans, E)	0	84	Hexachloroethane	0
38	1,1,2-Trichloroethane	0	85	Nitrobenzene	0
39	Toluene	100	86	*n*-Dodecane	51
40	1,3-Dichloropropane	0	87	1,2,4-Trichlorobenzene	0
41	Ethyl methacrylate	0	88	Naphthalene	40
42	Methyl isobutyl ketone	24	89	Hexachlorobutadiene	0
43	2-Hexanone	0	90	1,2,3-Trichlorobenzene	0
44	Dibromochloromethane	0	91	*n*-Tridecane	17
45	*n*-Octane	12	92	*n*-Tetradecane	85
46	Hexanal	0	93	*n*-Pentadecane	35
47	1,2-Dibromoethane	0	94	*n*-Hexadecane	28

Table S5. Spearman rank correlation coefficient for indoor and outdoor BTEX.

VOC	Benzene	Toluene	Ethylbenzene	*p,m*-Xylene	*o*-Xylene	BTEX	TTVOCs
Benzene	1.000						
Toluene	0.133	1.000					
Ethylbenzene	0.460 **	0.427 **	1.000				
p,m-Xylene	0.363 **	0.586 **	0.985 **	1.000			
o-Xylene	0.450 **	0.452 **	0.940 **	0.938 **	1.000		
BTEX	0.250 **	0.857 **	0.908 **	0.839 **	0.819 **	1.000	
TTVOCs	0.222 **	0.466 **	0.472 **	0.484 **	0.493 **	0.555 **	1.000

** Denotes $p < 0.01$; BTEX: Benzene, toluene, ethylbenzene and xylene.

Table S6. Spearman rank correlation coefficient for indoor and outdoor alkanes.

	C_6	C_7	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	Alkanes	TTVOCs
C_6	1.000									
C_7	−0.030	1.000								
C_{11}	−0.032	0.293 **	1.000							
C_{12}	0.009	−0.042	0.157	1.000						
C_{13}	−0.031	−0.048	0.063	0.390 **	1.000					
C_{14}	0.035	−0.122	0.086	0.334 **	0.109	1.000				
C_{15}	0.105	−0.020	−0.070	0.244 **	0.288 **	0.365 **	1.000			
C_{16}	−0.028	−0.088	0.066	0.450 **	0.237 **	0.333 **	0.498 **	1.000		
Alkanes	0.517 **	0.287 **	0.278 **	0.378 **	0.280 **	0.457 **	0.440 **	0.379 **	1.000	
TTVOCs	0.312 **	0.224 **	0.375 *	0.374 **	0.297 **	0.321 **	0.327 **	0.272 **	0.617 **	1.000

** Denotes $p < 0.01$; * Denotes $p < 0.05$.

Table S7. Spearman rank correlation coefficient for indoor and outdoor terpenes.

VOC	α-Pinene	d-Limonene	Terpenes	TTVOCs
α-Pinene	1.000			
d-Limonene	0.512 **	1.000		
Terpenes	0.595 **	0.986 **	1.000	
TTVOCs	0.439 **	0.751 **	0.745 **	1.000

** Denotes $p < 0.01$.

Table S8. Associations between VOCs and classroom characteristics/teacher survey in schools in the present study.

Variable	**Rooms/Group**	**BTEX**			**Alkanes**			**Terpenes**			**Formaldehyde**			**TTVOCs**		
		β [1]	**SE** [2]	*p* [3]	β [1]	**SE** [2]	*p* [3]	β [1]	**SE** [2]	*p* [3]	β [1]	**SE** [2]	*p* [3]	β [1]	**SE** [2]	*p* [3]
Floor materials																
Vinyl	75	0.45	0.14	**0.00**	0.07	0.10	0.47	0.56	0.26	**0.03**	0.37	0.07	**0.00**	0.12	0.13	0.35
Carpet	85	−0.59	0.14	**0.00**	−0.16	0.10	0.12	−1.59	0.23	**0.00**	−0.34	0.08	**0.00**	−0.59	0.12	**0.00**
Rugs	36	0.39	0.16	**0.02**	0.05	0.11	0.68	0.45	0.29	0.12	0.16	0.09	0.07	0.10	0.14	0.49
Wood	37	0.52	0.16	**0.00**	0.20	0.11	0.07	0.66	0.28	**0.02**	0.42	0.08	**0.00**	0.23	0.14	0.11
Plastic	46	0.48	0.15	**0.00**	0.05	0.10	0.65	0.50	0.27	0.06	0.23	0.08	**0.01**	0.09	0.13	0.49
Metal	44	0.71	0.14	**0.00**	0.17	0.10	0.11	0.98	0.26	**0.00**	0.46	0.07	**0.00**	0.36	0.13	**0.01**
Chemical sources																
Science supply	2	1.33	0.58	**0.03**	0.60	0.40	0.14	2.36	1.05	**0.03**	0.52	0.32	0.12	1.31	0.51	**0.01**
Cleaning supply	51	−0.02	0.15	0.92	0.05	0.10	0.65	0.45	0.26	0.09	0.04	0.08	0.66	0.19	0.13	0.16
Air freshener	34	−0.07	0.17	0.66	0.27	0.11	**0.02**	0.18	0.30	0.55	−0.02	0.09	0.80	0.12	0.15	0.43
Plants/animals																
Plants	14	−0.11	0.24	0.64	−0.20	0.16	0.21	0.47	0.42	0.26	0.33	0.13	**0.01**	−0.02	0.21	0.92
Pet-open habitat	10	−0.29	0.27	0.29	0.12	0.19	0.54	1.24	0.48	**0.01**	0.21	0.15	0.16	0.42	0.24	0.08
Pet-close habitat	4	0.31	0.42	0.47	0.25	0.29	0.39	1.12	0.75	0.14	−0.25	0.23	0.28	0.93	0.37	**0.01**
Near emissions																
Mechanical (inside)	1	0.19	0.84	0.83	0.22	0.57	0.70	3.4	1.5	0.02	−0.25	0.46	0.60	1.78	0.73	**0.02**
Bus idling (outside)	20	−0.10	0.20	0.64	−0.14	0.14	0.32	−0.93	0.35	**0.01**	−0.19	0.11	0.08	−0.31	0.18	0.09
Exhaust (outside)	8	0.62	0.30	**0.04**	0.30	0.21	0.15	−0.06	0.55	0.92	0.34	0.17	**0.04**	0.06	0.27	0.82
Teacher survey																
How would you rate the general cleanliness of your classroom	No to constant (5 levels)	−0.10	0.12	0.42	0.00	0.09	0.99	−0.41	0.23	0.08	−0.17	0.07	**0.02**	−0.02	0.12	0.90
How often experienced carpet odors in classroom	No to constant (6 levels)	0.03	0.11	0.78	0.08	0.08	0.33	0.13	0.22	0.55	0.12	0.07	0.07	0.01	0.11	0.95
How often experienced raw gasoline in classroom	No to constant (6 levels)	−0.46	0.82	0.58	0.82	0.61	0.18	3.49	1.54	**0.03**	−0.29	0.50	0.57	1.93	0.75	**0.01**
How often experienced asphalt in classroom	No to constant (6 levels)	0.68	0.41	0.10	0.85	0.30	**0.01**	1.39	0.80	0.08	0.10	0.26	0.70	1.17	0.38	**0.00**

Bold values are statistically significant ($p < 0.05$). [1] β: coefficients of linear regression models that are the slopes of models. [2] SE: standard error of the coefficients. [3] *p*: *p* -value for each model.

Table S9. Statistics of indoor VOC concentrations by grade in schools in the present study.

Indoor VOC	**Grade Level ***	
	ANOVA	**K-W**
Aromatics		
Benzene	0.2273	**0.0476**
Toluene	0.8894	0.1565
Ethylbenzene	0.8943	0.5546
p-Xylene, *m*-Xylene	0.8981	0.6904
o-Xylene	0.9843	0.5654
1,2,4-TMB	0.7562	0.5211
BTEX	0.8979	0.4641
Alkanes		
C_6	0.1456	0.1201
C_7	0.9648	0.8331
C_{11}	0.0567	**0.0008**
C_{12}	0.8460	0.6092
C_{13}	0.6591	0.7099
C_{14}	0.9213	0.5847
C_{15}	0.2331	0.3908
C_{16}	0.6452	0.3075
MCH	0.6903	0.5876
Alkanes	0.3321	0.6263
Terpenes		
α-Pinene	0.1119	0.7426
d-Limonene	0.8395	0.9068
Terpenes	0.7100	0.8744
Other		
Ethyl acetate	0.5407	0.3887
MIBK	0.8143	0.3650
Naphthalene	0.7970	0.8207
DCM	0.4223	0.8336
Chloroform	0.5415	0.7053
p-DCB	0.6760	0.6692
Formaldehyde	0.4149	0.2123
TTVOCs	0.7858	0.8451

* grade level = PK-K, 1–3.5, 4–8, others (art, music, special, and resources); *n* for grade PK-K = 22, 1–3.5 = 51, 4–8 = 60, others = 7; Bold values are statistically significant ($p < 0.05$).

Table S10. Statistics of VOC concentrations measured indoors and outdoors by season in schools in the present study.

Parameter	**Fall (µg/m³)**				**Winter (µg/m³)**				**Spring (µg/m³)**				**Season: Fall, Winter, and Spring**			
	Indoor (*n* = 42)		**Outdoor (*n* = 11)**		**Indoor (*n* = 50)**		**Outdoor (*n* = 11)**		**Indoor (*n* = 52)**		**Outdoor (*n* = 13)**		**Indoor**		**Outdoor**	
Temp (°C)	22.2± 1.5		16.7 ± 3.4		21.8 ± 1.4		6.3 ± 5.9		22.3 ± 1.8		12.4 ± 4.4					
RH (%)	39.1 ± 8.9		52.8 ± 11.7		24.2 ± 7.3		56.3 ± 10.1		25.1 ± 7.2		56.5 ± 14.5					
Avg. AER (h^{-1})	0.8 ± 0.8		-		0.7 ± 0.4		-		0.8 ± 0.4		-					
Daytime AER (h^{-1})	1.4 ± 1.5		-		1.3 ± 0.8		-		1.5 ± 0.8		-					
VOC	Ave	Med	Ave	Med	Ave	Med	Ave	Med	Ave	Med	Ave	Med	ANOVA	K-W	ANOVA	K-W
Benzene	0.67	0.43	0.43	0.31	0.52	0.43	0.63	0.51	0.36	0.35	0.56	0.54	**0.01**	**0.01**	0.70	0.42
Toluene	3.46	1.08	0.74	0.44	1.37	0.52	1.02	0.51	0.90	0.58	1.08	0.42	0.20	**0.00**	0.82	0.91
Ethylbenzene	0.40	0.19	0.19	0.07	0.23	0.07	0.10	0.07	0.09	0.07	0.07	0.07	**0.00**	**0.00**	0.12	0.41
p,m-Xylene	1.69	0.90	0.70	0.14	0.76	0.24	0.30	0.16	0.38	0.31	0.13	0.08	**0.00**	**0.00**	0.08	**0.04**
o-Xylene	0.53	0.33	0.28	0.05	0.24	0.05	0.10	0.05	0.15	0.05	0.06	0.05	**0.00**	**0.00**	0.07	0.06
1,2,4-TMB	0.42	0.36	0.28	0.03	0.43	0.22	0.44	0.03	0.13	0.03	0.04	0.03	**0.00**	**0.00**	0.41	0.11
BTEX	6.75	3.54	2.33	1.14	3.12	1.42	2.15	1.99	1.88	1.55	1.90	1.44	**0.01**	**0.00**	0.82	0.98
C_6	3.31	2.38	3.62	2.66	2.59	2.09	3.05	1.95	3.59	2.16	3.56	2.06	0.32	0.38	0.55	0.26
C_7	1.16	0.19	0.18	0.12	1.09	0.12	0.20	0.12	0.53	0.12	0.29	0.12	0.10	**0.05**	0.77	1.00
C_{11}	0.35	0.06	0.06	0.06	0.23	0.06	0.06	0.06	0.30	0.06	0.06	0.06	0.69	0.60	1.00	1.00
C_{12}	0.39	0.22	0.22	0.22	0.55	0.22	0.23	0.22	0.73	0.55	0.25	0.22	**0.00**	**0.00**	0.60	0.81
C_{13}	0.14	0.08	0.08	0.08	0.21	0.08	0.08	0.08	0.17	0.08	0.11	0.08	0.38	0.20	0.41	0.40
C_{14}	1.57	1.15	0.07	0.07	0.98	0.80	0.11	0.07	1.37	1.07	0.07	0.07	**0.05**	**0.03**	0.15	0.15
C_{15}	0.51	0.04	0.04	0.04	0.28	0.04	0.04	0.04	0.68	0.20	0.04	0.04	0.06	**0.02**	1.00	1.00
C_{16}	0.23	0.06	0.06	0.06	0.24	0.06	0.06	0.06	0.44	0.06	0.06	0.06	**0.05**	**0.01**	1.00	1.00
MCH	2.81	1.25	1.25	1.25	4.48	1.25	1.89	1.25	1.81	1.25	3.03	1.25	0.08	**0.02**	0.15	0.23
Alkanes	7.66	5.52	4.34	3.76	6.16	5.21	3.83	3.36	7.81	6.55	4.43	4.54	0.15	0.21	0.51	0.45
α-Pinene	0.61	0.17	0.54	0.08	3.45	0.11	0.08	0.08	0.44	0.08	0.08	0.08	**0.03**	0.22	0.29	0.09
d-Limonene	15.09	4.56	0.18	0.13	15.11	4.36	0.13	0.13	4.60	2.60	0.13	0.13	**0.03**	**0.01**	0.31	0.31
Terpenes	15.7	4.73	0.72	0.21	18.56	4.44	0.21	0.21	5.05	2.81	0.21	0.21	**0.02**	**0.01**	0.22	**0.02**
Ethyl acetate	0.55	0.25	0.25	0.25	0.87	0.25	0.25	0.25	0.84	0.25	0.25	0.25	0.42	0.44	1.00	1.00
MIBK	0.17	0.04	0.04	0.04	0.26	0.04	0.04	0.04	0.20	0.04	0.04	0.04	0.64	**0.03**	1.00	1.00
Naphthalene	0.23	0.12	0.31	0.12	0.26	0.13	0.14	0.12	0.24	0.12	0.12	0.12	0.91	0.07	0.17	0.29
DCM	2.00	0.75	2.20	0.75	1.50	0.75	2.53	0.75	4.63	0.75	2.46	0.75	**0.04**	0.78	0.98	0.69
Chloroform	1.11	0.13	1.94	0.13	1.75	0.13	1.25	0.13	2.14	0.13	3.40	1.54	0.26	0.09	0.32	0.29
p-DCB	0.25	0.03	0.03	0.03	0.07	0.03	0.03	0.03	0.03	0.03	0.03	0.03	**0.00**	**0.00**	1.00	1.00
Formaldehyde	11.59	9.00	-	-	8.39	6.00	-	-	6.13	6.00	-	-	**0.00**	**0.00**	-	-
TTVOCs	49.33	36.61	10.92	8.96	45.89	32.49	10.12	10.40	30.89	24.71	12.76	9.81	0.07	0.22	0.37	0.71

Bold values are statistically significant ($p < 0.05$); RH: relative humidity; AER: air exchange rate.

Table S11. Statistics of VOC concentrations measured indoors and outdoors by dominant identified community outdoor source type in schools in the present study.

VOC	No source (μg/m³)				Road (μg/m³)				Industrial (μg/m³)				Community: No Source, Road, and Industrial			
	Indoor (n = 50)		Outdoor (n = 12)		Indoor (n = 43)		Outdoor (n = 11)		Indoor (n = 51)		Outdoor (n = 12)		Indoor		Outdoor	
	Ave	**Med**	**Ave**	**Med**	**Ave**	**Med**	**Ave**	**Med**	**Ave**	**Med**	**Ave**	**Med**	**ANOVA**	**K-W**	**ANOVA**	**K-W**
Benzene	0.46	0.39	0.45	0.47	0.40	0.39	0.46	0.43	0.65	0.47	0.71	0.64	0.06	0.07	0.29	0.44
Toluene	2.95	0.96	0.62	0.41	0.76	0.55	0.67	0.32	1.59	0.74	1.55	0.56	0.33	**0.02**	0.18	0.34
Ethylbenzene	0.38	0.11	0.15	0.07	0.11	0.07	0.10	0.07	0.19	0.07	0.10	0.07	**0.00**	**0.00**	0.59	0.86
p,m-Xylene	1.47	0.64	0.57	0.14	0.45	0.23	0.26	0.08	0.74	0.40	0.25	0.11	**0.00**	**0.00**	0.45	0.44
o-Xylene	0.50	0.28	0.20	0.05	0.14	0.05	0.13	0.05	0.22	0.05	0.09	0.05	**0.00**	**0.00**	0.60	0.63
1,2,4-TMB	0.31	0.20	0.15	0.03	0.20	0.14	0.16	0.03	0.45	0.13	0.41	0.03	0.07	0.29	0.61	0.87
BTEX	5.75	2.63	2.00	1.20	1.86	1.30	1.61	0.96	3.39	1.84	2.70	0.34	**0.05**	**0.00**	0.50	0.28
C_6	2.52	1.96	2.62	2.34	3.75	2.55	4.37	2.71	3.35	2.27	3.35	3.04	0.22	**0.01**	0.17	0.21
C_7	0.96	0.12	0.18	0.12	0.31	0.12	0.12	0.12	1.43	0.12	0.37	0.12	**0.01**	**0.01**	0.31	0.38
C_{11}	0.28	0.06	0.06	0.06	0.16	0.06	0.06	0.06	0.43	0.06	0.06	0.06	0.17	0.22	1.00	1.00
C_{12}	0.57	0.39	0.22	0.22	0.62	0.22	0.22	0.22	0.54	0.22	0.26	0.22	0.65	0.54	0.23	0.16
C_{13}	0.16	0.08	0.08	0.08	0.12	0.08	0.08	0.08	0.24	0.08	0.12	0.08	0.09	**0.05**	0.41	0.40
C_{14}	1.25	1.00	0.07	0.07	1.53	1.25	0.07	0.07	1.18	0.84	0.10	0.07	0.28	**0.01**	0.15	0.15
C_{15}	0.26	0.04	0.04	0.04	0.61	0.04	0.04	0.04	0.66	0.04	0.04	0.04	0.06	**0.02**	1.00	1.00
C_{16}	0.24	0.06	0.06	0.06	0.38	0.06	0.06	0.06	0.33	0.06	0.06	0.06	0.40	0.66	1.00	1.00
MCH	2.82	1.25	1.25	1.25	1.60	1.25	1.25	1.25	4.55	1.25	3.76	1.25	0.07	**0.01**	**0.01**	**0.01**
Alkanes	6.24	5.27	3.33	2.99	7.48	6.76	5.02	3.36	8.16	6.52	4.36	4.21	0.18	0.29	0.19	0.18
α-Pinene	0.33	0.09	0.09	0.08	0.61	0.08	0.53	0.08	3.70	0.08	0.08	0.08	**0.02**	0.57	0.32	0.56
d-Limonene	5.66	3.54	0.17	0.13	11.59	4.08	0.13	0.13	17.61	2.92	0.13	0.13	**0.05**	0.40	0.41	0.40
Terpenes	5.99	3.72	0.27	0.21	12.20	4.29	0.66	0.21	21.31	4.28	0.21	0.21	**0.02**	0.46	0.36	0.38
Ethyl acetate	0.95	0.25	0.25	0.25	0.53	0.25	0.25	0.25	0.83	0.25	0.25	0.25	0.28	0.21	1.00	1.00
MIBK	0.33	0.04	0.04	0.04	0.07	0.04	0.04	0.04	0.23	0.04	0.04	0.04	**0.04**	0.00	1.00	1.00
Naphthalene	0.21	0.12	0.17	0.12	0.22	0.12	0.26	0.12	0.31	0.12	0.12	0.12	0.28	0.95	0.46	0.79
DCM	3.70	0.75	1.33	0.75	1.85	0.75	2.25	0.75	2.76	0.75	3.61	0.75	0.40	0.71	0.30	0.33
Chloroform	0.78	0.13	0.80	0.13	3.05	1.66	4.29	2.90	1.41	0.13	1.88	0.13	**0.00**	**0.00**	0.07	**0.05**
p-DCB	0.12	0.03	0.03	0.03	0.20	0.14	0.16	0.03	0.45	0.13	0.03	0.03	0.45	0.20	1.00	1.00
Formaldehyde	9.22	6.00	-	-	8.45	6.00	-	-	8.15	6.00	-	-	0.49	0.14	-	-
TTVOCs	36.33	28.10	6.60	5.56	37.71	32.44	12.51	10.40	51.60	32.11	15.04	12.73	**0.05**	0.44	**0.04**	**0.02**

Bold values are statistically significant ($p < 0.05$).

Table S12. Comparison of indoor and outdoor VOC concentrations by building type in schools in the present study.

VOC	Indoors (µg/m³)											Outdoors (µg/m³)									
	Conventional (*n* = 39)			Energy Start (*n* = 58)			LEED (*n* = 47)			*p*-Value *		Conventional (*n* = 10)			Energy Start (*n* = 15)			LEED (*n* = 10)			*p*-Value *	
	% DF	Ave	Med	% DF	Ave	Med	% DF	Ave	Med	ANOVA	KW-Test	% DF	Ave	Med	% DF	Ave	Med	% DF	Ave	Med	ANOVA	KW-Test
Benzene	97	0.04	0.49	100	0.05	0.41	79	0.06	0.34	**0.01**	**0.00**	90	0.59	0.60	93	0.61	0.53	70	0.39	0.39	0.50	0.40
Toluene	100	2.21	0.73	100	2.85	0.88	100	1.18	0.59	0.27	0.14	100	0.76	0.49	100	0.84	0.33	90	1.34	1.17	0.70	0.28
Ethylbenzene	41	1.98	0.07	37	0.07	0.07	30	0.07	0.07	**0.00**	0.11	30	0.20	0.07	13	0.09	0.07	10	0.08	0.07	0.09	0.14
p,m-Xylene	74	0.39	0.49	84	0.24	0.48	81	0.10	0.30	**0.00**	0.12	40	0.71	0.08	53	0.25	0.11	40	0.18	0.08	0.10	0.62
o-Xylene	49	0.05	0.05	53	0.05	0.09	49	0.06	0.09	**0.01**	0.37	30	0.29	0.05	20	0.09	0.05	20	0.08	0.05	0.08	0.57
1,2,4-TMB	77	0.08	0.24	60	0.06	0.18	42	0.24	0.03	0.12	**0.00**	40	0.30	0.03	13	0.28	0.03	40	0.13	0.03	0.74	0.28
BTEX	100	4.66	1.64	100	3.25	2.04	100	1.47	1.33	0.14	**0.01**	100	2.54	1.39	100	1.87	1.19	90	2.06	1.67	0.62	0.67
C_6	100	1.07	2.31	94	2.60	2.32	93	2.78	1.85	0.20	0.12	100	4.30	3.86	93	2.50	2.35	90	3.92	2.51	0.17	0.12
C_7	33	0.58	0.12	45	0.59	1.55	23	0.33	0.12	0.16	0.30	10	0.19	0.12	13	0.32	0.12	0	<0.12	<0.12	0.71	0.96
C_{11}	23	14.54	0.06	24	6.38	0.06	2	15.48	0.06	0.96	0.37	0	<0.06	<0.06	0	<0.06	<0.06	0	<0.06	<0.06	1.00	1.00
C_{12}	21	0.43	0.22	52	0.50	0.30	77	0.29	0.74	**0.00**	**0.00**	0	<0.22	<0.22	13	0.24	0.22	20	0.23	0.22	0.55	0.43
C_{13}	3	0.23	0.08	21	0.15	0.08	23	0.32	0.08	0.13	**0.03**	0	<0.08	<0.08	7	0.11	0.08	0	<0.08	<0.08	0.49	0.48
C_{14}	87	0.09	1.09	81	0.18	0.87	88	0.20	1.04	**0.05**	0.08	0	<0.07	<0.07	0	<0.07	<0.07	20	0.11	0.07	0.12	0.11
C_{15}	31	1.61	0.04	23	0.96	0.04	58	1.46	0.44	**0.01**	**0.00**	0	<0.04	<0.04	0	<0.04	<0.04	0	<0.04	<0.04	1.00	1.00
C_{16}	18	0.60	0.06	21	0.22	0.06	47	0.83	0.06	0.21	**0.04**	0	<0.06	<0.06	0	<0.06	<0.06	0	<0.06	<0.06	1.00	1.00
MCH	23	1.25	1.25	35	1.25	1.25	21	1.23	1.25	0.38	0.22	0	<1.25	<1.25	27	3.00	1.25	10	1.64	1.25	0.39	0.34
Alkanes	100	19.16	5.32	100	11.58	5.44	100	21.75	6.25	0.74	0.91	100	5.02	4.71	93	3.41	3.31	100	4.62	3.16	0.17	0.12
α-Pinene	49	0.46	0.08	48	0.30	0.08	44	0.17	0.08	**0.01**	0.34	20	0.58	0.08	0	<0.08	<0.08	0	<0.08	<0.08	0.25	0.06
d-Limonene	97	0.13	3.59	94	0.13	3.47	93	0.37	3.60	0.13	0.49	10	0.18	0.13	0	<0.13	<0.13	0	<0.13	<0.13	0.27	0.26
Terpenes	100	0.59	3.59	97	0.44	3.73	95	0.54	5.33	0.09	0.42	10	0.77	0.21	0	<0.21	<0.21	0	<0.21	<0.21	0.18	**0.01**
Ethyl acetate	23	2.51	0.25	19	0.96	0.25	37	2.33	0.25	**0.03**	0.18	0	<0.25	<0.25	0	<0.25	<0.25	0	<0.25	<0.25	1.00	1.00
MIBK	10	0.09	0.04	27	2.83	0.04	30	1.08	0.04	0.43	0.10	0	<0.04	<0.04	0	<0.04	<0.04	0	<0.04	<0.04	1.00	1.00
Naphthalene	49	0.27	0.12	31	0.44	0.12	44	0.85	0.12	**0.05**	0.07	30	0.34	0.12	7	0.12	0.12	0	<0.12	<0.12	0.09	0.06
DCM	21	1.59	0.75	27	3.07	0.75	9	3.43	0.75	0.42	0.15	20	2.25	0.75	40	3.29	0.75	20	1.22	0.75	0.84	0.81
Chloroform	41	0.16	0.13	13	0.13	0.13	49	0.16	0.13	**0.03**	**0.00**	50	3.08	1.51	7	0.40	0.13	70	4.26	2.86	0.07	0.01
p-DCB	13	0.41	0.03	18	0.33	0.03	12	0.21	0.03	0.09	0.37	0	<0.03	<0.03	0	<0.03	<0.03	0	<0.03	<0.03	1.00	1.00
Formaldehyde	31	10.23	6.00	32	9.03	6.00	5	6.34	6.00	**0.00**	**0.00**	-	-	-	-	-	-	-	-	-	-	-
TTVOCs	100	42.01	30.76	100	33.31	25.82	100	39.64	27.16	0.40	0.93	100	12.80	14.74	100	10.38	8.96	100	11.37	8.88	0.38	0.08

Bold values are statistically significant ($p < 0.05$). * *p*-value test for difference by building type.

Table S13. Comparison of indoor and outdoor VOC concentrations in school studies.

Location	Year	Season	*n*	Indoor Concentration (μg/m³)								*n*	Outdoor Concentration (μg/m³)								Note	Reference
				Benzene	Toluene	Ethyl Benzene	*m*/*p*-Xylene	*o*-Xylene	BTEX	α-Pinene	*d*-Limonene		Benzene	Toluene	Ethyl Benzene	*m*/*p*-Xylene	*o*-Xylene	BTEX	α-Pinene	*d*-Limonene		
Minneapolis, MN, USA	2000	Winter	39	0.6	2.9	0.6	2.3	0.8	7.2	0.2	4.6	8	1.3	2.6	0.6	2.3	0.8	7.6	0.0	0.1	Median	Adgate et al. [3]
		Spring	47	0.6	1.6	0.3	1.2	0.4	4.1	0.2	1.9	10	1.1	2.7	0.5	2	0.7	7.0	0.1	0.4		
California, USA	2001	fall	4	NA	1.8 **	NA	NA	NA	NA	NA	NA	4	NA	NA	NA	NA	NA	NA	NA	NA		Hodgson et al. [4]
Ann Arbor, Michigan, USA	2003	Spring	64	0.1	2.8	0.2	2.3	0.2	5.7	1.4	4.4	9	0.1	0.5	<0.01	0	<0.01	0.6	0.1	0.3	Mean	Godwin and Batterman, [5]
Kocaeli, Turkey	2006	Summer	3	7.5	55.1	11.1	9.6	5.9	89.1	NA	NA	3	4.8	18.2	6.1	6.8	5.6	41.4	NA	NA	Mean	Pekey and Arslanbas [6]
	2006–2007	Winter	3	19.8	77.8	12.4	21.5	11.2	142.6	NA	NA	3	16.4	42.0	8.8	20.2	10.0	97.4	NA	NA	Mean	
11 cities in Europe *	2003–2008	Winter	188	4.4	12.6	2.4	6.2	2.2	27.8	3.2	9.4	188	3.2	11.5	2.2	5.7	2.0	24.6	0.1	0.3	Mean	Geiss et al. [8]
		Summer	188	2.6	7.1	1.3	2.9	1.2	15.1	1.5	2.6	188	2.1	4.8	1.1	2.5	0.9	11.4	0.0	0.2	Median	
Lisbon, Portugal	2009	Spring	28	0.3	3.0	2.0	4.3	3.2	12.9	NA	NA	14	0.3	2.1	0.7	1.4	0.5	4.9	NA	NA	Mean	Pegas et al. [9]
		Autumn	28	0.5	5.0	1.1	2.7	3.8	12.3	NA	NA	14	0.5	1.9	0.4	1.0	0.4	4.1	NA	NA		
		Winter	28	1.2	6.0	4.5	12.0	13.2	34.4	NA	NA	14	1.2	2.9	0.5	0.9	0.4	5.2	NA	NA		
Bari, Italy	NA	NA	24	0.9	2.3	0.6	2.7	NA	6.4	4.9	6.7	8	0.6	1.9	0.5	1.1	NA	4.1	1.0	7.1	Mean	de Gennaro et al. [12]
MI, IL, IN, OH, USA	2015–2016	Autumn	42	0.4	1.1	0.2	0.9	0.3	3.5	0.2	4.6	11	0.3	0.4	0.1	0.1	0.1	1.1	0.1	0.1	Median	This study
		Winter	50	0.4	0.5	0.1	0.2	0.1	1.4	0.1	4.4	11	0.5	0.5	0.1	0.2	0.1	2.0	0.1	0.1	Median	
		Spring	52	0.4	0.6	0.1	0.3	0.1	1.6	0.1	2.6	13	0.5	0.4	0.1	0.1	0.1	1.4	0.1	0.1	Median	

* Arnhem (Netherlands), Nijmegen (Netherlands), Athens (Greece), Brussels (Belgium), Budapest (Hungary), Catania (Italy), Dublin (Ireland), Helsinki (Finland), Leipzig (Germany), Nicosia (Cyprus), Thessaloniki (Greece). 188 samples included public buildings, schools, and homes. ** Indoor minus outdoor concentration.

One-Zone IAQ Model

A simple IAQ model was used for examination of the relationship between the AER and VOC concentration.

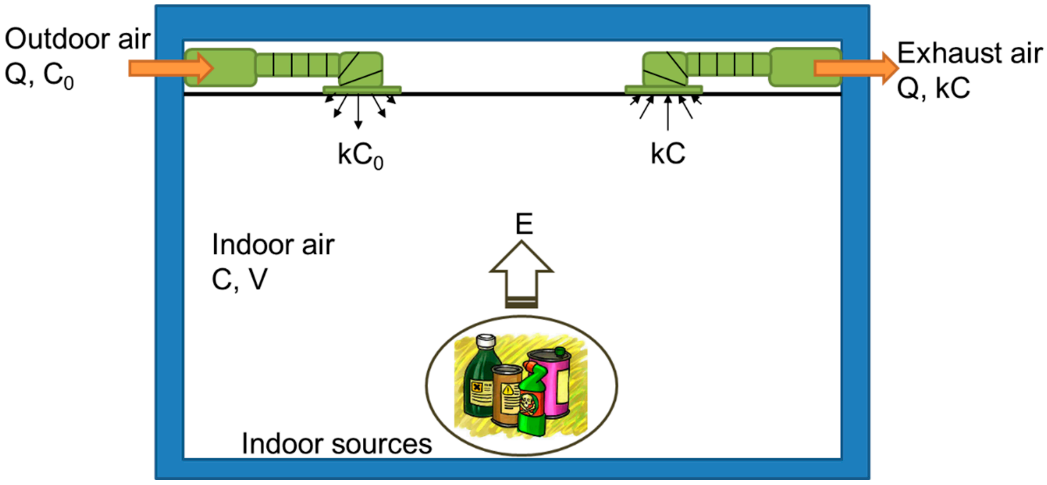

Figure S1. One-zone IAQ model.

The mass balance of contamination inside the room with is

$$V\frac{dC}{dt} = E + kQC_0 - kQC \tag{1}$$

At steady state, the indoor VOC concentration can be expressed as Equation (2) when the initial VOC concentration inside the room is negligible.

$$C = \left(\frac{E}{kQ} + C_0\right)\left(1 - e^{-\mathrm{k}nt}\right) \approx \frac{E}{kQ} + C_0 = \frac{E}{knV} + C_0 \tag{2}$$

Assuming there is no indoor source, Equation (2) can be simplified to:

$$C = C_0 \tag{3}$$

Assuming the outdoor air is very clean, Equation (2) can be simplified to:

$$C = \frac{E}{kQ} = \frac{E}{knV} \tag{4}$$

where V = room volume (m^3); C = room air VOC concentration (μg/m^3); C_0 = outdoor air VOC concentration (μg/m^3); E = emission rate of indoor sources (μg/h); n = air exchange rate (h^{-1}); and k = a mixing factor.

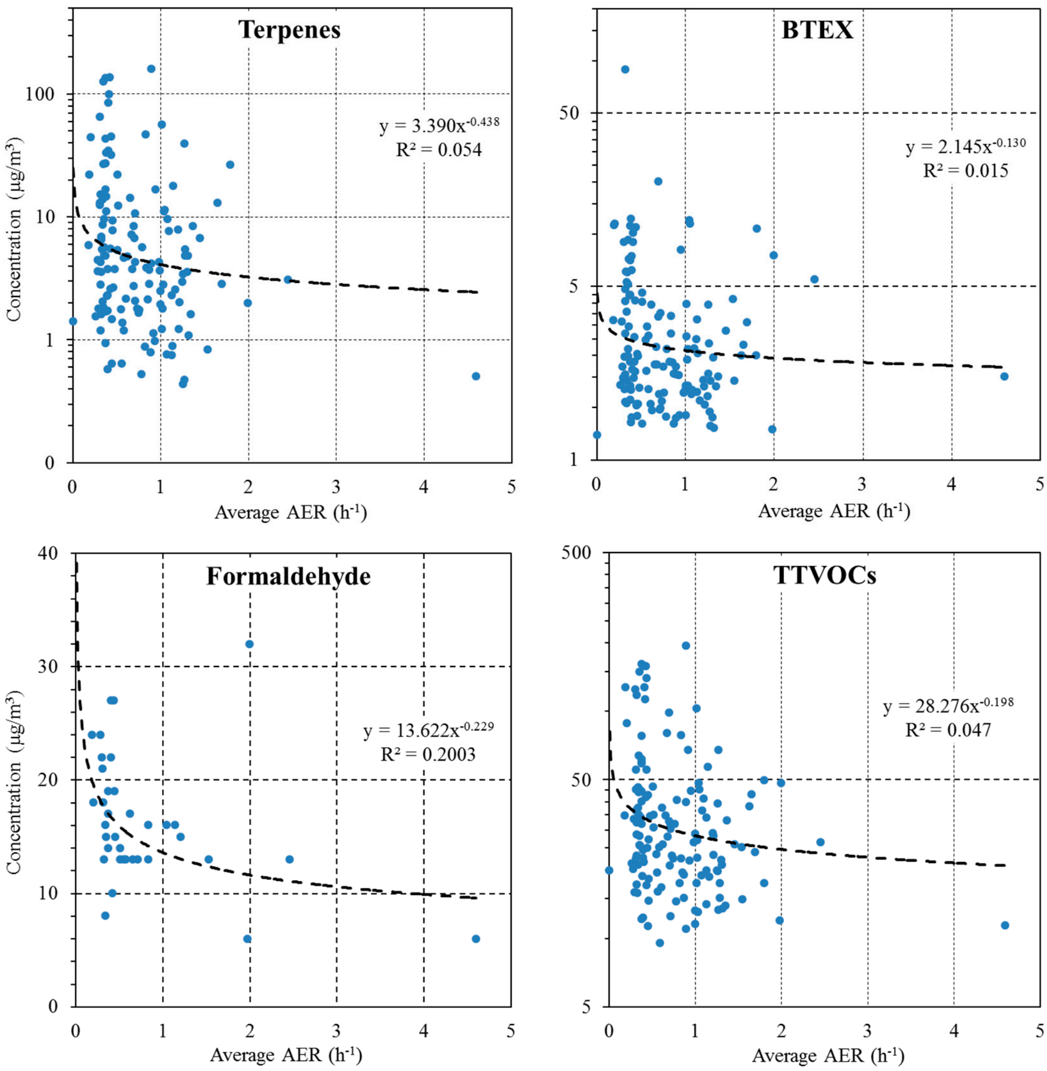

Figure S2. Indoor measured concentrations of terpenes, BTEX, formaldehyde, and TTVOCs against average AERs.

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