

US EPA ARCHIVE DOCUMENT

Supporting Information to:

Predicting Residential Air Exchange Rates from Questionnaires and Meteorology: Model Evaluation in Central North Carolina

Michael S. Breen,^{a*} Miyuki Breen,^{b,c} Ronald W. Williams,^a Bradley D. Schultz^a

^a National Exposure Research Laboratory, Human Exposure and Atmospheric Science Division, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, USA

^b National Health and Environmental Effects Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, USA

^c Biomathematics Program, Department of Statistics, North Carolina State University, Raleigh, NC 27695, USA

*** Correspondence should be addressed to:**

Michael S. Breen, Ph.D.
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
109 T.W. Alexander Drive, Mail E205-02
Research Triangle Park, NC 27711
tel: 919-541-9409
fax: 919-541-9444
email: breen.michael@epa.gov

This supporting information has 15 pages (S1-S15) that includes six figures (Figures S1-S6), and 11 tables (Tables S1-S11).

FIGURE LEGENDS

Supporting Information, Figure S1. Climatic regions across the United States used to determine scale factor for SF model

Supporting Information, Figure S2. Distribution of measured AER across all days

Supporting Information, Figure S3. Comparison of distributions between model-predicted and measured AER for each model. Results are separated by season, cohort (Raleigh, CH-Chapel Hill), and across all days. Shown are medians with 25th and 75th percentiles.

Supporting Information, Figure S4. Comparison of signed differences for Δ (A) and ε (B) between individual model-predicted and measured AER for each model. Results are separated by season, cohort (Raleigh, CH-Chapel Hill), and across all days. Shown are medians with 25th and 75th percentiles. Positive and negative values indicate model overestimation and underestimation, respectively.

Supporting Information, Figure S5. Comparison of signed differences for Δ (A) and ε (B) between individual model-predicted and measured AER for each model. Results are separated by window status and weather conditions. Shown are medians with 25th and 75th percentiles. Positive and negative values indicate model overestimation and underestimation, respectively.

Supporting Information, Figure S6. Scatter plots of model-predicted and measured AER for each model. Points above and below the 1:1 line indicate model overestimation and underestimation, respectively.

Table S1. Stack coefficient $k_s \left[\frac{(L/s)^2}{(cm^4 \cdot K)} \right]$

	House height (stories)		
	One	Two	Three
Stack coefficient	0.000145	0.000290	0.000435

Table S2. Wind coefficient $k_w \left[\frac{(L/s)^2}{(cm^4 \cdot (m/s)^2)} \right]$

Shelter class	House height (stories)		
	One	Two	Three
1	0.000319	0.000420	0.000494
2	0.000246	0.000325	0.000382
3	0.000174	0.000231	0.000271
4	0.000104	0.000137	0.000161
5	0.000032	0.000042	0.000049

Table S3. Local sheltering

Shelter class for LBL and LBLX models ¹	Shelter class for SF model ²	Description ¹
1	Exposed	No obstructions or local shielding
2	Normal	Typical shelter for an isolated rural house
3	Normal	Typical shelter caused by other buildings across street from building under study
4	Normal	Typical shelter for urban buildings on larger lots where sheltering obstacles are more than one building height away
5	Well-shielded	Typical shelter produced by buildings or other structures immediately adjacent (closer than one building height): e.g., neighboring houses on same side of street, trees, bushes, etc.

¹ ASHRAE Handbook-Fundamentals, 2009

² US EPA, Energy Star Home Sealing Specification, 2001

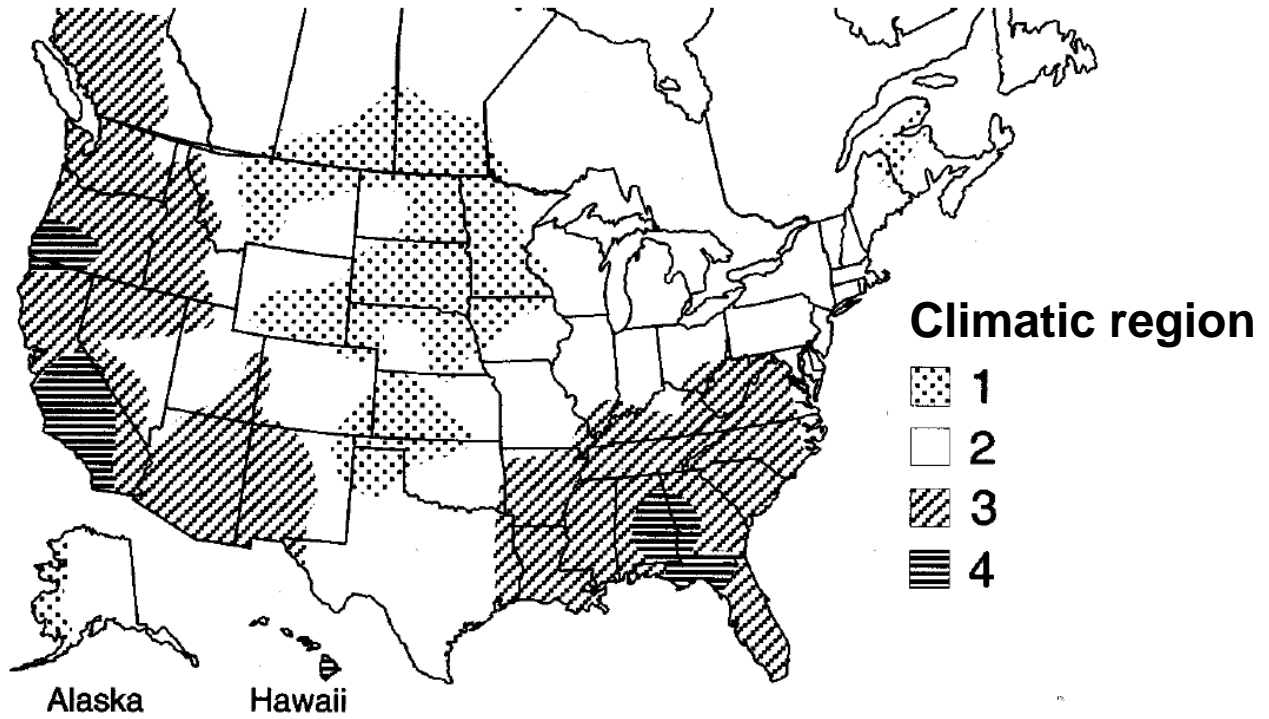


Figure S1

Table S4. Scale factor F for SF model (dimensionless)

Climatic region	Shelter class	House height (stories)			
		1	1.5	2	3
1	Well-shielded	18.6	16.7	14.9	13.0
1	Normal	15.5	14.0	12.4	10.9
1	Exposed	14.0	12.6	11.2	9.8
2	Well-shielded	22.2	20.0	17.8	15.5
2	Normal	18.5	16.7	14.8	13.0
2	Exposed	16.7	15.0	13.3	11.7
3	Well-shielded	25.8	23.2	20.6	18.1
3	Normal	21.5	19.4	17.2	15.1
3	Exposed	19.4	17.4	15.5	13.5
4	Well-shielded	29.4	26.5	23.5	20.6
4	Normal	24.5	22.1	19.6	17.2
4	Exposed	22.1	19.8	17.6	15.4

Table S5. Summary statistics, including percentiles (p), of housing characteristics, meteorological data, and window opening behavior used as model inputs

Model Input	Sample											
	size	Mean	SD	Min	p5	p10	p25	p50	p75	p90	p95	Max
Floor area (m ²)	642	131.0	42.6	69.7	74.3	87.3	103.9	111.5	148.6	219.1	223.0	227.6
Summer	203	129.2	40.4	69.7	74.3	87.3	104.4	111.5	148.6	215.7	219.1	227.6
Fall	167	132.7	43.5	69.7	74.3	87.3	104.4	111.5	148.6	218.4	223.0	227.6
Winter	129	127.4	44.0	69.7	74.3	87.3	102.2	110.3	141.6	219.1	223.0	227.6
Spring	143	134.7	43.2	69.7	74.3	87.3	104.6	122.9	148.6	219.8	224.6	227.6
House age (yr)	642	33.7	16.5	1	9	12	24	36	42	50	64	80
Summer	203	34.7	16.9	1	9	12	24	36	42	60	64	80
Fall	167	34.2	17.0	1	9	12	24	36	40	60	64	80
Winter	129	34.9	17.3	1	9	12	24	37	46	50	60	80
Spring	143	30.6	14.4	1	6	11	22	31	40	46	50	80
Indoor temperature ¹ (°C)	642	23.6	2.0	16.1	20.4	21.1	22.3	23.8	25.0	26.0	26.5	29.7
Summer	203	24.8	1.6	21.5	22.2	22.7	23.8	24.9	25.9	26.5	27.3	29.7
Fall	167	23.0	2.6	16.1	17.9	20.0	21.5	23.5	24.6	25.4	25.9	26.7
Winter	129	22.6	1.8	18.1	19.5	20.6	21.6	22.5	23.6	24.6	26.4	28.1
Spring	143	23.6	1.4	19.4	21.1	21.7	22.6	23.8	24.6	25.3	25.7	27.0
Outdoor temperature ² (°C)	642	17.9	7.4	-2.2	4.3	5.9	13.3	18.4	24.1	27.0	27.8	30.8
Summer	203	25.4	2.4	19.6	21.6	22.6	23.9	25.4	27.4	28.1	29.2	30.8
Fall	167	16.2	4.4	6.5	7.4	10.7	14.1	16.0	18.6	22.7	24.0	25.7
Winter	129	8.1	5.1	-2.2	0.2	2.2	4.4	7.3	12.0	15.2	17.2	17.2
Spring	143	18.1	4.8	5.0	5.8	11.8	14.8	18.6	21.6	23.1	25.1	25.4
Indoor-outdoor temperature difference (°C)	642	6.7	5.6	0	0.5	0.9	2.2	5.1	9.7	16.1	18.4	27.6
Summer	203	2.3	1.5	0	0.2	0.4	1.0	2.1	3.2	4.4	5.1	7.6
Fall	167	6.8	3.4	0.4	1.0	1.9	4.8	6.8	8.8	11.3	12.4	17.7
Winter	129	14.5	4.9	4.5	6.8	7.7	10.9	14.4	18.2	20.7	22.2	27.6
Spring	143	5.9	4.6	0	0.5	1.0	2.3	4.5	8.6	12.5	14.7	21.4
Wind speed ³ (km-hr ⁻¹)	642	5.2	2.0	1.8	2.3	2.9	3.7	4.9	6.2	8.0	8.7	13.0
Summer	203	5.3	2.0	2.2	2.5	3.1	3.9	5.0	6.3	8.0	8.7	13.0
Fall	167	4.6	1.8	1.8	2.2	2.3	3.0	4.5	6.1	7.4	8.1	8.2
Winter	129	5.5	2.4	2.3	2.4	3.0	3.7	4.8	7.1	8.4	10.2	12.2
Spring	143	5.5	1.7	3.0	3.3	3.7	4.3	5.4	6.0	7.8	9.9	10.6
Window opening height ⁴ (cm)	642	9.2	25.5	0	0	0	0	0	5.7	24.5	50.8	182.9
Summer	203	15.0	37.2	0	0	0	0	0	6.9	50.8	95.0	182.9
Fall	167	8.0	17.0	0	0	0	0	0	10.2	25.4	39.5	141.0
Winter	129	1.7	6.1	0	0	0	0	0	0	5.1	7.7	50.8
Spring	143	9.1	22.5	0	0	0	0	0	7.6	19.3	50.0	125.4

¹ 24-hr average of continuous 1-min temperature measurements indoors at home (time-matched to AER measurements)

² 24-hr average of hourly temperature measurements at State of North Carolina monitoring platform in Raleigh, North Carolina (time-matched to AER measurements)

³ 24-hr average of hourly wind speed measurements at 2 m elevation at State of North Carolina monitoring platform in Raleigh, North Carolina (time-matched to AER measurements)

⁴ 24-hr average from daily window opening data (sum of opening height multiplied by duration across all open windows) collected in daily questionnaire (time-matched to AER measurements)

Table S6. Summary statistics of housing type, house height, and local sheltering used as model inputs

Model Input	Summer ¹	Fall ¹	Winter ¹	Spring ¹	All
Housing type					
Low-income ²	175 (86%)	144 (86%)	114 (88%)	122 (85%)	555 (86%)
Conventional ³	28 (14%)	23 (14%)	15 (12%)	21 (15%)	87 (14%)
House height					
One story	118 (58%)	98 (59%)	90 (70%)	81 (57%)	387 (60%)
Two story	85 (42%)	69 (41%)	39 (30%)	62 (43%)	255 (40%)
Local sheltering					
Class 2, Normal	14 (7%)	12 (7%)	7 (5%)	7 (5%)	40 (6%)
Class 5, Well-shielded	189 (93%)	155 (93%)	122 (95%)	136 (95%)	602 (94%)

¹ Percentages relative to corresponding sample size in each season are shown in parentheses

² Raleigh cohort considered low to moderate socioeconomic status

³ Chapel Hill cohort considered moderate socioeconomic status

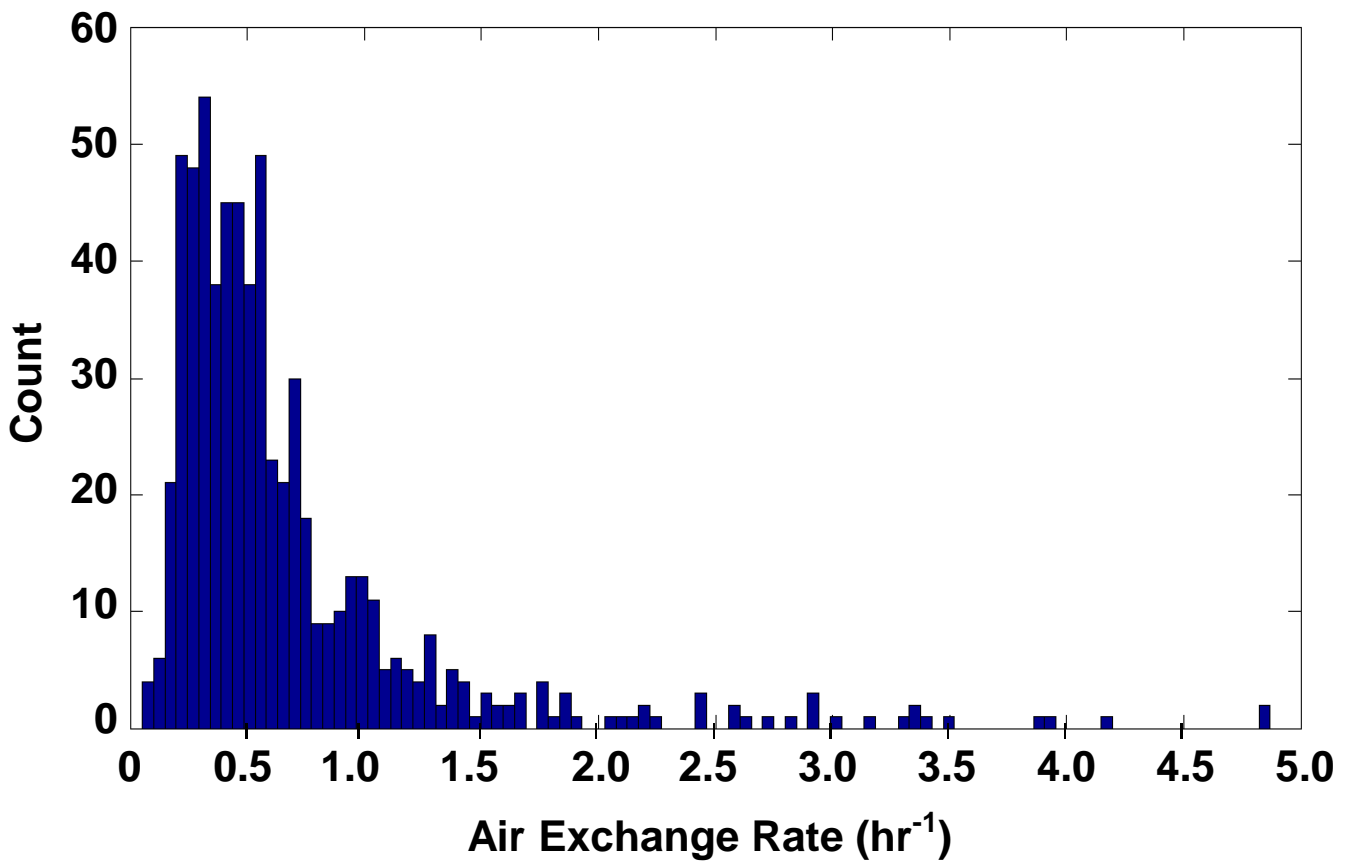


Figure S2

Table S7. Summary statistics, including percentiles (p), of model-predicted air exchange rates for each season and cohort

Model	Sample Size	Air Exchange Rates (hr ⁻¹)						
		Mean	SD	p10	p25	p50	p75	p90
SF	642	0.59	0.15	0.37	0.49	0.61	0.69	0.74
Season: Summer	203	0.60	0.15	0.37	0.50	0.61	0.69	0.75
Fall	167	0.59	0.15	0.38	0.46	0.59	0.69	0.75
Winter	129	0.60	0.15	0.37	0.49	0.62	0.70	0.73
Spring	143	0.56	0.14	0.36	0.49	0.59	0.69	0.71
Cohort: Raleigh	555	0.62	0.12	0.45	0.55	0.62	0.70	0.75
Chapel Hill	87	0.35	0.05	0.31	0.31	0.31	0.37	0.45
LBL	642	0.40	0.20	0.17	0.24	0.37	0.53	0.67
Season: Summer	203	0.26	0.10	0.14	0.18	0.25	0.32	0.40
Fall	167	0.42	0.15	0.21	0.27	0.43	0.53	0.61
Winter	129	0.62	0.19	0.37	0.49	0.63	0.76	0.86
Spring	143	0.37	0.16	0.18	0.23	0.35	0.47	0.59
Cohort: Raleigh	555	0.42	0.20	0.19	0.27	0.40	0.56	0.69
Chapel Hill	87	0.24	0.08	0.15	0.18	0.21	0.29	0.36
LBLX	642	0.53	0.49	0.19	0.27	0.42	0.60	0.85
Season: Summer	203	0.49	0.66	0.15	0.19	0.27	0.40	1.14
Fall	167	0.49	0.26	0.23	0.31	0.46	0.57	0.70
Winter	129	0.64	0.20	0.37	0.49	0.64	0.77	0.87
Spring	143	0.52	0.57	0.19	0.27	0.40	0.51	0.70
Cohort: Raleigh	555	0.56	0.51	0.20	0.29	0.46	0.63	0.90
Chapel Hill	87	0.29	0.12	0.16	0.20	0.26	0.34	0.43

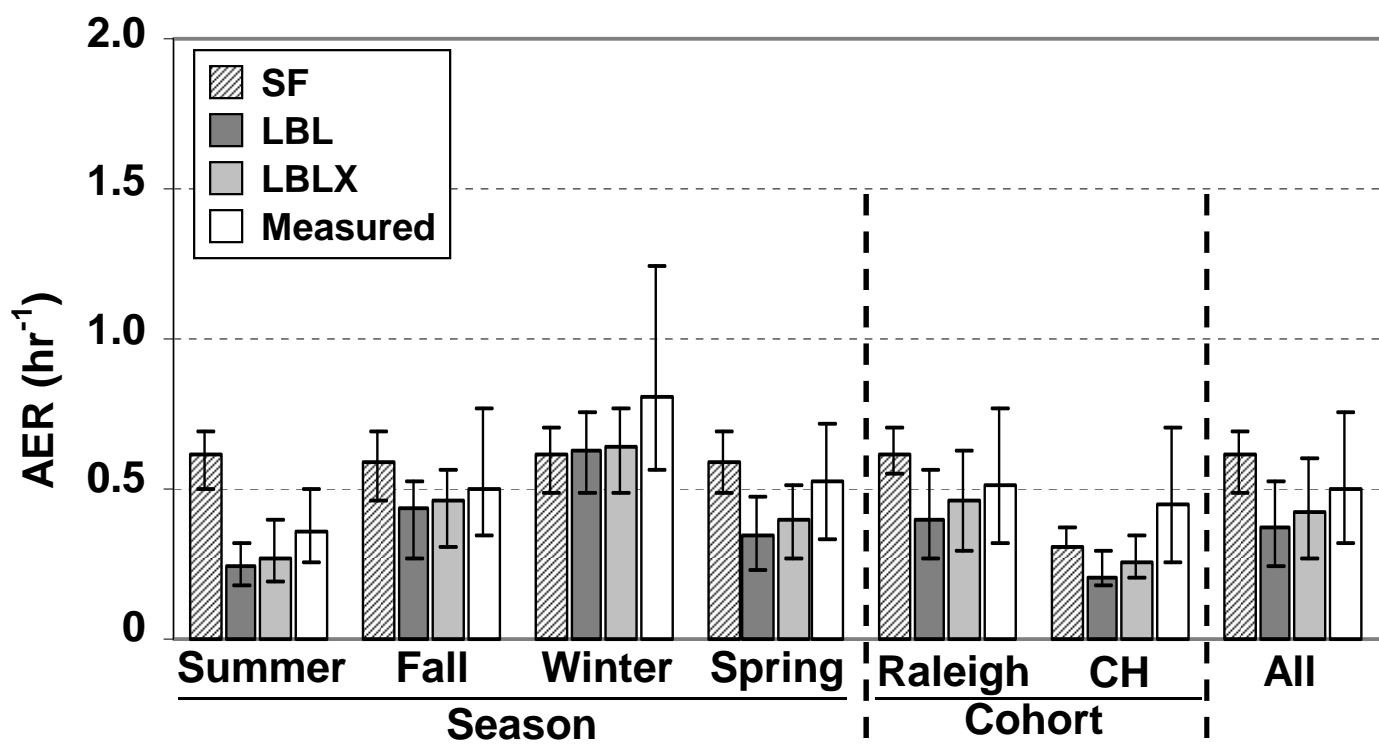


Figure S3

Table S8. Summary statistics, including percentiles (p), of model evaluation for each season and cohort

Model	Sample Size	Δ (hr ⁻¹)							ε (%)						
		Mean	SD	p10	p25	p50	p75	p90	Mean	SD	p10	p25	p50	p75	p90
SF	642	0.50	0.37	0.05	0.13	0.25	0.38	0.70	69	65	9	24	50	82	146
Season: Summer	203	0.33	0.44	0.07	0.15	0.26	0.38	0.46	92	100	12	30	71	132	184
Fall	167	0.28	0.23	0.06	0.14	0.25	0.35	0.51	58	50	9	26	49	70	129
Winter	129	0.60	0.80	0.06	0.13	0.29	0.72	1.89	43	28	9	22	39	67	78
Spring	143	0.31	0.38	0.04	0.10	0.23	0.34	0.66	56	49	8	20	43	76	129
Cohort: Raleigh	555	0.38	0.51	0.06	0.13	0.26	0.38	0.68	66	71	10	23	50	85	150
Chapel Hill	87	0.32	0.39	0.04	0.11	0.17	0.34	0.94	60	60	11	29	48	75	104
LBL	642	0.35	0.54	0.03	0.08	0.17	0.37	0.78	43	31	9	21	43	60	75
Season: Summer	203	0.28	0.56	0.03	0.07	0.14	0.24	0.46	47	36	9	26	45	61	78
Fall	167	0.27	0.28	0.04	0.08	0.17	0.34	0.61	43	31	11	17	43	59	72
Winter	129	0.57	0.77	0.04	0.12	0.24	0.72	1.87	41	27	8	18	39	61	74
Spring	143	0.32	0.41	0.03	0.09	0.20	0.39	0.78	42	25	9	22	41	60	75
Cohort: Raleigh	555	0.35	0.56	0.03	0.08	0.17	0.35	0.76	42	31	8	19	39	59	75
Chapel Hill	87	0.35	0.38	0.05	0.11	0.24	0.42	0.88	55	27	26	44	58	67	75
LBLX	642	0.34	0.50	0.03	0.08	0.17	0.39	0.86	48	51	7	18	40	59	77
Season: Summer	203	0.28	0.40	0.03	0.07	0.14	0.30	0.61	59	72	9	24	44	62	99
Fall	167	0.26	0.28	0.03	0.08	0.16	0.37	0.59	45	46	8	17	40	58	75
Winter	129	0.57	0.77	0.04	0.12	0.24	0.72	1.87	40	27	8	17	39	61	74
Spring	143	0.32	0.44	0.02	0.06	0.17	0.37	0.79	42	37	6	17	37	58	75
Cohort: Raleigh	555	0.34	0.51	0.03	0.08	0.17	0.37	0.83	47	52	7	17	38	58	77
Chapel Hill	87	0.33	0.38	0.03	0.08	0.18	0.41	0.88	54	47	11	34	50	68	79

Table S9. Summary statistics, including percentiles (p), of model evaluation for each season and cohort

Model	Sample Size	Δ (hr ⁻¹)							ϵ (%)						
		Mean	SD	p10	p25	p50	p75	p90	Mean	SD	p10	p25	p50	p75	p90
SF	642	-0.09	0.61	-0.70	-0.18	0.09	0.26	0.37	34	89	-57	-26	20	80	146
Season: Summer	203	0.10	0.55	-0.17	0.02	0.24	0.36	0.42	78	111	-25	3	69	132	184
Fall	167	-0.02	0.36	-0.51	-0.19	0.13	0.25	0.33	30	71	-51	-29	24	69	129
Winter	129	-0.51	0.86	-1.89	-0.72	-0.20	0.06	0.16	-21	47	-76	-59	-27	9	40
Spring	143	-0.08	0.48	-0.66	-0.15	0.03	0.25	0.34	24	70	-57	-24	6	65	129
Cohort: Raleigh	555	-0.08	0.63	-0.68	-0.15	0.13	0.28	0.37	38	89	-53	-23	25	85	150
Chapel Hill	87	-0.21	0.46	-0.94	-0.34	-0.10	0.11	0.19	5	85	-75	-50	-24	42	104
LBL	642	-0.28	0.57	-0.78	-0.37	-0.13	0.02	0.13	-19	50	-70	-55	-29	5	45
Season: Summer	203	-0.24	0.58	-0.46	-0.24	0.12	-0.01	0.10	-22	55	-71	-55	-36	-2	45
Fall	167	-0.19	0.34	-0.61	-0.34	-0.10	0.06	0.18	-11	51	-63	-53	-21	14	61
Winter	129	-0.49	0.82	-1.87	-0.72	-0.21	0.04	0.17	-21	44	-73	-58	-25	7	37
Spring	143	-0.27	0.45	-0.78	-0.39	-0.17	0.00	0.10	-25	42	-73	-58	-35	1	35
Cohort: Raleigh	555	-0.28	0.59	-0.76	-0.35	-0.19	0.03	0.14	-17	49	-68	-52	-25	8	47
Chapel Hill	87	-0.33	0.39	-0.88	-0.42	-0.24	-0.10	0.05	-38	49	-74	-64	-54	-35	32
LBLX	642	-0.16	0.58	-0.62	-0.30	-0.08	0.07	0.21	-3	70	-64	-48	-18	18	72
Season: Summer	203	-0.01	0.49	-0.38	-0.19	-0.07	0.07	0.31	7	92	-62	-47	-23	26	99
Fall	167	-0.12	0.37	-0.53	-0.33	-0.06	0.08	0.20	1	64	-58	-45	-13	23	75
Winter	129	-0.47	0.83	-1.87	-0.72	-0.18	0.06	0.17	-19	45	-73	-58	-24	10	41
Spring	143	-0.11	0.53	-0.55	-0.29	-0.07	0.06	0.18	-9	56	-66	-48	-19	16	49
Cohort: Raleigh	555	-0.14	0.60	-0.58	-0.28	-0.07	0.08	0.23	0	70	-61	-44	-15	-21	73
Chapel Hill	87	-0.28	0.42	-0.88	-0.41	-0.17	0.02	0.08	-22	68	-74	-63	-43	5	44

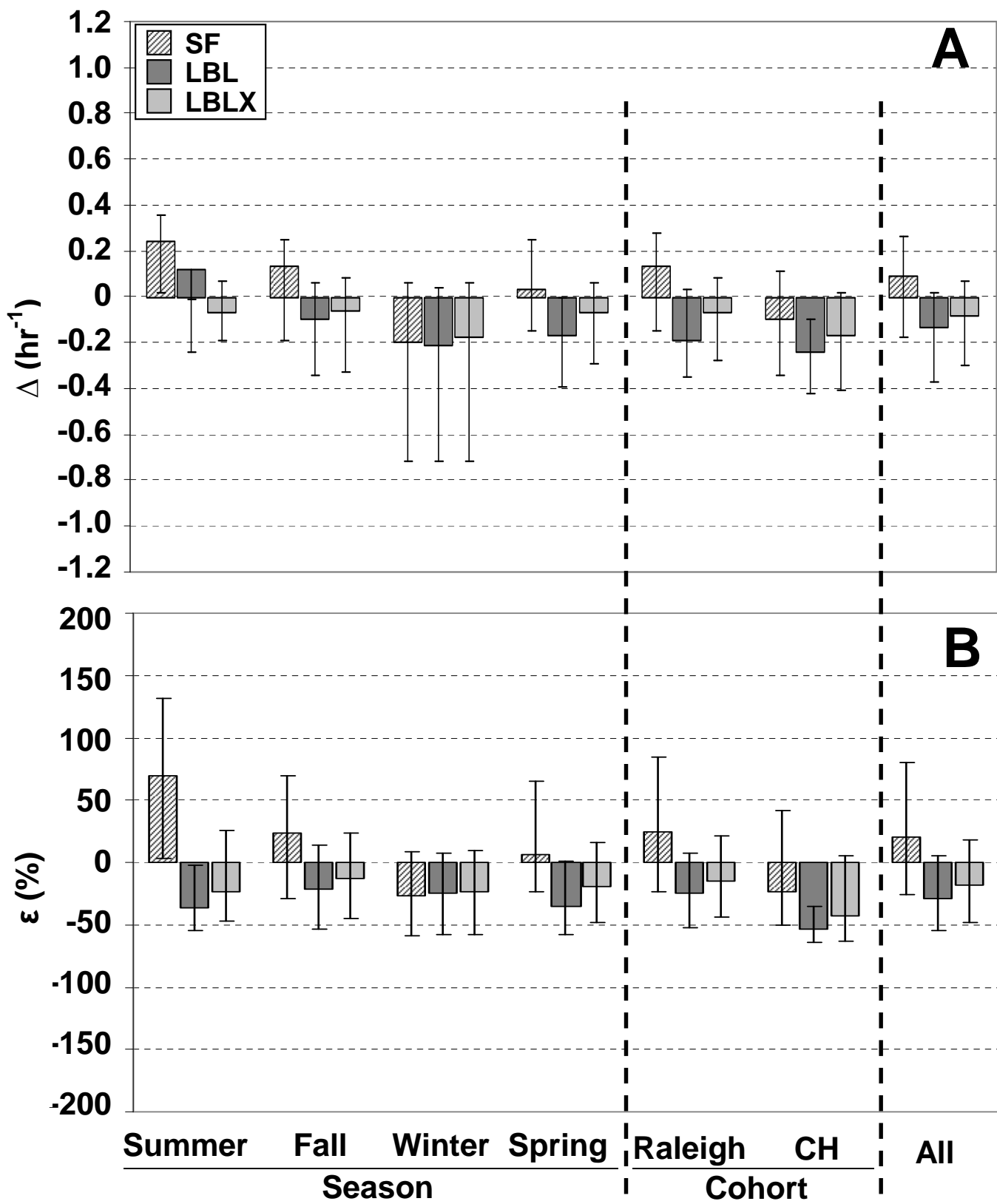


Figure S4

Table S10. Summary statistics, including percentiles (p), of model evaluation for different weather and window conditions

Model	Sample Size	Δ (hr ⁻¹)							ε (%)						
		Mean	SD	p10	p25	p50	p75	p90	Mean	SD	p10	p25	p50	p75	p90
SF															
Weather: Stack dominated	110	0.63	0.78	0.06	0.13	0.31	0.91	1.75	46	30	9	23	40	70	81
Wind dominated	132	0.25	0.28	0.04	0.09	0.23	0.33	0.43	70	70	8	20	50	104	167
Window: Closed	389	0.50	0.37	0.06	0.14	0.26	0.38	0.64	77	81	10	29	59	102	164
Opened	253	0.36	0.50	0.05	0.11	0.22	0.40	0.80	48	40	9	20	37	64	109
LBL															
Weather: Stack dominated	110	0.61	0.75	0.06	0.12	0.28	0.87	1.75	45	28	11	21	46	68	75
Wind dominated	132	0.27	0.36	0.03	0.07	0.17	0.34	0.57	46	29	10	26	46	62	79
Window: Closed	389	0.29	0.49	0.03	0.07	0.14	0.27	0.65	42	34	6	18	38	59	75
Opened	253	0.42	0.59	0.06	0.11	0.24	0.45	1.01	45	24	12	26	48	61	76
LBLX															
Weather: Stack dominated	110	0.62	0.76	0.06	0.12	0.28	0.88	1.73	45	30	9	21	45	68	76
Wind dominated	132	0.27	0.37	0.02	0.06	0.14	0.31	0.51	48	49	7	20	42	60	79
Window: Closed	389	0.41	0.49	0.03	0.07	0.14	0.27	0.65	42	34	6	18	38	59	75
Opened	253	0.29	0.49	0.03	0.09	0.25	0.49	1.07	56	69	8	19	41	60	95

Table S11. Summary statistics, including percentiles (p), of model evaluation for different weather and window conditions

Model	Sample Size	Δ (hr ⁻¹)							ϵ (%)						
		Mean	SD	p10	p25	p50	p75	p90	Mean	SD	p10	p25	p50	p75	p90
SF															
Weather: Stack dominated	110	-0.56	0.83	-1.76	-0.91	-0.26	0.02	0.16	-24	49	-77	-63	-34	3	34
Wind dominated	132	0.05	0.37	-0.25	-0.08	0.13	0.29	0.38	50	86	-34	-14	30	104	167
Window: Closed	389	-0.05	0.62	-0.64	-0.12	0.15	0.30	0.37	49	101	-57	-20	33	102	164
Opened	253	-0.16	0.60	-0.80	-0.27	-0.04	0.19	0.36	11	61	-55	-32	-7	47	109
LBL															
Weather: Stack dominated	110	-0.53	0.82	-1.75	-0.87	-0.25	0.04	0.20	-22	48	-74	-61	-30	7	46
Wind dominated	132	-0.23	0.38	-0.57	-0.34	-0.17	-0.02	0.07	-26	48	-74	-59	-40	-6	42
Window: Closed	389	-0.21	0.53	-0.65	-0.26	-0.08	0.07	0.16	-9	54	-66	-48	-18	18	57
Opened	253	-0.39	0.61	-1.01	-0.45	-0.23	-0.09	0.06	-36	37	-74	-60	-46	-17	-16
LBLX															
Weather: Stack dominated	110	-0.50	0.84	-1.74	-0.87	-0.22	0.07	0.22	-19	52	-74	-60	-28	12	48
Wind dominated	132	-0.05	0.46	-0.41	-0.20	-0.08	0.04	0.14	-5	68	-64	-48	-23	15	69
Window: Closed	389	-0.21	0.53	-0.65	-0.26	-0.08	0.07	0.16	-9	54	-67	-48	-18	18	57
Opened	253	-0.07	0.64	-0.60	-0.34	-0.10	0.08	0.54	5	89	-61	-48	-20	18	95

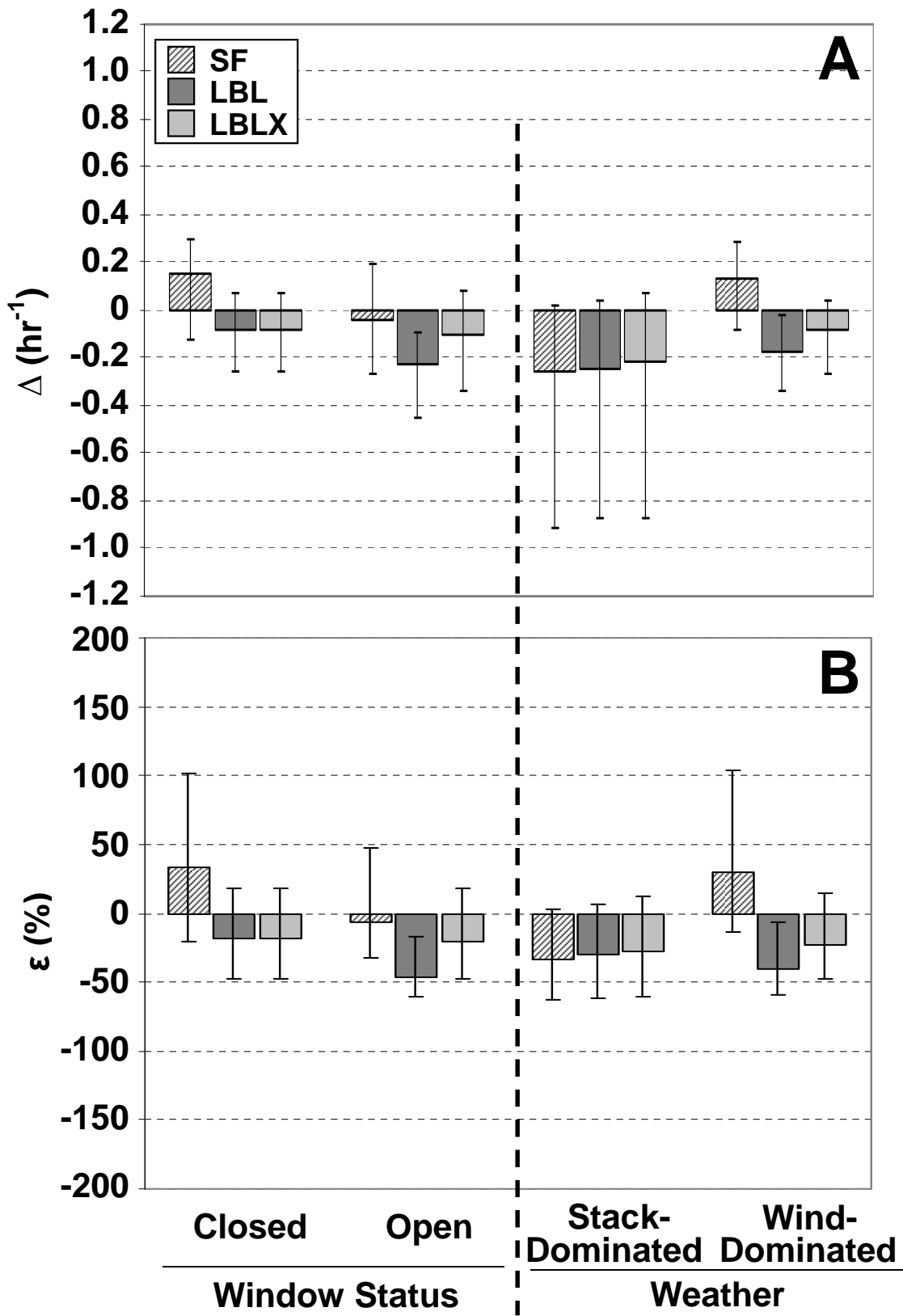


Figure S5

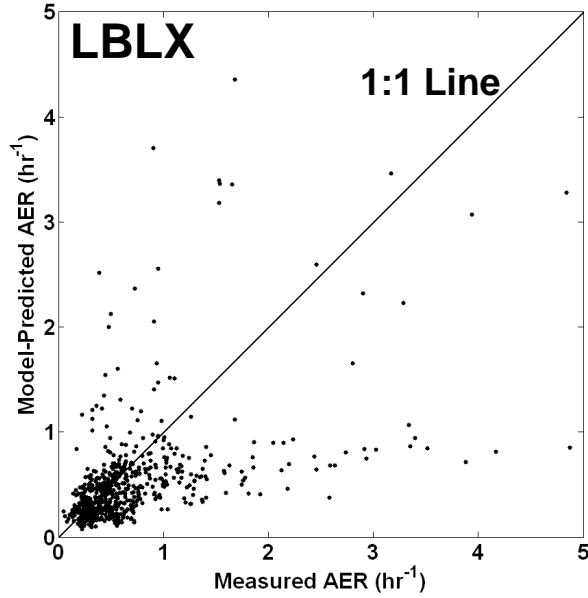
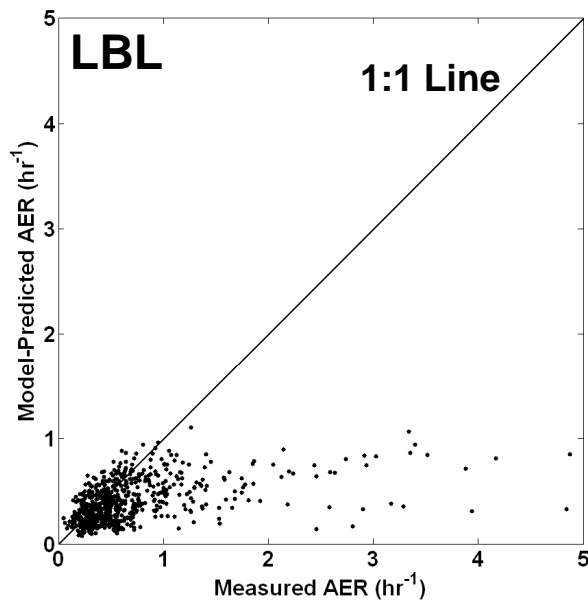
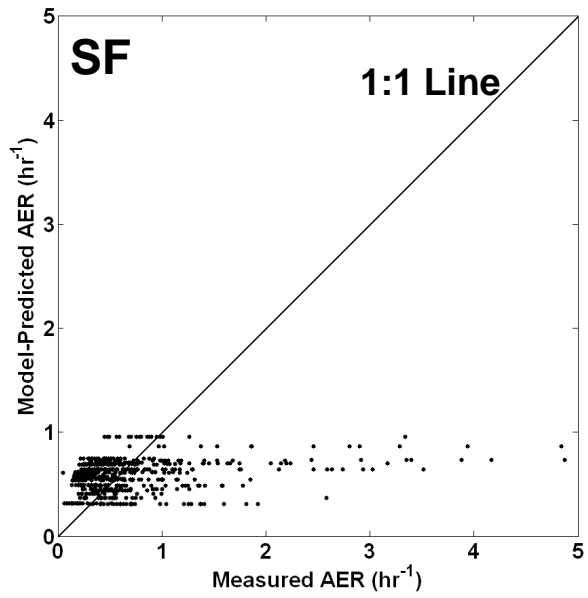


Figure S6