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Better sustainability assessment of green buildings with high-frequency data

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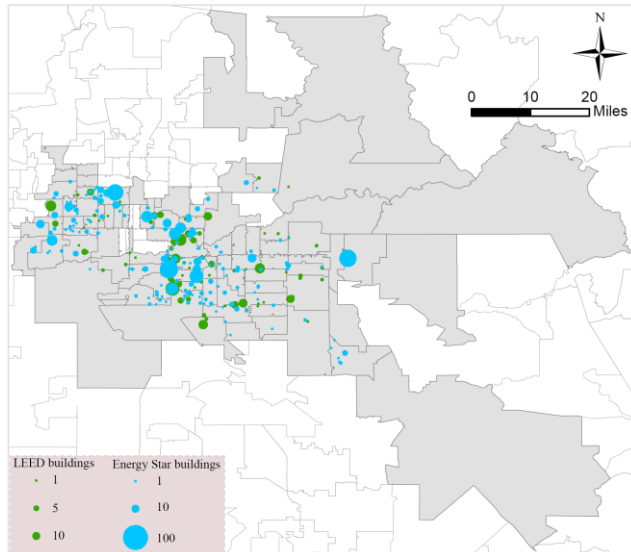
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Supplementary Information

Supplementary Notes:

Descriptive statistics



Supplementary Figure 1. Locations of business customers located in Energy Star and LEED buildings

In Supplementary Tables 1 and 2, the SMDs are smaller than 0.25 and VRs are between 0.5 and 2, indicating that the treatment and control groups in the pre-certification stage are indeed comparable in terms of electric load profiles. For LEED analysis, Supplementary Tables 3 and 4 show that the

control and treatment groups are generally balanced on sample mean (SMDs are smaller than 0.25) and sample distribution (VRs are greater than 2). However, due to much smaller sample of LEED buildings compared to Energy Star buildings, the matched sample is not balanced well on sample mean for some hours in the summer (5am, 12pm, 1pm, 2pm, and 4pm). For these hours, the SMDs are between 0.26-0.29, not too far away from the threshold of 0.25.

Supplementary Table 1. Summary statistics and balancing check for Energy Star analysis; Summer; Subsample, only accounts with both pre-certification and post-certification high frequency electricity demand data

Pre-certification, Summer							
Treatment group: 33 accounts						Balancing check	
	# of Observations	Mean	Std. Dev.	Min	Max	SMD	VR
kWh 1am	6,282	50.53	76.81	0	383.09	0.00	1.05
kWh 2am	6,282	49.84	75.53	0	376.99	0.00	1.05
kWh 3am	6,282	49.51	75.80	0	377.33	0.00	1.04
kWh 4am	6,282	49.79	75.95	0	381.07	0.02	1.08
kWh 5am	6,282	54.22	79.68	0	372.48	0.05	1.13
kWh 6am	6,282	65.50	90.81	0	405.90	0.12	1.21
kWh 7am	6,282	75.95	102.59	0	423.27	0.11	1.18
kWh 8am	6,282	88.46	115.36	0	465.66	0.08	1.03
kWh 9am	6,282	100.83	124.62	0	486.90	0.13	1.14
kWh 10am	6,282	109.66	131.30	0	520.02	0.15	1.18
kWh 11am	6,282	114.45	135.97	0	499.32	0.14	1.18
kWh 12pm	6,282	117.19	138.54	0	520.92	0.13	1.19
kWh 1pm	6,282	118.69	140.48	0	519.84	0.12	1.19
kWh 2pm	6,282	119.20	141.31	0	521.28	0.12	1.19
kWh 3pm	6,282	119.33	141.63	0	511.92	0.12	1.21
kWh 4pm	6,282	114.03	135.56	0	502.38	0.12	1.20
kWh 5pm	6,282	105.97	128.49	0	465.05	0.11	1.13
kWh 6pm	6,282	100.87	123.01	0	459.65	0.08	1.03
kWh 7pm	6,282	94.26	116.96	0	446.26	0.08	1.06
kWh 8pm	6,282	92.47	114.79	0	466.92	0.11	1.14
kWh 9pm	6,282	87.73	110.62	0	470.59	0.10	1.20
kWh 10pm	6,282	75.23	100.96	0	456.34	0.08	1.17
kWh 11pm	6,282	63.87	90.37	0	431.64	0.06	1.06
kWh 0am	6,282	53.94	80.65	0	397.30	0.01	1.00
Control group: 33 accounts							

	# of Observations	Mean	Std. Dev.	Min	Max
kWh 1am	6,070	50.78	75.00	0	330.24
kWh 2am	6,070	49.68	73.63	0	320.16
kWh 3am	6,070	49.20	74.29	0	324.24
kWh 4am	6,070	48.52	73.20	0	316.26
kWh 5am	6,070	50.26	74.93	0	329.76
kWh 6am	6,070	55.19	82.67	0	368.46
kWh 7am	6,070	64.86	94.42	0	446.22
kWh 8am	6,070	78.89	113.66	0	512.46
kWh 9am	6,070	85.12	116.70	0	524.07
kWh 10am	6,070	91.35	120.87	0	503.73
kWh 11am	6,070	96.44	124.93	0	514.89
kWh 12pm	6,070	99.58	127.26	0	492.30
kWh 1pm	6,070	101.89	128.93	0	475.83
kWh 2pm	6,070	103.13	129.80	0	467.19
kWh 3pm	6,070	102.90	128.95	0	477.00
kWh 4pm	6,070	98.09	123.93	0	473.94
kWh 5pm	6,070	92.16	121.11	0	471.06
kWh 6pm	6,070	90.63	120.93	0	454.14
kWh 7pm	6,070	84.68	113.73	0	414.00
kWh 8pm	6,070	80.78	107.33	0	396.00
kWh 9pm	6,070	76.75	100.99	0	387.18
kWh 10pm	6,070	67.05	93.49	0	387.00
kWh 11pm	6,070	58.33	87.78	0	383.40
kWh 0am	6,070	53.32	80.76	0	357.96

Supplementary Table 2. Summary statistics and balancing check for Energy Star analysis; Winter; Subsample, only accounts with both pre-certification and post-certification high frequency electricity demand data

Pre-certification, Winter							
Treatment group: 33 accounts						Balancing check	
	# of Observations	Mean	Std. Dev.	Min	Max	SMD	VR
kWh 1am	3,389	39.48	54.50	0	281.47	0.06	1.00
kWh 2am	3,389	38.43	53.78	0	282.82	0.05	0.99
kWh 3am	3,389	38.63	54.40	0	288.19	0.05	0.95
kWh 4am	3,389	39.33	54.68	0	292.85	0.07	0.97
kWh 5am	3,389	44.17	58.60	0	287.09	0.13	1.08
kWh 6am	3,389	55.25	71.20	0	361.44	0.19	1.33
kWh 7am	3,389	71.73	90.44	0	491.31	0.21	1.49

kWh 8am	3,389	80.24	101.31	0	455.40	0.19	1.35
kWh 9am	3,389	84.28	104.80	0	438.21	0.21	1.37
kWh 10am	3,389	84.67	101.80	0	421.38	0.19	1.25
kWh 11am	3,389	85.27	101.86	0	395.10	0.17	1.22
kWh 12pm	3,389	85.63	102.51	0	417.87	0.16	1.20
kWh 1pm	3,389	84.89	102.06	0	412.20	0.15	1.19
kWh 2pm	3,389	82.48	100.82	0	405.36	0.13	1.18
kWh 3pm	3,389	81.53	100.32	0	409.05	0.13	1.19
kWh 4pm	3,389	76.85	95.51	0	404.19	0.14	1.17
kWh 5pm	3,389	71.04	88.90	0	375.75	0.13	1.07
kWh 6pm	3,389	70.98	85.41	0	341.71	0.12	0.99
kWh 7pm	3,389	68.76	83.11	0	343.25	0.10	1.05
kWh 8pm	3,389	66.45	80.98	0	344.83	0.11	1.15
kWh 9pm	3,389	62.11	77.67	0	330.19	0.12	1.23
kWh 10pm	3,389	56.33	72.94	0	315.00	0.14	1.24
kWh 11pm	3,389	51.12	66.83	0	299.14	0.16	1.17
kWh 0am	3,389	44.04	59.07	0	279.29	0.10	1.02
Control group: 33 accounts							
	# of Observations	Mean	Std. Dev.	Min	Max		
kWh 1am	3,168	35.99	54.58	0	285.84		
kWh 2am	3,168	35.51	54.13	0	291.96		
kWh 3am	3,168	35.88	55.90	0	297.18		
kWh 4am	3,168	35.71	55.43	0	300.96		
kWh 5am	3,168	36.62	56.45	0	312.48		
kWh 6am	3,168	42.30	61.69	0	317.16		
kWh 7am	3,168	53.96	74.15	0	311.22		
kWh 8am	3,168	62.20	87.30	0	454.95		
kWh 9am	3,168	63.69	89.48	0	464.49		
kWh 10am	3,168	66.09	90.95	0	447.57		
kWh 11am	3,168	68.29	92.36	0	385.02		
kWh 12pm	3,168	69.50	93.46	0	401.67		
kWh 1pm	3,168	70.00	93.59	0	398.16		
kWh 2pm	3,168	69.64	92.99	0	373.14		
kWh 3pm	3,168	68.72	92.09	0	371.07		
kWh 4pm	3,168	64.02	88.18	0	361.08		
kWh 5pm	3,168	59.85	86.13	0	353.43		
kWh 6pm	3,168	60.31	85.75	0	349.02		
kWh 7pm	3,168	60.68	81.16	0	325.98		
kWh 8pm	3,168	57.95	75.46	0	324.00		
kWh 9pm	3,168	53.04	69.91	0	312.84		
kWh 10pm	3,168	46.40	65.39	0	313.02		
kWh 11pm	3,168	40.75	61.92	0	306.90		
kWh 0am	3,168	37.98	58.42	0	302.40		

Supplementary Table 3. Summary statistics and balancing check for LEED analysis; Summer; Subsample, only accounts with both pre-certification and post-certification high frequency electricity demand data

Pre-certification, Summer							
Treatment group: 8 accounts						Balancing check	
	# of Observations	Mean	Std. Dev.	Min	Max	SMD	VR
kWh 1am	3,057	27.28	39.72	0	164.88	0.15	0.89
kWh 2am	3,057	25.32	38.82	0	160.02	0.12	0.90
kWh 3am	3,057	24.81	38.02	0	158.04	0.13	0.91
kWh 4am	3,057	24.59	37.73	0	163.44	0.13	0.92
kWh 5am	3,057	34.92	63.37	0	341.46	0.29	2.61
kWh 6am	3,057	37.30	65.96	0	349.56	0.25	1.97
kWh 7am	3,057	36.89	57.29	0	303.66	0.08	0.56
kWh 8am	3,057	41.66	63.17	0	318.24	0.17	0.78
kWh 9am	3,057	51.34	77.60	0	360.18	0.21	0.89
kWh 10am	3,057	57.38	88.49	0	383.58	0.24	1.11
kWh 11am	3,057	60.60	95.07	0	399.6	0.25	1.24
kWh 12pm	3,057	62.73	99.24	0	414.72	0.26	1.33
kWh 1pm	3,057	63.83	101.10	0	425.88	0.28	1.44
kWh 2pm	3,057	63.35	101.80	0	437.04	0.26	1.41
kWh 3pm	3,057	64.23	104.00	0	444.24	0.25	1.44
kWh 4pm	3,057	63.95	103.76	0	448.56	0.26	1.48
kWh 5pm	3,057	61.55	99.01	0	435.42	0.25	1.43
kWh 6pm	3,057	53.19	86.30	0	382.68	0.21	1.27
kWh 7pm	3,057	38.37	51.15	0	234.9	0.22	1.12
kWh 8pm	3,057	34.69	48.33	0	240.48	0.21	1.08
kWh 9pm	3,057	33.30	46.20	0	193.86	0.21	1.03
kWh 10pm	3,057	32.03	44.42	0	184.86	0.20	0.99
kWh 11pm	3,057	31.36	43.17	0	178.92	0.21	0.98
kWh 0am	3,057	29.27	41.85	0	170.1	0.18	0.96
Control group: 8 accounts							
	# of Observations	Mean	Std. Dev.	Min	Max		
kWh 1am	2,260	20.97	41.99	0	200.07		
kWh 2am	2,260	20.42	41.00	0	197.91		
kWh 3am	2,260	19.92	39.96	0	193.41		
kWh 4am	2,260	19.68	39.44	0	188.28		
kWh 5am	2,260	19.66	39.19	0	187.29		
kWh 6am	2,260	22.91	46.98	0	230.58		
kWh 7am	2,260	31.19	76.24	0	378.99		
kWh 8am	2,260	30.09	71.58	0	379.8		
kWh 9am	2,260	34.65	82.34	0	462.06		

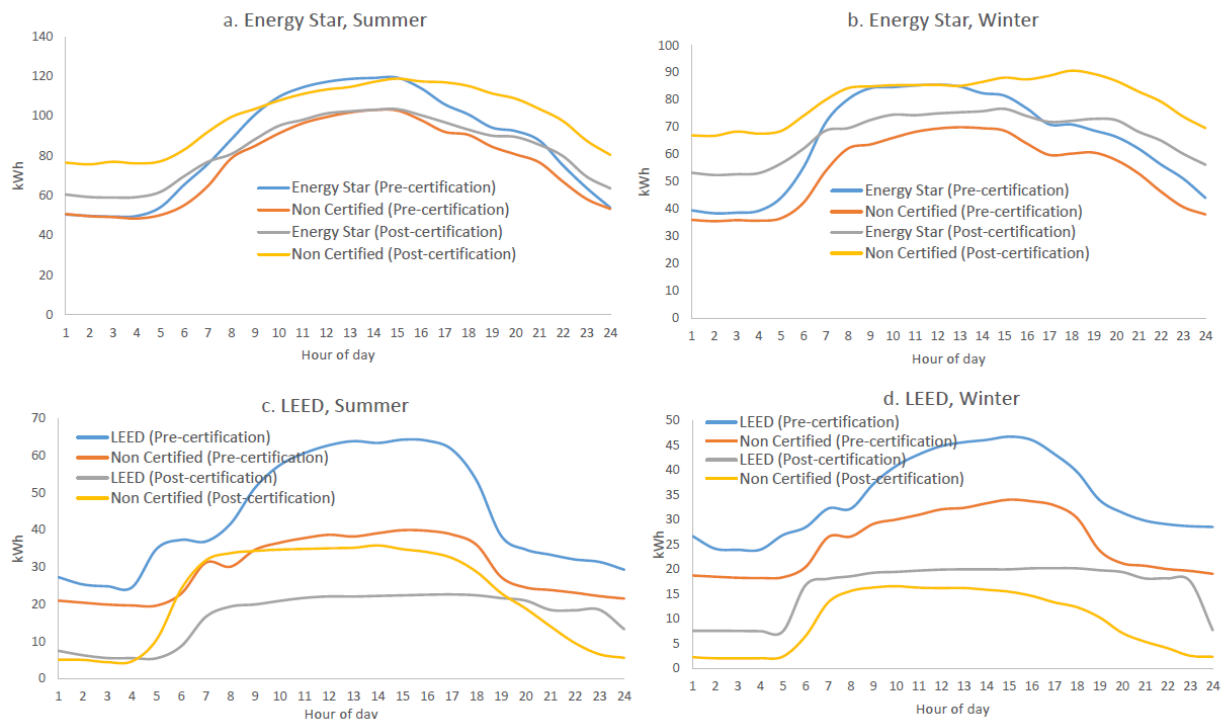
kWh 10am	2,260	36.54	84.18	0	438.75
kWh 11am	2,260	37.78	85.33	0	430.56
kWh 12pm	2,260	38.65	86.08	0	425.16
kWh 1pm	2,260	38.20	84.30	0	423.9
kWh 2pm	2,260	39.10	85.59	0	432.18
kWh 3pm	2,260	39.89	86.66	0	429.93
kWh 4pm	2,260	39.71	85.27	0	422.01
kWh 5pm	2,260	38.73	82.77	0	417.15
kWh 6pm	2,260	35.92	76.52	0	377.73
kWh 7pm	2,260	27.30	48.38	0	267.66
kWh 8pm	2,260	24.50	46.55	0	240.93
kWh 9pm	2,260	23.82	45.41	0	226.17
kWh 10pm	2,260	23.08	44.60	0	221.4
kWh 11pm	2,260	22.18	43.52	0	217.08
kWh 0am	2,260	21.52	42.82	0	210.87

Supplementary Table 4. Summary statistics and balancing check for LEED analysis; Winter; Subsample, only accounts with both pre-certification and post-certification high frequency electricity demand data

Pre-certification, Winter							
Treatment group: 8 accounts						Balancing check	
	# of Observations	Mean	Std. Dev.	Min	Max	SMD	VR
kWh 1am	2,287	26.66	33.51	0	115.92	0.23	0.87
kWh 2am	2,287	24.13	33.14	0	116.28	0.17	0.87
kWh 3am	2,287	23.90	32.74	0	117.36	0.17	0.87
kWh 4am	2,287	23.94	32.81	0	118.8	0.17	0.88
kWh 5am	2,287	26.88	38.78	0	158.76	0.23	1.21
kWh 6am	2,287	28.45	41.06	0	162.9	0.20	1.09
kWh 7am	2,287	32.22	43.92	0	187.38	0.11	0.59
kWh 8am	2,287	32.21	44.14	0	189.9	0.11	0.65
kWh 9am	2,287	37.19	52.26	0	216.36	0.14	0.74
kWh 10am	2,287	40.79	59.42	0	252.72	0.18	0.87
kWh 11am	2,287	43.11	64.25	0	269.28	0.19	0.94
kWh 12pm	2,287	44.80	67.03	0	285.3	0.19	0.95
kWh 1pm	2,287	45.58	68.26	0	298.26	0.19	0.96

kWh 2pm	2,287	46.05	69.61	0	310.5	0.18	0.94
kWh 3pm	2,287	46.70	71.16	0	319.14	0.18	0.94
kWh 4pm	2,287	46.02	70.30	0	316.26	0.17	0.95
kWh 5pm	2,287	43.20	65.14	0	303.12	0.15	0.88
kWh 6pm	2,287	39.59	56.07	0	262.98	0.16	0.83
kWh 7pm	2,287	33.91	42.79	0	162.36	0.24	1.04
kWh 8pm	2,287	31.40	39.50	0	148.14	0.26	1.00
kWh 9pm	2,287	29.79	37.36	0	136.62	0.24	0.92
kWh 10pm	2,287	29.04	36.52	0	130.5	0.24	0.92
kWh 11pm	2,287	28.65	35.80	0	129.42	0.25	0.92
kWh 0am	2,287	28.51	35.39	0	127.44	0.26	0.94
Control group: 8 accounts							
	# of Observations	Mean	Std. Dev.	Min	Max		
kWh 1am	1,742	18.68	36.02	0	145.89		
kWh 2am	1,742	18.44	35.57	0	141.57		
kWh 3am	1,742	18.23	35.15	0	141.75		
kWh 4am	1,742	18.17	34.98	0	140.94		
kWh 5am	1,742	18.32	35.24	0	159.024		
kWh 6am	1,742	20.42	39.32	0	172.53		
kWh 7am	1,742	26.45	57.21	0	306		
kWh 8am	1,742	26.56	54.74	0	274.59		
kWh 9am	1,742	29.11	60.90	0	304.65		
kWh 10am	1,742	29.99	63.78	0	318.78		
kWh 11am	1,742	30.94	66.13	0	320.49		
kWh 12pm	1,742	32.04	68.66	0	326.7		
kWh 1pm	1,742	32.35	69.73	0	334.71		
kWh 2pm	1,742	33.27	71.81	0	342.81		
kWh 3pm	1,742	34.00	73.44	0	350.1		
kWh 4pm	1,742	33.67	71.97	0	332.73		
kWh 5pm	1,742	32.85	69.47	0	325.17		
kWh 6pm	1,742	30.29	61.44	0	301.86		
kWh 7pm	1,742	23.73	41.94	0	181.53		
kWh 8pm	1,742	21.15	39.60	0	166.23		
kWh 9pm	1,742	20.65	39.01	0	160.056		
kWh 10pm	1,742	19.98	37.98	0	160.104		
kWh 11pm	1,742	19.61	37.30	0	152.856		
kWh 0am	1,742	19.03	36.50	0	149.85		

Supplementary Figure 2 shows the average summer and winter load profiles for control and treatment groups for Energy Star matched sample and LEED matched sample. For Energy Star samples, both the summer and winter figures show that the load curves for occupants in Energy Star buildings become flatter after certification. This means that these occupants use less energy during peak hours while more energy during non-peak hours after certification. For occupants in non-certified buildings, they actually use more energy in all hours in post-certification period, making load curves shift upwards. For LEED samples, the summer figure shows that occupants in LEED buildings use less energy in all hours and also the load curve becomes flatter after certification. For non-certified buildings, the load curve does not shift that much. Winter figure still shows that occupants in LEED buildings use less energy in all hours and also the load curve becomes flatter, but occupants in non-certified buildings also use less energy in all hours.



Supplementary Figure 2. Average load profiles of control and treatment customers

Tables of econometric regression results

Supplementary Table 5 is for Energy Star analysis and Supplementary Table 6 is for LEED analysis. Models 1& 2 in each table are for summer months (May-Oct) and Models 3 & 4 are for winter months. Models 1& 3 in each table are from estimating equation (1) in *Methods* and Models 2 & 4 are from estimating equation (2).

Supplementary Table 5. Energy Star high frequency demand data analysis; Dependent variable: hourly kWh; Subsample, only accounts with both pre-certification and post-certification high frequency electricity demand data

Model number	1	2	3	4
Season	Summer		Winter	
Energy Star Certification * 1am	3.274*** (0.710)	3.530*** (0.699)	0.864 (0.586)	0.865 (0.573)
Energy Star Certification * 2am	2.641*** (0.710)	2.917*** (0.699)	0.546 (0.586)	0.576 (0.573)
Energy Star Certification * 3am	2.220*** (0.711)	2.568*** (0.700)	0.080 (0.586)	0.138 (0.573)
Energy Star Certification * 4am	2.868*** (0.711)	3.182*** (0.700)	0.722 (0.586)	0.797 (0.573)
Energy Star Certification * 5am	3.081*** (0.711)	3.380*** (0.701)	2.251*** (0.586)	2.336*** (0.573)
Energy Star Certification * 6am	3.520*** (0.711)	3.899*** (0.701)	1.402** (0.593)	1.703*** (0.579)
Energy Star Certification * 7am	1.201* (0.711)	1.501** (0.700)	-2.543*** (0.593)	-2.234*** (0.579)
Energy Star Certification * 8am	-6.199*** (0.711)	-5.867*** (0.700)	-8.140*** (0.593)	-7.826*** (0.579)
Energy Star Certification * 9am	-6.340*** (0.710)	-6.167*** (0.699)	-6.479*** (0.586)	-6.838*** (0.573)
Energy Star Certification * 10am	-6.024*** (0.710)	-5.982*** (0.699)	-7.297*** (0.586)	-7.246*** (0.573)
Energy Star Certification * 11am	-7.269*** (0.710)	-7.292*** (0.699)	-8.531*** (0.586)	-8.507*** (0.573)
Energy Star Certification * 12pm	-5.252***	-5.520***	-8.517***	-8.497***

	(0.710)	(0.699)	(0.586)	(0.573)
Energy Star Certification * 1pm	-5.597***	-5.900***	-7.949***	-7.904***
	(0.710)	(0.699)	(0.586)	(0.573)
Energy Star Certification * 2pm	-6.017***	-6.334***	-7.500***	-7.412***
	(0.710)	(0.699)	(0.586)	(0.573)
Energy Star Certification * 3pm	-4.707***	-5.250***	-6.916***	-6.779***
	(0.711)	(0.700)	(0.586)	(0.573)
Energy Star Certification * 4pm	-3.674***	-4.231***	-6.760***	-6.590***
	(0.711)	(0.700)	(0.586)	(0.573)
Energy Star Certification * 5pm	-0.933	-0.844	-6.825***	-6.670***
	(0.716)	(0.706)	(0.586)	(0.573)
Energy Star Certification * 6pm	-1.736**	-1.638**	-6.294***	-6.544***
	(0.716)	(0.706)	(0.586)	(0.573)
Energy Star Certification * 7pm	0.579	0.689	-4.663***	-5.032***
	(0.716)	(0.705)	(0.586)	(0.573)
Energy Star Certification * 8pm	-0.256	-0.549	-2.415***	-2.869***
	(0.710)	(0.699)	(0.586)	(0.573)
Energy Star Certification * 9pm	0.016	-0.233	-2.013***	-2.486***
	(0.710)	(0.699)	(0.586)	(0.573)
Energy Star Certification * 10pm	3.643***	3.429***	-1.114*	-1.212**
	(0.710)	(0.699)	(0.586)	(0.573)
Energy Star Certification * 11pm	3.012***	2.937***	-0.344	-0.451
	(0.710)	(0.699)	(0.586)	(0.573)
Energy Star Certification * 0 am	3.032***	3.244***	0.417	0.339
	(0.710)	(0.699)	(0.586)	(0.573)
Marginal price	-66.841***	-78.977***	79.609***	-0.777
	(12.194)	(12.146)	(12.686)	(12.447)
Price*E32 price plan	619.690***	540.276***	329.753***	287.095***
	(12.548)	(12.520)	(13.191)	(12.921)
Price*E33 price plan	29.850**	21.090*		
	(12.622)	(12.564)		
E32 price plan	-54.692***	-48.769***	-25.968***	-25.257***
	(1.589)	(1.577)	(1.267)	(1.243)
Constant	69.683***	92.957***	58.199***	55.481***
	(5.658)	(6.510)	(1.312)	(1.898)
Temperature spline	Yes	Yes	Yes	Yes
Account fixed effects	Yes	Yes	Yes	Yes
Year of sample fixed effects	Yes		Yes	
Month of year fixed effects	Yes		Yes	
Day of month fixed effects	Yes		Yes	
Hour of day fixed effects	Yes	Yes	Yes	Yes
Day of sample fixed effects		Yes		Yes
Number of accounts	66	66	66	66
Number of observations	591,096	591,096	447,828	447,828

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; Clustered standard errors in parentheses; Standard errors clustered at account level

Supplementary Table 6. LEED high frequency demand data analysis; Subsample; Dependent variable: hourly kWh; Subsample, only accounts with both pre-certification and post-certification high frequency electricity demand data

Model number	1	2	3	4
Season	Summer		Winter	
LEED Certification * 1am	0.985 (1.532)	1.467 (1.505)	1.582 (1.033)	1.849* (1.009)
LEED Certification * 2am	1.017 (1.532)	1.530 (1.505)	2.794*** (1.033)	2.942*** (1.009)
LEED Certification * 3am	0.611 (1.532)	1.228 (1.506)	2.966*** (1.033)	3.146*** (1.009)
LEED Certification * 4am	0.741 (1.532)	1.432 (1.506)	2.935*** (1.033)	3.137*** (1.009)
LEED Certification * 5am	-4.469*** (1.532)	-3.696** (1.506)	1.627 (1.033)	1.828* (1.009)
LEED Certification * 6am	-3.516** (1.532)	-2.749* (1.506)	9.574*** (1.033)	9.737*** (1.009)
LEED Certification * 7am	1.542 (1.533)	2.415 (1.507)	7.105*** (1.033)	7.348*** (1.010)
LEED Certification * 8am	2.202 (1.533)	3.067** (1.507)	7.607*** (1.033)	7.888*** (1.010)
LEED Certification * 9am	-3.662** (1.532)	-3.054** (1.505)	4.981*** (1.033)	5.244*** (1.010)
LEED Certification * 10am	-6.212*** (1.532)	-5.931*** (1.505)	2.945*** (1.033)	3.108*** (1.009)
LEED Certification * 11am	-7.238*** (1.532)	-7.226*** (1.505)	1.743* (1.033)	1.745* (1.009)
LEED Certification * 12pm	-7.231*** (1.532)	-7.563*** (1.505)	0.781 (1.033)	0.644 (1.009)
LEED Certification * 1pm	-7.402*** (1.532)	-7.968*** (1.505)	0.433 (1.033)	0.172 (1.010)
LEED Certification * 2pm	-7.090*** (1.532)	-7.861*** (1.506)	-0.052 (1.033)	-0.409 (1.010)
LEED Certification * 3pm	-6.836*** (1.533)	-7.807*** (1.507)	-0.610 (1.033)	-1.004 (1.010)
LEED Certification * 4pm	-6.348*** (1.533)	-7.406*** (1.507)	-0.000 (1.033)	-0.427 (1.010)
LEED Certification * 5pm	-4.658*** (1.533)	-5.743*** (1.507)	1.580 (1.033)	1.175 (1.010)
LEED Certification * 6pm	0.300 (1.533)	-0.736 (1.507)	4.255*** (1.033)	3.861*** (1.010)
LEED Certification * 7pm	9.893*** (1.532)	8.993*** (1.506)	8.503*** (1.033)	8.261*** (1.009)
LEED Certification * 8pm	11.355***	10.755***	10.213***	10.096***

	(1.532)	(1.505)	(1.033)	(1.009)
LEED Certification * 9pm	9.382***	9.093***	9.943***	9.911***
	(1.532)	(1.505)	(1.033)	(1.009)
LEED Certification * 10pm	9.791***	9.794***	10.461***	10.581***
	(1.532)	(1.505)	(1.033)	(1.009)
LEED Certification * 11pm	10.344***	10.507***	10.251***	10.383***
	(1.532)	(1.505)	(1.033)	(1.009)
LEED Certification * 0 am	5.703***	6.040***	0.646	0.774
	(1.532)	(1.505)	(1.033)	(1.009)
Marginal price	-607.803***	-547.374***	158.686***	91.786***
	(44.878)	(46.489)	(17.529)	(17.251)
Price*E32 price plan	1455.649***	1309.611***	329.753***	287.095***
	(46.088)	(47.641)	(13.191)	(12.921)
E32 price plan	-105.516***	-96.470***	-7.111***	-10.307***
	(5.029)	(5.206)	(0.600)	(0.611)
Constant	55.222***	49.707***	7.345***	14.765***
	(9.631)	(10.813)	(1.617)	(2.364)
Temperature spline	Yes	Yes	Yes	Yes
Account fixed effects	Yes	Yes	Yes	Yes
Year of sample fixed effects	Yes		Yes	
Month of year fixed effects	Yes		Yes	
Day of month fixed effects	Yes		Yes	
Hour of day fixed effects	Yes	Yes	Yes	Yes
Day of sample fixed effects		Yes		Yes
Number of accounts	16	16	16	16
Number of observations	157,704	157,704	132,336	132,336
Notes: * p < 0.1, ** p < 0.05, *** p < 0.01; Clustered standard errors in parentheses; Standard errors clustered at account level				

Results using a larger sample

In order to have a larger sample size, we also conduct the matching and econometric analysis including those buildings that obtained green certificates prior to 2013 which gives us total of 128 accounts for Energy Star analysis and 42 accounts for LEED analysis. For the buildings that obtained green certificates prior to 2013, we cannot match the electric customers based on load profiles which rely on high frequency electricity usage data. Instead, we match the customers based on industry NAICS code, zip code, and pre-certification summer and winter average monthly kWh and monthly maximum demand (kW). Supplementary Tables 7 & 8 show the balancing checks of the pre-certification kWh and kW of the treatment and control groups for those customers that are matched but do not have pre-certification high frequency data.

We then conduct the econometric analysis on the full sample of matched control and treatment groups including those with both pre- and post-certification high frequency data and those who only have post-certification high frequency data. This gives us larger sample size: total of 128 accounts for Energy Star analysis and 42 accounts for LEED analysis. The results are listed in Supplementary Tables 9 & 10. Supplementary Figure 3 plots the coefficients for the interaction terms of green certification variables and hour of day indicator variables, from running equation (2) with hour-of-sample fixed effects. The results are similar to those using only the subsample of customers with both pre- and post-certification high frequency data. Supplementary Figure 3 panels a & b show that Energy Star certification helps building occupants save energy from 7am to about 8pm. Supplementary Figure 3 panels c & d show that LEED certification helps building occupants save energy from 10am to about 5pm. These hours with electricity savings are the peak and shoulder peak hours for summer electric load profiles of electric utilities.

The drawback of this larger sample size analysis is that it includes a subsample that only has post-treatment high frequency electricity demand data and we cannot test whether electricity load profiles of the treatment and control groups prior to certification in this subsample are comparable. Thus our discussion is still based on our main analysis with the subsample that has both pre- and post-certification high frequency electricity demand data.



Supplementary Figure 3. Intraday electricity savings by hour using full sample. The figures show the coefficients of the interaction terms of Energy Star/LEED certification dummy variable and the dummy variable indicating hour of day. The solid dots indicate the magnitudes of the coefficients; the vertical lines show the 90% confidence intervals.

Supplementary Table 7. Summary statistics of the Energy Star treatment and control groups for those without pre-treatment high frequency electricity demand data

Pre-certification, Summer							Balancing check	
Treatment group							SMD	VR
Variable	# of accounts	# of Observations	Mean	Std. Dev.	Min	Max		
kWh	31	1,158	108238.1	113557.7	0	588942.6		
kW	31	1,158	214.4	210.9	0	791		
Control group								
Variable	# of accounts	# of Observations	Mean	Std. Dev.	Min	Max		
kWh	31	1,173	87285.12	115966.8	0	645890.7		
kW	31	1,173	171.9	230.0	0	948		
Pre-certification, Winter							SMD	VR
Treatment group								
Variable	# of accounts	# of Observations	Mean	Std. Dev.	Min	Max		
kWh	31	1,140	89556.77	93280.7	0	398861.2		
kW	31	1,140	181.1	175.0	0	712		
Control group								
Variable	# of accounts	# of Observations	Mean	Std. Dev.	Min	Max		
kWh	31	1,183	69760	91782.1	0	321314.9		
kW	31	1,183	144.1	195.8	0	874		

Supplementary Table 8. Summary statistics of the LEED treatment and control groups for those without pre-treatment high frequency electricity demand data

Pre-certification, Summer							Balancing check	
Treatment group								
Variable	# of accounts	# of Observations	Mean	Std. Dev.	Min	Max	SMD	VR
kWh	13	939	56874.7	144249.0	0	1048177		
kW	13	939	147.5	323.1	0	2340		
Control group								
Variable	# of accounts	# of Observations	Mean	Std. Dev.	Min	Max		
kWh	13	1,455	57473.1	98424.6	0	602976		
kW	13	1,455	153.1	222.3	0	1052		
Pre-certification, Winter								
Treatment group								

Variable	# of accounts	# of Observations	Mean	Std. Dev.	Min	Max	SMD	VR
kWh	13	944	45948.3	118524.5	0	928715	0.00	1.77
kW	13	944	137.5	275.8	0	1861	0.04	2.29
Control group								
Variable	# of accounts	# of Observations	Mean	Std. Dev.	Min	Max		
kWh	13	1,495	46273.0	89097.9	62	661783		
kW	13	1,495	128.3	182.4	0	974		

Supplementary Table 9. Energy Star high frequency demand data analysis; Dependent variable: hourly kWh;
Full sample

Model number	1	2	3	4
Season	Summer		Winter	
Energy Star Certification * 1am	0.716* (0.392)	0.910** (0.390)	-3.913*** (0.334)	-3.845*** (0.332)
Energy Star Certification * 2am	2.058*** (0.392)	2.264*** (0.390)	-2.854*** (0.334)	-2.801*** (0.332)
Energy Star Certification * 3am	2.720*** (0.392)	2.957*** (0.390)	-2.341*** (0.334)	-2.285*** (0.332)
Energy Star Certification * 4am	4.560*** (0.392)	4.805*** (0.390)	-0.204 (0.334)	-0.144 (0.332)
Energy Star Certification * 5am	5.105*** (0.392)	5.362*** (0.390)	1.626*** (0.334)	1.686*** (0.332)
Energy Star Certification * 6am	1.665*** (0.392)	1.929*** (0.390)	0.034 (0.335)	0.011 (0.333)
Energy Star Certification * 7am	-4.836*** (0.392)	-4.639*** (0.390)	-3.810*** (0.335)	-3.856*** (0.333)
Energy Star Certification * 8am	-10.286*** (0.392)	-10.105*** (0.390)	-6.766*** (0.335)	-6.809*** (0.333)
Energy Star Certification * 9am	-6.929*** (0.392)	-6.797*** (0.390)	-4.910*** (0.334)	-5.008*** (0.333)
Energy Star Certification * 10am	-10.047*** (0.392)	-9.954*** (0.390)	-9.128*** (0.334)	-9.108*** (0.332)
Energy Star Certification * 11am	-13.319*** (0.392)	-13.256*** (0.390)	-12.543*** (0.334)	-12.540*** (0.332)
Energy Star Certification * 12pm	-12.132*** (0.392)	-12.204*** (0.390)	-13.312*** (0.334)	-13.320*** (0.332)
Energy Star Certification * 1pm	-13.094*** (0.392)	-13.188*** (0.390)	-14.818*** (0.334)	-14.829*** (0.332)

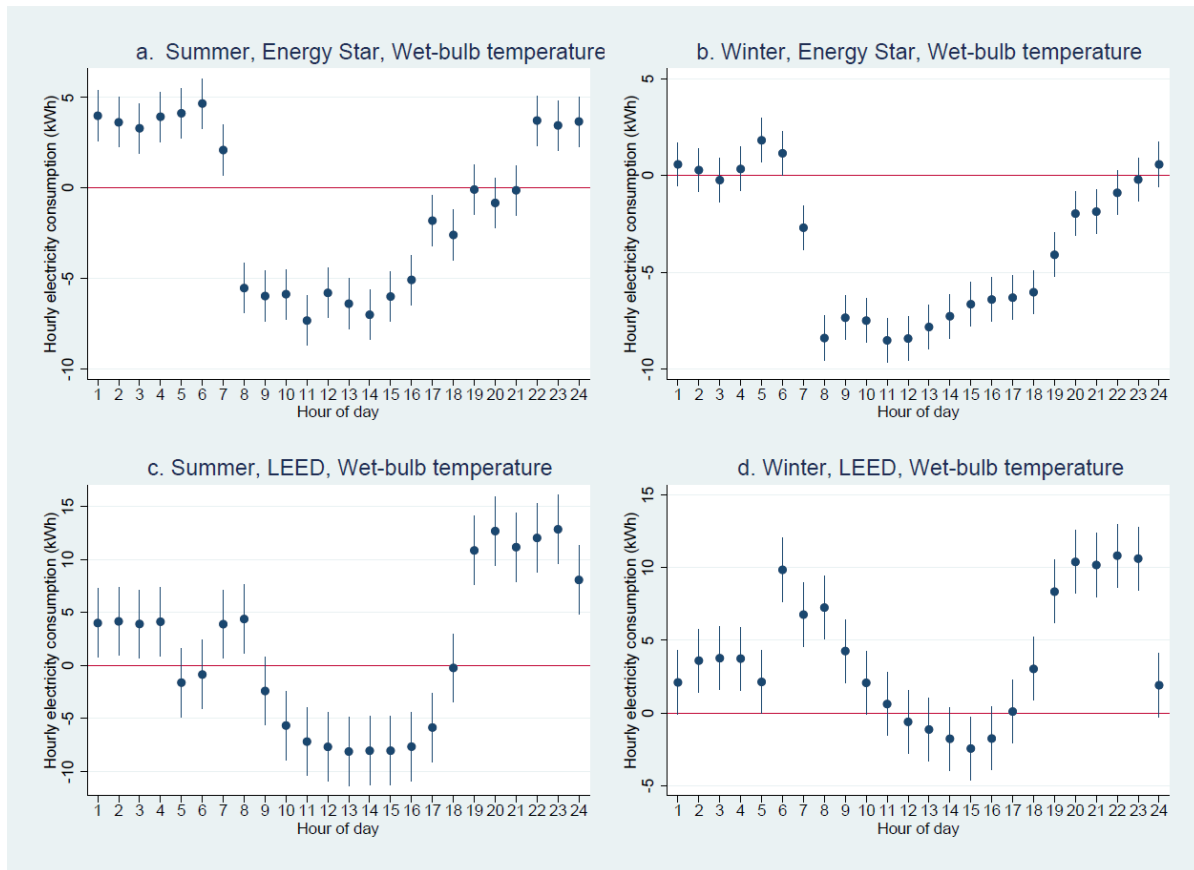
Energy Star Certification * 2pm	-12.281*** (0.392)	-12.386*** (0.390)	-14.430*** (0.334)	-14.443*** (0.332)
Energy Star Certification * 3pm	-9.760*** (0.393)	-9.986*** (0.390)	-14.025*** (0.334)	-14.034*** (0.332)
Energy Star Certification * 4pm	-9.614*** (0.393)	-9.848*** (0.390)	-14.832*** (0.334)	-14.838*** (0.332)
Energy Star Certification * 5pm	-7.333*** (0.393)	-7.526*** (0.391)	-14.137*** (0.334)	-14.141*** (0.332)
Energy Star Certification * 6pm	-7.230*** (0.393)	-7.421*** (0.391)	-12.655*** (0.334)	-12.767*** (0.332)
Energy Star Certification * 7pm	-4.573*** (0.393)	-4.748*** (0.391)	-9.831*** (0.334)	-9.937*** (0.332)
Energy Star Certification * 8pm	-2.644*** (0.392)	-2.724*** (0.390)	-6.696*** (0.334)	-6.797*** (0.332)
Energy Star Certification * 9pm	0.036 (0.392)	-0.015 (0.390)	-5.297*** (0.334)	-5.389*** (0.332)
Energy Star Certification * 10pm	7.061*** (0.392)	7.039*** (0.390)	-0.483 (0.334)	-0.451 (0.332)
Energy Star Certification * 11pm	3.822*** (0.392)	3.851*** (0.390)	-2.186*** (0.334)	-2.136*** (0.332)
Energy Star Certification * 0 am	0.692* (0.392)	0.856** (0.390)	-3.717*** (0.334)	-3.668*** (0.332)
Marginal price	-108.795*** (9.644)	-89.495*** (9.640)	90.689*** (12.001)	60.680*** (11.945)
Price*E32 price plan	585.108*** (9.954)	528.158*** (9.955)	168.729*** (12.484)	158.207*** (12.419)
Price*E33 price plan	32.332*** (10.151)	3.124 (10.142)		
E32 price plan	-44.807*** (1.080)	-39.796*** (1.079)	-6.052*** (1.001)	-5.602*** (0.996)
Constant	77.353*** (3.848)	111.049*** (4.391)	60.815*** (1.054)	68.057*** (1.335)
Temperature spline	Yes	Yes	Yes	Yes
Account fixed effects	Yes	Yes	Yes	Yes
Year of sample fixed effects	Yes		Yes	
Month of year fixed effects	Yes		Yes	
Day of month fixed effects	Yes		Yes	
Hour of day fixed effects	Yes	Yes	Yes	Yes
Day of sample fixed effects		Yes		Yes
Number of accounts	128	128	128	128
Number of observations	1,924,464	1,924,464	1,549,306	1,549,306
Notes: * p < 0.1, ** p < 0.05, *** p < 0.01; Clustered standard errors in parentheses; Standard errors clustered at account level				

Supplementary Table 10. LEED high frequency demand data analysis; Dependent variable: hourly kWh; Full sample

Model number	1	2	3	4
Season	Summer		Winter	
LEED Certification * 1am	-0.508 (0.921)	-1.795** (0.908)	2.820*** (0.721)	2.552*** (0.702)
LEED Certification * 2am	0.179 (0.921)	-1.086 (0.908)	3.577*** (0.721)	3.319*** (0.702)
LEED Certification * 3am	0.341 (0.921)	-0.892 (0.908)	3.994*** (0.721)	3.727*** (0.702)
LEED Certification * 4am	4.345*** (0.922)	3.133*** (0.909)	4.454*** (0.721)	4.184*** (0.702)
LEED Certification * 5am	9.105*** (0.921)	7.926*** (0.908)	4.656*** (0.721)	4.386*** (0.702)
LEED Certification * 6am	13.200*** (0.921)	12.007*** (0.909)	4.277*** (0.723)	6.846*** (0.704)
LEED Certification * 7am	9.339*** (0.922)	8.295*** (0.909)	4.592*** (0.723)	7.132*** (0.704)
LEED Certification * 8am	5.448*** (0.922)	4.369*** (0.909)	3.809*** (0.723)	6.344*** (0.704)
LEED Certification * 9am	-0.022 (0.921)	-1.221 (0.909)	-0.942 (0.723)	1.687** (0.704)
LEED Certification * 10am	-2.790*** (0.921)	-4.119*** (0.908)	-1.188* (0.721)	-1.473** (0.702)
LEED Certification * 11am	-3.314*** (0.921)	-4.760*** (0.908)	-2.385*** (0.721)	-2.609*** (0.702)
LEED Certification * 12pm	-8.836*** (0.921)	-8.460*** (0.908)	-2.669*** (0.721)	-2.901*** (0.702)
LEED Certification * 1pm	-8.634*** (0.921)	-8.338*** (0.908)	-3.423*** (0.720)	-3.689*** (0.701)
LEED Certification * 2pm	-9.658*** (0.921)	-9.443*** (0.908)	-4.951*** (0.720)	-5.188*** (0.701)
LEED Certification * 3pm	-15.949*** (0.923)	-13.839*** (0.912)	-5.687*** (0.720)	-5.824*** (0.702)
LEED Certification * 4pm	-15.256*** (0.923)	-13.177*** (0.912)	-3.512*** (0.721)	-3.615*** (0.702)
LEED Certification * 5pm	-7.555*** (0.924)	-5.569*** (0.912)	2.048*** (0.721)	1.940*** (0.702)
LEED Certification * 6pm	0.774 (0.924)	2.779*** (0.912)	1.864*** (0.721)	4.141*** (0.703)
LEED Certification * 7pm	11.272*** (0.924)	13.321*** (0.912)	7.342*** (0.721)	9.535*** (0.703)
LEED Certification * 8pm	21.248*** (0.921)	21.524*** (0.908)	10.193*** (0.721)	12.258*** (0.702)

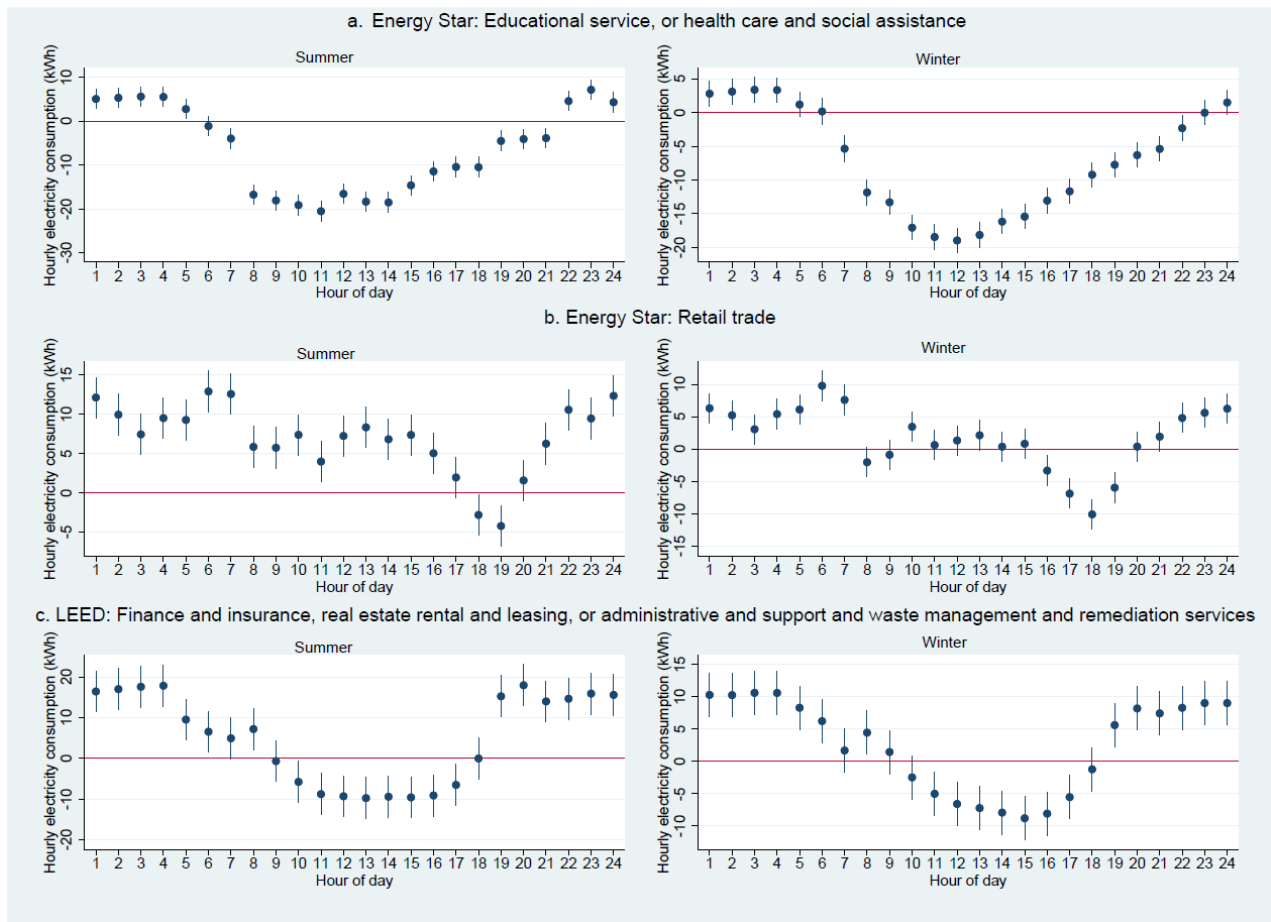
LEED Certification * 9pm	20.775*** (0.921)	21.197*** (0.908)	10.127*** (0.722)	12.219*** (0.703)
LEED Certification * 10pm	18.652*** (0.920)	19.224*** (0.907)	13.952*** (0.721)	13.670*** (0.702)
LEED Certification * 11pm	-0.893 (0.920)	-0.311 (0.906)	6.955*** (0.721)	6.691*** (0.702)
LEED Certification * 0 am	-0.041 (0.920)	-1.356 (0.907)	2.125*** (0.721)	1.866*** (0.702)
Marginal price	-243.722*** (13.616)	-353.687*** (17.746)	66.876* (34.378)	-52.623 (33.475)
Price*E32 price plan	531.787*** (13.825)	535.042*** (17.944)	157.211*** (34.460)	146.449*** (33.524)
Price*E33 price plan	275.511*** (17.151)	358.333*** (20.503)		
E32 price plan	-22.202*** (2.035)	-31.379*** (2.493)	-17.915*** (2.867)	-22.576*** (2.810)
Constant	25.851*** (6.349)	52.309*** (7.350)	37.062*** (2.926)	36.524*** (3.175)
Temperature spline	Yes	Yes	Yes	Yes
Account fixed effects	Yes	Yes	Yes	Yes
Year of sample fixed effects	Yes		Yes	
Month of year fixed effects	Yes		Yes	
Day of month fixed effects	Yes		Yes	
Hour of day fixed effects	Yes	Yes	Yes	Yes
Day of sample fixed effects		Yes		Yes
Number of accounts	42	42	42	42
Number of observations	353,064	353,064	257,852	257,852
Notes: * p < 0.1, ** p < 0.05, *** p < 0.01; Clustered standard errors in parentheses; Standard errors clustered at account level				

Results using wet-bulb temperature



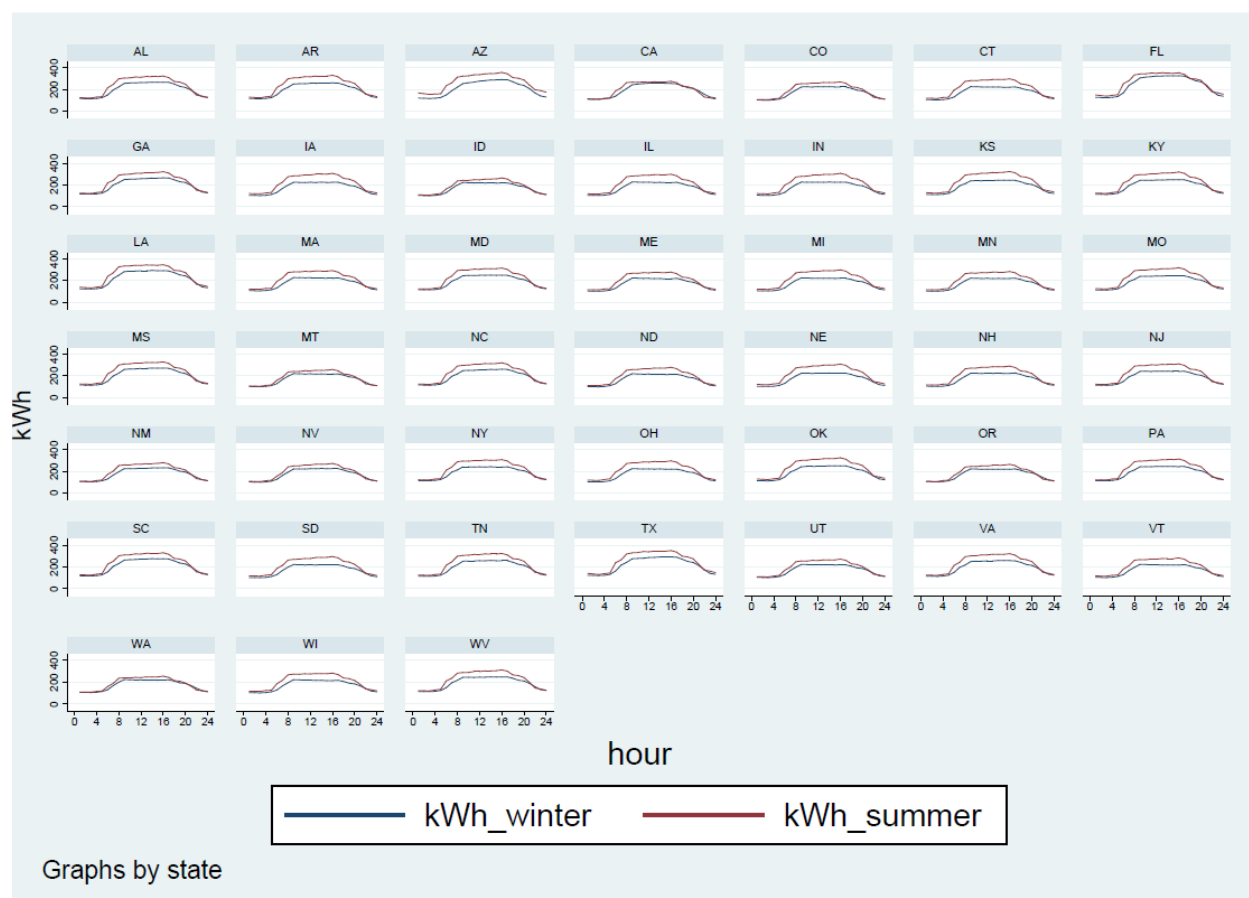
Supplementary Figure 4. Intraday electricity savings by hour using wet-bulb temperature data. The analysis uses subsample with both pre-treatment and post-treatment hourly consumption data. The figures show the coefficients of the interaction terms of Energy Star/LEED certification dummy variable and the dummy variable indicating hour of day. The solid dots indicate the magnitudes of the coefficients; the vertical lines show the 95% confidence intervals. The value of the coefficients shows the change in energy consumption at a particular hour due to green buildings. Negative values indicate electricity savings.

Analysis by industry type



Supplementary Figure 5. Intraday electricity savings by industry type. The figures show the coefficients of the interaction terms of Energy Star/LEED certification dummy variable and the dummy variable indicating hour of day. The solid dots indicate the magnitudes of the coefficients; the vertical lines show the 95% confidence intervals. The value of the coefficients shows the change in energy consumption at a particular hour due to green buildings. Negative values indicate electricity savings.

Analysis by for other states



Supplementary Figure 6. Average commercial building load profile in a major city of each U.S. continental state. Load profile data source is <https://openei.org/doe-opendata/dataset/commercial-and-residential-hourly-load-profiles-for-all-tmy3-locations-in-the-united-states>



Supplementary Figure 7. Hourly electricity savings due to Energy Star and LEED certification in a major city of each U.S. continental state. Negative values indicate electricity savings while positive values indicate increase in electricity consumption.



Supplementary Figure 8. Avoided environmental damages from CO₂ in a major city of each U.S. continental state. The blue columns show the avoided damages using hourly savings while the red columns show the avoided damages using aggregate savings. Positive values indicate increase in environmental damages while negative values indicate drop in environmental damages.



Supplementary Figure 9. Avoided environmental damages from SO₂ in a major city of each U.S. continental state. The blue columns show the avoided damages using hourly savings while the red columns show the avoided damages using aggregate savings. Positive values indicate increase in environmental damages while negative values indicate drop in environmental damages.



Supplementary Figure 10. Avoided environmental damages from NO_x in a major city of each U.S. continental state. The blue columns show the avoided damages using hourly savings while the red columns show the avoided damages using aggregate savings. Positive values indicate increase in environmental damages while negative values indicate drop in environmental damages.



Supplementary Figure 11. Avoided environmental damages from PM in a major city of each U.S. continental state. The blue columns show the avoided damages using hourly savings while the red columns show the avoided damages using aggregate savings. Positive values indicate increase in environmental damages while negative values indicate drop in environmental damages.