Summary of Results: Evaluation of Uplight Energy Saving Actions Using ResStock™

Nathan Moore and Dane Christensen

National Renewable Energy Laboratory

Produced under direction of Uplight by the National Renewable Energy Laboratory (NREL) under Technical Services Agreement number TSA-18-1068.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Strategic Partnership Project Report
NREL/TP-5500-76167
August 2020

Summary of Results: Evaluation of Uplight Energy Saving Actions Using ResStock™

Nathan Moore and Dane Christensen

Suggested Citation
Moore, Nathan and Dane Christensen. 2020. *Summary of Results: Evaluation of Uplight Energy Saving Actions Using ResStock™*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-76167. https://www.nrel.gov/docs/fy20osti/76167.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Strategic Partnership Project Report
NREL/TP-5500-76167
August 2020

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Support for the work was also provided by Uplight under Technical Services Agreement TSA-18-1068. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

Introduction

As part of a portfolio of product offerings, Uplight produces energy savings estimates to inform a utility's residential customers of the expected benefits that would arise from adopting energy efficiency measures, which are termed "energy saving actions." Uplight's current practice is to use a proprietary building simulation model to estimate energy and cost benefits from these actions, as discussed in Maguire et al. Uplight requested that the National Renewable Energy Laboratory (NREL) provide an independent estimate of the energy savings for a defined list of energy saving actions. NREL performed this study using two established building energy simulation tools: EnergyPlus® (*EnergyPlus*) and ResStock™ (Wilson et al.).

A brief summary of the tools, approaches, and methods is provided in this whitepaper's Appendix.

Climate Regions

Results are summarized by climate region, which are defined as shown in Figure 1.

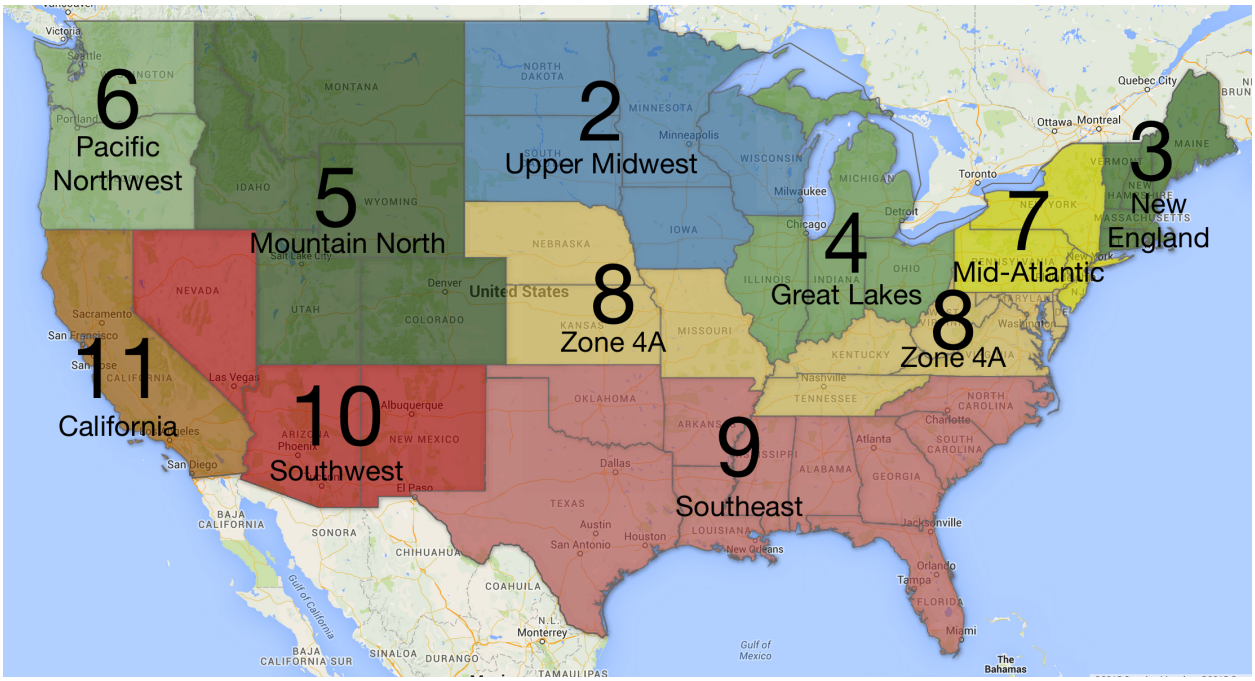

Figure 1. Map defining climate regions

Results are calculated across all ResStock results, based on where the weather station was located within that geographic climate region. Mean and standard deviation of energy savings for each measure were calculated in a weighted fashion (e.g., if a ResStock archetype represented 150 homes, it received five times the weight of an archetype that represented only 30 homes when calculating the mean and standard deviation).

Results by Climate Region

The following tables summarize the annual mean energy savings for each climate region.

Table 1. Summary of Annual Household Electricity Savings for Climate Region 2: Upper Midwest

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	740	696
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	59	515
Baseboard/radiant heating to high efficiency minisplit	-2,683	9,420
Cease use of clothes dryer	25	48
Central air source heat pump to variable-speed heat pump	4,024	2,035
Close window blinds	45	49
Combustion boiler to condensing boiler	24	59
Combustion furnace to variable-speed heat pump	-9,539	6,309
Combustion furnace to condensing furnace	30	70
Cook outside in summer	78	43
Cooling setpoint to 80°F	1,062	585
Cooling setback from no setback	735	409
Cover pool	904	934
Crawlspace ceiling insulation	11	130
Crawlspace wall insulation	1,268	3,110
Duct sealing and insulation to R-8, 10% leakage	181	382
Electric furnace to variable-speed heat pump	9,722	4,754
Electric vehicle, 5,000 miles	-1,852	6
ENERGY STAR clothes dryer	211	187
ENERGY STAR clothes washer	301	243
ENERGY STAR dishwasher	60	59
ENERGY STAR freezer	150	19
ENERGY STAR refrigerator	206	228
ENERGY STAR roof	66	88
ENERGY STAR windows	443	723
Energy recovery ventilation	-394	300
Finished basement wall insulation	211	506
Ground source heat pump	-5,924	6,563
Heat recovery ventilation	-439	366
Heat pump clothes dryer	342	199
Heating setbacks from no setbacks	296	690
Install 4 kW of PV on south-facing roof	5,294	98
Insulate vaulted ceiling	0	6
Insulate water pipes	45	57
Lower heating setpoint by 2 degrees	215	480
Natural ventilation	78	43
R-38 attic insulation	164	463
R-49 attic insulation	165	443
R-60 attic insulation	142	399
Radiant barrier	46	64
Raise cooling setpoint by 2 degrees	338	194
Reduce clothes dryer usage	159	117
Reduce covered pool temp to 78°F	80	80
Reduce lighting usage	95	51
Reduce pool pump size	576	198
Reduce uncovered pool temp to 78°F	258	267
Reduce water use	522	749
Seasonal energy efficiency ratio 15 air conditioner (AC)	527	345
Seasonal energy efficiency ratio 18 air conditioner (AC)	666	397
Seasonal energy efficiency ratio 24 air conditioner (AC)	1,139	501
Seal rim joist	593	2,255
Spray foam wall insulation	1,050	2,616
Storm windows	376	562
Tank water heater to condensing tank	50	218
Tank water heater to condensing tankless	1,397	1,949
Tank water heater to premium tank	30	200
Tank water heater to tankless	-166	679
Unfinished basement wall insulation	392	541
Unplug second refrigerator	165	72
Use low-flow water fixtures	27	59
Wall insulation for uninsulated wood walls	286	1,221
Wash laundry in cold water	55	119
Water heater to 50-gal heat pump water heater	-1,221	2,152
Water heater to 80-gal heat pump water heater	-485	1,836

Table 2. Summary of Annual Household Electricity Savings for Climate Region 3: New England

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	654	610
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	41	259
Baseboard/radiant heating to high efficiency minisplit	-4,040	5,189
Cease use of clothes dryer	13	32
Close window blinds	30	40
Combustion boiler to condensing boiler	22	44
Combustion furnace to variable-speed heat pump	-8,243	5,552
Combustion furnace to condensing furnace	38	64
Cook outside in summer	80	42
Cooling setpoint to 80°F	890	671
Cooling setback from no setback	636	479
Cover pool	848	878
Crawlspace ceiling insulation	9	87
Crawlspace wall insulation	274	1,021
Duct sealing and insulation to R-8, 10% leakage	49	101
Electric furnace to variable-speed heat pump	13,641	6,490
Electric vehicle, 5,000 miles	-1,852	8
ENERGY STAR clothes dryer	210	181
ENERGY STAR clothes washer	297	215
ENERGY STAR dishwasher	51	51
ENERGY STAR freezer	152	16
ENERGY STAR refrigerator	206	224
ENERGY STAR roof	82	147
ENERGY STAR windows	224	356
Energy recovery ventilation	-205	215
Finished basement wall insulation	55	245
Ground source heat pump	-7,632	5,505
Heat recovery ventilation	-215	234
Heat pump clothes dryer	323	186
Heating setbacks from no setbacks	118	338
Install 4 kW of PV on south-facing roof	5,153	78
Insulate vaulted ceiling	0	7
Insulate water pipes	35	50
Lower heating setpoint by 2 degrees	122	332
Natural ventilation	80	42
R-38 attic insulation	129	487
R-49 attic insulation	118	440
R-60 attic insulation	127	447
Radiant barrier	53	132
Raise cooling setpoint by 2 degrees	311	240
Reduce clothes dryer usage	178	106
Reduce covered pool temp to 78°F	72	75
Reduce lighting usage	84	45
Reduce pool pump size	550	181
Reduce uncovered pool temp to 78°F	242	251
Reduce water use	387	662
Seasonal energy efficiency ratio 15 air conditioner (AC)	469	292
Seasonal energy efficiency ratio 18 air conditioner (AC)	570	329
Seasonal energy efficiency ratio 24 air conditioner (AC)	1,013	413
Seal rim joist	12	774
Spray foam wall insulation	279	974
Storm windows	180	257
Tank water heater to condensing tank	16	158
Tank water heater to condensing tankless	1,186	1,802
Tank water heater to premium tank	4	125
Tank water heater to tankless	-240	664
Unfinished basement wall insulation	151	189
Unplug second refrigerator	167	72
Use low-flow water fixtures	23	51
Wall insulation for uninsulated wood walls	182	706
Wash laundry in cold water	38	93
Water heater to 50-gal heat pump water heater	-1,459	1,993
Water heater to 80-gal heat pump water heater	-897	1,728

Table 3. Summary of Annual Household Electricity Savings for Climate Region 4: Great Lakes

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	660	633
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	123	498
Baseboard/radiant heating to high efficiency minisplit	3,773	11,441
Cease use of clothes dryer	24	45
Central air source heat pump to variable-speed heat pump	4,389	2,431
Close window blinds	45	48
Combustion boiler to condensing boiler	22	53
Combustion furnace to variable-speed heat pump	-7,632	5,436
Combustion furnace to condensing furnace	22	56
Cook outside in summer	66	45
Cooling setpoint to 80°F	1,226	672
Cooling setback from no setback	835	464
Cover pool	851	885
Crawlspace ceiling insulation	17	264
Crawlspace wall insulation	1,069	2,832
Duct sealing and insulation to R-8, 10% leakage	224	455
Electric furnace to variable-speed heat pump	10,842	5,651
Electric vehicle, 5,000 miles	-1,852	13
ENERGY STAR clothes dryer	204	180
ENERGY STAR clothes washer	245	226
ENERGY STAR dishwasher	53	53
ENERGY STAR freezer	151	23
ENERGY STAR refrigerator	201	221
ENERGY STAR roof	97	160
ENERGY STAR windows	429	650
Energy recovery ventilation	-310	288
Finished basement wall insulation	189	443
Ground source heat pump	-5,496	7,070
Heat recovery ventilation	-351	345
Heat pump clothes dryer	336	193
Heating setbacks from no setbacks	238	523
Install 4 kW of PV on south-facing roof	5,044	130
Insulate vaulted ceiling	0	13
Insulate water pipes	35	48
Lower heating setpoint by 2 degrees	296	605
Natural ventilation	66	45
R-38 attic insulation	276	800
R-49 attic insulation	246	724
R-60 attic insulation	255	721
Radiant barrier	82	180
Raise cooling setpoint by 2 degrees	402	229
Reduce clothes dryer usage	132	115
Reduce covered pool temp to 78°F	75	77
Reduce lighting usage	85	49
Reduce pool pump size	550	187
Reduce uncovered pool temp to 78°F	243	253
Reduce water use	414	667
Seasonal energy efficiency ratio 15 air conditioner (AC)	597	388
Seasonal energy efficiency ratio 18 air conditioner (AC)	706	433
Seasonal energy efficiency ratio 24 air conditioner (AC)	1,283	552
Seal rim joist	479	2,176
Spray foam wall insulation	912	2,247
Storm windows	368	491
Tank water heater to condensing tank	49	166
Tank water heater to condensing tankless	1,009	1,638
Tank water heater to premium tank	23	158
Tank water heater to tankless	-96	533
Unfinished basement wall insulation	362	475
Unplug second refrigerator	166	76
Use low-flow water fixtures	23	53
Wall insulation for uninsulated wood walls	584	1,636
Wash laundry in cold water	40	98
Water heater to 50-gal heat pump water heater	-1,241	1,892
Water heater to 80-gal heat pump water heater	-604	1,528

Table 4. Summary of Annual Household Electricity Savings for Climate Region 5: Mountain North

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	646	615
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	-25	348
Baseboard/radiant heating to high efficiency minisplit	848	6,495
Cease use of clothes dryer	12	31
Central air source heat pump to variable-speed heat pump	3,840	1,905
Close window blinds	30	47
Combustion boiler to condensing boiler	10	51
Combustion furnace to variable-speed heat pump	-4,632	3,871
Combustion furnace to condensing furnace	22	72
Cook outside in summer	83	41
Cooling setpoint to 80°F	769	693
Cooling setback from no setback	558	501
Cover pool	867	870
Crawlspace ceiling insulation	9	178
Crawlspace wall insulation	628	1,770
Duct sealing and insulation to R-8, 10% leakage	148	304
Electric furnace to variable-speed heat pump	6,583	3,959
Electric vehicle, 5,000 miles	-1,852	8
ENERGY STAR clothes dryer	200	176
ENERGY STAR clothes washer	288	201
ENERGY STAR dishwasher	48	47
ENERGY STAR freezer	147	18
ENERGY STAR refrigerator	194	212
ENERGY STAR roof	56	147
ENERGY STAR windows	285	473
Energy recovery ventilation	-365	253
Finished basement wall insulation	127	315
Ground source heat pump	-4,464	4,931
Heat recovery ventilation	-390	303
Heat pump clothes dryer	320	182
Heating setbacks from no setbacks	213	478
Install 4 kW of PV on south-facing roof	5,992	270
Insulate vaulted ceiling	-0	7
Insulate water pipes	25	45
Lower heating setpoint by 2 degrees	214	455
Natural ventilation	83	41
R-38 attic insulation	163	430
R-49 attic insulation	147	394
R-60 attic insulation	163	413
Radiant barrier	48	92
Raise cooling setpoint by 2 degrees	253	233
Reduce clothes dryer usage	174	104
Reduce covered pool temp to 78°F	73	76
Reduce lighting usage	82	47
Reduce pool pump size	549	182
Reduce uncovered pool temp to 78°F	247	249
Reduce water use	330	611
Seasonal energy efficiency ratio 15 air conditioner (AC)	467	317
Seasonal energy efficiency ratio 18 air conditioner (AC)	640	383
Seasonal energy efficiency ratio 24 air conditioner (AC)	941	442
Seal rim joist	316	1,376
Spray foam wall insulation	522	1,063
Storm windows	256	384
Tank water heater to condensing tank	9	143
Tank water heater to condensing tankless	863	1,616
Tank water heater to premium tank	-5	143
Tank water heater to tankless	-123	503
Unfinished basement wall insulation	245	359
Unplug second refrigerator	159	70
Use low-flow water fixtures	13	49
Wall insulation for uninsulated wood walls	244	668
Wash laundry in cold water	35	93
Water heater to 50-gal heat pump water heater	-1,514	1,881
Water heater to 80-gal heat pump water heater	-918	1,549

Table 5. Summary of Annual Household Electricity Savings for Climate Region 6: Pacific Northwest

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	472	470
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	238	537
Baseboard/radiant heating to high efficiency minisplit	9,724	8,164
Cease use of clothes dryer	34	57
Central air source heat pump to variable-speed heat pump	2,743	1,850
Close window blinds	16	37
Combustion boiler to condensing boiler	13	41
Combustion furnace to variable-speed heat pump	-3,240	3,103
Combustion furnace to condensing furnace	16	41
Cook outside in summer	83	42
Cooling setpoint to 80°F	531	562
Cooling setback from no setback	390	413
Cover pool	773	822
Crawlspace ceiling insulation	184	792
Crawlspace wall insulation	1,387	2,411
Duct sealing and insulation to R-8, 10% leakage	386	757
Electric furnace to variable-speed heat pump	7,071	5,138
Electric vehicle, 5,000 miles	-1,852	23
ENERGY STAR clothes dryer	193	169
ENERGY STAR clothes washer	373	224
ENERGY STAR dishwasher	73	67
ENERGY STAR freezer	135	34
ENERGY STAR refrigerator	164	196
ENERGY STAR roof	-22	216
ENERGY STAR windows	353	524
Energy recovery ventilation	-247	238
Finished basement wall insulation	244	412
Ground source heat pump	-1,409	6,233
Heat recovery ventilation	-285	297
Heat pump clothes dryer	328	179
Heating setbacks from no setbacks	491	834
Install 4 kW of PV on south-facing roof	4,736	348
Insulate vaulted ceiling	-0	21
Insulate water pipes	49	56
Lower heating setpoint by 2 degrees	636	967
Natural ventilation	83	42
R-38 attic insulation	375	1,164
R-49 attic insulation	298	952
R-60 attic insulation	320	943
Radiant barrier	60	233
Raise cooling setpoint by 2 degrees	190	203
Reduce clothes dryer usage	175	95
Reduce covered pool temp to 78°F	71	74
Reduce lighting usage	60	44
Reduce pool pump size	511	172
Reduce uncovered pool temp to 78°F	221	236
Reduce water use	804	703
Seasonal energy efficiency ratio 15 air conditioner (AC)	302	223
Seasonal energy efficiency ratio 18 air conditioner (AC)	382	262
Seasonal energy efficiency ratio 24 air conditioner (AC)	627	334
Seal rim joist	978	1,902
Spray foam wall insulation	1,858	2,885
Storm windows	360	461
Tank water heater to condensing tank	25	294
Tank water heater to condensing tankless	1,963	1,823
Tank water heater to premium tank	27	209
Tank water heater to tankless	-334	697
Unfinished basement wall insulation	279	390
Unplug second refrigerator	143	83
Use low-flow water fixtures	41	69
Wall insulation for uninsulated wood walls	1,068	2,138
Wash laundry in cold water	86	125
Water heater to 50-gal heat pump water heater	-328	1,701
Water heater to 80-gal heat pump water heater	73	1,508

Table 6. Summary of Annual Household Electricity Savings for Climate Region 7: Mid-Atlantic

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	679	638
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	162	461
Baseboard/radiant heating to high efficiency minisplit	-1,276	8,501
Cease use of clothes dryer	18	40
Central air source heat pump to variable-speed heat pump	4,205	2,376
Close window blinds	46	51
Combustion boiler to condensing boiler	23	52
Combustion furnace to variable-speed heat pump	-7,276	5,589
Combustion furnace to condensing furnace	26	62
Cook outside in summer	63	46
Cooling setpoint to 80°F	1,312	746
Cooling setback from no setback	906	520
Cover pool	889	900
Crawlspace ceiling insulation	7	191
Crawlspace wall insulation	337	1,045
Duct sealing and insulation to R-8, 10% leakage	131	250
Electric furnace to variable-speed heat pump	12,608	6,335
Electric vehicle, 5,000 miles	-1,852	14
ENERGY STAR clothes dryer	207	181
ENERGY STAR clothes washer	230	215
ENERGY STAR dishwasher	50	50
ENERGY STAR freezer	153	22
ENERGY STAR refrigerator	205	223
ENERGY STAR roof	113	181
ENERGY STAR windows	380	548
Energy recovery ventilation	-179	245
Finished basement wall insulation	169	381
Ground source heat pump	-6,765	6,759
Heat recovery ventilation	-201	285
Heat pump clothes dryer	331	190
Heating setbacks from no setbacks	184	444
Install 4 kW of PV on south-facing roof	5,064	120
Insulate vaulted ceiling	0	14
Insulate water pipes	33	46
Lower heating setpoint by 2 degrees	249	558
Natural ventilation	63	46
R-38 attic insulation	224	646
R-49 attic insulation	210	594
R-60 attic insulation	228	604
Radiant barrier	83	170
Raise cooling setpoint by 2 degrees	440	258
Reduce clothes dryer usage	133	117
Reduce covered pool temp to 78°F	72	77
Reduce lighting usage	87	48
Reduce pool pump size	554	188
Reduce uncovered pool temp to 78°F	254	257
Reduce water use	367	616
Seasonal energy efficiency ratio 15 air conditioner (AC)	652	430
Seasonal energy efficiency ratio 18 air conditioner (AC)	762	474
Seasonal energy efficiency ratio 24 air conditioner (AC)	1,389	612
Seal rim joist	-76	830
Spray foam wall insulation	584	1,645
Storm windows	309	371
Tank water heater to condensing tank	52	145
Tank water heater to condensing tankless	996	1,597
Tank water heater to premium tank	25	152
Tank water heater to tankless	-99	530
Unfinished basement wall insulation	269	313
Unplug second refrigerator	167	75
Use low-flow water fixtures	21	49
Wall insulation for uninsulated wood walls	395	1,225
Wash laundry in cold water	35	89
Water heater to 50-gal heat pump water heater	-1,290	1,834
Water heater to 80-gal heat pump water heater	-701	1,477

Table 7. Summary of Annual Household Electricity Savings for Climate Region 8: Zone 4A

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	659	637
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	263	630
Baseboard/radiant heating to high efficiency minisplit	7,580	8,569
Cease use of clothes dryer	42	57
Central air source heat pump to variable-speed heat pump	4,119	2,358
Close window blinds	72	69
Combustion boiler to condensing boiler	36	69
Combustion furnace to variable-speed heat pump	-2,908	2,885
Combustion furnace to condensing furnace	31	73
Cook outside in summer	89	40
Cooling setpoint to 80°F	1,639	743
Cooling setback from no setback	1,052	489
Cover pool	870	894
Crawlspace ceiling insulation	23	282
Crawlspace wall insulation	1,702	2,812
Duct sealing and insulation to R-8, 10% leakage	496	678
Electric furnace to variable-speed heat pump	10,265	5,554
Electric vehicle, 5,000 miles	-1,852	18
ENERGY STAR clothes dryer	209	184
ENERGY STAR clothes washer	355	224
ENERGY STAR dishwasher	69	61
ENERGY STAR freezer	149	24
ENERGY STAR refrigerator	200	222
ENERGY STAR roof	131	197
ENERGY STAR windows	687	762
Energy recovery ventilation	-345	338
Finished basement wall insulation	300	360
Ground source heat pump	-1,804	6,138
Heat recovery ventilation	-418	421
Heat pump clothes dryer	355	199
Heating setbacks from no setbacks	457	661
Install 4 kW of PV on south-facing roof	5,425	112
Insulate vaulted ceiling	-0	18
Insulate water pipes	57	53
Lower heating setpoint by 2 degrees	549	773
Natural ventilation	89	40
R-38 attic insulation	372	931
R-49 attic insulation	365	854
R-60 attic insulation	404	866
Radiant barrier	122	243
Raise cooling setpoint by 2 degrees	561	264
Reduce clothes dryer usage	187	109
Reduce covered pool temp to 78°F	74	78
Reduce lighting usage	84	52
Reduce pool pump size	554	191
Reduce uncovered pool temp to 78°F	248	256
Reduce water use	702	687
Seasonal energy efficiency ratio 15 air conditioner (AC)	965	640
Seasonal energy efficiency ratio 18 air conditioner (AC)	1,047	684
Seasonal energy efficiency ratio 24 air conditioner (AC)	1,988	883
Seal rim joist	831	2,203
Spray foam wall insulation	1,701	2,534
Storm windows	551	496
Tank water heater to condensing tank	131	310
Tank water heater to condensing tankless	1,759	1,702
Tank water heater to premium tank	82	236
Tank water heater to tankless	-143	615
Unfinished basement wall insulation	550	493
Unplug second refrigerator	162	75
Use low-flow water fixtures	36	64
Wall insulation for uninsulated wood walls	922	1,846
Wash laundry in cold water	63	103
Water heater to 50-gal heat pump water heater	-275	1,669
Water heater to 80-gal heat pump water heater	186	1,451

Table 8. Summary of Annual Household Electricity Savings for Climate Region 9: Southeast

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	618	581
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	288	469
Baseboard/radiant heating to high efficiency minisplit	7,499	4,098
Cease use of clothes dryer	49	58
Central air source heat pump to variable-speed heat pump	3,195	1,725
Close window blinds	111	98
Combustion boiler to condensing boiler	25	61
Combustion furnace to variable-speed heat pump	856	1,793
Combustion furnace to condensing furnace	28	81
Cook outside in summer	86	41
Cooling setpoint to 80°F	2,023	864
Cooling setback from no setback	1,167	530
Cover pool	826	843
Crawlspace ceiling insulation	1	130
Crawlspace wall insulation	1,184	2,010
Duct sealing and insulation to R-8, 10% leakage	516	492
Electric furnace to variable-speed heat pump	6,139	3,454
Electric vehicle, 5,000 miles	-1,852	16
ENERGY STAR clothes dryer	209	185
ENERGY STAR clothes washer	321	202
ENERGY STAR dishwasher	68	55
ENERGY STAR freezer	157	26
ENERGY STAR refrigerator	224	246
ENERGY STAR roof	342	323
ENERGY STAR windows	851	748
Energy recovery ventilation	-249	299
Finished basement wall insulation	309	216
Ground source heat pump	-1,749	3,615
Heat recovery ventilation	-317	381
Heat pump clothes dryer	362	201
Heating setbacks from no setbacks	464	642
Install 4 kW of PV on south-facing roof	5,647	206
Insulate vaulted ceiling	0	16
Insulate water pipes	68	45
Lower heating setpoint by 2 degrees	425	559
Natural ventilation	86	41
R-38 attic insulation	402	938
R-49 attic insulation	441	926
R-60 attic insulation	485	940
Radiant barrier	232	378
Raise cooling setpoint by 2 degrees	815	352
Reduce clothes dryer usage	183	111
Reduce covered pool temp to 78°F	71	74
Reduce lighting usage	79	46
Reduce pool pump size	525	177
Reduce uncovered pool temp to 78°F	236	241
Reduce water use	666	571
Seasonal energy efficiency ratio 15 air conditioner (AC)	1,585	1,048
Seasonal energy efficiency ratio 18 air conditioner (AC)	1,325	1,076
Seasonal energy efficiency ratio 24 air conditioner (AC)	3,155	1,403
Seal rim joist	395	1,574
Spray foam wall insulation	1,123	1,427
Storm windows	535	353
Tank water heater to condensing tank	175	271
Tank water heater to condensing tankless	1,573	1,363
Tank water heater to premium tank	111	190
Tank water heater to tankless	-26	456
Unfinished basement wall insulation	546	337
Unplug second refrigerator	173	79
Use low-flow water fixtures	29	60
Wall insulation for uninsulated wood walls	487	953
Wash laundry in cold water	45	70
Water heater to 50-gal heat pump water heater	144	1,279
Water heater to 80-gal heat pump water heater	423	1,179

Table 9. Summary of Annual Household Electricity Savings for Climate Region 10: Southwest

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	609	567
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	162	340
Baseboard/radiant heating to high efficiency minisplit	5,567	5,397
Cease use of clothes dryer	25	38
Central air source heat pump to variable-speed heat pump	2,869	1,803
Close window blinds	99	121
Combustion boiler to condensing boiler	3	18
Combustion furnace to variable-speed heat pump	38	3,409
Combustion furnace to condensing furnace	9	41
Cook outside in summer	70	44
Cooling setpoint to 80°F	1,233	7,53
Cooling setback from no setback	861	538
Cover pool	828	830
Crawlspace ceiling insulation	3	77
Crawlspace wall insulation	940	1,674
Duct sealing and insulation to R-8, 10% leakage	548	539
Electric furnace to variable-speed heat pump	3,675	4,956
Electric vehicle, 5,000 miles	-1,852	16
ENERGY STAR clothes dryer	204	178
ENERGY STAR clothes washer	249	194
ENERGY STAR dishwasher	51	47
ENERGY STAR freezer	156	25
ENERGY STAR refrigerator	222	247
ENERGY STAR roof	419	429
ENERGY STAR windows	725	797
Energy recovery ventilation	-226	199
Finished basement wall insulation	319	249
Ground source heat pump	-3,138	4,018
Heat recovery ventilation	-251	224
Heat pump clothes dryer	334	187
Heating setbacks from no setbacks	218	507
Install 4 kW of PV on south-facing roof	6,800	89
Insulate vaulted ceiling	0	16
Insulate water pipes	47	47
Lower heating setpoint by 2 degrees	229	443
Natural ventilation	70	44
R-38 attic insulation	320	788
R-49 attic insulation	328	744
R-60 attic insulation	369	758
Radiant barrier	203	310
Raise cooling setpoint by 2 degrees	517	332
Reduce clothes dryer usage	153	111
Reduce covered pool temp to 78°F	68	74
Reduce lighting usage	78	44
Reduce pool pump size	519	173
Reduce uncovered pool temp to 78°F	237	237
Reduce water use	390	529
Seasonal energy efficiency ratio 15 air conditioner (AC)	1,715	1,306
Seasonal energy efficiency ratio 18 air conditioner (AC)	1,405	1,291
Seasonal energy efficiency ratio 24 air conditioner (AC)	2,938	1,687
Seal rim joist	369	1,307
Spray foam wall insulation	1,112	1,466
Storm windows	499	400
Tank water heater to condensing tank	88	202
Tank water heater to condensing tankless	919	1,286
Tank water heater to premium tank	65	175
Tank water heater to tankless	-9	378
Unfinished basement wall insulation	671	419
Unplug second refrigerator	171	78
Use low-flow water fixtures	16	49
Wall insulation for uninsulated wood walls	375	869
Wash laundry in cold water	24	62
Water heater to 50-gal heat pump water heater	-545	1,357
Water heater to 80-gal heat pump water heater	-274	1,179

Table 10. Summary of Annual Household Electricity Savings for Climate Region 11: California

Residential Upgrade	Mean (kWh)	Standard Deviation (kWh)
100% light-emitting diode lighting	580	558
Air leakage 25% reduction, with mech. vent. under 7 air changes per hour at 50 pascals	7	217
Baseboard/radiant heating to high efficiency minisplit	3,905	3,470
Cease use of clothes dryer	3	25
Central air source heat pump to variable-speed heat pump	2,164	1,626
Close window blinds	44	71
Combustion boiler to condensing boiler	0	27
Combustion furnace to variable-speed heat pump	-196	1,930
Combustion furnace to condensing furnace	1	22
Cook outside in summer	48	42
Cooling setpoint to 80°F	1,275	1,176
Cooling setback from no setback	916	845
Cover pool	800	831
Crawlspace ceiling insulation	-14	115
Crawlspace wall insulation	236	1,061
Duct sealing and insulation to R-8, 10% leakage	211	329
Electric furnace to variable-speed heat pump	3,677	3,407
Electric vehicle, 5,000 miles	-1,852	16
ENERGY STAR clothes dryer	198	177
ENERGY STAR clothes washer	141	159
ENERGY STAR dishwasher	36	35
ENERGY STAR freezer	152	26
ENERGY STAR refrigerator	210	234
ENERGY STAR roof	225	375
ENERGY STAR windows	355	500
Energy recovery ventilation	-202	203
Finished basement wall insulation	104	140
Ground source heat pump	-2,966	2,894
Heat recovery ventilation	-211	221
Heat pump clothes dryer	314	180
Heating setbacks from no setbacks	212	547
Install 4 kW of PV on south-facing roof	6,260	274
Insulate vaulted ceiling	0	16
Insulate water pipes	18	35
Lower heating setpoint by 2 degrees	212	496
Natural ventilation	48	42
R-38 attic insulation	199	661
R-49 attic insulation	210	651
R-60 attic insulation	228	664
Radiant barrier	138	298
Raise cooling setpoint by 2 degrees	482	433
Reduce clothes dryer usage	90	104
Reduce covered pool temp to 78°F	68	73
Reduce lighting usage	74	46
Reduce pool pump size	516	174
Reduce uncovered pool temp to 78°F	229	238
Reduce water use	122	335
Seasonal energy efficiency ratio 15 air conditioner (AC)	895	779
Seasonal energy efficiency ratio 18 air conditioner (AC)	838	799
Seasonal energy efficiency ratio 24 air conditioner (AC)	1,855	1,156
Seal rim joist	11	974
Spray foam wall insulation	239	923
Storm windows	240	280
Tank water heater to condensing tank	3	149
Tank water heater to condensing tankless	224	826
Tank water heater to premium tank	-19	158
Tank water heater to tankless	-24	235
Unfinished basement wall insulation	172	222
Unplug second refrigerator	169	79
Use low-flow water fixtures	7	30
Wall insulation for uninsulated wood walls	139	639
Wash laundry in cold water	8	42
Water heater to 50-gal heat pump water heater	-1,405	1,311
Water heater to 80-gal heat pump water heater	-1,009	960

Bibliography

EnergyPlus. U.S. Department of Energy Building Technologies Office, managed by NREL, 2019. https://energyplus.net/.

Maguire, J., S. Horowitz, N. Moore, and P. Sullivan. *Validation of Tendril TrueHome Using Software-to-Software Comparison*. Tech. rep. NREL/TP-5500-70116. National Renewable Energy Laboratory, 2017. https://www.nrel.gov/docs/fy18osti/70116.pdf.

OpenStudio. Developed in collaboration by NREL, ANL, LBNL, ORNL, and PNNL, 2019. https://openstudio.net/.

QGIS Project, 2020. https://www.qgis.org/en/site/.

Wilson, E., C. Christensen, S. Horowitz, J. Robertson, and J. Maguire. *Energy Efficiency Potential in the U.S. Single-Family Housing Stock*. Tech.rep. NREL/TP-5500-68670. NREL, 2017. https://www.nrel.gov/docs/fy18osti/68670.pdf. Also see https://resstock.nrel.gov/.

Appendix. Review of Methods and Tools

Methodology

Approach

NREL used ResStock (Wilson et al.) to simulate approximately 300,000 homes across the contiguous United States in order to evaluate how savings vary across important building features such as size, climate, and vintage. ResStock's multiplier for each archetypal home modeled allowed the 300,000 homes to be scaled up such that the study represents the approximately 100 million homes in the United States.

Each of these homes was first simulated in the baseline configuration, and then again with each appropriate energy saving action applied to it. The difference in annual energy consumption for each action was then calculated to determine energy saved.

Energy Saving Actions

Uplight provided NREL with a list of energy saving actions, with appropriate detail on how such actions are implemented in Uplight's existing software workflow. NREL's first task was to establish which actions could be implemented in the tools chosen for this independent analysis. Not all energy saving actions could be simulated, because for some actions there was either no applicable technology or human behavior model in EnergyPlus, we lacked input data to confidently and accurately represent the action in EnergyPlus, or both.

After reviewing all energy saving actions, 63 were identified as appropriate for this independent study. NREL then developed a method for mapping these actions into the ResStock workflow for comparative analysis.

Tools Used

EnergyPlus

EnergyPlus is the U.S. Department of Energy (DOE)'s premiere building energy simulation tool. An open-source multicontributor effort led by NREL, EnergyPlus is an established software for whole-building energy simulation used by architects, engineers, and researchers. Its primary purpose is for estimating energy consumption in buildings and providing design guidance by comparing alternative solutions. It is used as the simulation engine within OpenStudio®, and it is behind the scenes of some of the world's leading building design software platforms.

ResStock

NREL recently developed a simulation package for performing analysis on the nation's entire residential building stock. The ResStock tool (Wilson et al.) uses a best-in-class database of housing stock information to perform large-scale energy analysis, leveraging DOE's open-source building energy modeling tools, EnergyPlus (*EnergyPlus*) and OpenStudio (*OpenStudio*).

NREL and Uplight agreed that ResStock was appropriate for this effort, based on the following benefits:

- It uses large public and private data sources to produce an open-source input database that is peer reviewed and publicly accessible
- It statistically samples to increase accuracy in representing the diversity of real-world buildings
- It uses detailed subhourly simulations of the homes
- It relies on high-performance computing to increase the number of buildings, thereby producing highly granular results.

Results

ResStock outputs a set of files showing specific characteristics of the home as modeled, energy use per sector of the home (lighting, cooling, water heating, heating, miscellaneous electric loads (MELs), etc.) and total gross and net energy use of the home. Net energy use can differ from total energy use in the case of on-site energy generation,

typically photovoltaic (PV) panels. NREL gathered the annual energy output (total and net) for electricity and natural gas for each home before and after each upgrade. Electricity savings, in kilowatt-hour (kWh), were calculated by subtracting the base home's energy use from the upgraded home's energy use.

Outcomes

These annual energy savings data were compiled in a database, which can be queried to examine how energy usage is affected by vintage, square footage, climate region, fuel type, and a number of other factors.

Inspection of Results

The data were inspected in several ways to evaluate the quality of results, and to identify and correct any simulation errors that may have occurred. Many blank spaces were found in the data, which were traced to nonsensical inputs, as expected. For instance, an upgrade that improves a combustion heater (furnace/boiler) to a condensing version of the same would not be applied to homes with electric baseboard heat. All records where savings in both gas and electricity were "null" were removed. This reduced the total number of records by roughly one-third. Further investigation showed the results from simulations of dehumidifiers and window air conditioner (AC) were not realistic. While the exact cause for this is under investigation, all dehumidifier and window AC results in this analysis were eliminated.

NREL also developed visualization methods to examine the results and view trends. Savings values were aggregated by weather station to observe how energy savings are affected by climate. QGIS (*QGIS Project*) was used to map the results, producing colored points across the country that represent average savings for each upgrade. One map showing an example of mean savings for a given measure across the nation is shown in Figure 2.

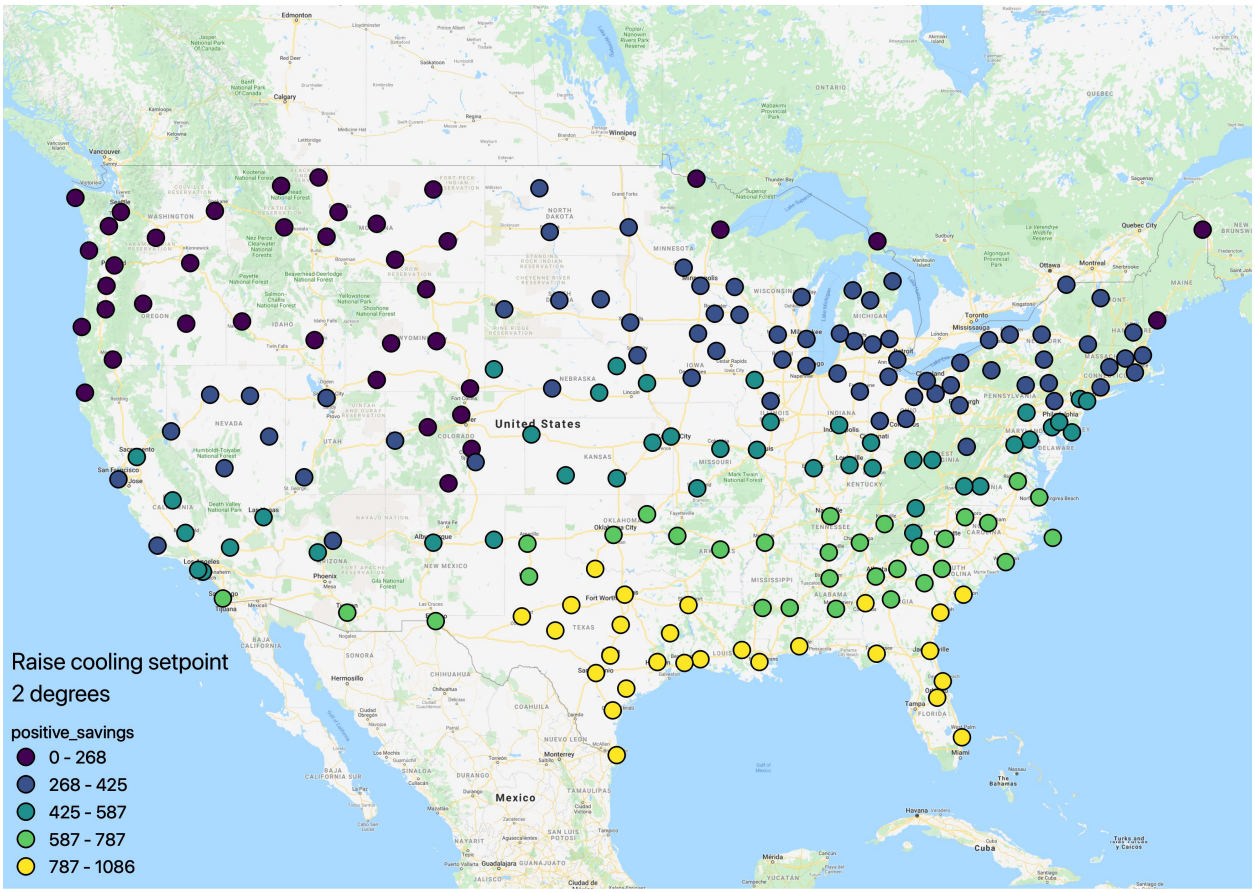

Figure 2. Map of annual mean household electric energy savings from raising cooling setpoint 2 degrees, in kWh

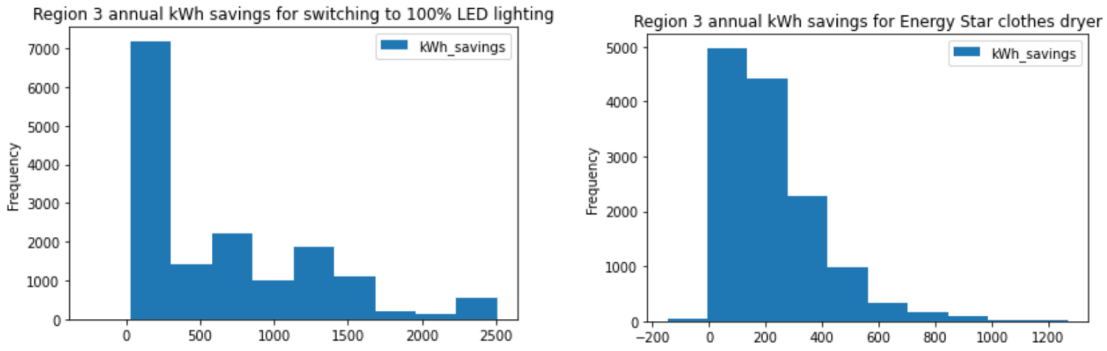

Figure 3. Histogram of annual household energy savings for LED lighting (left) and ENERGY STAR clothes dryer (right) in Region 3 homes