Building energy baseline model: next stage – non-linear methods with rich feature set

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1 Hypothesis

Using more complicated non-linear models with rich feature set could improve the prediction accuracy of 1) energy consumption and 2) the change point when heating or cooling system switches on.

2 Broad idea

From the discussing with Professor Matt Gormley, the broad approach should be: first create a rich feature set with all potentially related features included, and use a non-linear model on the rich feature set so that the training data can be nearly perfectly predicted. Then applying some regularization to also drive down the test error. Finally try to interpret the model by evaluating the accuracy drop by leaving each feature out, or by incrementally adding a feature in random order and evaluate the accuracy gain by adding that feature.

3 Collect input variables and representation

A list of variables that might be important are

- Environmental variable
  - Temperature (measured, average, or categorical):
    - outdoor air temperature
      - as numerical: mean [3, 6–8], degree-day [4, 10, 13], Radio Basis Function Kernel (RBFs) [15], exact [2, 9, 17]
      - as categorical variables [16]
    - indoor air temperature [7]
  - Humidity
    - relative humidity (RH) [3]
    - dew point temperature [2]
    - exponential smoothing applied to humidity with time constant of 24h [1]
  - Solar:
    - solar radiation (W/m^2) [3, 7]
    - solar flux [9]

    * solar aperture (m^2) [7], different in different time of year
    * solar gains ($Q_S = SI$, unit: W) [7]
  - Wind
    * speed [9]
    * velocity [1]

- Occupancy
  - Number of occupants [16]
  - Operation schedules [13]
  - Occupancy ratio (ratio of occupied vs non-occupied days) [12]
- Industry type
- Building construction
  - Detached vs apartment, categorical [16]
  - Construction material: wooden vs non-wooden [16]
- Building Mechanical System data
  - BAS data
  - System type
- Time
  - swing season (spring vs fall)
  - day type (every-day, weekday, weedend) [6]
  - hour of day ([6, 15], [5] mean-week and day-time-temperature regression model)
  - day of week ([5] mean-week, day-time-temperature, and LBNL regression model)
  - time lag (k), the number of previous readings to include in the model [7]
  - unit circle representation of time of day, week, month, and year [1]
- Energy
  - power (W, it's an auto-regressive component: use energy to predict energy) [7]([11] has some experiment about prediction of different time horizon using different time resolution)

  - fuel type: Electric vs non-electric [16]

- Floor area [16]
- Building dynamics
  - Heat loss coefficient (W/m^2K) [16]
  - Equivalent leakage area (cm^2/m^2) [16]
- Retrofit type / time
  - pre-retrofit period [8]

4 Features

Table 1: Features in the study

Category	Variable Name	Type	Note	source
environment	Clearsky DHI	Q	Modeled solar radiation on a horizontal surface received from the sky excluding the solar disk. - This is assuming clear sky condition	NRSDB
	Clearsky DNI	Q	Modeled solar radiation obtained from the direction of the sun. - This is assuming clear sky condition	NRSDB
	Clearsky GHI	Q	Modeled solar radiation on a horizontal surface received from the sky. - This is assuming clear sky condition	NRSDB
	Cloud Type	C	Obtained from PATMOS-X	NRSDB
	Dew Point	Q	Calculated from specific humidity	NRSDB

Table 1: Features in the study

Category	Variable Name	Type	Note	source
	DHI	Q	Modeled solar radiation on a horizontal surface received from the sky excluding the solar disk.	NRSDB
	DNI	Q	Modeled solar radiation obtained from the direction of the sun.	NRSDB
	GHI	Q	Modeled solar radiation on a horizontal surface received from the sky.	NRSDB
	Snow Depth	Q	Source: MERRA	NRSDB
	Solar Zenith Angle	Q	Angle between the sun and the zenith	NRSDB
	Temperature	Q	Source: MERRA	NRSDB
	Pressure	Q	Source: MERRA	NRSDB
	Relative Humidity	Q	Calculated from specific humidity	NRSDB
	Precipitable Water	Q	Source: MERRA	NRSDB
	Wind Direction	Q	Source: MERRA	NRSDB
	Wind Speed	Q	Source: MERRA	NRSDB
building	Region	I	GSA Region	
	Age	Q	computed from Year_Built	
	Gross_Square_Feet_(GSF)	Q		
	Owned	I	whether a building is owned or leased	
	in_facility	I	if it is part of a large facility	
	use_Electric_EUAS	I	whether a building uses electric	
	use_Steam_EUAS	I	whether a building uses Steam	
	use_Gas_EUAS	I	whether a building uses gas	
	use_Oil_EUAS	I	whether a building uses oil	
time	spring	I	within Mar. 20 to Jun. 20	
	summer	I	within Jun. 20 to Sep. 22	
	fall	I	within Sep. 22 to Dec. 21	
	winter	I	within Dec. 21 to Mar. 20	
	Day of week	C		

Table 1: Features in the study

Category	Variable Name	Type	Note	source
	holiday	I	is holiday >= 50% people take day off	https://en.wikipedia.org/wiki/Public_holidays_in_the_United_States

5 Data sources

5.1 Building metadata source

5.1.1 Building list

The buildings in the analysis are from the GSA portfolio. http://128.2.109.159:8080/

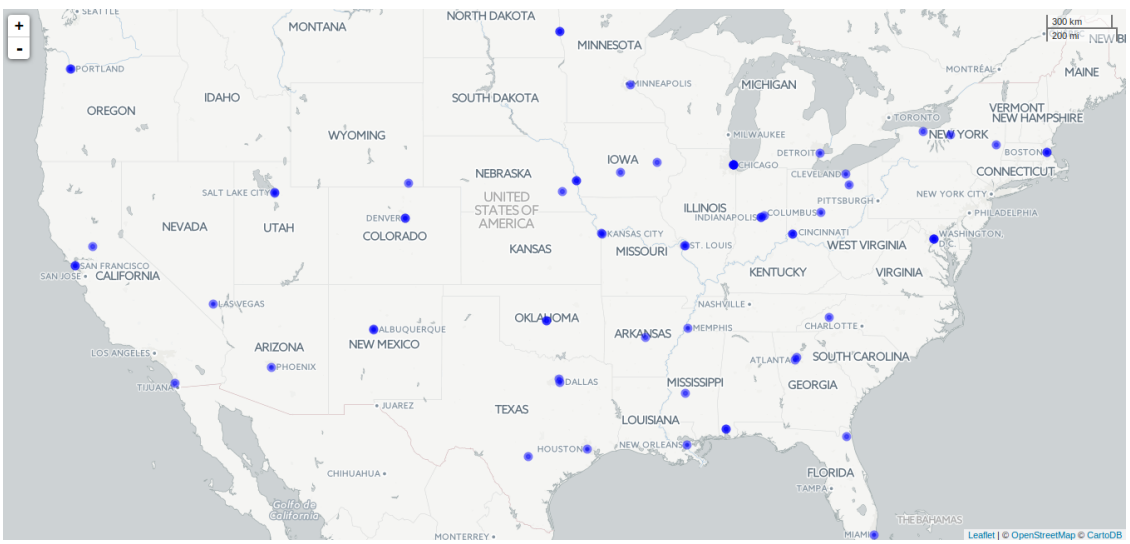


Figure 1: building locations

GSA/interval/mapped.html

The table Table 2 contains the names and location of the building in the study. More detailed descriptions of the buildings could be found in https://www.gsa.gov/portal/category/22227 under each region and facility, but seems only less than 10% of the building has such detailed information (e.g. JOHN W. MCCORMACK BUILDING), most of them is just a contact phone number.

Table 2: List of buildings in the study

Building_Number	Building_Name	City	State	Region
MA0131ZZ	JFK FEDERAL BUILDING	BOSTON	MA	1

Table 2: List of buildings in the study

Building_Number	Building_Name	City	State	Region
MA0013ZZ	JOHN W. MCCORMACK BUILDING	BOSTON	MA	1
NY0281ZZ	JAMES M HANLEY FB	SYRACUSE	NY	2
NY0304ZZ	KENNETH B KEATING FB	ROCHESTER	NY	2
NY0300ZZ	LEO W OBRIEN FB	ALBANY	NY	2
FL0067ZZ	CHAS. E. BENNETT FB	JACKSONVILLE	FL	4
TN0088ZZ	CLIFFORD DAVIS-ODELL HORTON	MEMPHIS	TN	4
MS0083ZZ	DR. A. H. MC COY FB	JACKSON	MS	4
AL0076AB	FEDERAL BUILDING	MOBILE	AL	4
GA0010AE	IRS ANNEX	CHAMBLEE	GA	4
NC0002AE	VEACH-BALEY FEDERAL COMPLEX	ASHEVILLE	NC	4
AL0039AB	JOHN A CAMPBELL USCT	MOBILE	AL	4
FL0010ZZ	WILKIE D. FERGUSON, JR.	MIAMI	FL	4
GA1007ZZ	SAM NUNN ATLANTA FED. CTR.	ATLANTA	GA	4
IN0048ZZ	BIRCH BAYH FED BLDG & US CTHSE	INDIANAPOLIS	IN	5
IL0032ZZ	CUSTOMHOUSE	CHICAGO	IL	5
IL0205ZZ	EVERETT M. DIRKSEN	CHICAGO	IL	5
IL0236FC	JOHN C. KLUCZYNSKI FED. BLDG.	CHICAGO	IL	5
OH0194ZZ	JOHN F SEIBERLING FB & US CTHS	AKRON	OH	5
OH0189CN	JOHN WELD PECK	CINCINNATI	OH	5
OH0046ZZ	KINNEARY US CTHSE	COLUMBUS	OH	5
IN1703ZZ	MAJOR GENERAL EMMETT J. BEAN	INDIANAPOLIS	IN	5
IL0303ZZ	METCALFE BUILDING	CHICAGO	IL	5
OH0033ZZ	METZENBAUM U.S. COURTHOUSE	CLEVELAND	OH	5
IN0133ZZ	MINTON-CAPEHART F/B	INDIANAPOLIS	IN	5
OH0028CN	POTTER STEWART U.S. COURTHOUSE	CINCINNATI	OH	5
MI0029ZZ	THEODORE LEVIN US COURTHOUSE	DETROIT	MI	5
IL0235FC	USPO LOOP STATION	CHICAGO	IL	5
MN0087ZZ	W E BURGER FB & US CTHS	SAINT PAUL	MN	5
KS0094ZZ	ROBERT J. DOLE US CTHSE	KANSAS CITY	KS	6
IA0121ZZ	CEDAR RAPIDS COURTHOUSE	CEDAR RAPIDS	IA	6
MO0050ZZ	CHARLES EVANS WHITTAKER CTHS	KANSAS CITY	MO	6
NE0051ZZ	EDWARD ZORINSKY FED BLDG	OMAHA	NE	6
NE0036ZZ	HRUSKA US COURTHOUSE	OMAHA	NE	6
IA0112ZZ	NEAL SMITH FEDERAL BUILDING	DES MOINES	IA	6
NE0531ZZ	ROBERT DENNEY FB&CT	LINCOLN	NE	6
MO0106ZZ	ROBT A YOUNG FED BLD	SAINT LOUIS	MO	6
MO0095ZZ	THOMAS F. EAGLETON COURTHOUSE	SAINT LOUIS	MO	6
TX0211ZZ	B CASEY COURTHOUSE	HOUSTON	TX	7
NM0030ZZ	D CHAVEZ FEDERAL BLDG	ALBUQUERQUE	NM	7
LA0085ZZ	H BOGGS FED BLDG/COURTHOUSE	NEW ORLEANS	LA	7

Table 2: List of buildings in the study

Building_Number	Building_Name	City	State	Region
AR0030RK	LITTLE ROCK USPO/COURTHOUSE	LITTLE ROCK	AR	7
OK0046CT	OKC POST OFFICE/COURTHOUSE	OKLAHOMA CITY	OK	7
OK0101ZZ	OKLAHOMA CITY FEDERAL BUILDING	OKLAHOMA CITY	OK	7
NM0050ZZ	PETE DOMENICI COURTHOUSE	ALBUQUERQUE	NM	7
TX0501HS	SAN ANTONIO FEDERAL BLDG WEST	SAN ANTONIO	TX	7
TX0057ZZ	TERMINAL ANNEX FEDERAL BLDG	DALLAS	TX	7
TX0302ZZ	THE CENTRE PHASE 5	FARMERS BRANCH	TX	7
CO0061ZZ	ALFRED A. ARRAJ	DENVER	CO	8
CO0009ZZ	BYRON WHITE US CRTHS	DENVER	CO	8
ND0006ZZ	FB-CT	FARGO	ND	8
ND0046ZZ	FB-PO	FARGO	ND	8
UT0017ZZ	FRANK E MOSS COURTHOUSE	SALT LAKE CITY	UT	8
WY0029ZZ	JOSEPH C O'MAHONEY FED CENTER	CHEYENNE	WY	8
UT0032ZZ	WALLACE F BENNETT FB	SALT LAKE CITY	UT	8
CA0167ZZ	EDWARD J. SCHWARTZ FOB & CTHS	SAN DIEGO	CA	9
CA0096DD	JAMES R. BROWNING U.S. CRTHSE	SAN FRANCISCO	CA	9
NV0304ZZ	LLOYD D. GEORGE COURTHOUSE	LAS VEGAS	NV	9
CA0154ZZ	PHILLIP BURTON,FB CT	SAN FRANCISCO	CA	9
CA0306ZZ	ROBERT T MATSUI US COURTHOUSE	SACRAMENTO	CA	9
AZ0303ZZ	SANDRA D. O'CONNOR COURTHOUSE	PHOENIX	AZ	9
OR0033PE	911 FEDERAL BLDG	PORTLAND	OR	10
OR0052ZZ	MARK O. HATFIELD U.S. CRTHSE	PORTLAND	OR	10
DC0021ZZ	GSA	WASHINGTON	DC	11
DC0083ZZ	ORVILLE WRIGHT	WASHINGTON	DC	11
DC0084ZZ	WILBUR WRIGHT	WASHINGTON	DC	11

5.1.2 Basic information

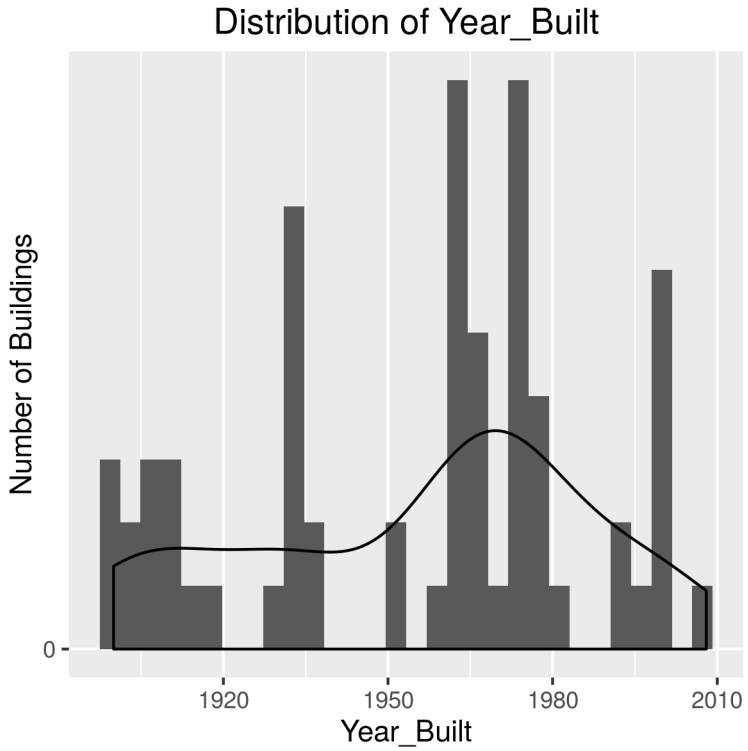


Figure 2: Distribution of built year

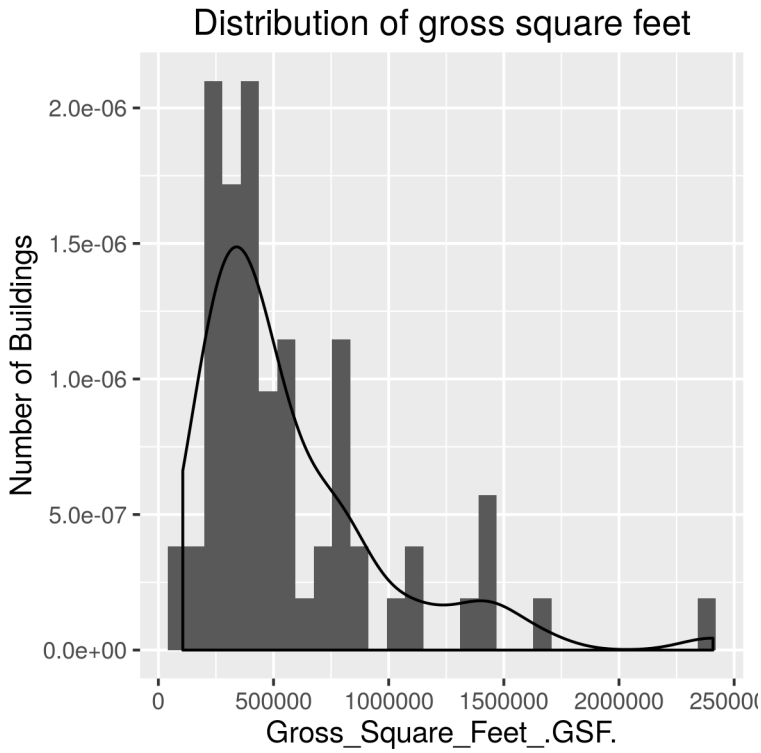


Figure 3: Distribution of gross square feet

Table 3: Basic information of buildings in the study

Building_Number	Region	Year_Built	Gross_Square_Feet	Owned	in_facility	Type
MA0131ZZ	1	1966	1045836	1	1	Office
MA0013ZZ	1	1933	793165	1	1	Office
NY0281ZZ	2	1979	391031	1	1	Courthouse
NY0304ZZ	2	1974	256230	1	1	Courthouse
NY0300ZZ	2	1975	256954	1	1	Office
FL0067ZZ	4	1967	334195	1	1	Office
TN0088ZZ	4	1963	444745	1	1	Office
MS0083ZZ	4	1979	445829	1	1	Office
AL0076AB	4	1974	212841	1		
GA0010AE	4	1999	417147	1		Office
NC0002AE	4	1998	271793	1		
AL0039AB	4	1932	115014	1		
FL0010ZZ	4	2008	586108	1	1	Office
GA1007ZZ	4		2407916		1	Office
IN0048ZZ	5	1905	554238	1	1	Courthouse
IL0032ZZ	5	1932	279320	1	1	Office
IL0205ZZ	5	1964	1465043	1	1	
IL0236FC	5	1973	1428620	1		
OH0194ZZ	5	1974	425515	1	1	Courthouse
OH0189CN	5	1964	791748	1		
OH0046ZZ	5	1935	282878	1	1	Courthouse
IN1703ZZ	5	1953	1660353	1	1	Office
IL0303ZZ	5	1991	839461	1	1	Office
OH0033ZZ	5	1910	245368	1	1	Office
IN0133ZZ	5	1974	636046	1	1	Office
OH0028CN	5	1938	542823	1		
MI0029ZZ	5	1934	771904	1	1	Courthouse
IL0235FC	5	1973	288104	1		
MN0087ZZ	5	1965	415309	1	1	Courthouse
KS0094ZZ	6	1994	286446	1	1	Courthouse
IA0121ZZ	6	1912	305999	1	1	Courthouse
MO0050ZZ	6	1998	753500	1	1	Courthouse

Table 3: Basic information of buildings in the study

Building_Number	Region	Year_Built	Gross_Square_Feet	Owned	in_facility	Type
NE0051ZZ	6	1960	428932	1	1	Office
NE0036ZZ	6	1900	364173	1	1	Courthouse
IA0112ZZ	6	1967	405238	1	1	Office
NE0531ZZ	6	1975	506318	1	1	Courthouse
MO0106ZZ	6	1933	1131929	1	1	Office
MO0095ZZ	6	1900	1310877	1	1	Courthouse
TX0211ZZ	7	1962	538700	1	1	Office
NM0030ZZ	7	1965	365232	1	1	Office
LA0085ZZ	7	1976	709366	1	1	Office
AR0030RK	7	1932	283694	1		
OK0046CT	7	1912	221497	1		
OK0101ZZ	7	1903	180756	1	1	Office
NM0050ZZ	7	1998	375094	1	1	Office
TX0501HS	7	1975	180230	1		Office
TX0057ZZ	7	1930	254768	1	1	Office
TX0302ZZ	7	1983	558200	1	1	Office
CO0061ZZ	8	1902	326686	1	1	Office
CO0009ZZ	8	1916	270106	1	1	Courthouse
ND0006ZZ	8	1931	106032	1	1	Office
ND0046ZZ	8	1969	271034	1	1	Office
UT0017ZZ	8	1905	234288	1	1	Courthouse
WY0029ZZ	8	1964	207835	1	1	Courthouse
UT0032ZZ	8	1963	391726	1	1	Office
CA0167ZZ	9	1976	895247	1	1	Courthouse
CA0096DD	9	1905	457392	1		
NV0304ZZ	9	1900	454896	1	1	Courthouse
CA0154ZZ	9	1964	1427966	1	1	Office
CA0306ZZ	9	1999	773985	1	1	Office
AZ0303ZZ	9	2000	831061	1	1	Courthouse
OR0033PE	10	1953	312447	1		Office
OR0052ZZ	10	1997	591688	1	1	Courthouse
DC0021ZZ	11	1917	755935	1	1	Office

Table 3: Basic information of buildings in the study

Building_Number	Region	Year_Built	Gross_Square_Feet	Owned	in_facility	Type
DC0083ZZ	11	1963	1114225	1	1	Office
DC0084ZZ	11	1964	421317	1	1	Office

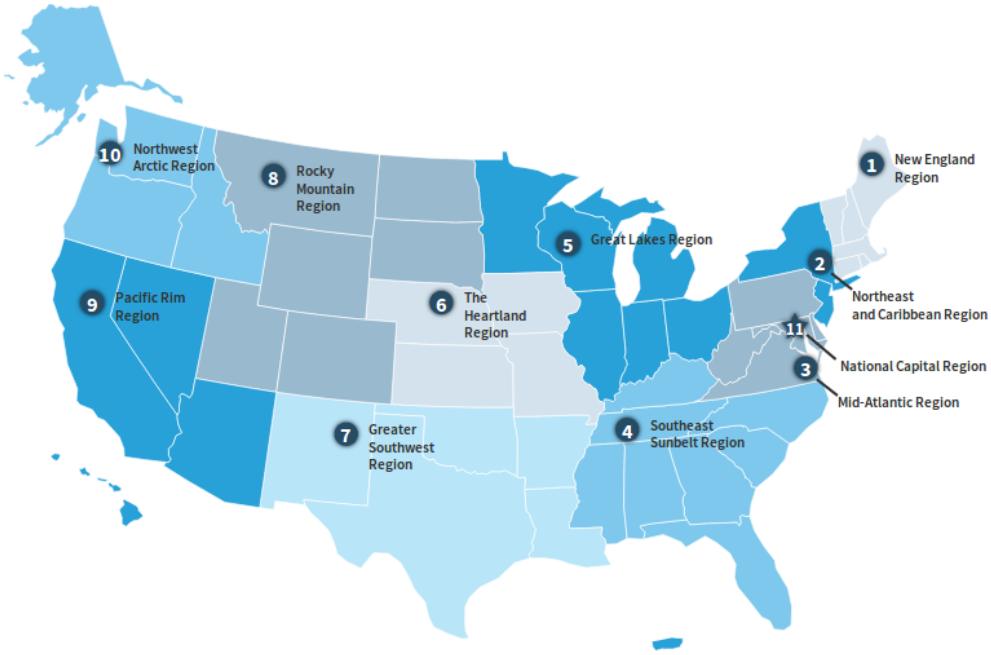


Figure 4: GSA region map

https://www.gsa.gov/portal/category/22227

5.1.3 Energy data availability

Table 4: Energy data availability for buildings in the study

Building_Number	has_electric	has_gas
MA0131ZZ	1	
NY0281ZZ	1	1
NY0304ZZ	1	
NY0300ZZ	1	1
FL0067ZZ	1	1
TN0088ZZ	1	1

Table 4: Energy data availability for buildings in the study

Building_Number	has_electric	has_gas
MS0083ZZ	1	
AL0076AB	1	1
GA0010AE	1	1
NC0002AE	1	1
AL0039AB	1	1
FL0010ZZ	1	
GA1007ZZ	1	1
IN0048ZZ	1	
IL0032ZZ	1	1
IL0205ZZ	1	1
IL0236FC	1	
OH0194ZZ	1	1
OH0189CN	1	
OH0046ZZ	1	1
IN1703ZZ	1	1
IL0303ZZ	1	
OH0033ZZ	1	1
IN0133ZZ	1	
OH0028CN	1	1
MI0029ZZ	1	
IL0235FC	1	
MN0087ZZ	1	
KS0094ZZ	1	
IA0121ZZ	1	1
MO0050ZZ	1	
NE0051ZZ	1	
NE0036ZZ	1	
IA0112ZZ	1	1
NE0531ZZ	1	1
MO0106ZZ	1	1
MO0095ZZ	1	

Table 4: Energy data availability for buildings in the study

Building_Number	has_electric	has_gas
TX0211ZZ	1	1
NM0030ZZ	1	1
LA0085ZZ	1	1
AR0030RK	1	1
OK0046CT	1	
OK0101ZZ	1	
NM0050ZZ	1	1
TX0501HS	1	
TX0057ZZ	1	1
TX0302ZZ	1	
CO0061ZZ	1	
CO0009ZZ	1	
ND0006ZZ	1	1
ND0046ZZ	1	1
UT0017ZZ	1	1
WY0029ZZ	1	1
UT0032ZZ	1	1
CA0167ZZ	1	
CA0096DD	1	
NV0304ZZ	1	
CA0154ZZ	1	
CA0306ZZ	1	
AZ0303ZZ	1	
OR0033PE	1	1
OR0052ZZ	1	1
DC0021ZZ	1	
DC0083ZZ	1	
DC0084ZZ	1	
MA0013ZZ		1
total	65	34

5.1.4 Building energy record period

Table 5: Energy recording period

Building_Number	energy_start	energy_stop
AL0039AB	2013-Sep-09 22:15:00	2016-Jun-27
AL0076AB	2013-Sep-09 22:15:00	2016-Jun-27
AR0030RK	2013-Sep-09 22:15:00	2016-Jun-30 10:45:00
AZ0303ZZ	2013-Oct-24 13:15:00	2016-Jun-30 6:15:00
CA0096DD	2013-Sep-09 20:15:00	2014-Oct-30 11:45:00
CA0154ZZ	2014-Apr-07 7:15:00	2016-Jun-30 6:15:00
CA0167ZZ	2013-Sep-09 20:15:00	2016-Jun-17 22:30:00
CA0306ZZ	2013-Oct-29 8:00:00	2016-Jun-30 6:15:00
CO0009ZZ	2013-Sep-09 21:15:00	2016-Jun-30 7:45:00
CO0061ZZ	2013-Sep-09 21:15:00	2016-Jun-30 7:45:00
DC0021ZZ	2015-Feb-19 12:15:00	2016-Jun-30 9:30:00
DC0083ZZ	2013-Sep-09 23:30:00	2016-Jun-30 9:30:00
DC0084ZZ	2013-Sep-09 23:30:00	2016-Jun-30 9:30:00
FL0010ZZ	2013-Dec-18 14:45:00	2016-Jun-27
FL0067ZZ	2013-Sep-09 23:15:00	2016-Jun-27
GA0010AE	2013-Sep-09 23:15:00	2016-Jun-27
GA1007ZZ	2013-Sep-09 23:15:00	2014-Oct-28 9:45:00
IA0112ZZ	2013-Sep-09 22:15:00	2016-Jun-27
IA0121ZZ	2013-Sep-09 22:15:00	2016-Jun-27
IL0032ZZ	2013-Sep-09 22:15:00	2016-Jun-27
IL0205ZZ	2013-Sep-09 22:15:00	2016-Jun-27
IL0235FC	2013-Sep-09 22:15:00	2016-Jun-27
IL0236FC	2013-Sep-09 22:15:00	2016-Jun-27
IL0303ZZ	2013-Sep-09 22:15:00	2016-Jun-27
IN0048ZZ	2013-Sep-09 23:30:00	2016-Jun-27
IN0133ZZ	2013-Sep-09 23:15:00	2016-Jun-27
IN1703ZZ	2013-Sep-09 22:15:00	2016-Jun-27
KS0094ZZ	2013-Sep-09 22:15:00	2016-Jun-27
LA0085ZZ	2013-Apr-20 21:30:00	2016-Jun-30 11:00:00
MA0131ZZ	2013-Sep-09 23:30:00	2016-Jun-27

Table 5: Energy recording period

Building_Number	energy_start	energy_stop
MI0029ZZ	2013-Sep-09 23:15:00	2016-Jun-27
MN0087ZZ	2013-Sep-09 22:15:00	2016-Jun-27
MO0050ZZ	2013-Sep-09 22:15:00	2016-Jun-27
MO0095ZZ	2013-Sep-09 22:15:00	2016-Jun-27
MO0106ZZ	2013-Sep-09 22:15:00	2016-Jun-27
MS0083ZZ	2013-Sep-09 22:15:00	2016-Jun-27
NC0002AE	2013-Dec-20 12:45:00	2016-Jun-27
ND0006ZZ	2013-Sep-09 21:15:00	2016-Jun-30 7:45:00
ND0046ZZ	2013-Sep-09 21:15:00	2016-Jun-30 7:45:00
NE0036ZZ	2013-Sep-09 22:15:00	2016-Jun-27
NE0051ZZ	2013-Sep-09 22:15:00	2016-Jun-27
NE0531ZZ	2013-Sep-09 22:15:00	2016-Jun-27
NM0030ZZ	2011-Sep-16 5:15:00	2016-Jun-25 13:15:00
NM0050ZZ	2011-Oct-11 18:30:00	2016-Jun-30 11:00:00
NV0304ZZ	2013-Sep-09 20:15:00	2016-Jun-30 6:15:00
NY0281ZZ	2013-Sep-09 23:15:00	2016-Jun-27
NY0300ZZ	2013-Sep-09 23:15:00	2016-Jun-27
NY0304ZZ	2013-Sep-09 23:15:00	2016-Jun-27
OH0028CN	2013-Sep-09 23:15:00	2016-Jun-27
OH0033ZZ	2013-Sep-09 23:15:00	2016-Jun-27
OH0046ZZ	2013-Sep-09 23:15:00	2016-Jun-27
OH0189CN	2013-Sep-09 23:15:00	2016-Jun-27
OH0194ZZ	2013-Sep-09 23:15:00	2016-Jun-27
OK0046CT	2012-Apr-06 6:30:00	2016-Jun-30 10:45:00
OK0101ZZ	2012-Apr-05 17:45:00	2016-Jun-30 3:00:00
OR0033PE	2013-Sep-09 20:15:00	2016-Jun-30 6:15:00
OR0052ZZ	2013-Sep-09 20:15:00	2016-Jun-28 6:00:00
TN0088ZZ	2013-Sep-09 22:15:00	2015-Mar-07 14:45:00
TX0057ZZ	2013-Sep-09 22:15:00	2016-Jun-30 10:45:00
TX0211ZZ	2013-Sep-09 22:30:00	2016-Jun-30 10:30:00
TX0302ZZ	2013-Sep-09 22:15:00	2016-Jun-30 10:45:00
TX0501HS	2013-Sep-09 22:15:00	2016-Jun-30 10:30:00

Table 5: Energy recording period

Building_Number	energy_start	energy_stop
UT0017ZZ	2013-Sep-09 21:15:00	2016-Jun-30 7:45:00
UT0032ZZ	2013-Sep-09 21:30:00	2016-Jun-30 7:45:00
WY0029ZZ	2013-Sep-09 21:15:00	2016-Jun-30 7:45:00

5.1.5 Building retrofit

There are 4 buildings with retrofit in the energy recording period.

Table 6: retrofit during the energy recording period

Building_Number	high_level_ECM	detail_level_ECM	Substantial_Completion_Date
FL0067ZZ	Advanced Metering	Building / Facility	2013-Nov-19
MS0083ZZ	Advanced Metering	Building / Facility	2014-Jun-13
MS0083ZZ	Building Envelope	New_Facade	2014-Jun-13
MS0083ZZ	Building Envelope	New_Roof	2014-Jun-13
MS0083ZZ	Building Envelope	New_Windows	2014-Jun-13
MS0083ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2014-Jun-13
MS0083ZZ	HVAC	New_Air Handler	2014-Jun-13
MS0083ZZ	HVAC	New_Boilers	2014-Jun-13
MS0083ZZ	HVAC	New_Chillers	2014-Jun-13
MS0083ZZ	HVAC	New_Controls	2014-Jun-13
MS0083ZZ	HVAC	New_Cooling Tower	2014-Jun-13
MS0083ZZ	HVAC	Repairs_Air Handler	2014-Jun-13
MS0083ZZ	HVAC	Repairs_Cooling Tower	2014-Jun-13
MS0083ZZ	Lighting	Indoor Daylighting or Lighting Strategies	2014-Jun-13
MS0083ZZ	Lighting	Indoor_Lighting Controls	2014-Jun-13
MS0083ZZ	Lighting	Indoor_Retrofit or Replacement	2014-Jun-13
MS0083ZZ	Lighting	Outdoor_Lighting Controls	2014-Jun-13

Table 6: retrofit during the energy recording period

Building_Number	high_level_ECM	detail_level_ECM	Substantial_Completion_Date
MS0083ZZ	Lighting	Outdoor_Retrofit or Replacement	2014-Jun-13
NM0050ZZ	Advanced Metering	Building / Facility	2013-Aug-12
NM0050ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2013-Aug-12
NM0050ZZ	HVAC	Repairs_Controls	2013-Aug-12
NM0050ZZ	HVAC	Repairs_Cooling Tower	2013-Aug-12
OH0046ZZ	Advanced Metering	Building / Facility	2013-Dec-26
OH0046ZZ	Building Envelope	Repairs_Facade	2013-Dec-26
OH0046ZZ	Building Envelope	Repairs_Windows	2013-Dec-26
OH0046ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2013-Dec-26
OH0046ZZ	HVAC	New_Air Handler	2013-Dec-26
OH0046ZZ	HVAC	New_Boilers	2013-Dec-26
OH0046ZZ	HVAC	New_Controls	2013-Dec-26
OH0046ZZ	HVAC	New_Cooling Tower	2013-Dec-26
OH0046ZZ	HVAC	Repairs_Air Handler	2013-Dec-26
OH0046ZZ	HVAC	Repairs_Boilers	2013-Dec-26
OH0046ZZ	HVAC	Repairs_Chillers	2013-Dec-26
OH0046ZZ	Lighting	Indoor_Daylighting	2013-Dec-26
OH0046ZZ	Lighting	Indoor_Lighting Controls	2013-Dec-26
OH0046ZZ	Lighting	Indoor_Retrofit or Replacement	2013-Dec-26
OH0046ZZ	Lighting	Outdoor_Lighting Controls	2013-Dec-26

5.1.6 Building Mechanical System

BAS data from sky spark.

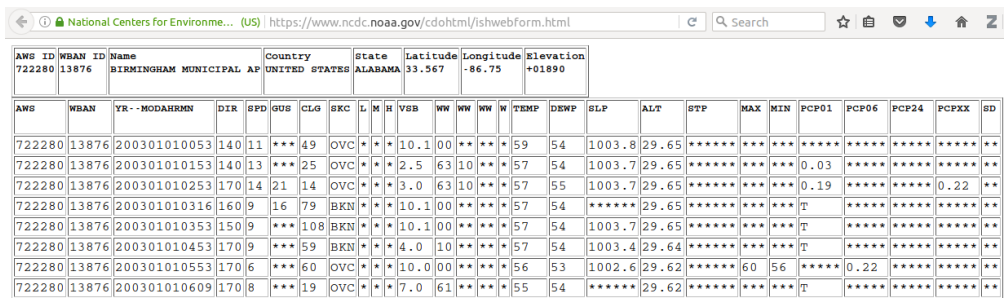
To be downloaded...

5.2 Environment data sources

TODO: check NLDAS stage 2 forcing data so that all data are grid based In the previous stage of the work, the data source for temperature, the only environmental variable is retrieved from the pisystem, whose source is weather underground web interface.

5.2.1 Integrated Surface Global Hourly Data from NOAA

- data sample



National Centers for Environme... (US) https://www.ncdc.noaa.gov/cdohtml/ishwebform.html

AWS ID	WBAN ID	Name	Country	State	Latitude	Longitude	Elevation
722280	13876	BIRMINGHAM MUNICIPAL AP	UNITED STATES	ALABAMA	33.567	-86.75	+01890

AWS	WBAN	YR--MODAHRMN	DIR	SPD	GUS	CLG	SKC	L	M	H	VSB	WW	WW	WW	W	TEMP	DEWP	SLP	ALT	STP	MAX	MIN	PCP01	PCP06	PCP24	PCPXX	SD
722280	13876	200301010053	140	11	***	49	OVC	*	*	*	10.1	00	**	**	*	59	54	1003.8	29.65	******	***	***	*****	*****	*****	*****	**
722280	13876	200301010153	140	13	***	25	OVC	*	*	*	2.5	63	10	**	*	57	54	1003.7	29.65	******	***	***	0.03	*****	*****	*****	**
722280	13876	200301010253	170	14	21	14	OVC	*	*	*	3.0	63	10	**	*	57	55	1003.7	29.65	******	***	***	0.19	*****	*****	0.22	**
722280	13876	200301010316	160	9	16	79	BKN	*	*	*	10.1	00	**	**	*	57	54	******	29.65	******	***	***	T	*****	*****	*****	**
722280	13876	200301010353	150	9	***	108	BKN	*	*	*	10.1	00	**	**	*	57	54	1003.7	29.65	******	***	***	T	*****	*****	*****	**
722280	13876	200301010453	170	9	***	59	BKN	*	*	*	4.0	10	**	**	*	57	54	1003.4	29.64	******	***	***	T	*****	*****	*****	**
722280	13876	200301010553	170	6	***	60	OVC	*	*	*	10.0	00	**	**	*	56	53	1002.6	29.62	******	60	56	*****	0.22	*****	*****	**
722280	13876	200301010609	170	8	***	19	OVC	*	*	*	7.0	61	**	**	*	55	54	******	29.62	******	***	***	T	*****	*****	*****	**

Figure 5: NOAA Integrated Surface Global Hourly Data

- Station distribution

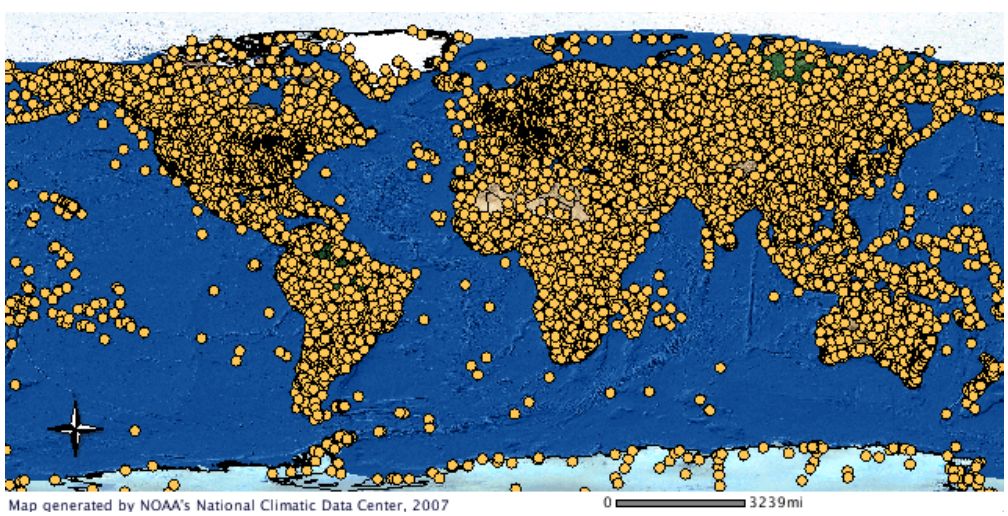


Figure 6: NOAA ISD station distribution

- download: `ftp://ftp.ncdc.noaa.gov/pub/data/noaa/`, or using NCEI CDO 1.0 Rest API example url: `https://www7.ncdc.noaa.gov/wsregistration/CDOServices.html`

```
% check for variables
https://www7.ncdc.noaa.gov/rest/services/variables/ish/?output=csv&token=cbacihgEFi
% query temperature
https://www7.ncdc.noaa.gov/rest/services/values/ish/72315003812/TMP/200101010000/20
```

- Data are ordered by year and station, each data file contains weather station identifier (USAF, and WBAN), table can be downloaded under `ftp://ftp.ncdc.noaa.gov/pub/data/noaa/`, file "isd-history.csv" (2.8MB version, there are a lot of different versions of the same file but different content)
- relevant fields: wind direction and speed, sky cover condition (clear, overcast, scattered, etc.), temperature, dew point, precipitation.
- time resolution: 1 to 2 observations per hour
- The list of weather stations associated of the buildings:

```
KNIP, KABQ, KOAK, KADS, KOKC, KAKR, KOLV, KALB, KOMA, KATL, KPDK,
KAVL, KPDX, KBFM, KPHX, KBKF, KROC, KBKL, KSAC, KBOS, KSAN, KCID,
KSFO, KCMH, KSLC, KCYS, KSSF, KDAL, KSTL, KDCA, KSTP, KDET, KSYR,
KDSM, KVGT, KEYE, KFAR, KHKS, KHOU, KLIT, KLNK, KLUK, KMDW, KMIA,
KMKC, KNEW
```

5.2.2 National Solar Radiation Data Base (NSRDB)

"The NSRDB is a serially complete collection of hourly and half-hourly values of the three most common measurements of solar radiationglobal horizontal, direct normal, and diffuse horizontal irradianceand meteorological data" `https://nsrdb.nrel.gov/background`. The old versions are station based, the new version is grid based ($4m \times 4m$ or 0.038 degrees)

Downloaded global horizontal (ghi), direct normal (dni), and diffuse horizontal irradiance (dni). Other meteorological data include wind speed, temperature, Solar Zenith Angle are also available (`https://nsrdb.nrel.gov/current-version`).

Table 7: Data Fields in NSRDB

var	type	unit	source	note
Clearsky DHI	Q	W/m2	NSRDB	- Modeled solar radiation on a horizontal surface received from the sky excluding the solar disk. - This is assuming clear sky condition
Clearsky DNI	Q	W/m2	NSRDB	- Modeled solar radiation obtained from the direction of the sun. - This is assuming clear sky condition
Clearsky GHI	Q	W/m2	NSRDB	- Modeled solar radiation on a horizontal surface received from the sky. - This is assuming clear sky condition
Cloud Type	C	Unitless	NSRDB	Obtained from PATMOS-X
Dew Point	Q	Degree C	NSRDB	Calculated from specific humidity
DHI	Q	W/m2	NSRDB	Modeled solar radiation on a horizontal surface received from the sky excluding the solar disk.
DNI	Q	W/m2	NSRDB	Modeled solar radiation obtained from the direction of the sun.
GHI	Q	W/m2	NSRDB	Modeled solar radiation on a horizontal surface received from the sky.
Snow Depth	Q	Meters	NSRDB	Source: MERRA
Solar Zenith Angle	Q	Degrees	NSRDB	Angle between the sun and the zenith
Temperature	Q	Degree C	NSRDB	Source: MERRA
Pressure	Q	Millibar	NSRDB	Source: MERRA
Relative Humidity	Q	Percent	NSRDB	Calculated from specific humidity
Precipitable Water	Q	Millimeter	NSRDB	Source: MERRA
Wind Direction	Q	Degrees	NSRDB	Source: MERRA
Wind Speed	Q	Meter per second	NSRDB	Source: MERRA

5.2.3 NLDAS

"The goal of the North American Land Data Assimilation System (NLDAS) is to construct quality-controlled, and spatially and temporally consistent, land-surface model (LSM) datasets from the best available observations and model output to support modeling activities." `https://ldas.gsfc.nasa.gov/nldas/` It has 1/8th-degree grid resolution and dates back to 1979.

introduction ppt about the dataset: `https://ldas.gsfc.nasa.gov/nldas/presentations/Cosgrove_GAPP_May2002.pdf`

Download and data specs: `https://disc.sci.gsfc.nasa.gov/uui/datasets?keywords=NLDAS` download page: `https://disc.sci.gsfc.nasa.gov/uui/datasets/NLDAS_FORB0125_`

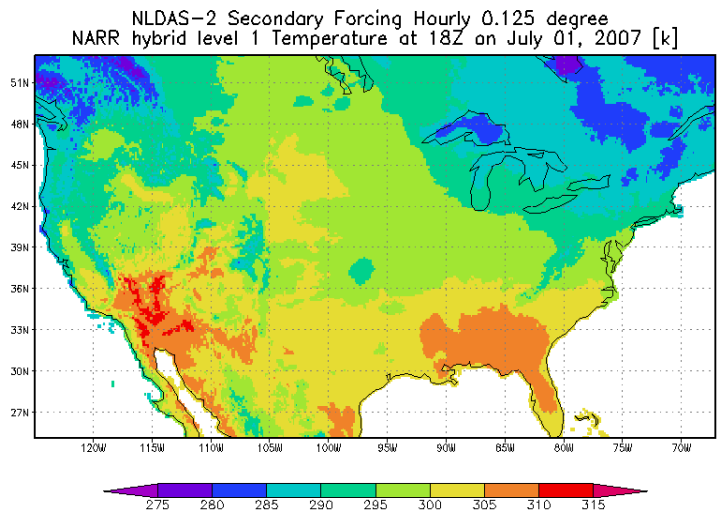


Figure 7: NLDAS data download

`H_V002/summary?keywords=NLDAS`

6 Non-linear models

6.1 Neuron Network with 1-2 hidden layer

6.2 Support Vector Regression with RBF kernel

6.3 Random forest regression [14]

6.4 piecewise linear regression as baseline (it's a simple non-linear model, but not expressive enough)

7 Appendix

7.1 Building ECM actions

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
CA0154ZZ	HVAC	New_Cooling Tower	2012-Feb-29
CA0154ZZ	HVAC	Repairs_Air Handler	2012-Feb-29
CA0154ZZ	HVAC	Repairs_Chillers	2012-Feb-29
CA0154ZZ	HVAC	Repairs_Controls	2012-Feb-29
CA0154ZZ	Lighting	Indoor_Daylighting	2012-Feb-29
CA0154ZZ	Lighting	Indoor_Lighting Controls	2012-Feb-29
CA0154ZZ	Lighting	Indoor_Retrofit or Replacement	2012-Feb-29
CA0154ZZ	Lighting	Outdoor_Retrofit or Replacement	2012-Feb-29
CA0167ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Mar-06
CA0167ZZ	HVAC	New_Chillers	2012-Mar-06
CA0167ZZ	HVAC	New_Controls	2012-Mar-06
CA0167ZZ	HVAC	New_Cooling Tower	2012-Mar-06
CA0167ZZ	HVAC	Repairs_Air Handler	2012-Mar-06

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
CA0167ZZ	Lighting	Indoor_Lighting Controls	2012-Mar-06
CA0306ZZ	Advanced Metering	Building / Facility	2012-Sep-26
CA0306ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Sep-26
CA0306ZZ	HVAC	New_Air Handler	2012-Sep-26
CA0306ZZ	HVAC	New_Boilers	2012-Sep-26
CA0306ZZ	HVAC	Repairs_Air Handler	2012-Sep-26
CA0306ZZ	HVAC	Repairs_Chillers	2012-Sep-26
CA0306ZZ	HVAC	Repairs_Controls	2012-Sep-26
CA0306ZZ	HVAC	Repairs_Cooling Tower	2012-Sep-26
CA0306ZZ	Lighting	Indoor_Daylighting	2012-Sep-26
CA0306ZZ	Lighting	Indoor_Lighting Controls	2012-Sep-26
CA0306ZZ	Lighting	Indoor_Retrofit or Replacement	2012-Sep-26
CA0306ZZ	Lighting	Outdoor_Retrofit or Replacement	2012-Sep-26
CO0009ZZ	Advanced Metering	Building / Facility	2011-Jun-21
CO0009ZZ	Advanced Metering	Submetering	2011-Jun-21
CO0009ZZ	Building Envelope	Repairs_Windows	2011-Jun-21
CO0009ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Jun-21
CO0009ZZ	HVAC	New_Boilers	2011-Jun-21
CO0009ZZ	HVAC	New_Cooling Tower	2011-Jun-21
CO0009ZZ	HVAC	Repairs_Air Handler	2011-Jun-21
CO0009ZZ	HVAC	Repairs_Chillers	2011-Jun-21
CO0009ZZ	HVAC	Repairs_Controls	2011-Jun-21
CO0009ZZ	HVAC	Repairs_Cooling Tower	2011-Jun-21

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
CO0009ZZ	Lighting	Indoor_Lighting Controls	2011-Jun-21
CO0009ZZ	Lighting	Indoor_Retrofit or Replacement	2011-Jun-21
DC0021ZZ	Advanced Metering	Building / Facility	2014-Jan-27
DC0021ZZ	Advanced Metering	Submetering	2014-Jan-27
DC0021ZZ	Building Envelope	New_Facade	2014-Jan-27
DC0021ZZ	Building Envelope	New_Roof	2014-Jan-27
DC0021ZZ	Building Envelope	New_Windows	2014-Jan-27
DC0021ZZ	Building Envelope	Repairs_Facade	2014-Jan-27
DC0021ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2014-Jan-27
DC0021ZZ	HVAC	New_Air Handler	2014-Jan-27
DC0021ZZ	HVAC	New_Chillers	2014-Jan-27
DC0021ZZ	HVAC	New_Controls	2014-Jan-27
DC0021ZZ	HVAC	New_Cooling Tower	2014-Jan-27
DC0021ZZ	HVAC	Repairs_Cooling Tower	2014-Jan-27
DC0021ZZ	Lighting	Indoor Daylighting or Lighting Strategies	2014-Jan-27
DC0021ZZ	Lighting	Indoor_Daylighting	2014-Jan-27
DC0021ZZ	Lighting	Indoor_Lighting Controls	2014-Jan-27
DC0021ZZ	Lighting	Indoor_Retrofit or Replacement	2014-Jan-27
DC0021ZZ	Lighting	Outdoor_Lighting Controls	2014-Jan-27
FL0010ZZ	Advanced Metering	Building / Facility	2011-Jun-17
FL0010ZZ	Building Envelope	New_Roof	2011-Jun-17
FL0010ZZ	Lighting		2011-Jun-17
FL0067ZZ	Advanced Metering	Building / Facility	2013-Nov-19
GA0010AE	Advanced Metering	Building / Facility	2012-Dec-04

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
GA0010AE	Building Envelope	Repairs_Windows	2012-Dec-04
GA0010AE	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Dec-04
GA0010AE	Lighting	Indoor Daylighting or Lighting Strategies	2012-Dec-04
GA0010AE	Lighting	Indoor_Lighting Controls	2012-Dec-04
GA0010AE	Lighting	Indoor_Retrofit or Replacement	2012-Dec-04
GA0010AE	Lighting	Outdoor_Lighting Controls	2012-Dec-04
GA0010AE	Lighting	Outdoor_Retrofit or Replacement	2012-Dec-04
GA1007ZZ	Advanced Metering	Building / Facility	2011-Mar-30
GA1007ZZ	Building Envelope	New_Roof	2011-Mar-30
GA1007ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Mar-30
GA1007ZZ	Lighting	Indoor_Lighting Controls	2011-Mar-30
GA1007ZZ	Lighting	Indoor_Retrofit or Replacement	2011-Mar-30
GA1007ZZ	Lighting	Outdoor_Retrofit or Replacement	2011-Mar-30
IA0112ZZ	Advanced Metering	Building / Facility	2011-Oct-24
IA0112ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Oct-24
IA0112ZZ	HVAC	New_Air Handler	2011-Oct-24
IA0112ZZ	HVAC	New_Cooling Tower	2011-Oct-24
IA0112ZZ	HVAC	Repairs_Air Handler	2011-Oct-24
IA0112ZZ	HVAC	Repairs_Boilers	2011-Oct-24
IA0112ZZ	HVAC	Repairs_Chillers	2011-Oct-24
IA0112ZZ	HVAC	Repairs_Controls	2011-Oct-24

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
IA0112ZZ	HVAC	Repairs_Cooling Tower	2011-Oct-24
IA0112ZZ	Lighting	Indoor_Daylighting	2011-Oct-24
IA0112ZZ	Lighting	Indoor_Lighting Controls	2011-Oct-24
IA0112ZZ	Lighting	Indoor_Retrofit or Replacement	2011-Oct-24
IA0112ZZ	Lighting	Outdoor_Retrofit or Replacement	2011-Oct-24
IL0032ZZ	Advanced Metering	Building / Facility	2011-Sep-06
IL0032ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Sep-06
IL0032ZZ	HVAC	Repairs_Air Handler	2011-Sep-06
IL0032ZZ	HVAC	Repairs_Boilers	2011-Sep-06
IL0032ZZ	HVAC	Repairs_Controls	2011-Sep-06
IL0032ZZ	Lighting	Indoor_Retrofit or Replacement	2011-Sep-06
IL0303ZZ	Advanced Metering	Building / Facility	2011-Sep-27
IL0303ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Sep-27
IL0303ZZ	HVAC	New_Controls	2011-Sep-27
IL0303ZZ	HVAC	Repairs_Air Handler	2011-Sep-27
IL0303ZZ	Lighting	Indoor_Daylighting	2011-Sep-27
IL0303ZZ	Lighting	Indoor_Lighting Controls	2011-Sep-27
IL0303ZZ	Lighting	Indoor_Retrofit or Replacement	2011-Sep-27
IL0303ZZ	Lighting	Outdoor_Retrofit or Replacement	2011-Sep-27
IN0048ZZ	Building Envelope	New_Roof	2013-Mar-15
IN0048ZZ	Building Envelope	New_Windows	2013-Mar-15

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
IN0048ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2013-Mar-15
IN0048ZZ	HVAC	New_Air Handler	2013-Mar-15
IN0048ZZ	HVAC	New_Controls	2013-Mar-15
IN0048ZZ	HVAC	New_Cooling Tower	2013-Mar-15
IN0048ZZ	HVAC	Repairs_Chillers	2013-Mar-15
IN0048ZZ	HVAC	Repairs_Cooling Tower	2013-Mar-15
IN0048ZZ	Lighting	Indoor_Lighting Controls	2013-Mar-15
IN0048ZZ	Lighting	Indoor_Retrofit or Replacement	2013-Mar-15
IN0048ZZ	Lighting	Outdoor_Retrofit or Replacement	2013-Mar-15
IN0133ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Oct-29
IN0133ZZ	HVAC	New_Air Handler	2012-Oct-29
IN0133ZZ	HVAC	New_Chillers	2012-Oct-29
IN0133ZZ	HVAC	New_Controls	2012-Oct-29
IN0133ZZ	HVAC	New_Cooling Tower	2012-Oct-29
IN0133ZZ	HVAC	Repairs_Cooling Tower	2012-Oct-29
IN0133ZZ	Lighting	Indoor_Lighting Controls	2012-Oct-29
IN0133ZZ	Lighting	Indoor_Retrofit or Replacement	2012-Oct-29
IN0133ZZ	Lighting	Outdoor_Lighting Controls	2012-Oct-29
IN0133ZZ	Lighting	Outdoor_Retrofit or Replacement	2012-Oct-29
IN1703ZZ	Advanced Metering	Building / Facility	2011-Aug-24
IN1703ZZ	Advanced Metering	Submetering	2011-Aug-24

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
IN1703ZZ	Building Envelope	New_Roof	2011-Aug-24
IN1703ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Aug-24
IN1703ZZ	Lighting	Indoor_Retrofit or Replacement	2011-Aug-24
IN1703ZZ	Lighting	Outdoor_Lighting Controls	2011-Aug-24
IN1703ZZ	Lighting	Outdoor_Retrofit or Replacement	2011-Aug-24
KS0094ZZ	Advanced Metering	Building / Facility	2011-Sep-20
KS0094ZZ	Building Envelope	New_Roof	2011-Sep-20
KS0094ZZ	Building Envelope	Repairs_Facade	2011-Sep-20
KS0094ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Sep-20
KS0094ZZ	HVAC	New_Chillers	2011-Sep-20
KS0094ZZ	HVAC	New_Controls	2011-Sep-20
KS0094ZZ	HVAC	New_Cooling Tower	2011-Sep-20
KS0094ZZ	HVAC	Repairs_Air Handler	2011-Sep-20
KS0094ZZ	HVAC	Repairs_Cooling Tower	2011-Sep-20
KS0094ZZ	Lighting	Indoor_Daylighting	2011-Sep-20
KS0094ZZ	Lighting	Indoor_Lighting Controls	2011-Sep-20
KS0094ZZ	Lighting	Indoor_Retrofit or Replacement	2011-Sep-20
KS0094ZZ	Lighting	Outdoor_Lighting Controls	2011-Sep-20
KS0094ZZ	Lighting	Outdoor_Retrofit or Replacement	2011-Sep-20
LA0085ZZ	Advanced Metering	Building / Facility	2012-Aug-24
LA0085ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Aug-24

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
LA0085ZZ	HVAC	Repairs_Chillers	2012-Aug-24
LA0085ZZ	HVAC	Repairs_Controls	2012-Aug-24
LA0085ZZ	HVAC	Repairs_Cooling Tower	2012-Aug-24
LA0085ZZ	Lighting	Indoor_Daylighting	2012-Aug-24
LA0085ZZ	Lighting	Indoor_Lighting Controls	2012-Aug-24
LA0085ZZ	Lighting	Indoor_Retrofit or Replacement	2012-Aug-24
LA0085ZZ	Lighting	Outdoor_Retrofit or Replacement	2012-Aug-24
MA0013ZZ	Advanced Metering	Building / Facility	2011-Feb-23
MA0013ZZ	Building Envelope	New_Roof	2011-Feb-23
MA0013ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Feb-23
MA0131ZZ	Building Envelope	Repairs_Windows	2013-Jul-25
MI0029ZZ	Advanced Metering	Building / Facility	2011-Jun-23
MI0029ZZ	Advanced Metering	Submetering	2011-Jun-23
MI0029ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Jun-23
MI0029ZZ	HVAC	New_Air Handler	2011-Jun-23
MI0029ZZ	HVAC	New_Chillers	2011-Jun-23
MI0029ZZ	HVAC	New_Controls	2011-Jun-23
MI0029ZZ	HVAC	Repairs_Air Handler	2011-Jun-23
MI0029ZZ	HVAC	Repairs_Cooling Tower	2011-Jun-23
MN0087ZZ	Advanced Metering	Building / Facility	2012-Dec-06
MO0050ZZ	Advanced Metering	Building / Facility	2011-Aug-22
MO0050ZZ	HVAC	Repairs_Controls	2011-Aug-22
MO0095ZZ	Advanced Metering	Building / Facility	2010-Nov-30
MO0095ZZ	Building Envelope	Repairs_Facade	2010-Nov-30

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
MO0095ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2010-Nov-30
MO0095ZZ	HVAC	New_Controls	2010-Nov-30
MO0095ZZ	HVAC	New_Cooling Tower	2010-Nov-30
MO0095ZZ	HVAC	Repairs_Chillers	2010-Nov-30
MO0095ZZ	HVAC	Repairs_Cooling Tower	2010-Nov-30
MO0095ZZ	Lighting	Indoor_Daylighting	2010-Nov-30
MO0095ZZ	Lighting	Indoor_Lighting Controls	2010-Nov-30
MO0095ZZ	Lighting	Indoor_Retrofit or Replacement	2010-Nov-30
MO0106ZZ	Advanced Metering	Building / Facility	2012-Mar-19
MO0106ZZ	Advanced Metering	Submetering	2012-Mar-19
MO0106ZZ	Building Envelope	New_Windows	2012-Mar-19
MO0106ZZ	Building Envelope	Repairs_Facade	2012-Mar-19
MO0106ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Mar-19
MO0106ZZ	HVAC	New_Controls	2012-Mar-19
MO0106ZZ	HVAC	Repairs_Air Handler	2012-Mar-19
MO0106ZZ	HVAC	Repairs_Chillers	2012-Mar-19
MO0106ZZ	Lighting	Indoor_Daylighting	2012-Mar-19
MO0106ZZ	Lighting	Indoor_Lighting Controls	2012-Mar-19
MO0106ZZ	Lighting	Indoor_Retrofit or Replacement	2012-Mar-19
MO0106ZZ	Lighting	Outdoor_Retrofit or Replacement	2012-Mar-19
MS0083ZZ	Advanced Metering	Building / Facility	2014-Jun-13
MS0083ZZ	Building Envelope	New_Facade	2014-Jun-13
MS0083ZZ	Building Envelope	New_Roof	2014-Jun-13
MS0083ZZ	Building Envelope	New_Windows	2014-Jun-13

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
MS0083ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2014-Jun-13
MS0083ZZ	HVAC	New_Air Handler	2014-Jun-13
MS0083ZZ	HVAC	New_Boilers	2014-Jun-13
MS0083ZZ	HVAC	New_Chillers	2014-Jun-13
MS0083ZZ	HVAC	New_Controls	2014-Jun-13
MS0083ZZ	HVAC	New_Cooling Tower	2014-Jun-13
MS0083ZZ	HVAC	Repairs_Air Handler	2014-Jun-13
MS0083ZZ	HVAC	Repairs_Cooling Tower	2014-Jun-13
MS0083ZZ	Lighting	Indoor Daylighting or Lighting Strategies	2014-Jun-13
MS0083ZZ	Lighting	Indoor_Lighting Controls	2014-Jun-13
MS0083ZZ	Lighting	Indoor_Retrofit or Replacement	2014-Jun-13
MS0083ZZ	Lighting	Outdoor_Lighting Controls	2014-Jun-13
MS0083ZZ	Lighting	Outdoor_Retrofit or Replacement	2014-Jun-13
ND0006ZZ	Building Envelope	Repairs_Facade	2011-May-02
ND0006ZZ	Building Envelope	Repairs_Windows	2011-May-02
ND0006ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-May-02
ND0006ZZ	HVAC	Repairs_Air Handler	2011-May-02
ND0006ZZ	HVAC	Repairs_Boilers	2011-May-02
ND0006ZZ	HVAC	Repairs_Controls	2011-May-02
ND0006ZZ	HVAC	Repairs_Cooling Tower	2011-May-02
ND0006ZZ	Lighting	Indoor_Lighting Controls	2011-May-02

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
ND0006ZZ	Lighting	Indoor_Retrofit or Replacement	2011-May-02
ND0006ZZ	Lighting	Outdoor_Retrofit or Replacement	2011-May-02
ND0046ZZ	Building Envelope	Repairs_Facade	2011-Aug-24
ND0046ZZ	HVAC	New_Boilers	2011-Aug-24
ND0046ZZ	HVAC	New_Chillers	2011-Aug-24
ND0046ZZ	HVAC	Repairs_Air Handler	2011-Aug-24
ND0046ZZ	HVAC	Repairs_Chillers	2011-Aug-24
ND0046ZZ	HVAC	Repairs_Controls	2011-Aug-24
ND0046ZZ	HVAC	Repairs_Cooling Tower	2011-Aug-24
ND0046ZZ	Lighting	Indoor_Lighting Controls	2011-Aug-24
ND0046ZZ	Lighting	Indoor_Retrofit or Replacement	2011-Aug-24
NE0036ZZ	Building Envelope	New_Roof	2011-Feb-23
NE0036ZZ	Building Envelope	Repairs_Roof	2011-Feb-23
NE0036ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Feb-23
NE0036ZZ	HVAC	New_Controls	2011-Feb-23
NE0531ZZ	Advanced Metering	Building / Facility	2011-May-16
NE0531ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-May-16
NE0531ZZ	HVAC	New_Controls	2011-May-16
NE0531ZZ	HVAC	New_Cooling Tower	2011-May-16
NE0531ZZ	HVAC	Repairs_Air Handler	2011-May-16
NE0531ZZ	HVAC	Repairs_Cooling Tower	2011-May-16
NM0050ZZ	Advanced Metering	Building / Facility	2013-Aug-12
NM0050ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2013-Aug-12

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
NM0050ZZ	HVAC	Repairs_Controls	2013-Aug-12
NM0050ZZ	HVAC	Repairs_Cooling Tower	2013-Aug-12
NV0304ZZ	Advanced Metering	Building / Facility	2012-May-18
NV0304ZZ	Advanced Metering	Submetering	2012-May-18
NV0304ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-May-18
NV0304ZZ	HVAC	New_Controls	2012-May-18
NV0304ZZ	HVAC	New_Cooling Tower	2012-May-18
NV0304ZZ	HVAC	Repairs_Air Handler	2012-May-18
NV0304ZZ	HVAC	Repairs_Chillers	2012-May-18
NV0304ZZ	HVAC	Repairs_Cooling Tower	2012-May-18
NV0304ZZ	Lighting	Indoor_Daylighting	2012-May-18
NV0304ZZ	Lighting	Indoor_Lighting Controls	2012-May-18
NV0304ZZ	Lighting	Indoor_Retrofit or Replacement	2012-May-18
NV0304ZZ	Lighting	Outdoor_Lighting Controls	2012-May-18
NV0304ZZ	Lighting	Outdoor_Retrofit or Replacement	2012-May-18
NY0281ZZ	Advanced Metering	Building / Facility	2012-Aug-15
NY0281ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Aug-15
NY0281ZZ	HVAC	Repairs_Air Handler	2012-Aug-15
NY0281ZZ	Lighting		2012-Aug-15
NY0300ZZ	Advanced Metering	Building / Facility	2012-Sep-27
NY0300ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Sep-27
NY0304ZZ	Advanced Metering	Building / Facility	2012-Sep-27

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
NY0304ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Sep-27
NY0304ZZ	HVAC	Repairs_Air Handler	2012-Sep-27
NY0304ZZ	HVAC	Repairs_Controls	2012-Sep-27
NY0304ZZ	HVAC	Repairs_Cooling Tower	2012-Sep-27
NY0304ZZ	Lighting		2012-Sep-27
OH0033ZZ	Advanced Metering	Building / Facility	2012-Jan-12
OH0033ZZ	Advanced Metering	Submetering	2012-Jan-12
OH0033ZZ	HVAC	New_Air Handler	2012-Jan-12
OH0033ZZ	HVAC	Repairs_Controls	2012-Jan-12
OH0033ZZ	Lighting	Indoor_Daylighting	2012-Jan-12
OH0033ZZ	Lighting	Indoor_Lighting Controls	2012-Jan-12
OH0033ZZ	Lighting	Indoor_Retrofit or Replacement	2012-Jan-12
OH0046ZZ	Advanced Metering	Building / Facility	2013-Dec-26
OH0046ZZ	Building Envelope	Repairs_Facade	2013-Dec-26
OH0046ZZ	Building Envelope	Repairs_Windows	2013-Dec-26
OH0046ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2013-Dec-26
OH0046ZZ	HVAC	New_Air Handler	2013-Dec-26
OH0046ZZ	HVAC	New_Boilers	2013-Dec-26
OH0046ZZ	HVAC	New_Controls	2013-Dec-26
OH0046ZZ	HVAC	New_Cooling Tower	2013-Dec-26
OH0046ZZ	HVAC	Repairs_Air Handler	2013-Dec-26
OH0046ZZ	HVAC	Repairs_Boilers	2013-Dec-26
OH0046ZZ	HVAC	Repairs_Chillers	2013-Dec-26
OH0046ZZ	Lighting	Indoor_Daylighting	2013-Dec-26
OH0046ZZ	Lighting	Indoor_Lighting Controls	2013-Dec-26

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
OH0046ZZ	Lighting	Indoor_Retrofit or Replacement	2013-Dec-26
OH0046ZZ	Lighting	Outdoor_Lighting Controls	2013-Dec-26
OH0194ZZ	Advanced Metering	Building / Facility	2012-May-16
OH0194ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-May-16
OH0194ZZ	Lighting	Indoor_Daylighting	2012-May-16
OH0194ZZ	Lighting	Indoor_Lighting Controls	2012-May-16
OH0194ZZ	Lighting	Indoor_Retrofit or Replacement	2012-May-16
OK0101ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2010-Dec-30
OR0033PE	Advanced Metering	Building / Facility	2011-Jul-28
OR0033PE	Advanced Metering	Submetering	2011-Jul-28
OR0033PE	Building Envelope	New_Roof	2011-Jul-28
OR0033PE	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Jul-28
OR0033PE	HVAC	New_Air Handler	2011-Jul-28
OR0033PE	HVAC	New_Boilers	2011-Jul-28
OR0033PE	HVAC	New_Chillers	2011-Jul-28
OR0033PE	HVAC	New_Controls	2011-Jul-28
OR0033PE	HVAC	New_Cooling Tower	2011-Jul-28
OR0033PE	HVAC	Repairs_Air Handler	2011-Jul-28
OR0033PE	HVAC	Repairs_Boilers	2011-Jul-28
OR0033PE	HVAC	Repairs_Cooling Tower	2011-Jul-28
OR0033PE	Lighting		2011-Jul-28
OR0052ZZ	Advanced Metering	Submetering	2011-Jun-30
OR0052ZZ	HVAC	New_Controls	2011-Jun-30
TN0088ZZ	Advanced Metering	Building / Facility	2012-Apr-30

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
TN0088ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2012-Apr-30
TN0088ZZ	HVAC	Repairs_Controls	2012-Apr-30
TN0088ZZ	Lighting	Indoor Daylighting or Lighting Strategies	2012-Apr-30
TN0088ZZ	Lighting	Indoor_Daylighting	2012-Apr-30
TN0088ZZ	Lighting	Indoor_Lighting Controls	2012-Apr-30
TN0088ZZ	Lighting	Indoor_Retrofit or Replacement	2012-Apr-30
TN0088ZZ	Lighting	Outdoor_Retrofit or Replacement	2012-Apr-30
TX0211ZZ	Advanced Metering	Building / Facility	2012-Sep-25
TX0211ZZ	Building Envelope	New_Roof	2012-Sep-25
TX0211ZZ	HVAC	Repairs_Controls	2012-Sep-25
TX0211ZZ	HVAC	Repairs_Cooling Tower	2012-Sep-25
TX0211ZZ	Lighting	Indoor_Daylighting	2012-Sep-25
TX0211ZZ	Lighting	Indoor_Lighting Controls	2012-Sep-25
TX0211ZZ	Lighting	Indoor_Retrofit or Replacement	2012-Sep-25
TX0211ZZ	Lighting	Outdoor_Retrofit or Replacement	2012-Sep-25
TX0302ZZ	Building Tuneup or Utility Improvements	Commissioning Measures	2011-Jun-23
TX0302ZZ	HVAC	New_Controls	2011-Jun-23
TX0302ZZ	HVAC	Repairs_Chillers	2011-Jun-23
TX0302ZZ	HVAC	Repairs_Cooling Tower	2011-Jun-23
TX0302ZZ	Lighting	Indoor_Lighting Controls	2011-Jun-23

Table 8: ECM actions for buildings in the study

Building_Number	high_level_ECM	detail_level_ECM	Completion_Date
TX0302ZZ	Lighting	Outdoor_Retrofit or Replacement	2011-Jun-23
TX0501HS	Building Envelope	Repairs_Facade	2012-Mar-27
TX0501HS	Building Envelope	Repairs_Windows	2012-Mar-27
TX0501HS	HVAC	New_Air Handler	2012-Mar-27
TX0501HS	HVAC	Repairs_Controls	2012-Mar-27
TX0501HS	HVAC	Repairs_Cooling Tower	2012-Mar-27
TX0501HS	Lighting	Indoor_Retrofit or Replacement	2012-Mar-27
UT0032ZZ	HVAC	New_Controls	2010-Nov-29
WY0029ZZ	Advanced Metering	Building / Facility	2011-Jun-15
WY0029ZZ	HVAC	New_Controls	2011-Jun-15
WY0029ZZ	HVAC	Repairs_Air Handler	2011-Jun-15
WY0029ZZ	Lighting	Indoor_Lighting Controls	2011-Jun-15
WY0029ZZ	Lighting	Indoor_Retrofit or Replacement	2011-Jun-15
WY0029ZZ	Lighting	Outdoor_Retrofit or Replacement	2011-Jun-15

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