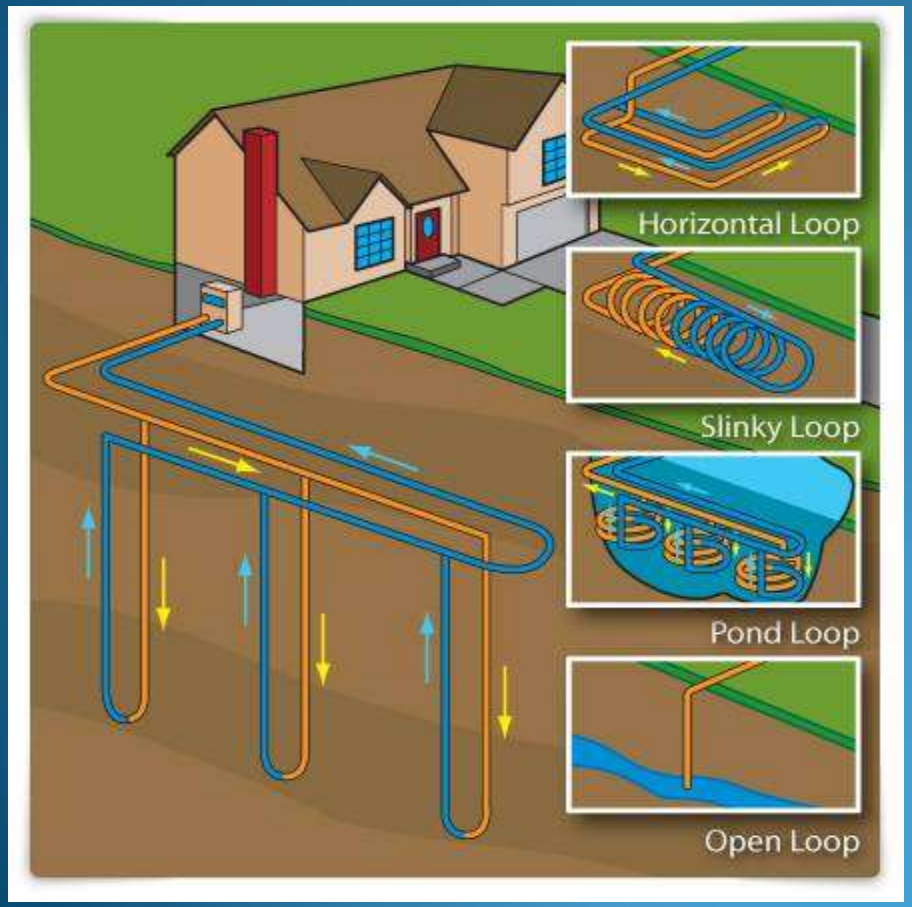
NC STATE UNIVERSITY | 125 YEARS

Feasibility Analysis of Implementing Ground Source Heat Pump Systems in the US

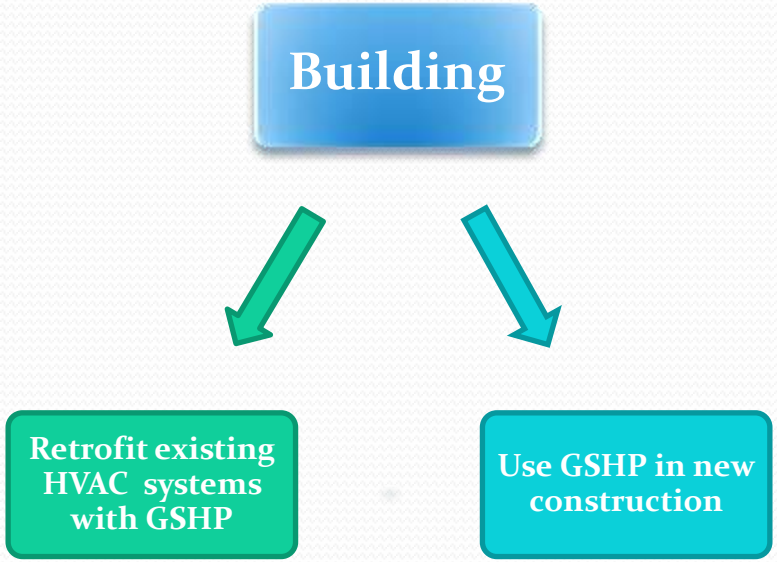


By
Saurabh Ray

North Carolina State University
Industrial Assessment Center

Department of
mechanical & aerospace
ENGINEERING

Introduction



- Projects are typically cost intensive
- Projects require some level of prescreening analysis prior to detailed and investment grade analysis

GSHPs have enormous potential in the United States

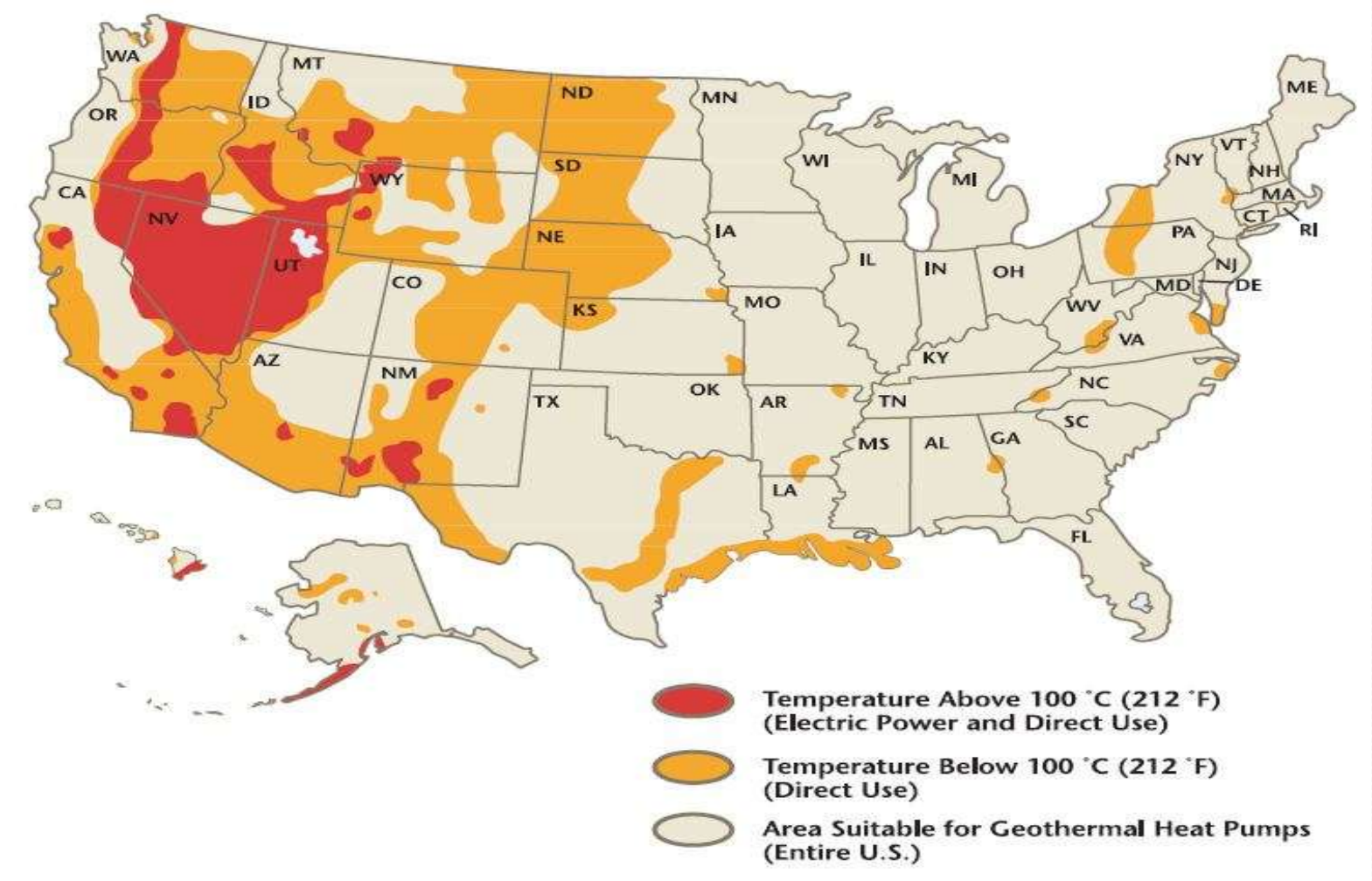


Figure : Area suitable for GSHP systems in the United States (NREL, 2006)

Problem Statement

- We want to save energy and money
- We know GSHP is good
- Problems are:
  - How good and feasible?
  - What are the considerations?
  - What is the cost effectiveness?

Goals & Objectives

- To analyze the GSHP application feasibility for different climate (outside) and ground conditions
- To identify energy and cost savings potential for different regions in the US
- To develop a comprehensive/integrated feasibility tool for building practitioners to pre-evaluate the effectiveness of GSHPs for their projects

Ground Source Heat Pumps (GSHPs)

- GSHPs operate using same principles as an ASHPs
- **GSHPs use** the **more stable ground or surface water** as a source for heating and sink for cooling
- GSHP systems typically have three components :
  1. The ground loop heat exchanger
  2. The heat pump itself
  3. The air delivery system

- The ground loop acts as the heat exchanger
- **The ground loop consists of pipes filled with an anti-freeze solution** for circulating the thermal energy
- The ductwork delivers the conditioned air to the space

GSHP Heating & Cooling Cycles

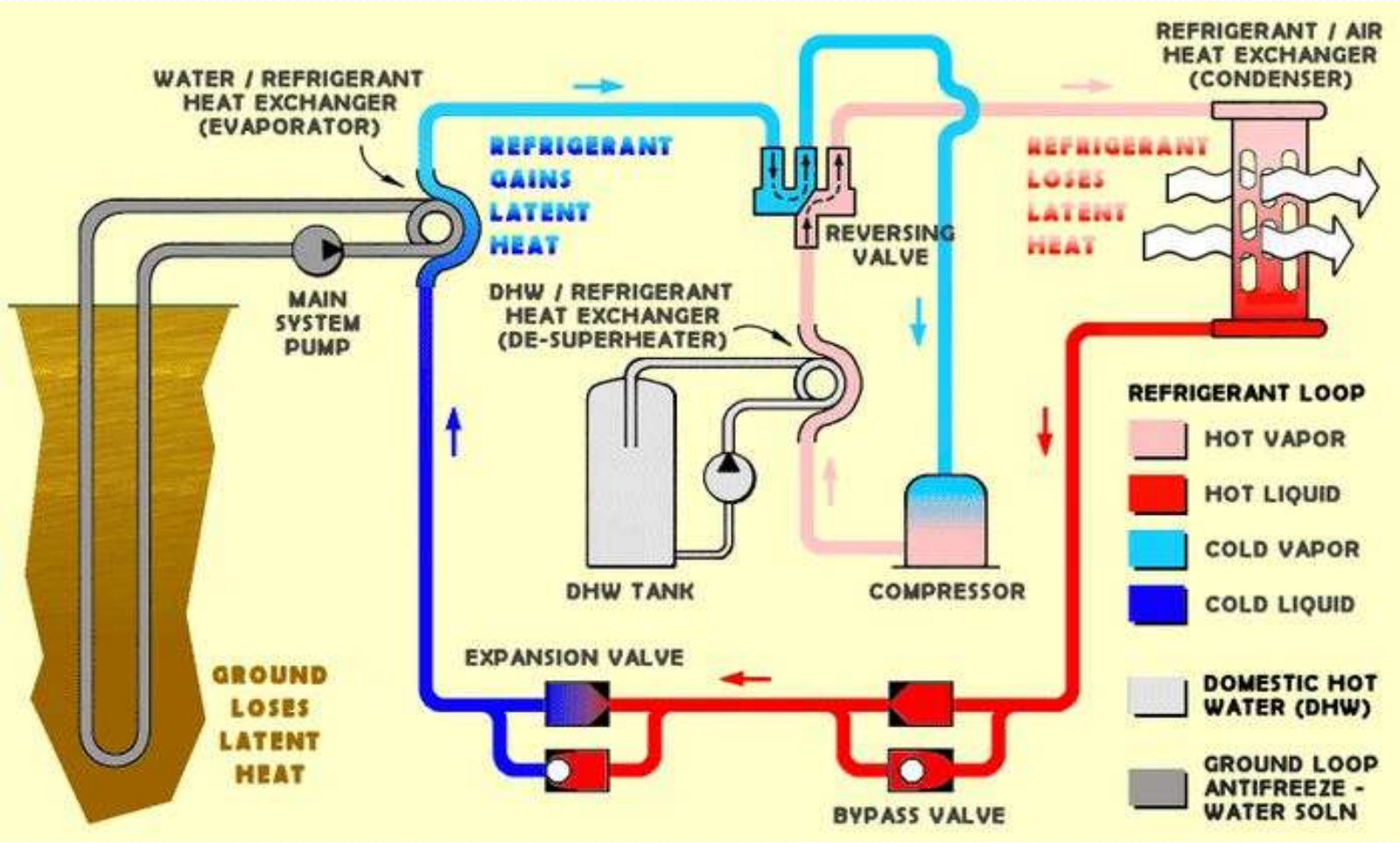


Figure : Operation of a GSHP during the heating cycle (Geo4VA, 2006)

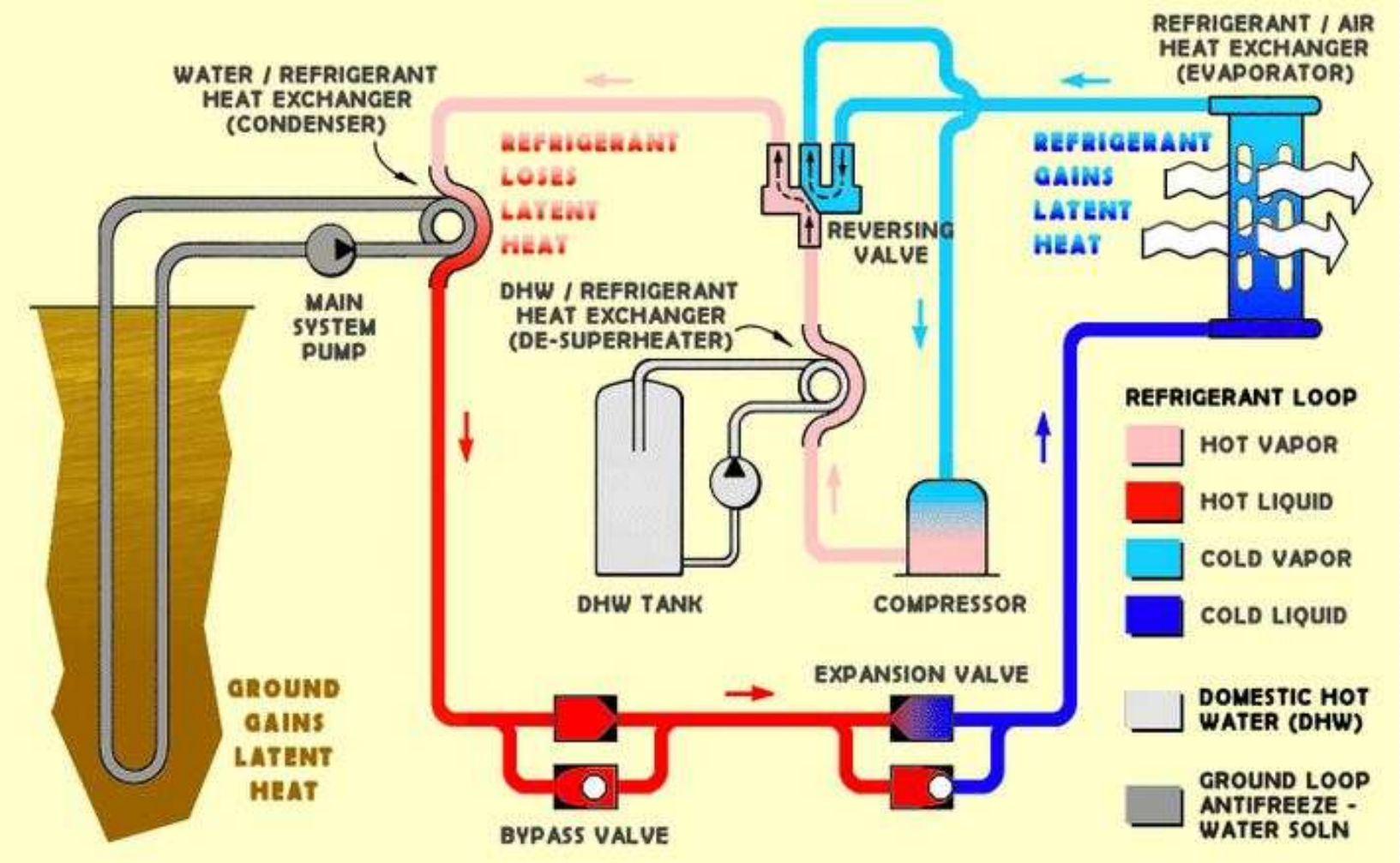
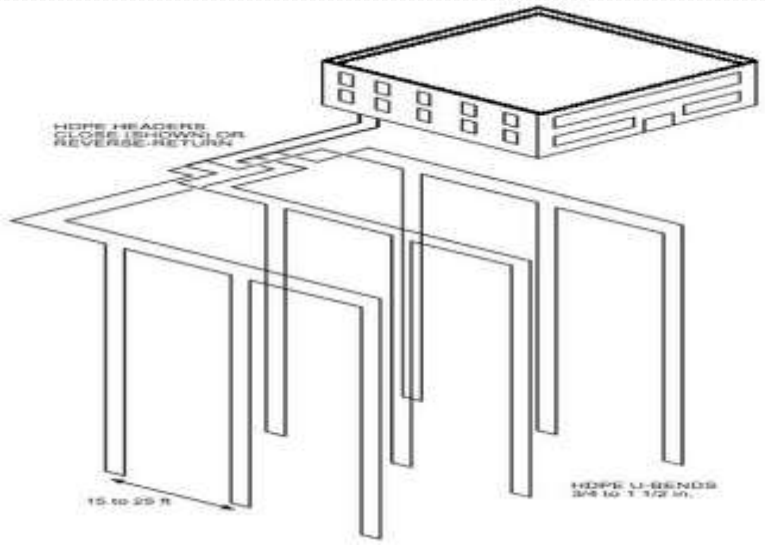


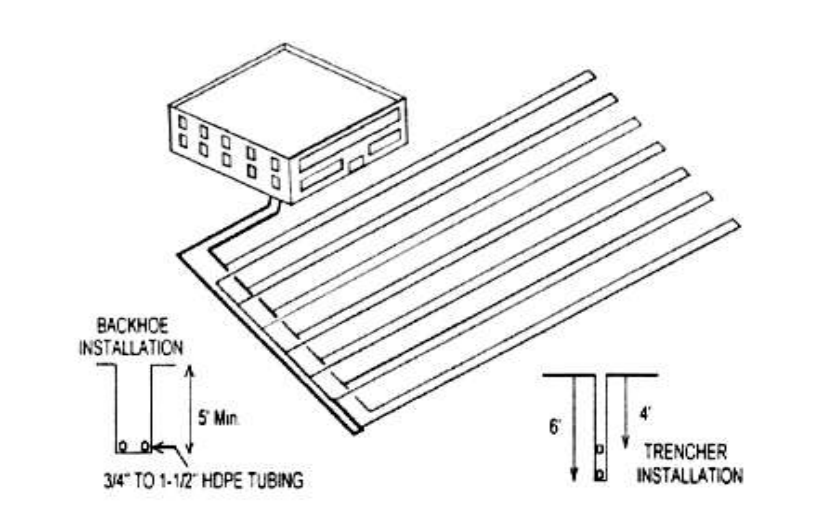
Figure : Operation of a GSHP during the cooling cycle (Geo4VA, 2006)

Types of GSHP systems

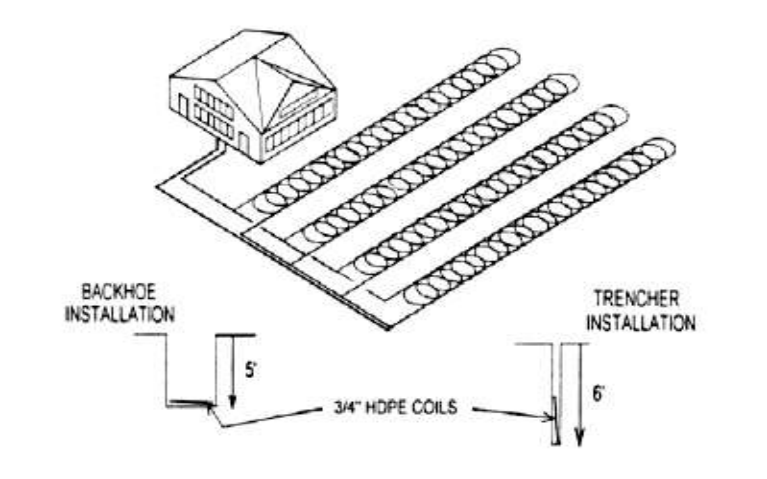
- GSHP systems are categorized into three basic types, which are:
  1. Ground-Coupled Heat Pumps (GCHPs)
  2. Ground Water Heat Pumps (GWHPs)
  3. Surface Water Heat Pumps (SWHPs)



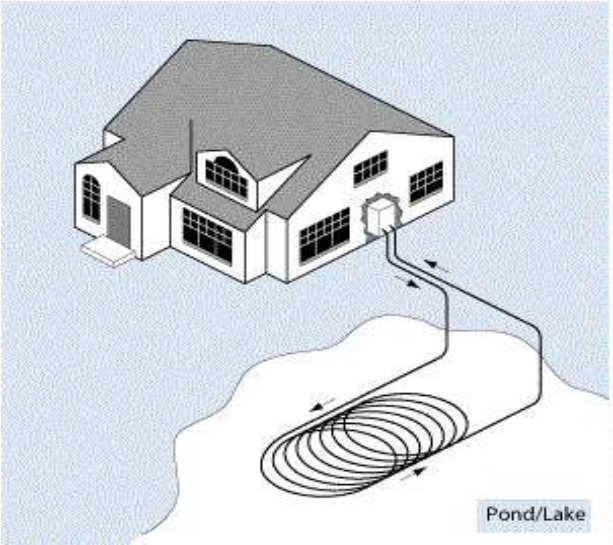
Vertical GCHP



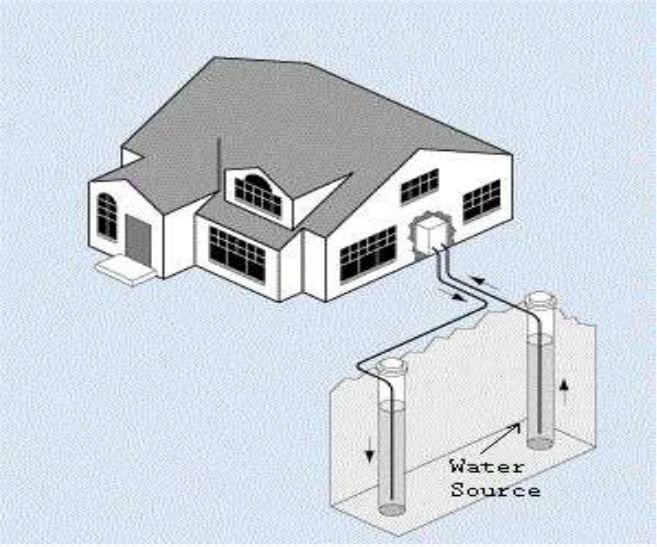
Horizontal GCHP



Slinky type Horizontal GCHP



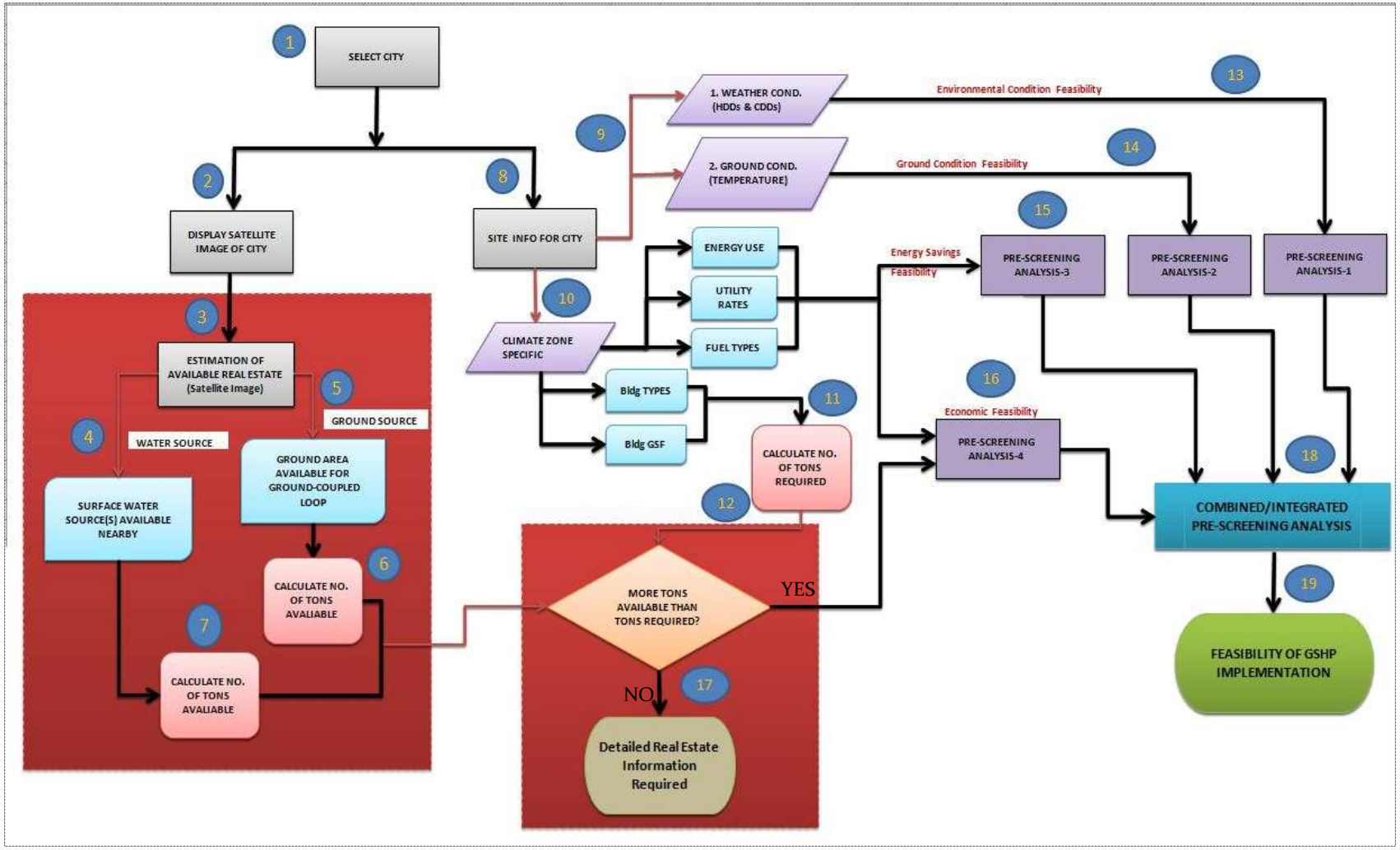
Closed loop SWHP system



Open loop GWHP system

METHODOLOGY

- Flow Chart



Data and Resources

Heating and Cooling Degree Days

- Heating Degree Days (HDD) and Cooling Degree Days (CDD) are the measure of heating and cooling requirements for a location or any specific building respectively

- **For this study, the values for annual HDD and CDD were taken from the 2009 ASHRAE Handbook, with T_b as 65°F**

Table : Annual HDD and CDD for 16 selected cities (ASHRAE, 2009)

NO.	CITY	STATE	CLIMATE ZONE	HDD65	CDD65	SUM
1	Miami	Florida	1A	130	4,458	4,588
2	Houston	Texas	2A	1,204	3,103	4,307
3	Phoenix	Arizona	2B	941	4,557	5,498
4	Atlanta	Georgia	3A	2,694	1,841	4,535
5	Los Angeles	California	3B-CA	1,284	617	1,901
6	Las Vegas	Nevada	3B-other	2,105	3,348	5,453
7	San Francisco	California	3C	2,708	142	2,850
8	Baltimore	Maryland	4A	4,567	1,228	5,795
9	Albuquerque	New Mexico	4B	4,069	1,348	5,417
10	Seattle	Washington	4C	4,729	177	4,906
11	Chicago	Illinois	5A	6,311	842	7,153
12	Denver	Colorado	5B	5,942	777	6,719
13	Minneapolis	Minnesota	6A	7,565	751	8,316
14	Helena	Montana	6B	7,699	311	8,010
15	Duluth	Minnesota	7	9,425	209	9,634
16	Fairbanks	Alaska	8	13,528	71	13,599

Climate Zones and Regions

- The International Energy Conservation Code (IECC®) divides the world into eight different climate zones
- These zones are classified based on the prevailing climate conditions and thermal criteria

Table: International Climate Zone Definitions (IECC®, 2009)

NO.	ZONE NUMBER	ZONE NAME	THERMAL CRITERIA
1	1A and 1B	Very Hot – Humid (1A) Dry (1B)	9,000 < CDD50°F
2	2A and 2B	Hot – Humid (2A) Dry (2B)	6,300 < CDD50°F ≤ 9,000
3	3A and 3B	Warm – Humid (3A) Dry (3B)	4,500 < CDD50°F ≤ 6,300
4	3C	Warm – Marine (3C)	CDD50°F ≤ 4,500 AND HDD65°F ≤ 3,600
5	4A and 4B	Mixed – Humid (4A) Dry (4B)	CDD50°F ≤ 4,500 AND 3,600 ≤ HDD65°F ≤ 5,400
6	4C	Mixed – Marine (4C)	3,600 < HDD65°F ≤ 5,400
7	5A, 5B and 5C	Cool – Humid (5A) Dry (5B) Marine (5C)	5,400 < HDD65°F ≤ 7,200
8	6A and 6B	Cold – Humid (6A) Dry (6B)	7,200 < HDD65°F ≤ 9,000
9	7	Very Cold	9,000 < HDD65°F ≤ 12,600
10	8	Subarctic	12,600 < HDD65°F

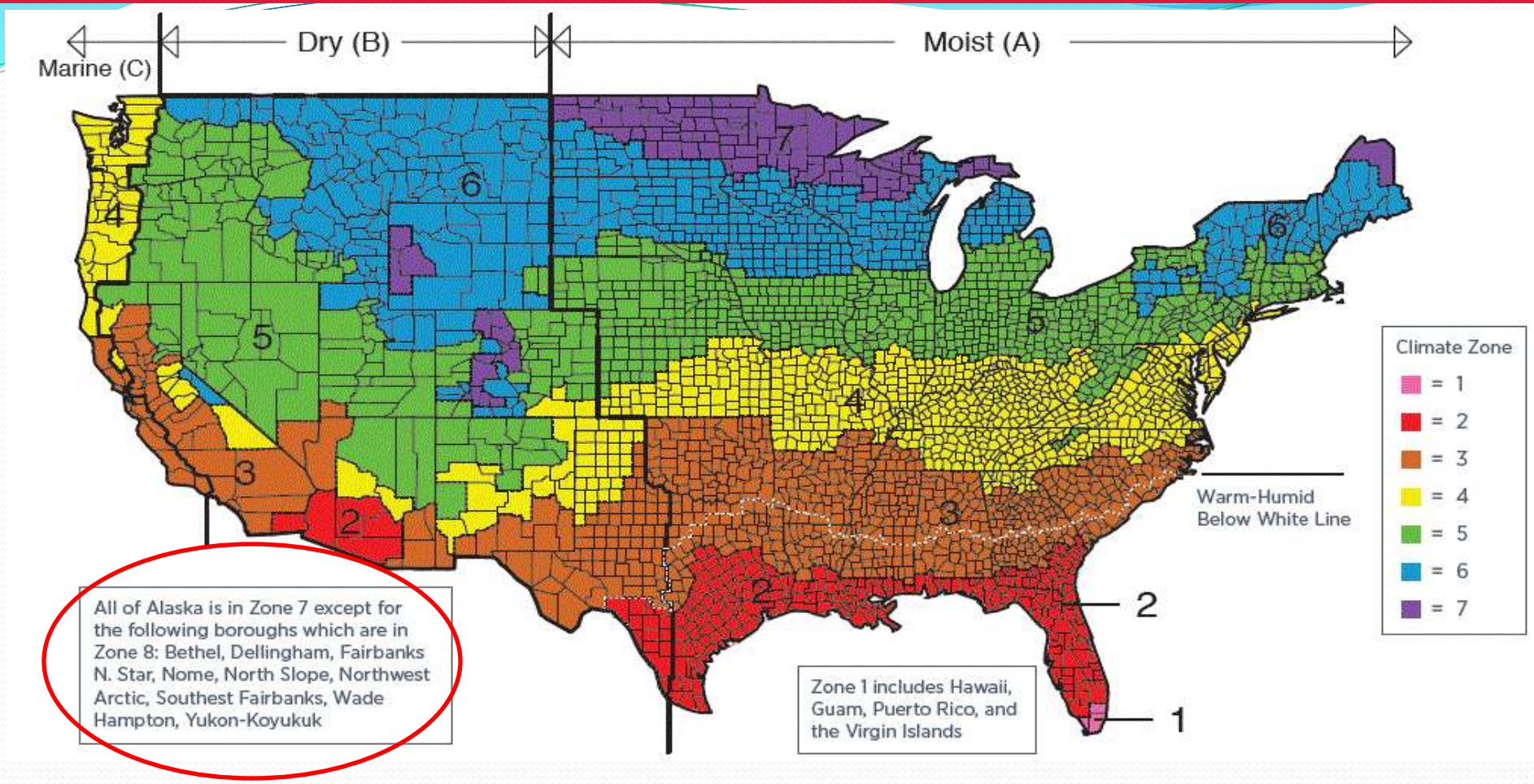


Figure : Climate Zones and Regions in USA (PNNL and ORNL, 2010)

- The USA is divided into 8 climate zones

- These zones are further sub-divided into 3 regions namely: Moist (A), Dry (B) and Marine (C)

Selected Cities for Representing Climate Zones in USA

- Due to the **diverse nature of climatic conditions in these zones**, it becomes essential to **select specific locations** that represent the **physical conditions** of every specific zone

- This study used **16 cities**

- The selection was **based on the research done by Pacific Northwest National Laboratory** (PNNL)

Table: Cities Representing 8 Climate Zones in USA (PNNL, 2009)

NO.	CITY	STATE	CLIMATE ZONE	ZONE NAME
1	Miami	Florida	1A	Very Hot - Humid
2	Houston	Texas	2A	Hot - Humid
3	Phoenix	Arizona	2B	Hot -Dry
4	Atlanta	Georgia	3A	Warm - Humid
5	Los Angeles	California	3B-CA	Warm - Dry
6	Las Vegas	Nevada	3B-other	Warm - Dry
7	San Francisco	California	3C	Warm - Marine
8	Baltimore	Maryland	4A	Mixed - Humid
9	Albuquerque	New Mexico	4B	Mixed - Dry
10	Seattle	Washington	4C	Mixed - Marine
11	Chicago	Illinois	5A	Cool - Humid
12	Denver	Colorado	5B	Cool - Dry
13	Minneapolis	Minnesota	6A	Cold - Humid
14	Helena	Montana	6B	Cold - Dry
15	Duluth	Minnesota	7	Very Cold
16	Fairbanks	Alaska	8	Subarctic

Summer and Winter Design Temperatures

- The design temperatures are important factors that indicate the peak heating and cooling load requirements
- Help understand equipment design and sizing to meet the thermal loads

- **The design temperature values were obtained from the 2009 ASHRAE Handbook Data**

Table : Heating and Cooling Design Temperatures for 16 cities (ASHRAE, 2009)

NO.	CITY	STATE	CLIMATE ZONE	Heating Design Temp. (°F) (99.6%)	Cooling Design Temp. (°F) (0.4%)
1	Miami	Florida	1A	47.7	91.8
2	Houston	Texas	2A	31.3	95.1
3	Phoenix	Arizona	2B	38.6	110.2
4	Atlanta	Georgia	3A	20.7	93.8
5	Los Angeles	California	3B-CA	44.4	83.7
6	Las Vegas	Nevada	3B-other	30.5	108.3
7	San Francisco	California	3C	38.8	83.0
8	Baltimore	Maryland	4A	12.9	93.9
9	Albuquerque	New Mexico	4B	17.7	95.2
10	Seattle	Washington	4C	24.0	86.1
11	Chicago	Illinois	5A	-4.0	91.9
12	Denver	Colorado	5B	0.7	94.3
13	Minneapolis	Minnesota	6A	-13.4	91.0
14	Helena	Montana	6B	-15.4	92.7
15	Duluth	Minnesota	7	-19.5	84.5
16	Fairbanks	Alaska	8	-43.3	81.2

Annual Average Ground Temperature

- Ground stays at a fairly constant temperature at depths > 30 feet

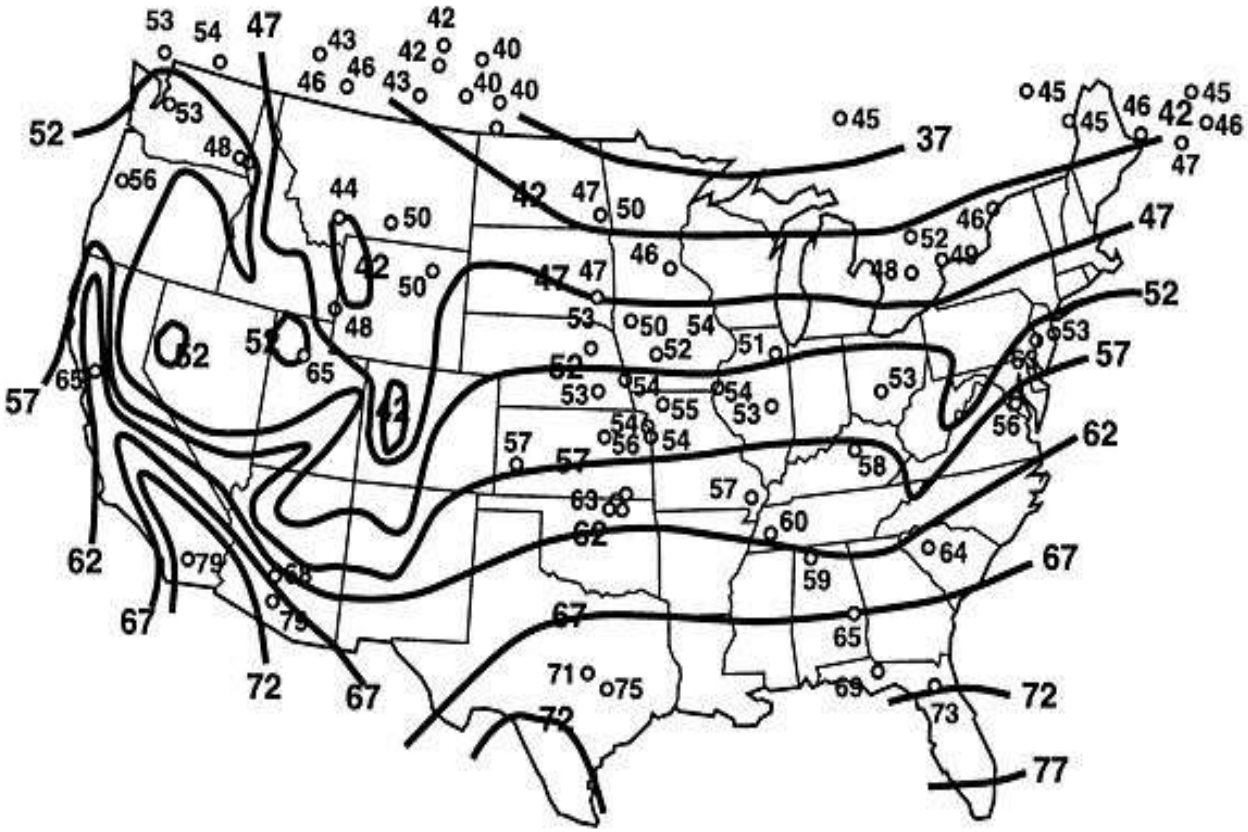


Figure: Annual average ground temperature across the US (Geo4VA, 2006)

- Based on observations from the previous figure, the values for the annual average ground temperature are listed in table below

Table : Annual Average Ground Temperature

NO.	CITY	STATE	CLIMATE ZONE	Annual Avg. Ground Temp. (°F)
1	Miami	Florida	1A	77
2	Houston	Texas	2A	71
3	Phoenix	Arizona	2B	67
4	Atlanta	Georgia	3A	62
5	Los Angeles	California	3B-CA	67
6	Las Vegas	Nevada	3B-other	62
7	San Francisco	California	3C	62
8	Baltimore	Maryland	4A	57
9	Albuquerque	New Mexico	4B	52
10	Seattle	Washington	4C	53
11	Chicago	Illinois	5A	50
12	Denver	Colorado	5B	52
13	Minneapolis	Minnesota	6A	42
14	Helena	Montana	6B	44
15	Duluth	Minnesota	7	38
16	Fairbanks	Alaska	8	32

Commercial Buildings Energy Consumption Survey (CBECS) Data

- CBECS database is the largest available statistical resource for commercial buildings across USA
- Latest data is CBECS 2003
- Data for CBECS 2014 is in progress
- Data based on 9 census division as shown in figure

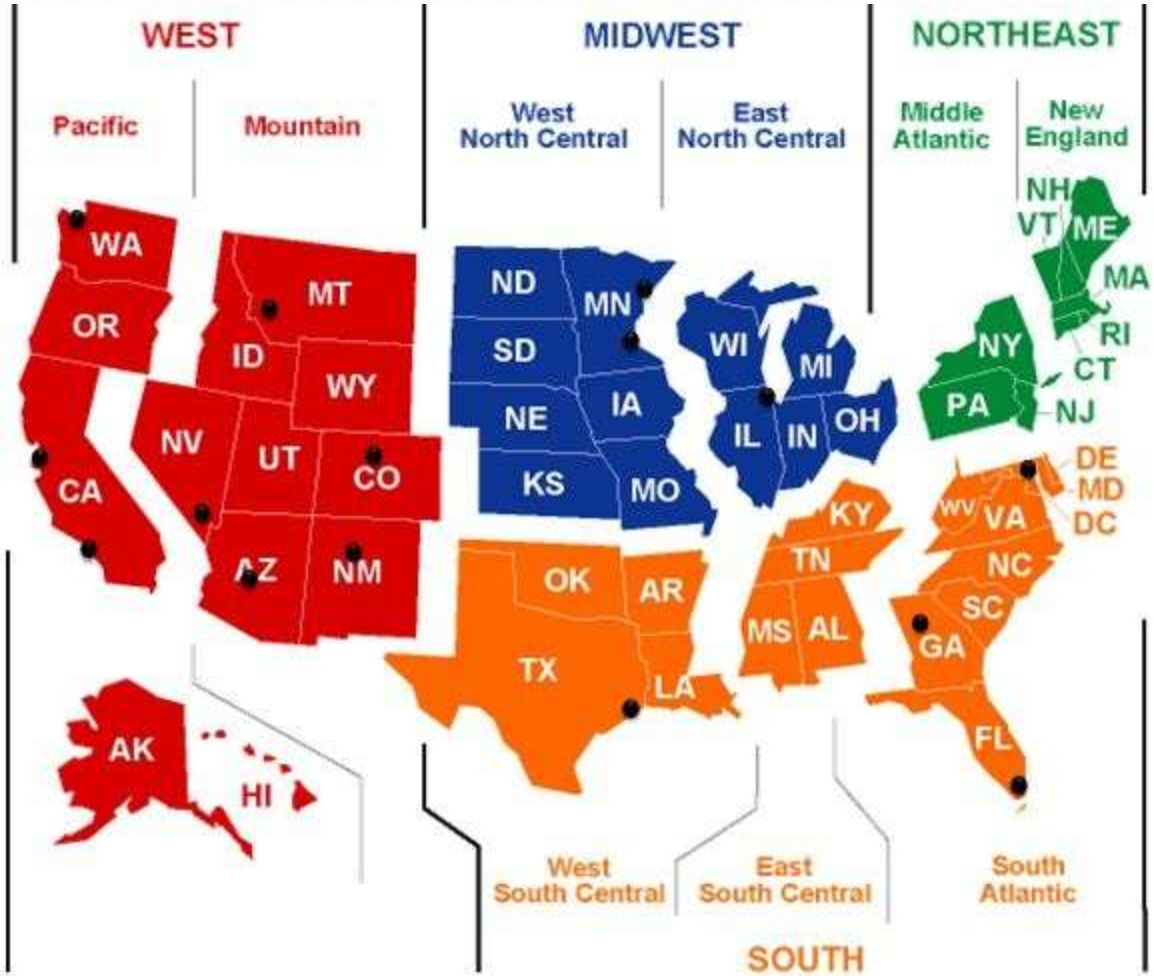


Figure : Census divisions for 2003 CBECS report (EIA, 2009)

Table : Summary of data obtained from 2003 CBECS report

OFFICE BUILDING DATA (CBECS 2003)	Census Region and Division								
	Northeast		Midwest		South			West	
	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
NO. OF BUILDINGS	47,000	108,000	134,000	97,000	125,000	41,000	84,000	62,000	125,000
TOTAL GSF (Million sq.ft)	578	2,434	2,190	799	1,958	481	1,343	629	1,796
Electricity Consumption (Billion Btu)	30,717	136,520	143,346	40,956	119,455	30,717	92,151	34,130	88,738
Natural Gas Consumption (Billion Btu)	0	73,944	86,268	19,513	12,324	0	12,324	19,513	17,459
Others (Fuel Oil + District Heat) (Billion Btu)	35,283	28,536	33,386	1,531	23,221	19,283	19,525	4,357	10,803
TOTAL ENERGY USE (Billion Btu)	66,000	239,000	263,000	62,000	155,000	50,000	124,000	58,000	117,000
EUI (kBtu/sq.ft-yr.)	114.60	98.00	120.10	77.60	79.30	103.20	92.30	91.90	65.10
Elect. Expenditure (Million $)	900	4,000	2,940	840	2,450	630	1,890	1,000	2,600
Nat. Gas Expenditure (Million $)	0	667	669	151	105	0	105	139	125
Others (Million $)	75	316	285	104	255	63	175	82	233
TOTAL EXPENDITURE (Million $)	975	4,984	3,894	1,095	2,809	693	2,169	1,221	2,958
Avg. Size/Office Bldg.(sq.ft)	12,298	22,537	16,343	8,237	15,664	11,732	15,988	10,145	14,368

Residential Energy Consumption Survey (RECS) Data

- RECS is a national survey for residential housing units in USA
- Latest data is RECS 2009
- Data based on 7 climate zones as shown in figure

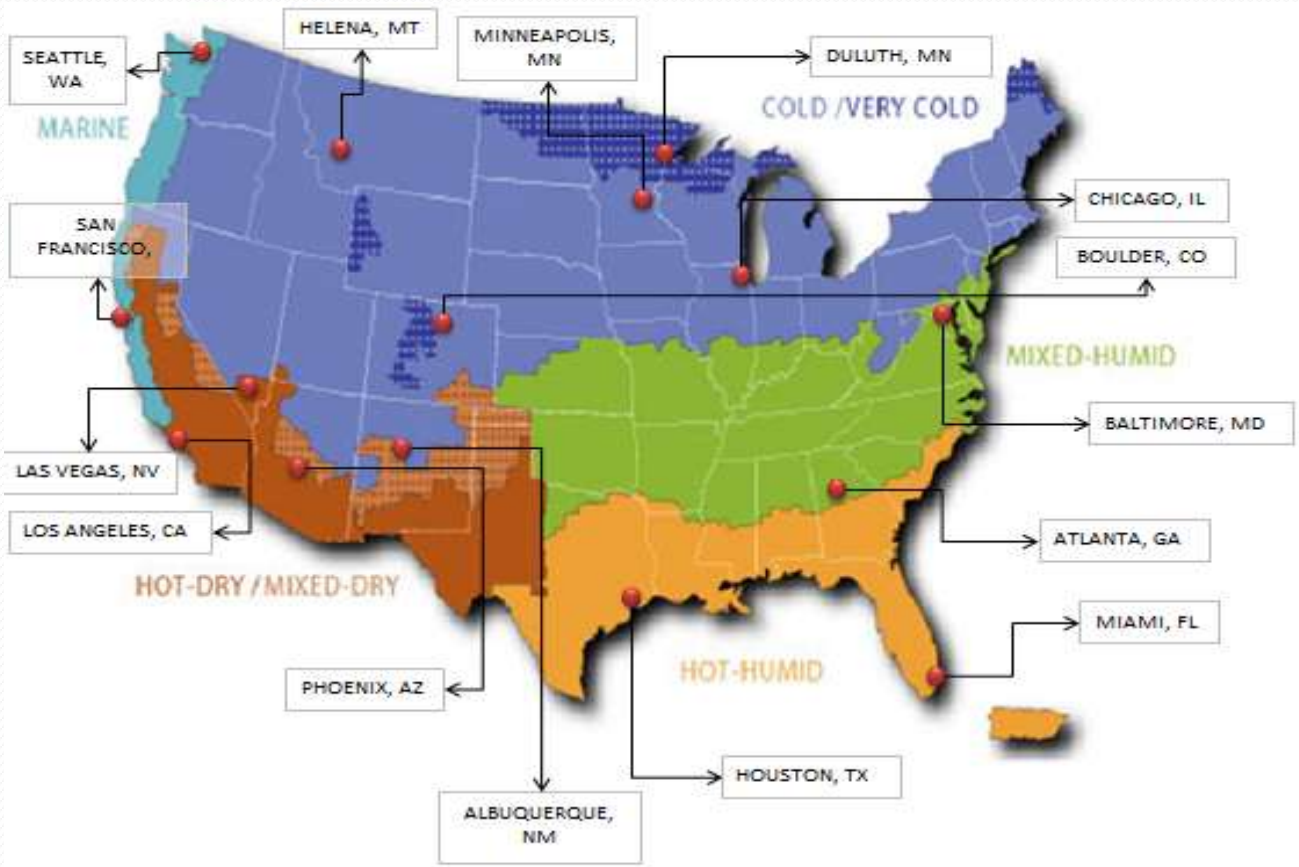


Figure : Climate Zones for 2009 RECS report (PPNL and ORNL, 2010)

Table : Summary of data obtained from 2009 RECS report

	Climate Region				
	Very Cold/Cold	Mixed-Humid	Mixed-Dry/Hot-Dry	Hot-Humid	Marine
TOTAL SQ. FT (AREA)	8.53.E+10	7.30.E+10	2.30.E+10	3.22.E+10	1.05.E+10
Electricity Consumption (kBtu)	1.25.E+12	1.54.E+12	4.40.E+11	9.60.E+11	2.00.E+11
Natural Gas Consumption (kBtu)	2.44.E+12	1.32.E+12	4.70.E+11	2.70.E+11	2.00.E+11
Propane/ LPG (kBtu)	2.30.E+11	1.80.E+11	3.00.E+10	4.00.E+10	1.00.E+10
Fuel Oil (kBtu)	3.80.E+11	1.90.E+11	0.00.E+00	0.00.E+00	0.00.E+00
Kerosene (kBtu)	2.00.E+10	1.00.E+10	0.00.E+00	0.00.E+00	0.00.E+00
TOTAL ENERGY USE (kBtu)	4.320.E+12	3.240.E+12	9.400.E+11	1.270.E+12	4.100.E+11
EUI (kBtu/sq.ft-yr.)	5.064.E+01	4.438.E+01	4.087.E+01	3.944.E+01	3.905.E+01
Elect. Expenditure ($)	4.38.E+10	5.04.E+10	1.72.E+10	3.48.E+10	6.16.E+09
Natural Gas Expenditure ($)	2.70.E+10	1.77.E+10	5.04.E+09	3.64.E+09	2.36.E+09
Propane/ LPG ($)	5.03.E+09	4.26.E+09	7.10.E+08	1.00.E+09	2.90.E+08
Fuel Oil ($)	6.55.E+09	3.57.E+09	0.00.E+00	0.00.E+00	0.00.E+00
Kerosene ($)	3.00.E+08	1.70.E+08	0.00.E+00	0.00.E+00	0.00.E+00
TOTAL EXPENDITURE ($)	8.26.E+10	7.60.E+10	2.29.E+10	3.94.E+10	8.81.E+09
Avg. Size/Single-Family Home (sq.ft)	2,696	2,546	2,000	2,023	2,090

GSHP Feasibility Analysis
Prescreening Tool

US NAVY & USMC Sites GSHP Feasibility Analysis Prescreening Tool

Thank You!

Questions?