United Technologies

Climate | Controls | Security

Options and Opportunities for Improving Energy Efficiency of Air Conditioning and Refrigeration

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Introduction

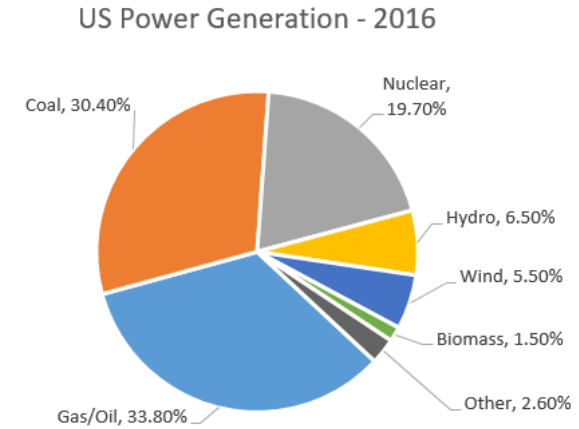
- In this quick presentation I will give you some background on why efficiency is important to the overall environmental improvement initiatives

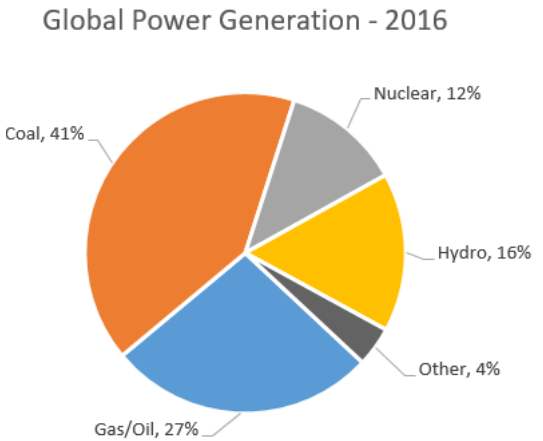
- I will show you show of the new opportunities and approaches being considered

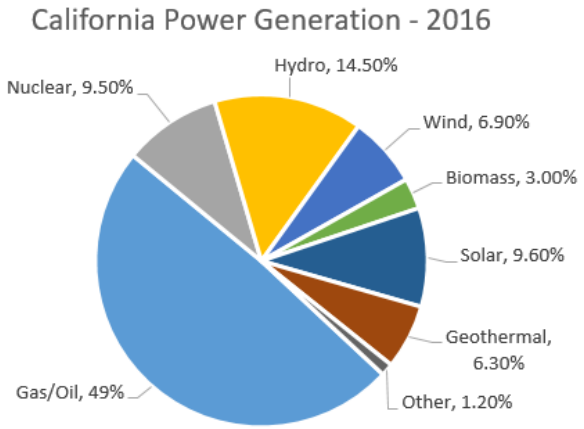
- I will also quickly review what initiatives are underway globally to look at energy efficiency in new and innovative ways including systems and subsystems approaches

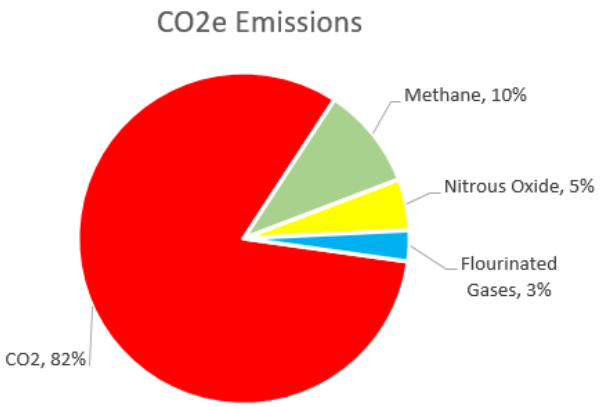
Overall Building Energy Use and Environmental Impact

- Overall Buildings and the HVAC&R Equipment used in buildings have a significant impact on the environment
  - Buildings use 65% of the US electricity
  - Account for 40% of total US energy use
  - Generate 66% US of the greenhouse gas emissions including direct and indirect
  - HVAC&R and water heating in commercial buildings consume about 45% of the total building energy
  - In the US 64.2% and globally 63.2% of the power is generated by fossil fuel (this is starting to change with renewable power generation i.e. California @ 49%)
  - 82% of the total greenhouse gas emissions are from indirect emissions from power generation and combustion
- For overall environmental improvements, **efficiency is a very important** area of focus and must be improved along with improvements in direct emissions from refrigerants used in HVAC&R equipment



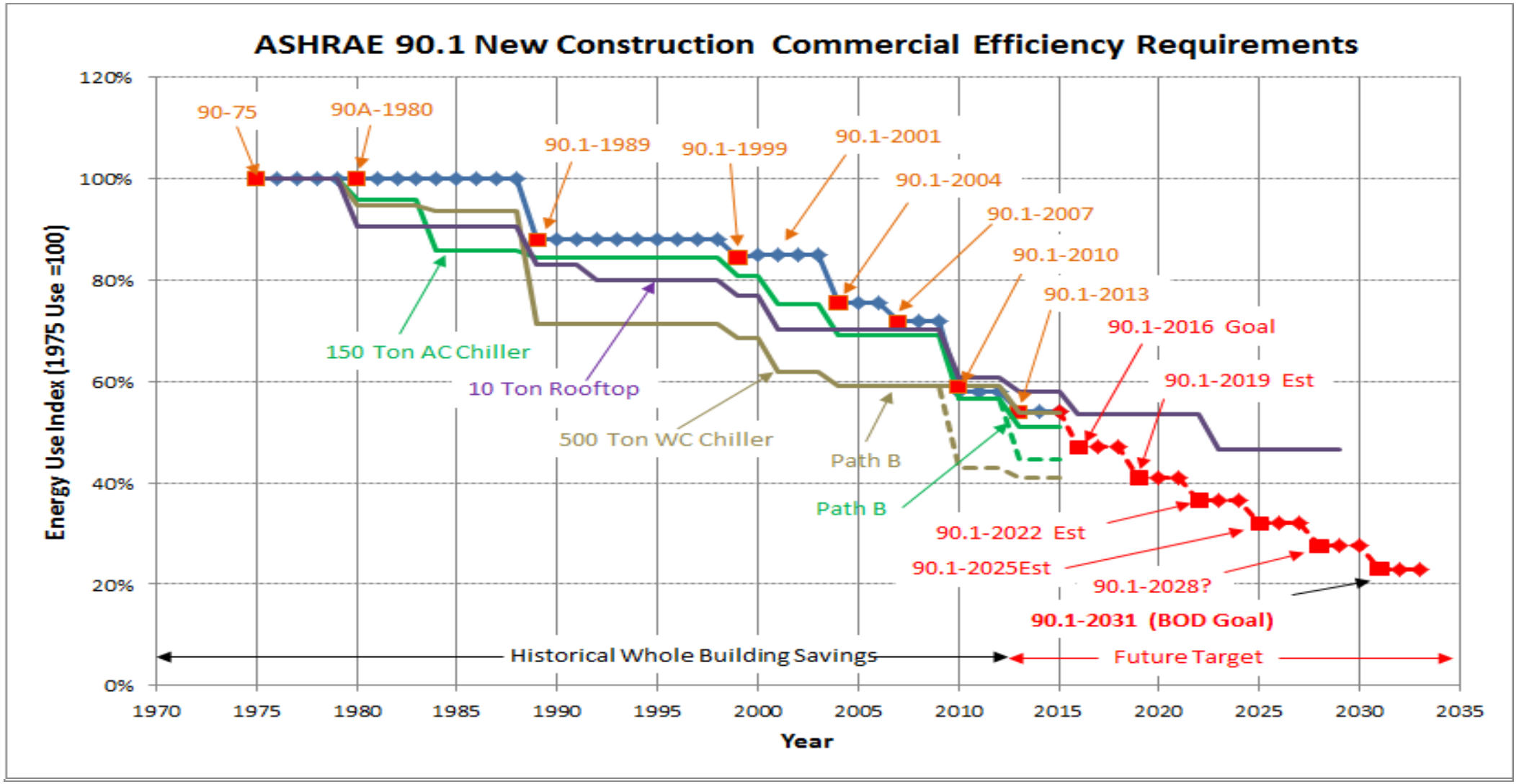




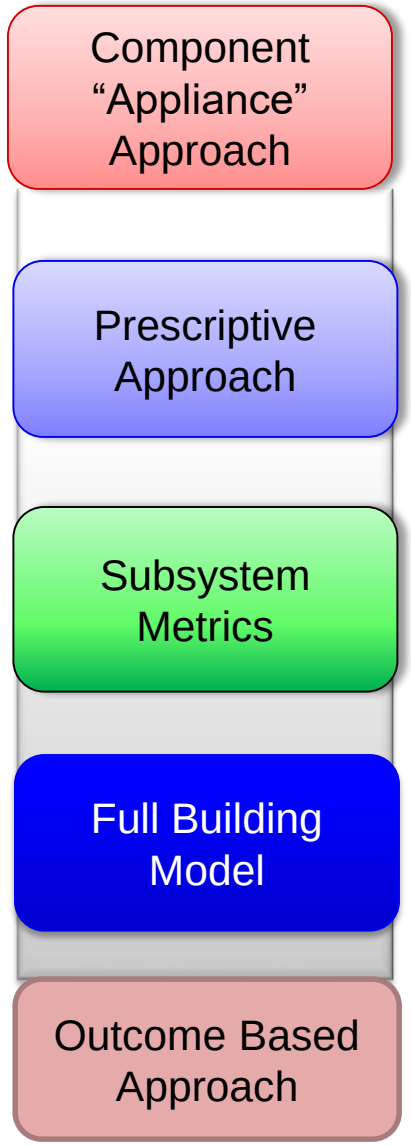


Commercial Building Efficiency Improvement – ASHRAE 90.1

Great progress has been made in overall commercial building efficiency improvements as designed



Building Efficiency Standard Improvement Approaches



Method 1 (expanding)

This method uses efficiency metrics like EER, SEER, COP, IPLV. IEER, etc. to define efficiency levels at a component level and typically at full load and at a common ambient rating point. This is the method used by most efficiency standards and regulatory bodies like DOE for HVAC&R and heating equipment. It does not cover system impacts, regional ambient conditions, building impact and can inhibit new technological approaches. There are many initiatives to improve as well as expand some of the requirements, but some are reaching "Max Tech", but these current occupy about 60-80% of industry resources

Method 2 (expanding)

This method is also currently commonly used were specific equipment and design requirements are defined based on know technological approaches and current design practices. Again it does not consider the overall system, new technological approaches and can limit innovative approaches. This method is also being expanded and some proposal are pushing for prescriptive approaches based on building types

Method 3 (new concept)

This is a new concept where higher level approaches are taken, typically on an annualized based with regional climate data and some building specific load profiles. This would allow for new concepts like hybrid systems, controls impact, and regional climate conditions. It will require regulatory changes and the use of new tools and equipment rating and modeling approaches

Option 4 (revised)

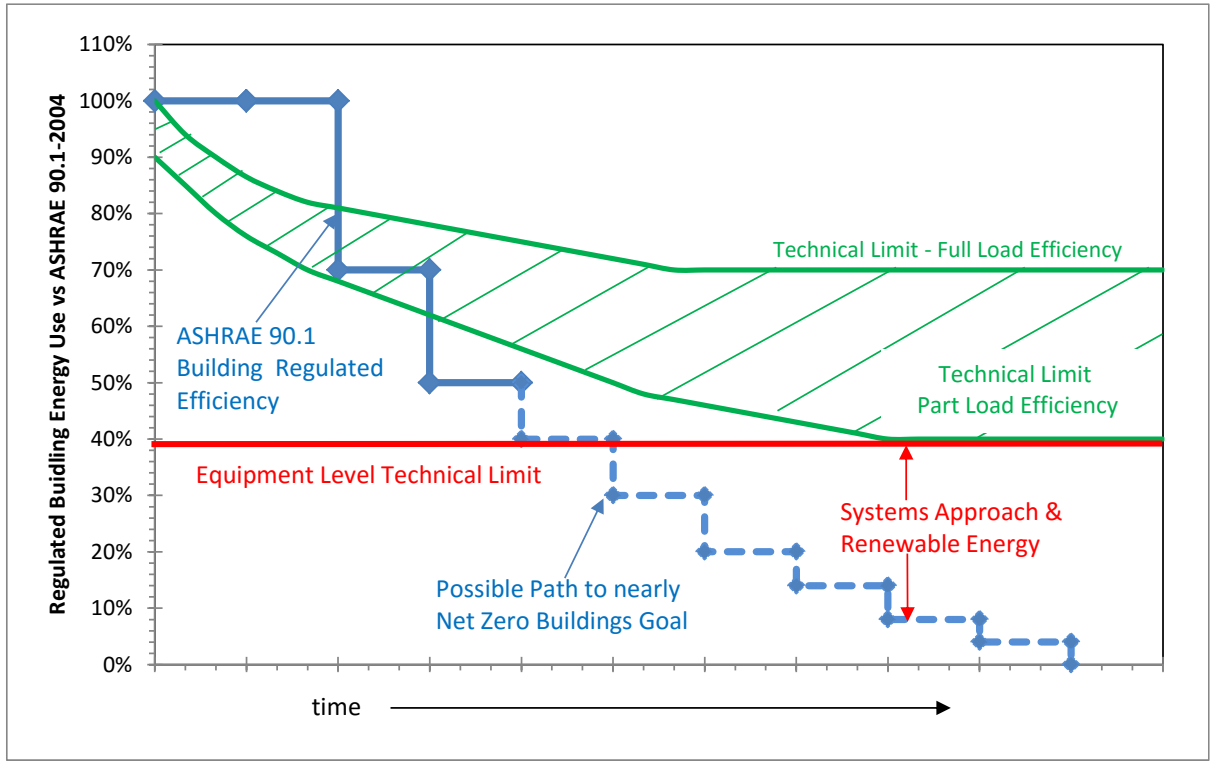
This is a full building approach where a proposed building is compared to a baseline building. It requires complex models and is expense and currently only used on about 20% of buildings and typically very large buildings but then typically for compliance but not for design optimization. There is considerable work to improve the modeling tools and data and ASHRAE 90.1 has introduced a new appendix G compliance path

Option 5 (new concept)

This is a very new approach proposed by New Building Institute, that can build on the above options but follows thru with commissioning, recommissioning and monitoring allowing for sustained high performance buildings. But the current model tools are not accurate enough to predict absolute building energy (EUI) and commission efforts and diagnostics are being developed

Equipment Efficiency Improvements

- There are limits on efficiency improvements due to fundamental laws of thermodynamics (first and second law, Carnot cycle and component limit
- There are also limits on economic payback and very long paybacks can actual have a negative impact on efficiency by delays in change-out of older equipment or switching to lower cost less efficient options
- Not all products are at the same point on the curve
- Also new refrigerants can have an impact on the product efficiency
- Also focusing on 1 product class can cause shifts in selection of equipment for the building
- Some believe there will be new technology and the same trend will continue until we are at net zero
- Others believe that when a product reaches ***"Max Tech"*** that DOE and ASHRAE 90.1 will stop

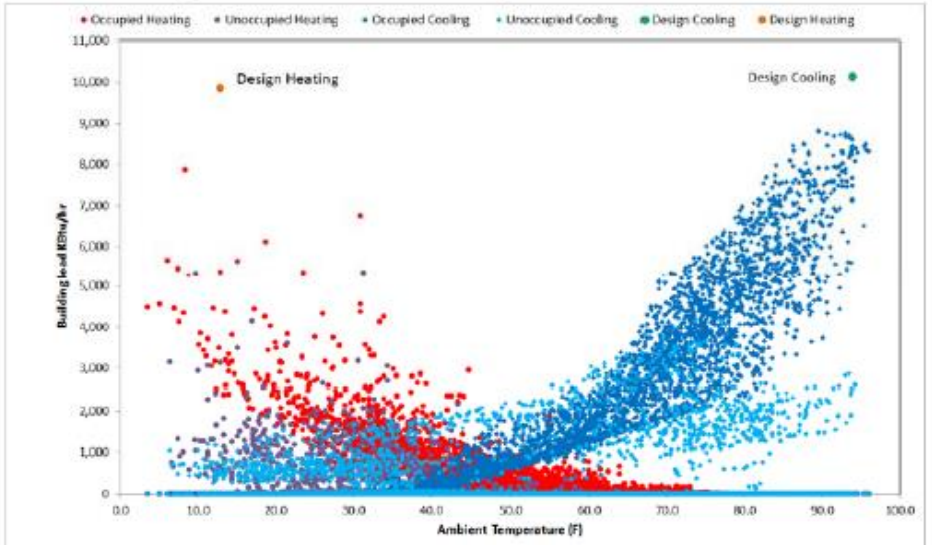


"Max Tech" is where a product reaches technological and economic justification limits

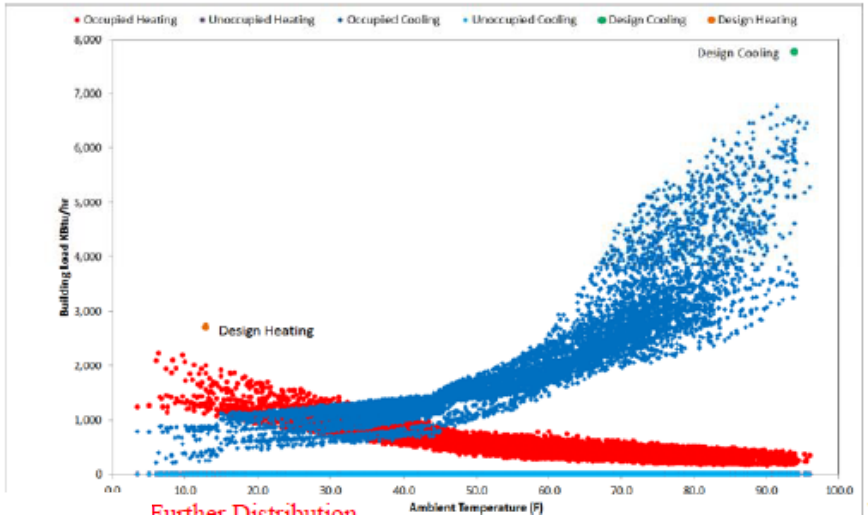
Understand what Drives Efficient HVAC&R

- Unlike other building systems most mechanical systems efficiency are highly dependent on building loads
- They **spend very little time**, if any at **full load** and design ambient, which is where we the current component efficiency regulations and standards are focused
- Building loads vary significantly by building type and needs to be considered when designing efficient systems and buildings
- Commercial building load profiles are different than residential load profiles and are more cooling dominated and operate more in the day than at might
- In general cooling loads are increasing due to tighter buildings more internal plug loads
- Air movement energy and ventilation air conditioning are a major part of the building energy but not a focus of most component metrics

Large Office Building, Baltimore Zone 4a



Hospital, Baltimore Zone 4a



Global Climate Zones (ASHRAE 169-2013)

Work recently has been done by the ASHRAE 169 standard to redo and expand the 17 standard climate zones to 19 and remap all the cities

They have also developed a global climate zone map

Typical efficiency standards use 1 common design ambient for regulations (i.e. 95 F)

There is some movement to have 3 design ambient with T1 (current), T2 (cold), and T3 (hot)

Focus is still on the design day but that is not where most of the operating hours are.

One of the major improvements is the industry now has developed global climate maps and zones

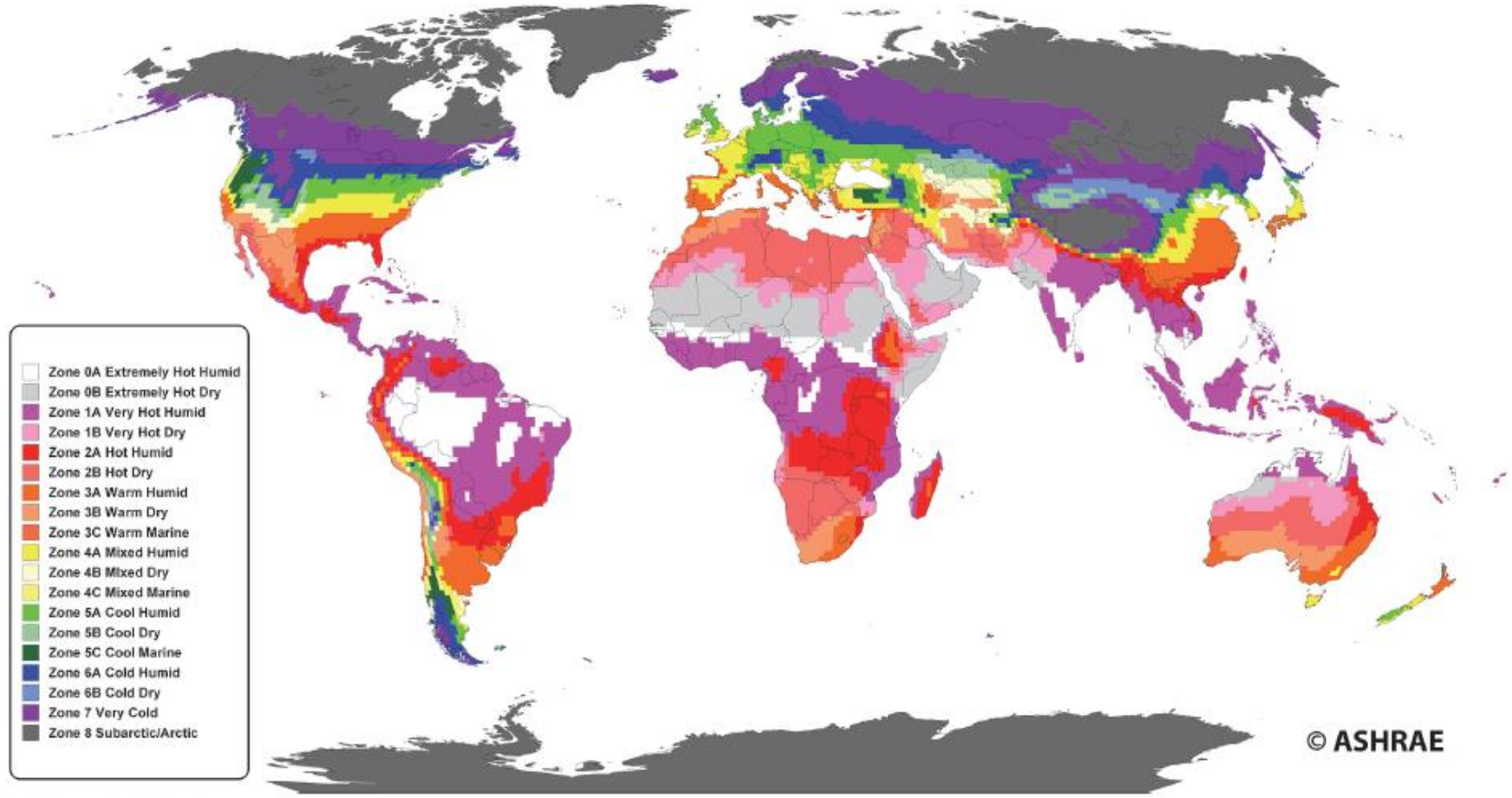
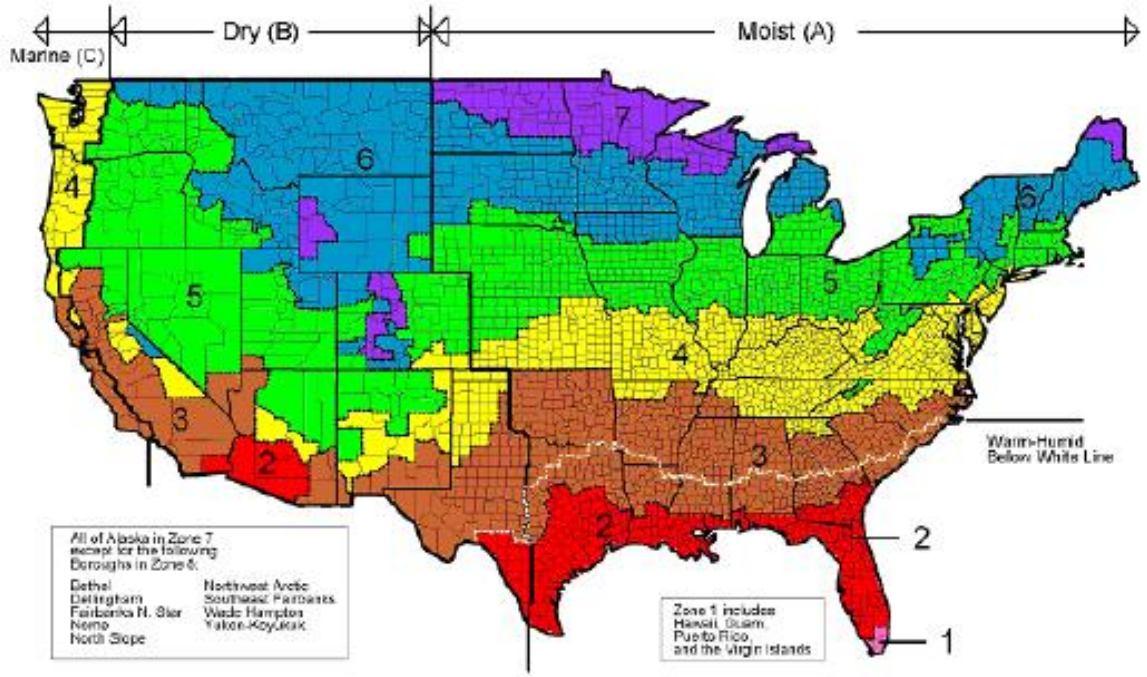


FIGURE C-2 World climate zones map.

New US Climate Zones (ASHRAE 169)

The figures below show the change in climate zones for the US as a result of the ASHRAE 169 work. It does show that temperatures have increases and some cities have moved to warmer climate zones



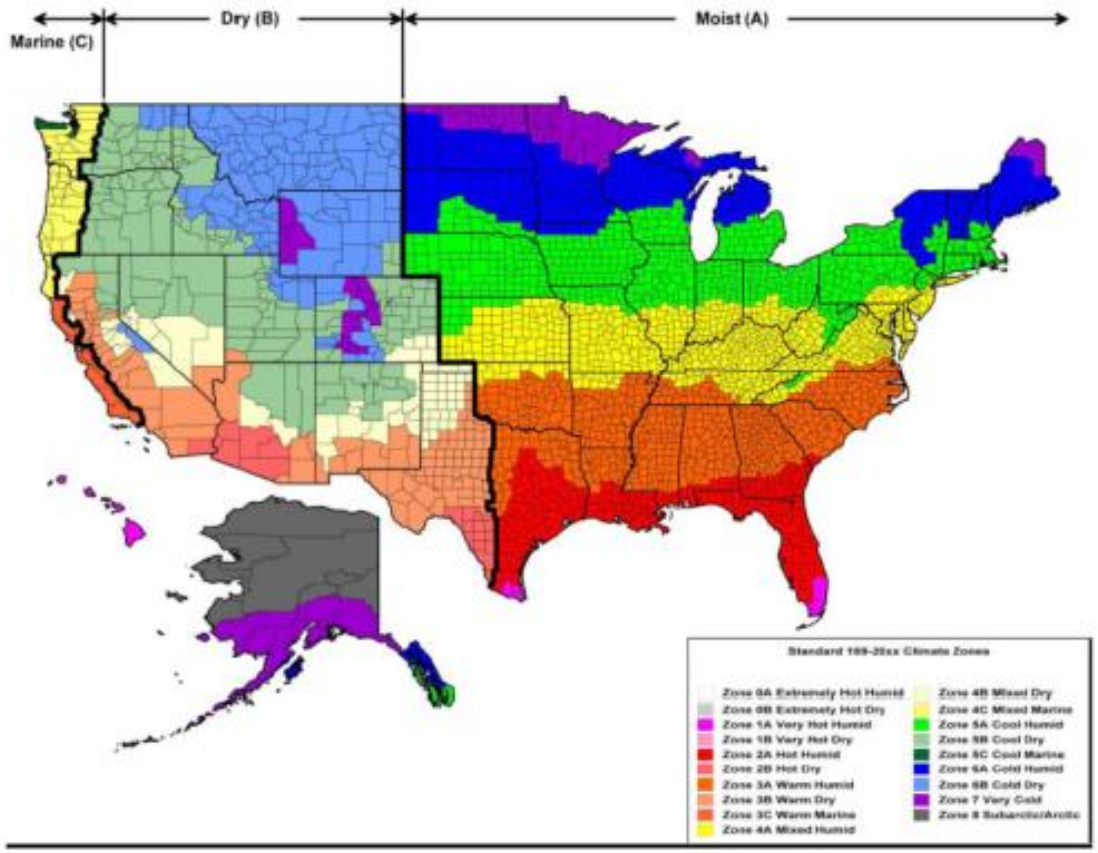
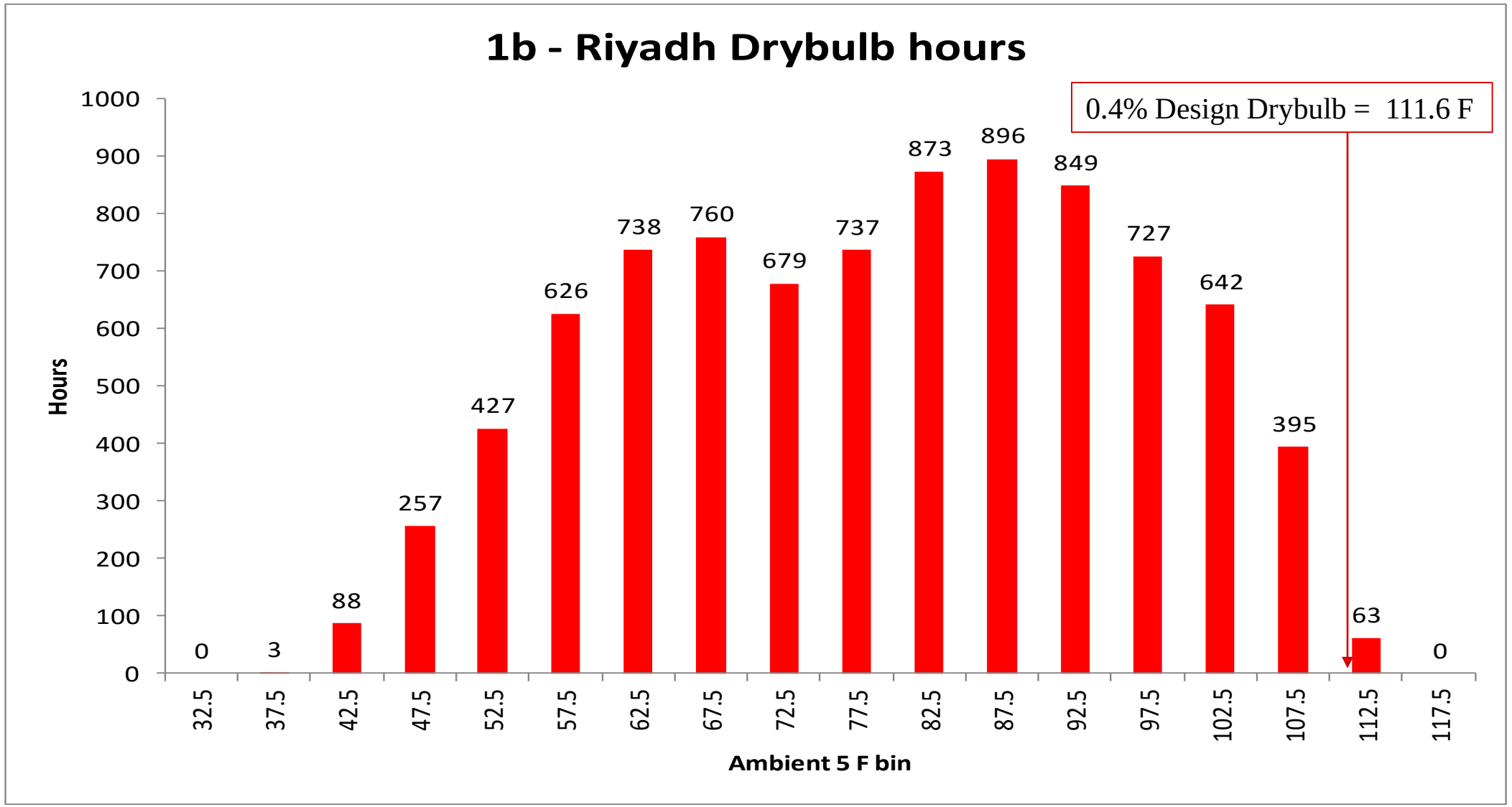


Figure B-1 Climate Zones for United States Counties

Climate Profile – Zone 0b (Riyadh)



ASHRAE 90.1 Benchmark Cities

ASHRAE 90.1 and the AES committee have developed standardized benchmark cities for each of the 19 climate zones which can be very useful for studies as well as future regulatory approaches

US Benchmark Cites

New Climate Zone	City	State
0A	no weather files	-
0B	no weather files	-
1A	Honolulu International Airport	Hawaii
1B	no weather files	-
2A	Tampa MacDill AFB	Florida
2B	Tucson Davis-Monthan AFB	Arizona
3A	Atlanta Hartsfield Int'l Airport	Georgia
3B	El Paso International Airport	Texas
3C	San Diego/Brown Field	California
4A	New York J F Kennedy Intl Airport	New York
4B	Albuquerque International Airport	New Mexico
4C	Seattle Seattle-Tacoma Int'l Airport	Washington
5A	Buffalo Niagara Int'l Airport	New York
5B	Buckley ANGB/Denver (Aurora)	Colorado
5C	Port Angeles William R Fairchild Airport	Washington
6A	Rochester International Airport,	Minnesota
6B	Great Falls International Airport, Montana	Montana
7	International Falls International Airport	Minnesota
8	Fairbanks International Airport	Alaska

Canada Benchmark Cites

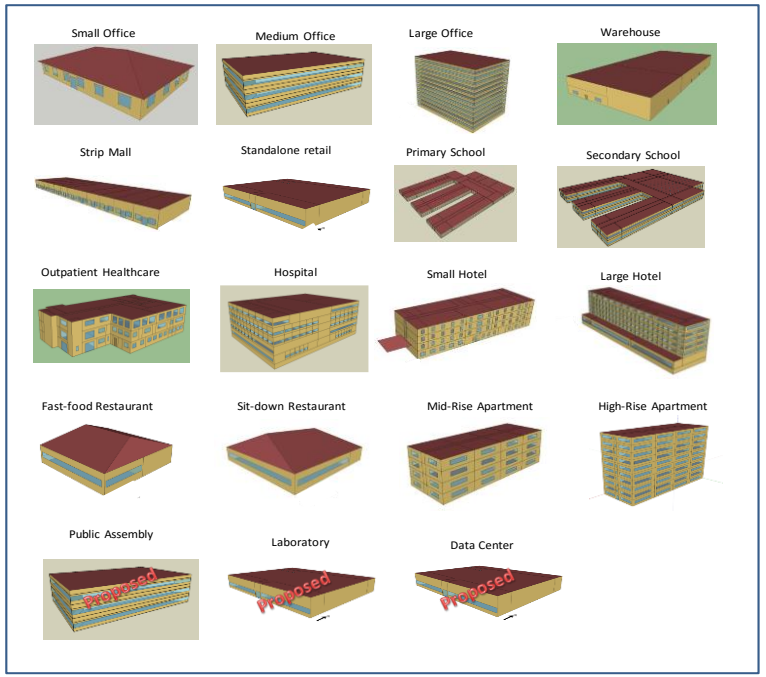
New Climate Zone	City	Province
5A	Windsor Airport	Ontario
5B	Kamloops Airport	British Columbia
5C	Comox Valley Airport,	British, Columbia
6A	Montreal/Pierre Elliott Trudeau Airport,	Quebec
6B	Medicine Hat Airport,	Alberta
7	Winnipeg Richardson International Airport,	Manitoba
8	Yellowknife Airport,	Northwest Territories

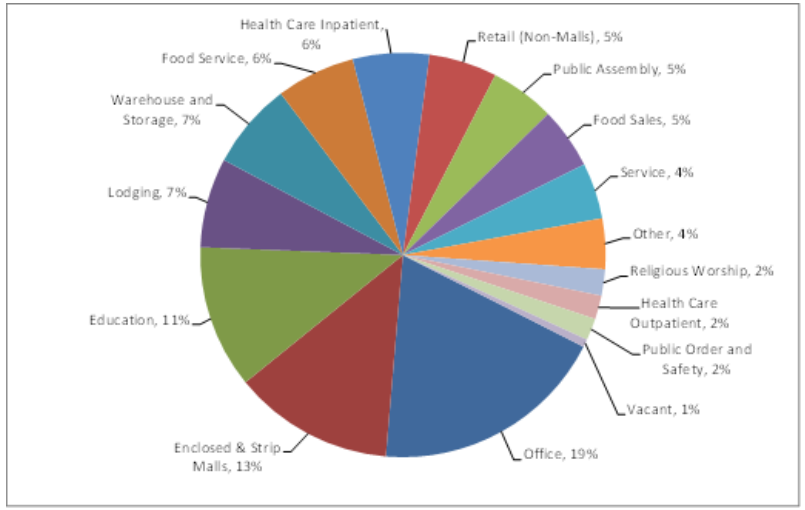
International Benchmark Cites

New Climate Zone	City	Province
0A	Tan Son Hoa (Ho Chi Minh City/Saigon)	Vietnam
0B	Dubai International Airport,	United Arab Emirates
1A	Kaohsiung Int'l Airport	Taiwan
1B	New Delhi/Safdarjun	India
2A	Nanning/Wuxi International Airport, Guangx	China
2B	Cairo International Airport	Egypt
3A	Tokyo	Japan
3B	Amman Marka International Airport	Jordan
3C	Cape Town Inernational Airport	South Africa
	Kunming	Yunnan China
4A	Seoul,	South Korea
4B	Shijiazhuang, Hebei	China
4C	Seattle Seattle-Tacoma Int'l Airport,	Washington USA
5A	Sapporo,	Japan
5B	Yinchuan, Ningxia	Ningxia China
5C	Van/Ferit Melen Airport	Turkey
6A	Montreal/Pierre Elliott Trudeau Airport,	Quebec Canada
6B	Hohhot, Nei Mongolia	China
7	Yekaterinburg, Sverdlovsk	Sverdlovsk, Russa
8	Magadan, Magadan	Russia

Commercial Building Types – Benchmark Buildings

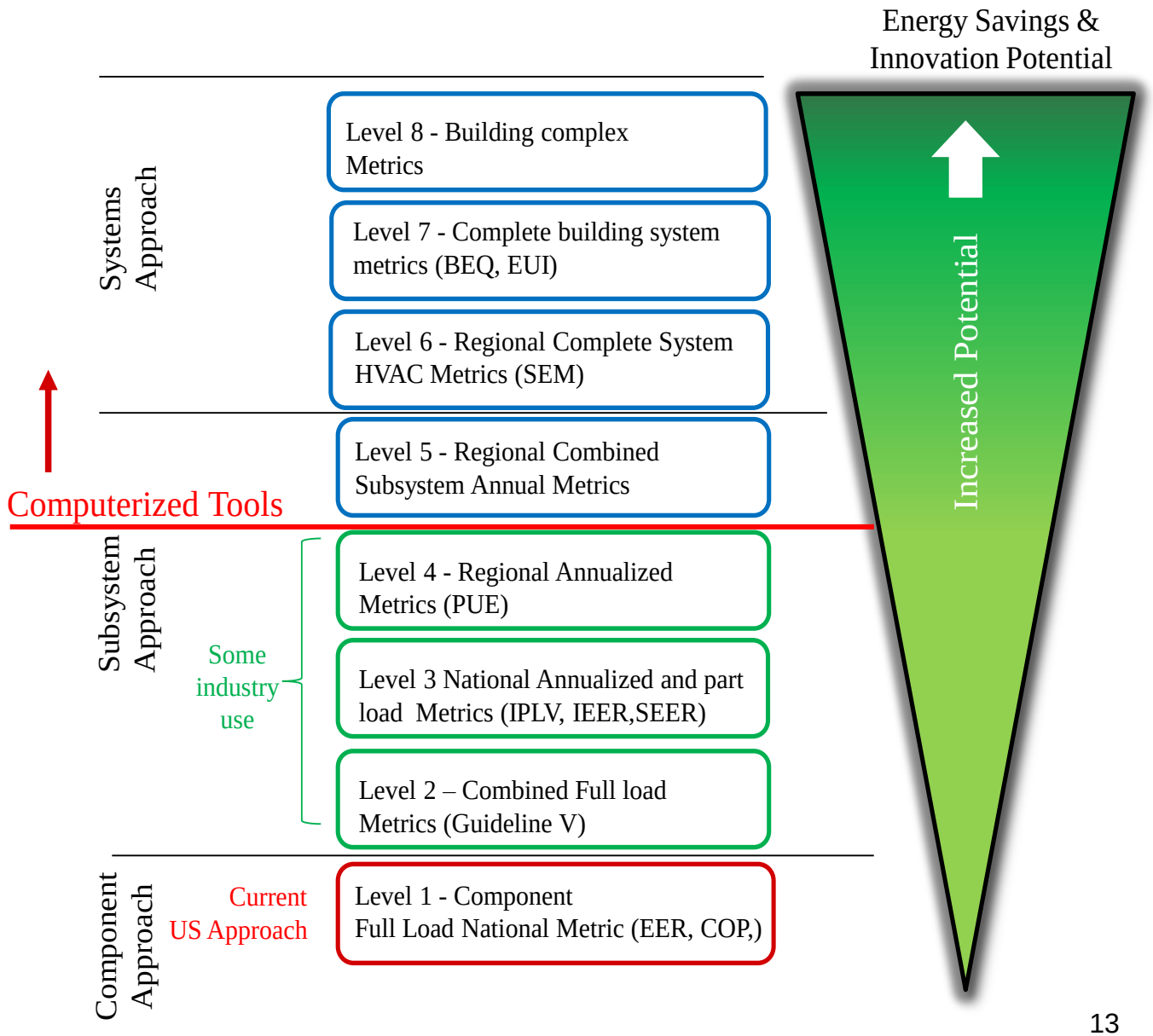
- There are many commercial buildings and the loads and operation can vary significantly
- Work has been done by ASHRAE 90.1 and PNNL to develop standardized benchmark buildings to cover about 85% of the market and they are working to cover more
- These are ASHRAE 90.1-2016 code compliant buildings and have been thru significant peer review
- They are being used to for many purposes;
  - Determination evaluation of ASHRAE 90.1
  - Evaluation of new proposals
  - Setting efficiency improvement requirements for appendix G
  - New compliance paths for systems and subsystems
  - Training and education





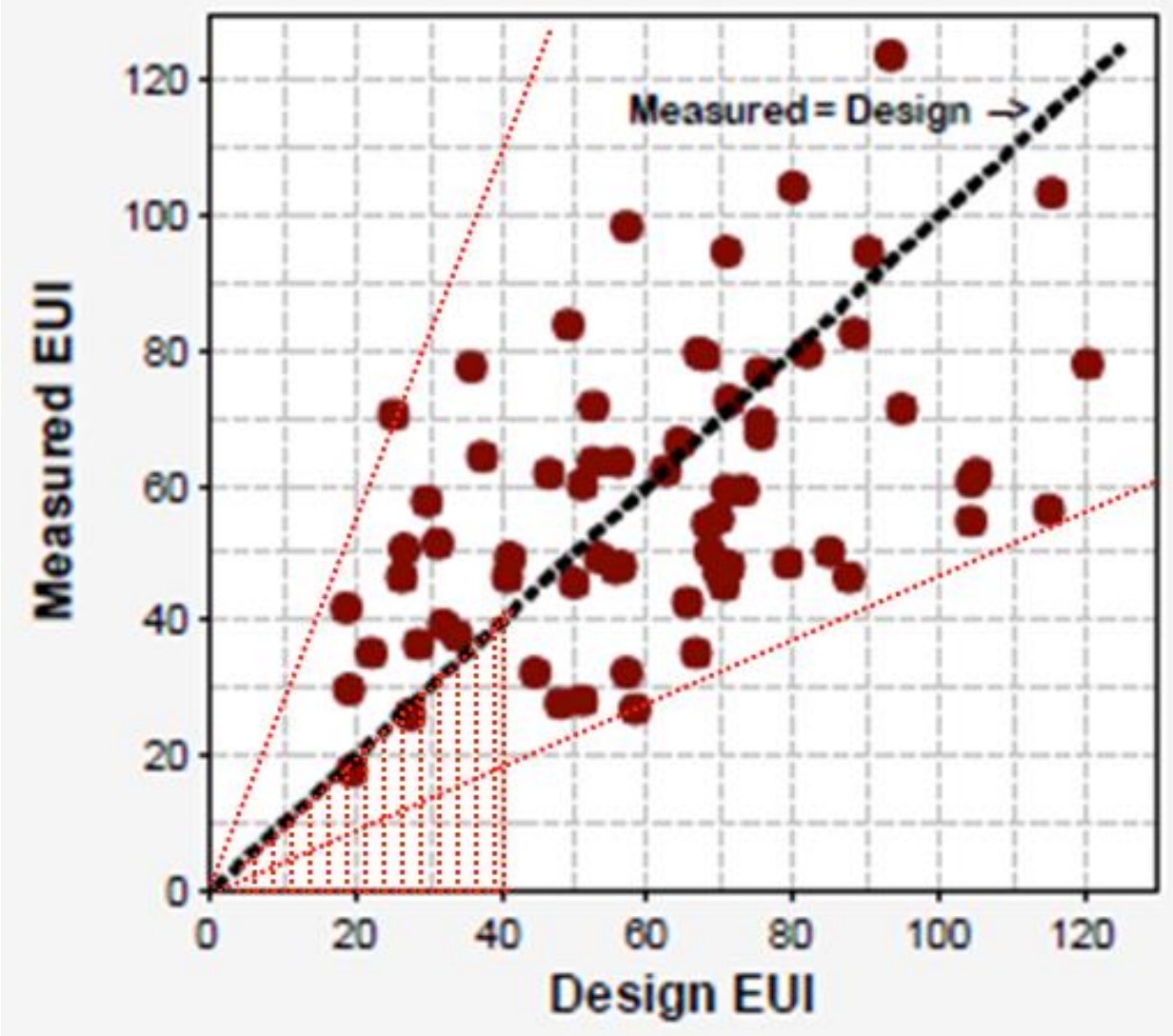
Development of New HVAC Metrics

- Alliance to Save Energy Definition - A ***building system*** has been defined "*as a combination of equipment, operations, controls, accessories, and means of interconnection that uses energy to perform a specific function*"
- The intent of a mechanical systems approach will be to move up the scale where we believe more energy savings can be obtained
- But conventional tools and ratings metrics will need to be revised to allow for this approach
- It also will likely enable and result in a move to regional requirements which for chillers is already occurring globally
- It also should be noted that a systems approach should also could includes commissioning, monitoring, reporting and maintenance and factor in benefits of connected equipment



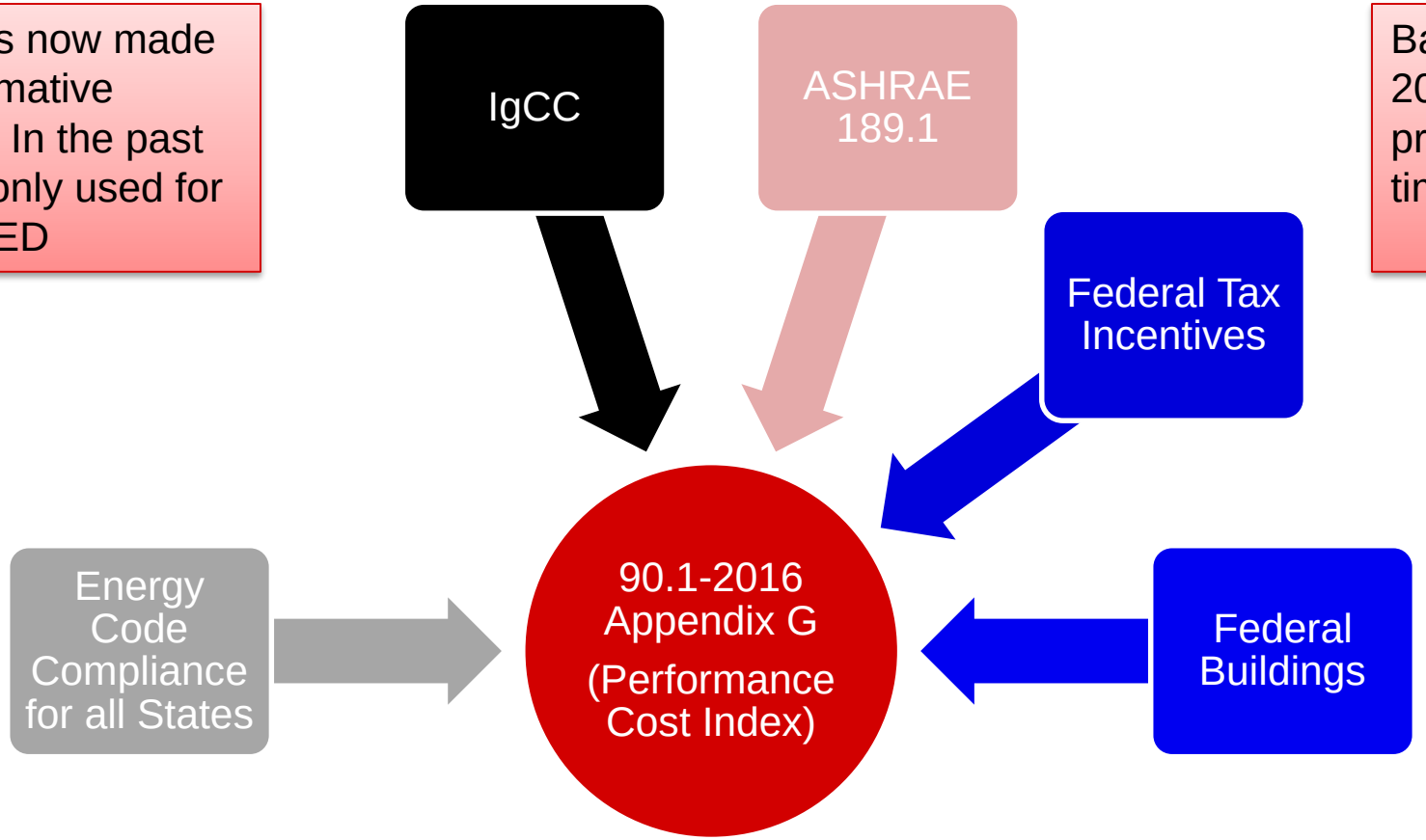
Why not Use Absolute Energy Use (EUI)

- Studies have been conducted by ASHRAE, National Labs and standards like CSA 873
- The curve to the right shows the results of a study conducted to compare modeled total building energy vs measured energy
- This is why all standards do not attempt to predict absolute energy and instead use a baseline building as defined by standards like ASHRAE appendix G
- But there are some that are proposing absolute EUI metrics, but there is significant uncertainty



New in 90.1-2016 - Appendix G - Fixed Baseline

ASHRAE 90.1 has now made appendix G a normative compliance path. In the past Appendix G was only used for standards like LEED



Baselines has been fixed at 2004 which allows for more predefined models and less time to model a building

- Create a larger market for automated software
- Same model used for multiple purposes
- Simpler, cheaper, more likely to be accurate

New ASHRAE 90.1 Appendix G Whole Building Metrics and Fixed Baseline

TABLE 4.2.1.1 Building Performance Factor (BPF)

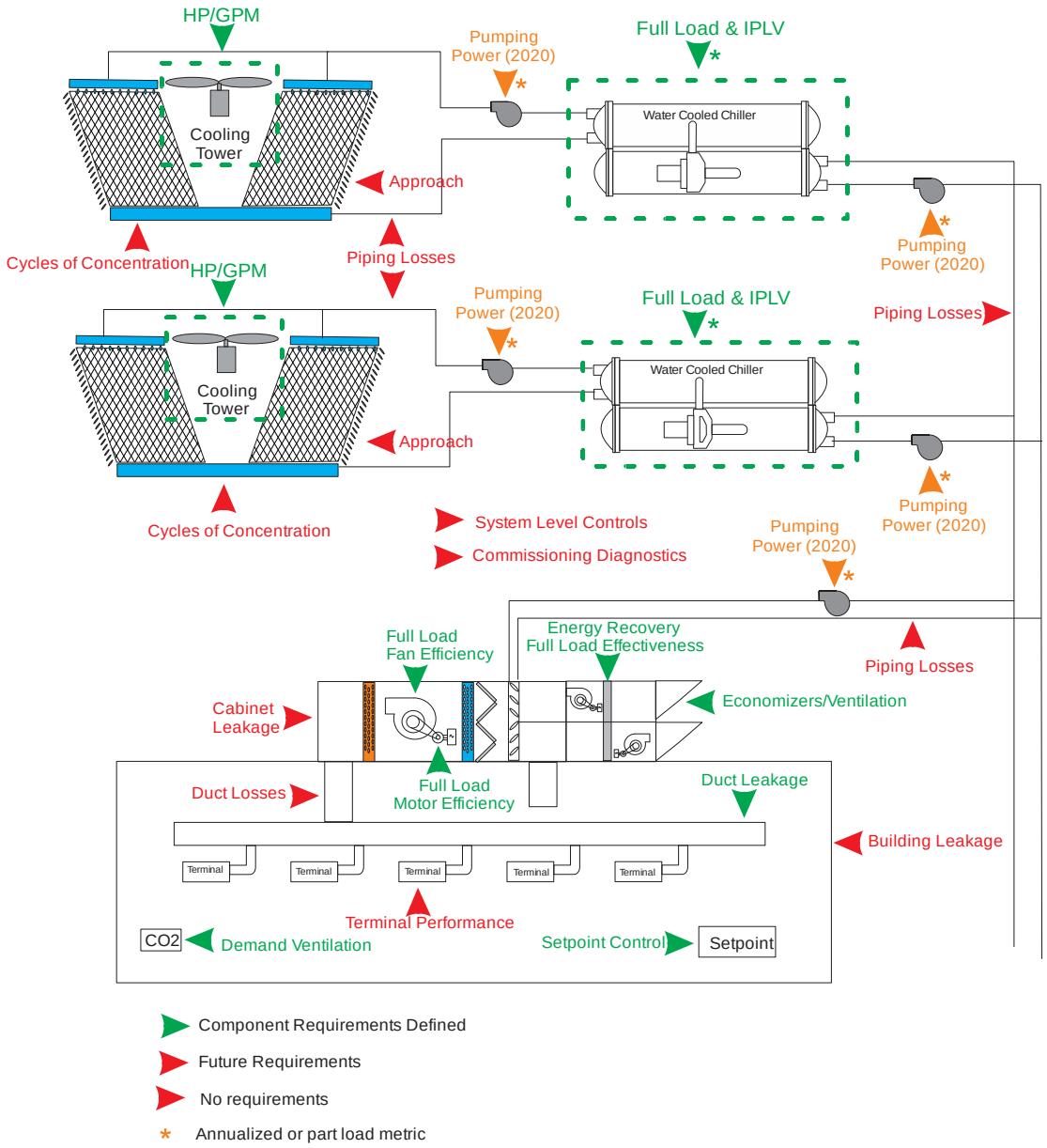
Building Area Type[a]	Climate Zone																
	0A and 1A	0B and 1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Multifamily	0.73	0.73	0.71	0.69	0.74	0.73	0.68	0.78	0.81	0.81	0.76	0.80	0.81	0.76	0.79	0.74	0.80
Healthcare/ hospital	0.64	0.56	0.60	0.56	0.60	0.56	0.54	0.57	0.53	0.55	0.59	0.52	0.55	0.57	0.52	0.56	0.56
Hotel/motel	0.64	0.65	0.62	0.60	0.63	0.65	0.64	0.62	0.64	0.62	0.60	0.61	0.60	0.59	0.61	0.57	0.58
Office	0.58	0.62	0.57	0.62	0.60	0.64	0.54	0.58	0.60	0.58	0.60	0.61	0.58	0.61	0.61	0.57	0.61
Restaurant	0.62	0.62	0.58	0.61	0.60	0.60	0.61	0.58	0.55	0.60	0.62	0.58	0.60	0.63	0.60	0.65	0.68
Retail	0.52	0.58	0.53	0.58	0.54	0.62	0.60	0.55	0.60	0.60	0.55	0.59	0.61	0.55	0.58	0.53	0.53
School	0.46	0.53	0.47	0.53	0.49	0.52	0.50	0.49	0.50	0.49	0.50	0.50	0.50	0.49	0.50	0.47	0.51
Warehouse	0.51	0.52	0.56	0.58	0.57	0.59	0.63	0.58	0.60	0.63	0.60	0.61	0.65	0.66	0.66	0.67	0.67
All others	0.62	0.61	0.55	0.57	0.56	0.61	0.59	0.58	0.57	0.61	0.57	0.57	0.61	0.56	0.56	0.53	0.52

a. In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply

Note this is a total building metric and is based on a baseline of ASHRAE 2004

Current Mechanical System Metric – Component Approach

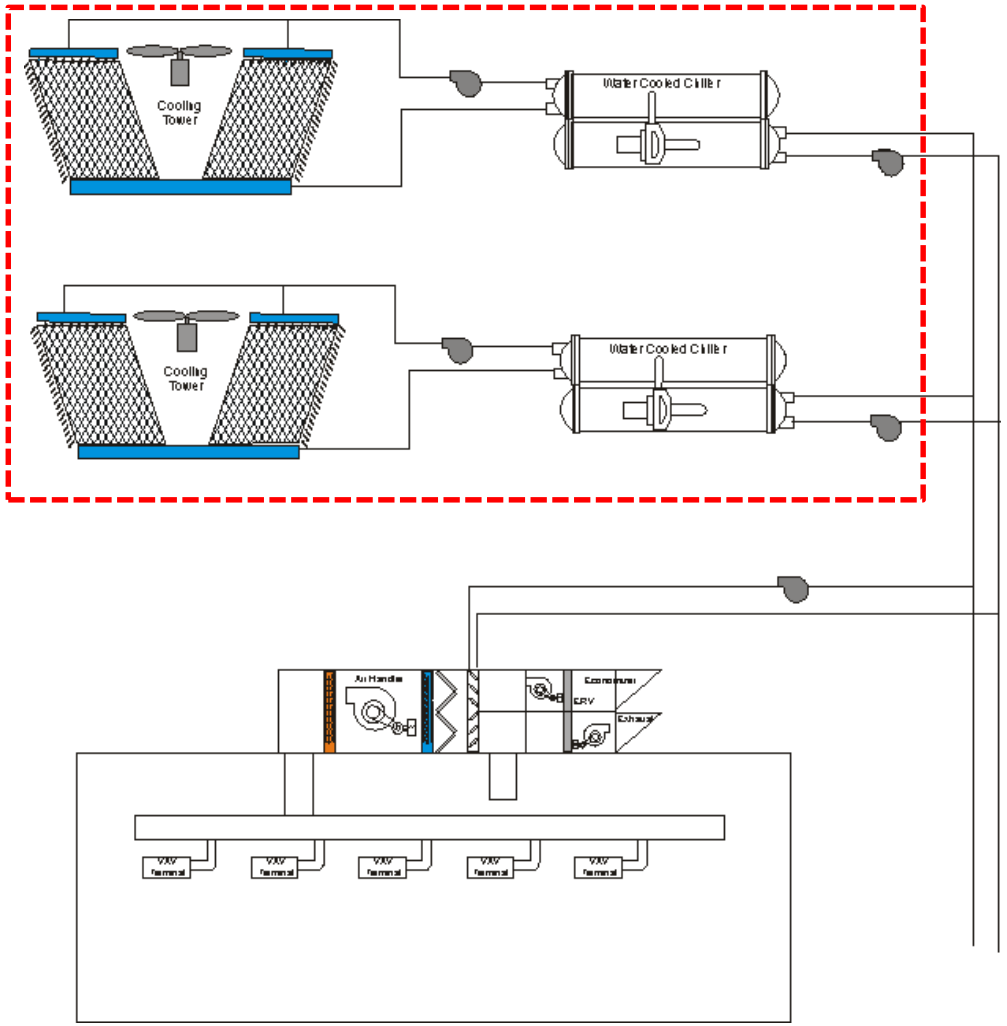
- Current metrics are based on appliance approach and focused on components and prescriptive design requirements
- Metrics are primary focused on design day loads and temperature but there is some movement to annualized and part load metrics
- Typically only 1 common metric is used for the US
- Overall systems are not typically evaluated or optimized at a system level
- Creative solutions are not always rewarded for their beneficial improvement (i.e.. Economizers, hybrid systems, duct design, etc.,)
- No focus on sustained performance (monitoring, commissioning, diagnostics)



Chilled Water System/Subsystem Approach Example

Alternate approach using subsystems and new metrics and tools

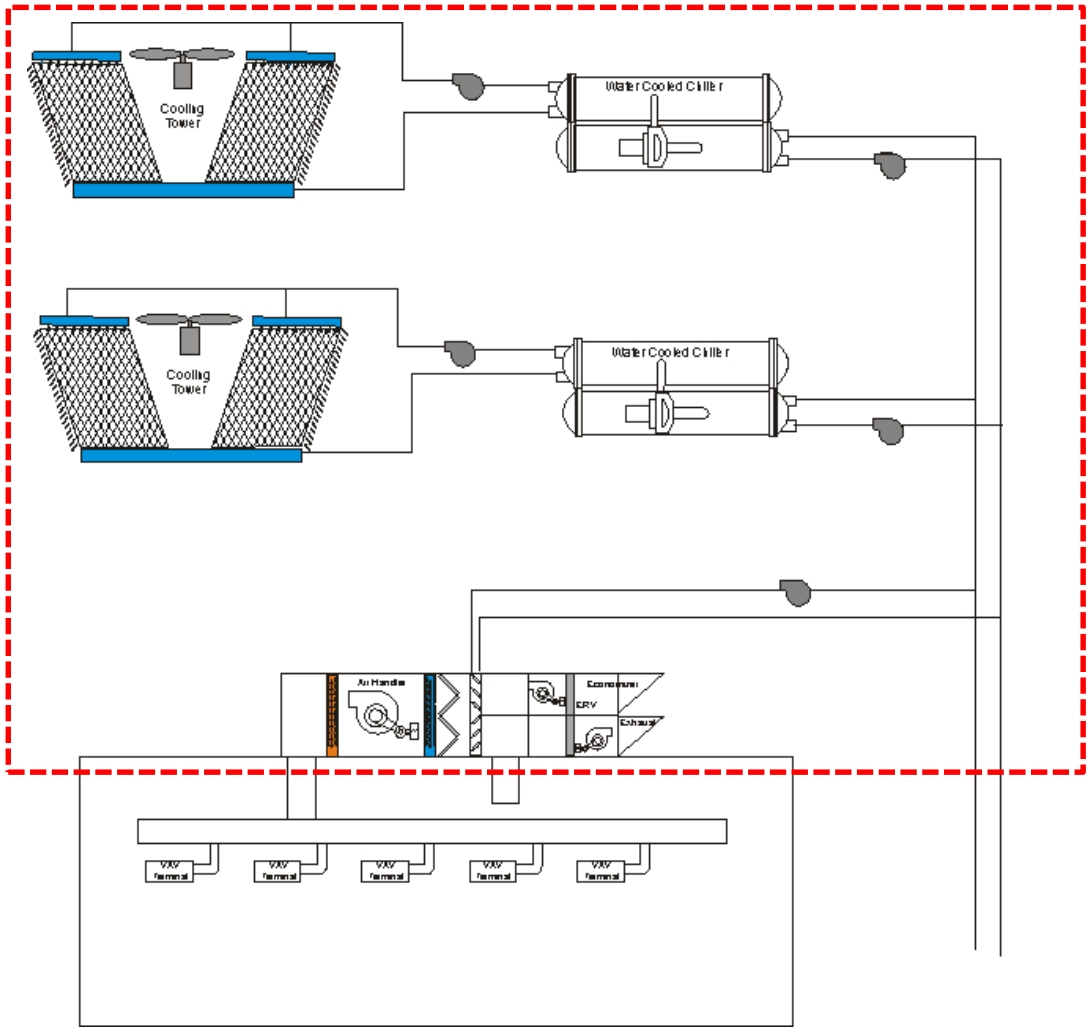
Option A1 – Chilled Water Subsystem



Chilled Water System/Subsystem Approach Example

Alternate approach using subsystems and new metrics and tools

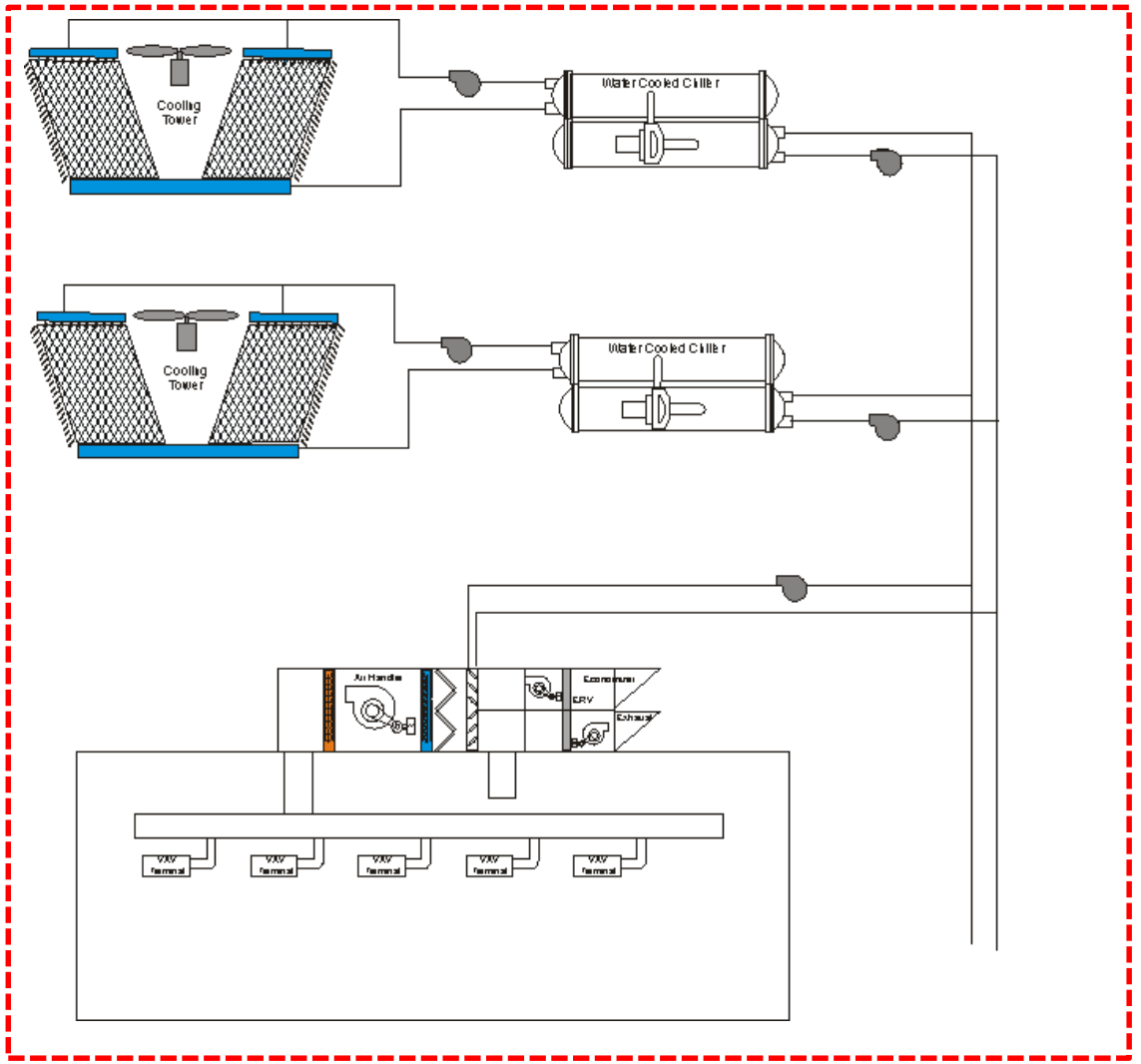
Option A2 – Chilled Water Subsystem



Chilled Water System/Subsystem Approach Example

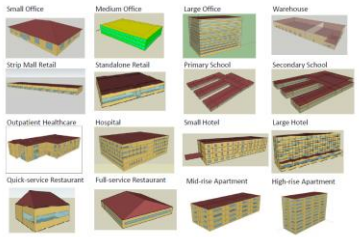
Alternate approach using subsystems and new metrics and tools

Option A3 – Chilled Water Subsystem

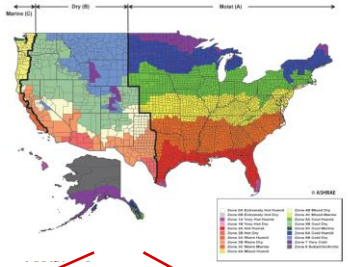


Subsystem Tool/Metrics Being Developed

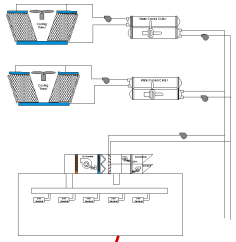
Benchmark Buildings



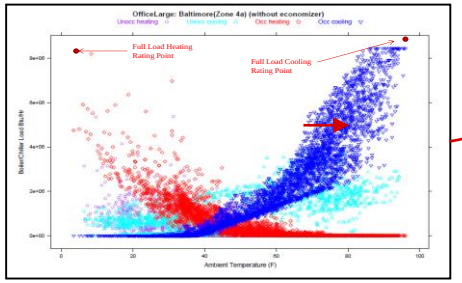
Benchmark Cities and Weather Data

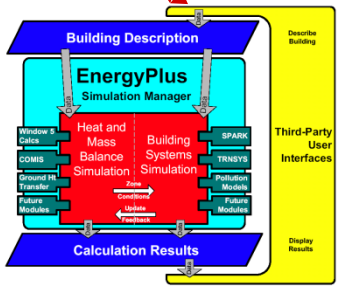


Proposed Chiller water System Design

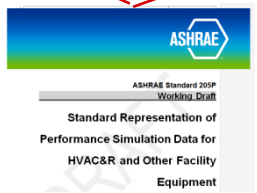


Typical Building Load Profile (pre-run and stored)

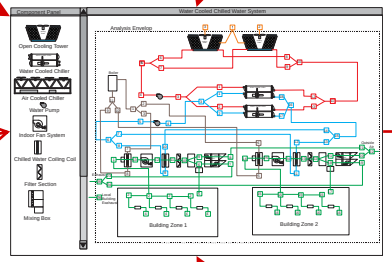




Used to pre-run Building models



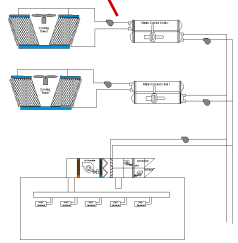
Equipment Models/Data (ASHRAE 205)



Visual Simulation Tool **(compliance tool)**

Approval

< Minimum metric established by climate zone and building and Tier



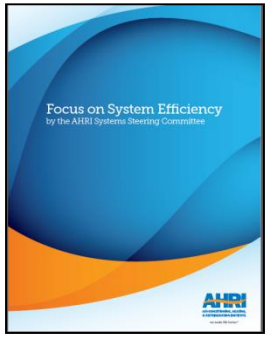
Baseline System Defined by ASHRAE 90.1

Goal is to make a very easy to use tool that can be used for compliance

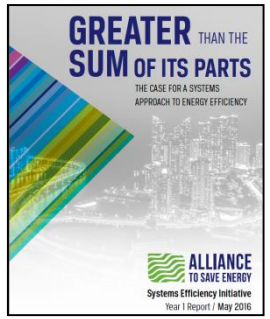
Industry Building Systems Activity

Many in the industry are now starting to support a higher level approach to building efficiency but progress is slow and people are more comfortable with current systems as well as concerned about multiple metrics and added regulations

AHRI Systems Committee

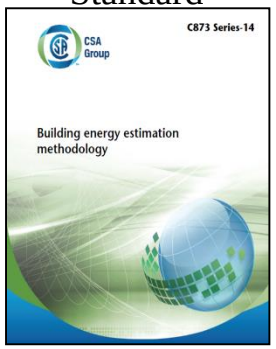


Alliance to Save Energy

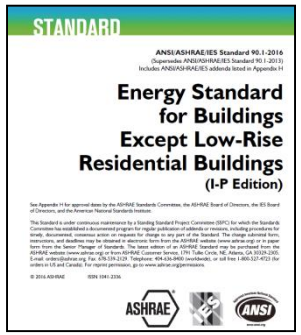


Second European Directive

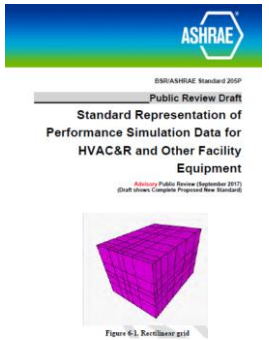
Canada Beam Standard



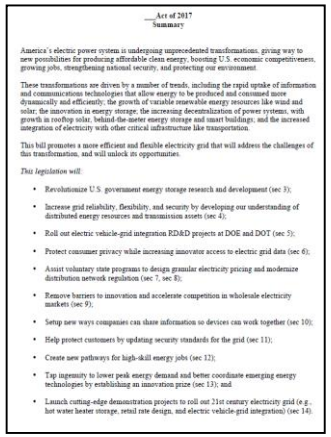
ASHRAE 90.1 Hydronic' s Chiller Proposal



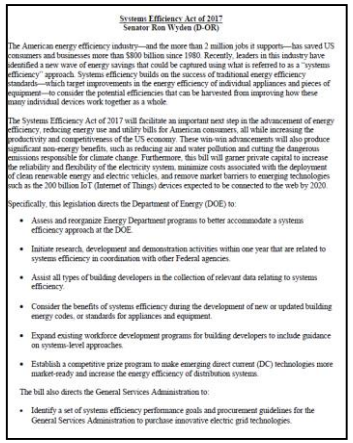
ASHRAE 205 Standard Equipment Models



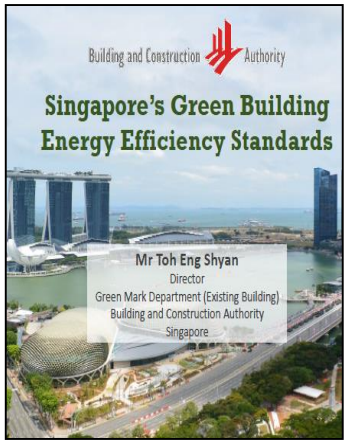
Wyden Flex Energy Bill



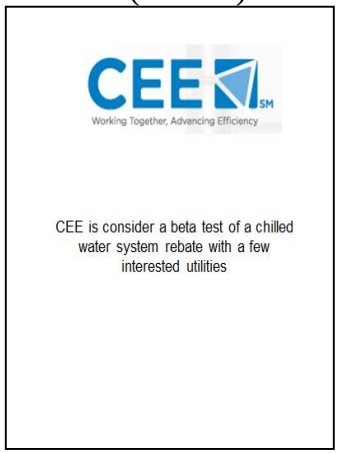
Wyden Systems Efficiency Act



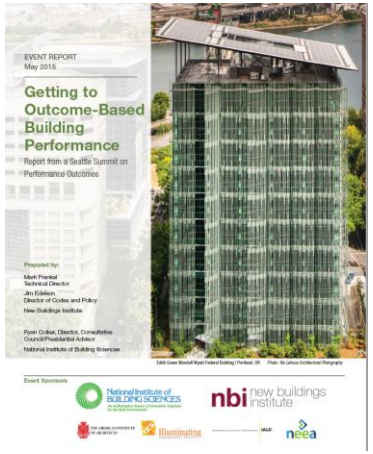
Singapore Green Standard



CEE Rebate Programs (utilities)



NBI Outcome Based Building Performance



Summary

- HVAC&R and heating efficiency is an important contributor to environmental improvements
- We are starting to reach the technical limits for the current appliance component approach to efficiency improvements and prescriptive approaches can limit the development and use of innovative approaches
- We are primarily focused on common rating points at full load and peak load design conditions
- There are new opportunities when the equipment is looked at using system and subsystem level and when factoring in the regional ambient conditions and building operation and load profiles
- There are also significant opportunities for sustained higher performance using commissioning, recommissioning, connected equipment, monitoring and diagnostics especial with IOT enabler
- To do this will require new industry metrics, rating procedures and compliance tools as well as new regulatory approaches

If change our approach and focus on higher level requirements and not component and prescriptive design solutions then it will enable the industry to consider new and innovative solutions using concepts like hybrid systems, energy recovery, renewable energy, and controls to make significant improvements in overall building and building complex energy use.

Questions