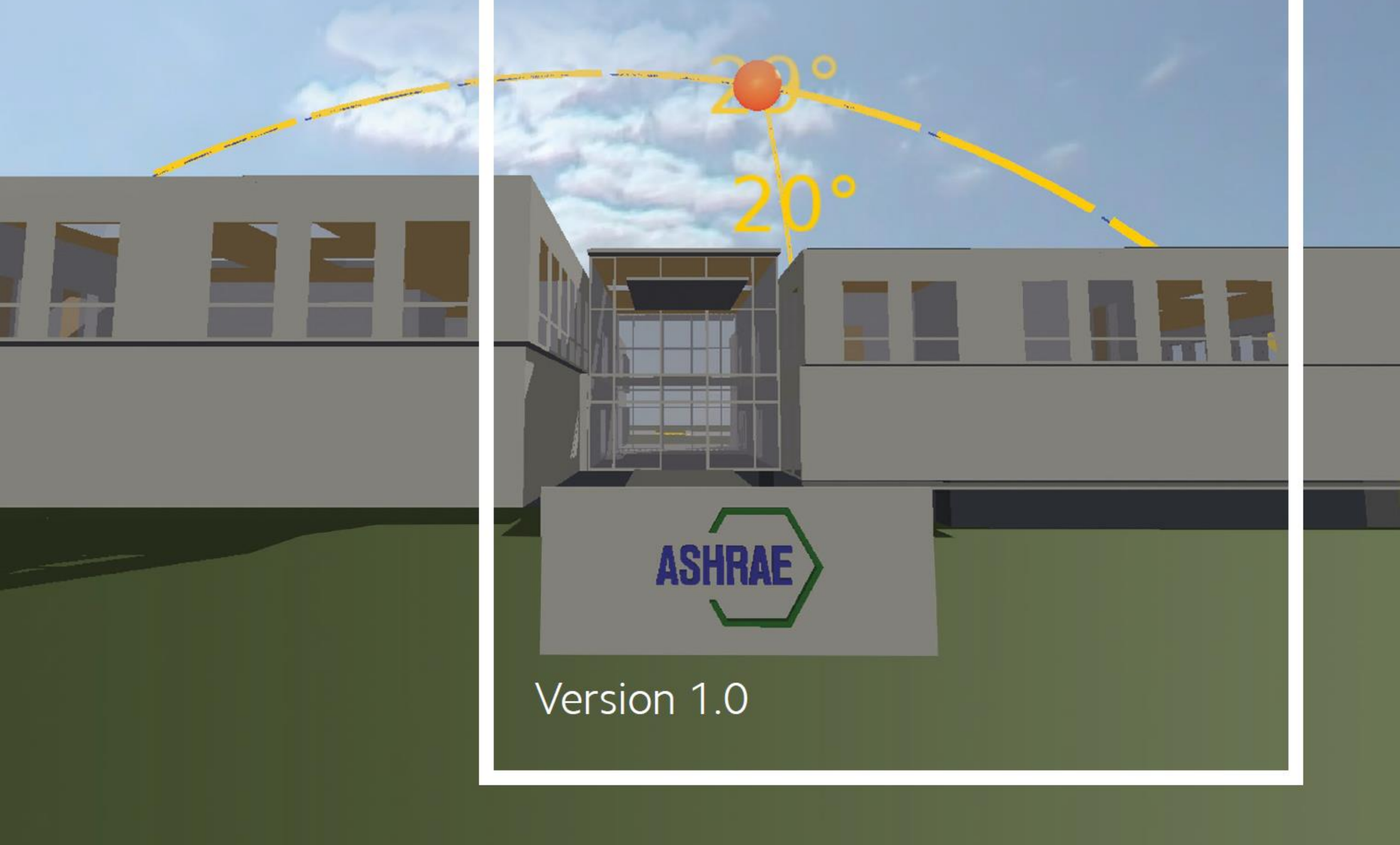
IES

Building Performance Modeling
Student Handbook

Supporting the architects, engineers and designers of the future



Version 1.0

Foreword

Welcome to Version 1.0 of the **Building Performance Modeling Student Handbook**. At IES Ltd., we believe that the students of today will have the biggest impact in the Architectural, Engineering & Construction industry of tomorrow. With guidance from the academic industry, we created this handbook to act as a lifelong technical aid to help portray the technical fundamental concepts of building science with the art of Building Performance Modeling (BPM).

- ✓ **For Students –** The BPM Handbook requires a basic knowledge of thermodynamics and heat transfer. If you are learning more about architecture, energy systems or HVAC engineering, this Handbook will help you. Where appropriate, we have included common AEC industry abbreviations, formulae and concepts to act as a continuous reminder. We have also included recommendations for your CV/resume.
- ✓ **For Educators –** The BPM Handbook is meant to act as a technical teaching aid. We have discovered that over 50% of building performance modeling questions have nothing to do with modeling, but rather are questions about building physics and flows of heat, light, air and water. The Handbook is rich with additional free tutorial videos for the student who wishes to learn more about a specific feature of buildings or who are competing in an industry student competition. If you have feedback, we'd love to hear it.
- ✓ **For Professionals –** The BPM Handbook recognizes the continuous learning curve with respect to buildings and building systems. Whether your current employment requires HVAC design, BEM analysis or meeting the local energy code requirements, this Handbook aims to maintain relevance with building technologies and modeling methods.

iesve.com/software/education

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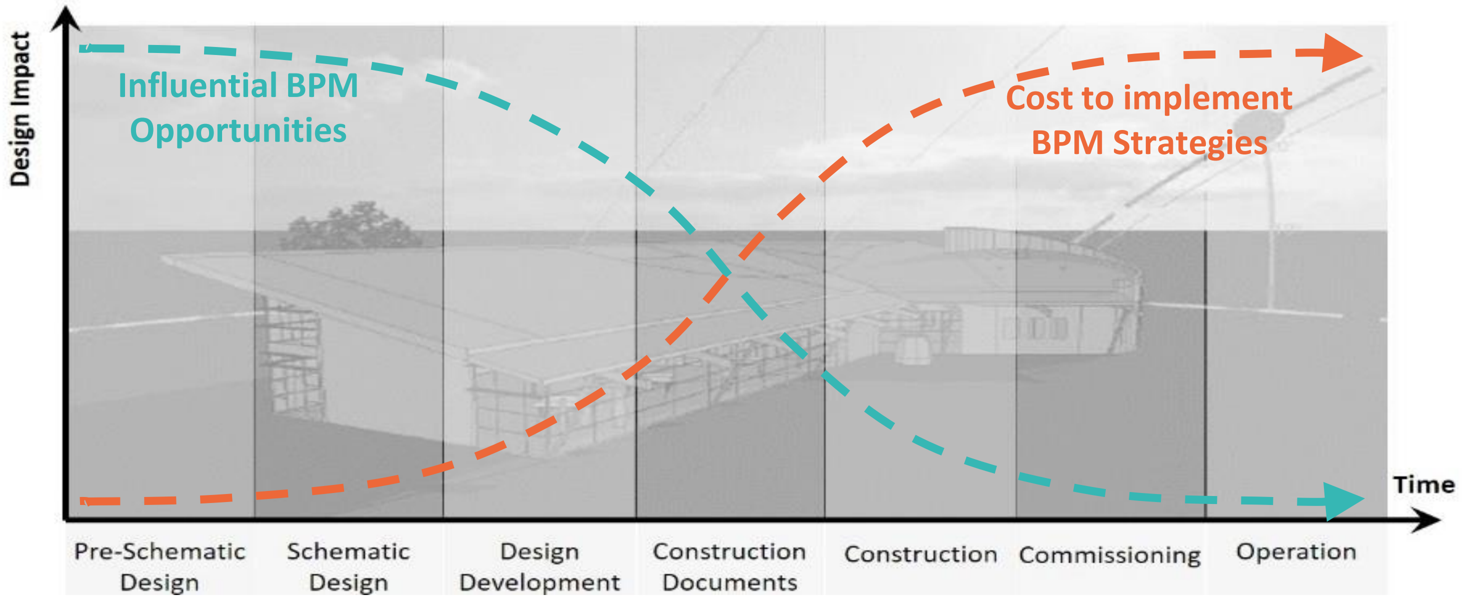
Contents

What is Building Performance Modeling?

Building Performance Modeling (BPM) refers to a number of types of analysis which can be done during the design of a building and/or during a building's operations. Some types of BPM discussed in this handbook include:

- Building Energy Modeling
- Lighting Calculations and Daylight Simulation
- HVAC Heating and Cooling Load Calculations
- Airflow Simulation
- Occupant Thermal Comfort Modeling

During early design phases of construction projects, analysis from BPM can have the most impact on the final performance of the building. As such, BPM is a **process** that requires **knowledge** of building physics and technical **skills** to analyze the building, or building systems, using physics-based modeling software tools to simulate the performance of various design scenarios. This Integrated Project Delivery style of design & construction requires many 'what-if' scenarios to be considered using BPM, often during a collaborative design team charette.



Careers in BPM will require curiosity, patience, good communication and the ability to solve technical problems, as no two buildings are the same. BPM can be frustrating at times but also can also be incredibly rewarding. Recommended BPM resources are included below.

BPM JOB TITLES TO SEARCH FOR:

- Mechanical Engineer
- Building Performance Engineer
- HVAC Engineer
- Lighting Designer
- Decarbonization Consultant

PROFESSIONAL BPM ORGANIZATIONS TO JOIN:

- ASHRAE
- IBPSA Chapters, e.g. IBPSA-USA
- LinkedIn: IESVE Users

BPM CV AND RESUME SKILLS:

- Heating & Cooling Load Calculations
- ASHRAE 62.1 Ventilation Calculations
- Psychrometric Calculations
- Sizing HVAC Equipment
  - Fan & Pump
  - Chiller, Boiler, Cooling Tower
- Building Energy Modeling (BEM)
- Daylight Simulation
- CFD Airflow Simulation
- Software: IESVE

Abbreviations and Acronyms

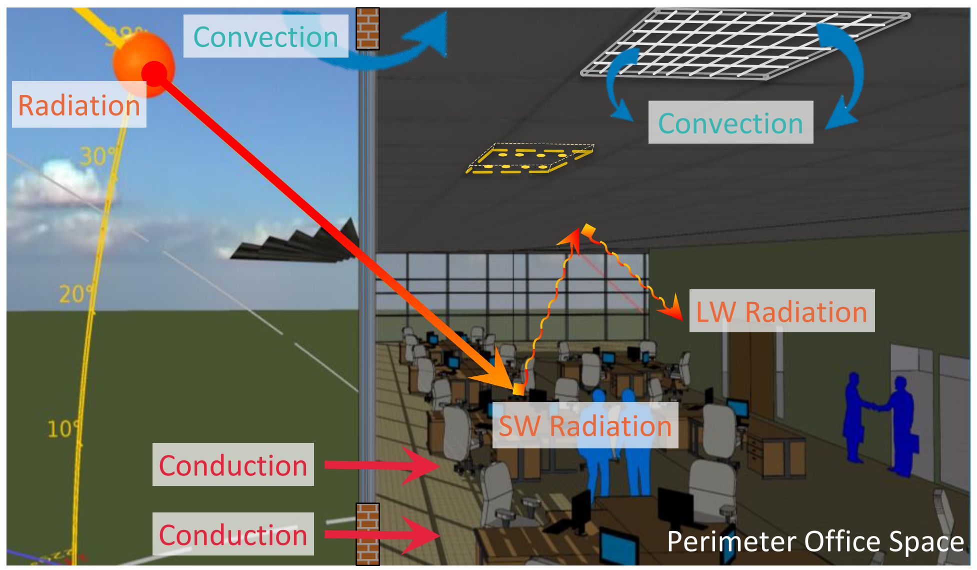
AAHP/ASHP – Air-Source (air-to-air) Heat Pump
ABCH – Absorption Chiller
ACB – Active chilled beam
ACC – Air-cooled chiller
ACE – Air change effectiveness
ACH – Air changes per hour
ACU/ACCU – Air-cooled condensing unit
AHJ – Authority Having Jurisdiction
AHU – Air Handling Unit
APACHE – Application for Air Conditioning & Heating Engineers
ASE – Annual Sunlight Exposure (%)
AQI – Air Quality Index
ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers
AWHP – Air-to-Water Heat Pump
BEM – Building Energy Modeling
BHP – Brake Horsepower
Btu – British Thermal Unit
CAV - Constant Air Volume
CC – Cooling Coil
CFM – Cubic Feet per Minute
CFD – Computational Fluid Dynamics
CHWR – Chilled Water Return
CHWS – Chilled Water Supply
CHST – Chilled Water Storage Tank
CIBSE – Chartered Institute of Building Services Engineers
CO2e – Carbon Dioxide Equivalent
COP – Coefficient of Performance
CT – Cooling Tower
CU – Condensing Unit
CW – Condenser Water
CWR – Condenser Water Return
CWS – Condenser Water Supply
DA – Daylight Autonomy
DHW – Domestic Hot Water
DOAS – Dedicated Outdoor Air System (Unit)
DWH – Domestic Water Heater
DV – Displacement Ventilation
EA – Exhaust Air
EAT – Entering Air Temperature
EER – Energy Efficiency Ratio
EF – Exhaust Fan
EPD – Equipment Power Density (plug load)
ESP – External Static Pressure
EUI – Energy Use Intensity ($kBtu/ft^2/year$ or $kWh/m^2/year$)
EW – Enthalpy Wheel
EWC – Electric Water-cooled chiller
EWT – Entering Water Temperature
FC – Fluid Cooler
FCU – Fan-coil Unit
GPM – Gallons per minute
GSHP – Ground Source Heat Pump
HC – Heating Coil
HHWR – Heating hot water return
HHWS – Heating hot water supply
HPWH – Heat Pump Water Heater
HRC/HPC – Heat recovery/heat pump chiller

HRV – Heat Recovery Ventilator
HX – Heat exchanger
IAQ – Indoor Air Quality
IBPSA – International Building Performance & Simulation Association
IDDE – Indirect/Direct evaporative cooler
IES – Integrated Environmental Solutions Ltd.
IPLV – Integrated Part Load Value
kW – Kilowatt, unit of power or load
kWh – Kilowatt Hour, unit of Energy
LAT – Leaving Air Temperature
LEED – Leadership in Energy and Environmental Design
LPD – Lighting Power Density (W/ft^2, W/m^2)
LWT – Leaving Water Temperature
MA – Mixed Air
MAT – Mixed Air temperature
MAU/MUA – Make-up Air Unit/Make-up Air
MBH – Thousand btu per hour
OA/OSA – Outdoor (ventilation) air
PHC – Pre-heat Coil
PMV – Predicted Mean Vote
PPD – Percent People Dissatisfied (%)
PSZ – Packaged Single Zone HVAC unit
PTAC - Packaged Terminal Air Conditioner
PTHP – Packaged Terminal Heat Pump
PV - Photovoltaics
PVT Panel – panel which generates both electricity and hot water
RA – Return Air
RF – Return Fan
RPM – Revolutions per minute
RTU – Rooftop Unit
R-value – thermal resistance of assembly/layer ($h*ft^2*°F/Btu$) [$(m^2*K)/W$]
SA – Supply Air
SDA – Spatial Daylight Autonomy (%)
SEER – Seasonal Energy Efficiency Ratio
SF – Supply Fan
SHGC – Solar Heat Gain Coefficient
SHW – Solar Hot Water or Service Hot Water
SWEE - Sanitary Wastewater Energy Exchanger
TDH – Total Design Head (Pressure)
TDV – Time Dependant Valuation
TES – Thermal Energy Storage
TMY – Typical Meteorological Year
Ton (cooling) – 12,000 Btu/hr
TSP – Total Static Pressure
TU – terminal unit (sometimes also called a VAV box)
UFAD – Underfloor Air Distribution system
U-Value – Heat Transfer Coefficient of an Assembly, ($Btu/h*ft^2*°F$) [$W/(m^2*K)$]
VAV – Variable Air Volume
VRF – Variable Refrigerant Flow
VRV – Variable Refrigerant Volume
VSD – Variable Speed Drive
WAHP/WSHP – Water source (Water-to-air) Heat Pump
WCU – Water-cooled condensing unit
WSE – Waterside Economizer
WWHP – Water Source (water-to-water) Heat Pump
WWR – Window-to-Wall Ratio
ΔT – temperature differential
ρ – Density (kg/m^3, lb/ft^3)

Fundamentals of Building Heat Transfer

Heat is the primary form of energy used (and wasted) in buildings. How heat is used (or moved) in a building is often the primary source of its energy consumption and carbon footprint. With some exceptions, heating and cooling a building is responsible for more than half of most building's energy consumption and energy cost. To maintain a constant deep tissue temperature of 37.2°C (99°F), our bodies must exchange heat with the environment by **conduction, convection, evaporation and radiation**.

- **Internal Heat Gains** (e.g. plug loads): Convective and radiant heat gains from electric and process equipment.
- **Occupant Gains**: Convective and radiant heat transfer by sensible and latent heat gains, dependent on person's clothing, activity and metabolic rate.
- **Lighting Gains**: Radiative and convective heat gain, may be controlled by illuminance and occupancy sensors.



- **Conductive** heat flow through the **building fabric** (walls, glazing, etc.) is influenced by the difference between indoor and outdoor temperatures, indoor air movement and external wind.
- **Convective** heat transfer due to **air infiltration and air exfiltration**, is mostly uncontrolled flow of air through cracks and gaps in the building fabric. This is influenced by indoor and outdoor temperatures, air buoyancy, wind, number of windows and other openings (e.g. louvres), building height and quality of construction.
- **Direct and Diffuse Solar (short-wave)** Radiation passes through glazing and is absorbed by materials inside. Re-radiated long-wave radiation is mostly trapped inside. Ground reflected radiation is also a factor.
- **Transient (non steady-state)** heat flow may be stored thermal energy, which is absorbed into and connected from the building fabric's thermal mass. Conduction, convection & radiation are all influential dynamic factors.
- Forced Convective heat from **Ventilation Air** is frequently conditioned by HVAC system components (e.g. coils).

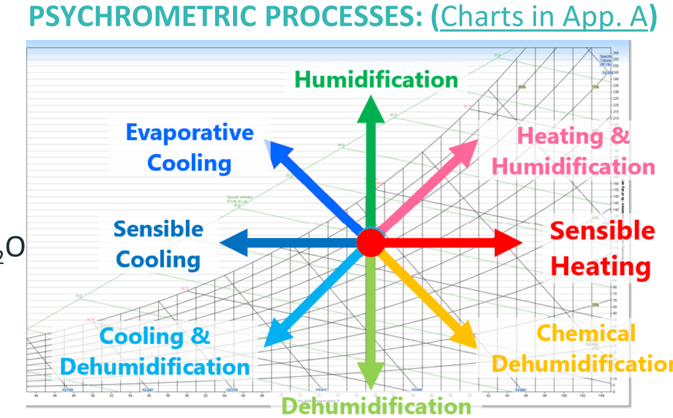
PSYCHROMETRIC (AIR) EQUATIONS:

Sensible Heat (Q_S):
- Q_S (Btu/h) = $cfm*1.094*\Delta T$, where T = Temperature °F.
- Q_S (kW) = $L/s*1.2*1.02*\Delta T$, where T = Temperature °C.

Latent Heat (Q_L):
- Q_L (Btu/h) = $cfm*4840*\Delta W$, where W = humidity ratio lb/lb
- Q_L (Btu/h) = $cfm*0.68*\Delta grains$, where 7,000 grains = 1 lb. H_2O
- Q_L (kW) = $L/s*3.0*\Delta W$, where W = moisture conc. g/kg

Total Heat (Q_T):
- Q_T (Btu/h) = $cfm*4.5*\Delta h$, where h = Enthalpy Btu/lb.
- Q_T (kW) = $cfm*1.2*1.02*\Delta h$, where h = Enthalpy kJ/kg.

PSYCHROMETRIC PROCESSES: (Charts in App. A)



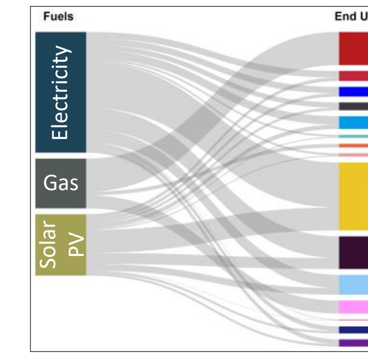
Building Energy and Carbon

Buildings consume 40% of the world's energy and are responsible for 33% of greenhouse gas emissions (CO2e) globally. They consume double the amount of energy as transportation systems and contribute 50% more to CO2e than transportation systems. In the USA, about 76% of all electricity is consumed by buildings.

Building Energy Modeling (BEM) is the best way to understand how energy is used by new buildings, by simulating its annual sub-hourly performance with validated BEM software (e.g. 8,760 hours annually). BEM is used for building design and to identify cost-effective strategies for reducing energy use, operational utility cost and carbon emissions.

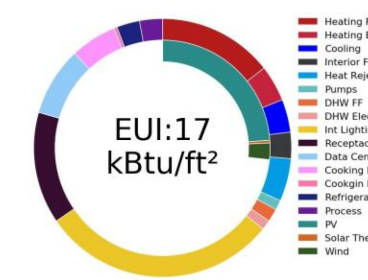
FUELS:

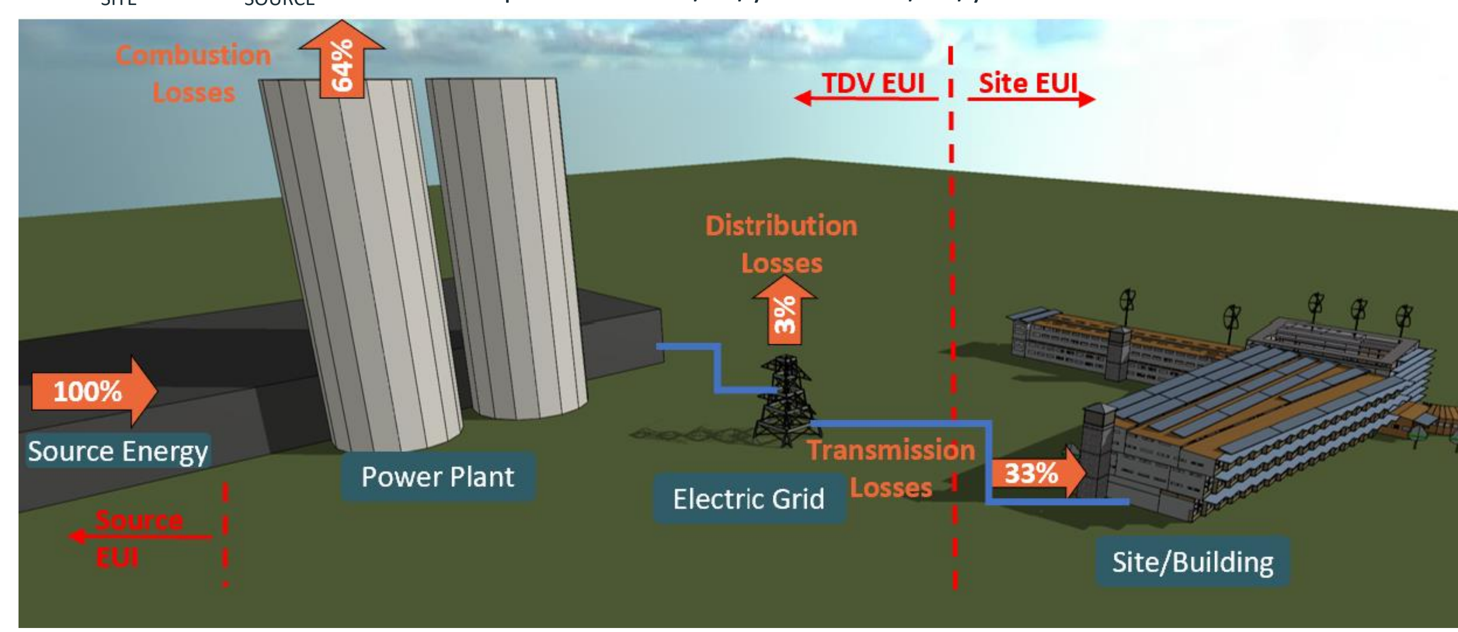
Buildings primarily use electricity and fossil fuels, notably natural gas. Other fuels like propane (or LPG) and renewable energy are sometimes used. Some buildings are connected to a campus or district energy plant, which generate energy off-site in the form of hot/chilled water, or steam. An understanding of the fuel (E.g. electricity) to energy end-use (E.g. Internal Lighting) is a critical component of understanding BEM-related metrics.



METRICS:

- **Site Energy Use Intensity (EUI_{SITE})** or Building EUI accounts for the net-energy used within the site or building(s) boundary. The inefficiencies associated with the creation, transportation, and distribution of electricity and fossil fuels are not accounted for. **[Net Energy = Energy Used – Energy Produced]**.
- **Source Energy Use Intensity (EUI_{SOURCE})** or Primary Energy Intensity accounts for all of the net-energy consumption from the operation of the building(s), but this metric accounts for the energy processes to create (E.g. Power plant), transport and distribute (E.g. Grid) the fuels and electricity to the building(s).
- EUI_{SITE} and EUI_{SOURCE} metrics are reported as kBtu/ft²/year or kWh/m²/year.





- **CO2e** – carbon dioxide equivalent measures the total GHG emissions generated within a building site boundary. CO2e is reported as $kgCO_2/ft^2/year$ or $kgCO_2/m^2/year$.
- Common BEM metrics include energy, carbon and cost, but there are many more used in industry.

Climate and Weather

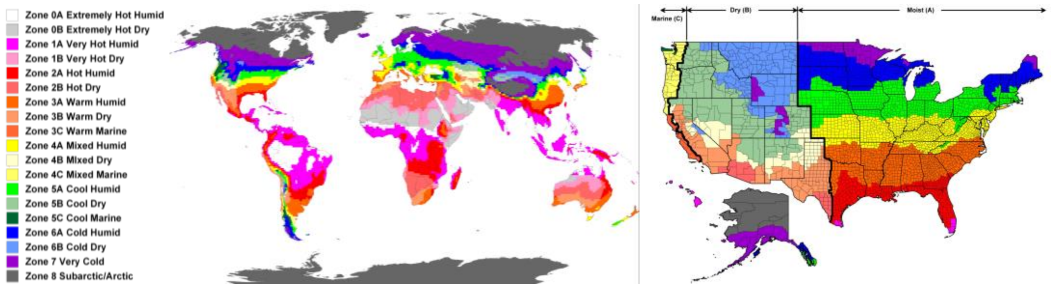
Weather refers to short-term (minutes to months) changes in the atmosphere, with respect to its effects upon life and human activities. It is often referred to in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure, as in high and low pressure.

Climate refers to long-term (e.g. 30 years) pattern of weather in a particular geographical region. Think of Climate as an average pattern of weather for a region. Weather is what we get in the moment; climate is what we can expect over time.

ASHRAE Standard 169: Climatic Data for Building Design Standards has classified **Climate Zones** & **Moisture Zones**.

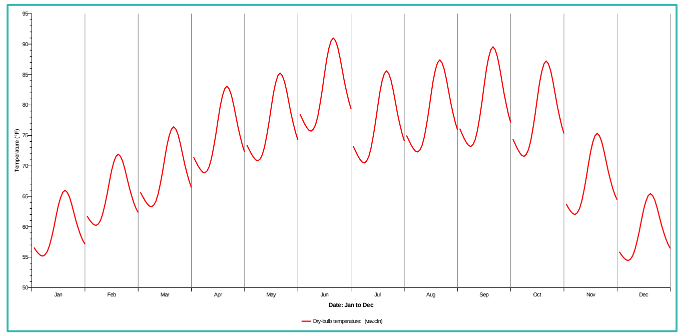
CLIMATE ZONES (CZ):
0, 1, 2, 3, 4, 5, 6, 7 and 8

MOISTURE ZONES:
(A) Humid
(B) Dry
(C) Marine

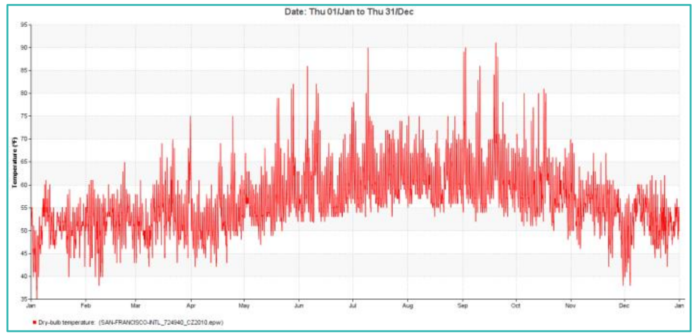


Designers often consider one, two, or three scenarios of the climate for analyzing the performance of a building.

1. Design Weather is often used to calculate the size and capacity of HVAC Systems and Equipment. These types of ***monthly*** design conditions are to be used for a conservative "worst-case" ***daily*** scenario.

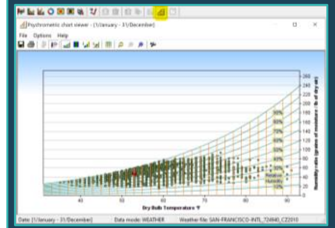


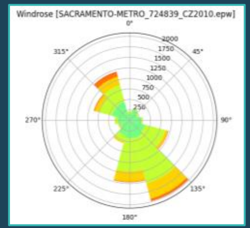
2. Annual Weather Data (All Hours) is used to estimate the typical performance of buildings. Common annual formats are Typical Meteorological Year (TMY) or Actual Meteorological Year (AMY).

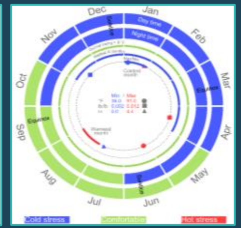


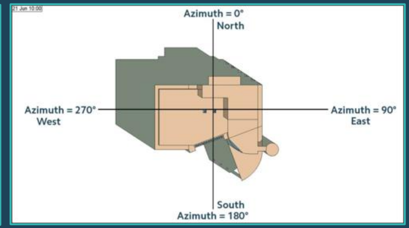
3. Future Annual Hourly Weather Data refers to morphed weather patterns for a given future scenario. These datasets are provided in a Typical (TMY) format and represent all 8,760 hours per year for a range of variables.

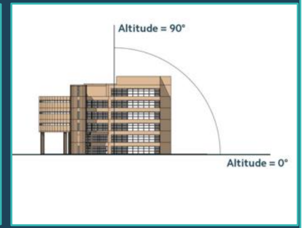
For any given weather data set, it may be important to analyze the State Frequencies of Air Conditions (Psychrometrics), Wind-Rose (direction & speed) Trends, Diurnal swings and Solar angles (Altitude & Azimuth).









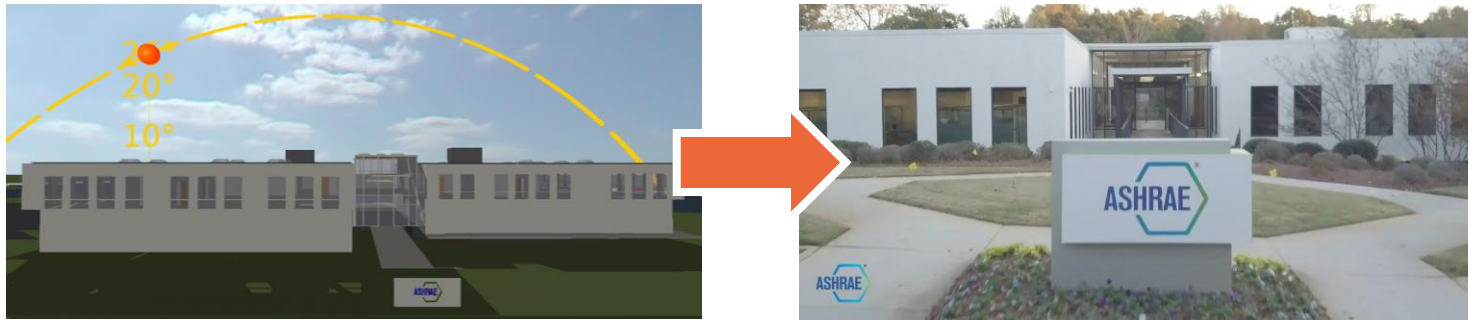


- Weather Files are available from: iesve.com/support/weatherfiles

Building Architecture

THE VIRTUAL MODEL BUILDING

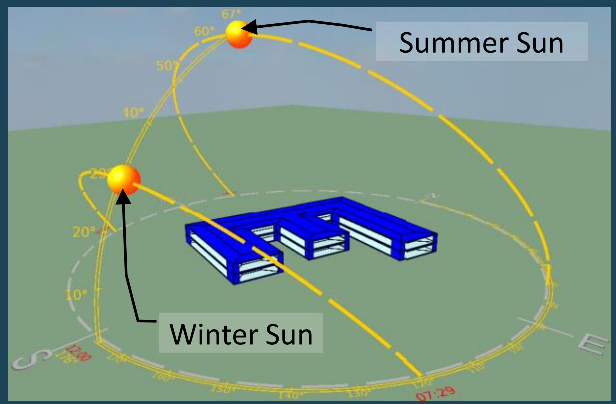
A 3-Dimensional (3D) digital version of a building design is often developed in order to consider various design options. For example, the impact of window shades may be considered to reduce solar gains and subsequently reduce cooling demands from the building spaces. The ASHRAE Headquarters building is a good example.



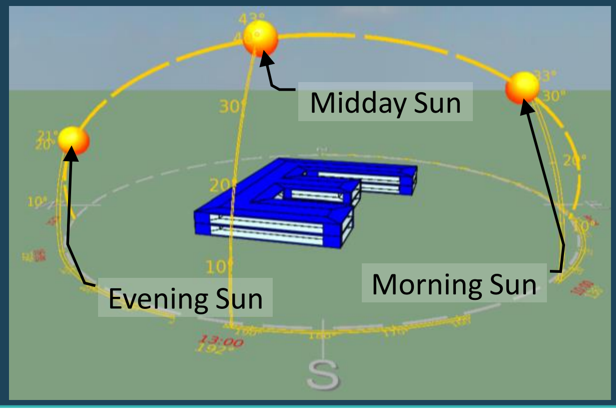
The architecture of a building often provides many opportunities to optimize the eventual building performance. Areas of architectural analysis may include [1] Building Form & Orientation, [2] Window-to-Wall Ratio (% Glazing), [3] External Shading devices and [4] Optimized Building Envelope (Daylighting).

SOLAR ANALYSIS AND ZONING STRATEGIES

Awareness of solar positions and building self-shading can help to influence the thermal/HVAC zoning strategies of spaces within the building.

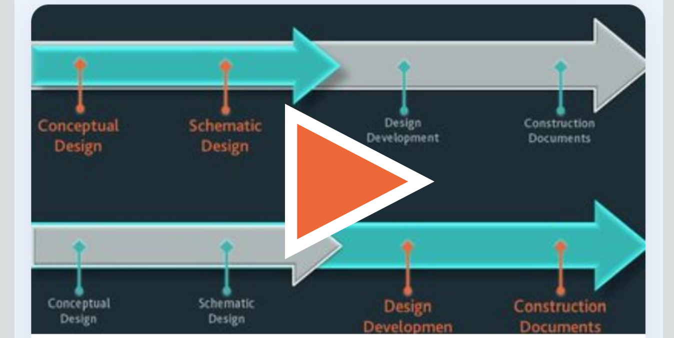


Example shown for Northern hemisphere.



LEARN HOW TO CREATE MODEL GEOMETRY FOR
1. Schematic Design (SD)
   - And Shoebox Modeling
2. Detailed Design (DD)

https://learn-on-demand.iesve.com/p/creating-model-geometry-in-iesve



Meet the AIA 2030 Commitment:

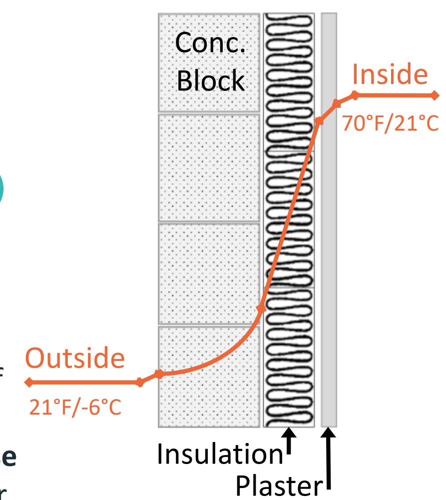
Learn how to support the AIA 2030 Challenge, by ensuring all new buildings shall be carbon-neutral by the year 2030.

https://www.iesve.com/software/aia-2030-ddx

Opaque Building Constructions and Assemblies

The thermal performance of the **Building Envelope** (roof, walls, floor, glazing) plays a significant role in heat flows, and therefore influences the HVAC system size and building energy use. An important balance of thermal performance must consider thermal inefficiencies such as glazing, in order to provide better visual performance, daylight and views for the occupants. The envelope functions as the barrier between the indoor and outdoor environment. The overall heat transfer coefficient of an envelope assembly is represented by a calculated **U-value** or **U-factor.**

- **U-value** = Heat Transfer Coefficient of an assembly, including for all layers (Btu/h*ft^2*Degree F) [W/(m^2*K)]. $U = (1/R_{TOTAL})$.
- R_{TOTAL} = Total thermal resistance of all assembly layers, including air resistance (h*ft^2*Degree F/Btu) [(m^2*K)/W].
  $R_{TOTAL} = (R_{OUTSIDE\ AIR} + R_{MATERIAL\ \#1} + R_{MATERIAL\ \#2} + R_{MATERIAL\ \#3} + \ldots + R_{INSIDE\ AIR})$
- **R** = Thermal resistance of heat flow for a material. $R = L / k$, where:
  L = Thickness of a Material (inches) [mm]
  k = Thermal Conductivity of a Material (Btu.in/h.ft^2.°F) [W/(m*K)].
- **Density (ρ)** – the mass per unit volume (lb/ft^3) [kg/m^3]
- **Specific Heat Capacity (c_p)** – amount of heat that must be added to one unit of mass to raise the temperature one unit (Btu/lb.°F) [J/(kg.K)]
- **Thermal mass** – ability of a material (or assembly) to **absorb, store, and release** heat. Note the non-linear temperature profile through the concrete block layer.



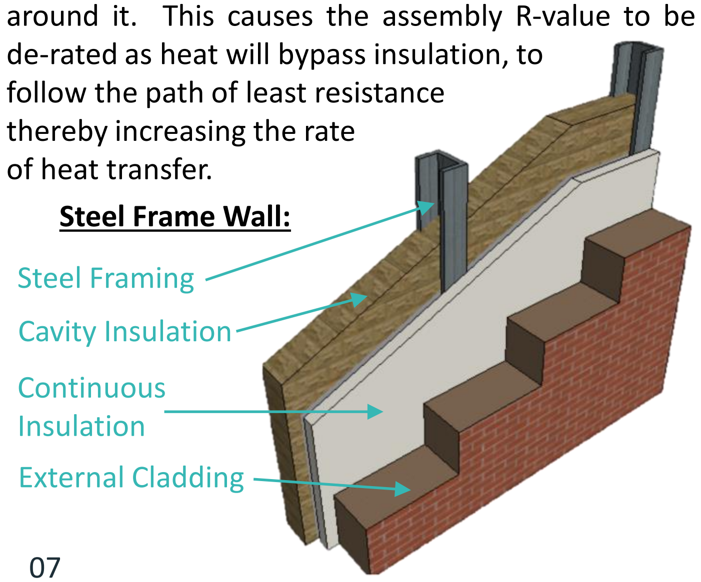
- **Envelope Heat Transfer (Q):** $Q = \text{U-value} * \text{Area of Assembly} * (Temp._{OUTSIDE} - Temp._{INSIDE})$
- **Vapor Resistivity** – measure of material's ability to resist permeation of water vapor (perm.in)$^{-1}$ [GN.s/(kg.m)]
- **Solar reflective index (SRI)** – indicator of the ability of a roof to return solar energy to the atmosphere
- **Emissivity** – effectiveness in emitting energy as thermal radiation.
- **Infiltration Sensible Heat Transfer** due to air leakage: $Q_S = CFM * c_p * (Temp._{OUTSIDE} - Temp._{INSIDE})$, where:
  $CFM = (ACH*Volume) / 60$, making as assumption of ACH due to infiltration. E.g. between 0.05 – 0.25.

Air tightness limits may be given for an entire assembly, e.g. 0.04 cfm/ft^2 under a specified pressure differential.

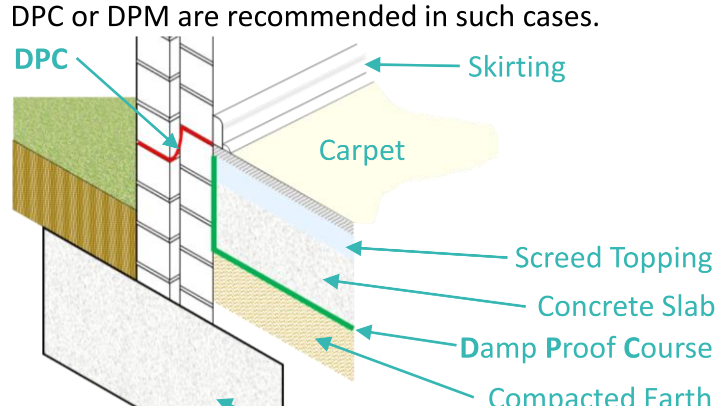
- **Characteristic Dimension (*B'*)** is an approximation used to calculate the building ground-contact heat transfer.
  Characteristic Dimension = Building Area / (0.5* Building Perimeter)

Thermal Bridging occurs when heat moves across an object that is more conductive than the materials around it. This causes the assembly R-value to be de-rated as heat will bypass insulation, to follow the path of least resistance thereby increasing the rate of heat transfer.

Steel Frame Wall:



Condensation will occur interstitially, if the vapor pressure *is equal or greater than* the saturated vapor pressure within a construction. Vapor Barriers like DPC or DPM are recommended in such cases.



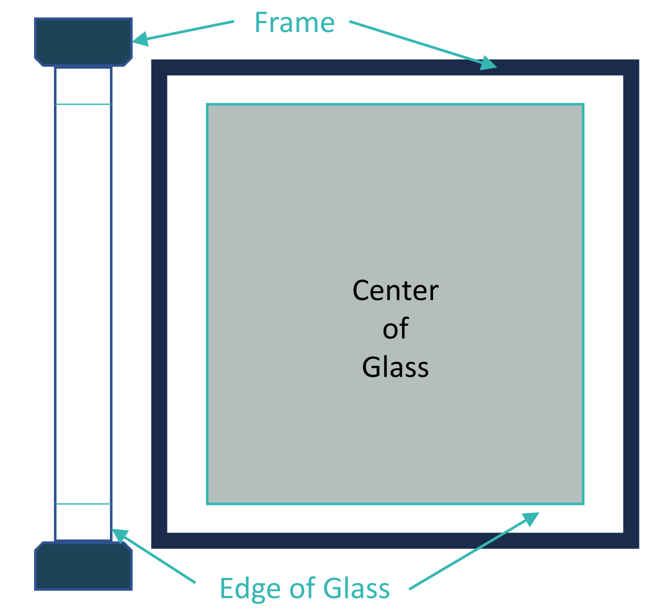
Ground Concrete Floor

Glazing – Thermal and Light

Glazing systems allow heat and light to transmit into and out of a building.

Thermal Properties of Glazing:

- **Center of glass (CoG) U-value** – the U-Value of glazing measuring only the glass itself.
- **Assembly U-value** – the U-Value of glazing including the effects of the frame and mullions. Typically, the assembly U-value is worse (higher) than the CoG U-value.
- **Solar Heat Gain Coefficient (SHGC)** – a measure of how effectively glass blocks heat (not light) from the sun. A lower SHGC value means a lower portion of solar heat is transferred through the glazing.
- **Shading Coefficient (SC)** – replaced by SHGC in the USA but still used in some international locations.
  $SHGC = (SC * 0.87)$
- Transmitted solar radiation is also a function of external shading and building self-shading.



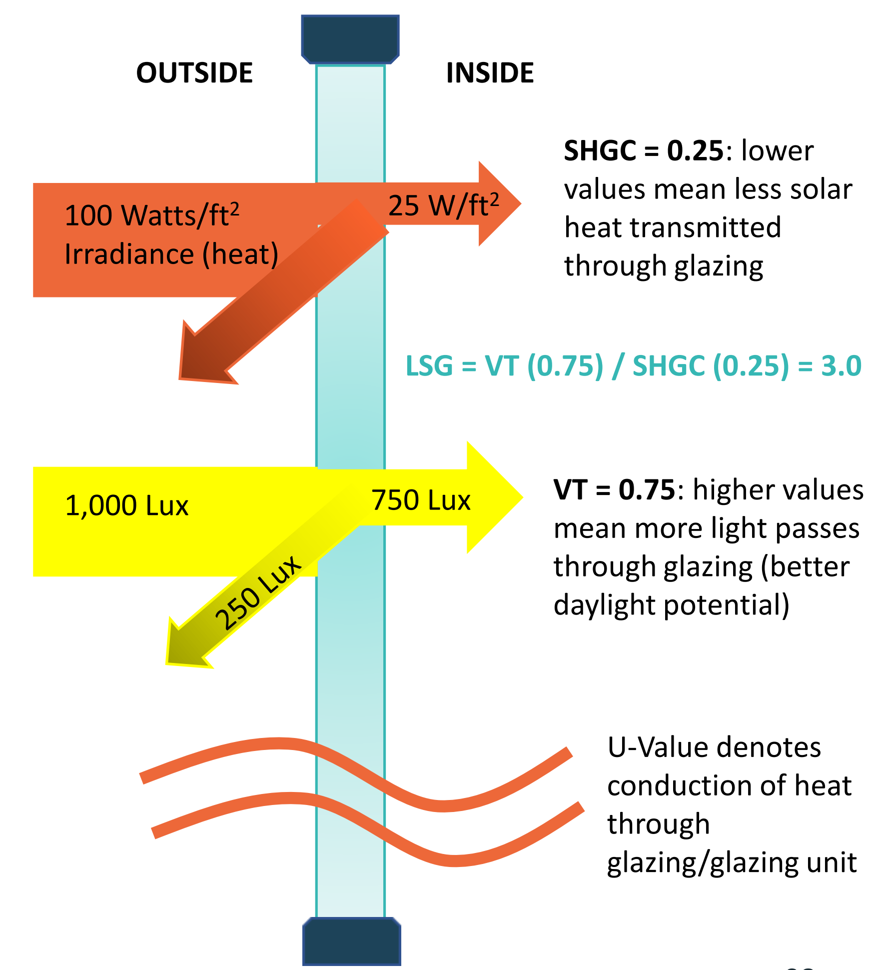
Visible Light Transmittance (VLT) or **Visible Transmittance (VT)**

- Measure of how much light in the visible spectrum passes through glazing (not heat). A lower VT means less visible light passes through the glazing.

Light to Solar Gain Ratio (LSG)

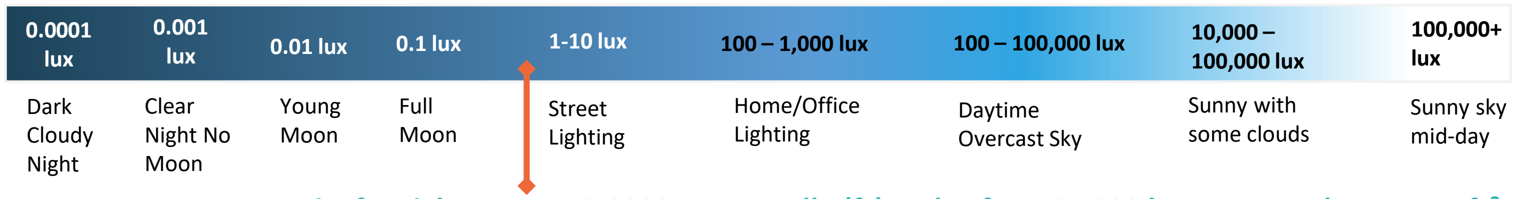
- The ratio of VT to SHGC. A high LSG ratio indicates better daylight potential. However, this must be balanced against the overall SHGC, orientation of the glazing, space type, and climate.

- **"Ideal" glazing properties depend on orientation, climate, window-to-wall ratio (WWR), shading, and building use.** Generally, lower SHGC values are desired in hot climates and lower SHGC values are desired in cold climates for passive solar heating.



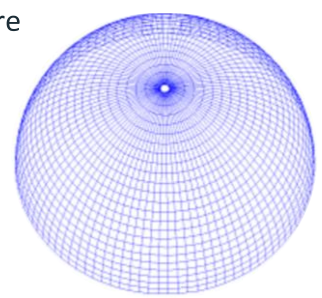
Daylight

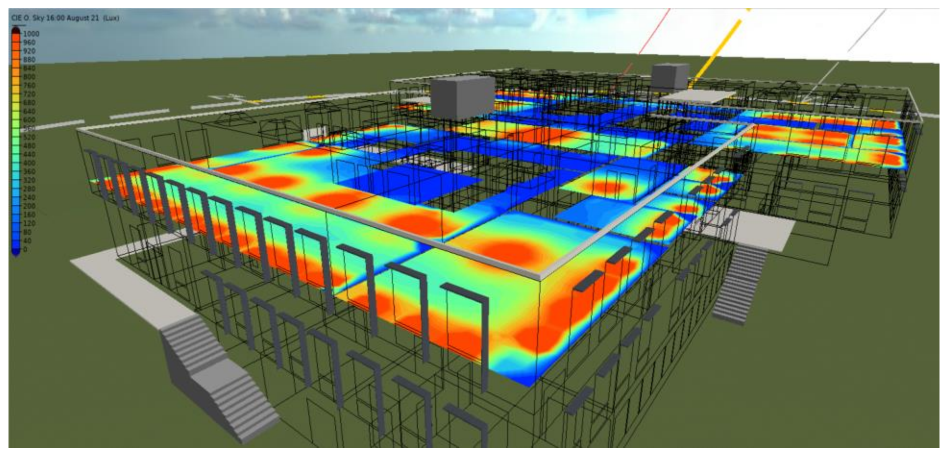
Useful daylight in buildings can be used to reduce energy consumption, by reducing the number of hours electric lighting systems are energized, which in turn, reduces the sensible lighting heat gains and reduces mechanical cooling demands. Views to outdoors and exposure to natural daylight offers health & wellness benefits to building occupants. A good daylight design can be achieved by optimizing the vertical & horizontal fenestration layouts, utilizing a high-VLT glazing specification and giving consideration to the external dynamic sky conditions.



Units for Light: 1 Lux = 0.0929 Foot.candle (fc) and 1 fc = 10.7639 lux. 1 Fc = 1 lumen per ft².

For dynamic daylight simulation, climate-based daylight modeling (CBDM), a sky resolution may split the sky hemisphere into up to 2,305 sky patches.

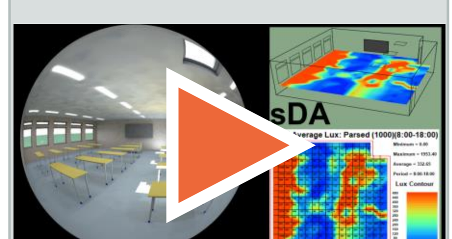




Sky conditions and **exterior obstructions** (trees, shades, blinds, overhangs, adjacent structures) will impact indoor daylight effectiveness and unwanted glare. These factors must be included in daylight model prediction. **Properties of materials** (reflectance, specularity, color, transmittance, etc.) should be included to account for useful & spatial daylighting and lighting effectiveness.

IMPORTANT DAYLIGHT METRICS:
Spatial Daylight Autonomy (sDA) is the annual sufficiency of daylight levels in a space. sDA examines the percentage of an analysis area (e.g. working plane) that meets a minimum illuminance level (e.g. 300 lux) for a specified fraction of the operating hours per year (e.g. 50% of the annual operational hours).
Useful Daylight Illuminance (UDI) is the annual occurrence of illuminances that is within a "useful" range for occupants. UDI ranges are defined as:
(1) Insufficient e.g. <100 lux; **(2)** Supplementary e.g. 100-500 lux.
(3) Autonomous e.g. 500 – 2,500 lux; **(4)** Exceedance > 2,500 lux.
Daylight Factor (DF %) is the ratio of the illuminance at a point on a plane in a room due to the light received from a sky of assumed or known luminance distribution, to that on a horizontal plane due to an unobstructed hemisphere of this sky.
- Definitions of other metrics including **Annual Sunlight Exposure (ASE)** and **Daylight Glare Probability (DGP)** can be reviewed ***here***.

Learn how to simulate daylight, glare probability and electric lighting systems: https://learn-on-demand.iesve.com/p/daylight-simulation-glare-modeling-lighting-energy-calculations

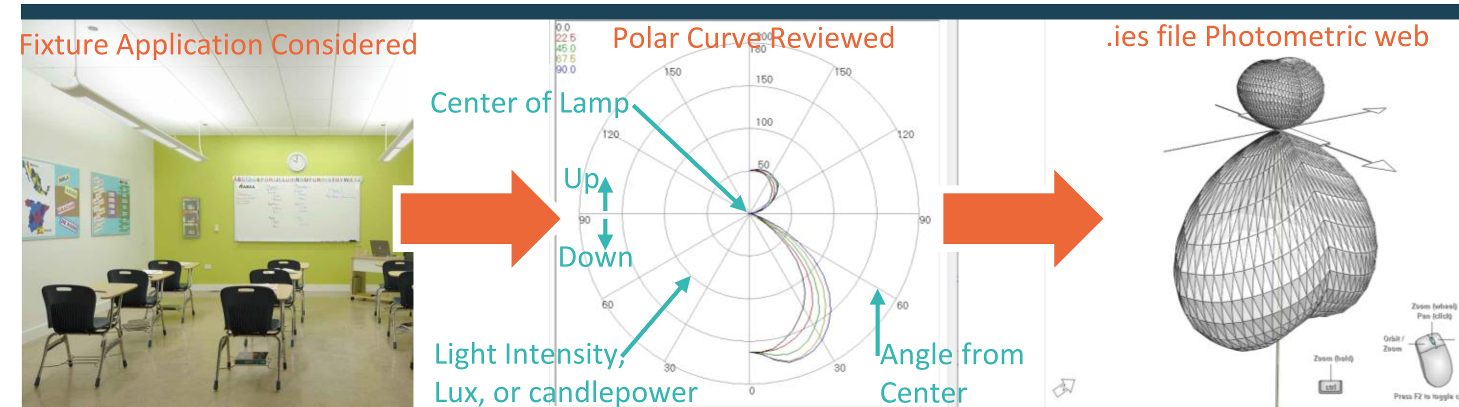


Electric Lighting

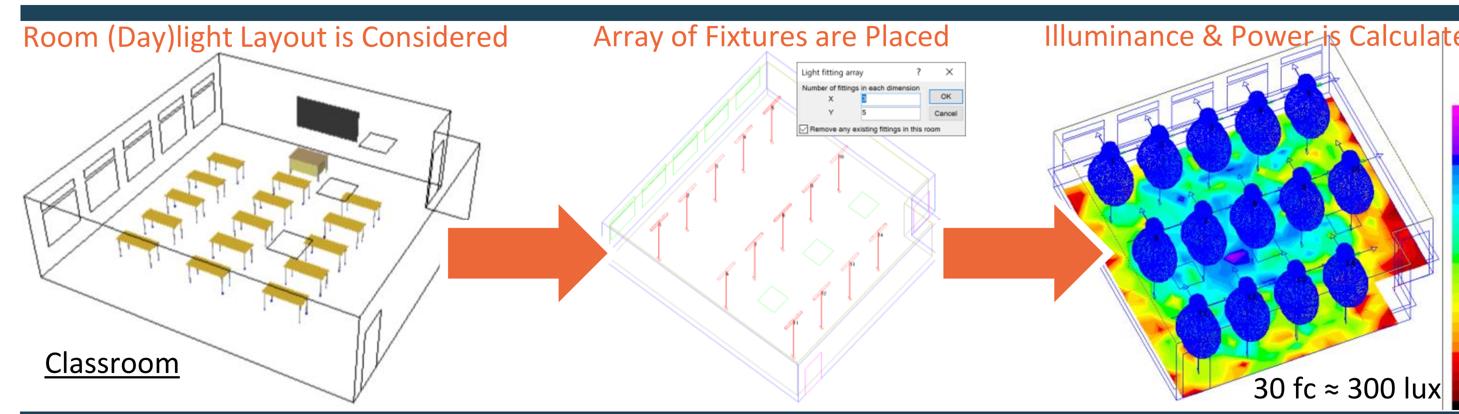
A **Luminaire** is a lighting fixture. E.g. a Recessed lighting fixture or a Direct/Indirect Pendant Lighting Fixture.
A **Lamp** is a component of a luminaire (or light fixture), sometimes referred to as the bulb.
Different types of lamp technology may be rated in terms of **Luminous Efficacy**. For example:

- L.E.D. technology is the most energy efficient with luminous efficacy of ~100-200+ lumens per watt.
- Fluorescent lamps (~90 lumens/watt) or incandescent lamps (~15 lumens/watt) are less efficient. Fluorescent lamps also require a ballast control device to restrict the amount of electric current to it.

Lighting manufacturers will often provide **luminous intensity distribution curves** for their light fixtures or lamps. These are sometimes referred to as or **Polar Curves** which are a graphical representation of the light output (or luminous intensity) from a lamp/luminaire.
A digital version of a Polar Curve is frequently available as an **.ies file**, viewed as a Photometric web below.



Lighting System design is frequently based on the **Point to Point Method (or Lumen Method)** to calculate the horizontal illuminance (lux) on a **work plane** (e.g. desk) in a space, as well as the **uniformity** of light distribution.



Typical recommended lighting levels and **Lighting Power Density (LPD)** for some space types are shown below.

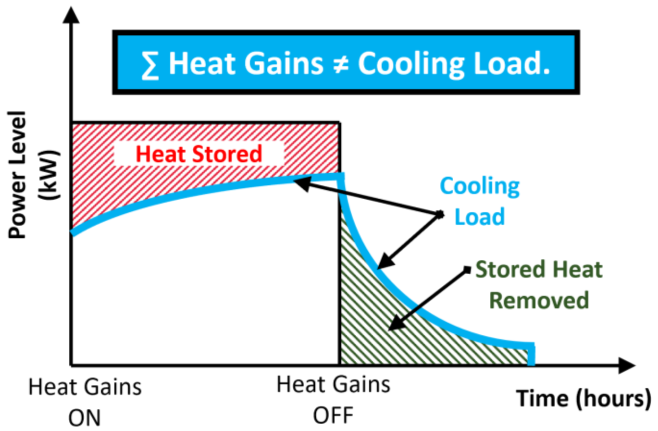
Room Function (values from IESNA)	Lighting Levels		Lighting Power Density (LPD) *	
	(Foot Candles)	(Lux)	(Watts per ft^2)	(Watts per m^2)
Classroom - General	30-50 FC	300-500 lux	0.71	7.64
Corridor - General	5-10 FC	50-100 lux	0.41	4.41
Kitchen / Food Prep	30-75 FC	300-750 lux	1.09	11.73
Laboratory (Professional)	75-120 FC	750-1200 lux	1.33	14.32
Office – Open Plan	30-50 FC	300-500 lux	0.61	6.57

*Lighting Power also generates heat to the space.

Internal Gains – Occupants and Plug Loads

Occupants

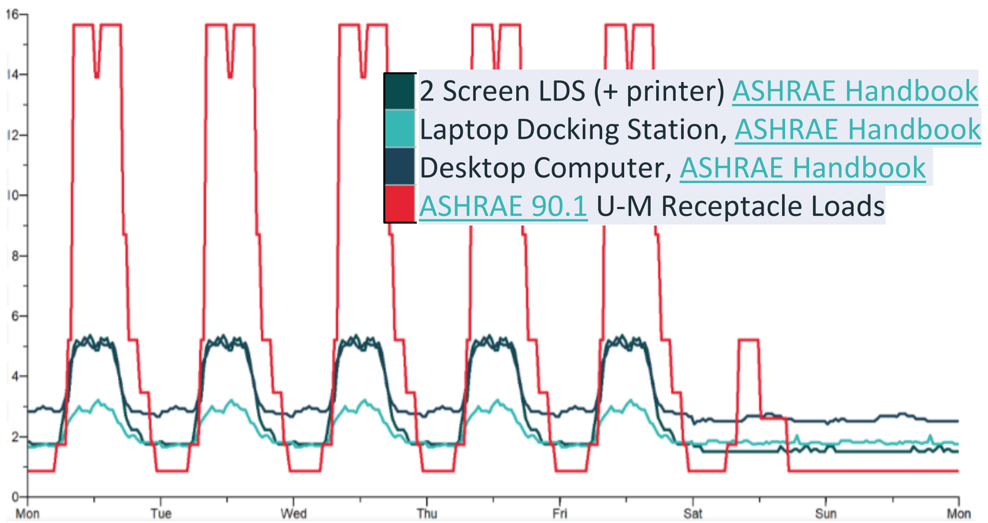
With the exception of some mission critical buildings (e.g. data centers) and storage facilities, most buildings exist for people to occupy. Each occupant adds both sensible and latent heat to the space depending on their activity level, metabolic rate, and age. Occupant heat gains are either calculated per person, or accounted for by occupant density, e.g. person per floor area.



INTERNAL GAINS AND LOAD CALCULATIONS

- **Cooling Loads for Room/Zones –** when space cooling loads are calculated, internal gains are typically conservatively considered to be 100% on during the design day calculation.
- **Cooling System Sizing –** in most (but not all) cases, internal gains are slightly reduced to account for load diversity. This is most commonly achieved by applying a diversity factor to the heat gains of 10-20%, depending on the gain.
- **Heating Loads –** internal gains (lighting, plug, occupants) are typically ignored for the heating load calculations so that equipment capacities are not undersized.

Level of Activity (values from ASHRAE)	Typical Application	Heat Gain (per/person)				Equipment Power Density	
		Sensible (Btu/h)	Latent (Btu/h)	Sensible (Watts)	Latent (Watts)	Sensible W/ft²	Sensible W/m²
Seated at rest	Theater	225	105	66	30	0.5	5.4
Seated, light work	Office	245	155	72	45	1.5	16.1
Moderate office work	Office	250	200	73	60	1.5	16.1
Standing, walking slowly	Retail Sales	250	250	73	73	0.5	5.4
Light bench work	Factory	275	475	80	140	1.0	10.7
Athletics/Dancing	Nightclub/Gym	350-550	545-870	100-161	160-255	0.5	5.4
Heavy work	Factory Workshop	635	965	185	283	1.0	10.7
Children	Classroom	150	105	45	30	1.0	10.7



Equipment Gains (Plug Loads)

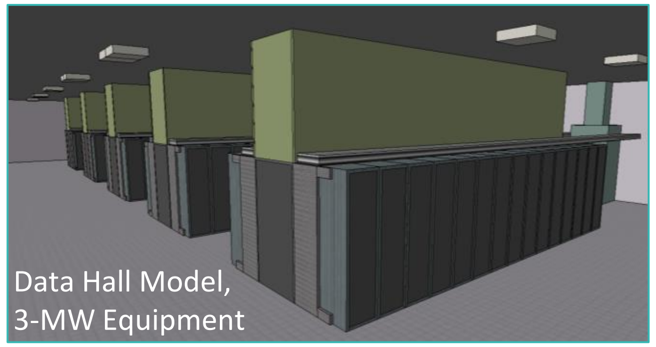
Most spaces have equipment that is plugged into receptacles (e.g. plug sockets in a wall) that use electricity and also give off heat – computers, televisions, table lamps, etc. Most frequently, equipment heat gains are input by space type in Watts, Watts/ft² or (W/m²). It is important to study the heat gain operation for a typical occupied weekday separately to weekends or holidays. E.g. a school's summer holidays.

Other End Uses and Process Energy

Commercial Kitchens are typically very energy intensive due to cooking energy demand from kitchen equipment (fryers, refrigeration, freezers, ovens, etc.); kitchen exhaust hoods and associated make-up air. from Cooking by products (steam, grease & odors) require thorough consideration for air pressurization and filtration. **Refrigeration Systems** include refrigerators, freezers, and ice making equipment.

Vertical Transportation: Multi-story buildings, especially high-rise multi-story buildings, require elevators and escalators to efficiently move people between floors. In addition to the equipment rooms, these systems can require pressurization fans. Note that escalators may operate continuously if no occupancy sensors exist, whereas elevators typically use energy during times of high occupant movement. E.g. morning, lunch and evening times in an office building.

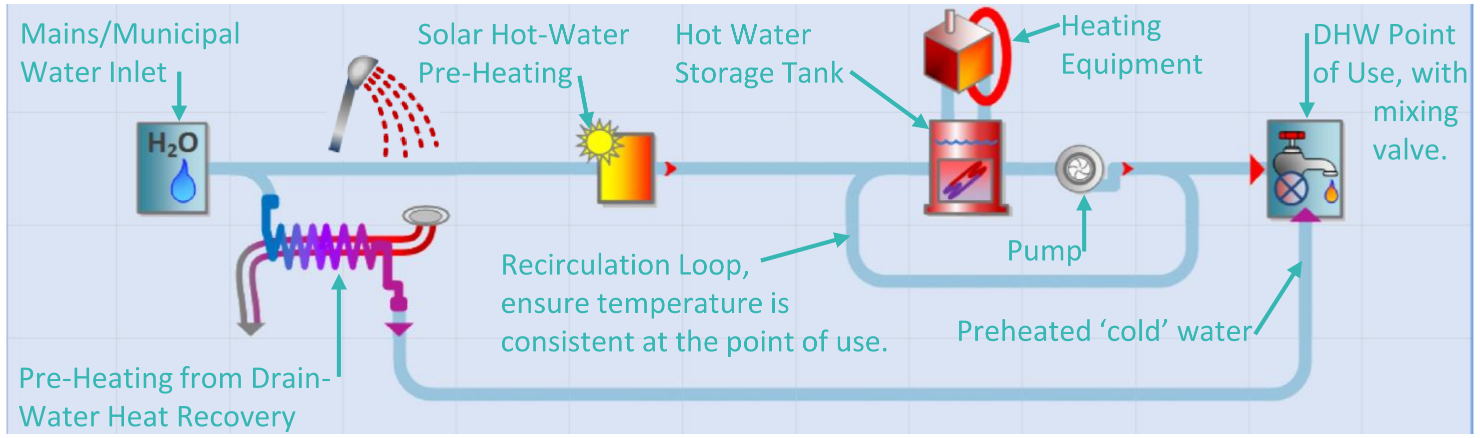
Energy Star
The US Department of Energy uses the Energy Star program to rate equipment in terms of energy efficiency. A full list of equipment and associated energy is HERE.



Data Hall Model, 3-MW Equipment

Computer Rooms: Most commercial buildings have some on-site I.T. computer room to house their server/comms equipment. ASHRAE differentiates a computer room from a data hall based on the energy intensity of the equipment installed. Computer rooms are defined by ASHRAE Standard 90.1 as having design power density of greater than 20 W/ft² (215 W/m²). Computer rooms require continuous mechanical cooling to maintain setpoints and prevent equipment from failing.

Exterior Lighting systems for buildings may be mounted on the external façade and within the site boundary. Examples include parking lighting, walkway lighting, retail entrances and lighting for secure ATM areas.
Process Energy examples may include manufacturing processes in a factory. **Other Process Energy** examples include snow melt systems, pump energy for water fountain features and Electric Vehicle (EV) charging stations. All of these should be accounted for in the energy model if the requirement is for *Site* Energy.
Service Hot Water or Domestic Hot Water (DHW) Heating is defined as heating water for domestic (DHW) or commercial purposes, other than space heating or process requirements. Water heating for commercial kitchens, showers, handwashing, cleaning and beauty salons are some examples of service water heating.

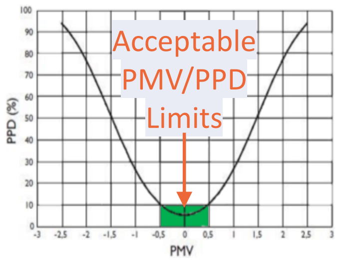


To avoid scalding, automatic temperature controls for public lavatory faucets/taps may be used to limit the outlet temperature to 110°F (43°C). Designers should be aware that the bacteria that causes Legionnaires' disease has been found in DHW systems and can colonize in hot water systems maintained below 115°F (46°C).

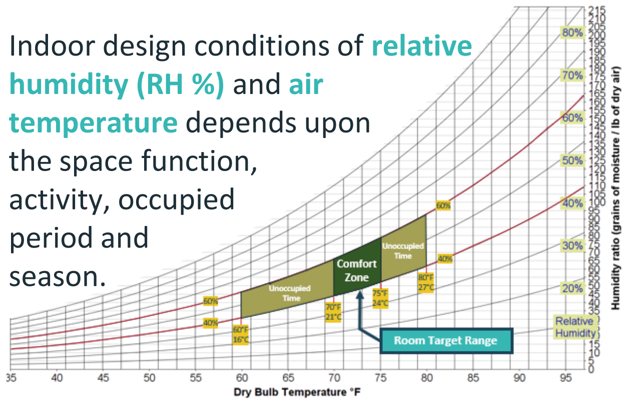
Occupant Thermal Comfort

The combinations of measurable indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space are defined in ASHRAE Standard 55.

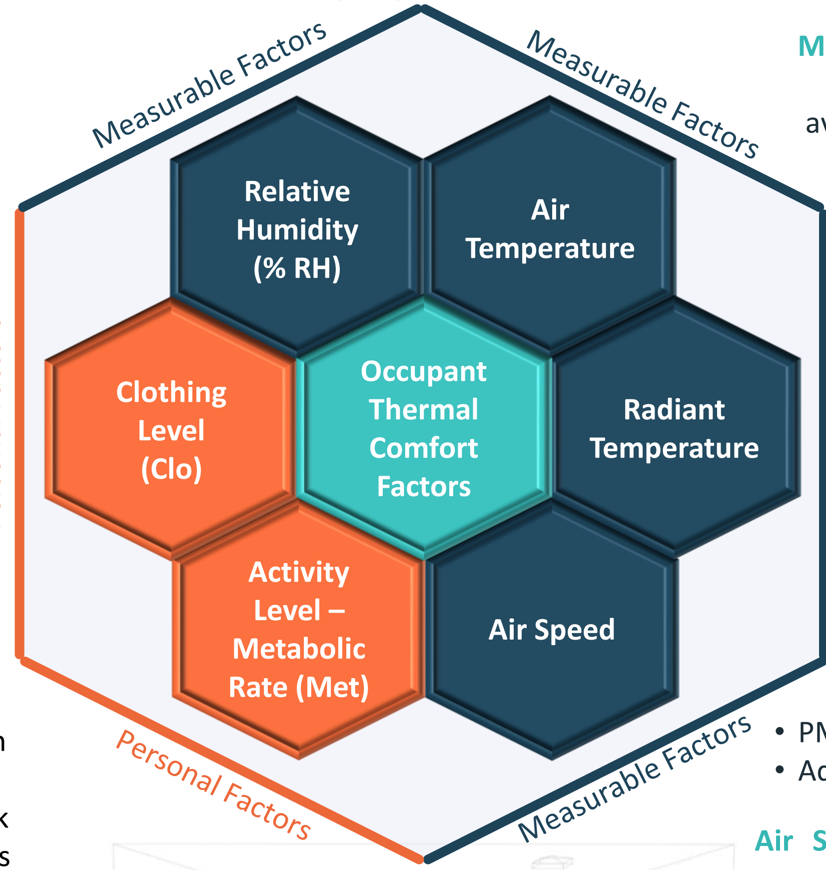
ASHRAE 55 Methods:
1. Analytical Comfort Zone Method uses Fanger's **7-point PMV-PPD** scale.
2. Graphic Comfort Zone
3. Elevated Air Speed Comfort Zone.



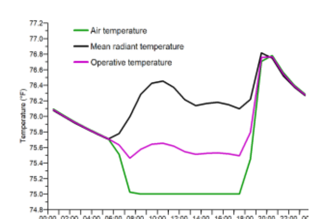
Indoor design conditions of **relative humidity (RH %)** and **air temperature** depends upon the space function, activity, occupied period and season.



Zone thermostatic controls are recommended by ASHRAE to provide an **air temperature range** of at least 5°F, within which the supply of heating and cooling energy to the zone is shut off or reduced to a minimum. E.g. 69°F-76°F or 18°C-24°C.

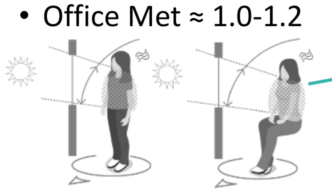


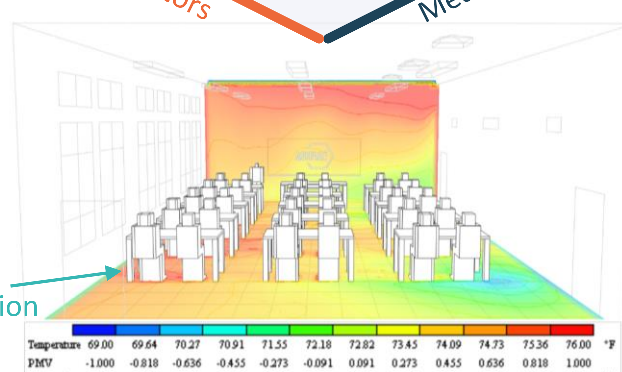
Mean Radiant Temperature (MRT) is a measure of the average temperature of the surfaces that surround a particular point, with which it will exchange thermal radiation.



Clothing Level (Clo) is used to express thermal insulation provided by clothing and varies depending on season & gender. Typical office Clo range is 0.5 to 1.1.
1 Clo = 0.88.ft²h°F/Btu & 0.155.m²°C/W.

Metabolic rate (Met) is the rate of transformation of chemical energy into heat and mechanical work in an organism. Met varies depending on occupant behavior. E.g.
- Resting Met ≈ 0.8
- Sporting Met ≈ 8.7
- Office Met ≈ 1.0-1.2

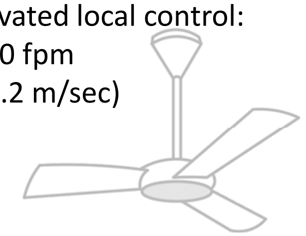




CFD comfort model shows the *range/gradient* of PMV & Operative Temperature in a room.

Operative Temperature is the ~average of the MRT & air temperature.
- PMV: 70–76°F, 21–24°C
- Adaptive: 64–86°F, 18–30°C

Air Speed is the rate of air movement at a point without regard to direction. 20-50 fpm (0.1-0.25 m/sec) is common. With elevated local control:
- 20-240 fpm
- (0.1-1.2 m/sec)



Ventilation and Indoor Air Quality

Humans require good Indoor Air Quality (**IAQ**) for health, wellness and productivity. Outdoor air, or ventilation air, that flows through a building is often used to **dilute and remove** indoor air contaminants. The common relevant phrase in industry is ***The Solution to Pollution is Dilution!***. Ventilation is the intentional introduction of air from the outside into a building; it is divided into natural ventilation and forced ventilation.

Forced ventilation is the intentional movement of air into and out of a building using fans, and intake & exhaust vents; it is also called **mechanical ventilation**. This ventilation has the greatest potential for control of air exchange when the system is properly designed, installed, and operated. It should provide acceptable IAQ when ASHRAE Standard 62.1 requirements are followed. Several alternative procedures may satisfy requirements of the Standard:
1. Ventilation Rate Procedure (**VRP**)
2. Indoor Air Quality Procedure (**IAQP**)
3. Natural Ventilation Procedure (**NVP**)

The Ventilation Rate Procedure (VRP) is the most commonly used ventilation calculation method and states IAQ is assumed to be acceptable if both:

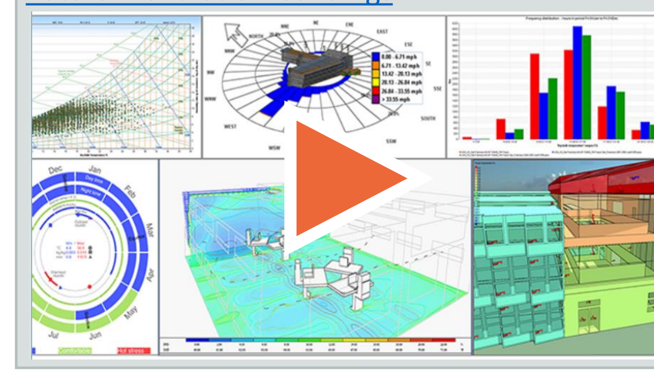
A. The concentrations of six pollutants in the incoming outdoor air meet the national ambient air quality standards. E.g. CO, O_3, $PM_{2.5}$, NO_2, sulfur oxides (SO_2, SO_3) and Lead.

B. The outdoor air (OA) supply rates meet or exceed values provided in a table, depending on the space type. The minimum outdoor air supply will maintain an indoor CO_2 concentration below 0.1% (1,000 parts per million) assuming a typical CO_2 generation rate per occupant. For example, an office minimum OA ventilation requirement is:

OA = 5 cfm/person + 0.06 cfm/ft^2.
OA = 2.5 L/s/person + 0.3 L/s/m^2.

Natural Ventilation is the intentional flow of air through open windows, doors, grilles, and other planned building envelope penetrations, and it is driven by natural and/or artificially produced pressure differentials.

Learn to model Natural Ventilation in Buildings: https://learn-on-demand.iesve.com/p/modeling-natural-ventilation-buildings



ASHRAE Standard 62.1 VRP Minimum OA rates

Space Type	CFM/person	L/s/person	cfm/ft²	L/s/m²
Classroom	0.12	5	0.18	0.9
Office	**5**	2.5	**0.06**	0.3
Science Lab	10	5	0.18	0.9
Bars	7.5	3.8	0.18	0.9
Corridors	-	-	0.06	0.3
Kitchen	7.5	3.8	0.12	0.6
Gym	20	10	0.18	0.9

Some spaces (healthcare, labs, etc.) require minimum air change rates (ACH) for primary, ventilation and exhaust air. ASHRAE Standard 170 provides guidance; E.g. **1 ACH = (CFM*60) / (Room Volume)**

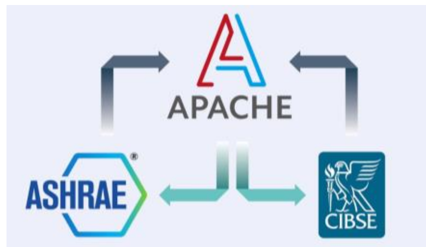
> *"To create high-IAQ, low-energy, climate resilient buildings for the future, we need to embrace alternatives to outside air ventilation to maintain healthy indoor environments. Building on key lessons from the COVID-19 pandemic about layered air cleaning strategies, the Clean First framework presented in this paper lays out a well-constructed, system-level approach to achieve Sustainable IAQ. I encourage designers and engineers to read the paper and consider incorporating its recommendations into future projects."*
> - Former ASHRAE President, William Bahnfleth, Ph.D., P.E., The Pennsylvania State University

Other IAQ Resources include ASHRAE IAQ Position Document, RESET Air Standard and Clean First Framework.

Heating and Cooling Loads Calculations

Calculating **Heating Loads** and **Cooling Loads** for rooms and thermal/HVAC zones is required to determine the amount of heat that must be added or removed to the spaces in order to maintain design setpoints in those spaces at the time of peak design weather conditions outside. Unless there are other requirements (e.g. primary ACH), room/zone loads calculations is normally the basis of HVAC emitter sizing for the room/zones. E.g. airflow diffusers, radiators, reheat coils, VAV boxes, etc. There are two predominant loads calculations methods used in industry, defined as the **ASHRAE Heat Balance Method** and **CIBSE Admittance Method**; tutorials included below.

ASHRAE Heat Balance Method



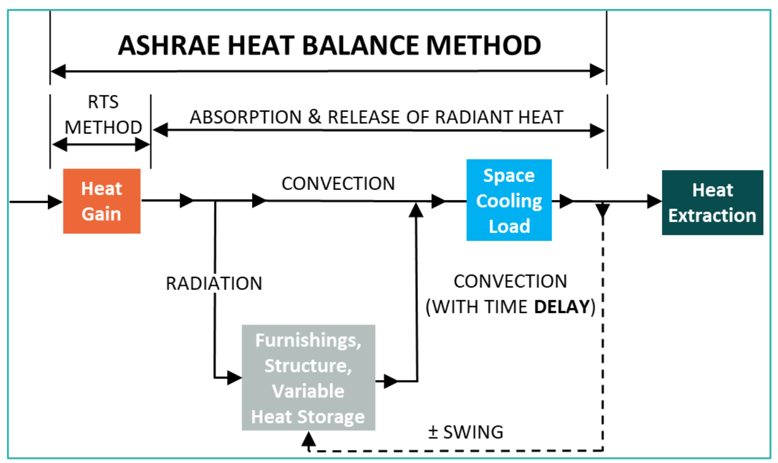
APACHE Calculation Engine

CIBSE Admittance Method

Loads calculation methods in APACHE require *validation* under ANSI/ASHRAE/ACCA Standard 183 and the ISO 52000 Standards series, via locally adopted versions such as the German DIN EN 12831 or U.K. BS EN 12831.

Some requirements for Heating & Cooling Loads Calculations include:

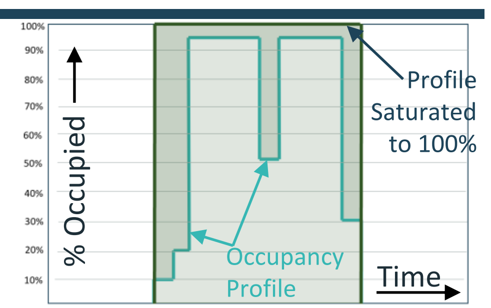
- Design Weather Data and Indoor Design Conditions
- Hourly solar radiation through fenestrations for **all** building room surfaces, with/without accounting for effects of blinds, shades or drapes.
- Opaque building envelope components with thermal mass effects
- Sensible & latent heat gains from infiltration
- Hourly Internal Heat Gains; including hourly sensible & latent heat gains, convective & radiative apportionments, number of occupants & activity levels, diversity load factors and (recessed) lighting heat gain to a ceiling plenum.



- Heating Load including infiltration, cold processes (e.g. refrigerated cases) and the *optional* inclusion from internal heat gains.
- System Cooling and Heating Loads; including ventilation, duct leakage, fan & pump energy, heat transfer through pipes & ducts, diversity of occupants/equipment/lighting and pyschrometric processes for reheat, dehumidification, humidification, air-mixing & airside heat-recovery (e.g. ERV).

PRACTITIONER NOTES:

- Compare ASHRAE's peak Design Day Weather against recent peaks.
- Typical supply-to-room air ΔT is 20°F or 11°C.
- Safety/oversizing factors for peak loads range between 10-15%.
- Peak cooling loads don't always occur at the hottest summer day/time.
- Replace typical gains profiles (e.g. occupancy) with saturated profiles.
- Heat gains/losses from ventilation is frequently handled by the HVAC system (not room/zone loads). E.g. DOAS system.
  - Compare loads results against appropriate *rules-of-thumb*.



HVACR Theory

Heating, Ventilation, Air-Conditioning & Refrigeration systems are responsible for generating, rejecting & recovering heat by moving fluids, typically air, water and refrigerants. Some HVACR systems require fuels like gas (e.g. gas furnace), oil (e.g. boiler), electricity (e.g. air-cooled chiller) or water (e.g. evaporative cooler). The primary purposes of HVACR Systems is to provide:

- Thermal comfort for occupants of buildings.
- Healthy & safe environments for occupants of buildings, and for building equipment.

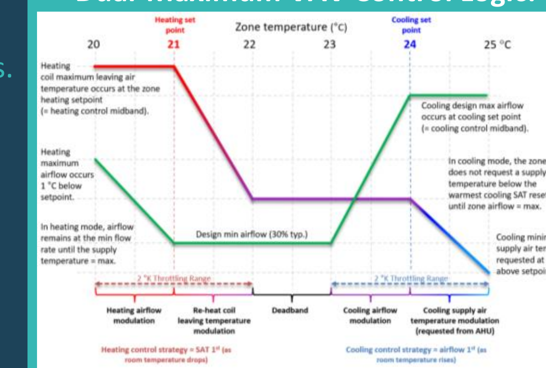
AFFINITY LAWS, for Fans and Pumps:

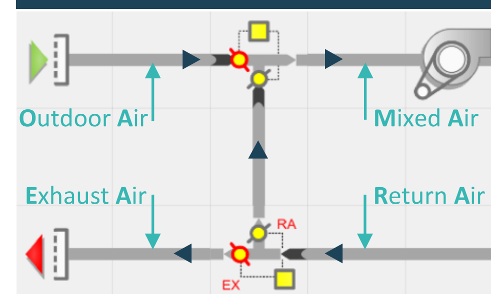
- **Law #1**: Speed (N) is **directly related** to flow (Q) and diameter:
  - $CFM_2 / CFM_1 = (RPM_2 / RPM_1)$ ... replace GPM for pumps.
  - $CFM_2 / CFM_1 = (Dia_2 / Dia_1)$
- **Law #2**: Pressure changes as the **square** of the flow (or speed):
  - $P_2 / P_1 = (CFM_2 / CFM_1)^2$
  - $P_2 / P_1 = (RPM_2 / RPM_1)^2$
- **Law #3**: Power (BHP) varies as the **cube** of the flow (or speed):
  - $BHP_2 / BHP_1 = (RPM_2 / RPM_1)^3$
  - $BHP_2 / BHP_1 = (CFM_2 / CFM_1)^3$

Pump Power, BHP = (Flow*Pressure) / (Efficiency of Pump)

Pump Motor Power = (Flow*Pressure) / (Efficiency of Pump)*(Efficiency of Pump Motor)

Dual-Maximum VAV Control Logic:





Mixed Air Temperature (T):

$$T_{MA} = \frac{(T_{OA} * CFM_{OA}) + (T_{RA} * CFM_{RA})}{CFM_{MA}}$$

Mixed Air Enthalpy (h):

$$h_{MA} = \frac{(h_{OA} * CFM_{OA}) + (h_{RA} * CFM_{RA})}{CFM_{MA}}$$

Hydronic Load (Q_{WATER}):

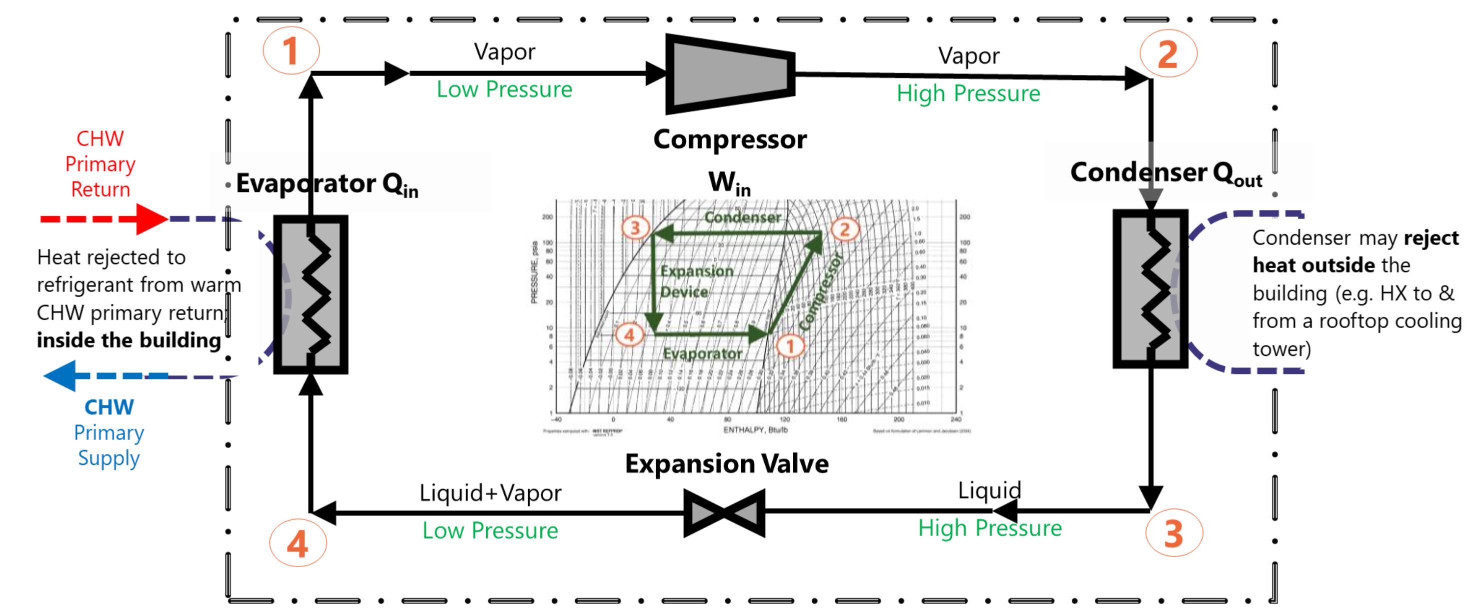
Btu/h = (gpm) * 500 * ΔT,

- where T = Temperature °F.

kW = (m³/s) * c_p * ρ * ΔT,

- where T = Temperature °C.
- ρ = 100 kg/m³;
- c_p = 4.2 kJ/kg.K.

Vapor Compression Cycle / Refrigeration Cycle:

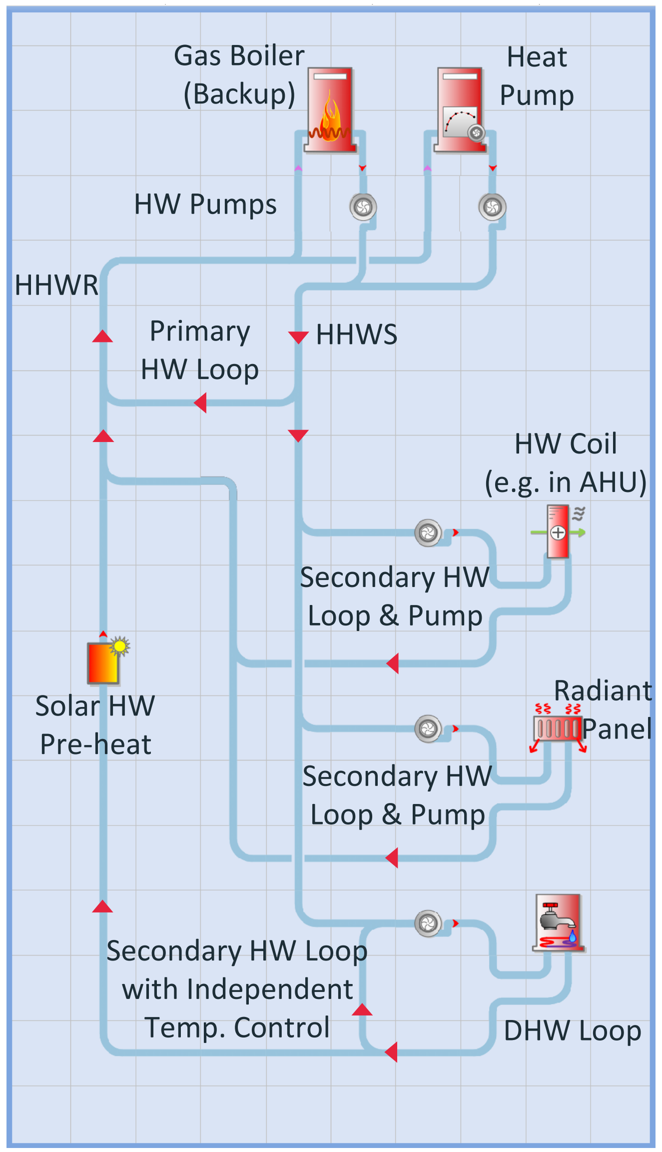


Closed Loop System Boundary: Chiller

Heating

Heating systems may be provided for Space Heating or Hot Water Heating (DHW). Systems may consist of distribution networks, a heating medium (E.g. air or water), a fuel supply, controls, heat emitters (E.g. coils, panels, beams, radiators, baseboard heaters) and heat generators (E.g. boiler, furnace, CHP, heat recovery chiller and heat pumps).
Space heating is achieved primarily through convection or radiation, with some conduction. Space heating system capacities are sized based on heating load calculations and usually account for backup equipment, heat losses due to distribution and safety (oversizing) factors.

Heating Schematic shown using a heat pump & boiler to heat water. HW pumps distribute water to coils, zone panels (radiators) and a DHW loop.



Heat Pump COP:
- Air-Source: ~2–5
- Water/ground: ~4–6

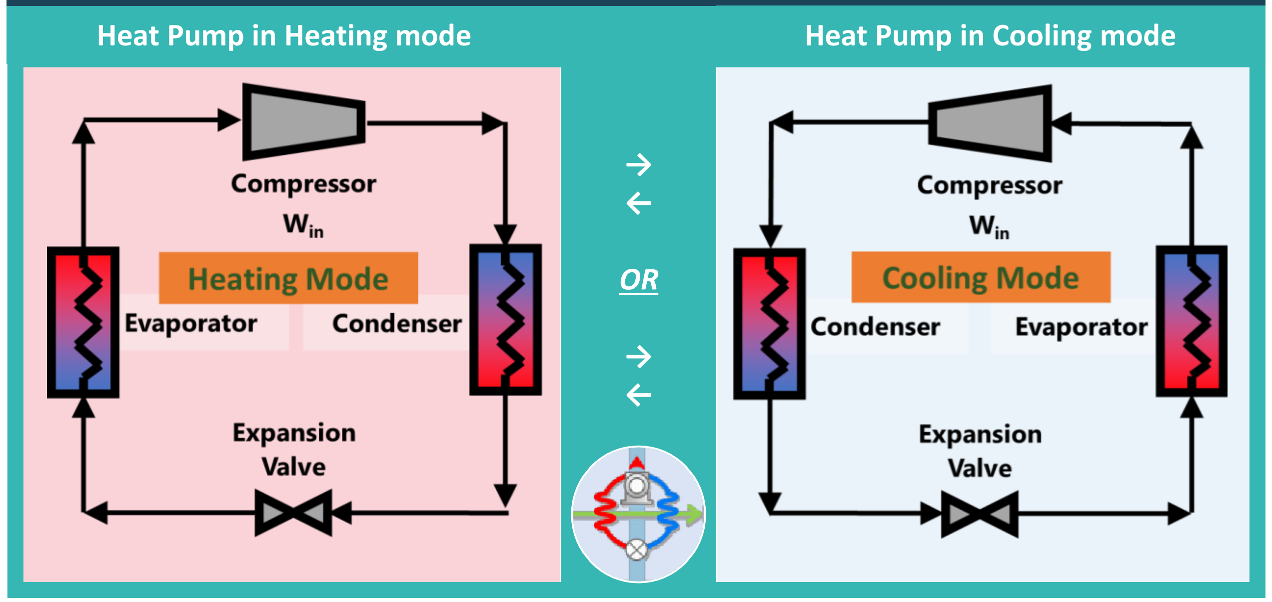
Boiler Efficiency:
- Condensing: ~97%
- Non-condensing: ~85%

Forced Air Heating systems use convection to warm the space. An example is a furnace in a home or coil in an AHU. Typical supply air temperatures are 90-95°F (32-35°C). Ventilation air from a DOAS may be delivered at a neutral room temperature (~70°F/21°C) to the space.

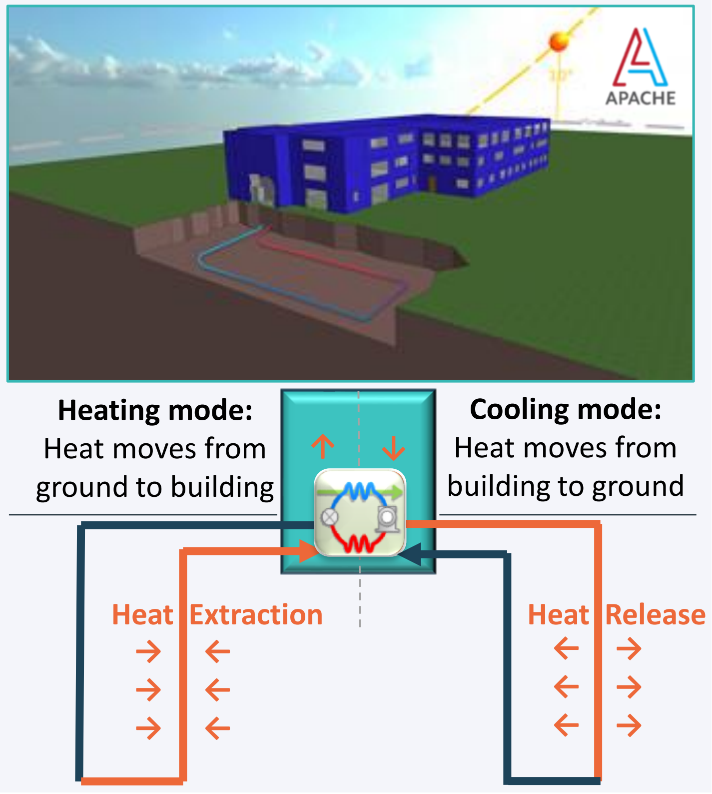
Radiant Heating systems use radiation to warm the space. An example is a floor with hot water tubes running through it served by a water (hydronic) boiler.
Floor surface temperatures should not exceed (~78°F/25.5°C), so requires lower supply water temperature than a traditional HW coil.

Cooling and Air Conditioning

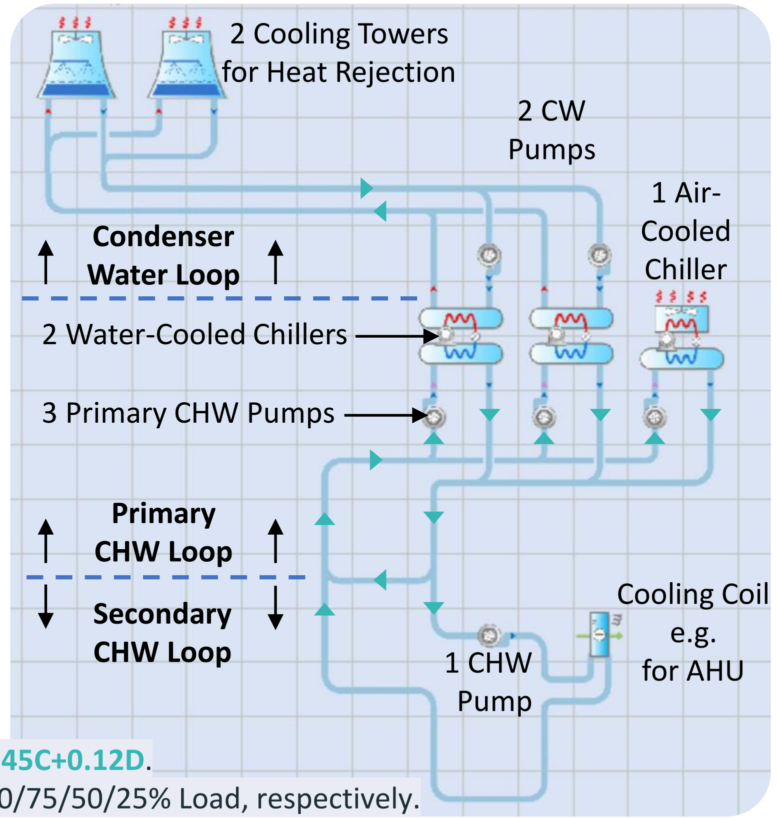
Heat Pumps are mechanical systems that can provide heating and cooling using a reversible refrigeration cycle. Heat pump technology can be air-to-air, air-to-water (VRF), water-to-air, water-to-water and even use the ground, lakes or sewers (SWEE) as heat sources or heat sinks. A Heat Pump Water Heater (HPWH) is used for DHW. Heat Pumps encourage all-electric design.



Ground Source or Water Source Heat Pump
- Uses the ground/water as a heat source or heat sink.
- Unlike air-source, they do not require a defrost cycle.

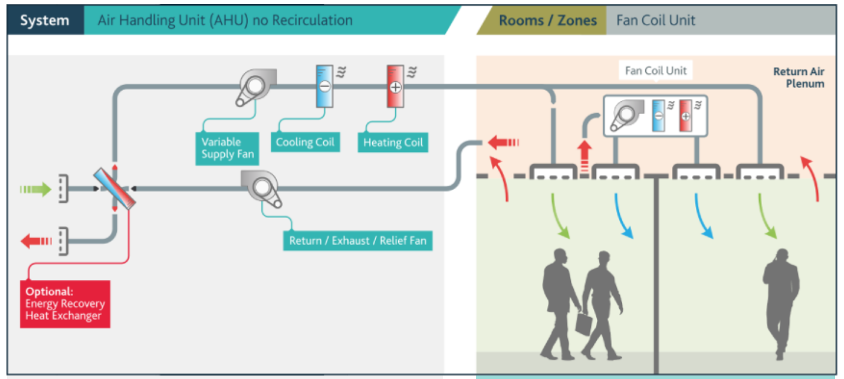


Cooling systems may be provided for Space Cooling or Process Cooling. Tutorials for [Airside System](#) setup and [Waterside/Plant System](#) detail the process for sizing cooling coils, fans, chillers, pumps and cooling towers.



Chiller Metrics:
- EER, COP, kW/ton
- IPLV, NPLV

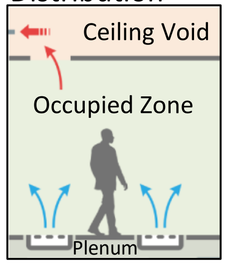
IPLV = 0.01A+0.42B+0.45C+0.12D.
- A,B,C,D = COP @ 100/75/50/25% Load, respectively.



Air Handling Units are typically designed to filter, cool and dehumidify air. For high latent loads, coil LAT is often below ~52°F/11°C. Air is commonly then re-heated to ~55°F/13°C before distribution to the space to minimize risk of condensation in supply air network.

Overhead air distribution systems are intended to mix the air in the space. Typical cooling supply air temperature (SAT) is ~ 55°F/13°C.
Integrated or independent cooling may exist at (or in) the zone. E.g. hotel room.

UFAD:
Underfloor Air Distribution

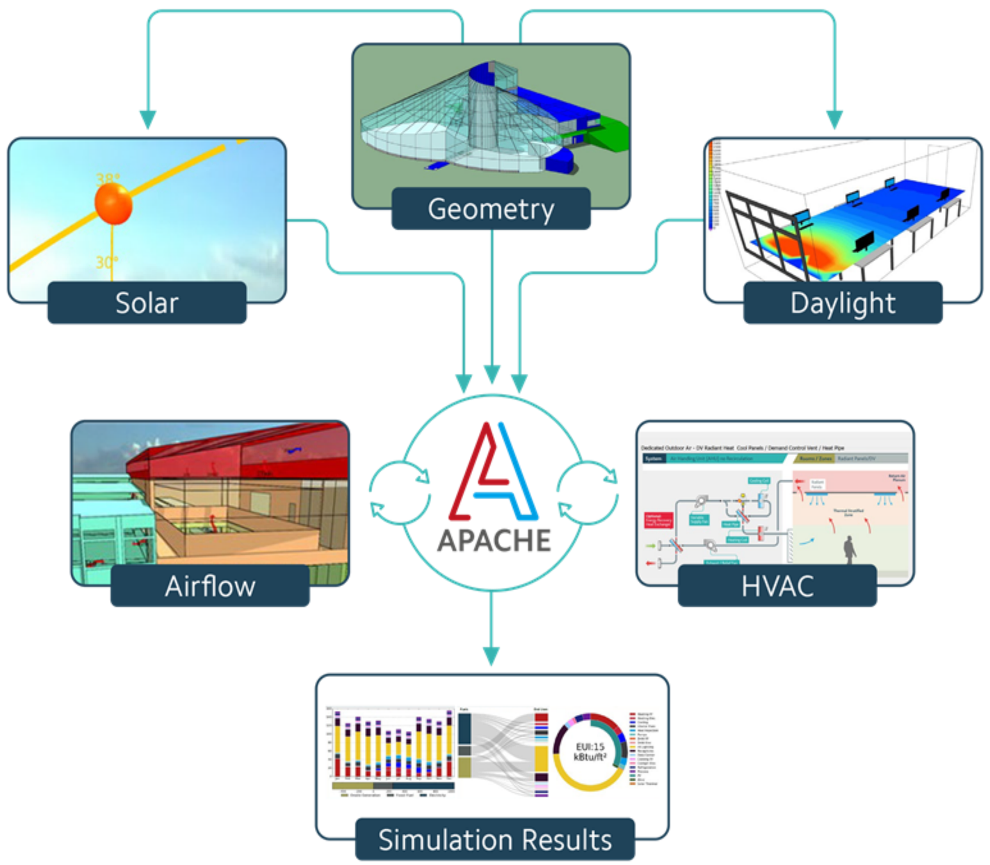


Displacement & UFAD systems are designed to purge (not mix) supply air in the space. Typical cooling supply air temperature is ~65°F/18°C.

Building Energy Modeling (BEM)

Building Energy Modeling (BEM) is used as a design process to predict building energy consumption, peak demands of fuels, carbon emissions, operational energy cost, water consumption and renewable energy production. For efficient and accurate BEM analysis, a validated BEM Software tool is required to create a virtual representation of the building, sometimes referred to as a Digital Twin.

Predictive BEM outputs are based on assumed inputs and are used to make design decisions about buildings, building systems and optimization strategies. Central to the performance prediction of Building Energy Model is a physics-based simulation engine. The most popular worldwide simulation engine for BEM is APACHE, which performs sub-hourly annual simulations for various design scenarios.



BEM INPUTS:

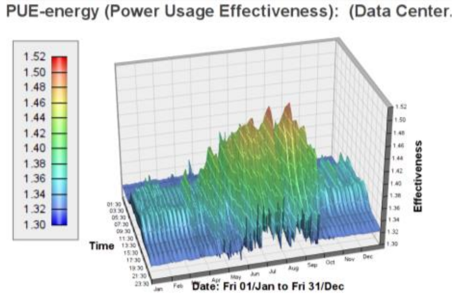
Some BEM inputs may include:

- Site location and orientation
- Hourly (8,760) annual weather data with calendar year, holidays, etc.
- 3-Dimensional (3D) digital model building & surrounding buildings.
- Local shading & solar calculations
- Hourly daylight illuminance per room with dynamic sky conditions
- Construction & materials properties
- Internal heat gains
- Operating schedules and profiles
- Ventilation and Infiltration
- Operable windows/louvres
- Domestic Hot Water (DHW) systems
- Thermal Comfort parameters
- HVAC System equipment, controls, sequences of operation, dynamic performance curve data & efficiencies, etc.
- Heat recovery systems
- Energy storage systems
- Renewable Energy Technologies
- Utility Tariff Costs

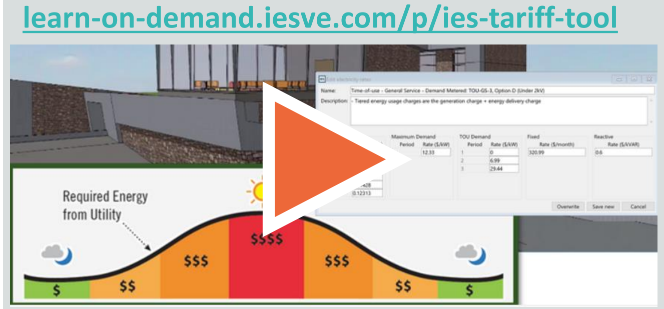
BEM OUTPUTS:

BEM results data can be summarized in reports, spreadsheets, charts and other graphics that can be used to view, understand, QA/QC and interrogate. There are many BEM output metrics and they can be connected with other digital platforms.

PUE-energy (Power Usage Effectiveness): (Data Center.



LEARN HOW TO ESTIMATE ENERGY COSTS:
learn-on-demand.iesve.com/p/ies-tariff-tool

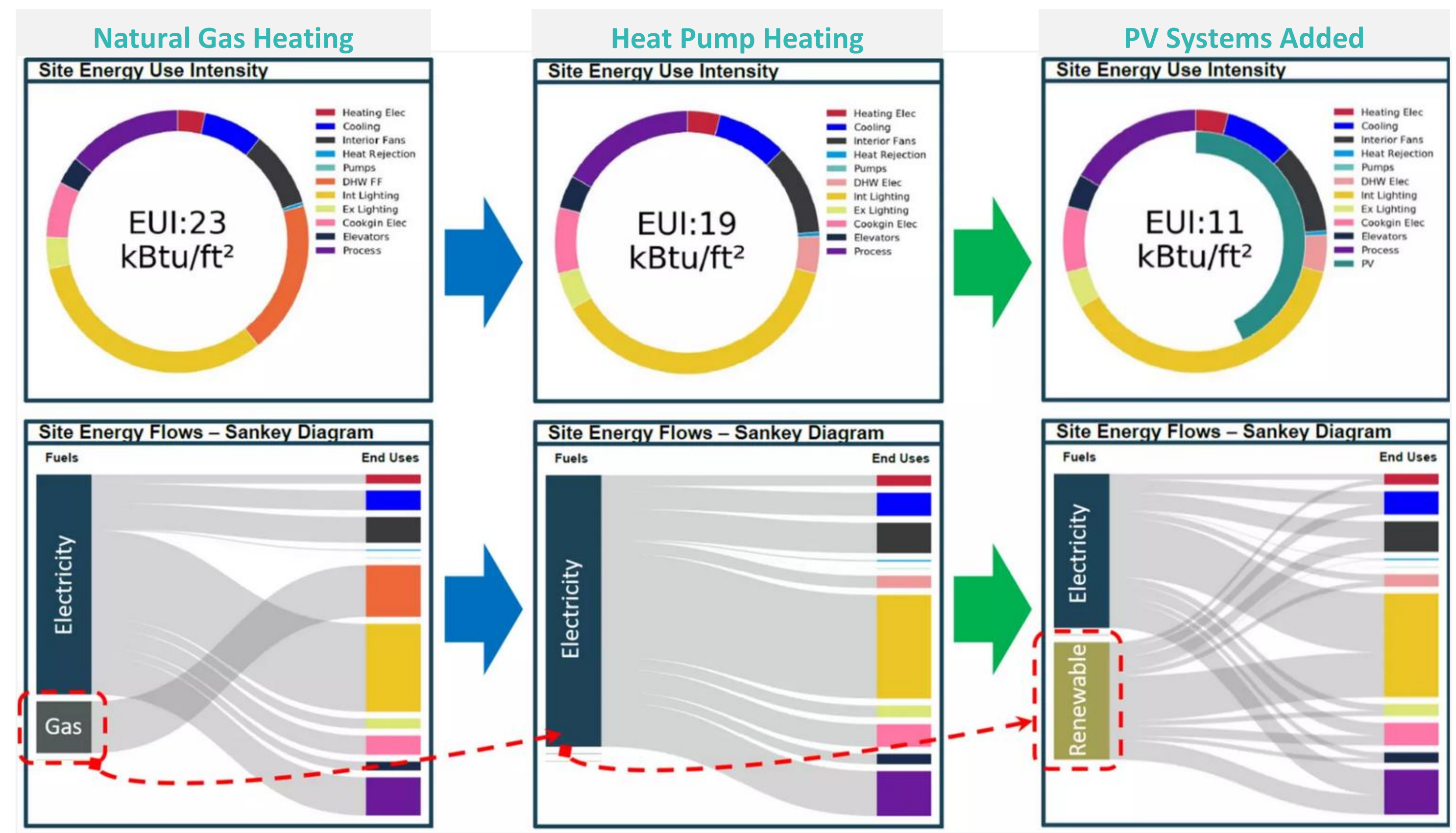


Electrification and Decarbonization

Buildings account for a significant amount (~40%) of energy consumption and carbon emissions, including construction & operation. The theme of Electrification & Decarbonization follows four core principles.

1. **Energy Conservation** is a process to reduce & recover all building energy demands, regardless of fuel. BEM is the most effective method used for quantification of Energy Conservation Measure (ECM) scenario analysis.
2. **Electrification** refers to eliminating non-electric fuels from being used in the building. Typical energy end-uses that directly consume fossil fuels include Space Heating, Hot Water Heating (DHW), Cooking and some Process Load end-uses. The adoption of efficient heat pumps is typically the first task for building designers.
3. **Renewable Energy Technology** installed at the building site will generate electricity to meet the increased demands for electric heating & cooking equipment. This will further reduce operational carbon emissions from the building, referred to the **CO_2e** emitted from operating a building
4. **Energy Storage** is also a common method to decarbonize the building.
   - **Thermal energy storage** from hot-or-chilled water tanks being used as heat sources or heat sinks. Charging the tanks with heat can be done during 'clean-carbon' hours of the day and be discharged during hours that have higher carbon-emission factors. The local utility provider often determines when the high-demands on the electric grid will occur, E.g. 5pm – 9pm.
   - **Electricity storage** is possible by charging/discharging batteries at the building. Batteries can be controlled for general electricity demands, optimized Time-Of-Use (TOU) control or Demand Response (DR). Advanced DR can be triggered from the utility provider to trim peak electricity demand.

One case study example of a High-Performance Multi-Family Affordable Housing project demonstrated each of these four core themes.

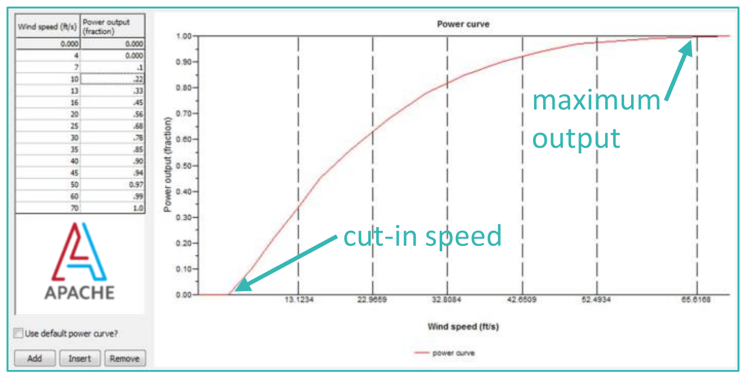


Decarbonization also includes **Embodied Carbon** which refers to the carbon needed to create the buildings materials, transport the materials to the construction site, and construct the building.

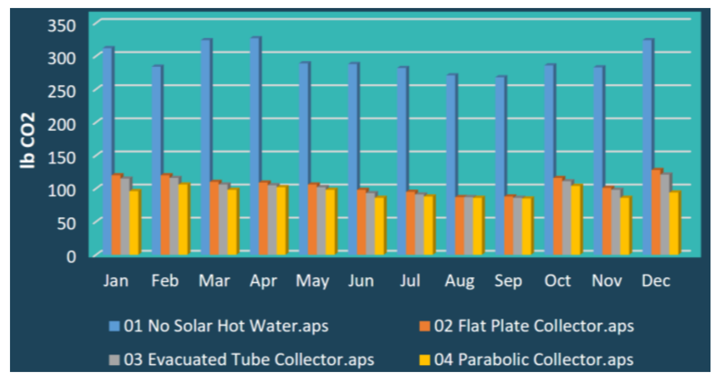
Renewable Energy and Energy Storage

A **Zero Net Energy (ZNE)** building is one in which the sum of all energy that is delivered to the property is less than the sum of all energy that is exported from the property. A ZNE building is not possible without incorporating some renewable energy technology on site. Generally, buildings have the opportunity to have solar photovoltaic (PV) panels, solar hot water (SHW) and wind energy on site. When renewable energy technologies are combined with decarbonization strategies, achieving **ZNE** buildings status is possible. BEM is normally required to estimate how much renewable energy is needed to achieve ZNE on an annual basis. **APACHE** is one of the most common BEM tools used to predict annual energy consumption and energy generation.

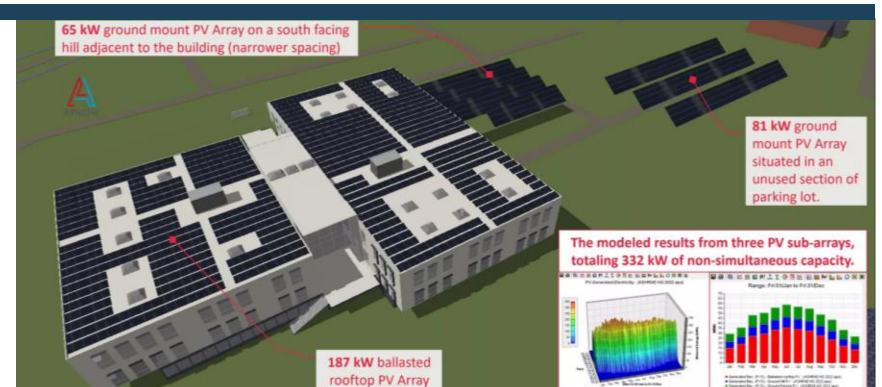
Wind Energy can generate limited on-site energy due to the requirement of consistent wind speed on site. This information is available in the weather file. Note that there is also a 'cut-in speed', as shown in the power curve. The power curve also shows a maximum output.



Solar Hot Water (SHW) requires a demand of low-temperature hot water E.g. 140°F/60°C. This **Carbon Case Study** compares model inputs & outputs from a Flat Plate Collector (FPC), Evacuated Tube Collector (ETC) and a Parabolic Collectors (PC).



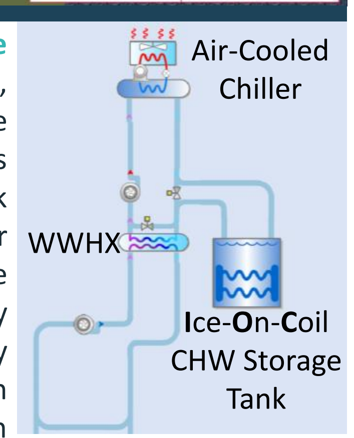
Solar Photovoltaic (PV) technology includes Monocrystalline Silicon (η=21%), Polycrystalline Silicon (η=17%) and others. PV panels should be placed on a model in order to capture the additional benefit of solar shading to the building. The **ASHRAE Headquarters Building** is a good net zero energy building example, with a 332 kW PV installation in Atlanta, GA with three PV sub-arrays.



Electric Storage requires **battery charging** from PV panels in the model and allows three types of controls:

1. **Basic:** discharges only when the PV system production is less than the on-site electrical load.
2. **Time-Of-Use (TOU):** Discharges during the Utility's highest seasonal/daily/hourly **prices** of TOU rates.
3. **Demand Response (DR):** Allows discharging into the grid upon receiving a demand response **signal** from a grid operator.

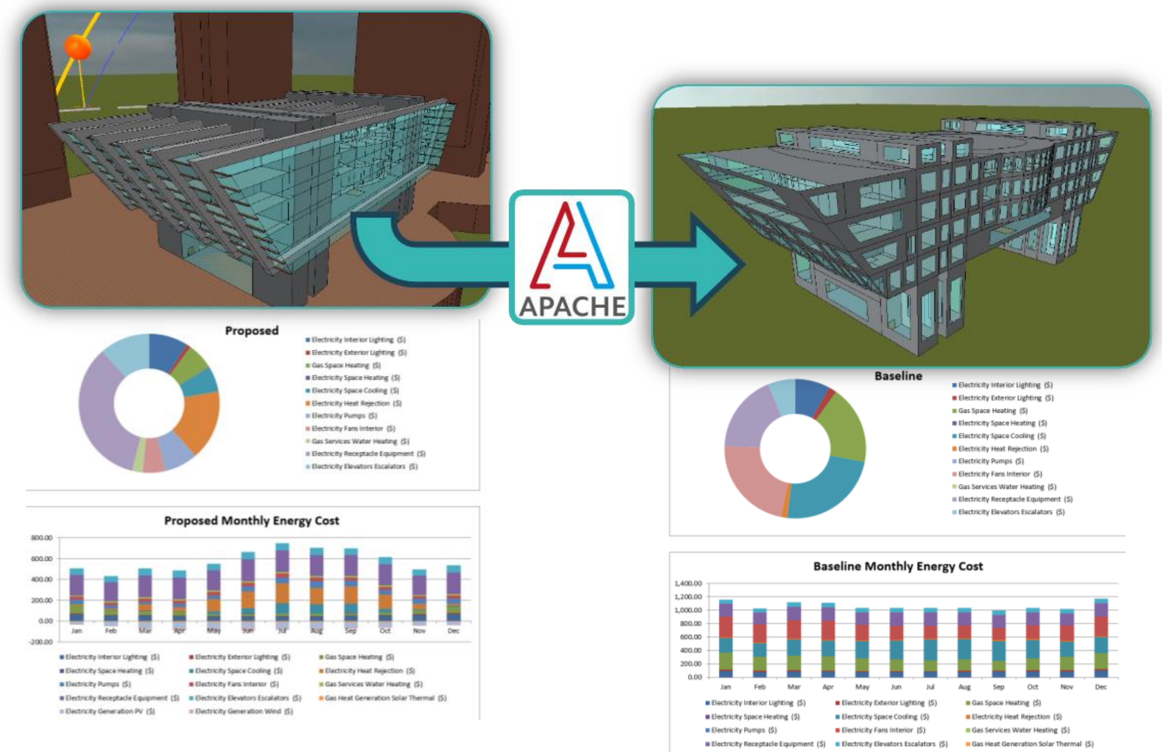
Thermal Energy Storage (TES) (e.g. Chilled Water, Ice, Hot Water) can also be used to ***store*** energy as heat and reduce peak heating or cooling loads, or ***shift*** the peak load of the building to a time of day when the cost of electricity may be cheaper or when the rate of carbon emissions is *cleaner*.



Building Energy Code Compliance

Typically, Building **Codes, Standards, Regulations & Rating Systems** are updated every 3–5 years. With every new code-cycle, revised energy-efficiency targets are established. With each new version, there are normally new stringencies for the building designers to consider, namely with requirements for the building envelope, lighting systems, DHW, HVAC systems and energy/carbon/cost targets. There are some jurisdictions also requiring minimum renewable energy/carbon measures; E.g. 'solar-ready' roof areas. While there have been major technological upgrades within the building envelope, lighting, DHW, HVAC and PV-system industries in recent times, most architectural designers continue to ***dilute*** those efficiency upgrades, likely upon instruction from the project owner, with continuous persistence towards inefficiently heavily-glazed buildings.

In most jurisdictions, there are options for *Prescriptive-based* Compliance or *Performance-based* Compliance. ***BEM*** is usually required for Performance-based Compliance path because it allows trade-offs between individual prescriptive requirements; e.g. non-compliant envelope compensated by a high-efficiency HVAC system. This performance path compares the 'as-designed' (E.g. proposed) building performance to a manufactured (E.g. baseline/reference/standard/notional) building, which is generated based on, in part, the proposed design plus rules defined in the appropriate code, standard or regulation. Some programs require energy cost to be the comparison metric, with identical utility rated being applied. BEM rules-processing tools like **APACHE** frequently require certification or ***validation***.



***Local* Authorities Having Jurisdiction (AHJs)** continue to mandate the latest versions that must be adhered to:

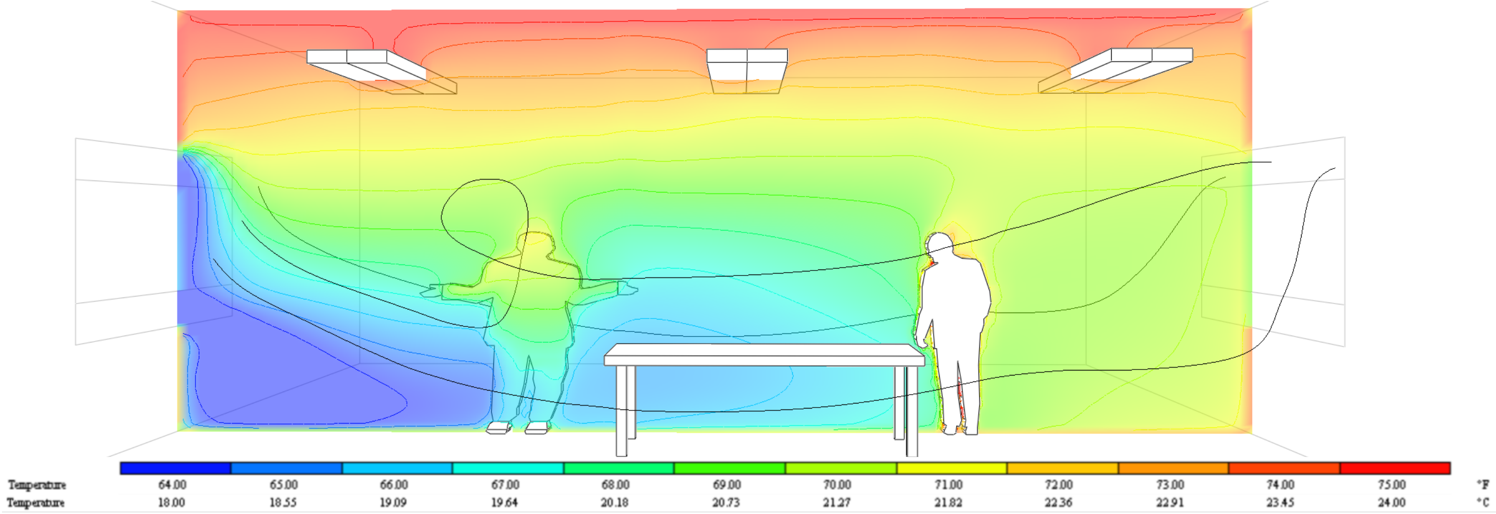
- ***iesve.com/software/compliance-rating-systems***

Canada TITLE24 ASHRAE 90.1 *E.g. Part L*

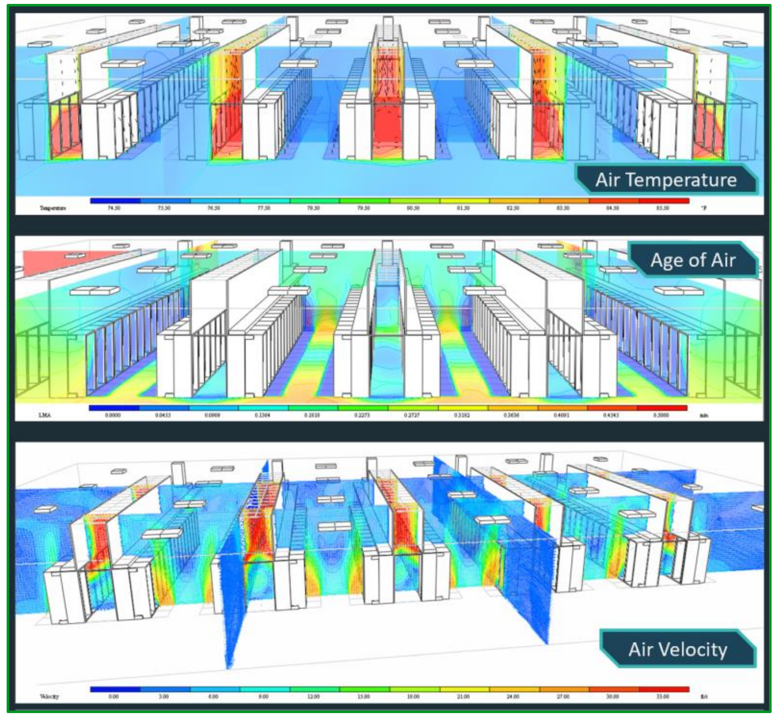
Airflow Simulation (CFD)

Computational Fluid Dynamics (CFD) simulates how a fluid like air moves in and around objects – including buildings, spaces within buildings and pedestrian areas outside buildings. Sophisticated CFD software is necessary for modeling detailed air temperature gradients, air velocities, pressure, water vapor, age of air, air change effectiveness (ACE), carbon dioxide (CO_2), carbon monoxide (CO) and occupant comfort simulation (PPD, PMV, Operative Temperature). There are a large number of building-specific applications for CFD.

Natural Ventilation is often used to reduce or eliminate the need for mechanical cooling, as well as providing increased ventilation air for occupants. For example, an architect may wish to consider façade design options with single-sided ventilation (e.g. low opening and high opening) versus cross ventilation as shown below.



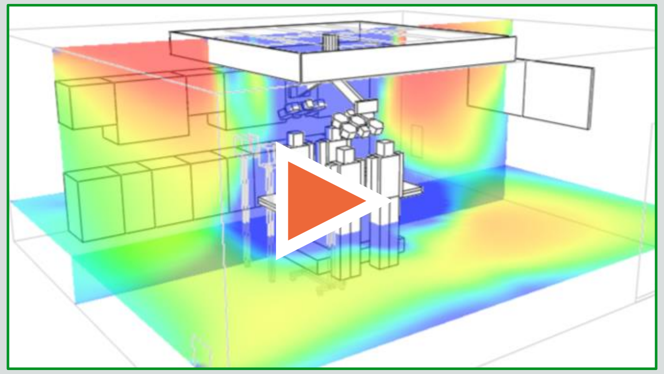
Mission Critical Data Centers produce extreme amounts of heat which frequently require containment to specific aisles, in order to maintain safety of the data equipment.



LEARN HOW TO PERFORM CFD SIMULATION FOR A HOSPITAL OPERATING ROOM:

- Laminar flow Supply diffusers
- Room Pressurization
- Operating Room Equipment & Occupants
- CFD Simulation Particle Tracking

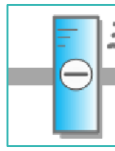
https://learn-on-demand.iesve.com/p/cfd-hospital



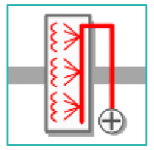
Water

The Water-Energy Nexus considers the interrelationship between water and energy. E.g. Power plants consume water for cooling systems, and Water plants consume power for treatment and distribution. Calculating water usage for a building accounts for all water used and recovered inside and outside the building. Aside from DHW demands, HVAC systems can use water and can reclaim water from HVAC processes. HVAC systems can be responsible for up to ~30% of a commercial building's total annual water use.

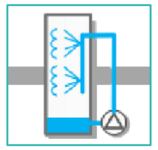
Cooling Coil Condensate Recovery: Latent heat is transferred by moisture in the air to the coil via the process of **condensing** on the surface of the cooling coil.



A Steam Humidifier produce mist by boiling or heating the water, along with increasing the humidity levels in the air. The warm vapors lost to the air requires **makeup** water.



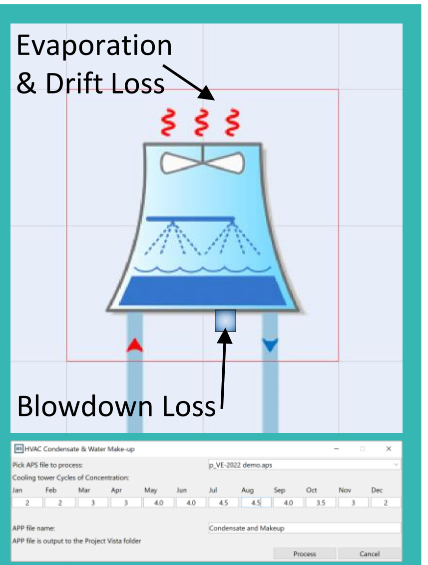
An Evaporative/Spray Cooler sprays fine water droplets in the air. The air temperature decreases and is humidified, with a constant enthalpy (**adiabatic**) Psychrometric process.



With an **Open Circuit Cooling Tower**, air is introduced into the tower and condenser water (CW) flows directly over the heat transfer surface (the fill) of the cooling tower. Varying *the control strategies* can impact the performance.

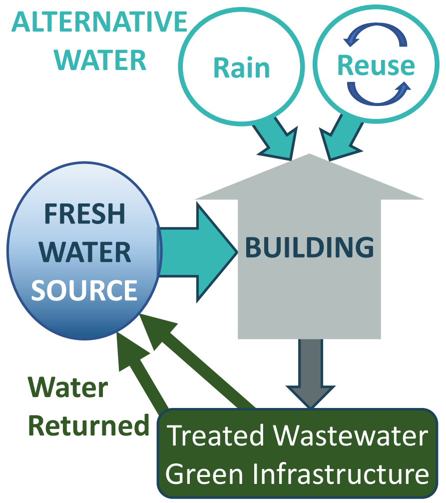
Cooling Tower Water Makeup water is subsequently required due to:

1. **Evaporation:** Occurs as part of the latent heat removal process.
2. **Drift:** Occurs when water droplets are entrained in the air-stream and removed from the tower.
3. **Blowdown:** Occurs when water is drained, or 'blown-down', from the cooling tower basin. The blowdown water has a higher **concentration** of dissolved solids (after some water was evaporated. When the water concentration of dissolved solids is too high (it becomes hard water) it needs to be diluted so that scaling will not occur in the basin/pipes. The 'Cycles of Concentration' vary by utility water provider and by season.

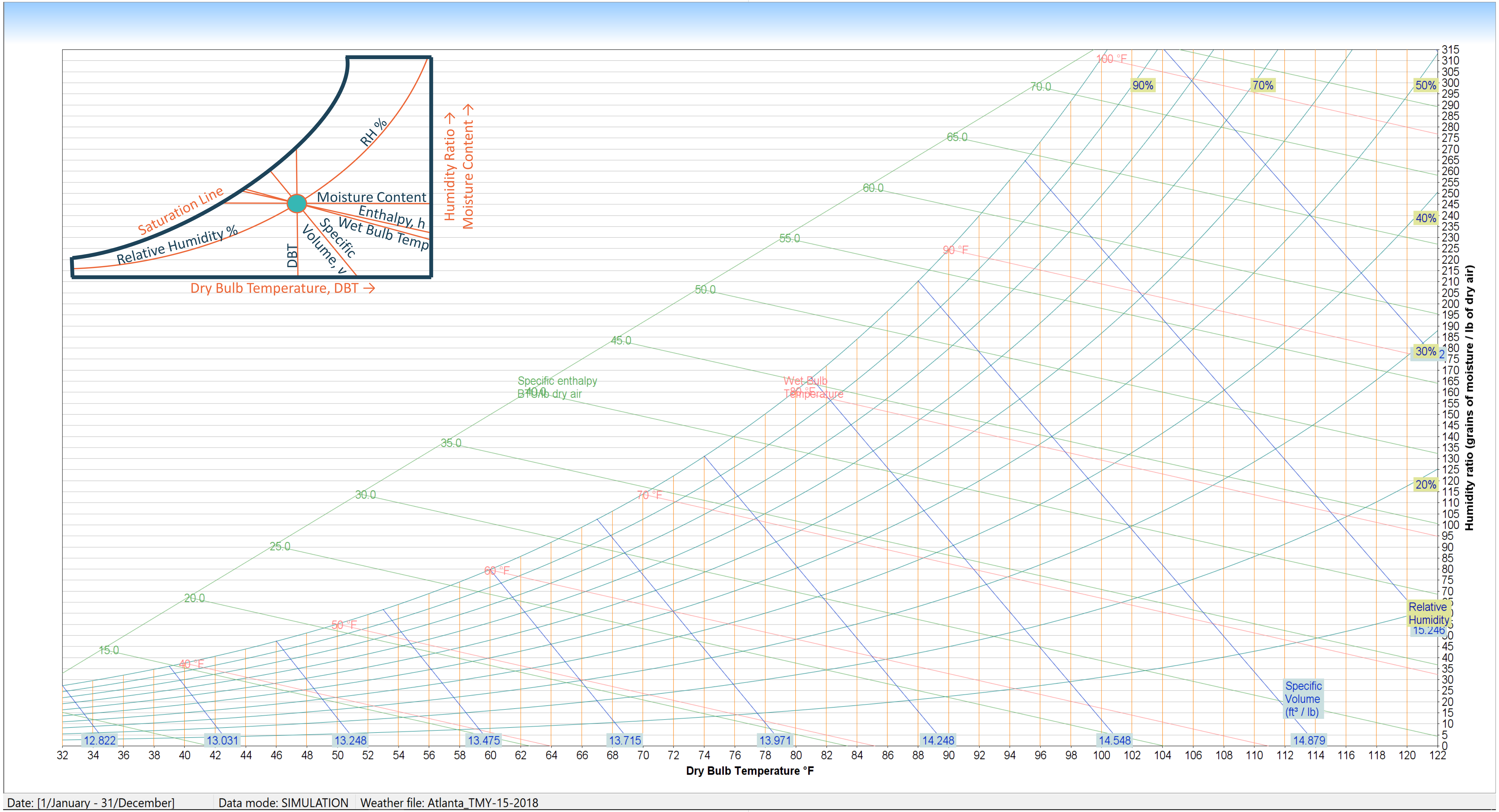


IESVE calculates hourly water losses from cooling towers, evaporative coolers & humidifiers; and simulates water reclaim from cooling coil condensate. Results can be input into LEED's water calculators listed below.

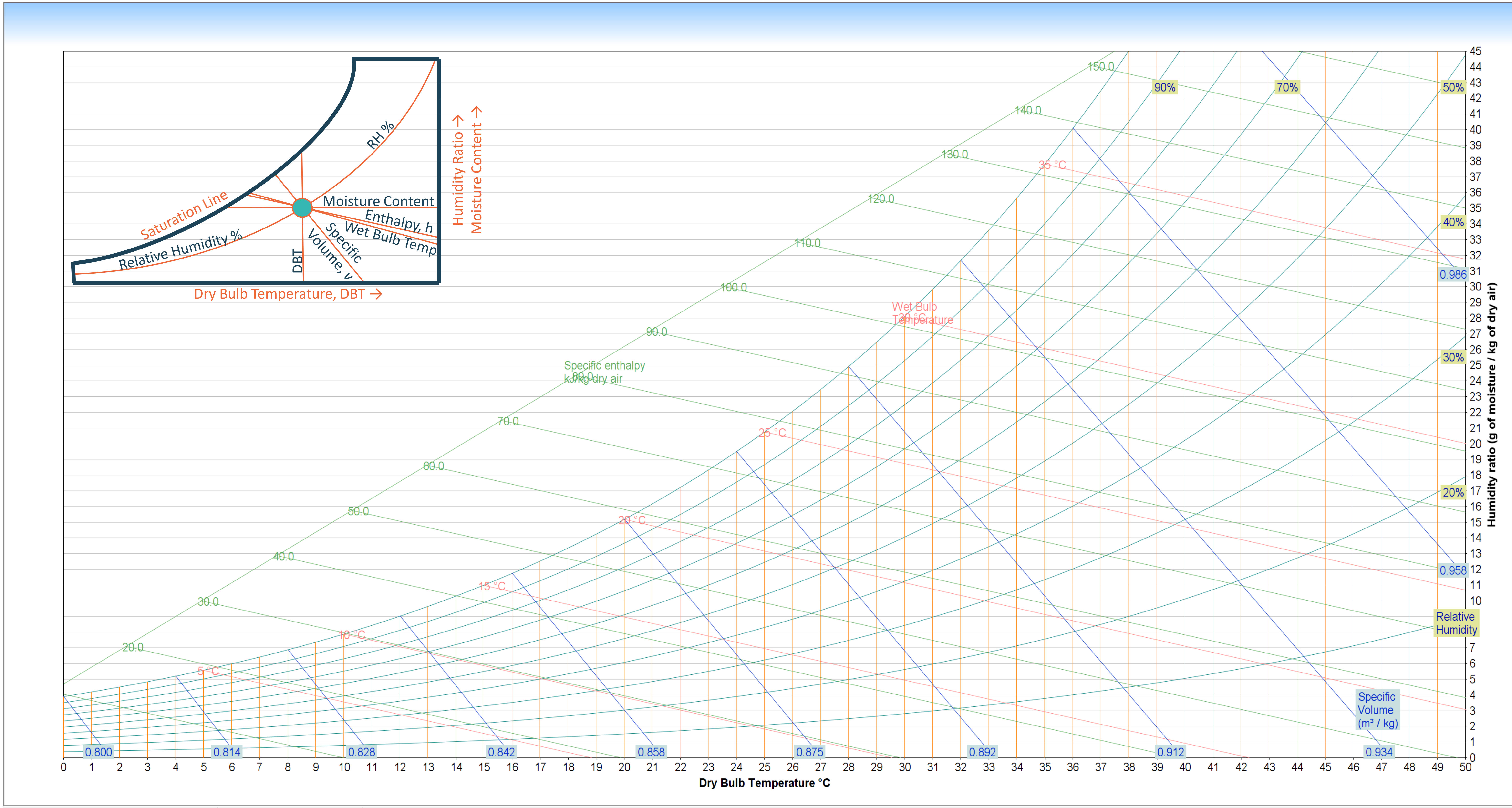
- **Potable Water** is treated to meet state and federal standards for consumption.
- **Freshwater** is sourced from surface/ground water such as lakes & rivers.
- **Alternative Water Use** includes harvested rainwater, stormwater, sump-pump water, graywater, condensate, rejected water from water purifiers and reclaimed wastewater.
- **Water Returned** is the amount of water collected from building systems and returned to its original source over a year.
- **Total Water Use** is the amount of water used from all sources.
  - **LEED** calculators are available for Indoor Water & Outdoor Water.
  - **Total Water Use = Water Returned + Alternative Water Use**
- **A Net Zero Water (NZW) building** consumes the same amount of water it generates on site over a year.



Appendix A – Psychrometric Chart (I-P)



Appendix A – Psychrometric Chart (SI)



Date: [1/January - 31/December] Data mode: SIMULATION Weather file: Atlanta_TMY-15-2018

Appendix B – FAQs

1) Where can additional technical modeling support be found?

There are a few available resources.

- FAQ Knowledge Base: https://www.iesve.com/support/ve/knowledgebase_faq
- Forum: https://forums.iesve.com/ - you are welcome to provide feedback on the BPM Student Handbook.
- Video Library: https://www.iesve.com/training/upskill-with-ies

2) Where can useful thermal input data be found (e.g. lighting power densities)?

In most cases, IESVE Compliance tools can be used where regionally appropriate. In each tool, there are 50+ Templates that are automatically imported. This Template data represents minimally compliant code cycle data.

3) How do Green-Building Rating Systems relate to Building Performance Modeling?

Building rating systems are very interweaved with BPM requirements. Some examples include:

- **LEED** (Leadership in Energy and Environmental Design) requires BEM within the "**Energy and Atmosphere**" credit category and daylight simulation within the "**Indoor Environmental Quality**" credit category. See: https://www.usgbc.org/credits. Note that LEED cites ASHRAE Standard 90.1 as an energy standard.
- **BREEAM** (Building Research Establishment Environmental Assessment Method) has an energy category that is focused heavily on CO_2 emissions to meet minimum code (E.g. Part L Building Regulations).
- The **Living Building Challenge**, created by the International Living Future Institute, is considered the most rigorous green building rating system and based solely on actual recorded performance. The energy category requires Zero Net Energy for a 12 month period, so energy metering is required. See https://living-future.org/lbc/.
- The **WELL Building Standard** is focused on Health & Wellness of the building occupant, and while it has no *direct* energy impacts, it has many *indirect* impacts (e.g. outdoor air requirements, daylight, thermal comfort). See https://standard.wellcertified.com/well.
- The **NABERS Building Standard** provides a rating from one to six stars for buildings efficiency across Energy, Water, Waste and Indoor environment. See https://www.nabers.gov.au/about/what-nabers.

4) How is Benchmarking achieved with Building Performance Modeling?

First, establish the benchmark value, there are a few useful resources whereby a building can be compared:

- ASHRAE Standard 100 - Energy Efficiency in Existing Buildings
- CBECS (Commercial Building Energy Consumption Survey) Data from the U.S. Energy Information Administration
- CIBSE Benchmarking Tool
- Performing an energy audit for an an existing building (E.g. ASHRAE Level 1, 2 & 3) may be required.

Alignment tasks for a Building Performance Model may include, but not be limited to:

- Using actual weather data (.AMY), rather than typical weather (.TMY) and use up-to-date utility tariffs.
- Using masterplan-level building geometry imported from OpenStreetMap.
- Use metered data, if available, as hourly scheduled inputs for the Building Performance Model.

5) Are there any useful resources for Title 24 in California?

- The Alternative Compliance Method (ACM) is explained in detail by EnergyCodeAce.
- Title 24 Compliance Modeling training video.

6) Are there any useful resources for ASHRAE 90.1 Compliance modeling?

Yes, videos for modeling various ASHRAE 90.1 code cycles are available here.

Appendix B – FAQs