Boston City Hall: Sustainability Guidelines for Building Performance

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Introduction

Regardless of the ultimate sustainability goals, the first step towards creating a sustainable building begins with the building's intrinsic performance - how the building functions before any mechanical systems are in place. Before the invention of artificial light, air conditioning, and many other modern amenities we now consider commonplace (sometimes even required), architects and designers had take advantage of the natural environment to provide a livable interior environment. However, the (perceived) abundance and expansion of energy into the 20th century lifestyle caused a reversal of this design methodology: the outdoor environment was ignored and indoor comfort maintained by whatever means necessary. This reversal has caused us to start talking about our built environment with such terms as sick building syndrome, smog advisories, chemical sensitivity, etc.

These guidelines' integral design approach for sustainable, comfortable, and economical environments for working is based on fundamental physical principles and strategies. This approach goes beyond the limited idea of energy conservation based on maximizing thermal properties of the building envelope or skin, requiring a holistic design process recognizing the interdependence of all building systems and components. This interdependence demands intense collaboration and brainstorming between the architect, structural engineers, MEP engineers and other design specialists.

It is the intent of these guidelines to encourage the use and integration of fundamental, pre-modern-era building design strategies into our modern definitions of comfort and quality in a specific, measurable way. They do so by being based on fundamental building principles and strategies (intrinsic performance) and existing "green" guidelines and other standards (modern requirements), and by being very specific in their implementation (measurability).

Climate

It is critical to consider the year-round climate and all possible operating conditions in order to achieve a high-performance building. The weather evaluation for Boston shows a temperate, humid climate.

Summer brings large amounts of sunlight and moderate-to-high temperatures, but large daily temperature variations. High humidity makes dehumidification a likely prerequisite to maintaining indoor comfort year-round. Moderate-temperature winds are from the southwest and are strong enough to provide some natural ventilation potential. In addition, over 50% of the hours of the year are between 50°F and 80°F, furthering the potential for natural ventilation in spring, fall, and cooler summer days.

Winter temperatures are moderately cold with modest sunlight availability. Winds are strongest in the winter and are primarily from the northwest. Protection from northwest winds is recommended, and aggressive passive heating strategies are necessary to limit fossil fuel usage for heating.

Figures 1-4 show the climate conditions in Boston. Typical meteorological year weather data should be used for all building performance simulations. The figures below were derived from TMY2 data for Boston.

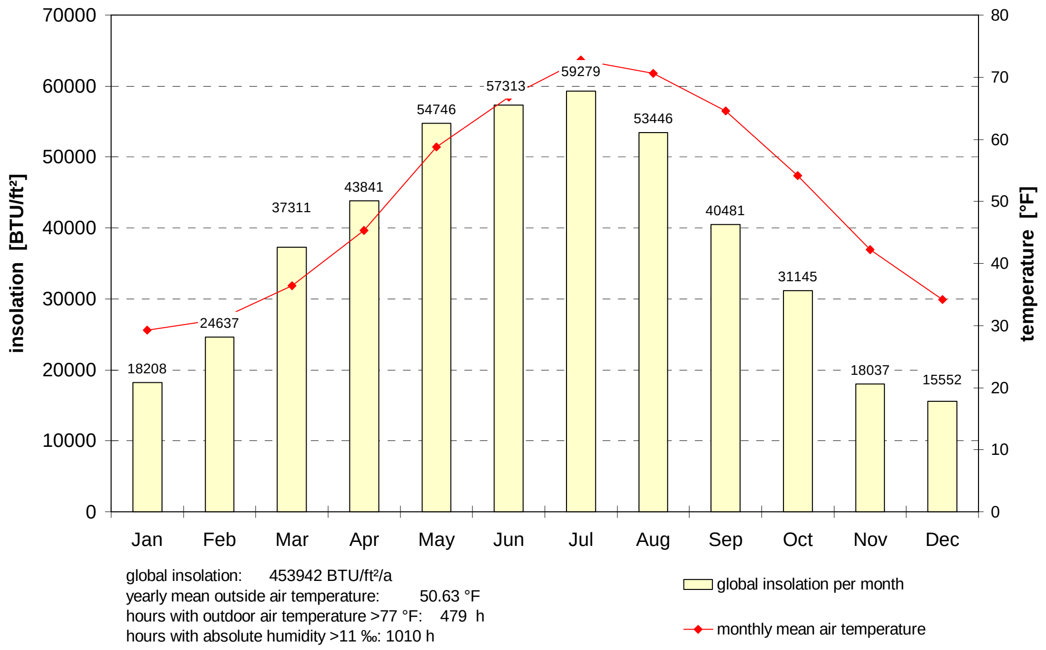

Figure 1: Monthly total available solar energy and average temperature for Boston

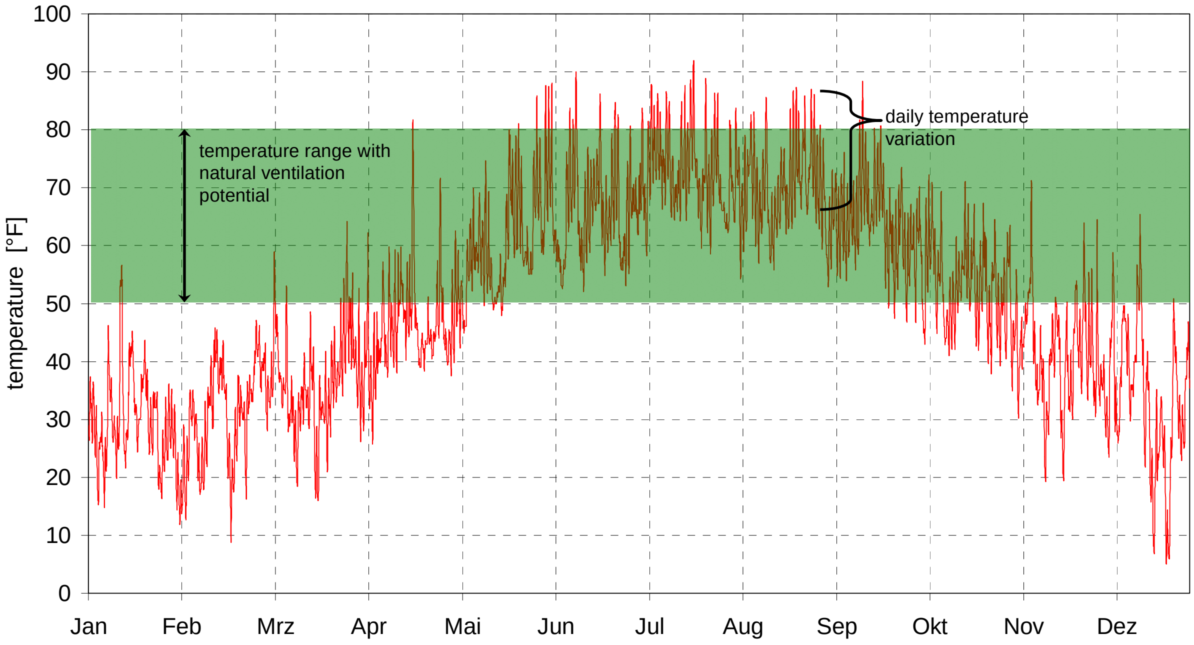

Figure 2: Annual hourly temperatures for Boston

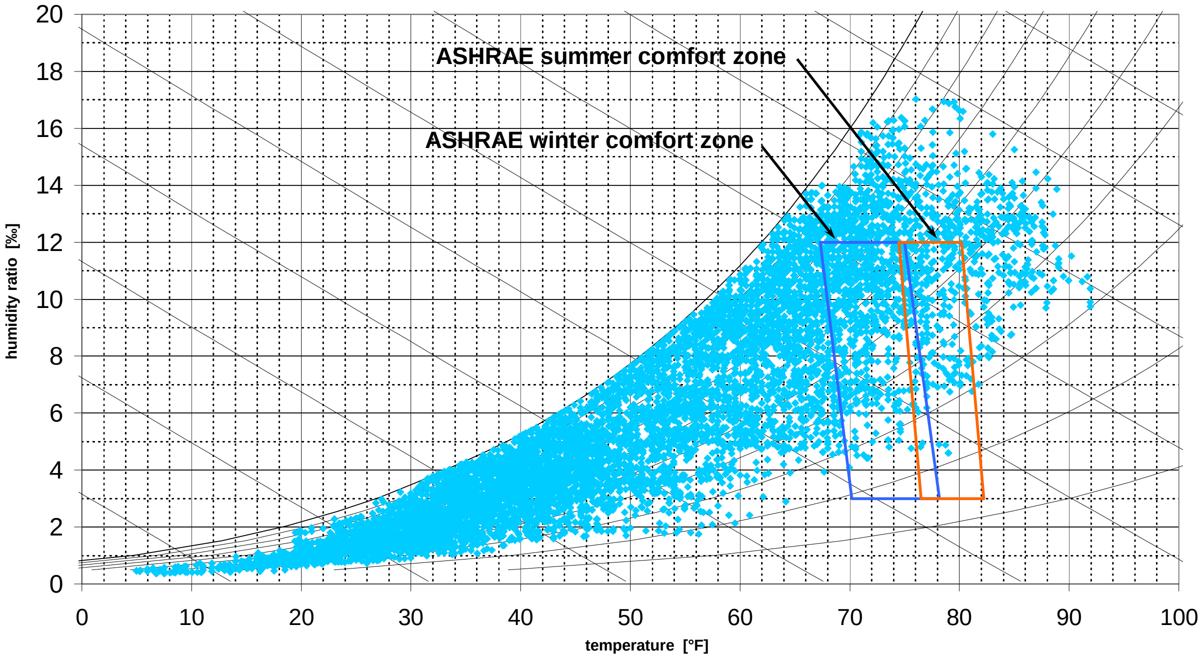

Figure 3: Psychrometric chart (temperature-humidity) for Boston with ASHRAE winter and summer comfort zones

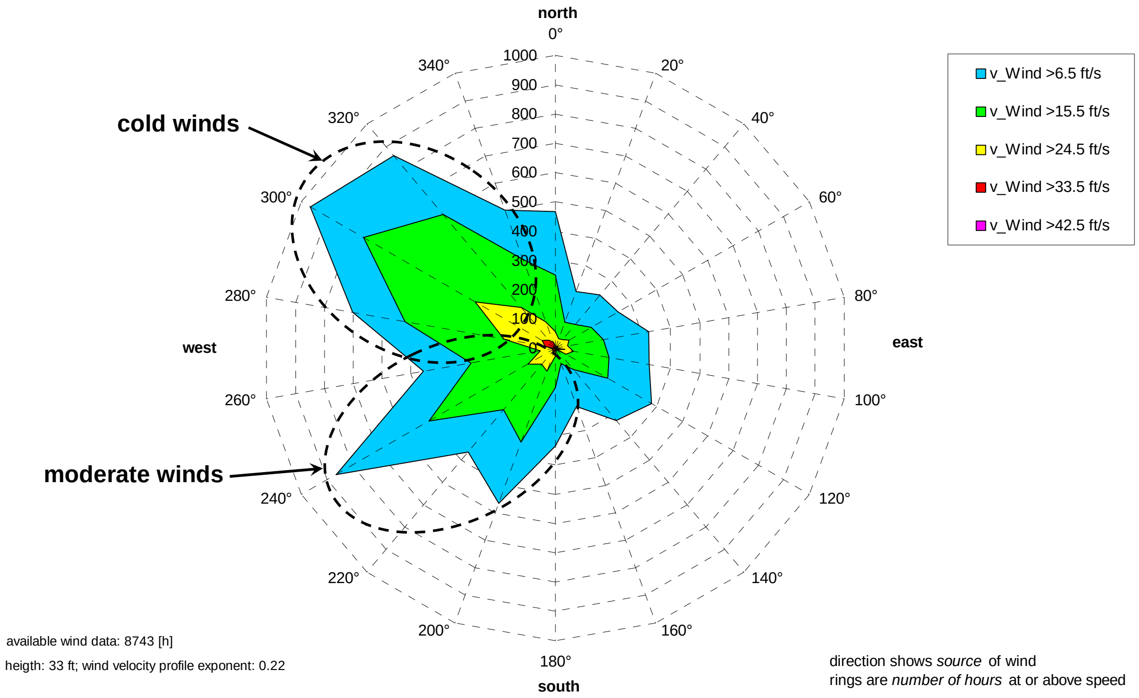

Figure 4: Wind rose for Boston

Thermal Comfort and Environmental Quality

The main purpose of any building is to provide a protected and controlled environment. If the building is to be occupied by people for any length of time, it must be comfortable in terms of temperature, air quality, noise, and other qualities. Spaces that are not comfortable for the occupants are unhealthy, unpleasant, distracting, and unproductive.

Thermal comfort of building occupants is affected by many more factors than air temperature. Surrounding surface temperatures, humidity, direct sunlight, air velocity, and clothing levels all affect occupant comfort. Therefore, several factors in addition to the traditional air temperature-based design criteria must be considered when creating a comfortable low-energy environment.

Because indoor air temperature is not the only factor influencing occupant comfort, it should not be used as the only parameter in the design of thermal comfort systems. Many metrics of varying complexity have been developed to take into account other thermal comfort factors. The factor most strongly affecting occupant comfort after air temperature is surrounding surface temperatures. The operative temperature is the mean of the air temperature and the mean surrounding surface temperature and provides a better measure of occupant comfort without introducing excessive complexity.

Different types of spaces require different thermal design parameters depending on the activity. Transitional spaces such as lobbies or hallways do not require the same level of comfort as offices and conference rooms. In addition, moving directly from an unconditioned outdoor environment to a fully conditioned indoor environment is often uncomfortable for occupants. Provision of partially conditioned spaces helps reduce this transitional discomfort. Finally, indoor spaces must not be over-conditioned (too cool). Overcooling results in occupant discomfort and waste of energy.

Finally, appropriate arrangement and designation of zones with different thermal design parameters and operating hours is critical to maximizing occupant comfort while minimizing energy use. Defining a thermal boundary between zones with different conditions prevents thermal losses and saves energy for cooling. The mixing of conditioned air between zones should be deliberately planned and controlled by defined openings and pressure conditions, automatic door closers, vestibules and adequate control strategies.

Benefits

- fewer occupant complaints
- reduced energy cost for partially conditioned spaces
- reduction of peak energy demand for cooling
- better comfort for occupants transitioning from outdoors into fully conditioned space
- multiple comfort conditions available to satisfy occupants with different comfort needs
- increased productivity

Requirements

- Condition regularly occupied interior spaces to ASHRAE 55-2004. Operative temperature must be considered in evaluation of compliance with ASHRAE 55-2004.
- Semi-condition predominantly glazed spaces (atria, wintergardens); provide local means for minimum comfort conditions, let temperature for remainder of space float.
- Provide individual occupant controls to adjust microclimate at workstations.
- Limit HVAC noise to 32 dBA[1] in private office spaces, 40 dBA in open-plan areas (a small amount of noise is beneficial for masking effects in multiple-occupant areas).

Potential Strategies

- use of TRNSYS, EnergyPlus, or equivalent thermal simulation tool capable of calculating operative temperatures as a design tool
- use of buffer spaces such as winter gardens, atria, double façades, etc.
- careful location and definition of borders between zones to reduce thermal losses
- design of openings or fans for deliberate, controlled airflow between zones
- underfloor air distribution with individually operable diffusers
- individually operable windows
- elimination of fans from occupied areas
- appropriate selection and evaluation of sound-absorbing materials

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[1] See Appendix A – Noise Levels for chart of noise levels

Building Envelope

The envelope design is a primary driver of energy demand in buildings. Many factors influence heat gains and losses through the building envelope. The thermal transmittance (U-value) of the facade affects the energy demand for cooling and heating. The thermal transmittance of opaque facade areas impacts the indoor surface temperatures that the occupants experience. The solar radiation striking windows is partially transmitted depending on the solar heat gain coefficient (SHGC). Special coatings on glass allow a high transmission of visual radiation while reflecting invisible solar radiation which causes unnecessary heat gain. To prevent overheating from solar gains, strategies to maximize shading and appropriate glazing materials are required, but sufficient daylight must still be allowed to pass through the facade.

Benefits
- reduce peak cooling/heating demand and costs
- reduced annual energy use
- reduced glare
- improved indoor surface temperatures for better indoor comfort

Requirements
- Exceed ASHRAE 90.1-2007 requirements by 20% for opaque wall and fenestration U-value and fenestration Solar Heat Gain Coefficient (SHGC)
- Provide effective shading to regularly occupied, non-transitional spaces:
  - Operable exterior shading (preferably with daylight redirection capability) on all glazed surfaces, except facades within 10° of true north if all direct sunlight is blocked by other means (fixed exterior shading, user-controlled interior shading, building form, or neighboring buildings) until 7 pm. Provide individual controls for shading at workspaces.

    -OR-

  - Fixed exterior shading (or general building form providing shade) to block all direct sunlight into workspaces between 10 am and 4 pm within 6 weeks of the summer solstice (May 10-August 2) AND provide interior shades with a highly reflective outside-facing surface (reflectivity > 0.7).

Potential Strategies
- decrease ratio of facade area to building volume
- minimize thermal bridges by using appropriate construction
- minimize SHGC on facades with maximum sun exposure

Daylighting and Views to Outside

Energy optimization always requires a balance of opposing forces. For example, daylighting has a beneficial impact on energy use because it reduces electricity needed for electric lights, which in turn results in a further reduction in air conditioning load. On the other hand, uncontrolled solar gains can lead to tremendous overheating problems and unnecessary air conditioning load. The key is to capture daylight in such a way that the related solar heat gain is rejected or controlled. Views to the outside are important for occupant comfort, happiness, and productivity.

Adaptable skins allow the thermal and visual properties of the building enclosure to adjust as needed to accommodate daily and seasonal cycles. A static skin must make trade-offs, while an adaptable skin can optimize building energy performance. The building form also requires optimization and trade-offs - a compact building form minimizes energy losses but also limits daylight access, while a more open form with limited building depth ensures natural illumination for major functions but increases skin losses.

Benefits

- reduced peak electricity and air conditioning load
- positive impact on occupant health and productivity
- views to outside
- less dependence on artificial lighting

Requirements

- 25 fc (270 lx) of daylight on a horizontal surface at 30” (76 cm) height for at least 75% of regularly occupied spaces, for a clear sky at noon on an equinox (LEED NC 2.2 Credit 8.1 Option 2)
- 90% of regularly occupied spaces have a direct line-of-sight view to the outside via vision glazing between 2’6” (76 cm) and 7’6”(229 cm) above the finished floor. (LEED NC 2.2 Credit 8.2)

Potential Strategies

- maximize regularly occupied spaces adjacent to the façade
- use of light shelves, atriums, light wells, daylight tracking systems, shading systems with function of redirecting light, prismatic glazing, etc.
- adequate ratio and position of openings (i.e. 50% window, 50% opaque)
- adequate window area depending on floor elevation, shading from other buildings and self-shading, and occupancy
- adequate floor to ceiling height
- use of clerestory window bands to allow daylight penetration deep into the indoor space

- use raytracing daylight simulation tools such as RADIANCE or equivalent to aid design of daylighting systems

Lighting

After daylight has been optimized through the architectural design, the artificial lighting system must also minimize energy use. This is first achieved through the use of energy efficient fixtures and lamps. Controls for the lighting of the facility should also be automated wherever possible to further reduce consumption.

The exterior lighting system design should include fixtures and layouts which limit the amount of light pollution. Exterior lighting should be controlled by a lighting control system with a photocell input to shut off lighting when sufficient daylight is available.

Benefits

- reduced peak electricity and air conditioning load
- positive impact on occupant health and productivity
- reduced impact on night sky
- less nighttime light intrusion on neighboring properties

Requirements

- Limit installed lighting power density (LPD) of overhead lighting in workspaces to 0.9 W/nsf (~20% less than ASHRAE 90.1-2007 for office space). Provide individual control, not more than 500 sqft per control, coordinated with daylight availability.
- Verify that resulting daylight and artificial lighting system provide at least 30 fc (325 lx) at workspaces to prevent need for additional lighting for typical office tasks.
- Follow LEED NC 2.2 Sustainable Sites Credit 8, Light Pollution Reduction, for site boundary luminous flux (limits luminous flux across site boundary, according to zones defined by IESNA RP-33). Furthermore, no direct light (light rays directly from lamp or reflection or diffusion surface of luminaire), interior (through windows) or exterior, shall cross the site boundary or escape to the sky.

Potential Strategies

- sufficient occupant control of lighting to meet various needs
- occupancy sensors (light on demand)
- daylight level sensors (dimming)
- use luminaires with high efficacy and a high ratio of direct light
- optimized use of ballasts for multiple lamp fixtures
- other controls including programmable low voltage relays and time clocks

- use raytracing daylight simulation tools such as RADIANCE or equivalent to aid design of lighting systems

Comfort Systems

Alternatives to all-air-cooled, completely sealed buildings must be considered in order to provide a high-performance building. A natural ventilation concept with surrounding radiant surface temperatures considered allows occupant comfort at a higher temperature level than with conventional cooling concepts such as mechanical ventilation (see Figure 5). Natural ventilation allows the facade design to have a positive impact on air quality by providing outdoor air directly into the indoor space through operable windows or other ventilation openings.

Occupant, equipment and radiant heat is absorbed not only by ventilation air but also by building mass. High thermal mass delays the impact of peak daily cooling and heating loads and also dampens (reduces the amplitude) of cyclical load variations. This allows high occupant comfort to be maintained without large equipment or excessive energy consumption and also increases the opportunity for effective radiant heating and cooling by providing large exposed surface area.

Occupants rate radiant surfaces for heating or cooling as much more comfortable than the hot or cold air that is used in many air conditioning systems. Radiant systems also provide significant energy savings because the transport energy for water-based systems is 10 times lower than for air-based systems. Radiant systems do not require any fan, such as used in traditional fan coil units, creating a quiet indoor environment to meet the noise goals stated early.

Where natural ventilation is not possible fan energy must be minimized while ventilation effectiveness is maximized. Alternatives to traditional fully mixing room air distribution such as displacement ventilation should be considered and fan pressure drop should be minimized.

Benefits

- greater control by occupants provides opportunity for more satisfied occupants
- lower capital investment costs for mechanical systems
- lower maintenance cost due to simplification of mechanical systems
- less space required for air ducts
- reduced peak energy demand for cooling / heating
- reduced diurnal indoor temperature variation

Requirements

- Provide operable openings for natural ventilation, minimum net open area of 4% of net occupiable floor area, within 25' (8 m) (ASHRAE 62.1-2004 §5.1.1).
- Provide a hydronic system for distribution of heating and cooling energy to occupied zones. Consider radiant systems, and if not feasible, demonstrate why.
- Provide minimum 65% of indoor ceiling area in regularly occupied spaces as exposed thermal mass (no suspended ceiling or other insulating material)
- Use highly efficient air handlers and related equipment to provide mechanical ventilation when outdoor air is not suitable for natural ventilation. Fan power should be no higher than 0.3 W/cfm (0.5 W/m^3/h).

Potential strategies

- significant difference in elevation between openings for natural ventilation, to encourage stack effect
- wind-driven natural ventilation with careful placement of windows for cross-ventilation or use of wind scoops and similar devices. Consider prevailing winds for placement of openings.
- solar heat gain to enhance stack effect, such as in solar chimneys (for exhaust)
- use of multizone airflow simulation or computational fluid dynamics such as TRNFLOW, COMIS, CONTAM, or Fluent to aid design of natural ventilation systems
- night purge to extract heat from thermal mass (natural or mechanical)
- concrete ceilings without coverings
- massive floors and walls, especially for transitional areas not sensitive to acoustics
- phase change material (PCM)
- appropriate control strategies to prevent condensation (e.g. dew point sensors)
- air-air heat recovery on ventilation systems
- displacement ventilation

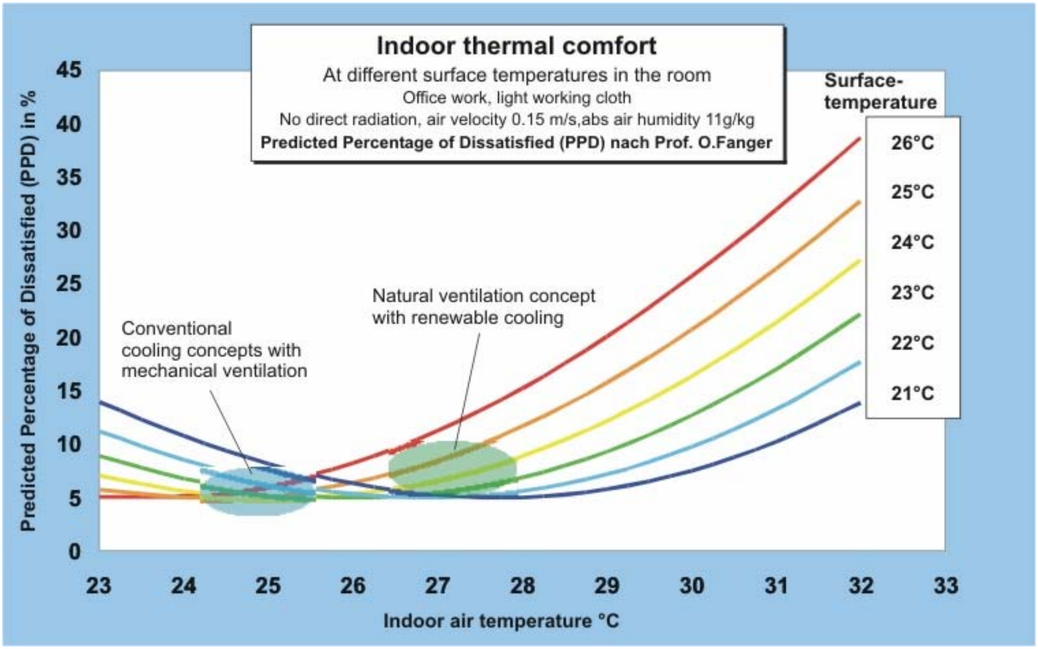

Figure 5: Range of internal thermal comfort with and without natural ventilation concept

Energy Supply

After the building architecture and systems have been optimized, the energy supply systems must be evaluated. The energy supply systems should be designed for the highest possible efficiency. A combination of low energy demand and high-efficiency energy supply systems makes it practical for renewable energy to contribute to a significant portion of the energy supply. In addition, waste energy should be used wherever possible.

Because of the higher possible coefficient of performance (COP), centralized energy production systems are preferred. Such systems allow the synergies of simultaneous production of chilled and hot water (e.g. heat pump-chiller-combined usage) to be fully utilized. When heating and cooling are available from district energy systems, these are often the most efficient options. When district systems are not available, a central plant for the building is preferred.

Use of electricity for heat generation is inherently inefficient, converting only about a third of a fuel's potential energy into usable energy. Heat generation in boilers burning fossil fuels is more efficient, but electricity must still be provided from traditional sources which are less than 33% efficient. Combined heat and electrical power (CHP) generation significantly increases overall system efficiency and eliminates the need for separate generation of heat. CHP is also an economically practical approach to reducing air pollutants by reducing emission of combustion products, whereas traditional pollution control achieved solely through flue gas treatment provides no profitable output and actually reduces efficiency and useful energy output.

Renewable energy should meet a portion of the building’s energy needs for a building to be considered truly sustainable. Solar thermal energy may generate hot water for a variety of uses, including heating, reheat after dehumidification, domestic hot water, and absorption chillers. Solar or wind-source electrical energy may augment all electrical needs of the building. In order for renewable energy systems to provide a meaningful contribution to building energy demand, the energy demands must first be minimized using the techniques described in the preceding sections.

Figure 5 and
Figure 7 show typical recommended central system principles for production of energy, hot water, and chilled water using the strategies outlined above.

Benefits

- reduced annual energy costs
- reduction of maintenance required within occupied areas

Requirements

- central heating hot water generation plant (if district energy is not available)
- 2.5% or more of annual energy demand to be met by renewable sources

Potential Strategies

- phase-change material such as ice storage for peak demand reduction
- absorption chillers (see Figure 47) in combination with CHP and/or solar thermal systems
- waste heat recovery to hot water systems
- water-side economizers for free cooling
- roof-mounted solar thermal panels
- roof-mounted wind turbines
- roof-mounted or building-integrated photovoltaics, conventional or thin-film

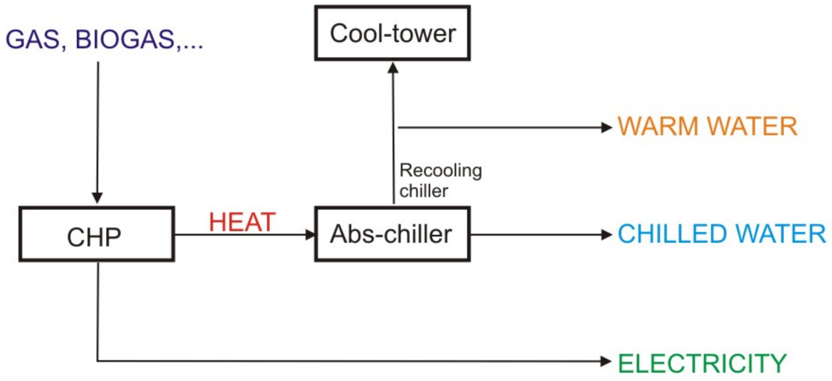

Figure 6: Principle of a CHP approach

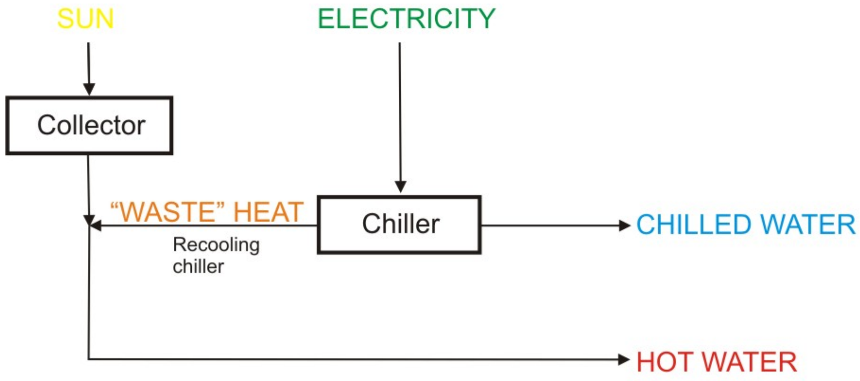

Figure 7: Principle of a chiller/heat pump/solar thermal approach

Water Use & Management

Strategies for reduction of water consumption and effective storm and graywater management have a threefold benefit: less demand on water resources and infrastructure, cost savings for the building owner, and reduced demand on stormwater and wastewater infrastructure.
The increasing worldwide scarcity of water makes water management as critical as climate change prevention.

Every building has numerous types of plumbing and similar fixtures which consume water. Many new technologies have been introduced to reduced water consumption by these fixtures. Significant water savings can be achieved by specification of low-flow fixtures and design of water reuse systems.

The main strategy for conserving water for irrigation is to plant native or adapted vegetation that requires little or no irrigation. Any remaining irrigation need should be met with graywater rather than valuable potable water. Similarly, for surface cleaning, materials which do not easily become dirty should be specified, minimizing the need for water for cleaning. Any water that is needed for cleaning should be provided from graywater systems before potable water is used.

Finally, cooling towers lose significant water through evaporation and discharge water in order to control condenser water chemical and biological content. Cooling tower water must be carefully managed to limit water usage and discharge.

Benefits

- reduction in utility costs for water
- reduction in sewage conveyance costs
- easing of load on existing and new municipal infrastructure and reduced development impact fees
- reduction of pumping costs
- reduction in size of distribution equipment

Requirements

- Comply with LEED-NC 2.2 WEc3.2 (30% water use reduction over Energy Policy Act of 1992 requirements).
- No potable water usage for irrigation (LEED-NC 2.2 WEc1.1)

Potential Strategies

- specify low-flow plumbing fixtures
- plant native or adapted vegetation that requires little or no irrigation

- reuse rainwater, graywater, or cooling tower discharge on-site for non-potable water systems
- specify materials which do not require frequent cleaning (e.g. smooth or self-cleaning)
- separate metering of cooling tower make-up and discharge water
- use of low-impact chemicals or physical alternatives for cooling tower water treatment

LEED and ASHRAE

The LEED (Leadership in Energy and Environmental Design) Green Building Rating System was developed by the U.S. Green Building Council (www.usgbc.org). LEED provides a single standard for improving and evaluating the environmental and economic performance of commercial buildings using established and/or advanced industry principles, practices, materials and standards. As with the remainder of the design guidelines, it is most achievable to reach a target LEED certification when the strategies for certification are considered from an early stage in the design process.

LEED certification is achieved by meeting certain minimum prerequisites and accruing points in various categories. The point total determines the level of certification. There are four possible certification levels:
Certified ➔ 26 to 32 points
Silver ➔ 33 to 38 points
Gold ➔ 39 to 51 points
Platinum ➔ 52 to 69 points

As a prerequisite, LEED requires compliance with several ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) standards, including ASHRAE 90.1-2004, *Energy Standard for Buildings Except Low-Rise Residential*. However, a more recent (and more stringent) version, ASHRAE 90.1-2007 is now available. Compliance with this standard will provide the best possible energy efficiency for Boston City Hall.

Benefits

- comprehensive evaluation of building sustainability across all topics
- comprehensive energy efficiency requirements include details not covered under these guidelines
- familiarity of most design team members with LEED and ASHRAE standards
- capability to market development as environmentally-friendly certified

Requirements

- Earn a LEED-NC 2.2 Gold certification
- Comply with ASHRAE 90.1-2007

Appendix A – Noise Levels

Sound level	Decibel Level	Examples
No Sound	0	Threshold of (undamaged) hearing
	10	Breathing
	15	Soft whisper
Very Quiet	20	Rustling leaves
	25	Recording Studio
	30	Quiet rural area, very quiet library.
	40	Very quiet residence
	45	Typical neighborhood.
Quiet	50	Quiet suburb, conversation at home, private office
	60	Normal conversation
Annoying	70	Highway traffic at 50 feet
	75	Typical car interior on highway
Loud	80	Dishwasher, noisy office
	85	City traffic (inside car).
	90	Shop tools, busy urban street, diesel truck, food blender
	95	Subway train at 200 feet
Very Loud	100	Jet takeoff 1000 feet, farm tractor, garbage truck, very heavy Traffic
	102	Motorcycle
	108	Home Theater (loud peaks)
	110	Chainsaw, pneumatic drill, typical rock concert, car horn at 3 feet
Painful	120	Loud thunderclap, typical live rock music
	130	Jet takeoff (300 feet), Noise level during a stock car race.
	140	Gun muzzle blast, aircraft carrier deck, jet engine at 100 feet
	150	Jet takeoff 75 feet
	180	Jet engine at 1 foot
	194	Loudest sound in air, air particle distortion (sonic boom)

Notes:
The dBA scale, or A-weighted decibel scale, is used to adjust sound levels to human perception of various frequencies, and is the most commonly used (but not best for all purposes) scale.

A change of 3 dBA is barely perceptible.
A change of 5 dBA is clearly perceptible.
A change of +/- 10 dBA is perceived as twice/half as loud.

Adapted from:
http://www.quietsolution.com/Noise_Levels.pdf