

Thermal Comfort Guidelines

1. Introduction

This guide presents the connection between building systems and comfort, productivity and operating costs. It identifies common problem areas, and gives design practices that can help create buildings that are comfortable, efficient and in demand.

2. Where to Start



Providing a comfortable and productive building environment is a shared responsibility between the owner, designer, contractor and building maintenance staff.

Integrated Design brings together the architects, engineers, owners, contractors, commissioning agents, and facility managers to participate in the design process as a team from the beginning, rather than as separate entities and stages to construction. All parties agree on a statement of design intent and communicate throughout the life of the project. The benefits are:

- significant improvements in the integration and operations of the buildings systems,
- greater consideration of the effect of the design, electrical and mechanical systems on occupants,
- upgrades in design and performance of equipment and systems,
- a building that is designed and operates as intended,
- clean, dry, comfortable and well ventilated indoor environment.

When the design team has worked together with the goal of providing thermal comfort for building occupants, the opportunities for innovation in mechanical system design and equipment selection increase. The building and envelope - its orientation, choice and placement of windows, effective use of natural light, interior space configurations, and consideration of the outdoor climate in design – are the key elements that set the stage for the design of the mechanical systems. Below is a checklist of the key areas of the building that need to be dealt with first.

Optimize the Thermal Envelope First

- ❑ Use available computer models to investigate the performance of various thermal envelope materials and configurations
- ❑ Optimize the thermal envelope before relying on building space conditioning systems for environmental control
- ❑ Recognize the influence of site and building orientation when designing building enclosure systems
- ❑ Understand the role of building mass in controlling thermal comfort especially in interiors
- ❑ Depend on thermal envelope performance and natural space conditioning and ventilation strategies before engaging mechanical systems
- ❑ If outside conditions are acceptable, maximize natural ventilation
- ❑ Assure the benefits of natural light are achieved without the discomfort of heat and glare by selecting high efficiency glazing options and optimum size and placement of windows for daylighting

Air Quality

To no surprise, the issue of indoor air quality has emerged in recent years, as building occupants have reacted to concerns over health issues from air contaminants. The building mechanical systems are engineered to provide outdoor air for ventilation but in many instances cannot respond to varying or intermittent pollutant loading within the building. The sealed skin of the building works to trap airborne contaminants from sources ranging from photocopying, printing, paint, carpeting, furnishings, and other interior products and activities.

In many instances the combination of inflexibility of overhead distribution of ventilation air and the obstruction in air flows by office cubicles make both the removal of air contaminants and the provision of fresh air an extremely challenging obstacle.

Source control is far more cost-effective than dilution of contaminants by ventilation. Many of the products used in office furniture, paints, carpets and copiers emit pollutants that can cause ailments ranging from general malaise to asthma, potentially costing U.S. businesses billions of dollars per year.

Improvement of products in terms of emissions from materials and from maintenance and cleaning chemicals, as well as prevention of moisture intrusion or condensation and accumulation leading to microbial growth, could contribute to improve indoor air quality. By limiting the sources of indoor pollution the mechanical system can better do its job of providing thermal comfort and ventilation. Resources listed at the end include sources for technical information on building materials and indoor pollutants.

3. Approach

Designing, constructing, starting up, controlling and maintaining building systems is very

complex. If done properly, the final product operates efficiently at reasonable cost, delivering comfort, safety and a healthy environment. If any part of this process breaks down, the product fails to deliver the benefits and operating costs can escalate.

Most designers, contractors and building owners / developers can tell stories about buildings that are uncomfortable, expensive to operate and have on going problems with the mechanical system. Suppliers have been forced to operate on a “least cost” model to fit the contract budget and get the job.

A new way of thinking about the role of mechanical systems in buildings has emerged over the last few years. This “integrated design” approach described above, looks beyond the simple question of mechanical system sizing and specification and sees the building's HVAC system as integral to the design process and ultimate occupant satisfaction. Below are the key design issues that need to be addressed to achieve thermal comfort:

Strategies
Use building orientation and envelope design to minimize the thermal load of the building
Use office equipment and lighting systems that reduce internal loads
Intake of clean outdoor air or filtration and cleaning of poor quality outdoor air
Minimize source pollution through material selections
Design of an effective ventilation supply and distribution system
Design of an effective thermal control scheme
Selection of efficient equipment and proper controls to implement the ventilation and thermal control design
Commission the design, installation and operation of the systems

4. System Design Choices

Since the commercial marketplace is dominated by the following “common” systems, that often operate very poorly, these systems are the most important ones to improve for thermal comfort and energy efficiency. This section breaks the systems into the components and described design improvements. Knowing the problem areas and remedies will save you and your client enormous amounts of time and money. The high performance systems provide examples of systems that are frequently used for larger projects.

Common

The term “**packaged systems**” generally refers to a class of unitary HVAC equipment, including single package rooftop air conditioners and heat pumps, split system air conditioners and heat pumps, packaged terminal air conditioners and heat pumps, (PTAC, PTHP).

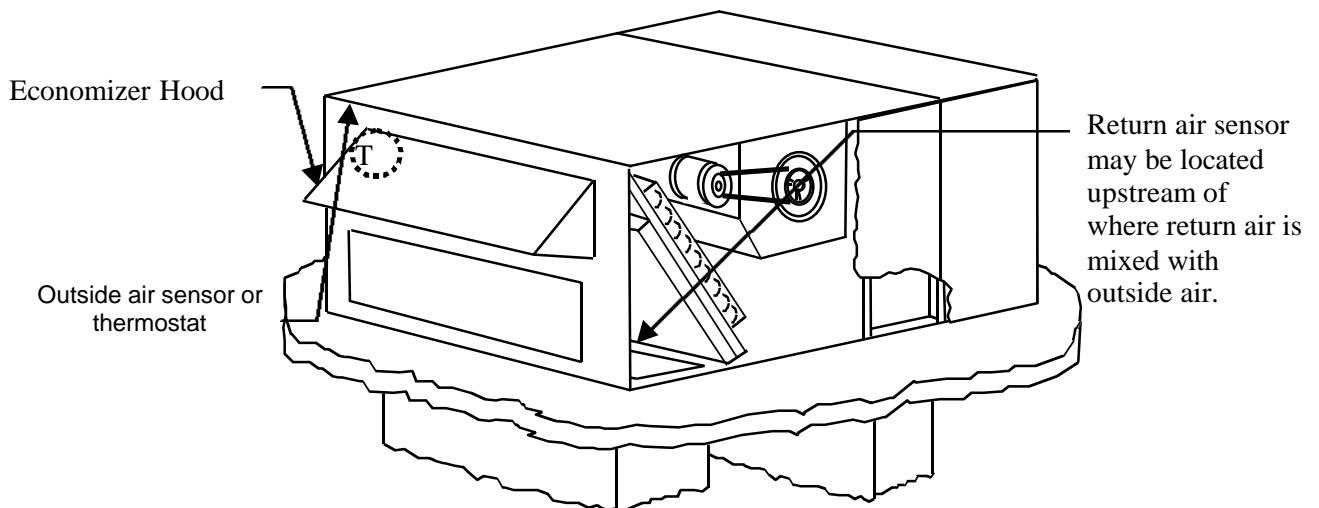
Controls on unitary equipment include internal control systems supplied with the equipment by the manufacturer and external controls that control the delivery of heating, cooling and ventilation services according to occupant requirements. Many IAQ complaints are the result of failure to maintain appropriate thermal conditions in the occupied spaces.

Consider using VAV changeover systems in conjunction with package systems to improve personal control.

Economizers. Economizers provide outside air at temperatures that can significantly minimize cooling requirements by the mechanical system. In the Northwest, there are a large percent of days that an economizer can supply fresh cool air to mix with the internal supply system.

Codes vs. Optimum. Meeting code is the lowest level acceptable by law. Designing for high performance and optimum thermal comfort should go well beyond the baseline of code. In economizers, usually units less than 54,000 Btu/hr nominal cooling capacity (5.25 tons and smaller) are exempt under building codes, yet economizers are widely available as an adder from manufacturers on 3 to 5 ton units.

Conversely, most units larger than 5 tons have outdoor air economizers as required by code. Codes also require an “integrated” economizer, which is capable of providing partial cooling, even when mechanical cooling is required to meet the remaining cooling load. Effective operation of an integrated economizer requires a compressor system that provides stable operation at partial cooling output. Units larger than 6 tons generally use multi-stage compressors to provide at least two discrete levels of cooling output.



The recommended control strategy in the Northwest with integrated economizer systems is differential temperature -- the economizer shuts off when the outdoor temperature exceeds the return air temperature.

Fan Controls / Ventilation. Building outdoor ventilation air is typically supplied during fan operation. Small commercial buildings typically do not have sophisticated energy management systems to control ventilation. The quantity of outdoor air is determined by the minimum outdoor air damper position. There is a growing body of evidence to suggest that proper operation of ventilation fans does not occur. The supply of continuous fresh air and even distribution during occupied hours relies on continuous operation of the HVAC unit supply fan.

Most simple thermostats used to control unitary equipment provide an easily accessible switch on the face of the thermostat that determines fan operation. **When set to the “on” mode, the fan runs continuously.** When set to the “auto” mode, the fan only runs when the space loads are sufficient to require heating or cooling. Supply fan operation, and thus ventilation requirements, rely on the manual daily setting of the fan on/auto switch to the “on” position.

Programmable thermostats are the first choice to improve the operations, ventilation, and flexibility of the system. They are widely available for packaged unitary equipment from many

sources including the unitary equipment manufacturers. Programmable thermostats have time of day and day of week features with a manual on/auto fan switch. They typically have 24 programmable time steps for each day type. This type of thermostat prevents under-ventilating because the fan is independently programmable from the temperature setpoint. By setting the fan to “auto” during unoccupied periods energy is saved, but ventilation is still maximized during full occupancy periods.

Zone Control. The major manufacturers offer *master* and *slave* programmable thermostats for buildings with multiple units. They also offer control panels that provide a central programming access point for the thermostats on all units. These features will provide the maximum thermal comfort by allowing zone control of settings. All programmable thermostats have over-ride features that allow the user to set up or back temperatures during non-business hours.

Air Distribution systems are the primary means of moving heating and cooling energy from systems to the various conditioned spaces of buildings. In package systems they consist of supply and return ducts or plenums through which heated or cooled air is moved. Duct systems should ideally be perfectly efficient, delivering to the conditioned spaces all of the air that is supplied by the central equipment, with no change in temperature. A duct leakage test can be used to ensure that the air distribution system has been tightly constructed.

In reality, however, duct systems meet neither of these ideals. These ducts and plenums can have two types of inefficiencies which impact the occupants comfort and the building’s energy consumption directly and indirectly:

1. Leaks in the ducts and plenums resulting in supply air being diverted to, and return air drawn in from, undesired locations;
2. Change in air temperature during distribution.

These air distribution system inefficiencies cause a number of problems including:

- Reduced efficiency of the overall space conditioning system.
- Reduced heating or cooling capacity, often resulting in oversized equipment being installed to compensate.
- Uneven conditioning across the building, resulting in occupant discomfort.
- Depressurization of the building. If natural draft combustion appliances are installed (such as gas water heaters) the depressurization increases the risk of appliance backdrafting. The resulting presence of NO₂ and water in the space can degrade the indoor air quality. If the appliance also has a malfunctioning burner, CO can be introduced to the space.
- Increases the overall building infiltration rate. This can cause increased energy consumption to heat and cool the infiltration air. Unfortunately, this infiltration air may be the unintended primary source of ventilation for the building, improving the indoor air quality of buildings through failures in system designs. Properly controlled ventilation systems should be the proper means of providing this benefit.

In addition, larger commercial buildings have fan power consumption that is on the same order of magnitude as the cooling energy. Since the fans should run continuously, reducing the required airflow reduces the fan power, thus having a potential for significant operational efficiencies.

There are several reasons for leakage problems in conventional air distribution systems. These include:

- Use of inadequate connection methods between pieces of the duct system. Most notorious is the use of poor quality duct tape to seal connections. These connections then fail either

immediately (the tape didn't stick because the surfaces were dusty or dirty) or in a short span of time (the tape adhesive was weak or was not able to handle the temperature cycles encountered).

- Improper installation of the ducts, particularly not adequately connecting different pieces of the system together is commonly found as a post-installation condition.
- Use of building cavities as air distribution plenums. In particular, drawing return air through the ceiling plenum can result in significant leakage from the outdoors.

An alternative to contractor installed sealing approaches is the use of an **aerosol based sealing technology**. Once the distribution system has been constructed and there are no gross leaks (such as ducts that are not connected), an aerosol sealant is sprayed into the ducts while they are pressurized by a fan. The sealant adheres to the edges of any leaks, building up to seal the leak.

The average duct leakage into unconditioned spaces in commercial buildings is 26%

An alternative to extensive requirements on duct system construction is to build the building with the air and thermal barrier co-located at the roof and extending down the outside walls of the ceiling plenum. Ductwork installed in the plenum is then inside the conditioned space, and any losses have negligible impact on the energy consumption of the building. (This is currently a requirement of ASHRAE/IESNA Standard 90.1-1999, which prohibits use of a suspended ceiling as the air or thermal barrier.)

Summary of Recommendations for Improved Common Systems

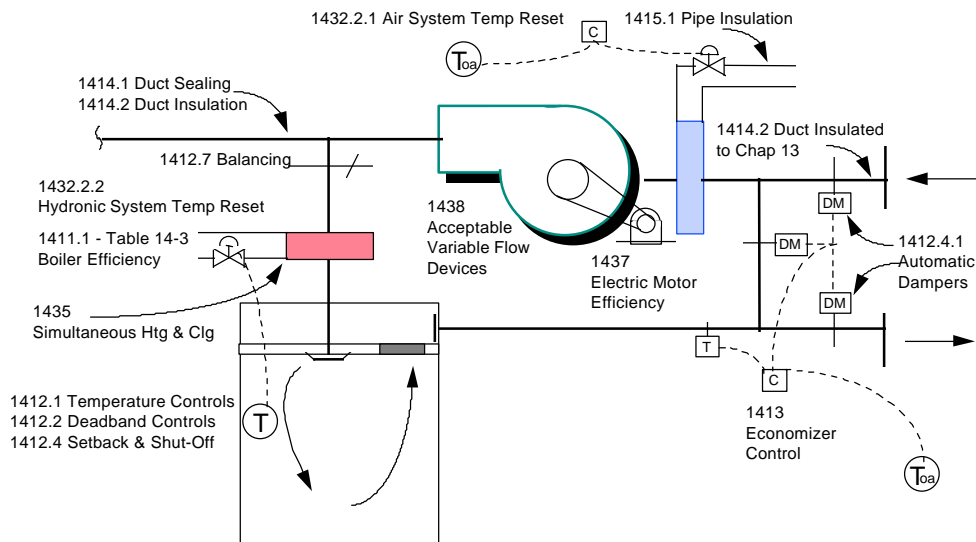
- Choose high-efficiency units (CEE Tier II)
- Consider demand control ventilation (CO₂) for high-occupancy spaces
- Economizer installed and tested on all units > 3 tons
- Outdoor damper set to provide proper ventilation air
- Air distribution systems tested & fixed for less than 6% leakage
- Consider VAV Changeover system to improve personal control
- Programmable thermostat set to run fan continuous during occupancy
- Programmable thermostat temperature setpoints correct

Good Performance

One approach is the *variable air volume* system (VAV). This approach to mechanical system design employs thermostats in the multiple zones of the building to sense necessary levels of heating and cooling. In most areas of the Pacific Northwest, the cooling needs of the building can be all or partially met by air from outside the building using an economizer. The economizer can provide both cooling needs as well as providing the necessary ventilation air.

In many buildings, the multiple zones of the building have varying heating and cooling requirements, both between the zones and within a zone over various times of the day. A common VAV system for such a multiple zone building will use a single supply fan with a cooling coil, a

set of VAV boxes for the interior zones of the building providing cooling only, and VAV boxes with electric thermal resistant or hot water heating for perimeter zones which can provide both heating and cooling.



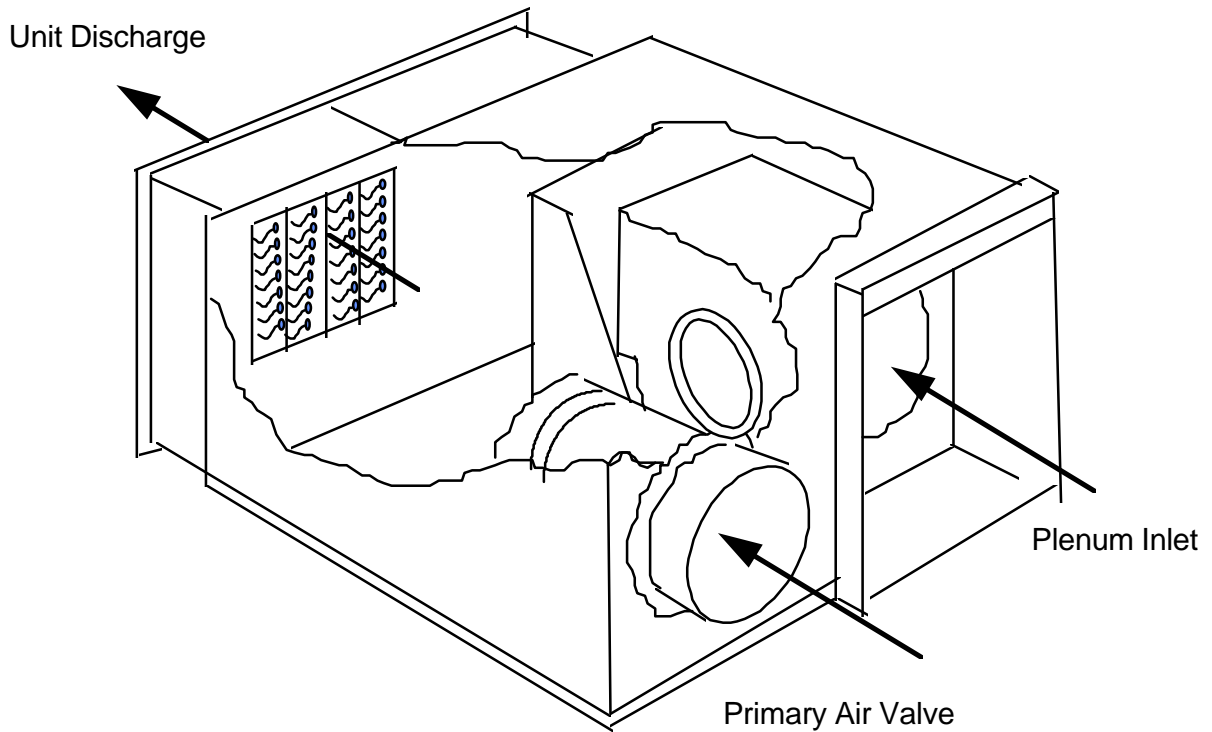
Typical VAV System Schematic

If You Can't Measure It, You Can't Control It

Variable flow system designs improve occupant comfort and reduce energy costs by delivering only the quality of air necessary to condition and ventilate the zone. Equipment for sensing air flows and pressures is instrumental in achieving the appropriate control of the system.

The VAV system design can further be improved by increased utilization of variable speed fans.

An adaptation of a VAV system, *terminal regulated air volume system (TRAV)* has essentially the same components but allows air flow to be directly regulated at each zone with a different set of criteria for establishing comfort levels. This approach gives occupants a greater level of control than is typical to a VAV system. The TRAV system will lower the amount of air and fan energy required to condition the space.



High Performance

VAV and VAV with TRAV systems improve operating efficiency and provide a variety of temperature controls, but the delivery of air to the space still comes from overhead, making occupant control over flow vanes impossible to access.

With regard to energy efficiency and occupant control, the best practice may be the *underfloor air volume* system. The underfloor system uses a similar variable flow approach, but as its name implies, the delivery of air comes from a floor plenum beneath the occupant. This plenum is set in above the actual floor level of the building.

Under Floor System Advantages

- Lowest life-cycle cost
- Increased space flexibility
- Green Buildings Design
- Enhances open structure
- Improves Indoor Air Quality
- Individual temperature and air control
- Reduced operational costs

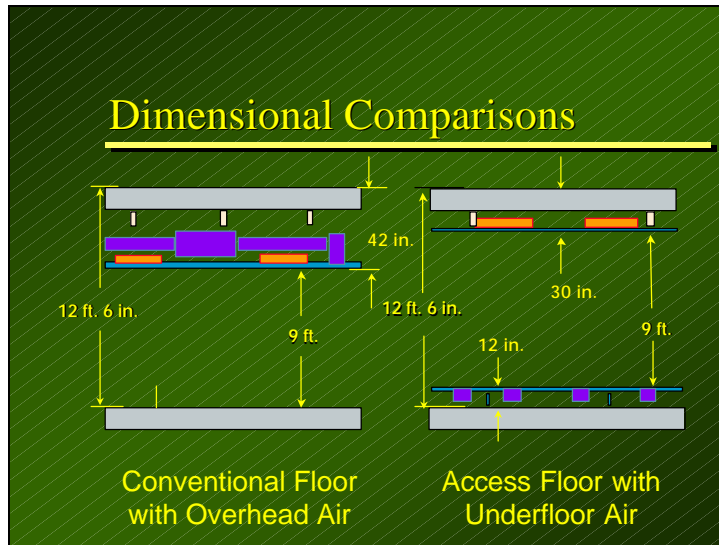


Illustration courtesy of Glumac International

In the underfloor system, air is delivered at relatively low pressures and volumes as it only needs to travel a short distance to reach building occupants. Occupant control is greatly enhanced since one only has to reach to floor level to adjust the flow of air. Air temperature can also be adjusted by manipulating dampers and flow vanes directly at the work area. The reduction in air volumes and velocities combined with increased accessibility to air delivery accomplishes the twin goals of reduced energy use and increased occupant control.

Another advantage to the underfloor system design is its ability to work in conjunction with operable windows. Since air volumes and pressures are delivered at low rates, the use of open windows for natural ventilation will not undermine the engineering of the system. This design also allows for easy under floor locating and access of communications and electrical wiring. Improving the owner's ability to rapidly reconfigure the space for changing tenant needs at greatly reduced costs. The underfloor system could add an additional \$1.75 to \$2.00 per square foot of construction cost. However, the advantages of the system in long term energy savings, occupant comfort, and flexibility for future change may offset this additional cost .

5. Equipment Selection

Equipment Efficiency

The Consortium for Energy Efficiency (CEE) a national organization that promotes improved markets for energy efficient products has established a two-tier rating for unitary equipment. Tier 1 is based on the ASHRAE 90.1 efficiencies (about 13% higher than current federal standards) while Tier 2 represents a 10% increase in efficiency from Tier 1 levels.

Package Equipment Efficiencies

CEE Guideline for Unitary Commercial Air Conditioners

<i>Equipment type</i>	Size category	Sub-category	<i>Tier 1 efficiency</i>	<i>Tier 2 efficiency</i>
Air Conditioner, Air Cooled (Cooling Mode)	<65,000 BTUh	Split system	12.0 SEER	13.0 SEER
		Single package	11.0 SEER	13.0SEER
	>65,000 BTUh and <135,000 BTUh	Split system	10.3 EER	11.0 EER
		Single package	10.6 IPLV	11.4 IPLV

For a complete listing of Tier 1 and Tier 2 equipment efficiency levels and qualifying equipment by manufacturer, visit the CEE web site at www.ceeformt.org

Glossary

Energy-Efficiency Ratio (EER)

- The ratio of the cooling capacity in Btu to the electric input to the air conditioner or heat pump in watt-hours.

Heating Seasonal Performance Factor (HSPF)

- The total heating output of a central air conditioning heat pump, in Btu, during its normal usage period for heating, divided by the total electric energy input in watt-hours during the same period.

Seasonal Energy-Efficiency Ratio (SEER)

- The ratio of the total cooling capacity in Btu during a normal annual usage period to the total electric input in watt-hours to the air conditioner or heat pump during the same period.

Single-Package System

- An air conditioner or heat pump with all major components housed in a single casing.

Split System

- An air conditioner or heat pump consisting of two or more major components which are not enclosed in one cabinet. For a split system, a compressor and condenser are generally installed outside the building and the cooling coil is generally installed within the building.

6. MOVING TO BEST PRACTICE

While the challenge of controlling energy use in commercial buildings and providing for occupant comfort is a substantial one, it can be - and is being done. In almost every successful example, the following practices were observed.

- ❑ Commitment from the beginning to an integrated design strategy
- ❑ Architects, engineers, owners, contractors, commissioning agents, and facility managers participate in the design process as a team. All parties agree on a statement of design intent and communicate throughout the life of the project.
- ❑ Involve a building commissioner at the design stage. The commissioning agent will help insure that the building systems actually achieve design intent.
- ❑ Involve a professional with building energy efficiency experience on the design team. This professional will help insure rapid code compliance and provide suggestions on optimization of building and mechanical system design features.
- ❑ Avoid value engineering changes that lower first cost at the sacrifice of comfort and building value.
- ❑ Train building operations staff to insure that design intent is achieved over the life of the building.

O&M

Achieving thermal comfort doesn't stop at the end of design or construction. Effective operation and maintenance is required. In addition to assuring comprehensive O&M manuals, operators should have some degree of hands on training on the new systems and clear performance objectives as their guide. Studies from across the country demonstrate energy savings of 6% to 14% in commercial and industrial facilities from improved equipment operation and maintenance.

The Building Operator Certification program aims to improve energy and resource efficiencies in the region's commercial buildings through specialized training for building operators and plant managers. The training program shows participants how they can use preventive maintenance practices to lower energy costs and improve tenant comfort in their buildings.

Businesses throughout the region are recognizing this consistent, competency-based training program. For more information contact www.neec.org

This guide was prepared by the New Building Institute for the Northwest Energy Efficiency Alliance.