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ARCHITECT'S AND ENGINEER'S GUIDE TO ENERGY CONSERVATION IN EXISTING BUILDINGS

Volume 2 - Energy Conservation Opportunities

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SUMMARY

This second volume of the Architect's and Engineer's Guide to Energy Conservation in Existing Buildings serves as a handbook for energy managers to assist them in deciding which energy conservation opportunities (ECOs) to pursue. While the first volume of the set deals in general with ECOs, this volume details specifics concerning 118 ECOs, including how to implement the ECO, the information required to analyze the ECO, and the use of a personal computer model, ASEAM, to analyze each ECO.

The 118 ECOs discussed in Chapter 1 and analyzed in Chapter 2 fall into the following eight categories: building equipment operation, building envelope, HVAC systems, HVAC distribution systems, water heating systems, lighting systems, power systems, and miscellaneous ECOs that do not fall into the other categories.

The two-volume guide is based on research performed by Pacific Northwest Laboratory[1] for the Federal Energy Management Program within the Office of Conservation.

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[1] Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute.

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1.0 ENERGY CONSERVATION OPPORTUNITIES

This chapter contains a discussion of 118 energy conservation opportunities (ECOs) (see Table 1.1). These ECOs address ways to reduce energy use and improve the operating efficiencies of space heating and cooling systems, water heating systems, lighting systems, and power systems. The ECOs discussed in this chapter fall into following categories:

- building equipment operation
- building envelope
- HVAC equipment systems
- HVAC distribution systems
- water heating systems
- lighting systems
- power systems
- miscellaneous.

An ECO may be realized either by implementing operation and maintenance (O&M) measures or by incorporating available technologies. In general, the O&M energy conservation measures involve little or no financial investment and should be implemented immediately.

The discussion of each ECO includes general guidelines for implementing the ECO. Where appropriate, the implementation procedure, the circumstances under which the ECO can be applied, and/or characteristics that may affect the implementation decisions are highlighted. The discussion of each ECO also contains a section describing what information is required to analyze and implement the ECO. Chapter 2 of this volume contains a discussion of how to analyze most of these ECOs using a PC-based computer simulation model, ASEAM.

1.1 BUILDING EQUIPMENT OPERATION

An enormous amount of energy is wasted because building equipment is operated improperly and unnecessarily. The most effective energy-conservation strategies in this area are to reduce the amount of time equipment is operated and to adjust the setpoints for temperature and humidity.

TABLE 1.1. Overview of Energy Conservation Opportunities

BUILDING EQUIPMENT OPERATION

Reduce Operating Hours

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ECO 2 - Reduce Operating Hours for Ventilation Systems
ECO 3 - Reduce Operating Hours for Water Heating Systems
ECO 4 - Reduce Operating Hours for Lighting Systems
ECO 5 - Reduce Operating Hours for Escalators and Elevators
ECO 6 - Reduce Operating Hours for Equipment and Machines

Adjust Space Temperature and Humidity Setpoints

ECO 7 - Lower Heating and Raise Cooling Temperature Setpoints
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BUILDING ENVELOPE

Reduce Heat Conduction Through Ceilings and Roofs

ECO 10 - Insulate Ceilings and Roofs
ECO 11 - Install Vapor Barriers in Ceilings and Roofs

Reduce Solar Heat Gain Through Roofs

ECO 12 - Install Reflective Roof Surfaces

Reduce Heat Conduction Through Walls

ECO 13 - Insulate Walls
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Reduce Heat Conduction Through Floors

ECO 15 - Insulate Floors

Reduce Heat Conduction and Long-Wave Radiation Through Glazing Areas

ECO 16 - Install Storm Windows and Multiple-Glazed Windows
ECO 17 - Insulate Movable Windows
ECO 18 - Install Operable Windows

Control Solar Heat Gain Through Glazing Areas

ECO 19 - Install Exterior Shading
ECO 20 - Install Interior Shading
ECO 21 - Use Tinted or Reflective Glazing or Films
ECO 22 - Install Air-Flow Windows

TABLE 1.1. (contd)

Reduce Infiltration

ECO 23 - Seal Vertical Shafts and Stairways
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HEATING, VENTILATION AND AIR-CONDITIONING (HVAC) SYSTEMS

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ECO 27 - Reduce the Generation of Indoor Pollutants
ECO 28 - Install Air-to-Air Heat Exchangers
ECO 29 - Install Air Cleaners
ECO 30 - Install Local Ventilation Systems

Improve Chiller Efficiency

ECO 31 - Clean Evaporator and Condenser Surfaces of Fouling
ECO 32 - Raise Evaporator or Lower Condenser Water Temperature
ECO 33 - Isolate Off-Line Chillers and Cooling Towers
ECO 34 - Install Evaporatively Cooled or Water-Cooled Condensers

Improve Boiler or Furnace Efficiency

ECO 35 - Clean Boiler Surfaces of Fouling
ECO 36 - Check Flue for Improper Draft
ECO 37 - Check for Air Leaks
ECO 38 - Install Flue Gas Analyzers for Boilers
ECO 39 - Preheat Combustion Air, Feed Water or Fuel Oil with Reclaimed Waste Heat
ECO 40 - Isolate Off-Line Boilers
ECO 41 - Install Automatic Vent Dampers
ECO 42 - Install Automatic Boiler Blow-Down Control
ECO 43 - Install Pulse or Condensing Boilers/Furnaces
ECO 44 - Install Air-Atomizing Burners (for Oil-Fired Systems)
ECO 45 - Install Low-Excess-Air Burners (for Oil-Fired Systems)
ECO 46 - Install Modular Units

Improve Air-Conditioner or Heat Pump Efficiency

ECO 47 - Clean Air Filters
ECO 48 - Install Add-On Heat Pumps
ECO 49 - Install Ground or Ground-Water Source Heat Pump

TABLE 1.1. (contd)

Reduce Energy Used for Tempering Supply Air

ECO 50 - Install Variable Air Volume Systems
ECO 51 - Reset Supply Air Temperatures
ECO 52 - Reset Hot/Chilled Water Temperatures

Use Energy-Efficient Cooling Systems

ECO 53 - Install Economizer Cooling Systems
ECO 54 - Install Evaporative Cooling Systems
ECO 55 - Install Desiccant Cooling Systems
ECO 56 - Install Cooling Tower Cooling Systems
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ECO 61 - Maintain Steam Traps
ECO 62 - Insulate Ducts
ECO 63 - Insulate HVAC System Pipes

Reduce System Flow Rates

ECO 64 - Reduce Air Flow Rates in Ducts
ECO 65 - Reduce Water or Steam Flow Rates in Pipes

Reduce System Resistance

ECO 66 - Clean Air Filters in Ducts
ECO 67 - Remove Scale from Water and Steam Pipes
ECO 68 - Rebalance Piping Systems
ECO 69 - Rebalance Ducting Systems
ECO 70 - Design Ducting Systems to Reduce Flow Resistance
ECO 71 - Install Booster Pumps

WATER HEATING SYSTEMS

Reduce Hot Water Loads

ECO 72 - Reduce Hot Water Consumption
ECO 73 - Lower Hot Water Temperatures
ECO 74 - Preheat Feedwater With Reclaimed Waste Heat

TABLE 1.1. (contd)

Reduce Hot Water Heating System Losses

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ECO 77 - Install Decentralized Water Heaters
ECO 78 - Use Smaller Water Heaters for Seasonal Requirements
ECO 79 - Use Heat Pump Water Heaters
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POWER SYSTEMS

Reduce Power System Losses

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Install Energy-Efficient Motors

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TABLE 1.1. (contd)

Reduce Peak Power Demand

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ECO 98 - Install a Cogeneration System
ECO 99 - Install a Cool Storage System

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Use Energy Management and Control Systems

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ECO 102 - Install Duty-Cycling Control System
ECO 103 - Install Supply Air Temperature Reset Control System
ECO 104 - Install Hot/Chilled Water Supply Temperature Reset Control System
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ECO 106 - Install Economizer Cooling Control System
ECO 107 - Install Demand Limiting Control System

Use Heat Reclaim Systems

ECO 108 - Install Double-Bundle Chillers
ECO 109 - Reclaim Heat from Boiler Blowdown
ECO 110 - Reclaim Incinerator Heat
ECO 111 - Reclaim Heat from Combustion System Flue
ECO 112 - Install Water-Loop Heat Pump Systems
ECO 113 - Reclaim Heat from Prime Movers
ECO 114 - Install Piggyback Absorption Systems
ECO 115 - Recover Heat from Light Systems
ECO 116 - Reclaim Heat from Refrigerator Hot Gas
ECO 117 - Reclaim Heat from Steam Condensate
ECO 118 - Reclaim Heat from Waste Water

1.1.1 Reduce Operating Hours

When the building is unoccupied, the building systems should be turned off or their operation reduced to a minimum. Depending on building operations, selected systems can also be curtailed during slack operating hours. Care must be taken to ensure that this ECO has no adverse impact on building operations and systems.

ECO 1 - Reduce Operating Hours for Space Heating and Cooling Systems

Typically, space heating and cooling systems account for most of the energy used in the building. The operation of space conditioning systems should be reduced or eliminated when the building is unoccupied. Reduction can often be accomplished by adjusting the thermostat setpoints (see ECO 7).

Implementation Guidelines. The minimal space conditioning requirements during unoccupied periods should be determined. For example, in cold climates, the temperature in the building must always be maintained at a level that will prevent the pipes from freezing. This ECO can often be implemented by shutting down the interior system and using the perimeter system to maintain minimum temperature levels. Buildings such as laboratories, archives, or medical facilities that must maintain specific indoor conditions at all times may not be able to take advantage of this ECO.

Different space conditioning systems have operation characteristics that affect system shutdown. For example, air-handling unit fans and pumps for multi-zone chiller and boiler systems that serve occupied zones should be turned off. When all multi-zone equipment has been turned off, central plant chillers, boilers, and related equipment can be shut off as well.

Systems can often be shut down half an hour to an hour before the building closes. However, a recovery period is required to condition the space for its next occupied period. This usually means starting the equipment up again before the occupants return. The length of the recovery period depends on the weather conditions, thermal integrity and mass of the building, as well as the capacity and characteristics of the space conditioning systems. (Optimal equipment start/stop is discussed in ECO 28.)

Required Information. Determine the schedules, setpoints and sizing of all HVAC equipment affected by this ECO (including pumps and fans). Examine existing controls to determine whether they are adaptable to implementation of this ECO.

ECO 2 - Reduce Operating Hours for Ventilation Systems

Ventilation systems bring fresh outdoor air into the building to provide the occupants with oxygen and to dilute internally-generated air pollutants. Reducing the operating times for discrete ventilation exhaust systems saves fan energy. Curtailing ventilation air reduces heating or cooling loads, except under economizer operation. When a building zone is unoccupied, the ventilation system should be turned off, unless it is "flushing" the building in an economizer mode (see also ECO 53 and ECO 106).

Implementation Guidelines. For spaces with transient or variable occupancy, the outdoor air quantity may be adjusted by use of dampers or by duty cycling of the system. When contaminants are generated independent of the occupants, the supply of outdoor air should be restored far enough in advance to ensure that acceptable conditions are attained before occupants return. On the other hand, if contaminants are generated solely by the occupants, restoration of outdoor air may actually lag somewhat behind occupancy. Figures 1.1 and 1.2 show the lag or lead times needed to achieve acceptable conditions for transient occupancy. Coordinate changes to ventilation air supply with changes to exhaust systems to maintain air balance in the space.

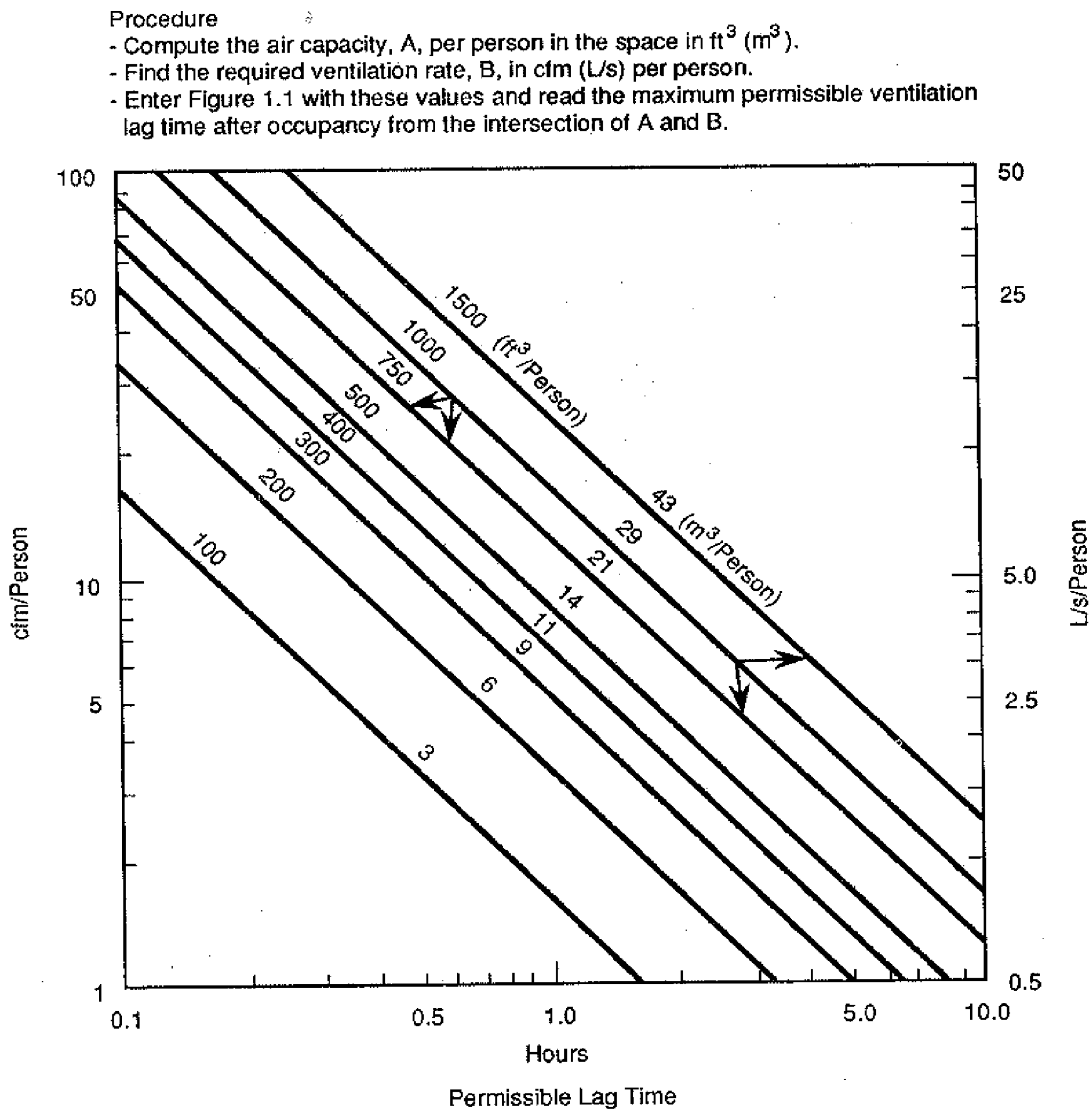

FIGURE 1.1. Maximum Permissible Ventilation Lag Time (Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from ASHRAE Standard 62-1981.)

Exhaust fans are generally used in areas with high concentrations of pollutants generated from occupants' activities. These exhaust requirements are rarely continuous, and the fans should operate only as needed. Kitchen exhaust fans and make-up air units should only operate while cooking is in progress. This can be accomplished with timers and manual overhead switches.

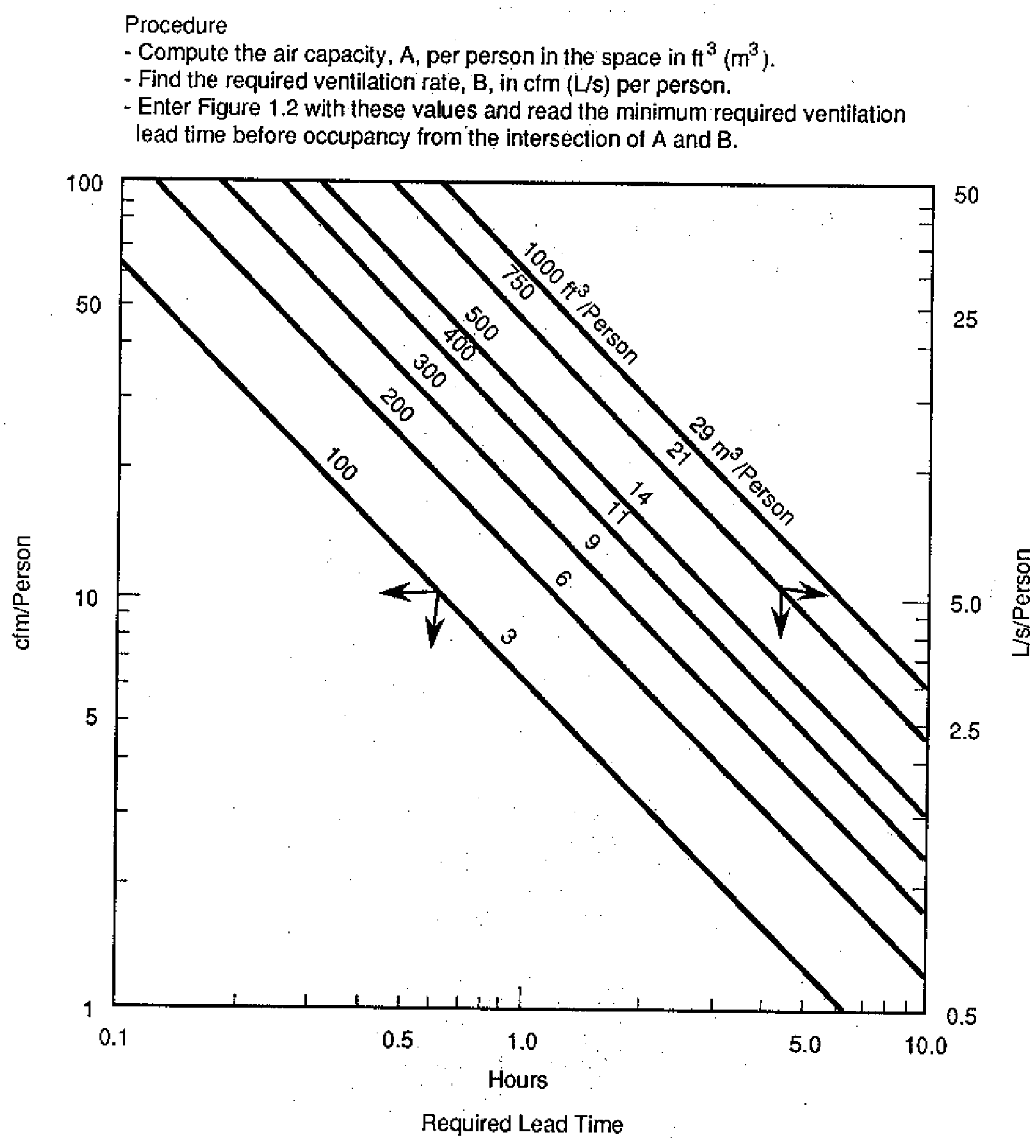

FIGURE 1.2. Minimum Permissible Ventilation Lead Time (Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from ASHRAE Standard 62-1981.)

Manual timers are applicable to bathroom exhaust fans. Sensors may be used to shut down fans in intermittently occupied rooms. Care should be exercised in controlling the exhaust from fume hoods used to vent toxic gases in laboratories. This ECO should be coordinated with ECO 1 such that ventilation savings are not double-counted.

Required Information. Survey the ventilation and exhaust systems to determine the quantity of ventilation and exhaust air. Other pertinent data that should be collected include existing damper controls and schedules, whether there are discrete ventilation and/or exhaust fans, and the rating of fan motors.

ECO 3 - Reduce Operating Hours for Water Heating Systems

Standby losses from domestic water tanks can be reduced by lowering the setpoint for water temperature or by clocking the system off when occupants are gone for lengthy periods. If a domestic water circulation pump is in use, it can often be controlled by a timer, saving pump energy and heat loss from piping.

Implementation Guidelines. Water heating systems should be restored early enough to provide hot water when needed by building occupants. If hot water is electrically heated, the kW demand can be reduced by restoring the water temperature before other building electrical systems are started up. Before implementing this ECO, make sure that piping does not run through areas that are subject to freezing. This ECO will reduce the savings obtained by insulating pipes (ECOs 75 and 76).

Required Information. If the building has a circulation pump, determine how much electricity (kW) the pump motor uses, linear feet of distribution piping, pipe diameter, R-value of pipe insulation, domestic hot water supply temperature, and ambient space temperature around the distribution piping. Also determine the fuel used to heat domestic water and the efficiency of the water heater.

If the heater itself is to be shut down (or the supply temperature reduced), determine the storage tank surface area, R-value of tank insulation, heating fuel, domestic hot water heat efficiency, tank temperature, and ambient room temperature.

ECO 4 - Reduce Operating Hours for Lighting Systems

Lighting systems consume large amounts of energy in most buildings. Energy is saved by reducing both lighting power consumption and the additional cooling load imposed by lighting. In winter, lights do help heat the building; however, in most cases, lighting is a less efficient heating source than the building HVAC system.

Implementation Guidelines. The lights should be turned off when an area is unoccupied, even if only for a short period. Rooms with intermittent use, such as storerooms, lavatories, etc., should have labeled, individual manual switches so that lights can be turned off when the room is not in use. Occupancy sensors are also effective in spaces that are used intermittently. Implementation of this ECO should be coordinated with ECO 83. Photo sensors may be used to control the lights in areas where daylighting is effective (see ECOs 90 and 91).

Required Information. Determine the power rating (kW) and operating schedule of all internal and external lighting fixtures. Ballast power consumption should be determined for fluorescent and high-intensity discharge (HID) lighting. The percentage of heat (given off by the light fixtures) that reaches the conditioned space can then be estimated.

ECO 5 - Reduce Operating Hours for Escalators and Elevators

The use of escalators and elevators can be reduced during light traffic hours and eliminated when the building is not occupied.

Implementation Guidelines. Escalators should be shut off during unoccupied periods or times of light traffic because their continuous operation wastes energy. This may cause inconvenience to a few users; however, an escalator that is shut down still provides a stairway.

The elevator speed should be as slow as possible while keeping the maximum waiting time to no more than two minutes. During light traffic periods, the number of operating elevators should be reduced.

Escalator and elevator motor-generator sets generally draw power regardless of whether the escalators or elevators are operating. A typical elevator motor-generator draws about 1 kW at idle. The sets should be de-energized when the units are shut down. Elevator controls are available that de-energize the motor-generator if an elevator is idle for ten minutes.

Required Information. Determine the amount of power the motor generator draws at idle and the number of hours operation can be reduced or eliminated.

ECO 6 - Reduce Operating Hours for Equipment and Machines

Energy can be saved by reducing the operating time for miscellaneous electrical equipment that is required for short periods, but is typically left on continuously. In addition to motors, other devices such as resistance heating, freeze protection and ice melting equipment, copy machines, electric cooking equipment, business machines, and other miscellaneous equipment and appliances can be identified for savings.

Implementation Guidelines. Energy consumption of miscellaneous equipment can be reduced to a minimum by limiting operations to the times when the equipment is needed. This reduction can be accomplished with controls, thermostats, time switches, or relays.

Required Information. Determine the power the equipment draws and the number of hours equipment operation can be curtailed. A suitable control device should be identified.

1.1.2 Adjust Space Temperature and Humidity Setpoints

The amount of heat (sensible and latent) supplied to or extracted from the indoors in order to maintain a comfortable indoor environment is directly proportional to the difference in temperature and humidity between indoors and outdoors. Consequently, the space temperature and humidity setpoints should be adjusted to minimize the space conditioning requirements.

The perception of comfort is influenced by the environmental factors of air temperature, mean radiant temperature, air movement and humidity, and by the personal factors of activity and clothing. These six thermal parameters may offset each other within limits to maintain comfort. Figure 1.3 shows the ASHRAE comfort zones, including the ranges of operative temperature (average of dry-bulb and mean radiant temperatures) and humidity which the occupants find comfortable. Lack of comfort can reduce the productivity of building occupants.

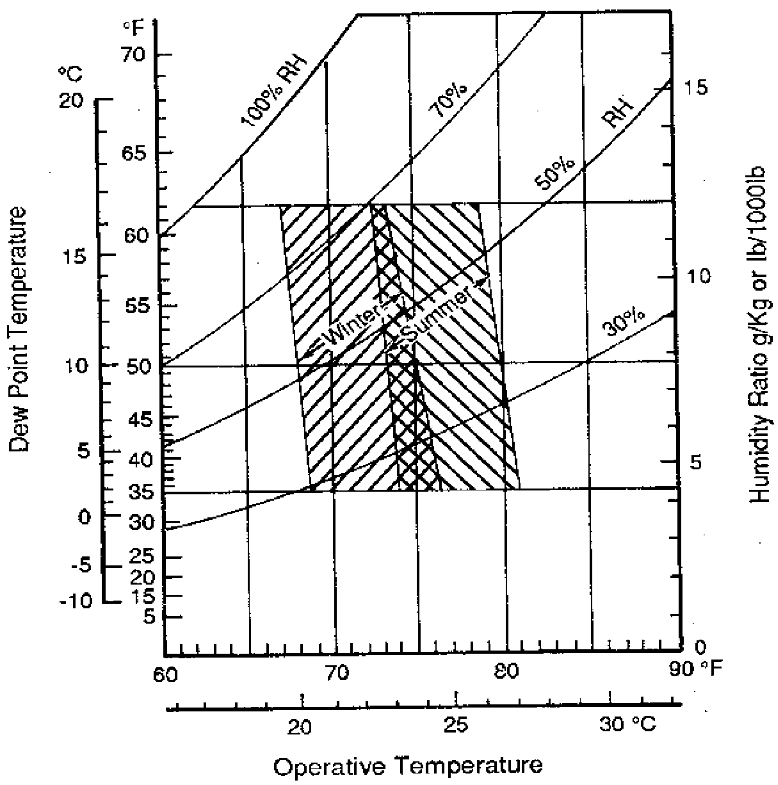

FIGURE 1.3. Acceptable Ranges of Operative Temperature and Humidity for Persons Clothed in Typical Summer and Winter Clothing, at Light, Mainly Sedentary Activity [≤1.2 mean effective temperature (met)] (Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from ASHRAE Standard 55-1981.)

This subcategory of ECOs is relatively easy and inexpensive to implement. Care must be taken in sensitive areas such as laboratories, where critical environments must be maintained. Temperature and humidity level changes can affect items such as paper and may be inappropriate for certain types of data processing or reproduction equipment.

ECO 7 - Lower Heating and Raise Cooling Temperature Setpoints

One of the most basic ways to reduce the space conditioning load is to narrow the gap between indoor and outdoor temperature. This can be accomplished by lowering the heating setpoint and increasing the cooling setpoint. This action also reduces the conditioning requirements for ventilation and infiltration air. Table 1.2 shows some recommended indoor temperature setpoints and their corresponding relative humidity levels for different types of buildings.

Implementation Guidelines. Determine the lowest heating temperature and highest cooling temperature required to satisfy the occupants' needs, and

TABLE 1.2. Suggested Indoor Temperatures and Humidity Levels in the Heating and Cooling Season (DOE 1980)

	Dry Bulb Occupied Hours Maximum Heating (°F)	Dry Bulb Unoccupied Hours (Set-Back) Heating (°F)	Dry Bulb Temperature Occupied (°F)[a]	Minimum Relative Humidity Occupied (°F)
Office Buildings, Residences, Schools				
Offices, school rooms, residential spaces	68	55	78	55
Corridors	62	52	Uncontrolled	Uncontrolled
Dead storage closets	50	50	Uncontrolled	Uncontrolled
Cafeterias	68	50	75	55
Mechanical equipment rooms	55	50	Uncontrolled	Uncontrolled
Occupied storage areas, gymnasiums	55	50	78	55
Auditoriums	68	50	78	50
Computer rooms	65	As required	75	55
Lobbies	65	50	82	60
Doctor offices	68	58	78	55
Toilet rooms	65	55	80	Uncontrolled
Garages	Do not heat	Do not heat	Uncontrolled	Uncontrolled
Retail Stores				
Department stores	65	55	80	55
Supermarkets	60	50	78	55
Drug stores	65	55	80	55
Meat markets	60	50	78	55

(a) Except where terminal reheat systems are used.

adjust the thermostat setpoints accordingly. Since this ECO is simple to implement, it should be done immediately. Adjustments to supply air may be required to eliminate hot and cold spots in the building. To compensate for any discomfort that may be caused by adjusting the temperature setpoints, less energy-intensive conditioning systems may be employed. For example, spot radiant heaters or fans may be used as needed in areas that have only a few occupants.

The temperature setpoint should be readjusted after certain energy conservation measures have been implemented. For example, adding insulation to walls, floor, and ceiling or adding storm windows or multiple glazing reduces the conduction and radiation heat loss from these surfaces. As a result, higher interior surface temperatures are maintained in the winter. Thus, the mean radiant temperature of the conditioned space is increased, and the air temperature can be reduced accordingly without affecting comfort.

Required Information. Survey both existing thermostat setpoints and building space temperatures. Do not assume the thermostats are calibrated.

ECO 8 - Lower Humidification and Raise Dehumidification Setpoints

A humidification system uses approximately 1060 Btu of energy to vaporize 1 lb of water. The level of humidification required depends on the air change rate, moisture content of the outdoor air, and the moisture generation rates from the occupants and their activities (such as cooking, showering, etc.). Sometimes humidification is required not just to maintain thermal comfort, but also to preserve material and prevent the building contents, particularly those made of wood, from drying. Static electricity under low-humidity conditions can also affect electronic equipment.

In summer, dehumidification is achieved by cooling the air to condense and remove excess moisture. In many HVAC systems, air is cooled to as low as 40 to 45°F, and then reheated before it is introduced to the space. Raising the dehumidification setpoint saves energy by raising the cooling setpoint and reducing or eliminating simultaneous heating and cooling.

Implementation Guidelines. Unless special conditions require it, building humidification should be minimized at all times. A 20% relative humidity should be sufficient; there is not sufficient evidence to support the contention that higher relative humidity levels promote health. The humidifiers should be shut off when the building is not occupied.

Required Information. Measure the relative humidity under heating and/or cooling conditions. Adjust equipment accordingly.

ECO 9 - Set Heating Setpoints Back When the Building Is Not Occupied

The heating load on a building is a function of the difference between indoor and outdoor ambient temperatures. A simple method of energy conservation is to lower the space temperatures when the building is not occupied. Since many buildings are unoccupied at night when ambient temperatures are at their lowest (and there is minimal internal gain and no solar heat gain), this is an effective energy conservation method.

Implementation Guidelines. The setback function can be accomplished with simple programmable thermostats. The setback schedule should allow time to restore a comfortable temperature before the building is occupied. The size of the HVAC system, the mass of the building, and the severity of the climate will affect the number of hours required for morning temperature "pull-up." Some energy management and control systems (EMCS) can vary the time when morning pull-up begins according to outside air temperature and specified building parameters. Severe night temperature setback could cause pipes to freeze in exterior walls.

Required Information. The existing temperature setpoints and thermostat schedules must be determined. Controls must be examined to determine whether they can be used to accomplish the new setback strategy or whether new controls are required. Building use and occupancy must be examined to determine whether proposed changes will affect occupants or functions or will damage materials or equipment.

1.2 BUILDING ENVELOPE

This category of ECOs deals with heat gains and losses through the building envelope. The net heat loss from a building during the heating season is referred to as the space heating load. The space heating load is primarily the result of 1) conduction and radiation to and from the building envelope and 2) exchange of indoor and outdoor air via infiltration and ventilation. Solar radiation and heat generated inside the building result in heat gains that help reduce the heating load.

Similarly, the net heat gain of a building in the cooling season is referred to as the space cooling load. The space cooling load includes sensible loads resulting from net heat gain via conduction; infiltration; ventilation; solar radiation and internal heat generation; and latent (or humidity) loads resulting from infiltration, ventilation, and internal sources. Energy is saved when the heat exchange between the building and the outside environment is reduced and/or solar and internal heat gains are controlled.

1.2.1 Reduce Heat Conduction Through Ceilings and Roofs

Heat conduction through the ceiling and roof is a function of the ceiling's and roof's resistance to heat flow (modified by the effect of solar radiation and wind) and the difference between the indoor and outdoor temperature. The mass of the ceiling and roof mitigates heat transfer by delaying the impact of outdoor temperature changes on the conditioned space. Adding thermal insulation and water vapor barriers increases the structural resistance to sensible and latent (water vapor) heat transfer and, consequently, lowers the space load.

ECO 10 - Insulate Ceilings and Roofs

The amount of heat conduction through ceiling and roof is proportional to its overall heat transfer coefficient (commonly called the U-factor) and the temperature difference between the conditioned space and its surrounding, modified by the effect of solar intensity and wind velocity on the exterior surfaces. One of the most effective ways to reduce heat transfer through ceilings and roofs is to retard heat conduction by adding insulation.

Implementation Guidelines. Where the existing roof is sound and directly accessible from an attic or ceiling void, polyurethane foam or mineral fiber may be sprayed on the under side, with rigid batt or other applicable insulation for the inside surface. Insulation, typically fiber-glass batt, may also be laid on the top of a ceiling, taking care not to cover up light fixtures. It is generally not practical to insulate the exterior of the roof unless the roof needs to be replaced. In this case, rigid insulation may be used, and protected with a new roof membrane.

As buildings become more insulated, the heat transfer through structural members becomes more significant, especially for buildings with metal structural members. Uninsulated structural members can degrade the performance of the insulation up to 20%, and resultant condensation can cause the structure to deteriorate. Therefore, care should be taken to properly insulate the structural members.

Often more energy can be conserved by insulating the ceiling rather than the roof unless the attic is being used for special storage, frequent access is required, or a moderate attic temperature is desired. However, if only the ceiling is insulated, any ducting or piping should be insulated to avoid excessive heat transfer or freezing. It is important to be sure that the attic is ventilated by providing 1 to 2 in.^{2} of ventilation area per square foot of attic.

For a more detailed discussion of thermal insulation, refer to Chapter 20 of the ASHRAE Handbook: 1985 Fundamentals on "Thermal Insulation and Water Vapor Retarders."

Required Information. Determine the square footage and overall U-value of the ceiling/roof to be insulated. Select the type of insulation to be used and find its U-value.

ECO 11 - Install Vapor Barriers in Ceilings and Roofs

In summer, the latent cooling load is a substantial portion of the space cooling load. Part of the energy supplied to the space cooling equipment is used to reduce the humidity level of the conditioned space. Primary sources of airborne indoor moisture are occupants, equipment, and outdoor air. In winter, moisture migrating through building surfaces can damage the building or its insulation. A water vapor barrier does not necessarily eliminate the transfer of water. It will, however, retard water vapor transmission, thereby keeping the insulation dry, preventing structural damage, and reducing paint problems.

Implementation Guidelines. There are three types of vapor barriers: rigid, flexible, and coating. Rigid barriers are sheets, such as reinforced plastics, aluminum, stainless steel, etc., that are relatively impervious to water vapor flows. Rigid barriers are usually held in place by mechanical means and vapor sealed at the joints. Flexible barriers include metal foils, laminated foil, treated papers, etc. They are supplied in rolls or as an integral part of the insulation. Accessory materials are required for sealing joints. Coating barriers are semi-fluid mastic type that can be applied by spray, brush, trowel, roller, dip or mop (ASHRAE 1985). Table 1.3 shows the vapor permeance of some typical vapor barriers and some building materials.

The vapor barrier's effectiveness depends on its permeance and location within the area to be insulated. The vapor barrier should be located at or near the surface that is exposed to the higher water vapor pressure. The effectiveness may be greatly reduced if even very small openings exist in the barrier. To avoid such reductions, care should be taken in installing or applying the barrier, making sure that joints are sealed, coating is sufficiently thick, caulking and flashing are correct, etc.

Required Information. Determine the area of the surfaces to be treated and select the type of vapor barrier to be used.

1.2.2 Reduce Solar Heat Gain Through Roofs

Solar heat gain through roofs has a large impact on space cooling loads. The amount of solar energy absorbed depends on the insulation, roof area, orientation, and the absorption coefficient of the roof material. For an existing building, the solar load can be reduced by lowering the absorption and altering the texture of the roof.

ECO 12 - Install Reflective Roof Surfaces

The color and texture of the roof affect the amount of solar energy absorbed by the roof. In general, smooth, light-colored finishes tend to reflect more solar energy than do dark, rough finishes.

Implementation Guidelines. The absorption coefficient of a roof may be reduced by applying paint or reflective finish. Any paint or reflective finish applied must be compatible with the existing roof and capable of withstanding abrasion. The absorption coefficient may also be reduced by adding a surface layer of white pebbles or gravel. Care must be taken to see that the weight of the addition layer does not exceed the load-bearing capacity of the roof and that gravel-stops are fitted around water drains. For pitched, shingled roofs, a light-colored shingle can be used when shingles are replaced.

TABLE 1.3. Permeance and Permeability of Materials to Water Vapor[a,b]

Material	Thickness (mm)	Permeance (Perm)	Resistance (Rep)[c]	Permeability (Perm m)	Resistance/in. (Rep/m)[c]
Materials Used in Construction					
Concrete (1:2:4 mix)				4.7	0.21
Brick masonry	102	46[d]	0.022		
Concrete block (cored, lime-stone aggregate)	203	137[d]	0.0073		
Tile masonry, glazed	102	6.9[d]	0.14		
Asbestos cement board	3	229-458[e]	0.0017-0.0035		
With oil base finishes		17-29[e]	0.0035-0.052		
Plaster on metal lath	19	860[d]	0.0012		
Plaster on wood lath		630[f]	0.0016		
Plaster on plain gypsum lath (with studs)		1140[d]	0.00088		
Gypsum wall board (plain)	9.5	2860[d]	0.00035		
Gypsum sheathing (asphalt impregnated)	13			29[e]	0.038
Structural insulating board (sheathing quality)				29-73[d]	0.038-0.014
Structural insulating board (interior, uncoated)	13	2860-5150[d]	0.00035-0.00019		
Hardboard (standard)	3.2	630[d]	0.0016		
Hardboard (tempered)	3.2	290[d]	0.0034		
Built-up roofing (hot mopped)		0.0	∞		
Wood, sugar pine				0.58-7.8[d,g]	172.0-131
Plywood (Douglas Fir, exterior glue)	6.4	40[d]	0.025		
Plywood (Douglas Fir, interior glue)	6.4	109[d]	0.0092		
Acrylic, glass fiber rein-forced sheet	1.4	6.9[e]	0.145		
Polyester, glass fiber rein-forced sheet	1.2	2.9[e]	0.345		

TABLE 1.3. (contd)

Material	Thickness (mm)	Permeance (Perm)	Resistance (Rep)[c]	Permeability (Perm m)	Resistance/in. (Rep/m)[c]
Thermal Insulations					
Air (still)				174[d]	0.0057
Cellular glass				0.0[e]	∞
Corkboard				3.0-3.8[e] 14[f]	0.33-0.26 0.076
Mineral wool (unprotected)				245[f]	0.0059
Expanded polyurethane (R-11 blown) board stock				0.58-2.3[e]	1.72-0.43
Expanded polystyrene--extruded				1.7[e]	0.57
Expanded polystyrene--bead				2.9-8.4[e]	0.34-0.12
Phenolic foam (covering removed)				38	0.026
Unicellular synthetic flexible rubber foam				0.029[e]	34-4.61
Plastic and Metal Foils and Films[h]					
Aluminum foil	0.025	0.0[e]	∞		
Aluminum foil	0.009	2.9[e]	0.345		
Polyethylene	0.051	9.1[e]	0.110		2133
Polyethylene	0.1	4.6[e]	0.217		2133
Polyethylene	0.15	3.4[e]	0.294		2133
Polyethylene	0.2	2.3[e]	0.435		2133
Polyethylene	0.25	1.7[e]	0.588		2133
Polyvinylchloride, unplasticized	0.051	39[e]	0.026		
Polyvinylchloride, plasticized	0.1	46-80[e]	0.032		
Polyester	0.025	42[e]	0.042		
Polyester	0.09	13[e]	0.075		
Polyester	0.19	4.6[e]	0.22		
Cellulose acetate	0.25	263[e]	0.0035		
Cellulose acetate	3.2	18[e]	0.054		

TABLE 1.3. (contd)

Material	Mass[i] (kg/m^2)	Permeance (Perm) Dry-Cup	Permeance (Perm) Wet-Cup	Permeance (Perm) Other	Resistance (Rep)[c] Dry-Cup	Resistance (Rep)[c] Wet-Cup	Resistance (Rep)[c] Other
Building Paper, Felts, Roofing Papers[j]							
Duplex sheet, asphalt laminated, aluminum foil one side	0.42	0.1	10		10	0.1	
Saturated and coated roll roofing	3.18	2.9	14		0.34	0.071	
Kraft paper and asphalt laminated, reinforced 30-120-30	0.33	17	103		0.059	0.0097	
Blanket thermal insulation back up paper, asphalt coated	0.30	23	34-240		0.043	0.029-0.0042	
Asphalt-saturated and coated vapor retarder paper	0.42	11-17	34		0.091-0.059	0.029	
Asphalt-saturated but not coated sheathing paper	0.21	190	1160		0.0053	0.00086	
6.8 kg asphalt felt	0.68	57	320		0.017	0.0031	
6.8 kg tar felt	0.68	230	1040		0.0043	0.00096	
Single-kraft, double	0.16	1170	2400		0.00056	0.00042	
Liquid-Applied Coating Materials							
Commercial latex paints (dry film thickness)[k]	(mm)						
Vapor retarder paint	0.070			26			0.038
Primer-sealer	0.031			360			0.0028
Vinyl acetate/acrylic primer	0.051			424			0.0024
Vinyl-acrylic primer	0.040			491			0.0020
Semi-gloss vinyl-acrylic enamel	0.060			378			0.0026
Exterior acrylic house and trim	0.042			313			0.0032
Paint-2 coats							
Asphalt paint on plywood			23			0.043	
Aluminum varnish on wood		17-29			0.059-0.034		
Enamels on smooth plaster				29-86			0.034-0.012
Primers and sealers on interior insulation board				51-20			0.020-0.0083
Various primers plus 1 coat flat oil paint on plaster				91-172			0.011-0.0058
Flat paint on interior insulation board				229			0.0044

TABLE 1.3. (contd)

Material	Mass[i] (kg/m^2)	Permeance (Perm) Dry-Cup	Wet-Cup	Other	Resistance (Rep)[c] Dry-Cup	Wet-Cup	Other
Water emulsion on interior insulation board				1716-4863			0.00058-0.00021
Paint-3 coats	(kg/m^2)						
Exterior paint, white lead and oil on wood siding		17-57			0.0059-0.017		
Exterior paint, white lead-zinc oxide and oil on wood		51			0.020		
Styrene-butadiene latex coating	0.6	629			0.0016		
Polyvinyl acetate latex coating	1.2	315			0.0032		
Chloro-sulfonated polyethylene mastic	1.1 2.2	97			0.010		
Asphalt cut-back mastic							
1.6 mm, dry		8.0			0.125		
4.8 mm, dry		0.0			∞		
Hot melt asphalt	0.6 1.1	29 5.7			0.034 0.175		

(a) Permeance, resistance, permeability and resistance per unit thickness values are given in the following units:
Permeance Perm = $ng/s{\cdot}m^2{\cdot}Pa$ Permeability Perm-in. = $ng/s{\cdot}m{\cdot}Pa$
Resistance Rep = $TPa{\cdot}m^2{\cdot}s/kg$ Resistance/unit thickness Rep/in. = $(TPa{\cdot}m^2{\cdot}s/kg)/m$.

(b) This table gives the water vapor transmission rates of some representative materials. The data are provided to permit comparisons of materials; but in the selection of vapor retarder materials, exact values for permeance or permeability should be obtained from the manufacturer of the materials under consideration or secured as a result of laboratory tests. A range of values shown in the table indicate variations among mean values for materials that are similar but of different density, orientation, lot or source. The values are intended for design guidance and should not be used as design or specification data. The compilation is from a number of sources; values from dry-cup and wet-cup methods were usually obtained from investigations using ASTM E96 and C355; values shown under others were obtained from investigations using such techniques as two-temperature, special cell, and air-velocity. Some values were obtained from unpublished tests conducted by Pennsylvania State University and the Building Research Division, National Research Council of Canada.

(c) Resistance and resistance/in. values have been calculated as the reciprocal of the permeance and permeability values.

(d) Other than dry- or wet-cup method.

(e) Dry-cup method.

(f) Wet-cup method.

(g) Depending on construction and direction of vapor flow.

(h) Usually installed as vapor retarders, although sometimes used as exterior finish and elsewhere near cold side where special considerations are then required for warm side barrier effectiveness.

(i) Basic weight in kg per 9.29 m^2.

(j) Low permeance sheets used as vapor retarders. High permeance used elsewhere in construction.

(k) Cast at 0.25 mm wet film thickness.

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Required Information. Measure the square footage of roof to be treated and note its color and texture. Select the appropriate color and texture of the replacement roof surface.

1.2.3 Reduce Heat Conduction Through Walls

Heat transmission through a wall is a function of its resistance to heat flow, and the difference between indoor and outdoor temperatures, modified by the effect of solar radiation and wind velocity on the exterior surfaces. The mass of the wall produces a thermal inertia that delays the impact of outdoor temperature changes on the conditioned space.

The amount of heat loss through walls is greatest in cold climates. Heat loss also varies according to wall orientation; the highest losses occur through the north walls and the lowest losses through the south walls because of the beneficial effects of the sun. This difference is more pronounced in walls with high solar absorption coefficients. Similar to the ceiling and roof, adding thermal insulation and water vapor barriers increases the resistance to sensible and latent (water vapor) heat transfer and reduces the space load. For buildings with more than three stories, heat loss through walls is generally more significant than heat transmission through roofs.

ECO 13 - Insulate Walls

Similar to the roof and ceilings, the amount of heat conduction through the walls is proportional to the temperature difference between the conditioned space and the outdoors. One of the most effective ways to reduce heat transfer through the walls is to retard heat conduction by adding insulation. Many older buildings were constructed without wall insulation.

Implementation Guidelines. Insulating materials may be added to interior surfaces, exterior surfaces, or to wall cavities. It should be noted that wall insulation generally has a longer payback period than ceiling insulation because of surface finish requirements. Insulating the exterior surfaces of the walls increases the effective internal thermal mass of the conditioned space. Thermal mass delays the effect of any changes in outdoor environment on the conditioned space. High thermal mass may be desirable both to store solar energy during the day and release it after night falls and to store the coolness of the night air to offset the warm indoor air during the day.

The insulation added to wall surfaces is generally in the form of pre-fabricated panels such as polystyrene. The insulation added to the outside surfaces must be weatherproof to prevent its deterioration from the effects of sun and/or moisture. Vapor barriers should be used to protect the insulation from moisture condensation, and wood panels or drywall should be used to protect it from general wear and tear. Granular or foam insulation may be added in the unobstructed internal voids of the walls. Granular insulation should be blown in under pressure to ensure a compressed fill, as it tends to pack down over time. Foams must be carefully mixed to minimize shrinkage.

As buildings become more insulated, the heat transfer through structural members becomes more significant, especially for buildings with metal structural members. Uninsulated structural membranes can degrade the performance of the insulation up to 20%, and resultant condensation can become a potential source of structural deterioration. Therefore, care should be taken to properly insulate the structural members.

Required Information. Determine the U-value and area of the existing wall. Select insulation material and calculate a new U-value with the insulation in place.

ECO 14 - Install Vapor Barriers in Walls

This ECO is identical to ECO 11, but is applied to walls rather than to ceilings.

1.2.4 Reduce Heat Conduction Through Floors

Heat transfer through slab-on-grade floors occurs mainly around the perimeter. Relatively little heat is transferred through the center of the floor because of the insulating effect of the earth. On the other hand, the heat transfer through a suspended floor over an unconditioned space occurs across the entire floor area. Added insulation can reduce the heat transfer.

ECO 15 - Insulate Floors

The amount of heat conduction through the floors is proportional to the temperature difference between the conditioned space, the outdoors and the ground, and is inversely proportional to the thermal resistance. One of the most effective ways to reduce heat transfer through the floors is to retard heat conduction by adding insulation.

Implementation Guidelines. Slab-on-grade floors should be insulated around the perimeter with rigid board or foam. The board or foam should be placed vertically along the outside edge of the floor and should extend down at least two feet below the surface of the floor. Insulation below ground should be applied in a bedding of hot asphalt. Existing flashing at ground level may have to be extended to cover the top edge of the insulation.

A floor suspended above an unheated space (such as a garage, basement, or crawlspace) may be insulated on the underside by applying spray foam, rigid insulation, or batt insulation between the floor joists. Similar to adding insulation to ceilings, care should be taken to insulate any duct or piping to avoid freezing.

Required Information. Determine the area and U-value of the surface to be insulated. Select the type of insulation that will be applied and determine its U-value.

1.2.5 Reduce Heat Conduction and Long-Wave Radiation Through Glazing Areas

Glazing areas are portions of the building envelope built with glass, plastic sheets or panes, or other materials with very high light transmittance, such as windows and skylights. Heat exchange between the conditioned space and the outdoors through the glazing area is a major design consideration, since 1 ft^2 of glazing can transmit as much energy as 10 to 20 ft^2 of wall. Heat transfer through these areas via conduction, solar radiation, and long-wave sky radiation can be reduced by adding additional layers of glass or through the use of movable insulation.

During the cooling season, heat gains due to conduction and long-wave radiation are relatively small (compared with that of solar radiation) because the interior/exterior temperature difference is small. Consequently, it is more cost-effective to employ energy conservation measures to reduce conduction and long-wave radiation losses in cold climates and to reduce solar heat gains in the hot climates.

ECO 16 - Install Storm Windows and Multiple-Glazed Windows

Conduction and long-wave (sky) radiation heat transfer can contribute significantly to the heating load. Adding extra panes of glazing to windows reduces this heat loss by increasing the thermal resistance and lowering the transmittance. A small reduction in the cooling load will also occur.

Implementation Guidelines. Storm windows may be added to either the inside or outside of existing windows. Existing single glazed windows may also be converted to double-glazed windows by adding additional permanent panes of glazing. In either case, the space between the window panes should be vented or otherwise protected against moisture buildup. If the existing window frame is in good condition and the glazing system permits, a single sheet of glass can be replaced by a sealed, double-glazed unit. If the existing window frame is in poor condition, a double or triple-glazed replacement unit, which will also reduce air infiltration, should be used.

Required Information. Determine which storm window system is to be used, and measure the square footage of glazing (by each orientation) to be affected. Determine the U-value before and after the glazing system is installed.

ECO 17 - Insulate Movable Windows

Conduction and radiation losses through windows amount to a substantial portion of the space heating loads, particularly at nighttime when the ambient and sky temperatures are low. Insulation materials may be used to cut down on these losses. Since insulation is not transparent, it will obstruct views, daylight, and solar radiation. Window insulation can be designed in such a way that it can be removed when the space is occupied.

Implementation Guidelines. Insulating fabric can be integrated with draperies or it can be made similar to conventional shades. These shades can be purchased ready-made or can be custom made to fit the windows. Beside manual control, movable window insulation may also be controlled by a timer.

Table 1.4 shows the overall heat transfer coefficients of windows with various thickness of insulation. It is assumed that the insulation has thermal conductivity typical of glass wool, beaded polystyrene and polyurethane foam. To be effective against air infiltration, window insulation should seal against the window frame when it is in place.

Required Information. Determine the square footage and orientation of windows to be insulated. Determine the U-value with and without the insulation in place and the hours when the insulation will cover the windows.

ECO 18 - Install Operable Windows

Depending on the building location and application, indoor comfort can often be increased during the spring and fall by manually opening windows. Since the occupants' decisions whether to open the windows are based solely on their perceived comfort, they are not likely to use operable windows in the most energy-efficient manner. In addition, operable windows in some types of buildings may pose safety and security concerns.

Implementation Guidelines. If the existing windows need to be replaced or renovated, operable windows should be considered. The HVAC system should not be operating when windows are open.

Required Information. Determine the area and orientation of operable glazing, and estimate a schedule for when the windows will be open.

1.2.6 Control Solar Heat Gain Through Glazing Areas

The solar heat gain through glazing areas plays a very important role in determining the total cooling load. Solar gain is also a major influence on the peak cooling load of a building, since there may be little or no thermal lag associated with this heat gain. Also, solar gain through glazing significantly affects the sizing of cooling equipment. On the other hand, solar heat gain reduces the heating load in the winter. Therefore, glazing must be designed to properly control the amount of solar gain in different seasons.

TABLE 1.4. Heat Transfer Coefficients of Windows with Insulation (DOE 1980)

Insulation Thickness (in.)	Composite "U" Value	
	Single Glazing	Double Glazing
0.5	0.28	0.23
1.0	0.18	0.16
1.5	0.13	0.12
2.0	0.11	0.10

Energy conservation features such as interior or exterior shades, tinted or reflective materials, or air flow windows aid the proper control of insolation.

ECO 19 - Install Exterior Shading

Solar radiation comprises direct insolation, which is directional, and diffuse insolation, which is nondirectional (i.e., scattered by air molecules, dust, and ground reflection). Direct insolation is the most substantial component of total insolation.

One of the most efficient ways to reduce summer solar gain is to intercept the direct insolation before it reaches the glazing area. This interception can be accomplished by using exterior shading. Totally shading the glazing from direct insolation can reduce solar heat gain by up to 80%.

Implementation Guidelines. Exterior shading may be applied as overhangs, fins, vertical and horizontal projections, awnings, etc. The shading should allow free air movement so heat will not build up under the shades and be absorbed by the shading materials. Overhangs are particularly useful on the southern, southeastern, and southwestern exposures during the late spring, summer, and early fall. The sun is generally too low for overhangs to effectively shade east and west windows; however, fins may be effective. Properly designed overhangs will shade southern windows in summer and will allow the sunlight to penetrate when it is beneficial for winter heating.

External, louvered sun screens may also be fitted on the outside surface of the windows. Such screens can be fixed permanently in position, arranged to slide in channels, or made movable to admit solar radiation in winter. In addition to man-made exterior shade, deciduous trees may be planted in proper locations to shade the glazing area.

Required Information. Data gathering for exterior shading can be complicated and can require a number of window and shading device dimensions. Whether the dominant space conditioning load is heating or cooling will depend on the location, orientation, and application of the building. The selection and design of shading should favor the dominant load. For proper sizing of overhangs and fins, refer to Chapter 27 of the *ASHRAE Handbook: 1985 Fundamentals*.

ECO 20 - Install Interior Shading

Compared with exterior shading, interior shading is less effective in reducing solar gains since the sunlight has already passed through the glazing and entered the building. The effectiveness of the internal shading devices depends on their ability to reflect the short-wave solar radiation back through the glazing areas before it is absorbed and converted into heat (e.g., long-wave radiation) within the conditioned space. Tables 1.5 through 1.8 and Figure 1.4 provide information on the average shading coefficients for windows with different types and panes of glass and different types of interior shading.

TABLE 1.5. Shading Coefficients for Single Glass with Indoor Shading by Venetian Blinds or Roller Shades

	Nominal Thickness (in.)[a]	Solar Trans.[b]	Type of Shading: Venetian Blinds		Roller Shade: Opaque		Roller Shade: Translucent
			Medium	Light	Dark	White	Light
Clear	2.5 to 6	0.87 to 0.80					
Clear	6 to 12	0.80 to 0.71					
Clear pattern	3 to 12	0.87 to 0.79	0.64	0.55	0.59	0.25	0.39
Heat-absorbing pattern	3	--					
Tinted	5 to 5.5	0.74, 0.71					
Heat-absorbing[c]	5 to 6	0.46					
Heat-absorbing pattern	5 to 6	--	0.57	0.53	0.45	0.30	0.36
Tinted	3 to 5.5	0.59, 0.45					
Heat-absorbing or pattern	--	0.44 to 0.30	0.54	0.52	0.40	0.28	0.32
Heat-absorbing[c]	10	0.34					
Heat-absorbing or pattern	--	0.29 to 0.15 0.24	0.42	0.40	0.36	0.28	0.31
Reflective Coated Glass							
S.C.[d] = 0.30			0.25	0.23			
0.40			0.33	0.29			
0.50			0.42	0.38			
0.60			0.50	0.44			

(a) Refer to manufacturer's literature for values.
(b) For vertical blinds with opaque white and beige louvers in the tightly closed position, SC is 0.25 and 0.29 when used with glass of 0.71 to 0.80 transmittance.
(c) Refers to gray, bronze and green tinted heat-absorbing glass.
(d) SC for glass with no shading device.
Source: Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from ASHRAE Handbook: 1985 Fundamentals.

Implementation Guidelines. Internal shading devices such as venetian blinds, vertical blinds, roller shades, and drapes are generally easier and less costly to install than are exterior shading devices. In addition, they can be manually adjusted to vary the amount of solar gain over the day, as well as during heating or cooling seasons.

Required Information. Determine the area and orientation of glazing to be shaded, and estimate a time schedule for shading operation.

ECO 21 - Use Tinted or Reflective Glazing or Films

Tinted or reflective translucent materials can be used to reduce the amount of solar radiation transmitted through the building glazing areas.

Implementation Guidelines. Tinted or reflective glass can be added to existing windows to convert them to double-glazed windows, or to replace them. Tinted or reflective film can also be applied directly to the inside

TABLE 1.6. Shading Coefficients for Insulating Glass[a] with Indoor Shading by Venetian Blinds or Roller Shades

				Type of Shading				
						Roller Shade		
	Nominal Thickness,	Solar Trans.[b]		Venetian Blinds[c]		Opaque		Trans-lucent
Type of Glass	Each Light	Outer Pane	Inner Pane	Medium	Light	Dark	White	Light
Clear out	2.5, 3 mm	0.87	0.87					
Clear in				0.57	0.51	0.60	0.25	0.37
Clear out								
Clear in	6 mm	0.80	0.80					
Heat-absorbing out[d]	6 mm	0.46	0.80	0.39	0.36	0.40	0.22	0.30
Clear in								
Reflective coated glass								
SC[e] = 0.20				0.19	0.18			
0.30				0.27	0.26			
0.40				0.34	0.33			

(a) Refers to factory-fabricated units with 5, 6 or 13 mm air space, or to prime windows plus storm windows.
(b) Refer to manufacturer's literature for exact values.
(c) For vertical blinds with opaque white or beige louvers, tightly closed, SC is approximately the same as for opaque white roller shades.
(d) Refers to bronze or green tinted, heat-absorbing glass.
(e) SC for glass with no shading device.
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TABLE 1.7. Shading Coefficients for Double Glazing with Between-Glass Shading

		Solar Trans.[a]			Type of Shading		
					Venetian Blinds		Louvered
Type of Glass	Nominal Each Pane	Outer Pane	Inner Pane	Description of Air Space	Light	Medium	Sun Screen
Clear out, clear in	2.5, 3 mm	0.87	0.87	Shade in contact with glass or shade separated from glass by air space.	0.33	0.36	0.43
Clear out, clear in	6mm	0.80	0.80	Shade in contact with glass-voids filled with plastic.	--	--	0.49
Heat-absorbing[b] out, clear in				Shade in contact with glass or shade separated from glass by air space.	0.28	0.30	0.37
	6 mm	0.46	0.80	Shade in contact with glass-voids filled with plastic.	--	--	0.41

(a) Refer to manufacturer's literature for exact values.
(b) Refers to grey, bronze and green tinted heat-absorbing glass.
Source: Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from ASHRAE Handbook: 1985 Fundamentals.

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TABLE 1.8. Shading Coefficients for Single and Insulating Glass with Draperies

Glazing	Glass Trans.	Glass SC[b]	SC for Index Letters in Figure 1.4[a] A	B	C	D	E	F	G	H	I	J
Single Glass												
6 mm clear	0.80	0.95	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35
12 mm clear	0.71	0.88	0.74	0.70	0.66	0.61	0.56	0.52	0.48	0.43	0.39	0.35
6 mm heat absorbing	0.46	0.67	0.57	0.54	0.52	0.49	0.46	0.44	0.41	0.38	0.36	0.33
12 mm heat absorbing	0.24	0.50	0.43	0.42	0.40	0.39	0.38	0.36	0.34	0.33	0.32	0.30
Reflective coated (see manufacturers' literature for exact values)	--	0.60	0.57	0.54	0.51	0.49	0.46	0.43	0.41	0.38	0.36	0.33
		0.50	0.46	0.44	0.42	0.41	0.39	0.38	0.36	0.34	0.33	0.31
		0.40	0.36	0.35	0.34	0.33	0.32	0.30	0.29	0.28	0.27	0.26
		0.30	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.21	0.21	0.20
Insulating Glass 12 mm Air												
Space clear out and clear in	0.64	0.83	0.66	0.62	0.58	0.56	0.52	0.48	0.45	0.42	0.37	0.35
Heat absorbing out and clear in	0.37	0.55	0.49	0.47	0.45	0.43	0.41	0.39	0.37	0.35	0.33	0.32
Reflective coated (see manufacturers' literature for exact values)	--	0.40	0.38	0.37	0.37	0.36	0.34	0.32	0.31	0.29	0.28	0.28
	--	0.30	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.24	0.24
	--	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.15	0.15

(a) Shading coefficient values for the SC line in Figure 1.4 for representative glazings. Substitute for SC index letters in Figure 1.4 values on the line of the glazing selected.
(b) For glass alone, with no drapery.
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Glazing indicated in table above
Draperies are 100% fullness
(Fabric width two times draped width)

Notes:

1. Shading Coefficients are for draped fabrics.
2. Other properties are for fabrics in flat orientation.
3. Use Fabric Reflectance and Transmittance to obtain accurate Shading Coefficients.
4. Use Openness and Yarn Reflectance or Openness and Fabric Reflectance to obtain the Various Environmental Characteristics, or to obtain Approximate Shading Coefficients.

Classification of Fabrics
I = Open Weave
II = Semi-open Weave
III = Closed Weave

D = Dark "Color"
M = Medium "Color"
L = Light "Color"

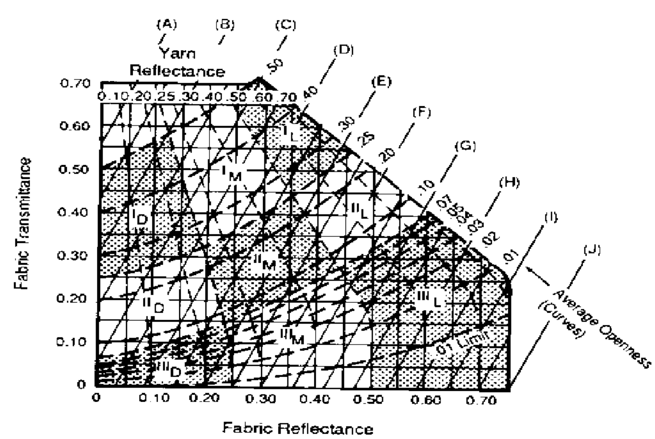

FIGURE 1.4. Indoor Shading Properties of Drapery Fabrics (Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from ASHRAE Handbook: 1985 Fundamentals.)

of the glazing. These films are easily abraded. To lengthen the service life of these films, they should be applied between the glazings of double-glazed areas. For thermopane windows, select a compatible film to avoid thermal stress and cracking of the glass. Figure 1.5 shows the effect of window reflectance on the shading coefficients for coated single glass.

Required Information. Determine the area and orientation of glass to be treated. Determine the shading coefficient of the tint or film to be used. If a second layer of glass is to be added, determine the change in the window's U-value.

ECO 22 - Install Air-Flow Windows

Channeling exhaust or recirculating room air between a multiple-glazed window can help control solar heat gain. In the summer, most of the absorbed solar energy can be removed from the window via the exhaust air. The shading coefficient of the window can also be reduced by closing the blinds. In winter, the window can act as a heat exchanger to improve thermal comfort by raising the inner glass temperature.

Implementation Guidelines. A venetian blind should be installed between the glazing of the window. Ventilation air from the room should be channeled through the glazing cavity. In the summer, the air exiting the windows

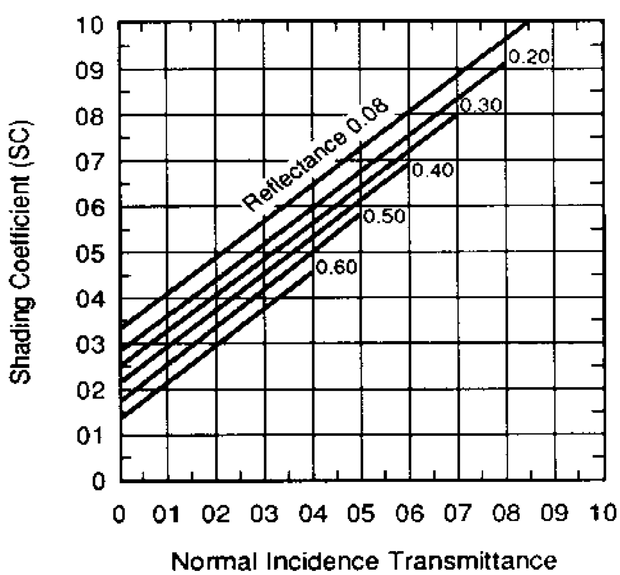

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FIGURE 1.5. Approximate Shading Coefficient Versus Transmittance for Coated Single Glass (Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from ASHRAE Handbook: 1985 Fundamentals.)

should be either exhausted outside or diverted to zones that require coincident heating. In the winter, the air should be returned through ducts to the central HVAC system (ASHRAE 1985).

In general, it is difficult to convert existing windows into air-flow windows. Air-flow windows should be considered only if the existing windows need replacement and the air distribution system can be suitably modified.

Required Information. Determine the area and orientation of glazing to be replaced and whether the windows can be integrated into the air distribution system.

1.2.7 Reduce Infiltration

Infiltration is the unintended entry of unconditioned air into the building through doors, windows, and other openings in the building envelope. Infiltration can be caused by wind blowing against the building, by the building stack effect, or by negative pressurization of the HVAC system.

Since infiltration is uncontrolled and consists of unconditioned air, it often leads to considerable discomfort for the building occupants. Infiltration can result in large increases in heating and cooling loads. Many infiltration control strategies are inexpensive and relatively simple to implement. Estimating infiltration rates requires considerable judgment. Infiltration rates can also be measured; however, this can be very expensive for commercial buildings.

Unlike conduction losses, infiltration results in both sensible and latent heat gains and losses. Energy can be saved by sealing vertical shafts and stairways, by caulking and weatherstripping, or by installing vestibules or revolving doors.

ECO 23 - Seal Vertical Shafts and Stairways

Tall buildings are subject to stack effect which results from the difference between indoor and outdoor temperatures. The stack effect is most predominant in open vertical spaces such as stairwells, elevator shafts and service shafts.

Implementation Guidelines. Vertical shafts and stairs should be sealed off from the conditioned areas. Open stairwells that connect with circulation spaces at each floor level should be isolated with walls and self-closing doors. Roof access doors at the top of stairwells should be caulked and weatherstripped. Gasketed covers should be installed over access holes into vertical service shafts. Holes at the shaft wall (to allow for passage of pipes and ducts at each floor level) should be sealed and sleeves around the pipes and ducts packed with materials.

Elevator shafts usually have an aperture at the top that allows the cables to pass into the equipment room. Other vents are often necessary as a smoke release. These openings can be responsible for large air movements through the elevator doors, up the shaft into the equipment room, and then outside through badly fitted doors and windows in the equipment room.

Weatherstripping these doors and windows can reduce the effect of stack losses through elevator shafts.

Required Information. Estimate the length and width of cracks to be sealed and cfm of air movement per linear foot of crack.

ECO 24 - Caulk and Weatherstrip Doors and Windows

One of the most commonly used methods for reducing air leakage through building structures is caulking and weatherstripping.

Implementation Guidelines. Particularly effective measures include caulking cracks around windows and door frames and weatherstripping around windows and doors. Tables 1.9 through 1.21 compare the ranges of leakage areas for various building components with and without caulking and weatherstripping.

TABLE 1.9. Component Leakage: Sill Foundation--Wall

Component	Best Estimate	Maximum	Minimum	Unit
Sill, caulked per m of perimeter	0.8	1.2	0.4	cm^2/m[(a)]
Sill, not caulked per m of perimeter	4	4	1	cm^2/m[(a)]

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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TABLE 1.10. Component Leakage: Joints Between Ceiling and Walls

Component	Best Estimate	Maximum	Minimum	Unit
Joints per m of wall; only if not taped or plastered and no vapor barrier	1.5	2.5	0.5	cm^2/m[(a)]

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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TABLE 1.11. Component Leakage: Windows

Component	Best Estimate	Maximum	Minimum	Unit
Casement weatherstripped per m^2 window	0.8	1.2	0.4	cm^2/m^2
Same, not weatherstripped	1.6	2.4	0.8	cm^2/m^2
Awning weatherstripped per m^2 window	0.8	1.20	0.4	cm^2/m^2
Same, not weatherstripped	1.6	2.4	0.8	cm^2/m^2
Single hung weatherstripped per m^2 window	2.2	2.9	1.8	cm^2/m^2
Same, not weatherstripped	4.4	5.8	3.6	cm^2/m^2
Double hung weatherstripped per m^2 window	3.0	4.4	1.6	cm^2/m^2
Same, not weatherstripped	6.0	8.8	3.2	cm^2/m^2
Single slider weatherstripped per m^2 window	1.8	2.7	0.9	cm^2/m^2
Same, not weatherstripped	3.6	5.4	1.8	cm^2/m^2
Double slider weatherstripped per m^2 window	2.6	3.8	1.4	cm^2/m^2
Same, not weatherstripped	5.2	7.6	2.8	cm^2/m^2

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Required Information. Estimate the length and width of cracks to be caulked and weatherstripped by orientation. Estimate the cfm of air movement per linear foot of crack. Select the type of caulking and weatherstripping to be used.

ECO 25 - Install Revolving Doors or Construct Vestibules

In buildings that experience heavy and continuous traffic through exterior doors, infiltration can be reduced by building vestibules for each external door or by replacing single-swing doors with revolving doors.

TABLE 1.12. Component Leakage: Doors

Component	Best Estimate	Maximum	Minimum	Unit
Single door weatherstripped per m² door	8	15	3	cm^2/m^2
Same, not weatherstripped	11	17	6	cm^2/m^2
Double door weatherstripped per m² door	8	15	3	cm^2/m^2
Same, not weatherstripped	11	22	7	cm^2/m^2
Access to attic or crawl-space weatherstripped per access	18	18	8	cm^2/m^2
Same, not weatherstripped	30	30	10	cm^2/m^2

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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TABLE 1.13. Component Leakage: Wall--Window Frame

Component	Best Estimate	Maximum	Minimum	Unit
Wood frame wall with caulking per m² window	0.3	0.5	0.3	cm^2/m^2
Same, no caulking	1.7	2.7	1.5	cm^2/m^2
Masonry wall with caulking per m² window	1.3	2.1	1.1	cm^2 each[(a)]
Same, no caulking	6.5	10.3	5.7	cm^2 each[(a)]

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TABLE 1.14. Component Leakage: Wall--Door Frame

Component	Best Estimate	Maximum	Minimum	Unit
Wood wall with caulking per m^2 door	0.3	0.3	0.1	cm^2/m^2
Same, no caulking	1.7	1.7	0.6	cm^2/m^2
Masonry wall with caulking per m^2 door	1.0	1.0	0.3	cm^2/m^2
Same, no caulking	5	5	1.7	cm^2/m^2

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TABLE 1.15. Component Leakage: Domestic Hot Water Systems

Component	Best Estimate	Maximum	Minimum	Unit
Gas water heater; only if in conditioned space	20	25	15	cm^2 each[a]

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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Implementation Guidelines. The vestibules should be sufficiently large so that the external and internal doors do not open simultaneously allowing the direct air exchange between the conditioned space and the outdoors. Depending on the particular characteristics of the building, vestibules can be constructed either inside or outside the building. They can also be manually operated and self-closing. If the traffic is particularly dense, the doors can be automatically opened and closed by pressure pads or photo-electric sensors. Vestibule heaters, if used, should be set to 55°F.

Required Information. Determine the number, area, and orientation of doors to be fitted with vestibules or revolving doors. Estimate the usage of each door.

TABLE 1.16. Component Leakage: Electric Outlets and Light Fixtures

Component	Best Estimate	Maximum	Minimum	Unit
Electric outlets and switches gasketed	0	0	0	cm^2 each[a]
Same, not gasketed	0.5	1.0	0	cm^2 each[a]
Recessed light fixtures	10	20	10	cm^2 each[a]

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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TABLE 1.17. Component Leakage: Pipe and Duct Penetrations Through Envelope

Component	Best Estimate	Maximum	Minimum	Unit
Pipe penetrations caulked or sealed	1	2	0	cm^2 each[a]
Same, not caulked	6	10	2	cm^2 each[a]
Duct penetrations sealed or with continuous vapor barrier	1.6	1.6	0	cm^2 each[a]
Same, unsealed and without vapor barrier	24	24	14	cm^2 each[a]

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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1.3 HVAC SYSTEMS

The ECOs discussed in the building envelope section conserve energy by reducing the loads imposed on the space heating and cooling systems. In this section, ECOs that improve the efficiency of HVAC systems themselves are discussed.

TABLE 1.18. Component Leakage: Fireplace

Component	Best Estimate	Maximum	Minimum	Unit
Fireplace without insert, damper closed	69	84	54	cm^2 each[(a)]
Same, damper open	350	380	320	cm^2 each[(a)]
Fireplace with insert, damper closed	36	46	26	cm^2 each[(a)]
Fireplace with insert, damper open or absent	65	90	40	cm^2 each[(a)]

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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TABLE 1.19. Component Leakage: Exhaust Fans

Component	Best Estimate	Maximum	Minimum	Unit
Kitchen fan, damper closed	5	7	3	cm^2 each
Same, damper open	39	42	36	cm^2 each
Bathroom fan, damper closed	11	12	10	cm^2 each
Same, damper open	20	22	18	cm^2 each
Dryer vent, damper closed	3	6	0	cm^2 each[(a)]

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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TABLE 1.20. Component Leakage: Heating Ducts and Furnace

Component	Best Estimate	Maximum	Minimum	Unit
Forced Air Systems				
Ductwork (only if in unconditioned space)				
Duct joints taped or caulked	72	72	32	cm^2 per house
Duct joints not taped or caulked	144	144	72	cm^2 per house
Furnace (only if in conditioned space)				
Sealed combustion furnace	0	0	0	cm^2 each
Retention head burner furnace	30	40	20	cm^2 each[(a)]
Retention head plus stack damper	24	40	18	cm^2 each[(a)]
Furnace with stack damper	30	40	20	cm^2 each[(a)]

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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TABLE 1.21. Component Leakage: Air Conditioner

Component	Best Estimate	Maximum	Minimum	Unit
Air conditioner wall or window unit	24	36	0	cm^2 each[(a)]

(a) Maximum and minimum are not in the literature. The given values of maximum and minimum are used in the calculations.

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The HVAC systems are made up of energy conversion equipment, which transforms electrical or chemical energy to thermal energy, and distribution and ventilation systems, which transport the thermal energy and supply fresh outdoor air to the conditioned space. Energy may be saved by reducing ventilation requirements; improving the performance of space conditioning equipment such as boilers, furnaces, chillers, air-conditioners, and heat pumps; using energy-efficient cooling systems; and reducing the occurrence of reheating or recooling.

1.3.1 Reduce Ventilation

Ventilation is the intentional introduction of outside air into the building through ventilators, doors and windows. (Mechanical ventilation requires the expenditure of fan or blower energy, while natural ventilation does not.) The ventilation system imposes heating and cooling loads on the space conditioning equipment. Mechanical ventilation results in fan energy consumption.

Ventilation substantially influences the indoor air quality as well as the space conditioning loads. Indoor pollution results from occupants' activities (such as smoking, cooking, operating appliances and equipment, and using chemicals, etc.); outgassing of building materials; and penetration of outdoor pollutants. Table 1.22 lists the sources, possible concentrations, and indoor-outdoor concentration ratios of some typical indoor air pollutants. These different pollutants can impair the health and well-being of the occupants.

The ventilation ECOs are designed to properly control ventilation to minimize space conditioning load while maintaining an acceptable indoor air quality. These ECOs must be selectively applied. Under certain conditions (air-conditioning economizer cycle or nocturnal flushing of the building), it is more cost-effective to maintain or increase ventilation rates.

ECO 26 - Reduce Ventilation Rates

The ventilation rates listed in Tables 1.23 through 1.26 are required for the occupied space if no unusual indoor air contaminants are present and the outdoor air quality is at an acceptable level, as listed in Tables 1.27 and 1.28.

Implementation Guidelines. Some buildings are ventilated at a rate in excess of the recommended values. To reduce the energy consumed by the ventilation system, the ventilation rates should be lowered according to Tables 1.23 through 1.26, unless atypically high levels of pollutants are being generated. (If human carcinogens or other harmful contaminants are suspected to be present in the occupied space, other relevant standards or guidelines, such as OSHA or NIH, must supersede the listed values.)

For spaces with transient or variable occupancy, the quantity of outdoor air should be adjusted by use of dampers, multi-speed ventilation fans, or by duty cycling the system. When contaminants independent of the occupants are generated in the space, the supply of outdoor air should lead occupancy so

TABLE 1.22. Sources, Possible Concentrations and Indoor-to-Outdoor Concentration Ratios of Some Indoor Pollutants

Pollutant	Sources of Indoor Pollution	Possible Indoor Concentration[(a)]	I/O Concentration Ratio	Location
Carbon monoxide	Combustion equipment, engines, faulty heating systems	100 ppm	>>1	Skating rinks, offices, homes, cars, shops
Respirable particles	Stoves, fireplaces, cigarettes, condensation of volatiles, aerosol sprays, resuspension, cooking	100-500 $\mu g/m^3$	>>1	Homes, office, cars, public facilities, bars, restaurants
Organic vapors	Combustion, solvents, resin products, pesticides, aerosol sprays	NA	>1	Homes, restaurants, public facilities, offices, hospitals
Nitrogen dioxide	Combustion, gas stoves, water heaters, dryers, cigarettes, engines	200-1,000 $\mu g/m^3$	>>1	Homes, skating rinks
Sulfur dioxide	Heating system	20 $\mu g/m^3$	<1	Removal inside
Total suspended particles without smoking	Combustion, resuspension, heating system	100 $\mu g/m^3$	1	Homes, offices, transportation, restaurants
Sulfate	Matches, gas stoves	5 $\mu g/m^3$	<1	Removal inside
Formaldehyde	Insulation, product binders, particleboard	0.05-1.0 ppm	>1	Homes, offices
Radon and progeny	Building materials, groundwater, soil	0.1-30 nCi/m^3	>>1	Homes, buildings
Asbestos	Fireproofing	<1 fiber/cc	1	Homes, schools, offices
Mineral and synthetic fibers	Products, cloth, rugs wallboard	NA	--	Homes, schools, offices
Carbon dioxide	Combustion, humans, pets	3,000 ppm	>>1	Homes, schools, offices
Viable organisms	Humans, pets, rodents, insects, plants, fungi, humidifiers, air conditioners	NA	>1	Homes, hospitals, schools, offices, public facilities
Ozone	Electric arcing, UV light source	20 ppb 200 ppb	<1 >1	Airplanes Offices

(a) Concentrations listed are only those reported indoors. Both higher and lower concentrations have been measured. No averaging times are given. NA indicates it is not appropriate to list a concentration.
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that acceptable conditions are attained before occupants return. On the other hand, if contaminants are generated solely by the occupants, the supply of outdoor air may lag occupancy. Figures 1.1 and 1.2 show the lag or lead times needed to achieve acceptable conditions for transient occupancy.

TABLE 1.23. Outdoor Air Requirements for Ventilation of Commercial Facilities (offices, stores, shops, hotels, sports facilities, etc.)

	Estimated Occupancy (persons per 1000 ft^2 or 100 m^2 floor area)[a]	Outdoor Air Requirements				Comments
		Smoking	Nonsmoking	Smoking	Nonsmoking	
Dry Cleaners and Laundries		cfm/person		L/s • person		
Commercial	10	--	15	--	7.75	A blank (--) indicates that smoking (or nonsmoking) in a space should not occur.
Storage/pick-up areas	30	35	10	17.5	5	
Coin-operated laundries	20	35	15	17.5	7.5	Dry cleaning processes may require more air.
Coin-operated dry cleaning	20	--	15	--	7.5	
Food and Beverage Services		cfm/person		L/s • person		
Dining rooms	70	35	7	17.5	3.5	
Kitchens	20	--	10	--	5	
Cafeterias, fast food facilities	100	35	7	17.5	3.5	
Bars and cocktail lounges	100	50	10	25	5	
Garages, Auto Repair Shops, Service Stations		cfm/ft^2 floor		L/s • m^2 floor		
Parking garages (enclosed)	--	1.5	1.5	7.5	7.5	Distribution must consider worker location and concentration of running engines; stands where engines are run must incorporate systems for positive engine exhaust withdrawal.
Auto repair workrooms (general)	--	1.5	1.5	7.5	7.5	
Hotels, Motels, Resorts, Dormitories, and Correctional Facilities		cfm/room		L/s • room		See also food and beverage services, merchandising, barber and beauty shops, garages.
Bedrooms (single, double)	5	30	15	15	7.5	Independent of room size.
Living rooms (suites)	20	50	25	25	12.5	
Baths, toilets (attached to bedrooms)		50	50	25	25	Independent of room size: installed capacity for intermittent use.

TABLE 1.23. (contd)

	Estimated Occupancy (persons per 1000 ft^2 or 100 m^2 floor area)[a]	Outdoor Air Requirements				Comments
		Smoking	Nonsmoking	Smoking	Nonsmoking	
		cfm/person		L/s • person		
Lobbies	30	15	5	7.5	2.5	
Conference rooms (small)	50	35	7	17.5	3.5	
Assembly rooms (large)	120	35	7	17.5	3.5	
Gambling casinos	120	35	7	17.5	3.5	
Offices		cfm/person		L/s • person		
Office space	7	20	5	10	2.5	
Meeting and waiting spaces	60	35	7	17.5	3.5	
Public Spaces		cfm/ft^2 floor		L/s • m^2 floor		
Corridors and utility rooms		0.02	0.02	0.10	0.10	
		cfm/stall or urinal		L/s • stall or urinal		
Public restrooms	100	75	--	37.5	--	
		cfm/locker		L/s • locker		
Locker and dressing rooms	50	35	15	17.5	7.5	
Retail Stores		cfm/person		L/s • person		
Sales floor and showrooms						
Basement and street floors	30	25	5	12.5	2.5	
Upper floors	20	25	5	12.5	2.5	
Storage areas (serving sales and storerooms)	15	25	5	12.5	2.5	
Dressing rooms	--	25	5	12.5	3.5	
Malls and arcades	20	10	5	5	2.5	
Shipping and receiving areas	10	10	5	5	2.5	
Warehouses	5	10	5	5	2.5	
Elevators	--	--	15	--	7.5	
Smoking rooms	70	50	--	25	--	
Specialty Shops		cfm/person		L/s • person		
Barber and beauty shops	25	35	20	17.5	10	
Reducing salons, health spas (exercise rooms)	20	--	15	--	7.5	
Florists	10	25	5	12.5	2.5	Ventilation to optimize plant growth may dictate requirements.
Greenhouses	1	--	5	--	2.5	

TABLE 1.23. (contd)

	Estimated Occupancy (persons per 1000 ft^2 or 100 m^2 floor area)[a]	Outdoor Air Requirements Smoking	Nonsmoking	Smoking	Nonsmoking	Comments
		cfm/person		L/s • person		
Show repair shops (combined workrooms/trade areas)	10	15	10	7.5	5	
		cfm/ft^2 floor		L/s • m^2 floor		
Pet shops	--	1	1	5	5	
Sports and Amusement Facilities		cfm/person		L/s • person		
Ballrooms and discos	100	35	7	17.5	3.5	
Bowling alleys (seating area)	70	35	7	17.5	3.5	When internal combustion engines are operated for maintenance of playing surfaces, increased ventilation rates will be required.
Playing floors (e.g., gymnasiums, ice arenas)	30	--	20	--	10	
Spectator areas	150	35	7	17.5	3.5	
Game rooms (e.g., cards and billiards rooms)	70	35	7	17.5	3.5	
Swimming pools		cfm/ft^2 area		L/s • m^2 area		
Pool and deck areas	--	--	0.5	00	2.5	Higher values may be required for humidity control.
		cfm/person		L/s • person		
Spectators area	70	35	7	17.5	3.5	
Theatres		cfm/person		L/s • person		
Ticket booths	--	20	5	10	2.5	
Lobbies, foyers, and lounges, and auditoriums in motion picture theatres, lecture, concert and opera halls	150	35	7	17.5	3.5	
Stages, television and movie studios	70	--	10	--	5	Special ventilation will be needed to eliminate special stage effects (e.g., dry ice vapors, mists, etc.).
Transportation		cfm/person		L/s • person		
Waiting rooms, ticket and baggage areas, corridors and gate areas, platforms, concourses	150	35	7	17.5	3.5	Ventilation within vehicles will require special consideration.

TABLE 1.23. (contd)

	Estimated Occupancy (persons per 1000 ft² or 100 m² floor area)[a]	Outdoor Air Requirements				Comments
		Smoking	Nonsmoking	Smoking	Nonsmoking	
Workrooms		cfm/person		L/s • person		
Meat processing rooms	10	--	5	--	2.5	Spaces maintained at low temperatures (-10°F to +50°F, or -23°C to +10°C) are not covered by these requirements unless the occupancy is continuous. Ventilation from adjoining spaces is permissible. When the occupancy is intermittent, infiltration will normally exceed the ventilation requirement (see ASHRAE Handbook, Fundamentals).
Pharmacists' workroom	20	--	7	--	3.5	
Bank vaults	10	--	5	--	2.5	
Photo studios						
Camera room, stages	10	--	5	--	2.5	
Darkrooms	10	--	20	--	10	
		cfm/ft² area		L/s • m² area		
Duplicating and printing rooms		--	0.5	--	2.5	Installed equipment must incorporate positive exhaust and control (as required) of undesirable contaminants (toxic or otherwise).
Educational Facilities		cfm/person		L/s • person		
Classrooms	50	25	5	12.5	2.5	
Laboratories	30	--	10	--	5	Special contaminant control systems may be required for processes or functions including laboratory animal occupancy.
Training shops	30	35	7	17.5	3.5	
Music rooms	50	35	7	17.5	3.5	
Libraries	20	--	5	--	2.5	

(a) Use only when design occupancy is not known.
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TABLE 1.24. Outdoor Air Requirements for Ventilation of Institutional Facilities

Hospital, Nursing and Convalescent Homes	Estimated Occupancy (persons per 1000 ft^2 or 100 m^2 floor area)[a]	Outdoor Air Requirements				Comments
		Smoking	Nonsmoking	Smoking	Nonsmoking	
						Special requirements or codes and pressure relationships may determine minimum ventilation rates and filter efficiency.
		cfm/bed		L/s • bed		
Patient rooms	10	35	7	17.5	3.5	
		cfm/person		L/s • person		
Medical procedure areas	10	35	7	17.5	3.5	
Operating rooms, delivery rooms	20	--	40	--	20	Procedures generating contaminants may require higher rates.
Recovery and intensive care rooms	20	--	15	--	7.5	
Autopsy rooms	20	--	100	--	50	Air shall not be recirculated into other spaces.
Physical therapy areas	20	--	15	--	7.5	

(a) Use only when design occupancy is not known.
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Required Information. Determine the existing ventilation rates and schedules. Compare existing ventilation with recommended values and space occupancy and with use profiles. Calculate acceptable ventilation reductions.

ECO 27 - Reduce the Generation of Indoor Pollutants

The outdoor air requirements for ventilation listed in Tables 1.23 through 1.26 are recommended only if no unusual indoor air contaminants are present. Otherwise, additional fresh air is required. The quantity of additional outdoor air needed can be minimized by controlling or removing the pollutants at their sources when feasible.

Implementation Guidelines. To minimize indoor air pollution, materials with low emission rates should be used. Sealants should be used to prevent outgassing. In addition, maximizing the combustion efficiencies of gas cooking and space and water heating systems also reduces the amount of pollutants generated. When exhaust hoods are replaced, make-up air hoods should be considered to reduce conditioning requirements for make-up air.

TABLE 1.25. Outdoor Air Requirements for Ventilation of Residential Facilities (private dwelling places, single or multiple, low or high rise)

	Outdoor Air Requirements		Comments
			Operable windows or mechanical ventilation systems shall be provided for use when occupancy is greater than usual conditions or when unusual contaminant levels are generated within the space.
	cfm/room	L/s • room	
General living areas	10	5	Ventilation rate is independent of room size
Bedrooms	10	5	Ventilation rate is independent of room size
All other rooms	10	5	Ventilation rate is independent of room size
Kitchens	100	50	Installed capacity for intermittent use; Ventilation rate is independent of room size
Baths, toilets	50	25	Installed capacity for intermittent use; Ventilation rate is independent of room size
	cfm/car space	L/s • car space	
Garages (separate for each dwelling unit)	100	50	
	cfm/ft^2 floor	L/s • m^2 Floor	
Garages (common for several units)	1.5	7.5	

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TABLE 1.26. Outdoor Air Requirements for Ventilation of Industrial Facilities[(a)]

	Outdoor Air Requirements				Comments
	Smoking	Nonsmoking	Smoking	Nonsmoking	
	cfm/person		L/s • person		
High activity level (2.5 met)[(b)]	35	20	17.5	10	Mining, foundry, etc.
Medium activity level (2.0 met)	35	10	17.5	5	Automotive repair, assembly line, etc.
Low activity level (1.5 met)	35	7	17.5	3.5	Laboratory work, light assembly, etc.

(a) Occupational safety laws in various states usually regulate process ventilation requirements. This list gives the requirements for the occupants only, assuming that the ventilated air is of a quality equal to or exceeding at limits listed in Section 6.1 of ASHRAE (1981b). Air of this quality may be included as part of the process ventilation.

(b) 1.0 mean effective temperature (met) = sedentary activity level = 18.4 Btu/hr • ft^2 body surface (58.2 W/m^2).

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TABLE 1.27. National Ambient Air Quality Standards[a]

Contaminant	Long Term Level	Long Term Time	Short Term Level	Short Term Time
Carbon monoxide			40 mg/m^3	1 hr
			10 mg/m^3	8 hr
Lead	1.5μg/m^3	3 mo		
Nitrogen dioxide	100 μg/m^3	1 yr		
Oxidants (ozone)			235 μg/m^3	1 hr
Particulates	75 μg/m^3	1 yr	260 μg/m^3	24 hr
Sulfur dioxide	80 μg/m^3	1 yr	365 μg/m^3	24 hr

(a) See Code of Federal Regulations, Title 40, Part 50. Pertinent local regulations should also be checked. Some regulations may be more restrictive than those given here, and additional substances may be regulated.

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Required Information. Survey the building to determine whether any areas have excessive ventilation rates because of high pollutant levels. Determine whether the pollutant source can be removed.

ECO 28 - Install Air-to-Air Heat Exchangers

Air-to-air heat exchangers are devices used to preheat the incoming cold air by transferring heat from the warm exhaust air to the supply air. Similarly, the hot outside air in the summer can be precooled. This reduces the impact of air exchange on the space conditioning loads while maintaining a desirable amount of ventilation.

Implementation Guidelines. A number of air-to-air heat exchanger systems are available. Depending on the specific building application, stand-alone units or central units can be used. Stand-alone units can be installed in windows or walls, but these serve only the immediate areas. Adaptation to internal zones may be difficult. Central units are integrated with the distribution systems. Exhaust and ventilation air for the building are both ducted through the device. The typical heat transfer efficiencies of the heat exchangers range from 60% to 90%. Separate blowers are required to move the air in the intake and exhaust streams. On very cold winter days, frost may form along the path of the exhaust air stream and heaters are often required to either preheat the outdoor air or to defrost heat exchange coils.

TABLE 1.28. Additional Ambient Air Quality Guidelines

Contaminant	Long Term Level[a]	Long Term Time	Short Term Level	Short Term Time
Acetone--O[b]	7 mg/m^3	24 hr	24 mg/m^3	30 min
Acrolein--O			25 µg/m^3	C[c]
Ammonia--O	0.5 mg/m^3	1 yr	7 mg/m^3	C
Beryllium	0.01 µg/m^3	30 days		
Cadmium	2.0 µg/m^3	24 hr		
Calcium oxide (lime)			20-30 µg/m^3	C
Carbon disulfide--O	0.15 mg/m^3	24 hr	0.45 mg/m^3	30 min
Chlorine--O	0.1 mg/m^3	24 hr	0.3 mg/m^3	30 min
Chromium	1.5 µg/m^3	24 hr		
Cresol--O	0.1 mg/m^3	24 hr		
Dichloroethane--O	2.0 mg/m^3	24 hr	6.0 mg/m^3	30 min
Ethyl acetate--O	14 mg/m^3	24 hr	42 mg/m^3	30 min
Formaldehyde--O			120 µg/m^3	C
Hydrochloric acid--O	0.4mg/m^3	24 hr	3 mg/m^3	30 min
Hydrogen sulfide--O	40-50 µg/m^3	24 hr	42 µg/m^3	1 hr
Mercaptans--O			20 µg/m^3	1 hr
Mercury	2 µg/m^3	24 hr		
Methyl alcohol--	O1.5 mg/m^3	24 hr	4.5 mg/m^3	30 min
Methylene	20 mg/m^3	1 yr	150 mg/m^3	30 min
chloride--	O50 mg/m^3	24 hr		
Nickel	2 µg/m^3	24 hr		
Nitrogen monoxide	0.5 mg/m^3	24 hr	1 mg/m^3	30 min
Phenol--O	0.1 mg/m^3	24 hr		
Sulfates	4 µg/m^3	1 yr		
	12 µg/m^3	24 hr		
Sulfuric acid--O	50 µg/m^3	1 yr	200µg/m^3	30 min
	100µg/m^3	24 hr		
Trichlorethylene--	O2 mg/m^3	1 yr	16 mg/m^3	30 min
	5 mg/m^3	24 hr		
Vanadium	2 µg/m^3	24 hr		
Zinc	50 µg/m^3	1 yr		
	100 µg/m^3	24 hr		

(a) Unless otherwise specified, all air quality measurements should be corrected to standard conditions of 24°C (77°F) temperature and 760 mm (29.92 in.) of mercury pressure, (101.3.kPa).

(b) These materials marked "O" have odors at concentrations sometimes found in outdoor air. The tabulated concentration levels do not necessarily result in odorless conditions.

(c) Ceiling, or maximum allowable concentrations.

Source: Adapted from ASHRAE Standard 62-1981. Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Some air-to-air heat exchangers have water-permeable surfaces that allow both heat and moisture transfer, recovering both the sensible and the latent heat. However, the disadvantage of such a device is that water-soluble pollutants may transfer back into the fresh air, which defeats the purpose of bringing in ventilated air. Always determine whether cross leakage of air occurs in the system(s) being considered.

Required Information. Determine whether the central air distribution systems are adaptable to an air-to-air heat exchanger. Select an appropriate heat exchanger system and determine its efficiency.

ECO 29 - Install Air Cleaners

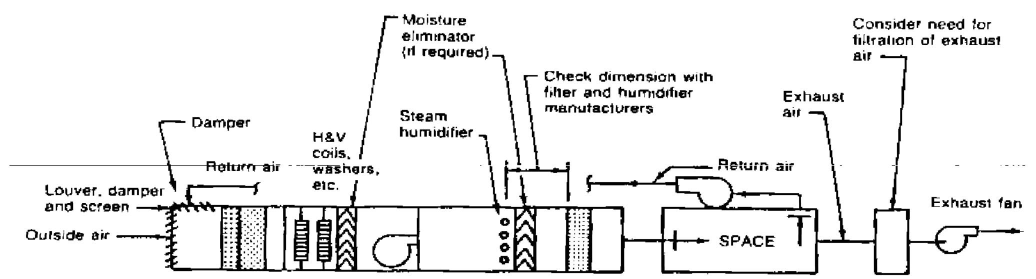
In order to reduce the amount of ventilation air required, air-cleaning devices may be employed to clean the recirculating air. The ventilation requirements listed in Tables 1.23 through 1.26 are for 100% outdoor air. However, if proper air cleaners are provided, part of the outdoor air may be replaced by recirculated air.

Implementation Guidelines. Different air-cleaners are required for the removal of particulate, vaporous, and gaseous pollutants. No single air-cleaning process can remove all types of contaminants. Therefore, multi-stage cleaning can be required if different types of pollutants are posing air quality problems. In this case, the particulate should be removed prior to the vaporous and gaseous pollutants. Filters and electronic air-cleaners are designed for the removal of airborne particles. Biological particles are usually removed by special filters, electronic air cleaners, or wet collectors. Table 1.29 shows the typical application of various types of filters classified according to their efficiencies. Sorption devices are used to clean gaseous and vaporous contaminants. Activated carbon and alumina impregnated with chemicals are effective air-cleaning media (ASHRAE 1988, Chapter 10). Maintenance is critical; the quality of indoor air depends on the air cleaner's performance.

The air-cleaning systems for recirculated air should be located in the recirculated air stream or in the plenum where the outdoor and return air mix (shown in Figure 1.6). The efficiency of the air cleaner and the recirculation rate for the system must be capable of providing indoor air quality equivalent to using outdoor air as specified in Tables 1.27 and 1.28 and at a rate specified in Tables 1.23 through 1.26. Note that a minimum amount of 5 cfm/person of fresh air is always required to dilute the carbon dioxide generated by the occupants (ASHRAE 1981b).

Required Information. Determine what type of air-cleaning devices are required, and whether they can be incorporated in the existing air distribution system. Determine the reduction of outside air cfm that can be obtained.

TABLE 1.29. Typical Filter Applications Classified by Filter Efficiency and Type[a]



Application	System Designator[b]	Prefilter		Prefilter 2/Filter		Final Filter	Space Requirement
Warehouse, storage, shop and process areas, mechanical equipment rooms, electrical control rooms, protection for heating and cooling coils	A1	None	None	50 to 85% arrestance	Panel-type or automatic roll	None	Reduce larger particle settling. Protect coils from dirt and lint.
	A2	None	None	25 to 30% dust spot	Pleated panel or extended surface	None	
Special process areas, electrical shops, paint shops, average general offices and laboratories	B1	None	None	75 to 90% arrestance 35 to 60% dust spot	Extended surface, cartridge, bag-type, or electronic (manually cleaned or replaceable media)	None	Average house cleaning. Reduces lint in air stream. Reduces ragweed pollen >85% at 35%. Removes all pollens at 60%, somewhat effective on particles causing smudge and stain.
Analytical laboratories, electronics shops, drafting areas, conference rooms, above-average general offices	C1	75 to 85% arrestance 25 to 40% dust spot	Extended surface, cartridge, or bag-type	>98% arrestance 80 to 85% dust spot	Bag-type, cartridge, or electronic (semi-automatic cleaning)	None	Above average house-cleaning. No settling particles of dust. Cartridge and bag types very effective on particles causing smudge and stain, partially effective on tobacco smoke. Electronic types quite effective on smoke.
	C2	None	None	>98% arrestance 80 to 85% dust spot	Electronic (agglomerator) with bag or cartridge section	None	
Hospitals, pharmaceutical R&D and manufacturing (non-aseptic areas only), some clean ("gray") rooms	D1	75 to 85% arrestance 25 to 40% dust spot	Extended surface, cartridge, or bag-type	>98% arrestance 80 to 85% dust spot	Bag-type, cartridge, electronic (semi-automatic cleaning)	95% DOP disposable cell	Excellent house-cleaning. Very effective on particles causing smudge and stain, smoke and fumes. Highly effective on bacteria.
	D2	None	None	>98% arrestance 80 to 95% dust spot	Electronic (agglomerator) with bag or cartridge section	None	
Aseptic areas in hospital and pharmaceutical R&D and manufacturing. Clean rooms in film and electronics manufacturing, radio-active areas, etc.[c]	E1	75 to 85% arrestance 25 to 40% dust spot	Extended surface, cartridge, bag-type	>98% arrestance 80 to 85% dust spot	Bag-type, cartridge, electronic (semi-automatic cleaning)	≥99.97% DOP disposable cell	Protects against bacteria, radioactive dusts, toxic dusts, smoke and fumes.

[a] Adapted from a similar table courtesy of E.I. du Pont de Nemours & Company.
[b] System designators have no significance other than their use in this table.
[c] Electronic agglomerators and air cleaners are not usually recommended for clean room applications.

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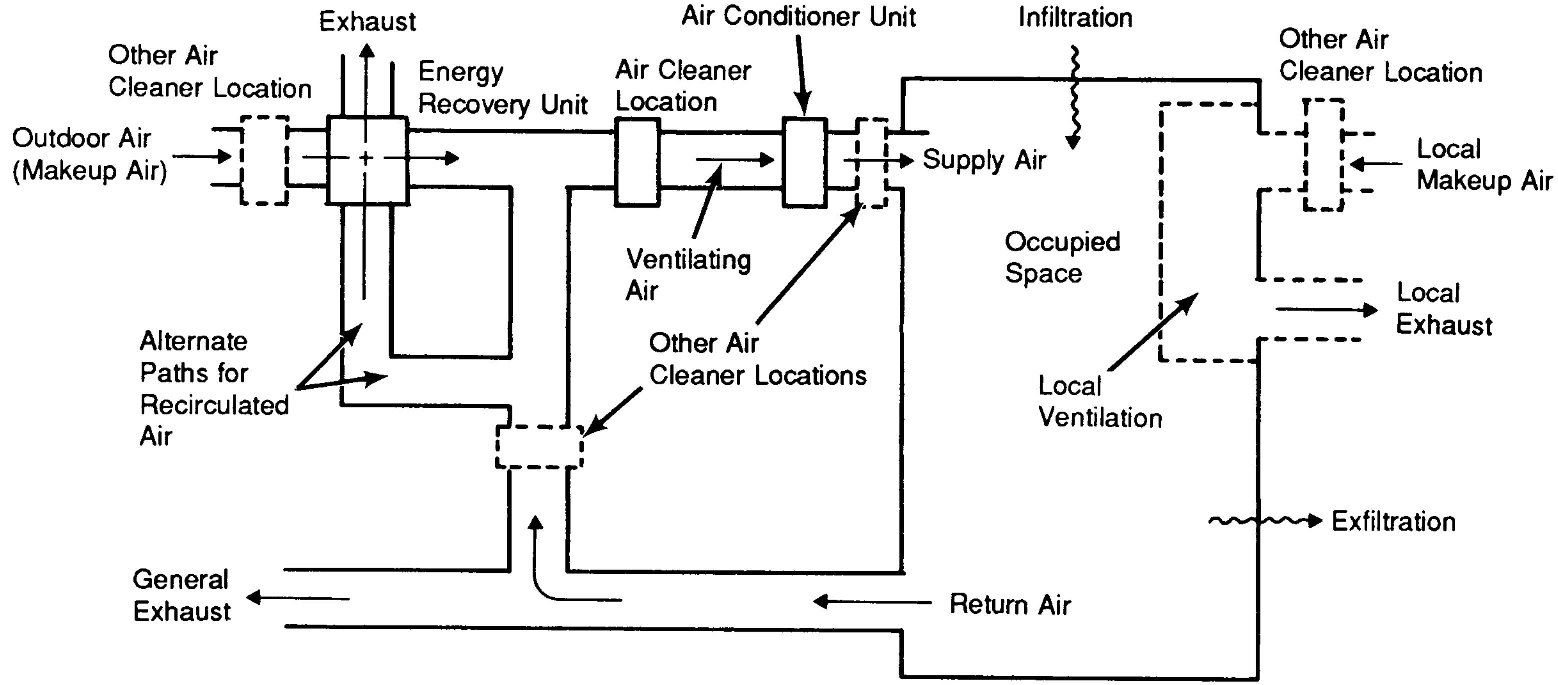

FIGURE 1.6. Ventilation System (Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from ASHRAE Standard 62-1981.)

ECO 30 - Install Local Ventilation Systems

Local ventilation/exhaust systems control indoor air pollution by exhausting the contaminants in areas with well-defined sources directly to the outdoors before they disperse into the general conditioned areas. This reduces the overall ventilation requirement of the building.

Implementation Guidelines. Local exhaust can be used effectively in smoking areas. As shown in Tables 1.23 through 1.26, higher ventilation rates are required for spaces where smoking is permitted. If possible, special smoking areas should be designated and the ventilation requirements for other building spaces lowered, provided that air circulation is contained in the smoking areas.

Other local exhaust systems that should be installed are hoods over cooking areas or over areas where chemicals are used. Bathrooms should also have local exhaust fans. A supply-air system that is completely or partially separate from the rest of the building HVAC systems should be installed to reduce the amount of energy wasted in conditioning the supply air to the exhaust hoods. In most cases, this separate system consists of ductwork, fans, dampers, etc., to draw in outdoor air and pass it through a tempering heating coil en route to the exhaust hood. This system maintains tolerable conditions immediately adjacent to the hood, while minimizing demands on the primary HVAC system.

Required Information. Determine the amount of control system ventilation air that can be eliminated. Determine the cfm, tempering and fan HP requirements for the local ventilation system.

1.3.2 Improve Chiller Efficiency

Chillers are commonly used in non-residential buildings for space cooling. The two types of chillers are vapor-compression and absorption. The key components of the chiller systems are the evaporators, condensers, compressors or generators, water pumps, and air-handling fans. Circulating water is chilled in the evaporator, and the chilled water is used to cool the conditioned space. The heat from the condensers is rejected to the ambient air directly or to cooling water that is circulated to cooling towers or is discharged. The overall energy efficiency of the chillers can be upgraded by improving their operating schedules, reducing losses, and replacing inefficient components. Chiller systems can consume 10% to 20% of building energy consumption.

ECO 31 - Clean Evaporator and Condenser Surfaces of Fouling

The evaporators and condensers provide the surfaces for heat transfer from the refrigerant to the chilled water and the ambient air or cooling water, respectively. As these heat transfer surfaces become fouled by water deposits, scales, dust, etc., their heat transfer capacities are reduced, lowering chiller efficiency.

Implementation Guidelines. Automatic tube cleaners can be used to clean the inside of heat exchanger tubes. The tube cleaners consist of cylindrical brushes in each tube. Periodically, the brushes are forced from one end of the tubes to the other by reversing the direction of water flow during operation.

In addition, water circulated in evaporatively cooled condensers and cooling towers should be filtered and chemically treated to reduce the formation of scale, algae, and chalky deposits. Dust collected on air-cooled condensers should be periodically cleaned.

Required Information. Determine the operating season of the chillers, and inspect all surfaces for scale build-up. Also determine coefficient of performance for the chiller design.

ECO 32 - Raise Evaporator or Lower Condenser Water Temperature

The efficiencies of chillers increase as the evaporator and condenser temperatures are brought closer together. Therefore, raising the evaporator temperature and/or lowering the condenser temperature will improve chiller efficiency.

Implementation Guidelines. Evaporator temperatures can be raised by implementing the following:

- Raise the chilled water temperature to follow the load by installing switches to measure whether the modulating or diversion valves are fully or partially open. Arrange the control circuits to vary the chilled water temperature setpoint such that one or more of the coil control valves is in fully open position.

- Raise supply air temperature to follow the load.

- Fully load one compressor before starting the next refrigeration unit module.

- Decrease superheat on the direct expansion (DX) coil.

The following strategies lower the condenser temperatures:

- Instead of using the cooling towers, use lower temperature well water, if available, as cooling water for the water-cooled condensers.

- Increase fan speed and/or water pump flow rates.

- Install pre-coolers for air-cooled condensers.

- Replace air-cooled condensers with evaporative cooled condensers.

To maintain the same cooling capacity, a chiller with higher evaporator temperature requires a corresponding increase in fan and pump energy consumption. Strategies to lower the condenser temperatures may result in an increase of auxiliary energy consumption for cooling tower pumps, fans, etc.

Required Information. Review the existing control strategies for the chiller system.

ECO 33 - Isolate Off-Line Chillers and Cooling Towers

For multiple chiller operations with one chiller operating during light load periods, chilled water is often circulating in parallel through all the chillers. This wastes pump energy and also forces the on-line chiller to operate at a higher load to offset the mixing effect and pipe losses of the off-line chillers. Pump and fan energy are also wasted by circulating water through the off-line cooling towers corresponding to the off-line chillers.

Implementation Guidelines. Off-line chillers and cooling towers should be isolated, and the chilled and condenser water flow rates correspondingly reduced. Unnecessary pumps should be shut off. Replace large pumps with multiple units or install multiple-speed drives on the present pumps.

Required Information. Review the control strategy and pumps for the existing coiled water system.

ECO 34 - Install Evaporatively-Cooled or Water-Cooled Condensers

Based on the laws of thermodynamics, the efficiency of a chiller increases as the condenser temperature is lowered, other parameters remaining unchanged. Evaporatively-cooled condensers and water-cooled condensers operate at lower condensing temperatures compared with the air-cooled condensers, resulting in improved chiller efficiencies and reduced energy requirements.

Implementation Guidelines. Replace the air-cooled evaporators that are at or near the end of their service lives with evaporatively-cooled or water-cooled condensers. An evaporatively-cooled condenser combines the functions of a condenser and cooling tower, resulting in higher chiller efficiency. The pumping requirement is lowered because of the piping runs are shorter and there is little resistance to spray water flow. Even greater savings are possible with water-cooled condensers if low-temperature ground water is available and municipal regulations permit its use.

Required Information. Survey the capacity of existing air-cooled condensers and cooling towers to be replaced. Determine the type and performance of replacement units.

1.3.3 Improve Boiler or Furnace Efficiency

Both boilers and furnaces are commonly used space heating equipment. Furnaces are more commonly found in residential and small commercial applications, while boilers are used in larger commercial building applications. The standard distinction between the two is that the fluid being heated in a furnace is air; whereas, the fluid being heated in a boiler is water, either liquid or vapor (steam). For both types of equipment, energy efficiencies can be improved by efficient combustion processes which are achieved through proper adjustment of fuel-to-air ratio, efficient heat transfer, and less cycling and standby losses.

ECO 35 - Clean Boiler Surfaces of Fouling

Heat transfer surfaces become less effective for heat transfer if they are fouled by products of combustion, dust, scaling, and other impurities. Any combustion heat that is not transferred to the heating fluid is discharged through the stack and wasted.

Implementation Guidelines. The fire-side heat transfer surface should be kept clean and free from soot or other deposits, the air- and water-side clean and free from scale deposit. The deposits should be removed by scraping where they are accessible, by chemical treatment, or by a combination of both.

For boilers, improper water treatment (or no water treatment) often results in a buildup of scale. Sediment or sludge may also settle inside, which hinders heat transfer. Correct water treatment and "blowdown" (see ECO 42) should be instituted to maintain optimal heat transfer conditions and boiler efficiencies. In addition, the dirty oil nozzles, fouled gas parts, etc., should be cleaned or replaced.

Required Information. Inspect heat transfer surfaces for deposits. Determine how frequently they are cleaned. Check the quality of boiler water.

ECO 36 - Check Flue for Improper Draft

Proper draft plays an important role in ensuring good combustion efficiency. A blocked flue restricts combustion air. Such blockage not only results in poor combustion efficiency (because of the high fuel-to-air ratio), but also causes a potentially dangerous operation condition. On the other hand, overdraft flue causes a high air-to-fuel ratio, which also results in poor combustion efficiency.

Implementation Guidelines. The chimney of the combustion equipment should periodically be checked for blockage or overdraft.

Required Information. Measure combustion efficiency of existing heating equipment.

ECO 37 - Check for Air Leaks

Primary and secondary air should be allowed to enter the combustion chamber only in regulated quantities and at the proper locations to ensure optimal fuel-to-air ratio. Air leaks in the combustor allow uncontrolled and varying quantities of air to enter the system. This increases the fuel-to-air ratio and lowers the combustion efficiency.

Implementation Guidelines. If spurious stack temperature and/or oxygen content readings are obtained, inspect for air leaks. Defective gaskets, cracked brickwork, broken casings, etc., should be repaired or replaced.

Required Information. Measure the combustion efficiency of equipment under present operating conditions. Inspect the physical condition of the equipment.

ECO 38 - Install Flue Gas Analyzers for Boilers

Insufficient combustion air causes incomplete combustion, which wastes fuel and generates poisonous carbon monoxide gas. Excessive combustion air must be heated, resulting in increased flue gas losses. In addition, this results in reduced efficiency because of soot deposits on the heat transfer surfaces. Figure 1.7 shows the relative trends of heat losses as a function of the combustion fuel-to-air ratio. At the optimal fuel-to-air ratio, the combined loss from an excess of heated air and combustible gases is minimal. The optimal combustion efficiency, which varies constantly with changing load and stack draft, can be achieved only through a continuous analysis of flue gas. Figure 1.8 shows the effect of flue gas composition and temperature on boiler efficiency.

Implementation Guidelines. An automatic flue gas analyzer should be installed to provide the information for manual adjustment of fuel-air ratio. Units with excess air trim systems are also available to automatically adjust the fuel-to-air ratio.

The three types of flue gas analyzing systems available are oxygen (O_2) trim; carbon monoxide (CO) trim; and carbon dioxide (CO_2) trim (so named for

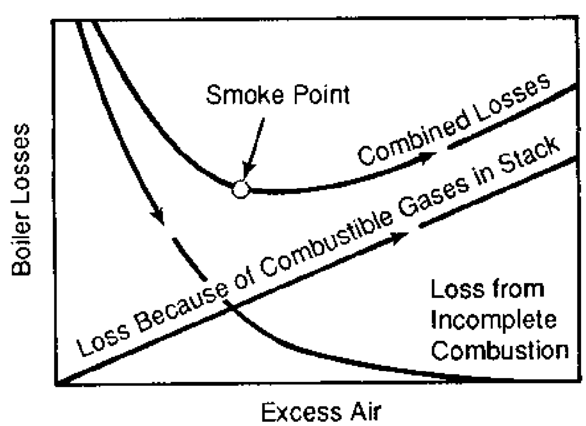

FIGURE 1.7. Losses from Boiler Operation with Excess Air (NCEL 1983b)

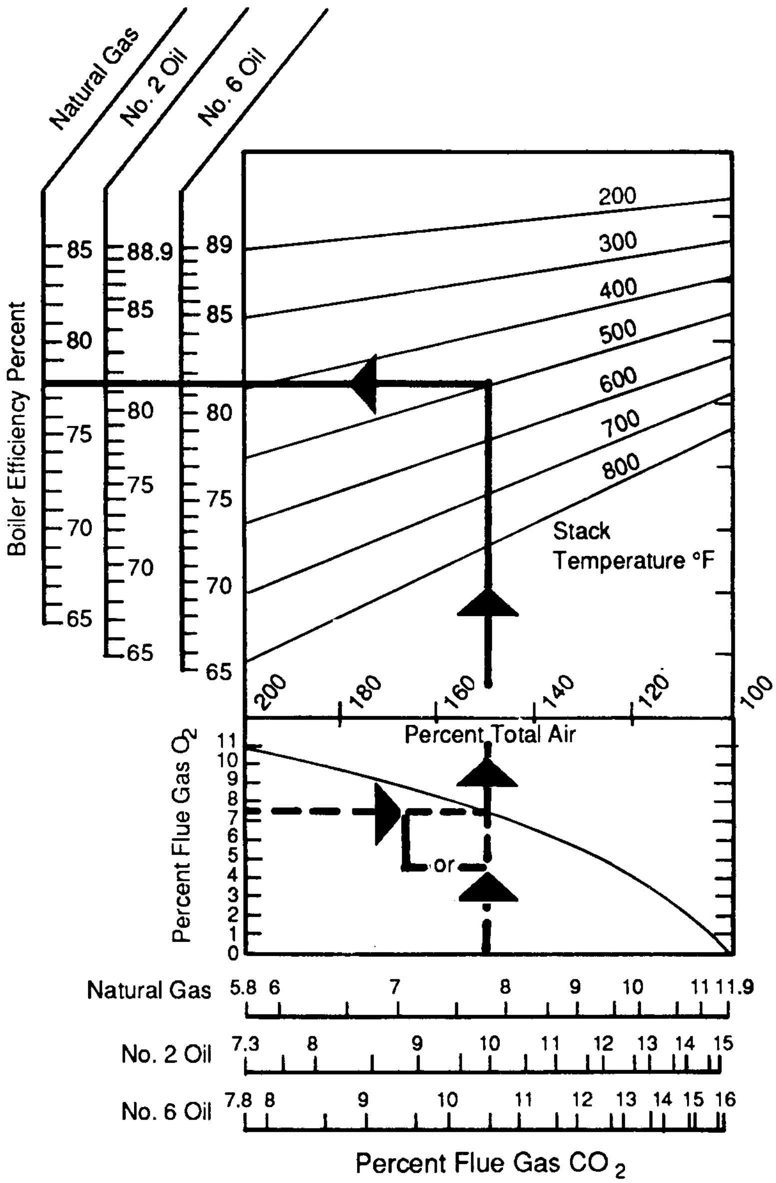

FIGURE 1.8. Heating Effect of Flue Gas Composition and Temperature on Boiler Efficiency (DOE 1980)

the component of the gas used to indicate boiler efficiency). Table 1.30 shows the suggested operating points in terms of flue gas characteristics for a temperature of 350°F. The oxygen system is relatively low cost and reliable. However, it cannot differentiate between the oxygen in the flue gas and that in the outside air drawn into the flue through leaks. The carbon monoxide system offers the greatest potential of fuel savings because it provides the true measure of the boiler efficiency. However, it can be several times more expensive than an oxygen system. The carbon dioxide system is most effective when only one kind of fuel is used. Its cost is comparable to the carbon monoxide system (NCEL 1983b).

TABLE 1.30. Recommended Boiler Operating Points for Highest Efficiency[a] (Reference 1)

Fuel	Excess Air (%)	O_2 (%)	CO (ppm)	CO_2 (%)
Natural gas	7	1.5	<100	11
Number 2 oil	10	2	<100	14.1
Number 6 oil	13	2.5	<100	14.5
Pulverized coal	16	3	<100	15.9

(a) All data for 350°F flue gas temperature.
Source: Dyer, D. and G. Maples (1979) as cited in NCEL (1983b).

For large plants, an automatic flue gas analyzer should be installed. However, local codes should first be checked for minimum excess air requirements.

Required Information. Check the size and efficiency of the existing plant.

ECO 39 - Preheat Combustion Air, Feed Water or Fuel Oil with Reclaimed Waste Heat

Waste heat may be recovered from combustion flue gases, condensate, boiler blowdown, jacket losses, etc., and used to preheat the combustion air, feedwater, and/or fuel oil. Preheating the combustion air increases the burner efficiency by reducing the cooling effect of the combustion air as it enters the combustion chamber. Preheating the feed water requires less from the combustor to reach the desired temperature. Fuel oil preheating is required to obtain complete atomization, and use of waste heat for preheat reduces energy consumption. The temperature for complete atomization for No. 4 oil is 135°F; for No. 5 oil, 185°F; and for No. 6 oil, 210°F. Preheating beyond these temperatures continues to improve efficiency; however, overheating can result in vapor locking, which could cause flameouts.

Implementation Guidelines. The maximum preheat temperature permissible is determined by the type of construction involved and by the materials of the firing equipment. For the fuel oil preheat, care should be taken not to overheat the fuel, which causes vapor locking and flameout.

Required Information. Examine the existing combustion plant to determine opportunities for preheating.

ECO 40 - Isolate Off-Line Boilers

Light heating-load demands on a multiple boiler installation are often met by a single boiler on-line while the other units remain on standby. The idling boilers continue to lose heat to their surroundings (i.e., standby losses). In many cases, the standby losses are further aggravated by a continuously induced flow of air through the idle boilers into the stack.

Implementation Guidelines. Control valves and dampers should be used to isolate standby boilers from the operating boiler, as well as from its stack and chimney. Large boilers should be fitted with bypass valves and regulating orifices to allow water to flow through the boiler. This conserves fuel while the boiler is kept warm to avoid thermal stress upon startup.

If a boiler containing water is isolated, the back-flow of cold air through the stack must be stopped to prevent the boiler water from freezing.

Required Information. Determine the existing multiple boiler controls and the controls required to isolate the standby boiler.

ECO 41 - Install Automatic Vent Dampers

Automatic vent dampers can reduce energy consumption and improve the seasonal efficiency of gas and oil combustion systems. Vent dampers reduce both the loss of previously heated air through draft hoods and the loss of retained heat after the burner has ceased firing.

Implementation Guidelines. Automatic vent dampers can be actuated electrically, mechanically, or thermally. They can be installed as retrofit devices or integrated with some types of newly-designed systems. Instructions for installing safety interlocks with the equipment control must be carefully observed when a gas vent damper is being retrofit. Verification of spill-free gas venting after the damper has been installed is mandatory with all types.

Required Information. Determine the draft and size of existing flues.

ECO 42 - Install Automatic Boiler Blowdown Control

Sludge from the natural feedwater and deposits from water treatment settle in the boiler. This can reduce heat transfer, causing metal overheating where scale is located and rupturing heat exchanger parts. The purpose of boiler blowdown is to remove the sludge and concentrated dissolved and suspended solids.

Implementation Guidelines. There are two types of blowdown: intermittent and continuous. For the intermittent blowdown, the blow-off valve is opened manually to remove the accumulated sludge from the bottom of the mud drum, waterwall headers, or lowest point of the circulating system. Hot water is generally wasted, and the control of boiler-water concentration is irregular. Continuous blowdown removes a small stream of boiler water continuously to keep the water concentration relatively constant.

The blowdown rate should be determined by the desired or permissible boiler-water concentration, which depends on the pressure of the system, alkalinity, silica, and iron oxide limits. Figure 1.9 shows the boiler water concentration limits and percent blowdown recommended by the American Boiler

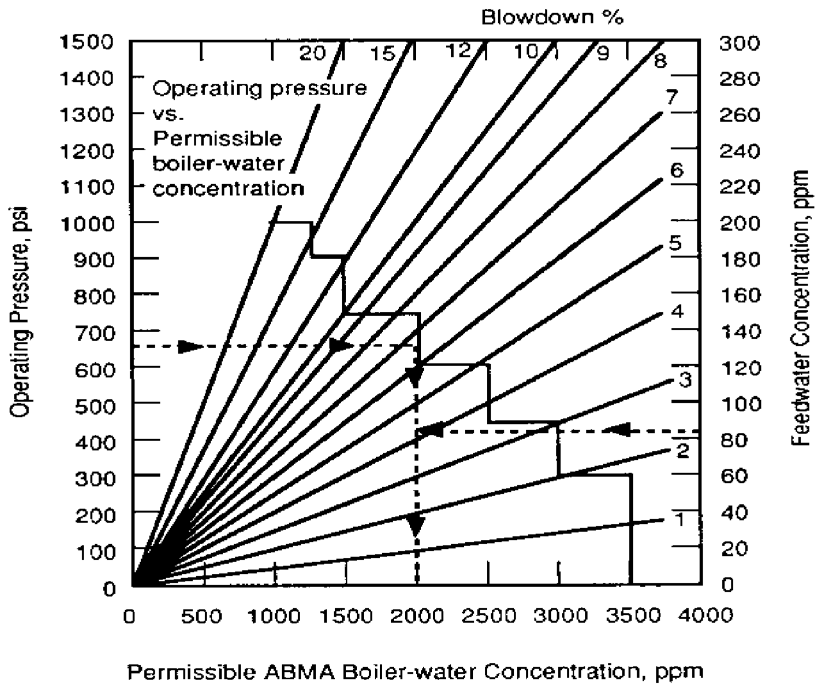

FIGURE 1.9. Boiler Water Concentration Limits and Percent Blowdown Recommended by the American Boiler Manufacturers Association (From Elonka and Kohan. Copyright © 1984 by McGraw-Hill, Inc. Reprinted with permission.)

Manufacturers Association (Elonka and Kohan 1984). An automatic blowdown control that will allow blowdown only when required to maintain acceptable water quality should be installed to monitor the conductivity and pH of the boiler.

Required Information. Determine the gpm of boiler blowdown required to maintain boiler water quality.

ECO 43 - Install Pulse or Condensing Boiler/Furnace

New boilers and furnaces on the markets generally attain efficiencies of above 80%. The efficiencies of pulse and condensing units can be above 90% and reduce the energy requirements considerably.

Implementation Guidelines. Boilers or furnaces at or near the end of their service life should be replaced with energy-efficient units. The size of the replacement unit should match the current and projected needs of the installation. Replacing original equipment with modular units with smaller capacities should be considered to reduce the cycling losses.

Required Information. Determine the active current building heating load and select appropriate replacement equipment. Determine the efficiency of the replacement equipment.

ECO 44 - Install Air-Atomizing Burners (for Oil-Fired Systems)

Oil burners prepare the fuel for combustion, and then mix it with the proper amount of air. The fuel may either be vaporized or gasified by heating within the burners or atomized by the burners so that vaporization can take place in the combustion chamber (Elonka and Kohan 1984). There are two types of atomizing burners: steam atomizing and air atomizing. A steam-atomizing burner uses approximately 1.5% of the boiler output to atomize the fuel oil. The more economical air-atomizing burner uses a simple electrically-driven air compressor to atomize the fuel oil (NECA-NEMA 1979).

Implementation Guidelines. When an existing steam-atomizing burner is at or near the end of its useful life, it should be replaced with an air-atomizing burner. In certain cases, the savings to be obtained from an air-atomizing burner warrant its installation even before existing burners need replacing.

Required Information. Determine the steam requirements of the existing steam-atomizing burner and compare this with the electrical requirements of the air-atomizing burner.

ECO 45 - Install Low-Excess-Air Burners (for Oil-Fired Systems)

Conventional burners require large quantities of excess air to ensure complete combustion. As a result, substantial amounts of heat are lost through the stack. Low-excess-air burners may be used to improve efficiency, as well as to reduce NO_x levels, by operating at 0.5% excess air at 70% to 100% part load, and 0.7% at 25% to 70% part load. These burners operate at low excess air by using venturi throats to provide turbulent air flow into the combustors. The air flow mixes air and fuel more uniformly (Elonka and Kohan 1984).

Implementation Guidelines. When an existing steam-atomizing burner is at or near the end of its useful life, it should be replaced with a low-excess-air burner.

Required Information. Compare the performance of the existing burner with replacement burners that are currently available.

ECO 46 - Install Modular Units

The size of heating and cooling equipment is generally based on design or maximum loads. During most of the seasons, the equipment will operate at part load, resulting in substantial cyclic losses. Energy conservation measures, which lower the building load, compound the problem by increasing the amount by which equipment is oversized.

A system of modular units operating independently has higher seasonal efficiency than one oversized unit. Each small unit has a relatively low thermal inertia, giving rapid response and low recovery losses. Typically, each module operates at 100% of its capacity, and fluctuation of loads are met by firing more of the modules.

Implementation Guidelines. At or near the end of the service lives of the existing equipment, it should be replaced by several smaller units.

Required Information. Determine the heating load of the building as it currently exists.

1.3.4 Improve Air-Conditioner or Heat Pump Efficiency

The operation of an air-conditioner is based on the same principle as vapor compression chillers; however, air is the heat transfer media. Heat pumps operate identically to air-conditioners, but can operate in both heating and cooling modes. Common heat transfer fluids are air or water. Air-conditioners or heat pumps are typically the cooling equipment used in residences or small commercial buildings. The energy consumption of this equipment can be reduced in two ways: improve its operating efficiency or replace existing units with more energy-efficiency systems.

ECO 47 - Clean Air Filters

One of the most important aspects of the energy-efficient operations of the heat pumps or air-conditioners is proper air flow. Dirty filters can limit air flow, cause compressor cycling, and reduce operating efficiency.

Implementation Guidelines. Permanent filters should be cleaned regularly with hot water (or soaked in a mild solution of detergent and water) and allowed to dry before reinstalling. Disposable filters should be inspected regularly and replaced as needed. Dirty coils may require steam cleaning.

Required Information. Determine the rated cfm of units with clogged filters.

ECO 48 - Install Add-On Heat Pumps

A heat pump and furnace combination is commonly called an "add-on" heat pump. This combination enables the most efficient operation of both the heat pump and furnace. A heat pump provides both heating and cooling in an energy-efficient manner except when outside air is cold and some form of supplementary heat is required. Electric resistance heaters, which are often used for supplementary heat, have a COP of 1.0 and significantly reduce the overall efficiency of the heat pump. Furnaces operate more economically at low outdoor temperatures because they experience less cycling and use a less expensive fuel.

Implementation Guidelines. Add-on heat pumps are generally controlled by two methods. In the first method, the heating system is controlled by a two-stage indoor thermostat. The first stage controls the heat pump. In cold weather, when the heat pump can no longer provide all the required heating, the second stage of the thermostat brings on the furnace and turns off the heat pump. The other method incorporates an outdoor thermostat to transfer heat from the heat pump to the furnace at a temperature equal to the economic balance point. (The economic balance point is the temperature at which the cost of heating with the heat pump is equal to the cost of heating with the furnace.)

Many residences have furnaces and air-conditioners for space heating and cooling. If the air-conditioner is at the end of its service life, replacement with a heat pump should be considered. The heat pump may be added to most existing forced-air furnaces, regardless of fuel type, in the same manner as adding air-conditioning.

Required Information. Determine the building cooling load to size the heat pump. Determine fossil and electric fuel rates and calculate the heat pump to furnace switchover temperature.

ECO 49 - Install Ground or Ground-Water Source Heat Pump

The efficiency and capacity of an air-source heat pump is a function of the outdoor temperature. Its cooling capacity and efficiency decrease when outdoor temperatures are high and the space cooling loads are high. Its heating capacity and efficiency decrease at low outdoor temperatures when the space heating loads are high. The ground and ground-water source heat pumps use the ground and ground water, respectively, as the heat source for heating and the heat sink for cooling. Since ground and ground-water temperatures are generally more moderate than the ambient air temperature, these heat pumps operate at higher efficiency.

Implementation Guidelines. For ground-source heat pumps, heat exchanger pipes are installed in vertical or horizontal arrays below ground. For ground-water heat pumps, water is generally pumped out of one part of the aquifer, used in the building, and then disposed of in a separate well or another part of the aquifer.

Ground and ground-water heat pumps are applicable in areas where ample open ground is available or where there is an accessible aquifer with moderate temperatures year-round. Local zoning ordinances must also permit excavation to install piping or to gain access to the aquifer. Because they are often on large parcels of land, buildings that are suitable for such systems include airports, hospitals, schools, and shopping malls.

Required Information. Determine the ground area available or whether a high water table exists in the area.

1.3.5 Reduce Energy Used for Tempering Supply Air

Depending on the operation and characteristics of the distribution systems, the supply air temperature generated by the heating and cooling equipment may be too high or too low compared with the space requirements. In order not to undercool or overheat the room, additional energy is required to reheat or recool the supply air. The energy used to temper the supply air amounts to a considerable portion of the total space conditioning energy requirement and should be minimized.

ECO 50 - Install Variable Air Volume Systems

Variable air volume (VAV) systems respond to changes in heating or cooling load by reducing the amount of warm or cool air flowing to the space. In contrast, constant volume air systems temper the supply air by reheating (mixing with warm air or using electric reheaters) or recooling (mixing with cool air). In general, the energy wasted for tempering the supply is more of a problem for cooling. The reheat function alone can consume as much energy as the cooling system to which it is applied. VAV systems can dramatically reduce the amount of energy for reconditioning the supply air. In addition, these systems use significantly less energy for air distribution.

Implementation Guidelines. VAV systems are most applicable as a retrofit to HVAC systems with medium-to-high air velocity (most typically dual-duct systems). Moreover, dual-duct system terminals can be converted to VAV terminals. Low-velocity ductwork may leak and bellow when operated at the higher static pressure present in a VAV system. A modified VAV system can be used with low-velocity HVAC systems. For this case, VAV terminals are not installed, but the main fan flow rate for cooling is controlled by the warmest zone in the building. A small amount of reheat may be required in zones other than the warmest one.

VAV systems require the use of VAV terminal boxes at each zone supplied, as well as control for the main HVAC fan. The fan is controlled by variable-speed motor drives, variable-pitch fans, fan inlet vanes, or fan discharge dampers. Duct and fan housing configurations sometimes make the retrofit of inlet vanes and discharge dampers difficult.

ECO 51 - Reset Supply Air Temperatures

Heating and cooling reheat energy can be minimized by resetting hot and cold deck temperatures to match requirements of those mixing boxes with the greatest load requirements. This ECO is applicable to dual-duct, multi-zone, and VAV systems.

See ECO 103 for further discussion and implementation of this ECO.

ECO 52 - Reset Hot/Chilled Water Temperatures

Plant heating and cooling energy may be saved by resetting hot and chilled water according to space heating and cooling loads. The reset schedules for occupied and unoccupied periods may be adjusted according to ambient air temperature, with override controlled by space temperature sensors.

See ECO 104 for further discussion and implementation of this ECO.

1.3.6 Use Energy-Efficient Cooling Systems

Many cooling systems may be used to replace or supplement the conventional chillers, air-conditioners, or heat pumps. By taking advantage of natural processes, such as desiccant cooling or evaporative cooling, these alternative cooling systems require less energy. They may also employ less energy-intensive equipment, such as fans, cooling towers, and ventilation systems.

ECO 53 - Install Economizer Cooling Systems

Economizer cooling systems produce cooling effect by bringing in extra ventilation air when the outdoor conditions are favorable. There are two types of economizer cooling control: dry-bulb control and enthalpy control. Dry-bulb control enables economizer cooling when the outdoor dry-bulb temperature is lower than the indoor dry-bulb temperature. Enthalpy control energizes the economizer only when the combined sensible and latent energy level (enthalpy) of outdoor air is lower than the indoor air.

Implementation Guidelines. An economizer system includes indoor and outdoor temperature sensors, damper motors, motor controls and dampers. For small packaged systems, economizer systems may be bought off-the-shelf. For large systems, the controls and dampers are generally custom designed. One economizer control and damper system is required for each separate air distribution system. In some cases, economizers cannot be installed because there is not enough space to install an outside air damper large enough to bring in 100% outside air. Moreover, economizers may not be suited for retrofit of some packaged cooling systems. For example, the compressor may burn out unless some protection, such as low lock-out temperature, is provided.

Economizer cooling is most applicable to temperate climates or locations with a large daytime and nighttime temperature swing. The energy savings are small for hot or humid areas (for humid locations, the enthalpy control should be employed). In addition, for buildings that normally have high ventilation requirements, the energy savings are not substantial because the ventilation and exhaust fans require energy to operate (Usibelli et al. 1985).

Required Information. Check air distribution systems to determine whether they can be retrofitted for an economizer cycle. Determine the maximum supply cfm for each unit.

ECO 54 - Install Evaporative Cooling Systems

Evaporative cooling systems produce a cooling effect by evaporating water into the airstream to remove its sensible heat. As a dry and hot air stream is brought in contact with water, the water absorbs some of the heat from the airstream and evaporates. Evaporative cooling uses this natural process and exchanges sensible heat with latent heat. The airstream exits an evaporative cooler at a lower dry-bulb temperature, but with a higher moisture content, than when it enters the cooler.

Implementation Guidelines. There are three types of evaporative coolers, the selection of which depends on the outdoor conditions and the desired indoor conditions. A direct evaporative cooler brings the outdoor airstream and water into direct contact by using a sprayer or wetted media. The supply air will be cooler, but also more humid than the outside air. For buildings that require low indoor humidity, an indirect evaporative cooler is more appropriate. In this case, the supply air is sensibly cooled by the evaporatively cooled airstream via a heat exchanger. The supply air humidity level will remain unchanged, but the efficiency of the system is lower because of the inefficiency of the additional heat exchanger. The most common configuration consists of a set of plastic heat exchanger tubes covered with cloth wicks. The supply air is sent through the tubes, while the outside air is passed over the tubes and sprayed with water. The third type of evaporative system is a combination cooler, which cools the supply air first by the direct method and then by the indirect method.

Evaporative cooling is applicable to any buildings that require cooling during periods when ambient wet-bulb temperatures are below 65°F and cooling needs cannot be met with economizer alone. Direct coolers are not suitable for spaces requiring strict humidity control, unless some kind of humidity controller is installed as well. Evaporative cooling is the most effective in dry climates because its cooling potential is limited by the absolute humidity level of the outdoor air (Usibelli et al. 1985).

Required Information. Determine the power consumption of the pump and blower power of the evaporative cooler unit to be installed. Size the unit based upon supply cfm required for the air distribution system.

ECO 55 - Install Desiccant Cooling Systems

The desiccant cooling systems produce cooling effect by removing water from the airstream to lower its latent heat. Desiccants absorb moisture when brought into contact with a moist airstream and release heat into the airstream as the water vapor condenses. A desiccant cooling system reduces the humidity level of the air, but raises its dry-bulb temperature. These systems basically exchange latent heat for sensible heat (i.e., basically a combined dehumidifier and heater).

Implementation Guidelines. Typical desiccant system components include a rotary desiccant wheel, an auxiliary heater, and a fan. These components should be connected in line with the conventional cooling system. If space is limited, system installation may be difficult and/or expensive. The heater and the fan are for desiccant regeneration. To regenerate the desiccants, heat has to be applied to evaporate the absorbed moisture. The amount of energy required to recover the desiccants may reduce the energy savings of the mechanical cooling systems. If waste heat with sufficiently high temperature is available, it can be used to regenerate the desiccants, as can solar energy (Usibelli et al. 1985).

Required Information. Determine the power consumption of the desiccant regeneration heater and fan. Determine whether waste heat is available that can be used in lieu of the auxiliary heater.

ECO 56 - Install Cooling Tower Cooling Systems

A cooling tower is generally used as a heat sink to reject condenser heat from water-cooled refrigeration and air-conditioning systems. The condenser water is pumped through the tower and brought into contact with the ambient air, where it is cooled sensibly. In addition, the relative heat level of the water and air causes portions of the water to evaporate. Because the heat of evaporation is supplied from the water in the liquid state, the water temperature is further reduced. A cooling tower can economically cool water to within 5°F to 10°F of the ambient wet-bulb temperature (ASHRAE 1988). Under certain conditions, cooling towers may produce water cold enough to cool the building directly, permitting shutdown of chillers.

Implementation Guidelines. A cooling tower cooling system requires piping and automatic valves to connect the chilled water system directly to the cooling tower. If the chilled water is injected directly into the chilled water circuit (i.e., "strainer cycle"), a filter should be installed to keep cooling tower water impurities from entering the chilled water loop. Alternatively, a plate heat exchanger should be installed between the circuit water and the tower water. This is a more conservative approach because the heat exchanger is easily flushed. If a strainer cycle is used and the water becomes contaminated, every cooling coil in the building may be fouled.

Cooling tower cooling is generally only economical if cooling towers are already available as part of the space cooling systems. However, this strategy may not be as effective as economizer controls (Usibelli et al. 1985).

Required Information. Determine cooling tower flow rate and approach temperature.

ECO 57 - Install Roof-Spray Cooling Systems

A roof-spray cooling system uses the evaporative cooling process to reduce the roof temperature, thereby lowering the heat gain through the roof.

Water is sprayed onto the roof intermittently. As the water evaporates, it absorbs heat from the hot roof, lowering its temperature.

Implementation Guidelines. The roof-spray system consists of a series of pipes and sprayheads that are laid on the roof. The system is controlled by temperature and humidity sensors at the roof. During peak cooling periods, roof-spray cooling can reduce the roof surface temperature by up to 50°F.

The system is most applicable to flat roofs because of aesthetic impacts of the system on a sloped roof and the need for more sophisticated flow controls to avoid drainage water loss. Before installing a roof-spray system, the roof of the building should be checked thoroughly for any possible leakage (Usibelli et al. 1985).

Required Information. Determine the square footage of the roof.

ECO 58 - Create Air Movement with Fans

Air movement is one of the six thermal parameters that determine the comfort level of the occupants. Fans may be used in the summertime to create air movement so as to offset the cooling temperature required for comfort. For an air movement increase of 30 fpm, the room temperature may be increased 1°F beyond 79°F and still maintain comfort. Figure 1.10 shows the average temperature and air movement tradeoffs permitted in the summer and extended summer comfort zones.

Implementation Guidelines. As fans are used and the indoor air movement increases, the indoor temperature setpoint should be raised (see Figure 1.10). However, it should be noted that the extreme condition is 82.5°F or 160 fpm of air velocity; there will be thermal discomfort beyond this condition. In addition, loose paper, hair, and other light objects may start to be blown around at 160 fpm.

Required Information. Determine the power rating of circulation fans to create air movement and the number of degrees the space temperature can be raised.

ECO 59 - Exhaust Hot Air from Attics

Solar radiation causes high temperatures on roof surfaces in the summertime, leading to high attic temperatures. In poorly vented attics, the temperature can be considerably higher than the outdoor temperature. If the ceiling is not properly insulated, the attic heat eventually finds its way into the conditioned space. Attic ventilation fans can be used to reduce the attic temperature.

Implementation Guidelines. Attic fans should be installed to exhaust hot air from the attic. Venting is also a common practice to control attic

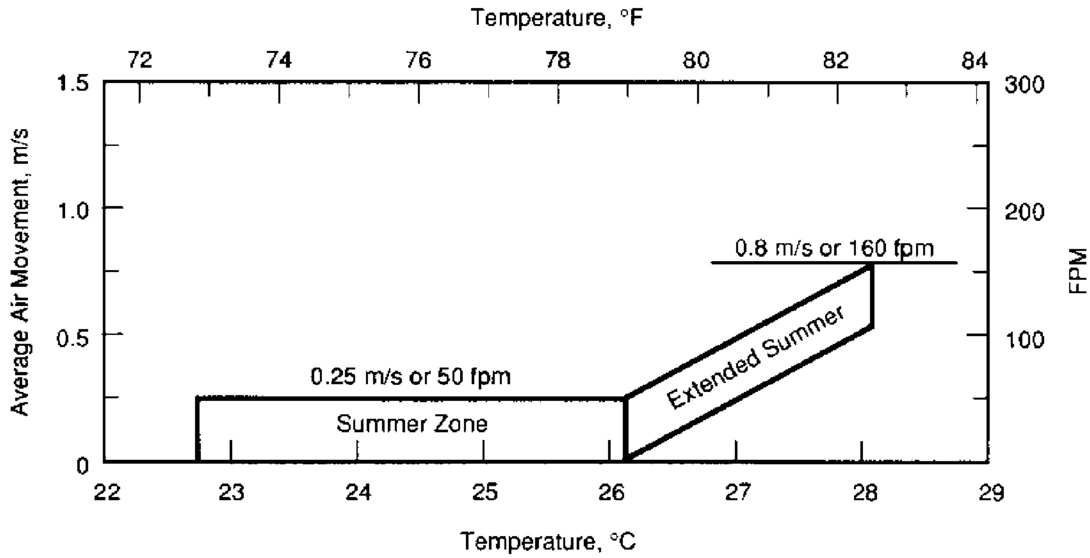

FIGURE 1.10. Range of Average Air Movements Permitted in the Summer and Extended Summer Zones (Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from ASHRAE Standard 55-1981.)

condensation. An exhaust fan can be installed with a thermostat that activates the fan when attic temperatures exceed 80°F to 90°F. The fan is typically installed inside a gable vent. More air is provided by soffit vents and/or a gable vent at the opposite side of the roof.

Required Information. Select an exhaust fan that can provide six to ten air changes per hour for the attic. Determine the power rating of the fan motor.

1.4 HVAC DISTRIBUTION SYSTEMS

HVAC distribution systems transport the heating and cooling fluids (generally air, water, or steam) from the central plants (chillers, boilers, etc.) to the conditioned space. The system is made up of a network of pipes, ducts, fans, pumps, grills, etc. Energy is required by the fans and pumps that transport the working fluids. In addition, thermal energy is lost from the distribution systems, reducing heating or cooling capacity. Consequently, ECOs for distribution systems fall into two areas: reduction of energy required to transport fluids and reduction of energy losses during transport.

1.4.1 Reduce Distribution System Energy Losses

As the working fluid is being transported through the distribution system, energy losses occur from heat conduction through bare or poorly insulated piping and ductwork; leaks in piping, steam traps, and valves; and infiltration through leaks, cracks and other defects in the system. These losses reduce heating or cooling capacity, requiring plant and system equipment to operate longer to satisfy space loads. Energy lost in transport is generally wasted unless the space in which the pipes and ducts are located also requires conditioning. In that case, overheating or overcooling may occur since the energy is lost at an uncontrolled rate.

ECO 60 - Repair Ducting and Piping Leaks

Leaks in pipes and ductwork may amount to substantial losses if they are left unrepaired. As working fluids leak out of the system, heating and cooling capacities are diminished. The equipment has to run longer, using more fan and pump energy, to compensate for lost capacity.

Implementation Guidelines. Pipes and ductwork should be inspected frequently and any leaks repaired. Low-pressure duct systems often have substantial leaks because of poor sealing during construction. If a pressurized plenum is used to supply conditioned air, it should be checked thoroughly.

Required Information. Survey pipes and ducts for evidence of leaks. Estimate the gpm or cfm of each leak, and note the average temperature difference between the working fluid and the ambient air.

ECO 61 - Maintain Steam Traps

Steam traps are found in steam piping, separators, and all steam-heated or steam-operated equipment. They are installed to remove condensate and noncondensables from the steam system as quickly as they accumulate. Over time, the internal parts of a steam trap begin to wear and fail to open and close properly. A closed trap reduces the heating capacity of the steam system. Condensate builds up in the system, which may cause water hammering and will eventually destroy valves and coils. In addition, condensate may freeze in cold climates and rupture lines and coils. When the trap fails to open, it passes steam to the condensate return lines, reducing system capacity and control (NCEL 1985). Figure 1.11 shows the relationship between trap orifice size and hourly steam loss. Note that the smallest leak results in hundreds of dollars in lost steam.

Implementation Guidelines. Steam traps should be periodically inspected and all worn or malfunctioning ones should be replaced.

Required Information. Survey all existing steam traps. Determine which traps have failed, and determine the size of the steam orifice.

ECO 62 - Insulate Ducts

Ducts provide air distribution. A complete duct system may include supply and return ducts, as well as outdoor air ducts for ventilation.

Ducts may be located in conditioned spaces; in areas exposed to outdoor conditions

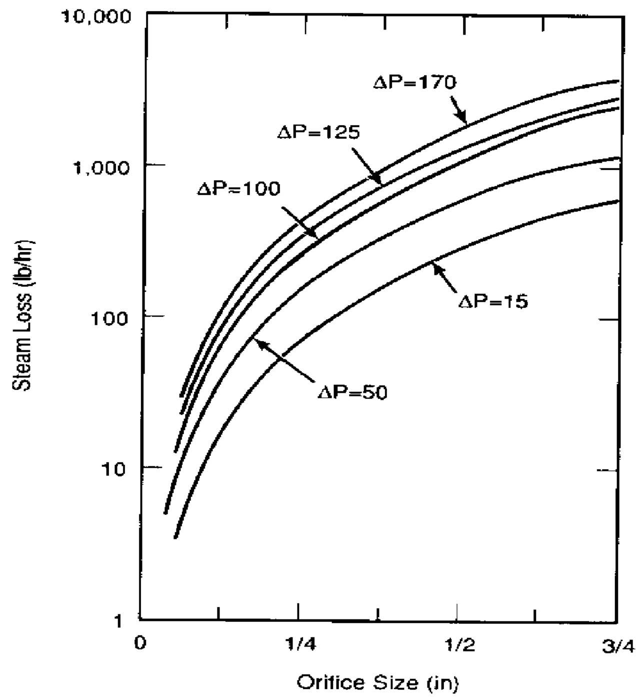

FIGURE 1.11. Steam Loss as a Function of Trap Orifice Size (NCEL 1985)

(such as ventilated crawl spaces or ventilated attics); in areas of intermediate conditions, such as basements or garages; or embedded in floor slabs. Local circumstances determine the need for insulation on ducts within the conditioned space, but all ducts exposed to the outdoors or unconditioned spaces should be insulated.

In addition to energy savings, insulating ductwork permits the supply of adequately conditioned air at distant outlets by reducing heat loss en route. Sometimes, reduced distribution losses permit reductions in the size of equipment such as fan motors.

Implementation Guidelines. Duct insulation includes semirigid boards and flexible-blanket types, composed of organic and inorganic materials in fibrous, cellular or bonded particle forms. Insulation used for cooling ducts requires vapor barriers to prevent condensation. Joints and laps in the vapor barriers should be sealed. Vapor barriers are not required for exterior insulation of heating-only ducts. To satisfy most building codes, the duct insulation must meet the fire hazard requirements of the National Fire Protection Association (ASHRAE 1985).

Required Information. Estimate the exposed area of the ductwork, the U-value of duct and insulation (if any), and the temperature difference between the ductwork and the ambient air.

ECO 63 - Insulate HVAC System Pipes

Insulation will save energy by reducing heat loss from pipes. In unconditioned or marginally conditioned spaces, this heat is lost; in conditioned spaces, pipe losses continue to heat the space, even when the thermostat is not calling for heat. The resulting lack of temperature control typically causes overheating in spring and fall. If a four-pipe fan coil system is in use in the building, the heat loss can fight the cooling system or create an artificial cooling load in the space.

Implementation Guidelines. Small pipes should be insulated with cylindrical half-sections of insulation or with flexible cell material. Large pipes should be insulated with flexible material. If access to the pipes for servicing is required, rigid insulation (curved or flat segments or cylindrical half-, third-, or quarter-sections) offers an advantage. Fittings such as elbows, valves, and tees may be insulated with preformed insulation, fabricated fitting insulation, individual pieces cut from sectional straight pipe insulation, or insulating cements. Fitting insulation should be cemented with pipe insulation (ASHRAE 1985).

In marginally heated spaces, the heat loss from the pipe might be used to maintain temperatures above freezing. In that case, it might be desirable to leave a portion of the pipe uninsulated. Savings achieved by insulating domestic hot water lines are minimal unless a circulation pump is in use. If domestic hot water is not circulated, only the first 10 or 15 ft of pipe should be insulated at the domestic water heater. In some cases, insulation of condensate return lines may have to terminate 20 or 30 ft from the condensate pump to prevent the condensate from flashing.

Required Information. Determine the number of feet of pipe to be insulated, the diameter of the pipe, the water temperature, and the average space temperature.

1.4.2 Reduce System Flow Rates

Reducing flow rates in pipes and ducts reduces the energy required for the fans and pumps. The flow rates of the working fluids in the pipes and ductwork are determined by the space conditioning loads. When building loads are reduced as a result of energy conservation measures, the HVAC equipment and distribution systems can be de-rated correspondingly.

ECO 64 - Reduce Air Flow Rates in Ducts

Fan flow rates are often higher than necessary because of oversizing in the original design process or because energy conservation measures have been implemented that reduce the space conditioning loads. For multi-vane centrifugal fans, which are commonly used in HVAC systems, the power requirements vary directly with the cube of the fan speed. A reduction in flow rate calls for reduction of the fan speed and results in substantial savings in fan power.

Implementation Guidelines. For constant-volume HVAC systems with oversized air flows, the flow rate of the fan should be chosen so that the peak space conditioning load can be met at the design air supply temperature. Reducing the fan flow rate involves changing the motor sheave for belt-driven fans, using a lower-speed motor for direct-driven fans, duty cycling of the fan at its original flow rate, or replacing the existing fan with a variable speed fan.

Required Information. Determine the cfm and horsepower of each supply fan. The percentage of reduction in the building load through implementation of ECOs should be calculated.

ECO 65 - Reduce Water or Steam Flow Rates in Pipes

Like air ducts, the transport losses from pipes can be lowered by reducing fluid flow rates. Water and steam flow rates are a function of the space conditioning load. Reducing building loads allows flow rates and pump speeds to be reduced accordingly.

Implementation Guidelines. The pump speeds can be reduced by changing the size of the motor sheaves for indirect drive pumps; installing a lower-speed motor for direct drive pumps; changing the size of the pump impeller; or replacing the existing pumps with variable speed pumps.

Required Information. Survey the piping system to determine fluid flow rates and pump horsepower.

1.4.3 Reduce System Resistance

The flow characteristics of a particular system are determined by the lengths and sizes of the piping or ducting systems and by the sizes and shapes of fittings, such as bends and tees. Obstructions along the flow path, including filters, and scale buildup in pipes also contribute to flow resistance. The resistance to flow exerted by a system is the sum of the resistance of all its individual parts in the circuit.

ECO 66 - Clean Air Filters in Ducts

The resistance to air flow through filters is a function of filter construction, type of media, and area of media to unit volume ratio. In general, resistance to air flow increases with filter efficiency, although there are some high-efficiency filters that also have low resistance. A primary cause of filter resistance to air flow is dirty filters. Many filters lose their ability to trap particles when they become dirty. This results in dirty coils, decreased heat transfer to supply air, and longer system run times to satisfy space loads.

Implementation Guidelines. In addition to implementing a rigorous program of filter cleaning and maintenance, install a manometer across each filter to indicate when the filters should be changed. The possibility of using a lower resistance filter should be investigated.

Required Information. Determine the condition of existing filters. For dirty filters, note the pressure drop and design cfm of the system.

ECO 67 - Remove Scale from Water and Steam Pipes

Scale buildup in water and steam pipes increases flow resistance and reduces heat transfer at coils. Heat exchangers and coils exert a high resistance to flow and are especially prone to fouling by scale deposits and dirt.

Implementation Guidelines. Scale should be removed mechanically or chemically and flushed out of coils and heat exchangers. Institute a maintenance program for heat exchangers and a water treatment program for the piping system.

Required Information. Inspect heat exchangers and piping for signs of scale buildup. Estimate the thickness of existing scale. Changes in deposits over time can be monitored by periodically observing the system temperature and pressure drop under similar load conditions.

ECO 68 - Rebalance Piping Systems

When piping systems are first installed, the flows are usually balanced with the balancing valves closed to a greater extent than is needed, imposing extra head pressure on the pump. To reduce such resistance, the systems should be rebalanced.

Implementation Guidelines. The system should be rebalanced by first fully opening the balancing valve on the index circuit and the pump valves. Another method is to remove or change orifice plates in the pump circuits progressing from the longest to the shortest circuit. This is a trial-and-error process. Each valve adjustment will affect flow rates in circuits already adjusted, but two or three successive adjustments of the whole system will give good balance.

Required Information. Inspect the system to determine the extent to which balancing valves are closed and whether orifice plates are in use.

ECO 69 - Rebalance Ducting Systems

It is a common and wasteful practice to reduce the volume of fan air by closing down dampers on the fan inlet or outlet, rather than by reducing fan speed. The fan speed should be lowered and the duct system rebalanced to achieve correct volumes at each grill or register. The system should also be rebalanced if uneven heating and cooling are occurring in spaces controlled by individual thermostats.

Implementation Guidelines. The system should be rebalanced by first fully opening any dampers that are not used to redirect air flow between branches or outlets. Identify the index outlet and fully open any dampers between this outlet and the fan. Measure the volume at the index outlet and adjust branch dampers successively until proportional volumes are achieved at each outlet. This is a process of trial and error that may require two or three successive adjustments. This ECO is usually required if ECO 64 (reduced air flow in ducts) has been implemented.

Required Information. Determine to what degree spaces within zones are improperly conditioned.

ECO 70 - Design Ducting Systems to Reduce Flow Resistance

Flow resistance can be reduced by better design layout, use of low-friction components, and use of larger-size components.

Implementation Guidelines. Better design layout calls for replacement of existing ductwork to minimize length and corners. Using multiple fans in a multi-story building, for example, is one way to reduce duct length. This can be considered if major renovations are planned.

Existing duct components may be replaced with more energy-efficient ones. Low-pressure-drop components, such as energy-efficient filters, outside air louvers, supply air terminals, etc., are now available for use in ducts.

Required Information. Determine whether existing filters, louvers, and registers can be replaced with more efficient components.

ECO 71 - Install Booster Pumps

Pumps must develop enough head to overcome the resistance to flow through the longest, or index, circuit. If the resistance of the index circuit grossly exceeds resistance of other circuits, excess pump head is required.

Implementation Guidelines. A small booster pump should be installed for the index circuit and the head of the main pump should be reduced accordingly.

Required Information. Examine the existing piping system to determine whether a booster pump should be considered. The head of each circuit can be quickly estimated by examining the building drawings.

1.5 WATER HEATING SYSTEMS

In general, the heating and distribution of hot water consume less energy than space conditioning and lighting. However, for some buildings, such as hospitals, restaurants, kitchens, and laundries, water heating requires substantial energy consumption. Water heating energy is conserved by reducing load requirements, reducing distribution losses, and improving water heater performance.

1.5.1 Reduce Hot Water Loads

The hot water load requirement is a function of both the amount of hot water required and the temperature difference between the feed water and the supply water. Lowering the consumption rate, lowering the supply water temperature, or raising the feed-water temperature will reduce the hot water load.

ECO 72 - Reduce Hot Water Consumption

Reduced hot water consumption saves energy used to heat the water. A secondary benefit could be savings in the energy required to treat supply water and sewage, if such systems are present.

Implementation Guidelines. To lower the water consumption, restrict flow rate and usage by installing flow restrictors in the faucets, showers, etc. In some instances, use of timers is appropriate.

Required Information. Determine the number and flow rate of existing showers and faucets, and estimate building hot water consumption.

ECO 73 - Lower Hot Water Temperatures

Lowering the hot water temperature decreases the amount of energy required to heat the water. In addition, distribution piping losses, which are proportional to the temperature difference between the hot water and its surroundings, will be reduced.

Implementation Guidelines. Set the water heater thermostat at the lowest temperature at which hot water will meet the occupants' needs. If the demand for hot water fluctuates and a lowered tank temperature will not meet the peak demand, install a mixing valve rather than lowering the tank temperature. If the entire system is set at a high supply temperature to serve the needs of a piece of equipment, consider reducing the tank temperature and installing an booster heater to serve that specific piece of equipment. Note that water in excess of 138°F can cause skin burns.

Required Information. Determine the hot water consumption of the building, the existing supply temperature, and the minimum required supply temperature.

ECO 74 - Preheat Feedwater With Reclaimed Waste Heat

Waste heat from other building equipment processes (such as boiler flue heat, chiller condenser heat, cogenerator engine exhaust heat, etc.) should be reclaimed to preheat feedwater, thus reducing the hot water load. This is often a good application for heat reclamation, especially if the waste heat is not at a very high temperature.

Implementation Guidelines. Since the hot water load profile may not match the profile of the energy available for reclamation, a storage tank may be required.

Required Information. Identify a source of energy that can be reclaimed. Compare the available energy, temperature, and load profile of the reclaim source with the hot water requirements. Select an appropriate heat exchanger and storage tank.

1.5.2 Reduce Hot Water Heating System Losses

Thermal losses from a hot water system can occur from either the storage tank or the distribution piping system. These losses are proportional to the temperature difference between the hot water and its surroundings and to the resistance of pipes and storage tanks to heat flow. These losses can be reduced by lowering the hot water temperature (as discussed in the previous ECO) or by adding insulation.

ECO 75 - Insulate Hot Water Pipes

Pipe insulation is the most effective way to reduce losses in the hot water piping system.

Implementation Guidelines. Bare pipes should be insulated and damaged insulation should be repaired or replaced if the hot water system has a circulation pump. If no circulator is present, insulate the first 15 or 20 ft of pipe exiting the storage tank to reduce thermosiphon losses. Small pipes should be insulated with cylindrical half-sections of insulation with flexible cell material. Large pipes can be insulated with flexible material. If access to the pipes for servicing is required, rigid insulation (curved or flat segments or cylindrical half-, third-, or quarter-sections) offers an advantage. Fittings such as elbows, valves, and tees should be insulated with pre-formed fitting insulation, fabricated fitting insulation, individual pieces cut from sectional straight pipe insulation, or insulating cements (ASHRAE 1985).

Required Information. Measure the length and diameter of the hot water pipe to be insulated. Determine the temperatures of the hot water and the surrounding spaces.

ECO 76 - Insulate Water Storage Tanks

The heat loss from hot water storage tanks must be continuously offset by a supply of heat to maintain the hot water at its temperature setpoint. This heat loss can be a significant fraction of the total water heating load.

Implementation Guidelines. Insulate bare tanks or apply additional insulation to tanks that are not sufficiently insulated. Replace or repair all torn or missing insulation as required. Applicable insulation materials include flat blocks, beveled lags, curved segments, blankets, or mineral fiber-inorganic binders. Closed cellular insulation should be used for surfaces below 185°F (ASHRAE 1985).

Required Information. Determine the tank area to be insulated and the R-value of existing insulation, if any. Select insulation and note its R-value. Determine the temperatures of the hot water and the tank mechanical space.

1.5.3 Use Energy-Efficient Water Heating Systems

The efficiency of water heating systems can be increased in several ways. Decentralized water heaters eliminate distribution losses. Separate water heaters permit shutdown of the central plant. Heat pump water heaters and solar water heating systems can reduce water heating costs in some applications.

ECO 77 - Install Decentralized Water Heaters

Domestic hot water is often generated by central units and distributed throughout the building. A centralized system offers advantages, such as ease of maintenance and control, but also disadvantages such as distribution losses, storage losses, and difficulty in maintaining uniform water temperature. Decentralized water heaters operate only when needed and provide water at the required temperature.

Implementation Guidelines. If the bulk of the hot water is centrally generated and centrally consumed, remote areas that require extensive piping should be isolated from the central system and provided with smaller local water heating units. When different temperature requirements are met by a central hot water system, the temperature setpoint should be determined by the maximum usage temperature. Lower temperature water should be attained by mixing with cold water at the tap. Where higher water temperatures are required only at a few specific locations, separate booster heaters should be used. When the building system requires hot water for short periods of heavy use at various locations in the building, replace the central system and its long runs of piping with smaller hot water heaters located closer to the points of use.

Gas-fired instantaneous water heaters that eliminate storage losses by heating the water directly at the point of use should be considered for use as decentralized heaters. A water flow sensor ignites the pilot light and automatically turns the burner off after use. Water is heated as it flows through the heat exchanger located over the burner and then flows directly to the faucet.

Required Information. Estimate the hot water load and use schedule, and determine points of use. Calculate distribution losses within the current system.

ECO 78 - Use Smaller Water Heaters for Seasonal Requirements

In addition to space heating, boilers are sometimes used to supply domestic hot water. In the summertime, when the only load imposed on the boiler is the hot water load, the boiler operates at low part-load and at low efficiency. A smaller water heater should be installed for summer use, allowing the central boiler to be shut down.

Implementation Guidelines. When the heating boilers also provide heat for domestic hot water during the cool season and, as a result, fire at an efficiency below 60%, smaller hot water boilers should be installed.

Required Information. Estimate the load on the central boilers to satisfy the hot water needs.

ECO 79 - Use Heat Pump Water Heaters

Hot water is often provided through fossil-fired heating units or electric resistance water heaters. To reduce energy consumption, electric resistance water heaters can be replaced with heat pump water heaters. These water heaters operate on the same principle as space conditioning heat pumps. Condenser and/or desuperheater heat exchangers provide the required water heating capacity.

Implementation Guidelines. Two basic types of heat pump water heaters are available: desuperheaters and dedicated heat pump water heaters. Desuperheaters are integrated with the space conditioning heat pumps. They generally offer good payback and low investment requirements; however, hot water is provided only when there is a call for space heating or cooling. If the existing space conditioning and water heating equipment are scheduled to be replaced, a heat pump with a desuperheater system should be considered to satisfy both end uses.

As their name implies, dedicated heat pump water heaters are stand-alone units, not integrated with the space conditioning equipment. They are moderate in cost and easy to install. They provide hot water on demand and minimal free localized cooling in the summer. If the existing water heating unit is scheduled to be replaced, the installation of dedicated heat pump water heaters should be considered.

Required Information. Determine the existing hot water requirements, energy type, and cost.

ECO 80 - Heat Water with Solar Energy

Solar water heaters use solar energy to supply the heat for service hot water. The energy efficiency of the solar water heaters depends on the climate and location. The annual solar fraction, which is the annual solar contribution to the water heating load, generally ranges from 30% to 80%, although more extreme values are possible (ASHRAE 1987).

Implementation Guidelines. An active solar water heater is made up of a variety of components including solar collectors, heat transfer fluids, thermal energy storage units, heat exchangers, expansion tanks, pumps/fans, systems piping, valves and gauges, control systems, and auxiliary heat sources.

Most solar water heating system components and their installation details are the same as those in the conventional water system, except for the solar collectors. Collectors should be placed as close to the storage tanks as possible to reduce piping costs and heat losses. The collector must be installed such that all fluid can be drained completely. For best annual performance, the collectors should be installed at a tilt angle, equal to the local latitude, above the horizontal. They should be oriented towards true south, not magnetic south.

There are two types of solar water heaters: direct and indirect. In direct water heating systems, the potable water is directly heated in the collector. In indirect water heating systems, potable water is heated by the collector working fluid through a heat exchanger. Commonly used working fluids include water, non-freezing fluids, and air. The fluid is transported by either natural or forced circulation. Natural circulation takes place via natural convection (or thermosiphoning), whereas forced convection needs pumps or fans. Forced circulation systems are controlled through differential thermostats.

The following six systems are commonly used:

- thermosiphon systems
- recirculation systems
- drain-down system
- drain-back system
- indirect water heating system
- air system.

Required Information. Determine the hot water capacity requirements and supply temperature. Determine whether there is a solar collector location at the building site.

1.6 LIGHTING SYSTEMS

Lighting accounts for a significant fraction of electrical energy consumed in a building. Energy is saved and electric demand is reduced by reducing illumination levels, improving lighting system efficiency, curtailing operating hours, and using daylighting. Reduction of lighting energy can also increase building heating consumption and decrease building cooling consumption, since internal heat gains are reduced. However, heat-of-light is an expensive method of heating a building. If the building cooling plant is to be replaced, implementation of lighting ECOs will reduce the required plant size.

1.6.1 Reduce Illumination Requirements

Electrical energy consumption, and in many cases, demand charges can be reduced by reducing illumination levels. This reduction in energy consumption is accomplished by cleaning and maintaining lighting systems, reducing operating time, and task lighting.

ECO 81 - Clean and Maintain Systems

The light output of a lighting fixture can decrease over time. Heat can cause lighting fixture lenses to yellow. Dirt can build up on lenses, reflectors, and the lamps themselves. Impurities from cigarette smoke accumulate on lenses and reflectors, further reducing light output. Some types of lamps, such as fluorescent tubes, lose light output (lumens/watt) as they near the end of their useful life. Decreased light output from older fixtures combined with an accumulation of dirt on lenses can reduce light output by 20% to 40% over time.

The first step in reducing illumination requirements is to ensure that the existing system is producing maximum attainable lighting.

Implementation Guidelines. Fixture lenses and reflectors should be cleaned periodically. A convenient time to do this is when lamps are replaced. Permanently yellowed lenses or faded reflectors should be replaced. In areas such as corridors, storerooms, equipment rooms, and rooms with high ceilings, some glare from lamps is acceptable. In such areas consider removing louvers or lenses from fixtures. Consider replacing all fluorescent tubes in a building area at the end of their rated useful life, rather than when they burn out. This is more cost-effective from a maintenance standpoint. The lamps that are removed can be discarded or used in maintenance areas until they burn out.

Required Information. Survey the existing lighting system to determine the quantity and type of fixtures and lamps in use in the building. Inspect fixtures for sign of dirt and discoloration. Measure lighting levels on selected work surfaces and in circulation areas. Compare measured values with required values. Clean several fixtures and/or replace discolored lenses and reflectors. Note any change in light output. With properly maintained fixtures, determine what percentage of lights could be removed without affecting light levels.

ECO 82 - Reduce Illumination Levels

During the 1950s and 1960s, building illumination levels rose dramatically. Many spaces were lit two or even three times more than required. Required lighting levels by task can be found in the IES Lighting Handbook: Application Volume (Kaufman and Haynes 1981). Reducing illumination levels saves both energy and demand charges.

Implementation Guidelines. Lighting levels can be reduced by installing lower wattage lamps or removing selected fixtures. For fluorescent fixtures, both power consumption and light output can be reduced by retrofitting energy-conserving ballasts. In most instances, two lamps can be removed from four-lamp fluorescent fixtures. Socket attachments can be purchased to control the remaining two lamps. Parabolic reflectors can be installed to maximize light output. Forty-watt tubes can be replaced with 32- or 34-watt tubes.

Incandescent spotlights can be replaced with lower wattage elliptic reflector lamps and lamp extenders. Screw-in fluorescent lamps, rated at 18 watts, offer additional savings. Exit signs can be retrofitted with fluorescent fixtures.

Remove as many lamps as possible. When removing fluorescent or HID lamps, also remove or disconnect the ballast to prevent them from continuing to consume energy.

Required Information. Task requirements, expected duration of tasks, possible future relocations, the quality of illumination and the frequency with which tasks may change should be carefully analyzed. Existing light levels need to be measured in the spaces being considered for improvements in efficiency. Light levels in standard footcandles can be determined with a portable illumination meter. Generally, measurements refer to average maintained horizontal footcandles either at the level of the task or in a horizontal plane 30 in. above the floor. Measurements should be made at any representative point between and under fixtures. An average of several readings may be necessary. Daylight should be excluded when readings are being taken.

ECO 83 - Reduce Time of Operation

One of the best ways to save energy is to turn off lights that are not needed. This saves energy, as well as extends the replacement time on lamps.
(While frequent switching may in some cases shorten lamp life, the savings in electrical power will more than compensate.)

Implementation Guidelines. The operating time of lighting systems can be reduced either automatically or manually. Automated controls are more reliable for ensuring that energy savings are achieved. Local switches can be labeled to encourage occupants to turn off lights when leaving an area. Individual switches in perimeter offices permit occupants to reduce lighting levels on sunny days. Control systems are now available that sense the presence of occupants and turn off lights automatically. Sophisticated lighting control systems are available, but they are costly to retrofit. They should be considered when the lighting system is being replaced. With the exception of security lights, storeroom lighting can be placed on timed switches that shut off after the selected interval. All exterior lighting, as well as interior lighting in glass-enclosed vestibules, should be placed on photocell and/or timer control.

Cleaning crews should be instructed to turn on lights only in the areas in which they are working.

Required Information. Survey the building to determine the use schedule for existing lights. Determine the wattage and the number of hours per day for which usage can be curtailed.

ECO 84 - Use Task Lighting

Many building spaces are lit to a uniformly high level. A lighting pattern that throws light equally on all areas regardless of task may waste up to 50% of the energy used for lighting in a building. In addition to being more energy efficient, it is often aesthetically pleasing to reduce lighting for circulation areas, with more intense lighting directed to the work surfaces.

Since lighting levels decrease as the square of the distance from the light source, a 30-watt fluorescent desk lamp can provide as much illumination on a desk surface as 200-300 watts of ceiling-mounted light. Consider lowering the ceiling lights. The energy saved by dropping the mounting height of a ceiling fixture from 14 ft to 9 ft in a 30 ft x 40 ft space, while maintaining the same illumination level, would be 10% of the annual energy presently consumed for lighting the same area. If lighting located in the ceiling cannot be lowered, fixtures should be positioned over work surfaces, at a minimum.

Reducing the connected lighting load will decrease both kWh consumption and demand changes.

Implementation Guidelines. Lighting levels should be maintained according to the task being performed. See Kaufman and Haynes (1981) for a more detailed discussion of task lighting. Offices should have higher lighting levels over desks than over files or seating areas. Circulation lighting levels can often be reduced. Storage and filing areas should have lights located above the aisles. Lights over library book stacks can be disconnected. Lighting in areas where computer terminals are in use should be positioned to minimize glare. In areas such as kitchens or shops, lamps should be positioned to avoid casting shadows on work surfaces.

Required Information. Survey building areas by function, installed wattage and lighting level. Determine which wattage can be removed and its operating schedule.

1.6.2 Install Energy-Efficient Lighting Systems

Lighting energy consumption can be reduced by using more efficient lamps, more efficient lighting sources, high-efficiency ballasts, lens removal or replacement delamping, or by reducing the wattage of existing luminaires.

Use of energy-efficient lighting sources will reduce both electrical consumption and demand charges. The reduction in internal heat gain will increase the building heating load and decrease the building cooling load.

ECO 85 - Use High-Efficiency Fluorescent Lighting

Fluorescent lighting is recommended for areas where color sensitivity is an important criterion (e.g., offices or small parts assembly rooms). Fluorescent tubes are currently available that produce a higher light output (more lumens per watt) than standard fluorescent tubes. There are efficient 40-watt lamps that produce 8% to 10% more light than standard lamps. The 34-watt fluorescent tubes use 15% less power than standard lamps, while producing about 8% less light. Since the human eye responds to light exponentially, rather than linearly, the difference is often unnoticeable. "T8" fluorescent lamps use only 32 watts, but existing fixtures must be replaced.

Screw-in fluorescent lamps are available to replace incandescent lamps. Power savings are typically 60%. Screw-in self-contained lamps, with a 10,000-hour life, can replace flood lights that have a 7,000-hour life. Screw-in circle light fixtures are also available. Finally, there are 13-watt fluorescent fixtures designed to fit inside exit signs.

Implementation Guidelines. When relamping a fluorescent fixture, replace all lamps. Never mix energy-efficient and standard lamps with the same ballast. Ensure that the fluorescent ballast is compatible with the energy-efficient lamps. Typically, energy-efficient fluorescent lamps will not start below 50°F and should not be used in marginally heated spaces. Energy-efficient fluorescent lamps may cause premature failure of ballasts that are near the end of their useful life. Screw-in fluorescent lamps are generally not compatible with dimmers.

New energy-efficient fluorescent lamps are continually being introduced. It is important to stay abreast of this technology so that the most efficient products may be used.

Required Information. Survey existing lighting levels and determine the total number of lamps that can be replaced. Calculate the wattage reduction and determine the operations schedule of the fixtures to be relamped.

ECO 86 - Use High-Pressure Sodium Lighting in Selected Areas

High-pressure sodium lamps produce 125 lumens/watt, compared with the 75 lumens/watt of mercury vapor lamps. They also produce a fuller light spectrum, improving nighttime visibility. High-pressure sodium lamps are typically used for warehouses and outdoor and parking lot lights. They can be used as indirect lighting sources in office areas; however, they must be mixed with other HID lighting sources to provide proper color rendition. Their use indoors may also require that ceiling and/or wall colors be changed to improve light quality.

Implementation Guidelines. High-pressure sodium lamps should be considered for use in non-critical areas that are currently lit by incandescent flood lamps or less efficient HID lighting sources. Eighteen-watt wall-mounted units are available (such units draw 30 watts, including the ballast) that can replace wall-mounted incandescent flood lights. Lamps are available in sizes up to 400 watts. Use of high-pressure sodium lamps typically requires ballast replacement when retrofitting other HID sources and fixture replacement when retrofitting incandescently lighted sources.

Required Information. Determine the wattage and schedule of existing lights that are to be replaced. Select replacement luminaires and calculate the wattage savings.

ECO 87 - Install Low-Pressure Sodium Lighting in Selected Areas

Low-pressure sodium lamps produce 175 lumens/watt. They are the most efficient lighting source currently available. However, their lighting quality is not considered to be as good as high-pressure sodium lamps. Low-pressure sodium lamps are typically used for street lighting and for nighttime security.

Implementation Guidelines. Low-pressure sodium lamps should be considered when replacing incandescent and lower-efficiency HID lighting sources in non-critical areas. Use of low-pressure sodium lamps will require that fixtures be replaced.

Required Information. Determine the wattage and schedule of existing lights that are to be replaced. Select replacement luminaires and calculate the wattage savings.

ECO 88 - Install High-Efficiency Ballasts

The power consumption of fluorescent lighting systems can be reduced by retrofitting high-efficiency ballasts. High-efficiency ballasts last twice as long as standard ballasts, and, because they burn at such high frequencies, ballast hum and lamp flicker are virtually eliminated. For example, electromagnetic ballasts reduce the power consumption of two 40-watt lamps and a standard ballast by 12 to 13 watts. The more costly electronic ballasts reduce the power consumption of two 40-watt lamps and a standard ballast by 24 watts. Electronic ballasts that can power four 40-watt lamps are also available. Similar savings are available for other sizes of fluorescent lamps.

Implementation Guidelines. Implement a building management policy of installing high-efficiency ballasts as existing fluorescent ballasts reach the end of their useful life. Replacement of ballasts not at the end of their useful life must be evaluated based upon utility rates.

Required Information. Determine how many ballasts are to be replaced. Select a compatible replacement ballast. Calculate the total wattage reduction, and then determine the lighting operating schedule.

ECO 89 - Remove or Replace Lenses

Yellowed and/or inefficient lenses restrict light output. New, efficient lenses pass more of the light into the space, eliminate glare, and diffuse the light more uniformly throughout the space.

Removal of lenses produces maximum light output and may be more beneficial than operating with degraded lenses; however, light distribution is less uniform throughout the space. When the lenses are removed, the light fixture loses more heat. Since lamps must maintain an operating temperature to operate properly, power consumption of fluorescent lighting systems will increase. The power consumption increase for two 4-ft lamps is approximately 6 watts.

Lens removal or replacement can be accompanied by delamping to maintain existing lighting levels and save energy. See ECO 81 regarding fixture maintenance.

Implementation Guidelines. The preferred approach is to replace degraded or inefficient lenses with efficient lenses before delamping is evaluated. Lens removal should only be considered if the increase in light output outweighs the increase in power consumption and if light distribution and glare without lenses is acceptable.

Required Information. Determine how many fixtures will be retrofitted with new lenses or will have lenses removed. To evaluate the efficiency of lenses in existing fixtures, refer to the manufacturer's coefficient of utilization (CU). Compare the CU of the present lens with that of the proposed replacement. Light levels should improve in direct proportion to the improvement in CU. Refit one fixture and measure the change in light output. If the lens is removed, also measure the power consumption before and after lens removal. Determine how many fixtures can be delamped or disconnected as a result of lens removal or replacement and the wattage and operating schedule of the delamped fixtures.

1.6.3 Use Daylighting

Natural light is particularly effective as a primary source of illumination in perimeter spaces. Daylighting requires proper design, otherwise the cooling required to offset the solar heat gain may outweigh savings in energy for lighting. However, since daylighting generates less heat per lumen of light than most electrical lighting, less demand may be imposed on the cooling system. Painting the surface that first reflects light from the window in a white or light pastel shade is a minor retrofit that will increase the illumination from daylighting.

ECO 90 - Install Dimming Controls with Windows

Lighting systems can be retrofitted with dimming controls that sense lighting levels and dim interior lighting when sufficient natural light is present. Care must be taken to ensure that the lighting system is compatible with dimming controls. Because illumination decreases as one moves away from the windows, electric or artificial lights should be layered parallel to the window plane so that rows of lights can be dimmed as needed. Dimming controls are available with either stepped or continuous dimming. They are normally equipped with time-delay relays to prevent excessive operation on partly cloudy days.

Peak demand savings may not occur because the required natural light is not always available. However, if dimming controls are also used to reduce lighting to acceptable levels, then peak demand will be reduced.

Implementation Guidelines. Dimming controls are often difficult and expensive to retrofit in existing buildings. They should be considered whenever a lighting system retrofit is contemplated and there is a significant amount of perimeter lighting.

Required Information. Measure lighting levels (both with lights on and off) in perimeter spaces for all building orientations. Determine natural lighting levels on clear and cloudy days. More light is available in summer; therefore, if the natural light in winter is significant, this ECO should be evaluated.

ECO 91 - Install Dimming Controls with Skylights

If a building has interior skylights, the natural light they provide can be used in place of artificial light. Two of the most common problems associated with skylights are heat gain and glare. Techniques for mitigating the effects of heat gain and glare include translucent white glazing; tinted or reflective film on the skylight; prismatic or diffusing lighting lenses or a reflector below skylights; an overhang above the skylight.

The installation of skylights should be considered especially if the building needs reroofing, as the cost of installation would be lowest at that time.

This ECO is implemented in a manner similar to ECO 90.

1.7 POWER SYSTEMS

The ECOs discussed in this section deal with reducing electric power distribution losses, improving motor efficiency, and reducing peak power demand.

1.7.1 Reduce Power System Losses

The inefficient operation of power systems stems mainly from a low power factor, which is caused by unbalanced loads on three-phase power systems. Certain electrical equipment with inductive characteristics can also contribute to a low power factor. Low power factors can be improved with power factor correction devices. Additional savings can sometimes be achieved by retrofitting energy-efficient transformers.

Note that power factor correction is generally more applicable in industrial facilities than in commercial buildings. Power factor correction is cost-effective when utility penalties are imposed.

ECO 92 - Correct Power Factors

The power factor is the ratio of actual power (kW) to apparent power (kva). A low power factor increases losses in electrical distribution and utilization equipment such as wiring, motors, and transformers. It also reduces the load-handling capacity and voltage regulation of the building electrical system. At a power factor of unity, losses are at a minimum. When a power factor is below a designated level (e.g., 70% to 80%), utilities often impose additional penalty charges. A lightly loaded motor is the best candidate for savings from installation of a device to correct its power factor.

Implementation Guidelines. Capacitors are the least expensive method of reducing the reactive power of the system. Capacitors can be installed at any point in the electrical system. They improve the power factor between the point of application and the power source. They can be added to each piece of offending equipment, ahead of groups of small motors, or at main services. For 1 to 60 kvac capacitance, one capacitor should be installed. For more than 60 kvac, banks of capacitors are required.

Synchronous condensers and synchronous motors are also potential solutions; however, there are disadvantages associated with each. Synchronous condensers are the most expensive solution to the problem and small synchronous motors are not practical in most commercial buildings.

In addition, NASA has developed a power factor controller to improve energy efficiency in induction motors. The power factor controller measures the difference in phase angle between voltage and current (i.e., power factor) and optimizes the torque of the motor by reducing the voltage. It may reduce electricity consumption by 30% for lightly loaded, single-phase, low-efficiency motors. However, the power factor controller is not economical for more heavily loaded motors, high-efficiency motors, or three-phase motors. In general, greater savings may be achieved by replacing low-efficiency motors with high-efficiency motors (see ECO 95), rather than installing a power factor controller (NCEL 1981 and 1984a).

Required Information. Survey existing motors, recording horsepower, kW under steady load, power factor, and operating schedule.

ECO 93 - Install Energy-Efficient Transformers

Most dry-type transformers range from 93% to 98% efficiency with losses deriving from the cores (magnetizing) and coils (resistance and impedance). Even when equipment served by the transformer is not operating, some energy is lost in the standby mode unless the primary power to the transformer is switched off.

Implementation Guidelines. To reduce the energy lost in the transformers:

- Select the most energy-efficient transformers (i.e., lowest temperature rise ratings) for replacement.
- If large liquid-filled transformers are required for new additions, select those with the highest efficiency.
- Disconnect from primary power the transformers that do not serve any active loads. (Avoid disconnecting transformers feeding clocks, heating control circuits, fire alarms, and other critical equipment).

Required Information. Determine whether any existing transformers are at or near the end of their useful life. Determine whether any large transformers can be disconnected during unoccupied hours.

1.7.2 Install Energy-Efficient Motors

Electric motors consume significant amounts of electrical energy to operate fans, pumps, compressors, etc. Considerable energy can be saved by replacing the existing motors with smaller and/or higher-efficiency motors or by installing variable-speed motor drives.

ECO 94 - Replace Oversized Motors

Because original load estimates for a building's mechanical equipment are usually conservative, most motors are oversized for the equipment loads they serve. When energy conservation measures reduce equipment loads, problems with oversized motors increase. Decreased load factors of oversized motors result in degraded power factors and reduced efficiency. Generally, motor efficiencies drop off sharply below half-load.

Implementation Guidelines. The motor's part-load running current should be measured with an ammeter. To find the load factors, the measured current is divided by the rated full-load current shown on the motor name-plates. Figure 1.12, which shows the typical variations of percent motor efficiency as a function of the motor load, should be used to estimate the motor efficiencies. The motors that are not loaded to at least 60% of their potential should be considered for replacement.

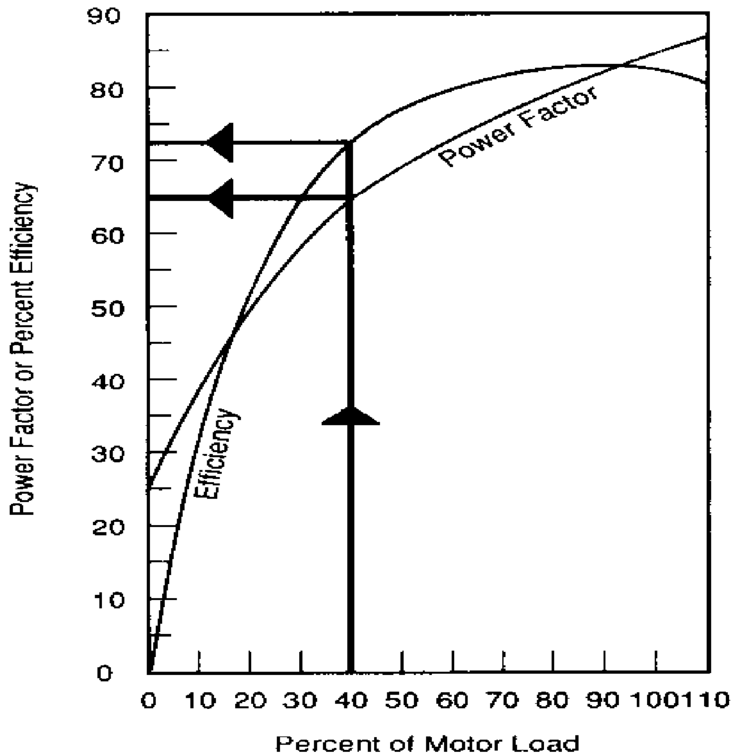

FIGURE 1.12. Percent Motor Efficiency as a Function of Motor Load (DOE 1980)

The characteristics of replacement motors should match those of the electrical distribution system as closely as possible. When available motors do not exactly match system voltage, the replacement selected for motors loaded to 75% or less of their capacities should be rated slightly higher than system voltage; for motors loaded to above 75%, the replacement motor should be rated slightly under system voltage.

Required Information. Survey existing motors to determine motor efficiency.

ECO 95 - Use High-Efficiency Motors

High-efficiency motors will perform the same function as standard motors, but will improve efficiency by reducing losses in the conversion of electrical to mechanical energy. For example, magnetic losses are reduced by using thinner, higher quality steel lamination in the stator and rotor core. The air gap between rotor and stator is minimized by manufacturing to higher tolerances. More copper is used in the stator windings to reduce resistive losses. On motors with fans, smaller and more efficient fans are used (Usibelli et al. 1985)

Implementation Guidelines. The best applications are generally those in which the motor operates at least eight hours or more per day (NCEL 1983a). In some cases, the savings in electrical energy consumption justifies immediate replacement. However, high-efficiency motors are not cost-effective when their premium cost cannot be recovered during the normal life of the motor because of limited hours of operation.

Required Information. Survey existing motors to determine the potential for efficiency improvement and determine the motors' daily operating hours.

ECO 96 - Use Variable Speed Motors

Variable speed drives save energy by sensing the load requirements and changing the motor's power and speed to meet these requirements.

Implementation Guidelines. There are two types of variable speed drives: mechanical and electronic. Mechanical variable speed drives consist of either magnetic clutches or variable ratio belt drives that allow the motor to run at a constant speed, while the motor-driven equipment speed varies. Electronic variable speed drives adjust the speed of the motors they control by electronically varying the input voltage and frequency to the motor. Both systems have enormous conservation potential. The electronic drives are more energy efficient than the mechanical, but are also more costly (Usibelli et al. 1985).

Centrifugal devices are the best candidates for variable speed drives. Centrifugal fans and pumps for water, sewage, refrigerant, and air are typical applications. Centrifugal devices whose flow rates and pressures are normally controlled by throttling can be replaced with variable speed drives. The more operating time below full load, the greater the payback potential of variable speed drives (NCEL 1984c).

Required Information. Survey existing centrifugal devices to determine which items operate for considerable periods of time below full load.

1.7.3 Reduce Peak Power Demand

Electric utility charges are typically based on some combination of electric energy consumption and power demand. The electric energy consumption is the total electric energy usage, read by a watt-hour meter in kWh. The power demand is the load integrated over specified time intervals of 15, 30, or 60 minutes, as determined by the utility. The peak demand is the maximum value of demand in kW measured during a billing period. Charges based on peak demand allow a utility to recover its capital investment in generating and distributing equipment used to meet the maximum demand for electric power. A high demand for just one demand interval can raise the demand charge for the entire billing period; therefore, controlling peak demand is an important strategy.

The peak power demand can be reduced by load-shedding, cogeneration, or cool storage systems that produce cold water or ice during off-peak hours. Load-shedding may also reduce the total power consumption as well as the demand. Cogeneration systems will increase the use of onsite energy, but can replace electricity consumption with less expensive fossil energy. Also, the waste heat from the cogeneration equipment can meet thermal loads. Cool storage systems shift the chiller demand to off-peak periods, reducing on-peak demand.

Evaluation of these ECOs requires determination of the building demand profile. Several weeks of data in 15-minute intervals should be taken with a recording meter. The measurements may have to be taken both in the cooling and heating season. Most electric utilities will provide this service at a nominal charge.

ECO 97 - Use Load-Shedding

The purpose of the load-shedding (or demand-limiting) program is to keep the peak power demand level below a predetermined limit by shedding, or disconnecting, nonessential loads during the peak demand period.

Implementation Guidelines. Both the utility rate structure and the times of peak demand should be analyzed. The peak demand analysis should identify when the equipment must be in operation, as well as when it can be disconnected without impairing the safety of occupants or equipment. Establish a manual or automatic load-shedding program to shut these loads down. Note that a manual program may not be effective.

Peak loads that cannot be predicted should be monitored. Equipment operation can be programmed to automatically de-energize selected loads at peak demand and to reactivate them when reduced demand permits. Available automatic load-limiting devices range in complexity from a simple thermal sensor to a unit that reads current and provides for shedding and restoring loads. Automatic load-shedding is also commonly accomplished with a watt-hour meter combined with time switches and load controllers.

Required Information. Determine the building's electric demand profile. Survey existing equipment to determine which loads can be shed and at what time periods without interfering with building operations. Select a load-shedding device that can accomplish this task.

ECO 98 - Install a Cogeneration System

Cogeneration systems generate electricity onsite and provide waste heat that can be recovered for space conditioning and/or water heating. Cogeneration systems can handle selective or peak capacity loads, or they can satisfy all site power requirements, in which case they are often referred to as total energy systems. In addition to reducing the peak loads, a cogeneration system can also be actively tied to the utility grid on a contractual basis and exchange power with the public utility. Such an arrangement lessens the need for redundant onsite generating capacity and allows the system to operate at maximum thermal efficiency (ASHRAE 1987).

Implementation Guidelines. The basic components of a cogeneration plant are prime movers, generators, waste heat recovery systems, control systems, electrical and thermal transmission and distribution systems, and connections to mechanical and electrical services. For a detailed discussion of each component, refer to Chapter 8 of the 1987 ASHRAE Handbook: HVAC Systems and Applications (ASHRAE 1987). The waste heat recovery systems are characterized under the section on heat reclaim systems.

Before an in-depth evaluation of cogeneration systems is initiated, consider the following criteria to determine whether the project is economically feasible:

- a high, fairly constant, annual energy demand for both electric power and waste heat
- fuel costs that are competitive with prevailing utility company electric rates
- heating and cooling (waste heat) demands that parallel electric power demands.

Multiple generator installations should be designed so that each generator system can be totally serviced and repaired without affecting the other units in operation. If a single generator system is used, arrangements should be made for an outside standby source of energy during maintenance or in case of a breakdown. Maintenance will be a significant cost item to include in the total energy system life-cycle analysis, even with the fully-automated systems. Sound shielding, particularly when a system is used in residential installations, is mandatory, as is air intake silencing. A cogeneration system with a high thermal efficiency can be a costly and complicated installation, but groups of buildings that individually reach peak loads at different times would be an ideal application.

Required Information. Determine the building electric demand profile and building annual heat load requirements.

ECO 99 - Install a Cool Storage System

Many utilities experience peak system demand in the cooling season. To encourage power conservation during this time, utilities often have peak rates that are higher than the off-peak rate (NBS 1984a). Because conventional cooling systems are designed to meet the cooling load at the time of cooling demand, the highest cooling loads generally coincide with a utility's peak hours. Cool storage systems level out or eliminate peak cooling loads by running the cooling equipment during off-peak periods, often at night. Cold water or ice is produced and stored for use in space cooling during peak periods.

Implementation Guidelines. Thermal storage tanks are the key component of a cool storage system. These are expensive to build and install, and they use up valuable space in most installations. Care should be taken to size the tank volume, based on the following factors:

- cooling equipment off-time

- cooling equipment load profile

- thermal solution temperature mixes

- tank design temperature drop (NEBB 1985).

The most common cool storage media are water and ice. An ice system requires a smaller storage tank than a chilled water system. However, the efficiency of the cooling equipment is lower because of the low evaporator temperature required to make ice. Also, the chiller must be capable of producing ice.

Required Information. Determine the size and duration of the building's cooling load peak. Use this information to determine the thermal storage requirements. The type of system and size of the storage tank should be selected based upon storage requirements, equipment performance and costs, and space considerations.

1.8 MISCELLANEOUS

This category of ECOs addresses energy management and control systems (EMCS) and heat reclaim systems. Energy is saved by automating the control of energy systems or by reclaiming waste heat that would otherwise be rejected.

1.8.1 Use Energy Management and Control Systems

Rising energy costs and decreasing prices for computers and microprocessors have encouraged the use of EMCSs. An EMCS can efficiently control the heating, ventilating, air-conditioning, lighting, and other energy-consuming equipment in the building. It selects optimum equipment operating times and setpoints as a function of electrical demand, time, weather conditions, occupancy, and heating and cooling requirements. The basic control principles for building energy conservation are

- operate equipment only when needed

- eliminate or minimize simultaneous heating and cooling

- supply heating and cooling according to actual needs

- supply heating and cooling from the most efficient source (ASHRAE 1987).

About 100 companies manufacture EMCSs, and new technology is constantly being developed. Potential users of EMCS should be thoroughly familiar with current marketplace offerings.

An EMCS may consist of individual self-contained controls mounted near the controlled loads. The controls can be programmed remotely or with a removable programming device. An EMCS is useful for controlling buildings that have a stable occupancy schedule and seldom require changes to the equipment operation once it is set up. The remote systems can be linked into a central system where the building is monitored and controlled from an operator's console. Centralized control systems are generally used in buildings or clusters of buildings that have an O&M staff or an operating requirement that changes frequently (NCEL 1982). Centralized control systems often involve significant investment, and the following guidelines should be observed before implementation:

- A good central control system should easily accommodate change to enable future modifications.

- The system justification must include an ample allowance for maintenance, support of mechanical and electrical system modifications, software support, and continuous improvements as system and operational needs become apparent.

- All portions of the system must be fully documented so that the system can be expanded and maintained by qualified personnel.

- Staffing is important when a centralized control system is complex; at least one full-time employee is necessary to ensure that the system works properly.

The many functions of modern building EMCSs are usually distributed among a number of computer processors. The EMCS software ranges from programs designed to supervise the operation of a wide variety of equipment and facilities to those that perform continuous, closed-loop control of individual devices. The implementation of control programs depends on the job requirements and system architecture. An application should be thoroughly analyzed before a new control strategy is implemented (ASHRAE 1987). The following subsections describe some EMCSs that should be considered for implementation.

ECO 100 - Install a Temperature Setup/Setback Control System

Turning off energy-consuming systems when they are not needed is the most basic energy conservation technique. When a building is occupied intermittently, energy savings can be realized by minimizing the time the heating or cooling system is operated when the building is closed. Building control algorithms should be implemented to delay startup until the last moment and to shut down as early as possible.

Implementation Guidelines. Because of the thermal inertia of both the building structure and its heating and cooling equipment, a preheat or precool time is almost always required to raise or lower the space temperature to the desired level before the occupants return. This start-up time depends on the outdoor environment, the thermal response of the building, and the thermal performance of the space conditioning equipment. Similarly, the thermal inertia of the building maintains the indoor temperature at a comfortable level for a short period of time after the equipment is shut off. It allows the system to be turned off before the end of an occupied period. An optimum start/stop control accounts for these factors.

A report by the National Bureau of Standards, An Optimum Start/Stop Control Algorithm for Heating and Cooling Systems in Buildings, introduces a simple optimum start/stop algorithm that has been developed for digital control of the heating and cooling systems (NBS 1983a).

Required Information. Determine which building systems can be controlled by setback/setup and what the operation schedule for each system should be.

ECO 101 - Install a Time-of-Day Control System

Time-of-day control is basically a timeclock function in which equipment is operated by controls that start and stop operation at predetermined times of the day on selected days of the week. This ECO is usually applied to shut a building down during unoccupied periods in order to save the energy that would otherwise be used to operate building equipment. The same type of control can be used to turn on equipment before the building is to become occupied.

Implementation Guidelines. Events initiated by time-of-day control may be as simple as starting or stopping equipment such as pumps, fans, compressors, or lights. However, the control is capable of functions as complex as a start-up sequence to turn on multiple fans with delays of five seconds between the starting times of the fans.

A time-of-day control algorithm is described in a report by the National Bureau of Standards entitled Time-of-Day Control and Duty Cycling Algorithms for Building Management and Control Systems (NBS 1983b).

Required Information. Survey building systems and required operating schedules to determine items that can be adapted to time-of-day control.

ECO 102 - Install a Duty-Cycling Control System

Duty-cycling is used to reduce energy consumption by periodically shutting down equipment that is not essential to the building environment or to critical building functions.

Implementation Guidelines. Duty-cycling should be applied to equipment such as fans and pumps. The use of duty-cycling on fans and pumps is justified because heating and cooling equipment are generally sized for peak design conditions. At off-design conditions, the full flow provided by a fan or pump is often not required to maintain space conditions.

Opinions differ as to the long-term effects of cycling on starters, bearings, and fan belts. More current is generally required to start equipment than to operate it. To be used for duty-cycling, the equipment should have sufficient capacity to return conditions to normal levels after any drift that may occur when the equipment is off.

A duty-cycling control algorithm is described in a report by the National Bureau of Standards, Time-of-Day Control and Duty Cycling Algorithms for Building Management and Control Systems (NBS 1983b).

Required Information. Determine which building systems can be duty-cycled, and estimate the percentage of duty-cycling.

ECO 103 - Install a Supply Air Temperature Reset Control System

Depending on the specific system, an air-handling unit may have one or two supply air conditions that must be maintained. Variable air volume (VAV) or reheat systems have only one supply air condition which is selected to match the space load. For multizone or dual duct systems, there is a hot deck and a cold deck supply air setpoint. The supply air condition must be selected both to match the space loads in the zones supplied and to minimize reheat and recool. The use of fixed design setpoints for air supply temperatures is an easy approach, but can result in energy loss through reheating or recooling of air, either by mixing of the hot and cold airstreams or by using terminal boxes to reheat the air at the entrance to each zone. Supply air reset is a method of changing the setpoints of the supply air to minimize system energy consumption by matching system output to the space load.

Implementation Guidelines. Some reset controls use outdoor air temperature as a load indicator, while others directly or indirectly measure the actual space heating and cooling requirements. The drawback to the use of outside air as an indicator is that it has no feedback to the control system to allow the system to sense if all zones are being sufficiently conditioned without waste. Table 1.31 (NBS 1984a) summarizes strategies for determining the methods to correct the setpoint to minimize energy consumption for different HVAC systems.

For detailed discussions of supply air reset and sample algorithms, refer to a report by the National Bureau of Standards, Control Algorithms for Building Management and Control Systems--Hot Deck/Cold Deck/ Supply Air Reset, Day/Night Setback, Ventilation Purging, and Hot and Chilled Water Reset (NBS 1984a).

Required Information. Determine which systems are adaptable to reset control, and select an appropriate control system. Determine the existing temperature setpoints.

ECO 104 - Install a Hot/Chilled Water Supply Temperature Reset Control System

HVAC equipment is usually sized to meet conditions at the design peak load. Coil water temperature setpoints are also chosen to meet the design load. However, during most hours of operation, the equipment operates at part-load. Use of design setpoints on water loops at part-load results in

TABLE 1.31. Supply Air Reset Criteria for Various System Types (NBS 1984a)

System Type	Zone Choice	Method
Mixing hot and cold air		
Hot deck	Largest hot deck	Lower setpoint if hot deck damper openingdamper not fully open. Raise if full open.
Cold deck	Maximum cold deck damper opening	Raise setpoint if cold deck damper not fully open. Lower if full open.
Reheat	Smallest amount of reheat (small percent of maximum capacity)	Raise setpoint to minimize reheat. Lower setpoint if reheat almost never on.
Packaged or unitary equipment and central air		
All zones heating	Smallest percent of maximum local heat	Raise setpoint to minimize heating.
All zones cooling	Smallest percent of maximum localcooling.	Lower setpoint to minimize cooling
Some zones cooling, some zones heating	Smallest percent of maximum cooling if winter, smallest percent of maximum heat if summer (or zone with most expensive local conditioning)	Raise setpoint to minimize heating if winter. Lower setpoint to minimize cooling if summer. Or adjust setpoint to minimize expensive local conditioning.
Variable air volume (nondumping)		
Minimum fan energy	Lowest percent of maximum supply air flow	Lower setpoint to minimize air flow if cooling or raise setpoint to minimize air flow if heating.
Minimum supply air conditioning	Largest percent of maximum supply air flow	Raise setpoint to maximize air flow if cooling or lower setpoint to maximize air flow if heating.

unnecessary thermal losses and equipment inefficiencies. Resetting the setpoint reduces energy consumption by matching hot or chilled water supply setpoints to the actual equipment load.

Implementation Guidelines. Reset of supply water temperature may be based on the outside air temperature or on the hot or chilled water demand. Except for buildings with dominant internal loads, the space load generally may be considered to be a function of the outdoor temperature. For example, as the outside air temperature rises, chilled water temperature is adjusted upward and hot water temperature is adjusted downward. Alternatively, a more accurate method is to reset the water temperature based on instrumentation readings.

For further discussion on the reset strategies and the selection algorithms of the hot and chilled water temperature setpoints, refer to a report by the National Bureau of Standards, Control Algorithms for Building Management and Control Systems--Hot Deck/Cold Deck/ Supply Air Reset, Day/Night Setback, Ventilation Purging, and Hot and Chilled Water Reset (NBS 1984a).

Required Information. Determine the existing hot and chilled water setpoints. Select an appropriate control system for reset.

ECO 105 - Install a Ventilation Purging Control System

Ventilation purging is a control strategy that uses outside ventilation air to reduce energy requirements and improve the occupants' comfort. Purging is generally used when the building is not occupied, provided the outside air conditions are desirable. This strategy is usually used for cooling; night air is brought in to precool and, thus, to reduce the cooling capacity required to achieve a comfortable temperature before the building's occupants return.

Implementation Guidelines. To make use of ventilation purging, the building air handlers must be capable of a "purge cycle." To begin the purge, the air-handling unit controller starts the supply fan, and possibly the return fan, and fully opens the outside air dampers. In some systems, such as VAV systems, the zone supply air boxes may have to be forced to a fully open condition. To end the purge, the air-handling unit fans are stopped and the outside air dampers are closed. Throughout the purge, no heating or cooling coils should be allowed to operate.

The ideal application for ventilation purging is a building with high thermal mass and low unoccupied internal gains, located in an area where the outdoor temperatures during the unoccupied period are lower than the temperatures during the occupied period. Ventilation purging is intended to operate in a building where space conditions can be allowed to range outside of an envelope of acceptable dry-bulb temperatures, humidity, and fresh air requirements during unoccupied periods. This method is not useful in a building that must maintain comfort conditions at all times or in locations with high humidity.

For further discussion on the subject and for sample algorithms, refer to the report by the National Bureau of Standards, Control Algorithms for Building Management and Control Systems--Hot Deck/ Cold Deck/ Supply Air Reset, Day/Night Setback, Ventilation Purging, and Hot and Chilled Water Reset (NBS 1984a).

Required Information. Determine whether the building location has cool, dry nights in summer and whether the existing air handlers can be adapted to a purge cycle.

ECO 106 - Install an Economizer Cooling Control System

Economizer cooling is the use of outdoor air to cool a building when the outdoor temperature and humidity conditions are desirable. There are two basic types of economizer cycles: a dry-bulb economizer and an enthalpy economizer. A dry-bulb economizer positions the outdoor, return, and relief air dampers by referencing the outside air temperature and the dry-bulb temperature of the return air. An enthalpy economizer performs the same function by referencing the enthalpy of the outdoor and return air.

Implementation Guidelines. The enthalpy control saves more energy, but requires that additional sensors be installed to measure the relative humidity or dew point temperatures of the outdoor and return air. These sensors require frequent maintenance and calibration to prevent measurement errors that can lead to a significant increase in building energy consumption through the improper use of outdoor air for cooling.

A report by the National Bureau of Standards, Economizer Algorithms for Energy Management and Control Systems, discusses in detail the control strategies and algorithms for economizer cooling (NBS 1984c).

Required Information. Determine whether existing air handlers are capable of supplying 100% outside air. Select an appropriate controller.

ECO 107 - Install a Demand Limiting Control System

The purpose of demand limiting is to maintain the peak demand level below a predetermined limit by shedding (disconnecting) nonessential loads during the peak demand period.

Implementation Guidelines. Load shedding should be carried out sequentially depending upon the priority of the load. The lowest priority load should be shed first and restored last, while the highest priority load should be cut off last and turned on first. However, when a number of loads are classified with the same priority, the order for shedding should be determined on a rotation basis.

In general, electric resistance and motor loads can be shed. Resistance loads include lighting, electric space heaters, electric boilers, electric furnaces, electric ovens, electric resistance heaters, battery chargers, etc. Motor loads include fans, pumps, air compressors, refrigeration compressors, etc. Selective loads to be controlled may be anything that can be turned off without harming equipment, significantly impairing comfort, endangering the safety of personnel, or affecting production capacity. Elevators, emergency equipment, essential lighting, and computers must be excluded from shedding.

For detailed discussions on the metering techniques, calculation principles, and load control algorithms, refer to a report by the National Bureau of Standards, Demand Limiting Algorithms for Energy Management and Control Systems (NBS 1984b).

Required Information. Survey building electric loads to identify which loads can be shed. Prioritize sheddable loads. Select an appropriate load shedding controller or software for an existing EMCS system.

1.8.2 Use Heat Reclaim Systems

Heat recovery is the reclamation and use of energy, including sensible and/or latent heat, that is otherwise rejected from the building. When applied properly, the heat reclaim system may be used to reduce energy consumption as well as peak power demand. The effectiveness of a heat reclaim system for energy conservation depends on the quantity and temperature of the heat available for recovery, as well as the application of the reclaimed heat.

Although the basic principles in energy recovery are the same, there are a variety of implementation methods. In general, they may be categorized as follows:

- air-to-air recovery systems (see Table 1.32 for the summary of their characteristics)
  - rotary wheel exchangers
  - fixed plate exchangers
  - thermosiphon (heat pipe) exchangers
  - run-around coil exchangers (coil recovery loop)
  - multiple tower exchangers
- hydronic recovery systems
  - two-pipe heat recovery systems
  - three-pipe heat recovery systems
  - four-pipe heat recovery systems.

For detailed discussions of the characteristics of the above systems, refer to ASHRAE's Equipment Handbook (ASHRAE 1987) and NEBB (1985). Selected heat reclaim technologies and opportunities are discussed in the following subsections.

TABLE 1.32. Characteristics of Air-to-Air Energy Recovery Devices

Type Exchanger	HVAC Applications	Exhaust to 250°F Supply -20° to 110°F	Exhaust 250° to 800°F Supply -40° to 500°F	Exhaust 800° to 1200°F Supply -40° to 500°F	Exhaust 1200° to 1800°F	Sensible Heat Recovery	Total Heat Recovery	Remote Airstreams	Possible Cross Contamination	Corrosive Gases Permitted (special construction)	Air-to-Air	Air-to-Liquid-to-Air
Rotary wheel												
Metallic	X	X				X			(a)	(b)	X	
Hygroscopic	X	X				X	X		(a)		X	
Ceramic			X	X	X	X			(a)	(b)	X	
Fixed plate	X	X	X	X	X	X				X	X	
Heat pipe	X	X	X	X		X				X	X	
Run-around coil	X	X	X			X		X		X		X
Multiple tower	X	X				X	X	X	(c)			X
Thermosiphon	X	X	X	X		X		X		X		X
Dry air cooler	X					X	(d)				X	

(a) Can be limited to less than 1% with a purge section.
(b) When used in process-to-process applications where cross-contamination can be tolerated.
(c) Gaseous cross-contamination can occur.
(d) Has evaporative cooling capabilities.
Source: Reprinted with permission of the National Environmental Balancing Bureau (NEBB) from the Environmental Systems Technology.

ECO 108 - Install Double-Bundle Chillers

The condenser heat of a chiller is usually rejected to the ambient air or to cooling water. However, if the building has coincident space or water heating requirements when the chiller is operating, this rejected heat may be reclaimed and used.

Implementation Guidelines. Double-bundle chillers are configured by installing additional heat exchanger tubes in the condenser water loop. These chillers are identical to conventional chillers except for the additional condenser tube bundle, which allows the open cooling tower loop to be isolated from the closed heating water loop. Instead of sending condenser heat to a conventional cooling tower, double-bundle chillers can send it to the heat exchanger to recover heat for space or water heating (Usibelli et al. 1985). Figure 1.13 shows the basic configuration of this system. The recovered heat is in the average range of 100°F to 130°F. A storage tank may be installed in conjunction with a double-bundle system to store heat during chiller operation (ASHRAE 1987).

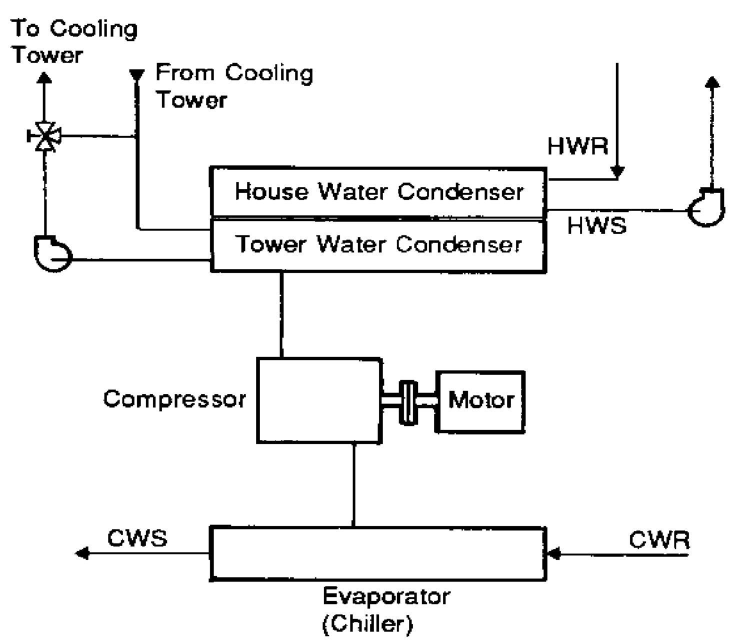

FIGURE 1.13. Heat Transfer System with Storage Tank (Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from 1987 ASHRAE Handbook: HVAC Systems and Applications.)

In general, the double-bundle chiller is applicable in buildings that have a significant heating load during chiller operation periods. Buildings with economizer cooling during coincident heating periods may not be suitable for a double-bundle system. (Usibelli et al. 1985). It should also be noted that the net cooling efficiency of the chiller, in terms of the cooling capacity per unit energy input, is lowered because of the warm water circulating through the condenser.

Required Information. Determine whether a large summer heating load exists that can be satisfied with a double-bundle chiller. Size hot water storage, if required, based on the schedule of the heating load to be satisfied.

ECO 109 - Reclaim Heat from Boiler Blowdown

Boiler blowdown cycles can waste 2% to 3% of boiler energy production. Boiler blowdown losses can be minimized by recovering some of the heat in the wastewater. The blowdown heat recovered can be used to preheat air, feed-water, or fuel oil.

Implementation Guidelines. The blowdown water can be piped through a heat exchanger or through a flash tank with a heat exchanger. Figure 1.14

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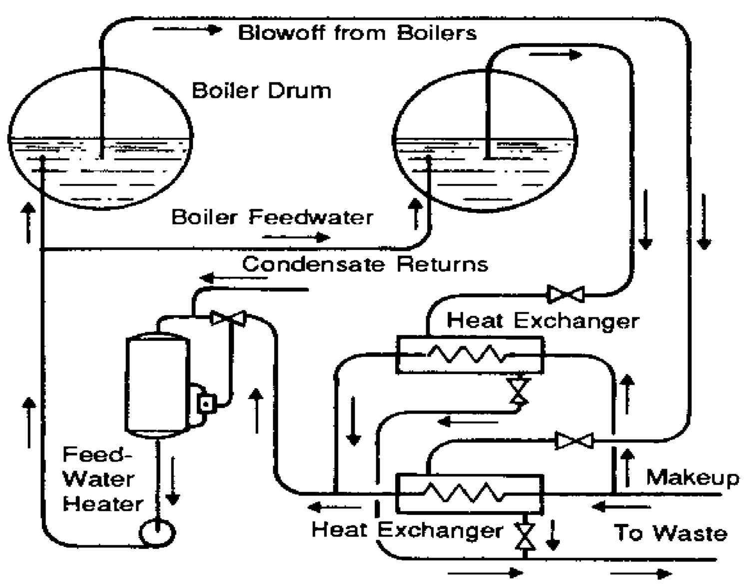

FIGURE 1.14. Recovery of Continuous Blowdown Heat to Preheat Feedwater (from Elonka and Kohan. Copyright © 1984 by McGraw-Hill, Inc. Reprinted with permission)

is a schematic showing the recovery of the continuous blowdown heat to preheat feedwater (Elonka and Kohan 1984).

Required Information. Determine the energy recovery potential of the boiler feedwater. Determine storage tank size, if required, depending upon the schedule of the heating load to be satisfied.

ECO 110 - Reclaim Incinerator Heat

Considerable energy can be saved by burning solid waste to generate steam. About 2 to 3 lb of steam can be generated for each pound of solid waste combusted, and 1.2 barrels of oil can be saved from each ton of trash fired. In addition, the volume of solid waste can be reduced by 80% to 90% (NCEL 1984b).

Implementation Guidelines. Incinerator heat reclaim generally is only cost-effective if the quantity of solid waste generated exceeds 1000 lb/day.

Required Information. Size the waste heat incinerator based upon the heating value of available trash. Ensure that dangerous materials and noncombustibles can be separated. Locate heat reclaim unit near the incinerator and ensure that it can be connected to supply water.

ECO 111 - Reclaim Heat from Combustion System Flue

The quantity of sensible heat available from flue products of a modern, properly-adjusted furnace or boiler that is burning oil or gas is roughly 10% to 15% of the rated input. This heat can be recovered from hot flue gas to temper ventilation air, preheat domestic hot water, or preheat combustion air.

Implementation Guidelines. Small accessory heat exchangers should be installed to fit between the combustion system and the chimney. The heat exchanger (flue heat extractor) should provide low flow resistance. If the heat exchanger is reasonably efficient and its gas vent passage has some flow resistance, there may be adverse effects from reducing both flow and gas temperature. Moisture may condense in the chimney or the draft hood spillage or both. Increasing the heat transfer efficiency increases the probability of both effects occurring simultaneously.

The use of heat exchangers in gas appliance venting systems requires careful evaluation of the value of recovered heat versus installed cost and of the potential for creating chimney safety and operating problems. Every heat exchanger installation should be given spillage tests. In solid fuel systems, the heat exchanger may itself collect creosote or tar deposits, or it may increase their formation and deposit downstream (ASHRAE 1988).

Required Information. Measure the stack draft and temperature. Determine the temperature to which stack gases can be lowered without condensing impurities. Select a reclamation device. Identify a use for the released heat. Determine whether a heat storage tank is required based upon the furnace or boiler operating profile and the time of day the heating load is to be met by the reclaimed energy.

ECO 112 - Install Water-Loop Heat Pump Systems

A heat recovery system using unitary air-to-water heat pumps can be used for buildings with multiple zones. The heat pump system is readily adaptable to installations that require simultaneous heating and cooling. Because of the high operating efficiency of the equipment under these conditions, this type of application often results in a considerable cost savings compared with other designs.

Implementation Guidelines. This system should be considered if the HVAC system is to be replaced. Figure 1.15 is a schematic of a typical system. The unitary heat pumps are connected hydronically in the same water loop. Each unit cools conventionally, supplying cool air to its individual zone and rejecting heat to the water loop through a shell-and-tube heat exchanger. If another unit is required to operate coincidentally in the heating mode, its heat source will be the same water loop. The heat pumps are operating at higher efficiencies because, in the heating mode, they obtain heat from the relatively high-temperature condenser water of the cooling units and, in the cooling mode, they reject heat to the relatively low-temperature evaporator water of the heating units. This system is most applicable to buildings that have high internal heat gains and that are in temperate climates.

To provide supplementary heating and cooling, the systems may be connected to packaged boilers, chillers, and cooling towers. The water loop should be maintained in a preset temperature range, typically 60°F to 90°F (ASHRAE 1987).

Required Information. Gather all information required to model the existing heating load so that the water-loop heat pump system can be analyzed.

ECO 113 - Reclaim Heat from Prime Movers

A prime mover is required to operate the generator for onsite electricity generation. The prime mover converts fuel energy to shaft energy. Typical conversion devices include reciprocating internal combustion engines, combustion gas turbines, and steam boiler-turbine combinations. Besides generating mechanical energy, these devices also produce thermal energy through turbine steam, turbine exhaust, and engine jacket heat. Adding waste-heat recovery capabilities to the electric generation equipment can increase total thermal efficiency to as high as 75% under favorable conditions. Waste heat can be recovered in many ways and is usually converted to hot water or low-pressure steam.

Implementation Guidelines. Steam extracted from the turbine or from the turbine exhaust outlet can be used by heat exchange equipment, absorption refrigeration equipment, and steam-turbine-driven centrifugal chillers.

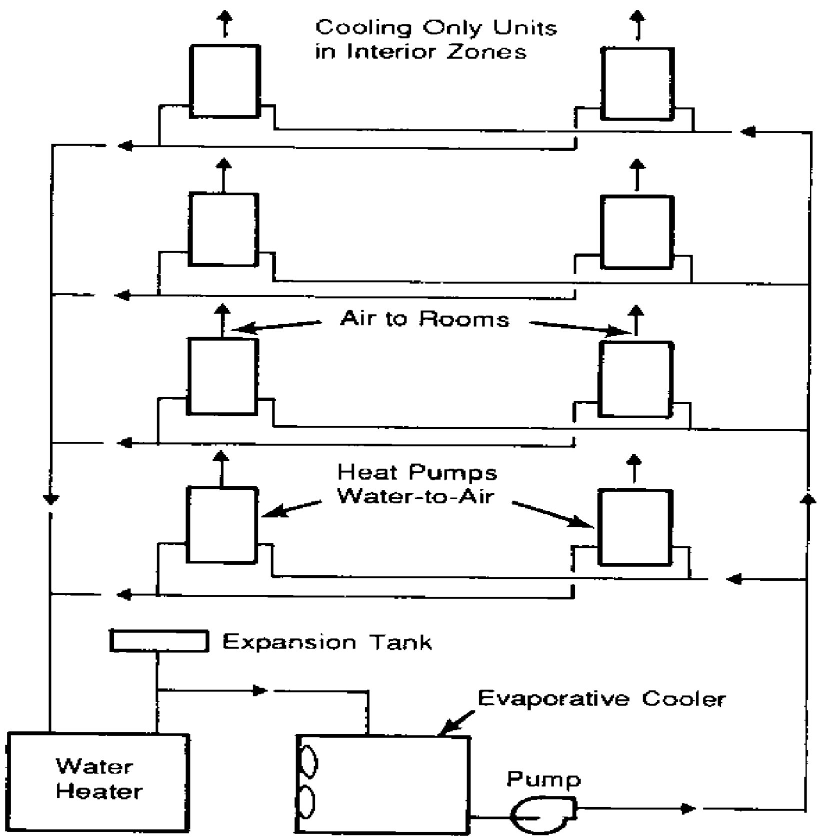

FIGURE 1.15. Heat Transfer System Using Water-to-Air Unitary Heat Pump (Reprinted by permission from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. from 1987 ASHRAE Handbook: HVAC Systems and Applications.)

The quantity of heat recoverable from turbine exhaust is greater than that of reciprocating engines because of the larger exhaust flow. With a large percentage of excess air in the turbine exhaust, afterburners can supplement the recovered heat during reduced turbine loads, with a possible efficiency increase to 90%. The engine exhaust heat recovery equipment also acts as a muffler or silencer.

The installation of heat exchanges may absorb as much as 30% of the heat input to a large reciprocating internal combustion engine. The engine's lubricating oil may absorb another 5% to 10%. A heat storage tank should be considered in this application. Not only will it buffer the machinery from over cooling in case of a sudden load, but it provides a reservoir for peak loads (NEBB 1985). Heat recovery equipment is optional with most packaged generation systems.

Required Information. Determine the energy recovery potential of generation equipment. Identify building heating loads that can be met with the reclaimed energy. Determine the size of storage tanks based upon generation equipment, operating schedules, and the heat load to be satisfied.

ECO 114 - Install Piggyback Absorption Systems

Absorption machines are heat-operated refrigeration machines. The absorption cycle differs from the vapor-compression cycle in that a heat-operated generator rather than a compressor produces the pressure differential required. An absorption chiller can use the high-temperature exhaust recovered from prime movers (ECO 113).

Implementation Guidelines. If the exhaust steam from steam turbines is condensed before returning as feedwater to the boiler, an absorption chiller should be substituted for the condenser to produce chilled water for space conditioning. This type of absorption system is particularly effective in buildings using purchased steam when condensate is not returned to the supplier or where no credit is given for the temperature of the returned condensate. In such cases, a large machine can be operated at outlet temperatures down to 180°F, claiming the maximum possible heat from the exhaust steam and condensate. If a reciprocating engine is the prime mover, a hot water absorption chiller can be used.

Required Information. Determine the cooling load in summer and the waste-heat available for absorption cooling. Size the storage tank to account for the difference between reclaimed energy and the building cooling load. A piggyback absorption system can use generated waste-heat during the cooling season.

ECO 115 - Recover Heat from Light Systems

The power input to lighting systems is eventually converted into heat, which reduces the space heating load but increases the space cooling load. The heat-of-light systems recover this heat, which can then be transferred to areas that need heat. The cooling effect will slightly increase the lamp's efficiency; however, the major advantage of heat-of-light systems lies in their reduction of space heating and cooling loads.

Implementation Guidelines. There are two types of heat-of-light systems: dry and wet. For dry heat-of-light systems, room air drawn through the lighting fixture passes over the lamp and ballast and is either ducted to a fan or drawn into the ceiling plenum space. The heated air from the lamp and fixture can be supplied to cooler perimeter zones during the heating season or recirculated back to an existing air-handling unit. During the cooling season, the heated air can be exhausted. If a ceiling plenum system is used, a separate fan should be used to draw the warm air from the ceiling plenum and deliver it to a cooler zone or to discharge it outdoors. When ceiling plenums are used as collection chambers, each zone must be isolated from the others by a vertical barrier. Ceilings over conditioned areas should be insulated to a U-factor of 0.1 or better to limit re-radiation to the occupied spaces.

The wet heat-of-light system requires built-in water passages and air inlets. Air flows through the fixture while water is circulated through the passages and then to the cooling tower where the heat is removed and the cool water piped back to the fixtures. The heat removed from the fixtures can be used for reheat purposes in the HVAC system instead of being rejected to the outdoors. The circulating water system can also be used to pick up heat from special water-cooled, louvered, venetian blinds to reduce solar heat gain at the windows, as well as to make the heat available for other uses.

In existing buildings, the installation of heat-of-light systems may be quite costly unless done in conjunction with building renovations that require completely new lighting and ductwork systems (NEBB 1985).

Required Information. Determine the lighting watts per square foot of the ceiling lighting system. Identify uses for the reclaimed heat.

ECO 116 - Recover Heat from Refrigerator Hot Gas

A typical refrigeration machine with a water-cooled condenser rejects approximately 15,000 Btu/hour for each ton (12,000 Btu/hour) of refrigeration. An air-cooled condenser rejects up to 17,000 Btu/hour. For the amount of heat rejected, up to 5000 Btu/hour can be recovered.

Implementation Guidelines. A heat exchanger should be installed in the hot gas line between the compressor and the condenser. (See example in Figure 1.16.) The temperature of the hot gas is generally in the range of 120°F to 130°F although temperature will vary according to the head pressure.

Required Information. Determine the capacity of existing refrigeration, and the building's domestic hot water load. Select a reclamation system that can supply all or part of the hot water load.

ECO 117 - Recover Heat from Steam Condensate

Large quantities of heat in the form of flash steam are exhausted from the condensate return portion of many steam systems when the hot condensate is reduced to atmospheric pressure in the condensate receiver. This waste heat can be recovered.

Implementation Guidelines. A heat exchanger installed in the condensate return main before the receiver can reduce condensate temperature to approximately 180°F. The heat recovered can be used to heat water in an arrangement such as the one shown in Figure 1.17. Evaluate the proposed installation, however, to ensure that the amount of energy required to reheat the

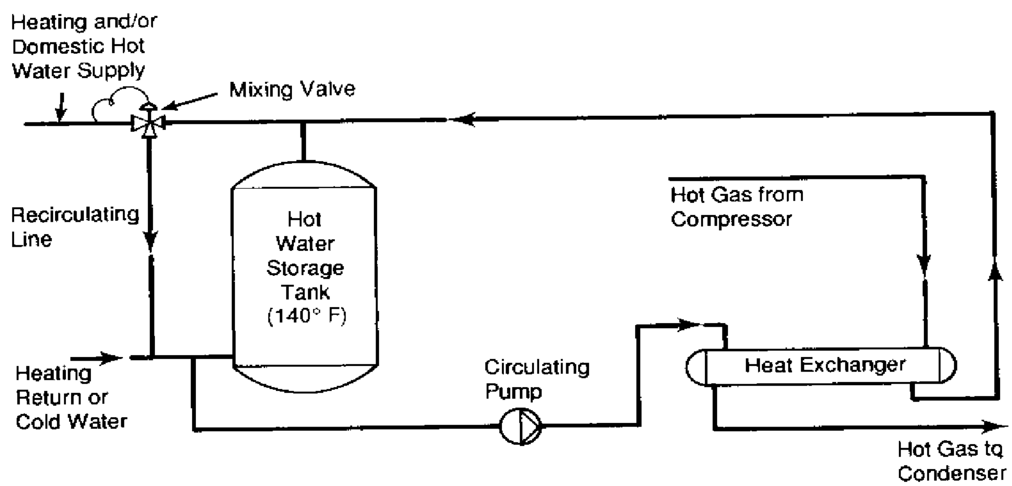

FIGURE 1.16. Compressor Heat Recovery [Reprinted with permission of the National Environmental Balancing Bureau (NEBB), from Environmental Systems Technology.]

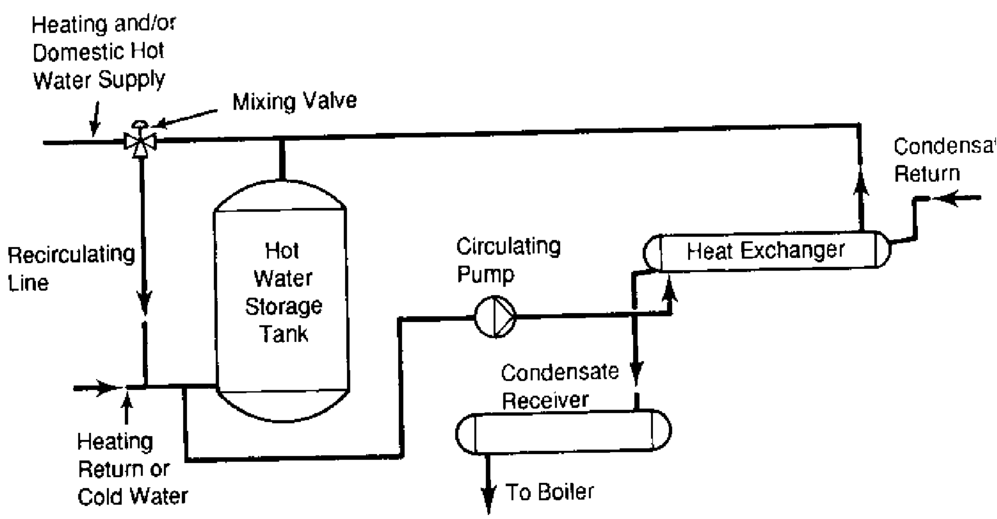

FIGURE 1.17. Condensate Heat Recovery [Reprinted with permission of the National Environmental Balancing Bureau (NEBB), from Environmental Systems Technology.]

condensate will not offset the expected heat-recovery savings (NEBB 1985). A mechanical vapor recompression system can also be evaluated for large systems.

Required Information. Determine the amount of condensate that is returned, and identify a use for the waste heat. Size a storage tank to accommodate differences between the reclaimed heat profile and the heat load to be satisfied.

ECO 118 - Recover Heat from Waste Water

Buildings with kitchens, laundries, and other service facilities that use large quantities of hot water, discharge hot waste water to drains. The heat thus discharged can be recovered.

Implementation Guidelines. By installing a heat exchanger that is easily flushed and by prefiltering the waste water to prevent heat exchanger clogging, heat can be recaptured and used to heat hot water for space heating or domestic use. Figure 1.18 is a schematic of a laundry and kitchen hot water heat-recovery system. The preheated water enters the hot water tank and is further heated to the desired temperature. A heat-recovering system is generally economical for preheating water from 50°F to 105°F (NEBB 1985).

Required Information. Determine the usage profile and temperature of waste water. Select a heat exchanger. Size a storage tank, if required, to match waste-water flow and hot water requirements.

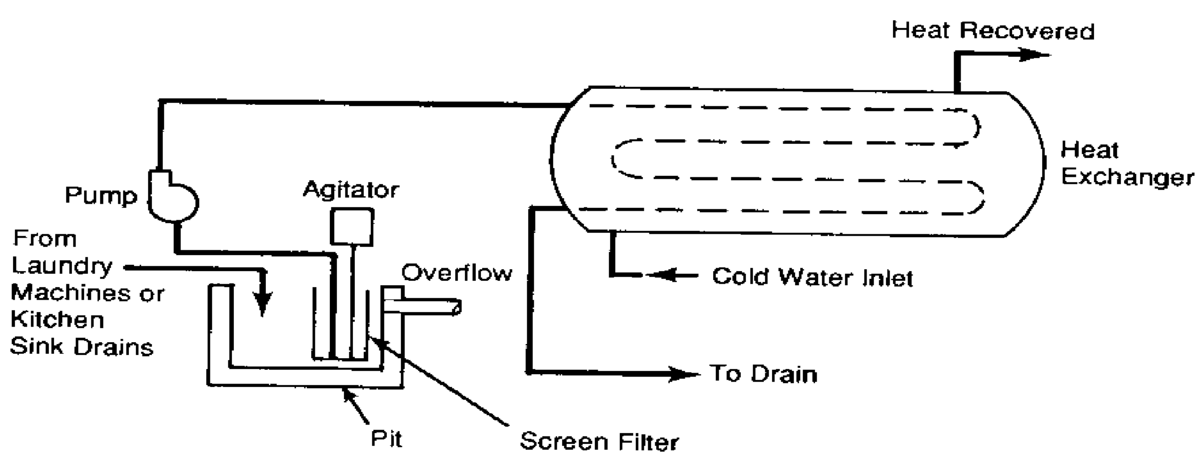

FIGURE 1.18. Schematic of Laundry and Kitchen Hot Water Heat Recovery System [Reprinted with permission of the National Environmental Balancing Bureau (NEBB), from Environmental Systems Technology.]

2.0 ANALYSIS OF ENERGY CONSERVATION OPPORTUNITIES

The material in this chapter reflects the impact that the personal computer has had on nearly all aspects of professional life, including building energy analysis. Before personal computers were widely used, building energy analysts had limited choices of calculation methods for evaluating ECOs. Typically, they used manual calculation methods and nomographs. Those methods are simple and require a relatively low level of effort from the user. However, those methods are not as accurate and comprehensive as automated methods of calculation.

In the past, automated calculation methods were usually available only on mainframe computers and were costly, complicated, and time consuming to use. However, those methods provided much greater accuracy and could evaluate building energy use hourly. With the advent of the personal computer, automated methods for analyzing building energy became accessible to a wider range of building professionals. Today, many software packages for analyzing building energy are available for the personal computer.

This chapter provides information on using automated calculation procedures for building energy analysis, especially for evaluating ECOs. Specifically, this chapter includes an overview of building energy models that are appropriate for different types of ECOs; specific information on how to use one such model, A Simplified Energy Analysis Method (ASEAM); and detailed procedures for analyzing ECOs with ASEAM.

2.1 ENERGY ANALYSIS NEEDS FOR FEDERAL ENERGY MANAGERS

As the largest building owner in the world, the federal government has diverse needs in the area of building energy analysis. The activities of federal building energy managers can include the following:

- building operations - managing and operating individual buildings, building complexes, and large-scale facilities such as military bases and public housing

- facility architectural and engineering (A&E) services - managing the in-house A&E designed construction of both new and existing buildings, managing contracted private-sector A&E services, and producing energy audits and facility energy plants using in-house staff or contracted services

- building design research - evaluating technology for advanced building systems; developing advanced, prototypical building designs; and initiating and managing building energy conservation projects

- implementation methods - developing methods for implementing energy conservation measures, especially in the area of innovative financing of building retrofits.

In all these activities, the federal energy manager needs practical information on implementing energy conservation and needs analytical tools and techniques. The recommended analytical tool--ASEAM--is flexible enough to be useful for a broad range of planning, design, implementation and research applications.

2.2 ENERGY MODELING OVERVIEW

Chapter 1.0 of this volume focuses on discussing 29 types of ECOs involving 118 specific ECOs. The purpose of this section is to present an overview of energy modeling concepts and strategies. Also, the section includes information on the appropriate techniques for calculating the energy use of the different types of ECOs and the limitations in the accuracy of those techniques.

All building energy consumption can be viewed conceptually as a rate times a time calculation (i.e., energy = rate * time). The maximum rate is specified or limited by parameter specifications of capacity or by intensity, such as wall U value, lighting watts/sq ft, or chiller tonnage. The rate over time is specified by the operating schedule or weather variables. The type of parameter and how it varies over time can be used to select the appropriate analysis technique. For example, an external lighting system uses energy at a constant rate, usually operates on a known schedule, and has no interaction with other patterns of building energy consumption. Therefore, a change in installed kW (rate) or operating schedule (time) can be calculated manually with precision.

For most ECOs, however, the calculation is not that simple. For example, the performance of heating and cooling systems is affected by internal heat gains and weather variables, which vary in a complex fashion over time. The efficiencies of the plant equipment and HVAC systems vary with percentage of load. Therefore, using an energy model rather than manual techniques offers the following accuracy improvements:

- Building parameters can be precisely scheduled.
- The impact of weather can be precisely determined.
- Equipment performance can be specified at partload.
- Variable interactions, such as the effect of internal lighting reduction on heating and cooling loads, can be calculated.

For most ECOs that are evaluated, ASEAM is an appropriate analysis tool. In some cases, an hourly analysis method is more appropriate, e.g., evaluating time-of-use energy rates. Dynamic phenomena such as passive solar heating and sizing of thermal storage tanks also require hourly analysis.

Some ECOs can be directly modeled by changing ASEAM's input variables, while other ECOs require engineering judgment. Examples of ECOs that can be directly modeled include reducing HVAC system operating hours or changing space temperatures or outside air ventilation. These systems can be specified to great detail in ASEAM. Also, changes in lighting systems, in heat conduction of the building envelope, in building system, or in plant type can be directly modeled.

Other ECOs require engineering judgment because the accuracy of the results depends on that judgment and on the degree to which existing conditions are known and can be measured. Evaluating these ECOs presents a significant challenge in the energy analysis. The following subsection discusses ECOs that must be evaluated indirectly.

2.2.1 ECO Types That Are Evaluated Indirectly

All ECOs are treated individually in Section 2.6; however, it is appropriate to present some modeling strategies to understand how these types of ECOs may be treated. Many ECOs must be evaluated indirectly, using engineering judgment. In the following paragraphs, several ECO types that are evaluated indirectly are discussed.

Most reductions of system operating hours and setpoints can be modeled directly. However, some systems are more complex. For example, to model water heating savings accurately, the base-case model input should include operating losses. If a circulation pump is used, it can be scheduled off during unoccupied hours. Hot water pipe losses should be shown as heat gains to the space, which can then be eliminated when the system is turned off. Storage tank losses will be reduced during the unoccupied cycle. In this example, circulation pump savings are easy to specify. Heat loss from piping and tanks must be estimated by determining the area of the pipes and tanks, R value and condition of the insulation, and temperature difference between the hot water and pipe surroundings. The modeling accuracy is limited by the accuracy of the variable specification.

Reducing elevator operating hours appears to be straightforward. However, elevator power consumption varies considerably with usage patterns. A typical elevator may draw 1 kW at idle, 20 kW at startup, and 5 kW upon steady movement. Power consumption may be estimated from miles traveled and rate of movement, if these data are available. Another approach is to monitor power consumption over time for one or two weeks.

Heat conduction through building surfaces can be modeled directly in most cases. However, roof spray cooling cannot be directly modeled. A spray cooling system lowers the temperature of the roof. This can be modeled in ASEAM by reducing the slope of the roof heat load curve in summer. Engineering judgment is required to determine how much of a reduction to specify.

Many infiltration ECOs are difficult to model precisely because infiltration is a significant and difficult-to-quantify building parameter. Sealing shafts, loading dock door seals, and accounting for open windows when the HVAC system is operating are all difficult to evaluate. Infiltration rates are influenced by local wind patterns, building pressurization, temperature differentials between inside and outside air, and the building stack.

Improvements in air and water distribution systems are modeled by altering the power consumption and operating schedules of pumps and fans. Adding insulation or repairing leaks can be modeled by estimating existing losses. Again, judgment is required.

Most plant ECOs are modeled by determining the efficiency improvements in equipment operation. Those savings can be specified by measuring existing variables such as stack draft when the boiler is not firing, and blowdown rates when the boiler is in operation. Boiler isolation savings can be determined from temperature and flow rate to the off-line boilers.

Reducing power system losses must be modeled by reducing the installed capacity of electrical systems. Similarly, motor replacements are evaluated by reducing the installed kW of the motors. Many energy monitoring and control systems ECOs are straightforward to model because the parameters and schedules that must be altered are standard ASEAM inputs.

In evaluating heat reclamation systems, the reclaimed energy rates must be matched against the requirements of the systems using the energy. If differences exist between recovery and use schedules, storage is required. ASEAM can model reclamation systems; but because it is not an hourly model, it will not indicate whether storage is undersized or oversized. If this is a concern, an hourly model should be used.

Similarly, an hourly model may be appropriate for demand reduction ECOs. If time-of-use rates are to be evaluated, the analyst must determine whether the model is capable of taking them into account.

2.3 SELECTION OF ASEAM

The method for analyzing building ECOs discussed in this report is the ASEAM program. The U.S. Department of Energy sponsored development of the program, which is in the public domain. The earlier version of this report used manual methods, primarily nomographs, to analyze ECOs (DOE 1980). Manual methods, although not as accurate, can still be used if time and money do not allow for any other techniques.

Although ASEAM can be used by anyone interested in building energy analysis, it includes features that are particularly useful to educators, researchers, and federal energy managers. Many other good programs offer automatic cost estimating and text reports for ECOs, more capabilities (e.g., number of zones, systems, and plant types modeled), less calculation time, and additional user-friendly features. ASEAM was selected to illustrate the ECO analysis procedures described in this chapter because it is in the public domain and provides many technical and user operation features. The emphasis in the design of ASEAM has been to

- show the engineering calculations

- provide an easy way to investigate the effects of changes in input variables through the parametric processor and ECO modes of calculations

- provide readable, structured source codes that can be changed.

ASEAM is a modified bin-method program for calculating the energy consumption of residential and simple commercial buildings. ASEAM runs on an IBM PC and compatibles with at least 256 kilobytes of memory and two disk drives: either two floppy disk drives or one hard disk and one floppy disk drive. ASEAM features are described below.

2.3.1 Input Features

ASEAM's input features are described below:

Full-screen editing - Entering data into ASEAM is easy and straightforward. Input questions are accessed through cursor control keys on the keyboard.

User-friendly features - ASEAM has many user-friendly features, including error checking, help messages, and default values. Data entry and editing features are included.

Quick input routine - Given a limited amount of input data, such as building shape and dimensions, percentage of glass, space types, and system types, ASEAM can calculate areas and use default values based on the information the user provides, and can write complete input files for the calculations.

2.3.2 Calculation Features

ASEAM's calculation features are described below:

- Use of standard algorithms - Wherever possible, ASEAM uses recognized algorithms from such sources as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) (1985), Illuminating Engineering Society (Kaufman and Haynes 1981), the DOE-2 Program Manual (Buhl and Hirsch 1986), and the National Bureau of Standards (NBS) (Ruegg and Peterson 1987; NBS 1988).

- Display of calculations - The calculations can be displayed and printed simply by pressing the function keys while the calculations are being performed. Many of the calculations are displayed graphically.

- Calculation speed and capacity - ASEAM can perform calculations for a typical five-zone building in 7 minutes. Up to 10 thermal load zones can be specified with different secondary HVAC systems assigned to each. The user can simulate 13 different system types, 5 heating plants, and 7 cooling plants.

- Peak load and equipment sizing - ASEAM calculates both zone and building peak loads and can automatically size equipment based on these loads. Equipment sizes can be specified.

- Calculation modes - Calculations can be performed in several modes:

  - Single or batch mode: As many as 20 combinations of input files can be selected for analysis. A wide range of outputs can be selected for each analysis.

  - Parametric processor mode: The parametric processor is a pow erful tool for analyzing many alternate building and system configurations. First, the base-case input files to be modi fied are defined. Next, both the input variables to be changed and the output variables for the report are selected. ASEAM then performs the calculations, automatically changing input values in a looping pattern. Variables can be studied individually or in combination with other variables. The selected calculation output variables are stored in a spreadsheet file.

  - ECO mode: ECOs can be analyzed with ASEAM by comparing origi nal (base-case) energy consumption and cost with alternative (ECO) energy consumption and cost. ECOs can be studied individually or in combination with other ECOs.

- Life-cycle costing (LCC) - Two LCC programs, developed by the National Bureau of Standards, are integrated into ASEAM (Ruegg and Peterson 1987; NBS 1988).

2.3.3 Output Features

The use of ASEAM allows specification of 39 different calculation output reports, many of which are spreadsheet-compatible. While the calculations are being performed, the user can either display or print the calculation parameters. Input data echo reports also are provided.

2.3.4 Public Domain

The source code of ASEAM is provided. The algorithms used can be studied in detail and changed if desired. The BASIC code is structured and documented. Wherever possible, equations in the BASIC source code are referenced to outside sources such as the DOE-2 Program Manual (Buhl and Hirsch 1986).

2.3.5 Weather

ASEAM can use bin weather data in three formats and from weather stations in 46 major U.S. cities. The user can add to or change ASEAM's weather files.

2.4 MODELING WITH ASEAM

The current version of ASEAM used in this analysis (ASEAM 2.1) is contained on 16 diskettes (ACEC 1987). Five diskettes contain compiled code (three for ASEAM2.1 itself and two for life-cycle costing); the program is run from these disks. The source code is contained on six disks (four for ASEAM2.1 and two for life-cycle costing), which will be used only to examine or change the program. A data disk with demonstration files is also included. The remaining four diskettes contain bin weather and solar data files for 46 stations across the United States.

Like most building energy analysis programs, ASEAM performs calculations in four segments:

- loads - Thermal heating and cooling loads (both peak and "diversified," or average) are calculated for each zone by month and by outside bin temperature. Lighting and miscellaneous electrical consumption are calculated in this segment.

- systems - The thermal loads calculated in the loads segment are then passed to the systems' segment, which calculates "coil" loads for boilers and chillers. (The system coil loads are not equal to the zone loads calculated above because of ventilation requirements, latent cooling, humidification requirements, economizer cycles, reheat, mixing, etc.) Some building energy requirements are calculated in the systems' segment (e.g., heat pump and fan electricity requirements).

- plant - All of the system's coil loads on the central heating and cooling plant equipment are then combined, and calculations are performed for each central plant type. (Plant equipment can also impose loads on other plant equipment, such as cooling tower loads from chillers, and boiler loads from absorption chillers or domestic hot water.) The plant calculations result in monthly and annual energy consumption figures for each plant type.

- economic (optional) - Energy consumption from all the building end-use categories is then totaled and reported. If specified, the life-cycle costs of the total energy requirements, combined with other parameters, are calculated and reported. Comparisons of a base case with alternative cases may also be performed in the parametric and ECO calculation modes.

In the following subsections, the steps in modeling buildings are discussed and instructions are given for zoning a building.

2.4.1 Modeling Buildings

Several steps are required when any building energy analysis tool is used to simulate building energy consumption. The steps may differ depending upon the type of analysis to be performed--for new buildings (not yet built) or existing buildings. Each type is discussed below.

Modeling New Buildings

In new buildings or those not built, several steps can be eliminated that are required when using an energy analysis program in existing buildings; these steps include such things as visiting the building, collecting data, and validating calculated energy consumption against actual energy bills. The user is also less constrained in investigating alternatives (e.g., comparing system and plant types, and architectural configurations). The cost-effectiveness of the same alternatives (new versus existing buildings) may vary greatly. Not only is the installation cost lower for alternatives in new buildings (as opposed to existing buildings), but the cost to change equipment size is also reduced. If the equipment in existing buildings is not changed, alternatives with major load changes may result in oversized equipment with lower operating efficiency.

Modeling Existing Buildings

In existing buildings, use of a building energy analysis program is more demanding. The building must be surveyed to get actual conditions; several runs may be required to validate predicted energy consumption against actual energy bills or metered data, if available; and the alternatives that can be investigated are more constrained.

2.4.2 Modeling Steps Using ASEAM

Several steps that may be required to use a building energy analysis program are outlined below. Again, the steps required may be different depending on the client's needs and the type of building analyzed (new or existing).

Step 1 - Obtain Pre-survey Information. Before visiting the building, obtain the following from the building contact person:

- architectural, mechanical and electrical blueprints - Because the drawings may be marked up, make copies of the blueprint pages of most importance: floor plans, elevations, HVAC distribution, HVAC schedules, lighting layouts, etc.

- energy bills - For existing buildings, ask the building representative to furnish recent energy bills for all utilities. Bills from the past two years should be adequate. Such factors as the addition of new equipment (e.g., maintenance) can significantly impact energy usage in buildings. Energy consumption data from the bills should be used to "calibrate" the energy calculations. If significant differences are discovered between anticipated and actual consumption, change the necessary input parameters to better simulate the building's energy usage (see Step 9 below).

- contact person - For existing buildings only, also obtain the names of people who are most familiar with the building's operation (e.g., maintenance foreman). Such people will be most useful because they "live" with the building and know its mechanical systems, problem areas, equipment not shown on the blueprints, present and future building uses, etc.

Step 2 - Visit Building For a Quick Walk-Through. After obtaining the necessary pre-survey information, briefly visit the building, if possible. The purpose of the visit is not to perform the complete data collecting, but to become familiar with the building and its operation and confirm the accuracy of the data collected in Step 1.

Interview the contact person to determine the building's operating schedule and if there are any planned changes or alterations that should be investigated. After the interview, walk through the building with the contact person to visit typical and atypical (e.g., computer rooms, kitchens, auditoriums) spaces and mechanical rooms. Note any changes from the blueprints.

Step 3 - Zone the Building. After the walk-through, "zone" the building by dividing it into smaller areas (called zones) of similar thermal and system loads. This is a very important step and is discussed in more detail in subsection 2.4.3.

Step 4 - Conduct Detailed Walk-Through and Collect Data (existing buildings). When the building has been zoned, data collection for the simulation can begin. If the blueprints accurately describe the building, the time needed to perform this step may be greatly reduced. You should also be familiar with the input data requirements for ASEAM for each segment (loads, systems, plant).

The input data are entered into ASEAM separately for each zone and system. Therefore, it is important to record the zone or system number for the data collected. The analyst may want to outline the different zones on small building plans before starting this step and then take notes on these plans. During a walk-through of each area, look for any items that consume energy or affect the heating or cooling loads in some manner. Look for ways to save energy, and collect data for any alterations noted. The alteration data should also include factors that impact the alteration cost.

A systematic plan is required to ensure complete data collection. For example, first walk around the exterior of the building to determine any security and parking lighting requirements. Next, visit several typical interior spaces to determine the type and condition of the windows, the typical lighting type and power requirements for lighting and receptacles, and the people density. After several typical areas have been visited, a pattern of similar lighting, people, and miscellaneous (receptacle) electric loads may begin to emerge. If so, note only the exceptions on the copies of the building plans.

After completing the data collection for typical spaces, survey areas in the building that have atypical characteristics. Such areas include computer rooms, kitchen areas, large conference rooms, and lobbies.

Consider a visit to the mechanical rooms to collect systems and plant input data. The contact person, again, should be the best source of information. For example, it is nearly impossible to determine if a system has discriminator controls just by looking at it. Likewise, heating and cooling availability schedules, and control of outside air (ventilation) dampers are very important input data items that can drastically affect energy calculations.

Again, collect data not only for the base-case run but also for any ECOs that will be studied. Note any operation and maintenance (O&M) items (e.g., disconnected damper linkages or dirty coils). If time and budget permit, use instrumentation to help with system and plant data requirements.

<u>Step 5 - Discuss Walk-Through Data with Building Contact Person (existing buildings)</u>. After collecting the data, discuss findings with the building contact person before entering any data into ASEAM for modeling. In general, discuss the following:

- any O&M problems noted

- any ECOs that are appropriate. The building contact person may rule out some ECOs because of their expense or operational problems and also may suggest a few ECOs.

- initially what ASEAM runs are to be performed. Based on the above discussions, the analyst and the building contact person should have a firm understanding of what ECOs and O&M items will be studied.

Suggest grouping the ECOs and O&M items that are assumed to be cost-effective into one run, labeling it "Base Case with Assumed Cost-Effective ECOs Implemented." Or, suggest studying ECOs individually first and eliminating those that are marginally cost-effective from any combination run performed later. This last method is recommended. However the runs are to be analyzed, the analyst and the building contact person should agree beforehand on how and which ECOs are to be investigated.

<u>Step 6 - Complete Input Forms</u>. Next, complete the data input forms found in the ASEAM 2.1 Manual (ACEC 1987). At the same time, keep data sheets. On these data sheets record, for example, how the U-factor for walls and wall areas was calculated or on what blueprint page the wall construction section is found.

Step 7 - Enter Input Data Into ASEAM2.1. Once the data input forms are completed, enter the "base-case" information into the ASEAM input programs. Because the building data are being entered for the first time, the sequence of steps outlined below [and discussed in more detail in the ASEAM2.1 User Manual (ACEC 1987)] must be followed. Enter only base-case input data first; ECO inputs will be entered later, in Steps 11 and 12. Data should be entered in the following sequence: 1) enter the Loads Input program first; and 2) after all of the Systems Input data have been entered and saved, enter the Plant Input.

Step 8 - Specify Base-Case Run Data and Run Calculations. The first calculation can be performed once the complete base-case input files for the loads, systems, and plant segments have been completed. Follow the instructions in the ASEAM2.1 User Manual (ACEC 1987).

Step 9 - Validate Base-Case Run (existing buildings). After the first energy calculation is performed, the predicted, or calculated, energy consumption is validated against the actual energy bills or metered data, if available. In this step, the input parameters may be changed, if necessary, to match the predicted and actual energy consumption more closely. This can be the most difficult and time-consuming step.

Experience with building energy analysis will help determine which inputs should be adjusted up or down and which have a significant impact on the predicted annual consumption. Many input items can be termed "soft," and assumptions about them will be necessary when entering data. Examples include infiltration rates, diversity factors, ventilation rates, and equipment efficiencies. Even the "hard" inputs can be erroneous. For example, wall U-factors may be incorrect if the insulation contains moisture; the wall areas may have been incorrectly calculated; or a large computer's power and cooling load requirements may have been omitted. The possibilities for input errors are nearly limitless.

By comparing the predicted and actual individual end-use energy consumption, potential input data corrections can be easily found. If, for example, a building's gas consumption is low, and gas is used only for heating, only inputs that affect the heating load need be adjusted. If, on the other hand, predicted electricity consumption is high, the lighting diversity factors may need to be reduced; this reduction will also affect the heating load in the building. If the building uses electricity as its only energy source, finding the right input values is more difficult.

Given such considerations, it is not necessary to match the energy consumption exactly. What is most valid in any building analysis are the comparative results while looking at alternatives. The predicted savings from most ECOs can be quite accurate, even though the base-case run cannot be closely validated. When validating base-case input data, change input parameters and rerun the calculations. This validation can be performed in one of two ways:

- If practicable, use an actual weather file covering the same 12 months as the energy billing data. ASEAM 2.1 allows the user to input weather data from the computer keyboard to generate an ASEAM compatible bin weather file.

- Change the suspect input data in the loads, systems, and plant input programs by editing the original file data. When the calculations are done and the new predicted consumption is determined, review the results. This procedure may have to be repeated many times.

- Use the parametric processor calculation mode to adjust the "soft" inputs, changing, for example, the infiltration rate, diversity factors, ventilation rates, and equipment efficiencies. Once the calculations are complete, sort them to find which combinations of inputs give the closest match to the actual. Then adjust the input values in the base-case input files, and rerun the calculations.

- For ECO analysis, the ASHRAE typical meteorological year (TMY) weather files supplied with ASEAM should be used to determine expected energy savings.

<u>Step 10 - Estimate ECO Costs</u>. When the base-case input files have been established through the validation step, begin the ECO modeling. First determine the cost for each ECO to be analyzed. If only a simple payback calculation is required, omit Step 11 below. If an LCC calculation is required, complete Step 11.

<u>Step 11 - Enter ECO/LCC Input Data</u>. To perform an LCC analysis, create an LCC input file for each ECO to be analyzed. If only a simple payback calculation is required, proceed to Step 12. Because both the LCC input files and the ECO files need to be created before performing the integrated ECO/LCC calculations, Step 12 can be performed before the LCC input data are entered.

<u>Step 12 - Enter ECO Input</u>. Create the ECO input data files for <u>each</u> ECO to be investigated. There are two ways of doing this; either or both methods can be used:

- editing the original loads, systems, or plant input files to model the ECO - Use this method for more complicated ECOs (e.g., changing the system and plant types). Use the input programs for each segment, saving each ECO with a different file name.

- using the ECO input program available in ASEAM2.1 (ACEC 1987) - This method is recommended wherever possible and can be used in conjunction with the first method. In this mode, only one change is allowed--either a different input file (loads, systems, or plant) or a single ECO file created in the ECO Input Program. All other data used in the calculations will be the same as in the base-case analysis. Specify the type of economic analysis to be performed: none, simple payback only, or detailed LCC.

Step 13 - Run ECO Calculations (Single). It is recommended that each ECO be analyzed individually before the combined effects of several ECOs are calculated. As a result, some ECOs can be eliminated from consideration before the combined ECO effects are analyzed.

To analyze each ECO individually, create all the ECO input files using one or both of the methods in Step 12. As many as 40 single ECO runs can be specified at one time. ASEAM will calculate the base-case run first; store the results; then automatically proceed with the calculations for the first ECO case, including LCC results if specified; store the results for this analysis; automatically start the second ECO case; and so on. The user does not need to be present during the calculations (in any mode). ASEAM will perform all analyses specified and store the results in output files.

Step 14 - Enter Combined ECO/LCC Input Data. After performing the ECO analyses individually, analyze the results to help determine which ECO combinations should be studied. For example, if an ECO is not cost-effective by itself, it is probably not cost-effective when combined with other ECOs. It may be useful to establish priorities for the individual ECOs from most to least cost-effective. If an LCC analysis is to be performed, create LCC input files for the combined ECO analyses.

Step 15 - Run ECO Calculations (combined). Input files have already been created that model the ECO cases individually. To study the combined effects of many ECOs, specify the ECO combinations that are to be analyzed together. Up to 39 individual ECOs can be combined into one run--13 each for loads, systems, and plant type ECOs. A maximum of 20 combination runs can be specified for overnight execution. The results of each ECO run, whether singularly or in combination, will be stored automatically in files on the data disk.

Step 16 - Present Findings. The final step is to present the results of the analysis to the building contact.

2.4.3 Zoning

As mentioned above, zoning the building is one of the most important steps in any building energy analysis program. This step must be performed before the data are collected and entered. Except for general building data, input data for all loads must be entered by zone. The accuracy of the model is largely determined by the definition of the thermal zones. Once the zones are defined and data are entered into the loads input program, it is difficult to change the zoning. If zones are added or deleted, the data must be collated again using the new zone definitions, and the data must be re-entered.

Zone Definition

A zone is an area of the building (more precisely, a volume) that is modeled as one thermal unit. It is defined to be at a uniform space temperature, and all thermal heat gains and losses are calculated on a per zone basis. Ideally, the areas served by each thermostat in the building would constitute a zone.

Realistically, however, those areas in a building with similar load profiles need to be combined into one zone. The heating and cooling loads of a zone can be satisfied by only one system. A system, on the other hand, may serve one or many zones. ASEAM can model up to ten zones.

Zoning Steps

There is not one fixed, correct way to zone a building. Different definitions of the zones will result in different zone loads, equipment operating time, and energy consumption.

The zones of a building must reflect both architectural and systems layout. If the building is served by more than one system (not counting baseboard heaters as a separate system), the zone boundaries should reflect, first, the system boundaries and, second, the architectural layout. If the building has only one system, however, the zone boundaries should reflect the architectural layout of the building. In that case, it is usual to have core and perimeter zones. Perimeter zones have exterior walls and windows; hence, the loads may be strongly driven by outdoor temperature and solar gains. The interior core zone, however, typically has relatively constant internal gains (people, lights, and equipment) and low conductive losses because its only exterior surface may be the roof.

Because the thermal heating and cooling load profiles for the core and perimeter areas are so different, these areas should be divided into different zones. Perimeter areas often are subdivided into exposures (i.e., north, south, east, and west, or one zone per building face) because the amount of solar gain varies widely from face to face throughout the day. For example, on an afternoon with moderate (e.g., 40°F) outside air temperature, an east-facing perimeter zone could require heating, and a west-facing perimeter zone could require cooling. If these two areas were combined into a single zone, the heating and cooling loads would be summed, canceling each other to some extent, and would therefore not accurately indicate the loads on the system.

The following steps may be used to zone the building:

1. Divide the building into areas served by each separate system. If the building has unitary system types (e.g., fan coil units and heat pumps), consider these as one system, not as a separate system for each room.

2. Divide the system areas defined above into thermostatic zones and areas with similar load profiles. (Some central system types may have only one thermostat for a relatively large area of the building.)

   If the system is capable of controlling each space individually, divide the system areas (from Step 1 above) into zones with similar load profiles (e.g., exposures). Such subdivisions would be appropriate only if the system has many thermostats (e.g., unitary systems), or large central systems with reheat boxes, mixing boxes (dual duct or multizone), or variable air volume boxes. If one discharge air temperature satisfied the entire area--as in the case of single zone furnaces, or heating and ventilating units, for example--it would not be appropriate to subdivide this area into separate zones by exposure. A house, for example, has different load profiles for each exposure, but generally only one thermostat.

In subdividing system areas into zones with similar load profiles, consider not only exposures but also the function or use of the areas. For example, a south-facing office area would have a different load profile than a south-facing computer room, cafeteria, conference room, or entrance lobby. Because ASEAM uses "diversified" (or average) loads for occupied and unoccupied periods, the division by use or function is more important than for building energy analysis programs that use hour-by-hour calculations.

3. Given the constraint that ASEAM can model a maximum of ten zones, it may be necessary to combine different areas into a single zone. In this case, weight-average the data entries. For example, the activity of (and heat generated by) people in a gymnasium zone varies widely, and the data entry should reflect a weighted average of all the people. If office areas with storage space, corridors, and toilets must be combined, the data requirements for lighting, people, miscellaneous electrical loads, and diversity factors should also be a weighted average value for the entire zone.

4. Finally, it may also be desirable to consider the ECOs in subdividing building areas into zones. If several changes in one particular area of the building are being investigated, it may be advantageous to make this area a unique zone. Because ECOs may only apply to certain areas, data entry can be facilitated by making these areas individual zones at the beginning rather than calculating new weighted average values (e.g., lighting) for all ECO changes.

2.5 MODELING CAVEATS AND BASE-CASE BUILDING PARAMETERS

The ECOs modeled in Section 2.6 should be regarded as examples for ECO modeling rather than as a report on ECO impacts. No attempt should be made to use these results to draw conclusions about the performance of a particular ECO without considering the specifics of the project at hand.

This warning is intended as a reminder that a building behaves as a "whole" unit in a dynamic manner. Energy performance involves the building envelope, occupant activities and requirements, climate, system types, control strategies, etc. Therefore, the energy impact of a particular modification must be evaluated within the context of the entire building and its components. For example, adding insulation to the walls may require additional cooling under certain conditions. If the impact of this ECO is analyzed as an autonomous item isolated from the system interaction (discriminators, economizer cycles, heat recovery, etc.), inaccurate conclusions may be drawn. As another example, a reduction in the building loads does not necessarily translate into a similar or proportional reduction in the building energy consumption. The system type and its control strategies will often determine how much energy will be saved.

The ASEAM modeling results presented in Section 2.6 can be examined only in the light of the previous discussion. Some of the ECOs yielded negative results to seemingly advantageous modifications. For example, the HVAC system modeled was a dual-duct constant volume system, an energy-inefficient system by today's standards. However, some of the ECOs that would be advantageous with variable air volume systems might not be appropriate for this particular system. For example, installing an economizer cycle on the dual-duct system may increase the building's net energy consumption. An economizer on a variable air volume system, however, will show a net energy savings.

The climate is also a major factor when examining the impacts of a particular ECO. ECOs intended to reduce heating energy consumption will perform best in cold climates. Likewise, the ECOs intended to reduce cooling consumption will work best in warm climates. The location used in this ECO modeling was Washington, D.C., which has somewhat average climatic conditions compared with cold or warm climates. Therefore, the ECOs' performance reported in this work may not be representative of the best performance possible from any given ECO.

The economic impact of a particular ECO should always be determined by the local energy costs, their escalation rates, the cost of ECO implementation, and other engineering economics parameters. The results presented in this work only provide an estimate of the cost of energy saved based on hypothetical energy prices. All of the appropriate economic parameters should be used when analyzing a particular ECO.

A typical office building was selected as a base case to illustrate the various ECO measures. The selection was meant to reflect a below-average energy performance; many of its features were purposefully energy inefficient to prepare them for the selected ECOs. Even with these deliberate inefficiencies, the building performed better than some existing buildings. The building consumed an estimated 180,000 Btu/ft^2-year, despite being 40% glass and being a relatively inefficient dual duct system.

The building modeled was a scaled down variation of the large office building used in the DOE-2.1C sample runs (Buhl and Hirsch 1986). The following is a summary of the major building features.

<u>Architecture</u>

Shape	Rectangular (100' x 200'), with major facade facing due east.Height3 occupied stories--13' floor-to-floor, 9' ceilings.
Areas (Gross)	Total building gross area of 60,000 ft^2.
Structure	Concrete walls and floors.

Floors — Bottom floor is a 4" concrete slab on grade. All others are 4" concrete. R-6 insulation was later added to perimeter bottom floors as an ECO (15).

Exterior Walls — 8" concrete wall with wall finishing and 1" insulation, R-5.4. As an ECO (13), R-6 insulation was later added.

Roof — Built-up roofing on concrete, with 2" insulation, R-10. As an ECO (10), R-10 insulation was added.

Ceilings — Suspended acoustical tile with lay-in fluorescent light fixtures.

Windows — Single pane, shading coefficient = 0.94. Windows are 6.5' high on every floor, occupying 40% of the gross wall area. Infiltration was above average and the windows had no interior or exterior shading. Several window ECOs were demonstrated, including the following:

- storm windows, ECO 16
- movable window insulation, ECO 17
- exterior shading, ECO 19
- interior shading, ECO 20
- reflective films, ECO 21
- weatherstripping and caulking, ECO 24.

Doors — Assumed to be in the middle of the east and west facades. They were not explicitly modeled for conduction losses-- only in filtration losses were modeled. The doors were assumed to be of a single swing type. The high traffic rate resulted in an infiltration rate of 1.8 air changes per hour (ACH) for the east and west zones. A vestibule was later added to the single swing doors as an ECO (25) and then replaced by revolving doors as an alternate ECO (25).

<u>Interior Conditions</u>

Lightin — Recessed fluorescent, 2.2 watts/ft^2, 20% heat to ceiling plenum. A provision for task lighting was made in the ASEAM input to allow it to be investigated as an ECO. Lighting ECOs investigated include the following:

- reduction of illumination level, ECO 82
- task lighting, ECO 84
- daylighting, ECO 91.

Misc. Equipment — Miscellaneous (receptacle) electrical equipment totaled 0.18 watts/ft^2.

People — About 100 ft^2 per person in exterior zones and 200 ft^2/person in interior zones.

Schedules

Occupancy — The base-case building is occupied between 7:00 AM and 8:00 PM. It is fully occupied from 8:00 AM to 4:00 PM except for a decrease during the lunch hour. After 4:00 PM, occupancy decreases until only the maintenance crew remains. This occupancy schedule resulted in the following daily diversity factors:

- 80% for occupied hours
- 5% for unoccupied hours.

Lighting — The lighting usage is close to 100% during the day, with a slight depression at lunch. After 4:00 PM, the usage steps down steadily to 20% at 10:00 PM, and near zero after midnight. This lighting schedule resulted in the following daily diversity factors:

- 95% for occupied hours
- 35% for unoccupied hours.

These diversity factors were later reduced to reflect the implementation of ECO 4.

Misc. Electric — The miscellaneous electric (office) equipment was used from 7:00 AM to 8:00 PM. Its usage was 50% during the morning, 75% in the afternoon, and 30% in the evening. This equipment schedule resulted in the following daily diversity factors:

- 65% for occupied hours
- 10% for unoccupied hours.

These diversity factors were later reduced to reflect the implementation of ECO 6.

Exterior Conditions

Location — Washington, D.C., longitude 75.05 West, latitude 38.08 North, and Eastern time zone.

HVAC System

Description — The entire building is supplied by one double duct constant volume system. Common plenums on each floor serve as the return air path. No economizer cycle was used in the base case; however, a temperature controlled economizer cycle was added later as an ECO (53). The minimum relative humidity was set at 40%, which was also changed as an ECO (8). A single duct variable air volume system was also considered as an ECO (50).

Design Temp. Cooling: 76°F (May through September)
Heating: 72°F (October through April)
Winter unoccupied temperature: 68°F
The occupied cycle temperature setpoints were later changed (ECO 7). The unoccupied cycle period heating setpoint was changed also as an ECO (9).

Supply Air The hot deck temperature was reset from 120°F at 15°F outside temperature to 70°F at 70°F outside temperature. The cold deck cooling discharge set point was 55°F. Mechanical cooling was available year-round when the outside temperature is above 40°F. The total air flow to the system was based on the summation of the zone's peak requirements. No cold deck temperature reset was used; however, discriminator controls on both the cold and hot deck were later added as an ECO (51). A 100-kW supply fan was used. The fan cycles with loads during the unoccupied hours. The air flow rate was reduced as an ECO (64) and the fan power was lowered accordingly.

Ventilation The minimum outside air was set at 20% for both the occupied and unoccupied periods using fixed dampers. This setting was then reduced as an ECO (26) to reflect lower outside air requirements. In a later run, another ECO (28) used a heat exchanger to preheat outside air when needed. An economizer cycle was also modeled as an ECO (53).

Controls The dual duct system is shut off during the weekends and holidays. The system is turned on at 6:00 AM and shut off at 5:00 PM; however, this time of operation was later reduced as an ECO (1). Heating is available from October through May, and mechanical cooling is always available when the outside temperature is above 40°F.

<u>HVAC Plants</u>

Boiler One gas-fired boiler was used with an output rated capacity of 2,500 KBTUH. Many boiler ECOs were considered, including the following:

- cleaning the surface fouling (ECO 35)
- adjusting the flue draft (ECO 36)
- preheating combustion air (ECO 39)
- automatic vent dampers (ECO 41)
- replacement with 3 smaller modular units (ECO 46).

Chiller — Two reciprocating chillers with a cooling capacity of 150 tons each were modeled in the base case. The chillers were connected in parallel and were both left on all the time. Many chiller ECOs were considered, including the following:

- cleaning the evaporator and condenser of fouling (ECO 31)
- raising the evaporator water temperature (ECO 32)
- isolating the off-line chiller (ECO 33).

Cooling Tower — Four cells with a total heat rejection capacity of 400 tons.

Domestic Hot Water — Natural-gas-fired domestic hot water heat with a hot water heating capacity of 90.1 KBTUH. Hot water is supplied at 140°F with a forced circulation pump operating continuously. The hot water pipes were initially not insulated. Many domestic hot water ECOs were considered, including the following:

- reduce operating hours (ECO 3)
- reduce hot water consumption (ECO 72)
- lower hot water temperature (ECO 73)
- preheat feed water with reclaimed waste heat (ECO 74)
- insulate pipes (ECO 75)
- insulate water storage tank (ECO 76)
- install decentralized water heaters (ECO 77).

Energy Costs — Gas is $0.50 per therm. Electricity is $0.05 per kWh.

Equipment Sizing — All equipment sizing was based on design peak loads for the base-case building. All sizes were fixed throughout the ECO analysis except when the ECO required a size change. This fixed sizing yields more realistic conclusions on the impact of the various ECOs.

2.6 ASEAM MODELING OF SAMPLE ENERGY CONSERVATION OPPORTUNITIES

Chapter 1.0 of this volume described 118 ECOs and how to implement them. In this section, ASEAM 2.1 is used to analyze 94 of these ECOs (ACEC 1987). The remaining 24 could not be analyzed by ASEAM for various reasons, including 1) the ECO recommended addition of equipment and/or systems that are not commonplace or state-of-the art HVAC systems at this time; 2) the ECO dealt with peak demand reduction or thermal storage; 3) the ECO concerned reducing losses in the electric power system, which ASEAM 2 cannot analyze; 4) the ECO recommended a central system that ASEAM could not simulate; and 5) the ECO dealt with an O&M item that ASEAM does not simulate.

In the rest of this section, the modeling approach and input data requirements are discussed for the 94 ECOs that ASEAM can simulate. Sample input and output pages are shown when appropriate; the input pages are boxed, whereas the output pages appear as tables. Many of the ECOs analyzed in this section used the ECO calculation discussed in Section 2.3. When this was done, the input screen that was changed is identified as it would appear in the ASEAM 2.1 program, for example, ASEAM2 ECO #210. Also, to further help the energy analyst, references to other sources of information concerning analysis of each specific ECO are also presented when appropriate.

<u>ECO 1 - Reduce Operating Hours for Space Heating and Cooling Systems</u>

In the base-case building, the heating and cooling system started two hours before the building was occupied (6 AM startup for 8 AM occupancy), and was shut off one hour after normal occupancy (system was shut down at 5 PM for 4 PM end of occupancy). To reduce the system operating hours, the Building Schedules screen (ASEAM2 ECO #210) is accessed and the operating schedule is changed (see below). The new schedule reflects system start up at 7 AM and system shut down at 4:30 PM.

```
+)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))),
*OCCUPANCY SCHEDULES                                                              *
*                                                                                 *
*---------------------------------------------------------------------------------*
*    Enter the typical OCCUPIED schedule - Use military time (5:30 pm = 1730)     *
*                                                                                 *
*            Values should be in 'hundreds' of hours  - 8 am = 800                *
*                                                                                 *
*              If UNOCCUPIED for entire day - use   0  to  0                      *
*                                                                                 *
*        (See Caution in User's Manual if Occupied for Entire Day)                *
*                                                                                 *
*                      Day of Week                                                *
*                                                                                 *
*                      Weekdays .... from   0700  to   1630                       *
*                      Saturdays ... from   0___  to   0___                       *
*                      Sundays ..... from   0___  to   0___                       *
*                                                                                 *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	45,634	3,417	7.0
Electricity	kWh	1,720,663	1,600,091	120,572	7.0
Gas	Dollars	24,525	22,817	1,708	7.0
Electricity	Dollars	86,033	80,005	6,029	7.0
Annual Totals	Dollars	110,559	102,822	7,737	7.0
Gas	MBTU	4,905.092	4,563.425	341.667	7.0
Electricity	MBTU	5,872.621	5,461.111	411.510	7.0
Annual Totals	MBTU	10,777.710	10,024.540	753.170	7.0

ECO 2 - Reduce Operating Hours for Ventilation Systems

This ECO is modeled in the same manner as ECO 1 because the heating and cooling system also provides the ventilation. For changes in the ventilation rate, see ECO 26. See ECO 1 for sample input and output pages for this ECO.

ECO 3 - Reduce Operating Hours for Water Heating Systems

The base-case building was modeled with a circulating pump running continuously during the occupied and unoccupied cycle. The constant flow of warm temperature water through the uninsulated pipes resulted in a large constant heat loss of 12,300 Btu/hr in addition to standby losses of 700 BTUH in a hot water tank.

In this ECO, we will simulate turning off the circulating pump during the unoccupied cycle by changing the pump kW and heat losses during the unoccupied cycle. These changes are made in the Domestic Hot Water (DHW) ECO screen (ASEAM2 ECO #570 - see below). The hot water tank standby losses are not eliminated because the hot water in the storage tank is still maintained at 140°F.

For information on pipe heat losses, refer to Stamper and Koral (1979).

```
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*ASEAM2 ECO INPUT: PLANT - Domestic Hot Water                 Input File:BASEBLDG*
*DOMESTIC HOT WATER                ECO No: 570   Case No: 1    ECO File:1PT3570A*
*-----------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                                 30_    therms *
*                                                                              *
*  Average hourly DHW usage - occupied cycle                       66__   gal/hou*
*  Average hourly DHW usage - unoccupied cycle                     0___   gal/hou*
*                                                                              *
*DHW Temperatures                                                              *
*  Domestic hot water supply temperature                           140    °F     *
*  DHW inlet temperature - design summer                           60     °F     *
*  DHW inlet temperature - design winter                           40     °F     *
*Circulating Pumps                                                             *
*  Circulating pump KW - occupied cycle                            2__    KW     *
*  Circulating pump KW - unoccupied cycle                          0__    KW     *
*DHW Efficiency and Losses                                                     *
*  Design DHW heating efficiency                                   75_    %      *
*  DHW losses - occupied cycle                                     13000_ BTUH   *
*  DHW losses - unoccupied cycle                                   700___ BTUH   *
.)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	48,107	944	1.9
Electricity	kWh	1,720,663	1,708,889	11,774	0.7
Gas	Dollars	24,525	24,054	472	1.9
Electricity	Dollars	86,033	85,444	589	0.7
Annual Totals	Dollars	110,559	109,498	1,061	1.0
Gas	MBTU	4,905.092	4,810.700	94.392	1.9
Electricity	MBTU	5,872.621	5,832.439	40.182	0.7
Annual Totals	MBTU	10,777.710	10,643.140	134.570	1.2

ECO 4 - Reduce Operating Hours for Lighting Systems

This ECO is modeled by reducing the occupied and/or unoccupied cycle diversity factors for lighting using the Diversity Factor ECO screen (ASEAM2 ECO #200). In the base-case building, a "lighting awareness" program was assumed to have been implemented by placing stickers on all the light switches. This measure was assumed to reduce the time that the lights are on (diversity factor) from 95% in the base case to 90% as a result of the ECO. This is illustrated in the following screen. Note that modeling this ECO may require some manual calculations and engineering assumptions.

```
+)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))),
*ASEAM2 ECO INPUT: ZONE  1 - ROOF-ZONE1-CORE                 Input File:BASEBLDG*
*OPERATING USE PROFILES (DIVERSIT  ECO No: 200   Case No: 1    ECO File:1PT4200A*
*-------------------------------------------------------------------------------*
*                                          OCCUPIED  UNOCCUPIED  MONTHLY DIV FC*
*                                           PERIOD     PERIOD     TABLE # (1-4)*
*People:                                                                       *
*           Average % of full occupancy       80__       5___                  *
*                                                                              *
*Lights:                                                                       *
*GENERAL    Average % of installed capacity   90__       35__                  *
*TASK       Average % of installed capacity   60__       5___                  *
*NA         Average % of installed capacity   ____       ____                  *
*NA         Average % of installed capacity   ____       ____                  *
*                                                                              *
*Electric Equipment:                                                           *
*MISC.      Average % of installed capacity   65__       10__                  *
*NA         Average % of installed capacity   ____       ____                  *
*                                                                              *
*Miscellaneous Sensible Loads:                                                 *
*NA         Average % of installed capacity   ____       ____                  *
*NA         Average % of installed capacity   ____       ____                  *
.))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,216	-165	-0.3
Electricity	kWh	1,720,663	1,698,740	21,923	1.3
Gas	Dollars	24,525	24,608	-83	-0.3
Electricity	Dollars	86,033	84,937	1,096	1.3
Annual Totals	Dollars	110,559	109,545	1,013	0.9
Gas	MBTU	4,905.092	4,921.641	-16.549	-0.3
Electricity	MBTU	5,872.621	5,797.799	74.822	1.3
Annual Totals	MBTU	10,777.710	10,719.440	58.270	0.5

ECO 5 - Reduce Operating Hours for Escalators and Elevators

ASEAM does not model energy use of elevators and escalators. Energy consumption values not calculated by ASEAM maybe entered for accounting purposes in the Miscellaneous Energy Consumption screen. As outlined in the ASEAM User's Manual (ACEC 1987), these user-entered values would include exterior lighting, vertical transportation, cooking, and other types not normally calculated by building thermal models.

The main advantage of entering energy consumption values in this screen is to have these miscellaneous consumption values automatically accounted for in each ASEAM run--just as if they were calculated by ASEAM. Otherwise, the energy consumption of these items would have to be added manually to the Building Energy End-Use Summary (called "BEPS") report generated for each ASEAM run.

In the base-case building, we predicted an annual elevator consumption of 50,000 kWh. By manual calculation, the electric consumption could be reduced by 5,000 kWh by decreasing the elevators' operating time. The new electric consumption (45,000 kWh) is entered in the Miscellaneous Energy Consumption ECO screen (ASEAM2 ECO #510). If this ECO were investigated in combination with many ECOs and life-cycle costs were analyzed, the advantages of automatic accounting would be obvious.

For a discussion on reducing elevators'/escalators' operating time, refer to the discussion of ECO 5 in Chapter 1 of this document.

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*ASEAM2 ECO INPUT: PLANT - Misc Energy Consumption           Input File:BASEBLDG*
*MISCELLANEOUS ENERGY CONSUMPTION  ECO No: 510   Case No: 1    ECO File:1PT5510A*
*-------------------------------------------------------------------------------*
*                                                                               *
*Label for Miscellaneous             Fuel Units        Annual Consumption      *
*Energy Consumption               (See Codes Below)      in Energy Units       *
*-------------------------------------------------------------------------------*
* Elevator_________________              3                  45000___           *
* _________________________              _                  ________           *
* _________________________              _                  ________           *
* _________________________              _                  ________           *
* _________________________              _                  ________           *
*                                                                               *
*-------------------------------------------------------------------------------*
*                    Fuel Code       Fuel Type      Energy Units                *
*                    ---------       ---------      ------------                *
*                        1           Natural Gas       therms                   *
*                        2           Oil               gallons                  *
*                        3           Electricity       KWH                      *
*                        4           Dist Heating      MBTU                     *
*                        5           Dist Cooling      MBTU                     *
.)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,051	0	0.0
Electricity	kWh	1,720,663	1,715,663	5,000	0.3
Gas	Dollars	24,525	24,525	0	0.0
Electricity	Dollars	86,033	85,783	250	0.3
Annual Totals	Dollars	110,559	110,309	250	0.2
Gas	MBTU	4,905.092	4,905.092	0.000	0.0
Electricity	MBTU	5,872.621	5,855.556	17.065	0.3
Annual Totals	MBTU	10,777.710	10,760.650	17.060	0.2

ECO 6- Reduce Operating Hours for Equipment and Machines

This ECO is modeled by reducing the miscellaneous equipment diversity factors in the Diversity Factor ECO screen (ASEAM2 ECO #200). In the base-case building, assume that 10% of the electrical equipment (computer terminals, coffee makers, etc.) were left on all night. If 50% of these terminals were turned off, the unoccupied cycle diversity factor would be changed to 5% (see below). For further discussion on reducing operating time for machines and equipment, refer to the discussion of ECO 6 in Chapter 1 of this document.

```
+))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))),
*ASEAM2 ECO INPUT: ZONE  1 - ROOF-ZONE1-CORE                  Input File:BASEBLDG*
*OPERATING USE PROFILES (DIVERSIT  ECO No: 200   Case No: 1    ECO File:1PT6200A*
*-------------------------------------------------------------------------------*
*                                          OCCUPIED  UNOCCUPIED  MONTHLY DIV FC*
*                                           PERIOD     PERIOD     TABLE # (1-4)*
*People:                                                                        *
*           Average % of full occupancy       80__       5___                   *
*                                                                               *
*Lights:                                                                        *
*GENERAL    Average % of installed capacity   95__       35__                   *
*TASK       Average % of installed capacity   60__       5___                   *
*NA         Average % of installed capacity   ____       ____                   *
*NA         Average % of installed capacity   ____       ____                   *
*                                                                               *
*Electric Equipment:                                                            *
*MISC.      Average % of installed capacity   65__       5___                   *
*NA         Average % of installed capacity   ____       ____                   *
*                                                                               *
*Miscellaneous Sensible Loads:                                                  *
*NA         Average % of installed capacity   ____       ____                   *
*NA         Average % of installed capacity   ____       ____                   *
.)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,121	-71	-0.1
Electricity	kWh	1,720,663	1,715,678	4,985	0.3
Gas	Dollars	24,525	24,561	-35	-0.1
Electricity	Dollars	86,033	85,784	249	0.3
Annual Totals	Dollars	110,559	110,345	214	0.2
Gas	MBTU	4,905.092	4,912.144	-7.052	-0.1
Electricity	MBTU	5,872.621	5,855.608	17.013	0.3
Annual Totals	MBTU	10,777.710	10,767.750	9.960	0.1

ECO 7 - Lower Heating and Raise Cooling Temperature Setpoints

This ECO is modeled by changing the values in the Thermostat Setpoints ECO screen (ASEAM2 ECO #220). The changes in the thermostat setpoints for this ECO are shown below:

	Existing Setpoint	Revised Setpoint
Summer Occupied Temperature	76	78
Winter Occupied Temperature	72	70

See ECO 9 for heating setback during the unoccupied cycle. For information on space conditions setpoints, refer to applicable standards and local codes.

```
*ASEAM2 ECO INPUT: ZONE  1                              Input File:2PT1220A*
*THERMOSTAT ECOS                  ECO No: 220   Case No: 1    ECO File:2PT1220A*
*-------------------------------------------------------------------------------*
*                                                                               *
*Zone label                       ROOF-ZONE1-CORE_________________________     *
*                                                                               *
*Thermostat Set Point Temperatures                                              *
*  Summer occupied temperature                          78__  °F               *
*  Winter occupied temperature                          70__  °F               *
*  Winter unoccupied temperature                        68__  °F               *
*                                                                               *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	47,617	1,434	2.9
Electricity	kWh	1,720,663	1,709,499	11,164	0.6
Gas	Dollars	24,525	23,809	717	2.9
Electricity	Dollars	86,033	85,475	558	0.6
Annual Totals	Dollars	110,559	109,284	1,275	1.2
Gas	MBTU	4,905.092	4,761.731	143.361	2.9
Electricity	MBTU	5,872.621	5,834.520	38.101	0.6
Annual Totals	MBTU	10,777.710	10,596.250	181.460	1.7

ECO 8 - Lower Humidification and Raise Dehumidification Setpoints

Changes to the winter relative humidification setpoints are entered in the system Humidification ECO screen (ASEAM2 ECO #330). In the base-case building, the winter relative humidity was changed from 40% to 30% (see below). Because the energy required for humidification depends on the amount of outside air introduced in the outside air dampers, the savings could also depend on the presence of ECOs that affect the ventilation rate: economizer cycles (ECO 53), discriminators (ECOs 51 and 103), and reduced ventilation rates (ECO 26).

The space relative humidity requirements will vary according to building types and space functions. Applicable codes must be reviewed to determine possible ECO implementation.

```
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*ASEAM2 ECO INPUT: SYSTEM  1                                 Input File:2PT2330A*
*HUMIDIFICATION                      ECO No: 330   Case No: 1    ECO File:2PT2330A*
*------------------------------------------------------------------------------*
*Humidification Availability                                                   *
*  Outside temperature above which humidification is off      45_ °F           *
*  Humidification available beginning month #                 10               *
*  Humidification available ending month #                    4_               *
*  Humidification available during unoccupied cycle (Y/N)     N                *
*                                                                              *
*Humidification Setpoints                                                      *
*  Minimum relative humidity maintained (% RH)                30  % RH         *
.))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	47,115	1,936	3.9
Electricity	kWh	1,720,663	1,720,572	91	0.0
Gas	Dollars	24,525	23,557	968	3.9
Electricity	Dollars	86,033	86,029	5	0.0
Annual Totals	Dollars	110,559	109,586	973	0.9
Gas	MBTU	4,905.092	4,711.474	193.618	3.9
Electricity	MBTU	5,872.621	5,872.313	0.308	0.0
Annual Totals	MBTU	10,777.710	10,583.790	193.920	1.8

ECO 9 - Set Heating Setpoints Back When the Building Is Not Occupied

The unoccupied cycle heating setpoint is changed in the Thermostat ECO screen (ASEAM2 ECO #220). In the base-case building, the unoccupied heating setpoint is changed from 68°F to 65°F (see below). Excessive thermostat setback during unoccupied hours will increase the startup energy requirements, especially for medium to high thermal mass buildings. These effects are not explicitly modeled by ASEAM because the bin method does not account for space temperature floating. In this case, the user should increase the startup time by turning the system on earlier in the occupancy schedule screens; the ECO would then be run as a multiple ECO.

```
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*ASEAM2 ECO INPUT: ZONE  1                                  Input File:2PT3220A*
*THERMOSTAT ECOS                  ECO No: 220   Case No: 1    ECO File:2PT3220A*
*-------------------------------------------------------------------------------*
*                                                                               *
*Zone label                       ROOF-ZONE1-CORE_________________________     *
*                                                                               *
*Thermostat Set Point Temperatures                                              *
*  Summer occupied temperature                             76__  °F             *
*  Winter occupied temperature                             72__  °F             *
*  Winter unoccupied temperature                           65__  °F             *
.)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	45,900	3,151	6.4
Electricity	kWh	1,720,663	1,717,413	3,250	0.2
Gas	Dollars	24,525	22,950	1,576	6.4
Electricity	Dollars	86,033	85,871	163	0.2
Annual Totals	Dollars	110,559	108,820	1,738	1.6
Gas	MBTU	4,905.092	4,589.958	315.134	6.4
Electricity	MBTU	5,872.621	5,861.529	11.092	0.2
Annual Totals	MBTU	10,777.710	10,451.490	326.220	3.0

ECO 10 - Insulate Ceilings and Roofs

The roof of the base-case building had a U-factor of 0.100 BTUH/ft^2-°F. The Roof ECO screen (ASEAM2 ECO #110) was accessed and the U-factor was changed to 0.05 to reflect the addition of R-10 insulation. No other roof data were changed (see below). Information on thermal insulation types and levels can be found in ASHRAE (1985).

```
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*ASEAM2 ECO INPUT: ZONE  1 - ROOF-ZONE1-CORE                 Input File:BASEBLDG*
*ROOF ECOS                          ECO No: 110   Case No: 1    ECO File:3PT1110A*
*-----------------------------------------------------------------------------*
*ROOFS                              Roof 1     Roof 2                          *
*Name (Optional)                    TYPROOF___ NA________                      *
*                                                                              *
*U-Factor (BTUH/ft²-°)              0.05_      _____                           *
*Roof Construction Code             9_         __                              *
*Color Correction                   1__        ___                             *
*                                                                              *
*       Roof Construction Codes - see ASHRAE F26.8 T5 - numbers 1 thru 13      *
*       Color Correction Codes   1 = Dark Colored or in an industrial area     *
*                              .5 = permanently light colored or in rural area  *
.)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	48,149	902	1.8
Electricity	kWh	1,720,663	1,718,407	2,256	0.1
Gas	Dollars	24,525	24,075	451	1.8
Electricity	Dollars	86,033	85,920	113	0.1
Annual Totals	Dollars	110,559	109,995	564	0.5
Gas	MBTU	4,905.092	4,814.921	90.171	1.8
Electricity	MBTU	5,872.621	5,864.924	7.697	0.1
Annual Totals	MBTU	10,777.710	10,679.850	97.860	0.9

ECO 11 - Install Vapor Barriers in Ceilings and Roofs

This ECO cannot be modeled by ASEAM.

ECO 12 - Install Reflective Roof Surfaces

The roof of the base-case building was dark, resulting in a color correction value of 1. If the roof color were changed by adding a thin layer of light-colored gravel, the color correction value would be changed to 0.5 in the Roof ECO screen (ASEAM2 ECO #110 - see below).

```
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*ASEAM2 ECO INPUT: ZONE  1 - ROOF-ZONE1-CORE                  Input File:BASEBLDG*
*ROOF ECOS                         ECO No: 110   Case No: 1    ECO File:4PT1110A*
*-------------------------------------------------------------------------------*
*ROOFS                             Roof 1     Roof 2                            *
*Name (Optional)                   TYPROOF___ NA________                        *
*                                                                               *
*U-Factor (BTUH/ft²-°)             0.1__      _____                             *
*Roof Construction Code            9_         __                                *
*Color Correction                  0.5        ___                               *
*                                                                               *
*       Roof Construction Codes - see ASHRAE F26.8 T5 - numbers 1 thru 13       *
*       Color Correction Codes   1 = Dark Colored or in an industrial area      *
*                               .5 = permanently light colored or in rural area *
.))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,451	-400	-0.8
Electricity	kWh	1,720,663	1,713,571	7,092	0.4
Gas	Dollars	24,525	24,726	-200	-0.8
Electricity	Dollars	86,033	85,679	355	0.4
Annual Totals	Dollars	110,559	110,404	154	0.1
Gas	MBTU	4,905.092	4,945.133	-40.041	-0.8
Electricity	MBTU	5,872.621	5,848.419	24.202	0.4
Annual Totals	MBTU	10,777.710	10,793.550	-15.840	-0.1

ECO 13 - Insulate Walls

The base-case building walls were insulated with 1 in. insulation (R-5.4, U-factor of 0.187 BTUH/ft^2-°F). In this case, exterior insulation (R-6) was added to the existing wall, resulting in a new U-factor of 0.088 and new color correction of 0.65 (light-colored instead of medium). The Wall ECO Screen (ASEAM2 ECO #100) was accessed, and both the U-factor entry and color correction values were changed (see below). Information on thermal insulation types and levels can be found in ASHRAE (1985).

```
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*ASEAM2 ECO INPUT: ZONE  2 - ROOF-ZONE2-EAST                 Input File:BASEBLDG*
*WALL ECOS                          ECO No: 100   Case No: 1    ECO File:5PT1100A*
*-------------------------------------------------------------------------------*
*WALLS                              Wall 1     Wall 2     Wall 3     Wall 4      *
*Name (Optional)                    EAST WALL_ NA________ NA________ NA________  *
*                                                                               *
*U-Factor (BTUH/ft^2-°)             .088_      ______     ______     ______      *
*Wall Construction Group            B          _          _          _           *
*Color Correction                   .65        ___        ___        ___         *
*                                                                               *
*           Wall Construction Groups - see page F26.9 ('A' through 'G')         *
*           Color Correction Codes     1=Dark   .83=Medium   .65=Light          *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	46,865	2,186	4.5
Electricity	kWh	1,720,663	1,714,543	6,120	0.4
Gas	Dollars	24,525	23,432	1,093	4.5
Electricity	Dollars	86,033	85,727	306	0.4
Annual Totals	Dollars	110,559	109,160	1,399	1.3
Gas	MBTU	4,905.092	4,686.498	218.594	4.5
Electricity	MBTU	5,872.621	5,851.733	20.888	0.4
Annual Totals	MBTU	10,777.710	10,538.231	239.479	2.2

ECO 14 - Install Vapor Barriers in Walls

ASEAM cannot model this ECO.

ECO 15 - Insulate Floors

This ECO is modeled with the Miscellaneous Conduction ECO screen (ASEAM2 ECO #150) using a perimeter losses approach because the floor heat loss was modeled with the Miscellaneous Conduction Screen. It was assumed that only perimeter zones were subject to ground losses and that the core zone does not exchange heat with the ground. This assumption is suitable for buildings with large floor-area-to-perimeter ratio. The original U-factor was changed in all lower level perimeter zones from 0.67 to 0.47 BTUH/ft^2-°F (see below).

Ground losses can be difficult to estimate because most of the information available deals with design conditions. However, some simplified methods can be used when enough data are known about the building ground coupling. These data include type of ground coupling [that is, slab-on-grade, crawl space or (un)heated basement], physical characteristics of all the ground coupling elements, heat gains from ducts or equipment to the crawl space or unheated basement when applicable, and ground temperature and conductivity. For one of the approaches used in the field, see Costello, Kusada, and Aso (1980).

```
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*ASEAM2 ECO INPUT: ZONE  7 - LOWER-ZONE2-EAST                Input File:BASEBLDG*
*MISCELLANEOUS CONDUCTION          ECO No: 150   Case No: 1    ECO File:6PT1150A*
*-------------------------------------------------------------------------------*
*MISCELLANEOUS CONDUCTION                              Type 1        Type 2       *
*                                                                               *
*Name (Optional)                                       GROUND LOSS._ NA__________ *
*                                                                               *
*U-Factor (BTUH/ft²-°)                                 0.47_         _____        *
*Reference temperature at design summer (°F)           80___         _____        *
*Reference temperature at design winter (°F)           17___         _____        *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	48,798	253	0.5
Electricity	kWh	1,720,663	1,720,677	-14	-0.0
Gas	Dollars	24,525	24,399	127	0.5
Electricity	Dollars	86,033	86,034	-1	-0.0
Annual Totals	Dollars	110,559	110,433	126	0.1
Gas	MBTU	4,905.092	4,879.778	25.314	0.5
Electricity	MBTU	5,872.621	5,872.671	-0.050	-0.0
Annual Totals	MBTU	10,777.710	10,752.450	25.260	0.2

<u>ECO 16 - Install Storm Windows and Multiple-Glazed Windows</u>

In the base-case building, storm windows were added to the existing leaky single-pane windows. To simulate this change, three input values were changed in the Window ECO screen (ASEAM2 ECO #120).

	Existing Condition	With Storm Windows
Window U-factor	1.10	0.40
Shading Coefficient	0.94	0.84
Leakage Coefficient	4	2

Information on glazing types and U-values can be found in ASHRAE (1985).

```
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*ASEAM2 ECO INPUT: ZONE  2 - ROOF-ZONE2-EAST                Input File:BASEBLDG*
*WINDOW ECOS                      ECO No: 120   Case No: 1    ECO File:7PT1120A*
*---------------------------------------------------------------------------------*
*WINDOWS                           Window 1   Window 2   Window 3   Window 4   *
*Name (optional)                   EAST______ NA________ NA________ NA________ *
*                                                                              *
*Shading coefficient               .84        ___        ___        ___        *
*U-Factor (BTUH/ft²-°)             .4__       ____       ____       ____       *
*Leakage coefficient               2_         __         __         __         *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	33,663	15,388	31.4
Electricity	kWh	1,720,663	1,698,359	22,304	1.3
Gas	Dollars	24,525	16,831	7,694	31.4
Electricity	Dollars	86,033	84,918	1,115	1.3
Annual Totals	Dollars	110,559	101,749	8,809	8.0
Gas	MBTU	4,905.092	3,366.266	1,538.826	31.4
Electricity	MBTU	5,872.621	5,796.499	76.122	1.3
Annual Totals	MBTU	10,777.710	9,162.765	1,614.945	15.0

ECO 17 - Insulate Movable Windows

The addition of movable window insulation is a modeling problem because the window U-factor changes between day and night and, possibly, between seasons (used primarily in the winter). The Window ECO screen (ASEAM2 ECO #120) should not be used because any new U-factor value entered in this screen is assumed to be constant. The only way to simulate this ECO in ASEAM is by using the Loads Reset ECO screen (ASEAM2 ECO #240). The ASEAM User's Manual discusses this ECO on page 172 (ACEC 1987).

The following data are used to determine the ASEAM ECO input values for adding R-6 movable insulation during the unoccupied cycle:

	Present Condition	Revised Condition
Window U-factor	1.10	0.145
Unoccupied Thermostat Setpoint	68	68

The following equation is used to calculate the conduction heat loss through the window:

Heat Loss = U-Factor * Area * (Toa - Tspace)

The first step in determining the input values is to estimate the change in heat loss resulting from the moveable insulation. Each zone can have different slope and intercept adjustments. For zone 2, with a window area of 1040 sq ft

Present Heat Loss (at 0°F) = 1.10 * 1040 * (0 - 68)
= - 77,792 BTUH

Revised Heat Loss (at 0°F) = .145 * 1040 * (0 - 68)
= - 10,254 BTUH

At 68°F outside temperature, the conduction heat loss is 0 for both cases because the temperature difference is zero. The change in heat loss is therefore as follows:

At 0°F outside temperature = (-10,254 - (-77,792))
= 67,538 BTUH

Note that the adjustment is <u>positive</u>--decreasing the heating load or adding heat!

At 68°F outside temperature = 0 BTUH

To enter this load change in the ECO screen, first express the load savings in the form of a slope and intercept. For this zone, the above heat loss savings can also be expressed as follows:

Slope = -993.2 BTUH per degree (negative!)
Intercept = 67,538 BTUH

The following screen shows how to enter the above load savings as an ECO.

The above calculations must be done for each zone because the slope and intercept values depend on the zone window area. However, because the slope and intercept are directly proportional to the window areas, one can calculate these parameters for any zone simply by multiplying the slope and intercept of the above zone by the ratio of the window area of the zone considered to that of the above zone (provided that all windows have the same U-value). This can be illustrated as follows. The second zone has a window area of 520 sq ft; therefore, it has (0.5 * window area) of the above zone. This results in a slope and intercept equal to one-half of those for the above zone; that is, -496.6 and 33,769, respectively.

Information regarding movable insulation types and insulation levels should be obtained from the manufacturer.

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*ASEAM2 ECO INPUT: ZONE  2 - ROOF-ZONE2-EAST                 Input File:BASEBLDG*
*LOADS RESET SCHEDULE              ECO No: 240   Case No: 1    ECO File:7PT2240A*
*-------------------------------------------------------------------------------*
*Enter Loads Reset Schedule in BTUH                                             *
*Schedule #1    Slope Adjustment  -993.2__ Constant Change  67538___            *
*Schedule #2    Slope Adjustment  ________ Constant Change  ________            *
*Schedule #3    Slope Adjustment  ________ Constant Change  ________            *
*Schedule #4    Slope Adjustment  ________ Constant Change  ________            *
*                                                                               *
*Applicable Months - Enter Schedule # (or 'blank')                              *
*          Occupied Schedule #         Unoccupied Schedule #                    *
*January             _                             1                            *
*February            _                             1                            *
*March               _                             1                            *
*April               _                             1                            *
*May                 _                             _                            *
*June                _                             _                            *
*July                _                             _                            *
*August              _                             _                            *
*September           _                             _                            *
*October             _                             1                            *
*November            _                             1                            *
*December            _                             1                            *
.)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	36,176	12,875	26.2
Electricity	kWh	1,720,663	1,698,004	22,659	1.3
Gas	Dollars	24,525	18,088	6,438	26.2
Electricity	Dollars	86,033	84,900	1,133	1.3
Annual Totals	Dollars	110,559	102,988	7,571	6.8
Gas	MBTU	4,905.092	3,617.573	1,287.519	26.2
Electricity	MBTU	5,872.621	5,795.288	77.333	1.3
Annual Totals	MBTU	10,777.710	9,412.860	1,364.850	12.7

ECO 18 - Install Operable Windows

The most accurate way to model this ECO would be to "schedule" the amount of infiltration so that moderate cooling loads on the exterior of the building could be matched by additional infiltration during periods of cooler outside air temperatures. However, this type of infiltration scheduling is not possible with ASEAM.

Estimate the energy savings for this ECO by making a simplifying assumption that operable windows remove the need for mechanical cooling below 70°F. To simulate this, access the Cooling ECO screen (ASEAM2 ECO #310) and set the outside temperature limits for cooling availability to 70°F. This estimate does not entirely simulate the operable windows because fan energy is still accumulated, and the actual cooling requirements of core zones (without operable windows) would be ignored.

ECO 19 - Install Exterior Shading

This ECO is more complex and requires many new input values that do not exist in the original loads input file for the base case. To properly simulate the addition of exterior shading devices (or any other complex ECO), create a new loads input file to reflect all the changes in the base-case file. The energy comparisons using this new loads input file is performed by ASEAM just like the simpler ECOs modeled by the ECO input program.

The base-case building had no exterior shading devices on the windows. In this ECO, louvered sun shades will be added to the exterior of the existing windows. South exposure windows will have a continuous 3 ft (36 in.) overhang placed 21 in. above the top of the window. The continuous overhang is modeled by setting the overhang extension beyond the left and right edges of the window to an high value (9999 in.). East and west exposure windows will have a 2 ft (24 in.) enclosure built around the top and sides of each window--modeled just like a window that is recessed.

The cooling energy savings estimated in this analysis represent a conservative estimate because of the way heat gains from solar radiation through externally shaded glazing areas are calculated in the ASEAM model.

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*ASEAM2 LOADS INPUT: ZONE  2 - ROOF-ZONE2-EAST                                  *
*EXTERNAL SHADING FOR WINDOWS                                  LOAD FILE:BCEXTSHD*
*-------------------------------------------------------------------------------*
*SHADING DETAILS (All dimensions in inches)       Model 1   Model 2   Model 3   *
*Window Model Name (or 'NA')                      EAST-WEST SOUTH____ NA_______ *
*Window Width                                     36_____   36_____   _______   *
*Window Height                                    78_____   78_____   _______   *
*Overhang Details                                                               *
* Overhang Depth                                  24_____   36_____   _______   *
* Top of Window to Overhang                       0______   21_____   _______   *
* Overhang extension beyond left edge of window   0______   9999___   _______   *
* Overhang extension beyond right edge of window  0______   9999___   _______   *
* Depth of vert projection at end of overhang     0______   0______   _______   *
*Left Fin Details                                                               *
* Depth of left fin                               24_____   0______   _______   *
* Left fin extension above top of window          0______   0______   _______   *
* Distance from left edge of window to left fin   0______   0______   _______   *
* Dist from left fin bottom to bottom of window   0______   0______   _______   *
*Right Fin Details                                                              *
* Depth of right fin                              24_____   0______   _______   *
* Right fin extension above top of window         0______   0______   _______   *
* Dist from right edge of window to right fin     0______   0______   _______   *
* Dist from right fin bottom to bottom of window  0______   0______   _______   *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,812	-761	-1.6
Electricity	kWh	1,720,663	1,701,516	19,147	1.1
Gas	Dollars	24,525	24,906	-380	-1.6
Electricity	Dollars	86,033	85,076	957	1.1
Annual Totals	Dollars	110,559	109,982	577	0.5
Gas	MBTU	4,905.092	4,981.152	-76.060	-1.6
Electricity	MBTU	5,872.621	5,807.273	65.348	1.1
Annual Totals	MBTU	10,777.710	10,788.430	-10.720	-0.1

<u>ECO 20 - Install Interior Shading</u>

In the base-case building, the single-pane clear glass had a shading coefficient of 0.94. By adding interior venetian blinds, the shading coefficient was changed to 0.55 in the Window ECO screen (ASEAM2 ECO #120 - see below).

ASEAM uses the same value for the shading coefficient year-round. Therefore, the different uses of interior shading cannot be simulated for the cooling and heating seasons. The cooling savings may be more than offset by additional heating penalties in some locations. In some cases, it may also be necessary to change the window's U-value in the same screen if the interior shading devices result in higher window R-value.

As noted earlier, this ECO results in some heating penalties that exceed the cooling energy savings. However, if the interior shadings are removed during the heating season, no heating penalty would occur. This analysis also neglects the fact that venetian blinds will somewhat affect the conduction losses of the windows, that is, reduce its U-value.

Information on interior shadings types and characteristics can be found in ASHRAE (1980).

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*ASEAM2 ECO INPUT: ZONE  2 - ROOF-ZONE2-EAST                 Input File:BASEBLDG*
*WINDOW ECOS                       ECO No: 120   Case No: 1    ECO File:8PT2120A*
*-------------------------------------------------------------------------------*
*WINDOWS                            Window 1   Window 2   Window 3   Window 4   *
*Name (optional)                    EAST______ NA________ NA________ NA________ *
*                                                                               *
*Shading coefficient                .55        ___        ___        ___        *
*U-Factor (BTUH/ft²-°)              1.1_       ____       ____       ____       *
*Leakage coefficient                4_         __         __         __         *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	53,322	-4,271	-8.7
Electricity	kWh	1,720,663	1,677,651	43,012	2.5
Gas	Dollars	24,525	26,661	-2,135	-8.7
Electricity	Dollars	86,033	83,883	2,151	2.5
Annual Totals	Dollars	110,559	110,543	15	0.0
Gas	MBTU	4,905.092	5,332.171	-427.079	-8.7
Electricity	MBTU	5,872.621	5,725.823	146.798	2.5
Annual Totals	MBTU	10,777.710	11,057.990	-280.280	-2.6

<u>ECO 21 - Use Tinted or Reflective Glazing or Films</u>

The single-pane clear glass in the base-case building had a shading coefficient of 0.94. By adding a reflective film the shading coefficient was changed to 0.58 in the Window ECO screen (ASEAM2 ECO #120 - see below). It may be necessary to change the window's U-value in the same screen if new glazing is added or existing glazing is replaced. Information on tinted/ reflective films or glazing types and characteristics should be obtained from the manufacturer.

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*ASEAM2 ECO INPUT: ZONE  2 - ROOF-ZONE2-EAST                Input File:BASEBLDG*
*WINDOW ECOS                         ECO No: 120   Case No: 1    ECO File:8PT3120A*
*-------------------------------------------------------------------------------*
*WINDOWS                              Window 1   Window 2   Window 3   Window 4   *
*Name (optional)                      EAST______ NA________ NA________ NA________ *
*                                                                               *
*Shading coefficient                  .58        ___        ___        ___        *
*U-Factor (BTUH/ft²-°)                1.1_       ____       ____       ____       *
*Leakage coefficient                  4_         __         __         __         *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	53,000	-3,949	-8.1
Electricity	kWh	1,720,663	1,680,981	39,682	2.3
Gas	Dollars	24,525	26,500	-1,974	-8.1
Electricity	Dollars	86,033	84,049	1,984	2.3
Annual Totals	Dollars	110,559	110,549	10	0.0
Gas	MBTU	4,905.092	5,299.973	-394.881	-8.1
Electricity	MBTU	5,872.621	5,737.188	135.433	2.3
Annual Totals	MBTU	10,777.710	11,037.160	-259.450	-2.4

ECO 22 - Install Air-Flow Windows

ASEAM cannot model this ECO.

ECO 23 - Seal Vertical Shafts and Stairways

The infiltration caused by vertical shafts and stairways in the base-case building are modeled by the air change method on the exterior zones. To simulate the reduced infiltration resulting from this ECO, the air changes per hour value would be changed in the Infiltration ECO screen (ASEAM2 ECO #140). See ECO 25 for a sample input screen. Estimating infiltration is one of the areas with the greatest uncertainties. However, some estimates are provided in ASHRAE (1985).

ECO 24 - Caulk and Weatherstrip Doors and Windows

In the base-case building, the leaky windows were modeled by having a moderately high leakage coefficient (4). When weatherstripping is added, the leakage coefficient should be changed to 1. This ECO is modeled with the Window ECO screen (ASEAM2 ECO #120 - see below).

Although the base-case building had no doors simulated, weatherstripping and caulking can also be simulated by changing the leakage coefficient values in the Door ECO screen (ASEAM2 ECO #130). Information on leakage coefficients can be found in the ASEAM2.1 Users Manual (ACEC 1987).

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*ASEAM2 ECO INPUT: ZONE  2 - ROOF-ZONE2-EAST                 Input File:BASEBLDG*
*WINDOW ECOS                          ECO No: 120   Case No: 1    ECO File:9PT2120A*
*-------------------------------------------------------------------------------*
*WINDOWS                               Window 1   Window 2   Window 3   Window 4   *
*Name (optional)                       EAST______ NA________ NA________ NA________ *
*                                                                               *
*Shading coefficient                   .94        ___        ___        ___        *
*U-Factor (BTUH/ft²-°)                 1.1_       ____       ____       ____       *
*Leakage coefficient                   1_         __         __         __         *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	44,659	4,392	9.0
Electricity	kWh	1,720,663	1,715,322	5,341	0.3
Gas	Dollars	24,525	22,330	2,196	9.0
Electricity	Dollars	86,033	85,766	267	0.3
Annual Totals	Dollars	110,559	108,096	2,463	2.2
Gas	MBTU	4,905.092	4,465.925	439.167	9.0
Electricity	MBTU	5,872.621	5,854.395	18.226	0.3
Annual Totals	MBTU	10,777.710	10,320.320	457.390	4.2

ECO 25 - Install Revolving Doors or Construct Vestibules

The infiltration caused by the building traffic rate is best modeled by the air change method. By adding revolving doors or vestibules, the air changes in the entrance zones (east and west lower-level zones) can be reduced from 1.8 ACH for a single swing door to 1.3 ACH for a single swing with vestibules and 0.5 ACH for a revolving door. See the Infiltration ECO screen (ASEAM2 ECO #140) shown below for the changes required to model this ECO. Information on the infiltration rates for various types of doors can be found in ASHRAE (1985) and Stamper and Koral (1979).

ECO Input Screen for the Vestibule

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*ASEAM2 ECO INPUT: ZONE  7 - LOWER-ZONE2-EAST                Input File:BASEBLDG*
*INFILTRATION ECOS                 ECO No: 140   Case No: 1    ECO File:9P3V140A*
*-------------------------------------------------------------------------------*
*INFILTRATION                                                                   *
*                                                                               *
*Occupied air change rate                           1.3_  Air changes per hour  *
*                                                                               *
*Unoccupied air change rate                         0___  Air changes per hour  *
*                                                                               *
*-------------------------------------------------------------------------------*
*                                                                               *
*          These entries exclude infiltration by crack length method            *
*                                                                               *
*-------------------------------------------------------------------------------*
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ECO Input Screen for the Revolving Doors

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*ASEAM2 ECO INPUT: ZONE  7 - LOWER-ZONE2-EAST                Input File:BASEBLDG*
*INFILTRATION ECOS                 ECO No: 140   Case No: 1    ECO File:9P3R140A*
*-------------------------------------------------------------------------------*
*INFILTRATION                                                                   *
*                                                                               *
*Occupied air change rate                           0.5_  Air changes per hour  *
*                                                                               *
*Unoccupied air change rate                         0___  Air changes per hour  *
*                                                                               *
*-------------------------------------------------------------------------------*
*                                                                               *
*          These entries exclude infiltration by crack length method            *
*                                                                               *
*-------------------------------------------------------------------------------*
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ECO Comparison with Base Case (vestibules)

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	48,541	509	1.0
Electricity	kWh	1,720,663	1,720,223	440	0.0
Gas	Dollars	24,525	24,271	255	1.0
Electricity	Dollars	86,033	86,011	22	0.0
Annual Totals	Dollars	110,559	110,282	277	0.3
Gas	MBTU	4,905.092	4,854.145	50.947	1.0
Electricity	MBTU	5,872.621	5,871.122	1.499	0.0
Annual Totals	MBTU	10,777.710	10,725.270	52.440	0.5

ECO Comparison with Base Case (revolving doors)

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	47,724	1,327	2.7
Electricity	kWh	1,720,663	1,719,557	1,106	0.1
Gas	Dollars	24,525	23,862	664	2.7
Electricity	Dollars	86,033	85,978	55	0.1
Annual Totals	Dollars	110,559	109,840	719	0.7
Gas	MBTU	4,905.092	4,772.367	132.725	2.7
Electricity	MBTU	5,872.621	5,868.847	3.774	0.1
Annual Totals	MBTU	10,777.710	10,641.210	136.500	1.3

ECO 26 - Reduce Ventilation Rates

The ventilation rates for ASEAM are changed in the Outside Air Control ECO screen (ASEAM2 ECO #360). In the base-case building, the existing outside air dampers were open a constant 20% (no economizer) when the fan was on. In this ECO, the outside air requirements were reduced to 5 cubic feet per minute (CFM) per person and determined the highest percentage of outside air required by the different zones. The highest percentage of outside air was required by the lower core zone and was determined to be 6.9%; a new minimum percentage of 7% outside air was used (see below). Because the existing system had fixed outside air dampers, reducing the amount of outside air when it is advantageous to bring in more outside air (economizer cycle) results in an energy penalty for these hours.

Outside air needs will vary according to building types and space functions. Local codes should be consulted for the particular application. Recent concerns about air quality may result in raising the outside air minimum requirements.

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*ASEAM2 ECO INPUT: SYSTEM  1                                  Input File:10P1360A*
*OUTSIDE AIR CONTROLS              ECO No: 360   Case No: 1    ECO File:10P1360A*
*-------------------------------------------------------------------------------*
*Occupied Cycle Only                                                            *
*  Outside air damper control method (see codes below)      2                   *
*  Minimum percent outside air intake                       7__ %               *
*  Dry bulb switchover temperature                          ___ °F              *
*                                                                               *
*Unoccupied Cycle Only                                                          *
*  Outside air damper control method (see codes below)      2                   *
*  Minimum percent outside air intake                       7__ %               *
*  Dry bulb switchover temperature                          ___ °F              *
*                                                                               *
*                                                                               *
*-------------------------------------------------------------------------------*
*                       Outside Air Damper Control Methods                      *
*     1=No Outside Air     2=Fixed Dampers      3=Dry Bulb      4=Enthalpy      *
*                                              (Economizer)    (Economizer)     *
*-------------------------------------------------------------------------------*
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	38,723	10,328	21.1
Electricity	kWh	1,720,663	1,689,132	31,531	1.8
Gas	Dollars	24,525	19,361	5,164	21.1
Electricity	Dollars	86,033	84,457	1,577	1.8
Annual Totals	Dollars	110,559	103,818	6,741	6.1
Gas	MBTU	4,905.092	3,872.268	1,032.824	21.1
Electricity	MBTU	5,872.621	5,765.008	107.613	1.8
Annual Totals	MBTU	10,777.710	9,637.275	1,140.435	10.6

ECO 27 - Reduce the Generation of Indoor Pollutants

This ECO is modeled in the same manner as ECO 26, by reducing the minimum amount of outside air intake. Once the reduced ventilation rates are determined, use the Outside Air Control ECO screen (ASEAM2 ECO #360) to change the minimum percentage of outside air intake. See ECO 26 for a sample screen.

ECO 28 - Install Air-to-Air Heat Exchangers

Air-to-air heat exchangers cannot be explicitly modeled in ASEAM. In some cases, however, the energy savings of this ECO can be estimated by changing the minimum outside air percentage to the heat recovery efficiency (ASEAM2 ECO #360). This method would only be applicable for total heat recovery systems (both sensible and latent recovery). In addition, the system must have 100% outside air and equal supply and exhaust air flow rates into the heat exchanger.

This ECO can also be modeled using the System Reset Schedule ECO screen (ASEAM2 ECO #410). For example, assume the base-case building has a constant exhaust rate of 5,000 CFM. If a heat exchanger with an effectiveness of 75% were installed, the heat recovered at 0°F would be as follows:

Total Heat Rejected (at 0°) = 5,000 * 1.08 * (70 - 0) = 378,000 BTUH

With an effectiveness of 75%,

Total Heat Recovered (at 0°) = 378,000 * 0.75 = 283,500 BTUH

At 70°F, there would be no heat recovery potential. Therefore, the slope and intercept for the above data would be based on the following two points:

-283,500 BTUH at 0°F and 0 BTUH at 70°F outside temperature

The first data point is negative; we are reducing the load on the boiler through this heat recovery ECO. Therefore, the slope and intercept are as follows:

Slope = (0 - (-283,500)) / (70 - 0) = 4,050 BTUH/°
Intercept = -283,500 - 4,050 * 0 = -283,500 BTUH

When ASEAM performs the systems' calculations, the loads on the various plant equipment are stored in a temporary file (SYSLOADS.TMP). When performing calculations in the ECO mode, just prior to performing the plant calculations, adjustments to the stored plant loads are made using the slopes and intercepts entered in this ECO.

The following table illustrates the reset loads' ECO.

Bin Temperature °F	Original Boiler Load (BTUH) (from Systems)	Reset Load from ECO (BTUH) (from ECO #410)	New Boiler Load (BTUH) (combined)
2.5	1,000,000	-273,375	726,625
7.5	950,000	-253,125	696,875
etc.			
52.5	100,000	- 70,875	29,125
57.5	50,000	- 50,625	0
62.5	0	- 30,375	0
67.5	0	- 10,125	0
72.5	0	+ 10,125	0
77.5	0	+ 30,375	0

Using the reset loads ECO between 57.5° and 70° would normally result in a negative load on the boiler. ASEAM "zeroes" out these negative loads. Because the reset loads ECO can also be used to <u>increase</u> plant loads, ASEAM ignores positive load adjustments if the product of the slope and intercept is negative. In the base-case building, this ECO is assumed to reduce the boiler load only during the occupied cycle winter months. The exhaust fan is assumed to be turned off during the unoccupied cycle. Information about air-to-air heat recovery systems can be found in ASHRAE (1988).

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*ASEAM2 ECO INPUT: SYSTEM  1 - MULTIZONE SYSTEM              Input File:BASEBLDG*
*SYSTEM RESET SCHEDULE            ECO No: 410   Case No: 1    ECO File:10P3410A*
*------------------------------------------------------------------------------*
*Type of Plant Load to Adjust                                        9_        *
*  1=Centrifugal   2=Absorption      3=DB Chiller    4=Reciprocating           *
*  5=Dist Cooling  6=Cooling Tower   7=DB Heat Recv  8=Elec Res HTG            *
*  9=Boiler       10=Dist Heating                                              *
*                                                                              *
*Enter Plant Loads Reset Schedule in BTUH                                      *
*Schedule #1    Slope Adjustment  4050____ Constant Change  -283500_           *
*Schedule #2    Slope Adjustment  ________ Constant Change  ________           *
*Schedule #3    Slope Adjustment  ________ Constant Change  ________           *
*Schedule #4    Slope Adjustment  ________ Constant Change  ________           *
*                                                                              *
*Applicable Months - Enter Schedule # (or 'blank')                             *
*Month      Occup   Unocc        Month     Occup   Unocc                       *
*January      1       _          July        _       _                         *
*February     1       _          August      _       _                         *
*March        1       _          September   _       _                         *
*April        1       _          October     1       _                         *
*May          _       _          November    1       _                         *
*June         _       _          December    1       _                         *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	47,479	1,572	3.2
Electricity	kWh	1,720,663	1,720,648	15	0.0
Gas	Dollars	24,525	23,740	786	3.2
Electricity	Dollars	86,033	86,032	1	0.0
Annual Totals	Dollars	110,559	109,772	787	0.7
Gas	MBTU	4,905.092	4,747.930	157.162	3.2
Electricity	MBTU	5,872.621	5,872.573	0.048	0.0
Annual Totals	MBTU	10,777.710	10,620.500	157.210	1.5

ECO 29 - Install Air Cleaners

This ECO will allow the minimum percentage of outside air intake to be lowered in the Outside Air Control ECO screen (ASEAM2 ECO #360) if you can assume no additional pressure resistance is introduced in the fan system. On existing constant volume systems, an increase in the ductwork resistance will decrease both the air flow rate and the fan power requirements. On VAV systems, additional resistance will not change the air flow rate (except possibly at design summer conditions) but will increase the fan power requirements.

To consider the changes in the air flow and fan power, batch mode modeling is required and modifications must be performed in possibly three system screens: the outside air control screen, the fan screen, and the zone air flow screen. Any energy used to run the air cleaners needs to be manually estimated and deducted from the amount of energy saved.

The outcome of this ECO is very similar to that of ECO 26. Refer to the ECO analysis of that section for a sample analysis procedure.

ECO 30 - Install Local Ventilation Systems

When included in the initial building design, this ECO will allow the ventilation-intensive spaces to be isolated from the remaining part of the building, therefore lowering the required percentage of outside air intake in spaces that are not ventilation-intensive. This ECO can be modeled using the Outside Air Control ECO screen (ASEAM2 ECO #360) if the isolated area is conditioned by a separate system. Otherwise, the building might need to be rezoned to reflect the impact of this ECO's implementation. In this case the batch mode should be used to perform this analysis. See ECO 26 for a sample input screen for this ECO.

ECO 31 - Clean Evaporator and Condenser Surfaces of Fouling

This ECO can be modeled by increasing the coefficient of performance (COP) in the Reciprocating Chiller ECO screen (ASEAM2 ECO #550). In the base-case building, the chiller was modeled with a COP of 2.5. In this ECO, the COP was increased to 2.7 (see below). The manufacturer should be consulted to establish the exact impact of this ECO on a particular chiller.

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*ASEAM2 ECO INPUT: PLANT - Reciprocating                    Input File:BASEBLDG*
*RECIPROCATING CHILLER             ECO No: 550   Case No: 1    ECO File:11P1550A*
*------------------------------------------------------------------------------*
*                                                       Type 1    Type 2       *
*Cooling Performance                                                           *
*  Design coefficient of performance                    2.7_      ____         *
*  Minimum unloading ratio (% of capacity)              25        __      %    *
*  Minimum part load ratio (% of capacity)              25        __      %    *
*  Load management/operating method                     1         _            *
*    (1 = always on   2 = as needed)                                           *
*                                                                              *
*Chilled Water Parameters                                                      *
*  Chilled water temperature at design load             44__      ____    °F   *
*  Chilled water temperature at minimum load            44__      ____    °F   *
*  Chilled water flow (blank=autosized)                 ____      ____    gpm  *
*  Chilled water pump KW (blank=autosized)              ___       ___     KW   *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,051	0	0.0
Electricity	kWh	1,720,663	1,679,302	41,361	2.4
Gas	Dollars	24,525	24,525	0	0.0
Electricity	Dollars	86,033	83,965	2,068	2.4
Annual Totals	Dollars	110,559	108,491	2,068	1.9
Gas	MBTU	4,905.092	4,905.092	0.000	0.0
Electricity	MBTU	5,872.621	5,731.459	141.162	2.4
Annual Totals	MBTU	10,777.710	10,636.550	141.160	1.3

ECO 32 - Raise Evaporator or Lower Condenser Water Temperature

This ECO is modeled directly in either the Reciprocating Chiller ECO screen (ASEAM2 ECO #550) for changes in the evaporator (chilled) water temperature, or in the Cooling Tower ECO screen (ASEAM2 ECO #560) for changes in the condenser water temperature.

In the base-case building, the chilled water temperature was maintained at a constant 44°F regardless of the chiller load. In this ECO, the chilled water temperature was reset to 50°F at low chiller loads, while keeping 44°F chilled water temperature at design chiller loads. ECO 52 (Reset Hot/Chilled Water Temperatures) and ECO 104 (Install Hot/Chilled Water Supply Temperature Reset Control System) are modeled similarly.

For further discussion of the effects of this ECO on the chiller performance, refer to the discussion of EC0 32 in Chapter 1.

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*ASEAM2 ECO INPUT: PLANT                                    Input File:11P2550A*
*RECIPROCATING CHILLER             ECO No: 550   Case No: 1    ECO File:11P2550A*
*-------------------------------------------------------------------------------*
*                                                       Type 1    Type 2        *
*Cooling Performance                                                            *
*  Design coefficient of performance                    2.5_      ____          *
*  Minimum unloading ratio (% of capacity)              25        __       %    *
*  Minimum part load ratio (% of capacity)              25        __       %    *
*  Load management/operating method                     1         _             *
*    (1 = always on   2 = as needed)                                            *
*                                                                               *
*Chilled Water Parameters                                                       *
*  Chilled water temperature at design load             44__      ____     °F   *
*  Chilled water temperature at minimum load            50__      ____     °F   *
*  Chilled water flow (blank=autosized)                 ____      ____     gpm  *
*  Chilled water pump KW (blank=autosized)              ___       ___      KW   *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,051	0	0.0
Electricity	kWh	1,720,663	1,703,918	16,745	1.0
Gas	Dollars	24,525	24,525	0	0.0
Electricity	Dollars	86,033	85,196	837	1.0
Annual Totals	Dollars	110,559	109,721	837	0.8
Gas	MBTU	4,905.092	4,905.092	0.000	0.0

Electricity	MBTU	5,872.621	5,815.471	57.150	1.0
Annual Totals	MBTU	10,777.710	10,720.560	57.150	0.5

<u>ECO 33 - Isolate Off-Line Chillers and Cooling Towers</u>

The base-case building had two small chillers that operated continuously--even at low load conditions. In this ECO, the load management/operating method was changed from '1' (always on) to '2' (as needed). With this operating method, one of the chillers will be off when one chiller can satisfy the total chiller load. For further discussion of the effects of this ECO on the system's performance, refer to the discussion of ECO 33 in Chapter 1.

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*ASEAM2 ECO INPUT: PLANT - Reciprocating                     Input File:BASEBLDG*
*RECIPROCATING CHILLER            ECO No: 550   Case No: 1    ECO File:11P3550A*
*------------------------------------------------------------------------------*
*                                                        Type 1    Type 2       *
*Cooling Performance                                                            *
*  Design coefficient of performance                     2.5_      ____         *
*  Minimum unloading ratio (% of capacity)               25        __      %    *
*  Minimum part load ratio (% of capacity)               25        __      %    *
*  Load management/operating method                      2         _            *
*    (1 = always on   2 = as needed)                                            *
*                                                                               *
*Chilled Water Parameters                                                       *
*  Chilled water temperature at design load              44__      ____    °F   *
*  Chilled water temperature at minimum load             44__      ____    °F   *
*  Chilled water flow (blank=autosized)                  ____      ____    gpm  *
*  Chilled water pump KW (blank=autosized)               ___       ___     KW   *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,051	0	0.0
Electricity	kWh	1,720,663	1,654,545	66,118	3.8
Gas	Dollars	24,525	24,525	0	0.0
Electricity	Dollars	86,033	82,727	3,306	3.8
Annual Totals	Dollars	110,559	107,253	3,306	3.0
Gas	MBTU	4,905.092	4,905.092	0.000	0.0
Electricity	MBTU	5,872.621	5,646.963	225.658	3.8
Annual Totals	MBTU	10,777.710	10,552.050	225.660	2.1

<u>ECO 34 - Install Evaporatively Cooled or Water-Cooled Condensers</u>

ASEAM models only cooling towers as heat rejection equipment for the chillers. Because other heat rejection equipment (for example, closed-loop fluid coolers) are not modeled by ASEAM, no energy comparisons can be made. For further discussion of the effects of this ECO on the chiller performance, refer to the discussion of ECO 34 in Chapter 1.

<u>ECO 35 - Clean Boiler Surfaces of Fouling</u>

Surface fouling cannot be explicitly modeled by ASEAM. However, it can be assumed that less heat is transferred to the water with surface fouling, resulting in a larger stack temperature. If surface fouling is reduced, less heat is lost up the stack.

In this ECO, the existing boiler stack temperature was 560°F. After cleaning, it is assumed that the stack temperature is reduced to 500°F. This ECO is modeled with the Boiler ECO screen (ASEAM2 ECO #580 - see below). The manufacturer should be consulted to determine the effects of this ECO on a particular boiler.

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*ASEAM2 ECO INPUT: PLANT - Boiler                            Input File:BASEBLDG*
*BOILER                            ECO No: 580   Case No: 1    ECO File:12P1580A*
*-------------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                      70__      ____   therms *
*                                                                               *
*  Load management/operation                            1         _             *
*    (1 = always on    2 = as needed)                                           *
*                                                                               *
*Boiler Performance                                                             *
*  Design boiler efficiency                             ____      ____   %      *
*  Combustion air temperature                           85_       ___    °F     *
*  Stack temperature                                    500       ___    °F     *
*  Air-Fuel ratio                                       20__      ____   Lb/Lb  *
*  Minimum part load operating ratio (% of capacity)    25        __     %      *
*  Boiler pump KW (blank=autosized)                     ___       ___    KW     *
*  Boiler losses - percent of capacity                  3_        __     %      *
*  Boiler losses - percent of load                      5_        __     %      *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	47,993	1,058	2.2
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	23,996	529	2.2
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	110,029	529	0.5
Gas	MBTU	4,905.092	4,799.258	105.834	2.2
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0

Annual Totals	MBTU	10,777.710	10,671.880	105.830	1.0

ECO 36 - Check Flue for Improper Draft

This ECO is typically an operational and maintenance (O&M) item that is modeled with the Boiler ECO screen (ASEAM2 ECO #580). In the base-case building, an overdraft condition was modeled by using a high value for the air-fuel ratio (20). In the ECO case the air-fuel ratio was changed to 17 (see below). For further discussion of the effects of this ECO on the boiler performance, refer to the discussion of ECO 36 in Chapter 1.

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*ASEAM2 ECO INPUT: PLANT - Boiler                            Input File:BASEBLDG*
*BOILER                            ECO No: 580   Case No: 1    ECO File:12P2580A*
*-------------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                       70__      ____   therms *
*                                                                               *
*  Load management/operation                             1         _            *
*    (1 = always on    2 = as needed)                                           *
*                                                                               *
*Boiler Performance                                                             *
*  Design boiler efficiency                              ____      ____   %     *
*  Combustion air temperature                            85_       ___    °F    *
*  Stack temperature                                     560       ___    °F    *
*  Air-Fuel ratio                                        17__      ____   Lb/Lb *
*  Minimum part load operating ratio (% of capacity)     25        __     %     *
*  Boiler pump KW (blank=autosized)                      ___       ___    KW    *
*  Boiler losses - percent of capacity                   3_        __     %     *
*  Boiler losses - percent of load                       5_        __     %     *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	47,766	1,285	2.6
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	23,883	642	2.6
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	109,916	642	0.6
Gas	MBTU	4,905.092	4,776.632	128.460	2.6
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0
Annual Totals	MBTU	10,777.710	10,649.250	128.460	1.2

ECO 37 - Check for Air Leaks

This measure is usually considered as a O&M item. If the change in the air-fuel ratio can be estimated, the same procedure described above in ECO 36 can be used to estimate the energy savings.

ECO 38 - Install Flue Gas Analyzers for Boiler

Flue gas analyzers can help diagnose improper combustion in the boiler. If an excess air-fuel ratio is found to exist, the Boiler ECO screen (ASEAM2 ECO #580) can be used to limit the excess air. Changing the air-fuel ratio is demonstrated in ECO 36 above.

The algorithm used by ASEAM to determine the boiler efficiency (when the calculated method is used) shows an inverse relationship between the air-fuel ratio and the boiler efficiency. While it is logical that larger air-fuel ratios (excess air) result in lower combustion efficiency, the algorithm does not work properly if there is insufficient combustion air. That is, combustion efficiency actually drops rapidly if there is insufficient combustion air. Therefore, ASEAM should not be used to determine the combustion efficiency if the air-fuel ratio is less than that of a complete combustion (that is, less than an air-fuel ratio of approximately 17). Low-limit error checks on the Boiler Input screen prevent entering lower values.

For further discussion of the effects of this ECO on boiler performance, refer to the discussion of ECO 38 in Chapter 1.

ECO 39 - Preheat Combustion Air, Feed Water or Fuel Oil with Reclaimed Waste Heat

The combustion air temperature can be modified in the Boiler ECO screen (ASEAM2 ECO #580). In the base-case building, the combustion air temperature was assumed to be 85°F. In this ECO, the combustion air is preheated to a temperature of 175°F with reclaimed waste heat from the stack. The stack temperature is also decreased from 560°F to 450°F.

Preheating the feed water or fuel oil cannot be modeled explicitly with ASEAM. If the amount of reclaimed heat is known as a function of outside temperature, the Systems Reset Schedule ECO screen (ASEAM2 ECO #410) could be used to adjust the boiler load. See ECO 28 for a discussion on resetting plant equipment loads. For further discussion of the effects of this ECO on boiler performance, refer to the discussion of ECO 39 in Chapter 1.

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*ASEAM2 ECO INPUT: PLANT                                    Input File:12P5580A*
*BOILER                        ECO No: 580   Case No: 1    ECO File:12P5580A*
*-----------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                        70__      ____   therms *
*                                                                             *
*  Load management/operation                              1         _             *
*    (1 = always on    2 = as needed)                                         *
*                                                                             *
*Boiler Performance                                                           *
*  Design boiler efficiency                               ____      ____   %      *
*  Combustion air temperature                             175       ___    °F     *
*  Stack temperature                                      450       ___    °F     *
*  Air-Fuel ratio                                         20__      ____   Lb/Lb  *
*  Minimum part load operating ratio (% of capacity)      25        __     %      *
*  Boiler pump KW (blank=autosized)                       ___       ___    KW     *
*  Boiler losses - percent of capacity                    3_        __     %      *
*  Boiler losses - percent of load                        5_        __     %      *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	45,705	3,346	6.8
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	22,852	1,673	6.8
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	108,886	1,673	1.5
Gas	MBTU	4,905.092	4,570.494	334.598	6.8
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0
Annual Totals	MBTU	10,777.710	10,443.120	334.590	3.1

ECO 40 - Isolate Off-Line Boilers

The base-case building had one 2.5-million BTUH boiler that operated continuously. Because there were no "off-line" boilers, this ECO cannot be modeled in this case. If the base-case building had multiple boilers, however, the "standby" losses could be modeled by specifying the boiler losses as a percentage of capacity.

ASEAM bypasses the boiler calculations if there is no "normal" load on the boiler--exclusive of load losses. This prevents boiler operation in the summer time if any losses are specified as a percentage of capacity. Only if there is a load on the boiler (normally from system's heating coils, but also from absorption chillers, backup to double bundle chillers, or domestic hot water) will the "losses" result in additional load. Note, however, that with the System Reset Schedule ECO (ASEAM2 ECO #410), additional loads can be "created" and existing plant equipment loads can be "saved" or reduced. See ECO 28 for a discussion of changing the plant equipment loads.

ECO 41 - Install Automatic Vent Dampers

This ECO can be modeled by changing the losses as a percentage of load from the existing 5% to a lower 3%. This is simulated through the Boiler ECO screen (ASEAM2 ECO #580 - see below). This method cannot be used if the existing or base-case boiler data in the plant input file did not specify these losses. The manufacturer should be consulted to establish the impact of this ECO on a particular boiler.

```
*ASEAM2 ECO INPUT: PLANT                                    Input File:12P7580A*
*BOILER                          ECO No: 580   Case No: 1   ECO File:12P7580A*
*-------------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                     70__      ____   therms *
*                                                                              *
*  Load management/operation                           1         _             *
*    (1 = always on    2 = as needed)                                          *
*                                                                              *
*Boiler Performance                                                            *
*  Design boiler efficiency                            ____      ____   %      *
*  Combustion air temperature                          85_       ___    °F     *
*  Stack temperature                                   560       ___    °F     *
*  Air-Fuel ratio                                      20__      ____   Lb/Lb  *
*  Minimum part load operating ratio (% of capacity)   25        __     %      *
*  Boiler pump KW (blank=autosized)                    ___       ___    KW     *
*  Boiler losses - percent of capacity                 3_        __     %      *
*  Boiler losses - percent of load                     3_        __     %      *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	48,396	655	1.3
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	24,198	327	1.3
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	110,231	327	0.3
Gas	MBTU	4,905.092	4,839.628	65.464	1.3
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0
Annual Totals	MBTU	10,777.710	10,712.250	65.460	0.6

ECO 42 - Install Automatic Boiler Blowdown Control

This ECO can be modeled in a similar manner as ECO 41 above by reducing the boiler losses. Once the blowdown losses are determined, the Boiler ECO screen (ASEAM2 ECO #580) can be used as illustrated in ECO 41 above. For further discussion of the effects of this ECO on the boiler performance, refer to the discussion of ECO 42 in Chapter 1.

ECO 43 - Install Pulse or Condensing Boilers/Furnaces

Condensing or pulse boilers/furnaces are high-efficiency heating units that can be modeled by the ASEAM ECO Boiler screen. When major plant equipment is replaced, many parameters, such as equipment size and efficiencies, are changed. In some cases, all the parameters can be changed in the Boiler ECO screen (ASEAM2 ECO #580). If all the new equipment parameters cannot be changed in the applicable ECO screen, it will be necessary to create a batch mode, in which a new plant input file is made.

In the base-case file, the boiler efficiency was calculated from several input variables (stack temperature, air-fuel ratio, combustion air temperature). In this case, the boiler efficiency method was set to "1=user entered" and the design boiler efficiency was entered. The batch approach was used in this case, in which a condensing boiler with a design efficiency of 95% was used.

The manufacturer should be consulted to obtain the information needed to complete the analysis for a particular system. The boiler's characteristics should be obtained to prepare for this analysis.

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*ASEAM2 PLANT INPUT                                                               *
*BOILER                                                      PLANT FILE:1210PBCH*
*--------------------------------------------------------------------------------*
*Boiler Energy                                                                    *
*  Boiler Energy Source                                 2         0               *
*    (0=None   1=Electric   2=Nat Gas   3=Oil)                                    *
*      (if oil)  Oil type (2 or 4 or 6)                 _         _               *
*      (if gas)  Annual pilot consumption               70__      ____   therms *
*Boiler Heating Capacity                                                          *
*  Boiler heating capacity (per boiler)                 2500__    ______ KBTUH  *
*    (or) % max heating load satisfied (per boiler)     ___       ___    %        *
*  Number of boilers with this capacity                 1         _               *
*  Load management/operation                            1         _               *
*    (1 = always on    2 = as needed)                                             *
*Boiler Performance                                                               *
*  Boiler efficiency method (1=user entered   2=calc)   1         _               *
*  Design boiler efficiency                             95__      ____   %        *
*  (if calc) Combustion air temperature                 ___       ___    °F       *
*  (if calc) Stack temperature                          ___       ___    °F       *
*  (if calc) Air-Fuel ratio                             ____      ____   Lb/Lb  *
*  Minimum part load operating ratio (% of capacity)    25        __     %        *
*  Boiler pump KW (blank=autosized)                     ___       ___    KW       *
*  Boiler losses - percent of capacity                  3_        __     %        *
*  Boiler losses - percent of load                      5_        __     %        *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	41,587	7,464	15.2
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	20,793	3,732	15.2
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	106,826	3,732	3.4
Gas	MBTU	4,905.092	4,158.658	746.434	15.2
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0
Annual Totals	MBTU	10,777.710	10,031.280	746.430	6.9

ECO 44 - Install Air-Atomizing Burners (for oil-fired systems)

This ECO can be modeled similarly to that of ECO 41 by reducing the boiler losses as a result of steam atomization. However, any electricity consumed by the atomizer has to be deducted from the energy savings provided by the simulation. For further discussion of the effects of this ECO on boiler performaance, refer to the discussion of ECO 44 in Chapter 1.

ECO 45 - Install Low-Excess-Air Burners (for oil-fired systems)

This ECO can be modeled by reducing the amount of excess air by lowering the air-fuel ratio in the Boiler ECO screen (ASEAM2 ECO #580). Refer to ECO 36 for sample modeling.

ECO 46 - Install Modular Units

This ECO can only be modeled through a batch mode. The boiler plant input data should be modified to reflect the ECO implementation. In the base case, the one large boiler will be replaced by three smaller boilers. In addition, instead of operating continuously, the smaller boilers will operate on an "as needed" basis. The same approach would be used with the cooling plant.

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*ASEAM2 PLANT INPUT                                                             *
*BOILER                                                     PLANT FILE:1013PBCH*
*------------------------------------------------------------------------------*
*Boiler Energy                                                                  *
*  Boiler Energy Source                               2         0               *
*    (0=None   1=Electric   2=Nat Gas   3=Oil)                                  *
*      (if oil)  Oil type (2 or 4 or 6)               _         _               *
*      (if gas)  Annual pilot consumption             70__      ____   therms  *
*Boiler Heating Capacity                                                        *
*  Boiler heating capacity (per boiler)               850___    ______ KBTUH   *
*    (or) % max heating load satisfied (per boiler)   ___       ___    %       *
*  Number of boilers with this capacity               3         _               *
*  Load management/operation                          2         _               *
*    (1 = always on    2 = as needed)                                           *
*Boiler Performance                                                             *
*  Boiler efficiency method (1=user entered   2=calc) 2         _               *
*  Design boiler efficiency                           ____      ____   %       *
*  (if calc) Combustion air temperature               85_       ___    °F      *
*  (if calc) Stack temperature                        560       ___    °F      *
*  (if calc) Air-Fuel ratio                           20__      ____   Lb/Lb   *
*  Minimum part load operating ratio (% of capacity)  25        __     %       *
*  Boiler pump KW (blank=autosized)                   ___       ___    KW      *
*  Boiler losses - percent of capacity                3_        __     %       *
*  Boiler losses - percent of load                    5_        __     %       *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	41,470	7,581	15.5
Electricity	kWh	1,720,663	1,712,826	7,837	0.5
Gas	Dollars	24,525	20,735	3,790	15.5
Electricity	Dollars	86,033	85,641	392	0.5
Annual Totals	Dollars	110,559	106,377	4,182	3.8
Gas	MBTU	4,905.092	4,147.042	758.050	15.5
Electricity	MBTU	5,872.621	5,845.875	26.746	0.5
Annual Totals	MBTU	10,777.710	9,992.916	784.794	7.3

ECO 47 - Clean Air Filters

Lowering the system resistance by replacing or cleaning dirty air filters will increase both air flow through the duct and fan power in constant volume systems. If only the dirty filters are changed, a net energy penalty rather than an energy savings may occur. On variable air volume systems, however, the dirty filters would increase fan power requirements.

Aside from the fan power changes described above, the effect of the reduced air flow on the performance or efficiency of air-conditioners and heat pumps is difficult to determine. Decreased air flow may result in decreased compressor cycling or higher part-load operating ratios. Increased operation time may result, however, for systems that cycle on and off to meet the cooling or heating load. For systems that must remain on, reduced air flow because of dirty filters restricts the ability of the system to offset the heating or cooling loads.

In the case of constant volume systems, this ECO would be modeled by increasing the air flow rates of the system and increasing the fan power requirements accordingly. In the case of variable air volume systems, the fan power should be decreased.

This ECO is not modeled because the base case does not use air conditioners or heat pumps.

ECO 48 - Install Add-on Heat Pumps

Assuming the base-case system type was a "furnace," ASEAM can model this ECO by changing the system type to "air/air heat pump." This would be considered a batch ECO because a new system input file would be required. The heat pump backup heating source would be a furnace. This ECO is not modeled because the system was a dual duct/multizone system in the base case.

ECO 49 - Install Ground or Ground-Water Source Heat Pump

This ECO cannot be modeled by ASEAM. Although water source heat pumps can be modeled as a system type, ASEAM does not allow the heat source or sink to be the ground. An alternative would be to specify a typical ground water loop temperature profile, and specify district heating and cooling as the heating and cooling sources. The district heating and cooling numbers in the ASEAM BEPS report should be ignored, however.

ECO 50 - Install Variable Air Volume Systems

This ECO must be modeled using the batch mode. A new system input file is created containing the characteristics of a variable air volume system. ASEAM does not simulate a dual duct variable air volume system. In this ECO, all of the dual duct input parameters were repeated for the variable air volume system except the control of the outside air dampers, where an economizer cycle was used in the variable air volume system. The same setpoints, such as percentage of outside air, fan kW, and air flow, used in the dual duct/multizone system (base case) were used in the variable air volume system.

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	62,873	-13,823	-28.2
Electricity	kWh	1,720,663	1,438,380	282,283	16.4
Gas	Dollars	24,525	31,437	-6,911	-28.2
Electricity	Dollars	86,033	71,919	14,114	16.4
Annual Totals	Dollars	110,559	103,356	7,203	6.5
Gas	MBTU	4,905.092	6,287.346	-1,382.254	-28.2
Electricity	MBTU	5,872.621	4,909.191	963.430	16.4
Annual Totals	MBTU	10,777.710	11,196.540	-418.830	-3.9

Note: The large increase in the heating energy was caused by additional humidification energy required for economizer cycle.

ECO 51 - Reset Supply Air Temperatures

This ECO is modeled by adding discriminator controls on both the Heating ECO screen (ASEAM2 ECO #300) and the Cooling ECO screen (ASEAM2 ECO #310). This ECO applies only to the larger central systems that serve multiple zones. Only the multizone/dual duct systems have discriminator control on the heating coil.

In the base-case building, supply air reset (discriminator) controls were added to the multizone system. Therefore, both the Heating and Cooling ECO screens had to be changed (see below). The maximum cooling discharge air temperature must also be supplied in the Cooling ECO screen. For further discussion of the various control strategies applicable to different systems, refer to ASHRAE (1984).

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*ASEAM2 ECO INPUT: SYSTEM  1                               Input File:14P2300A*
*HEATING                          ECO No: 300   Case No: 1    ECO File:14P2300A*
*------------------------------------------------------------------------------*
*Heating Availability                                                          *
*  Outside temperature above which heating is off          70_ °F              *
*  Heating available beginning month #                     10                  *
*  Heating available ending month #                        5_                  *
*                                                                              *
*Heating Discharge Conditions                                                  *
*  Design heating coil discharge temperature               120 °F              *
*                                                                              *
*(Dual Duct System Only)                                                       *
*  Discriminator Control (Y/N)                             Y                   *
*  Outside temperature at maximum hot deck temperature     ___ °F              *
*    Maximum hot deck temperature                          ___ °F              *
*  Outside temperature at minimum hot deck temperature     ___ °F              *
*    Minimum hot deck temperature                          ___ °F              *
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*ASEAM2 ECO INPUT: SYSTEM  1                               Input File:14P2310A*
*COOLING                          ECO No: 310   Case No: 1    ECO File:14P2310A*
*------------------------------------------------------------------------------*
*Cooling Availability                                                          *
*  Outside temperature below which cooling is off          40_ °F              *
*  Cooling available beginning month #                     1_                  *
*  Cooling available ending month #                        12                  *
*                                                                              *
*Cooling Discharge Conditions                                                  *
*  Design cooling coil discharge temperature               55  °F              *
*  Discriminator control (Y/N)                             Y                   *
*  Maximum cooling coil discharge temperature              63  °F              *
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```

ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	21,539	27,512	56.1
Electricity	kWh	1,720,663	1,582,103	138,560	8.1
Gas	Dollars	24,525	10,769	13,756	56.1
Electricity	Dollars	86,033	79,105	6,928	8.1
Annual Totals	Dollars	110,559	89,875	20,684	18.7
Gas	MBTU	4,905.092	2,153.888	2,751.204	56.1
Electricity	MBTU	5,872.621	5,399.717	472.904	8.1
Annual Totals	MBTU	10,777.710	7,553.606	3,224.104	29.93

ECO 52 - Reset Hot/Chilled Water Temperatures

The energy savings achieved by increasing the chilled water temperature is modeled in ECO 32. Hot water temperature reset does not result in the same plant efficiency improvement as does chilled water reset. Hot water reset analysis with ASEAM is best modeled as a reduction in boiler losses (see ECO 41).

ECO 53 - Install Economizer Cooling Systems

This ECO can be modeled using the Outside Air Control ECO screen (ASEAM2 ECO #360). Both the switchover temperature and the method of outside air damper control must be specified. In the base-case building system, fixed outside air dampers are replaced with a dry bulb economizer having a dry bulb switchover temperature of 70°F (see below). The minimum outside air ventilation rate remains at 20% in both cases. For further discussion of the various control strategies applicable to different systems, refer to ASHRAE (1984).

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*ASEAM2 ECO INPUT: SYSTEM  1                                 Input File:15P1360A*
*OUTSIDE AIR CONTROLS              ECO No: 360   Case No: 1    ECO File:15P1360A*
*-------------------------------------------------------------------------------*
*Occupied Cycle Only                                                            *
*  Outside air damper control method (see codes below)      3                   *
*  Minimum percent outside air intake                       20_ %               *
*  Dry bulb switchover temperature                          70_ °F              *
*                                                                               *
*Unoccupied Cycle Only                                                          *
*  Outside air damper control method (see codes below)      3                   *
*  Minimum percent outside air intake                       20_ %               *
*  Dry bulb switchover temperature                          70_ °F              *
*                                                                               *
*                                                                               *
*-------------------------------------------------------------------------------*
*                       Outside Air Damper Control Methods                      *
*     1=No Outside Air     2=Fixed Dampers      3=Dry Bulb      4=Enthalpy      *
*                                              (Economizer)    (Economizer)     *
*-------------------------------------------------------------------------------*
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	74,164	-25,113	-51.2
Electricity	kWh	1,720,663	1,531,013	189,650	11.0
Gas	Dollars	24,525	37,082	-12,557	-51.2
Electricity	Dollars	86,033	76,551	9,482	11.0
Annual Totals	Dollars	110,559	113,633	-3,074	-2.8
Gas	MBTU	4,905.092	7,416.410	-2,511.318	-51.2
Electricity	MBTU	5,872.621	5,225.349	647.272	11.0
Annual Totals	MBTU	10,777.710	12,641.760	-1,864.050	-17.3

Note: Using economizers in dual duct/multizone systems can substantially increase the hot deck energy because the temperature difference across the hot deck is increased.

ECO 54 - Install Evaporative Cooling Systems

ASEAM does not simulate evaporative cooling systems. For a discussion of evaporative cooling systems and applications, refer to ASHRAE (1984).

ECO 55 - Install Desiccant Cooling Systems

ASEAM cannot model desiccant cooling systems. This ECO is still in its experimental phase; therefore, few desiccant systems are commercially available. Among other organizations, the Solar Energy Research Institute (Golden, Colorado) is conducting some of the research and development work and can be contacted for further information.

ECO 56 - Install Cooling Tower Cooling Systems

ASEAM cannot model this ECO.

ECO 57 - Install Roof-Spray Cooling Systems

ASEAM cannot model this ECO.

ECO 58 - Create Air Movement with Fans

Using small personal fans in the office areas may increase the summer occupied thermostat setpoint. However, personal fans incur an additional electric consumption that reduces the net energy savings. To model this ECO, a batch mode was used that accessed four load screens in each zone: the general zone screen (summer thermostat raised to 80°F), the miscellaneous electrical equipment (add the electric load from personal fans), the diversity factor (add the diversity factor from personal fans), and the monthly schedules screens (allow personal fan operation only in the summer months).

The fans were assumed to be running during all of the occupied period for June through August and for half of May and September. A 55-watt fan was assigned to each person, and the summer space temperature was set at 80°F instead of the 76°F used in the base case.

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*ASEAM2 LOADS INPUT: ZONE  1 - ROOF-ZONE1-CORE                                  *
*                                                             LOAD FILE:15P6BTCH*
*-------------------------------------------------------------------------------*
*                                                                               *
*Zone label                        ROOF-ZONE1-CORE_________________________     *
*                                                                               *
*Thermostat Set Point Temperatures                                              *
*  Summer occupied temperature                              80__  °F            *
*  Winter occupied temperature                              72__  °F            *
*  Winter unoccupied temperature                            68__  °F            *
*                                                                               *
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*ASEAM2 LOADS INPUT: ZONE  1 - ROOF-ZONE1-CORE                                  *
*EQUIPMENT                                                    LOAD FILE:15P6BTCH*
*-------------------------------------------------------------------------------*
*ELECTRICAL EQUIPMENT                                 Type 1         Type 2     *
*                                                                               *
*Electric equipment name (or 'NA')                    MISC._________ Fan (60)______  *
*                                                                               *
*Installed watts/ft²                                  0.25_          ______     *
*  (times) Percent of zone area                       100            ___        *
*  (or) Total installed watts                         ________       3300____   *
*                                                                               *
*Hooded (Y/N)                                         N              N          *
*-------------------------------------------------------------------------------*
*                                                                               *
*                   All watts are converted to space heat gains                 *
*                                                                               *
*-------------------------------------------------------------------------------*
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*ASEAM2 LOADS INPUT: ZONE  1 - ROOF-ZONE1-CORE                                  *
*OPERATING USE PROFILES (DIVERSITIES)                         LOAD FILE:15P6BTCH*
*-------------------------------------------------------------------------------*
*                                            OCCUPIED  UNOCCUPIED  MONTHLY DIV FC*
*                                             PERIOD     PERIOD     TABLE # (1-4)*
*People:                                                                        *
*               Avg % of full occupancy       80__       5___       1___        *
*                                                                               *
*Lights:                                                                        *
*GENERAL        Avg % of installed capacity   95__       35__       1___        *
*TASK           Avg % of installed capacity   60__       5___       1___        *
*NA             Avg % of installed capacity   ____       ____       ____        *
*NA             Avg % of installed capacity   ____       ____       ____        *
*                                                                               *
*Electric Equipment:                                                            *
*MISC.          Avg % of installed capacity   65__       10__       1___        *
*Fan (60)       Avg % of installed capacity   100_       0___       2___        *
*                                                                               *
*Miscellaneous Sensible Loads:                                                  *
*NA             Avg % of installed capacity   ____       ____       ____        *
*NA             Avg % of installed capacity   ____       ____       ____        *
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*ASEAM2 LOADS INPUT: ZONE  1 - ROOF-ZONE1-CORE                                  *
*MONTHLY DIVERSITIES                                          LOAD FILE:15P6BTCH*
*-------------------------------------------------------------------------------*
*                                                                               *
*      Enter Monthly Diversity Factors (0 - 100 %) for each month/schedule      *
*                                                                               *
*  Month                        Mon Sch 1    Mon Sch 2    Mon Sch 3    Mon Sch 4  *
*  January                         100          0__          ___          ___   *
*  February                        100          0__          ___          ___   *
*  March                           100          0__          ___          ___   *
*                                                                               *
*  April                           100          0__          ___          ___   *
*  May                             100          50_          ___          ___   *
*  June                            100          100          ___          ___   *
*                                                                               *
*  July                            100          100          ___          ___   *
*  August                          100          100          ___          ___   *
*  September                       100          50_          ___          ___   *
*                                                                               *
*  October                         100          0__          ___          ___   *
*  November                        100          0__          ___          ___   *
*  December                        100          0__          ___          ___   *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,239	-188	-0.4
Electricity	kWh	1,720,663	1,719,242	1,421	0.1
Gas	Dollars	24,525	24,619	-94	-0.4
Electricity	Dollars	86,033	85,962	71	0.1
Annual Totals	Dollars	110,559	110,582	-23	-0.0
Gas	MBTU	4,905.092	4,923.896	-18.804	-0.4
Electricity	MBTU	5,872.621	5,867.772	4.849	0.1
Annual Totals	MBTU	10,777.710	10,791.670	-13.960	-0.1

Note: The heating penalty occurred in May, when the hot deck was active (heating was available). The higher thermostat setpoint caused additional heating energy to be used.

ECO 59 - Exhaust Hot Air from Attics

ASEAM cannot model this ECO. Attic ventilation allows some of the solar gains to be removed from the attic space, thus reducing the amount of heat gains to the conditioned space. Modeling the impact of this ECO could involve changing the attic space resistance according to the ventilation rate and the outside air temperature. ASHRAE (1985) lists effective attic space resistance as a function of ceiling resistance, ventilation rates, and both outdoor and sol-air temperature. For further discussion, see ASHRAE (1985).

ECO 60 - Repair Ducting and Piping Leaks

This ECO is not explicitly modeled by ASEAM. The energy savings achieved by repairing hot water or steam piping leaks can be modeled by decreasing the boiler losses proportionately. Leaks in chilled water pipes cannot be modeled with ASEAM. All these measures are O&M items that are not only cost-effective, but could eliminate potential water damage to the building.

The thermal energy lost in leaky ductwork located in plenums is difficult to determine. If cool air is leaked to the plenum on the way to a zone needing cooling, the return air temperature is decreased accordingly and returned to the system. Likewise, warm air lost to the plenum raises the return air temperature and is returned to the system. If the air in the duct is a mixture of outside air and return air (air-side economizer), no thermal energy is put into the air.

In some other systems, the thermal loss can be more substantial. If the ducts pass through unconditioned spaces, the thermal losses should be accounted for. Similarly, in dual duct systems, the plenum space could receive heat from the hot deck and reject heat to the cold deck.

The fan energy will decrease as leaks in the ducting are repaired. Sealing the ducts will raise the static pressure, lower the fan system flow rate, and, therefore, decrease the fan's electrical energy usage. In some cases where significant leaks have been repaired, the fan can be downsized to further decrease its energy consumption.

ECO 61 - Maintain Steam Traps

This ECO can be modeled as a reduction in boiler losses as a percentage of capacity. The boiler ECO screen (ASEAM2 ECO #580) should be used. Refer to ECO 41 for a sample run. For further discussion on heat losses through steam traps, refer to the discussion of ECO 61 in Chapter 1.

ECO 62 - Insulate Ducts

When ducts are routed through unconditioned spaces, their heat losses will impose an additional load on the boiler (or chiller). Insulating these ducts should therefore be modeled as a reduction of the boiler losses as a percentage of loads (see ECO 41).

ECO 63 - Insulate HVAC System Pipes

An additional load on the boiler (or chiller) will be imposed by heat losses from the hot or chilled water pipe running from the boiler/chiller to the various coils in the air-handling units. Insulating hot water pipes should therefore be modeled as a reduction of the boiler losses as a percentage of load. See ECO 41 for an example of how to model this ECO.

ECO 64 - Reduce Air Flow Rates in Ducts

This ECO was modeled by reducing the air flow rate to the zones by 5%. The electric fan energy usage was thus reduced accordingly, using the fan laws. A batch mode was used in which the zone CFM and fan parameters screens were accessed and modified to reflect the new conditions (see below). For further discussion of the effects of air flow rate reductions on the system's energy consumption, refer to the discussion of ECO 64 in Chapter 1.

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*SYSTEMS DATA: ZONE CFM FOR SYSTEM:  1 - DUAL DUCT/MULTIZONE                   *
*System Label: MULTIZONE SYSTEM                                  File:17P1BTCH*
*                                                                              *
*------------------------------------------------------------------------------*
*Loads      Zone Name                                            Zone         *
*Zone #      or Label                                            CFM          *
*   1     ROOF-ZONE1-CORE                                       7125___       *
*   2     ROOF-ZONE2-EAST                                       8550___       *
*   3     ROOF-ZONE3-NORTH                                      2850___       *
*   4     ROOF-ZONE4-WEST                                       9500___       *
*   5     ROOF-ZONE5-SOUTH                                      4750___       *
*   6     LOWER-ZONE1-CORE                                      8550___       *
*   7     LOWER-ZONE2-EAST                                      17575__       *
*   8     LOWER-ZONE3-NORTH                                     4750___       *
*   9     LOWER-ZONE4-WEST                                      18525__       *
*  10     LOWER-ZONE5-SOUTH                                     9025___       *
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*SYSTEMS DATA: FAN PARAMETERS FOR SYSTEM:  1 - DUAL DUCT/MULTIZONE             *
*System Label: MULTIZONE SYSTEM                                 File: 17P1BTCH*
*------------------------------------------------------------------------------*
*Supply Fans                                                                   *
*  Total supply fan power required (blank=default)           86_  KW           *
*    (or) Supply fan power per 1000 CFM                      ____ KW/1000 CFM*
*  Supply fan temperature rise (blank=default)               3___ °F           *
*                                                                              *
*Return Fans                                                                   *
*  Total return fan power required (blank=default)           ___  KW           *
*    (or) Return fan power per 1000 CFM                      ____ KW/1000 CFM*
*  Return fan temperature rise (blank=default)               ____ °F           *
*                                                                              *
*  (VAV) Minimum percent of design air volume when heating   ___  %            *
*  (VAV) Air volume control method                           _                 *
*   (1=Variable Speed   2=Discharge Dampers   3=Inlet Vanes)                  *
*                                                                              *
*Fan Control Method (1=On Continuously  2=Cycles with load)                   *
*  Occupied cycle fan control method                         _                 *
*  Unoccupied cycle fan control method                       2                 *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	48,214	837	1.7
Electricity	kWh	1,720,663	1,663,791	56,872	3.3
Gas	Dollars	24,525	24,107	419	1.7
Electricity	Dollars	86,033	83,190	2,844	3.3
Annual Totals	Dollars	110,559	107,296	3,262	3.0
Gas	MBTU	4,905.092	4,821.369	83.723	1.7
Electricity	MBTU	5,872.621	5,678.517	194.104	3.3
Annual Totals	MBTU	10,777.710	10,499.890	277.820	2.6

ECO 65 - Reduce Water or Steam Flow Rates in Pipes

ASEAM cannot model reductions in water or steam flow rates in pipes. For further discussion of the effects of water or steam flow rate reductions, refer to the discussion of ECO 65 in Chapter 1.

ECO 66 - Clean Air Filters in Ducts

Lowering the resistance of ductwork by replacing dirty air filters will increase both air flow through the duct and fan power. If only the dirty filters are changed, a net energy penalty may result instead of an energy savings. The effects of this ECO on the overall building energy consumption will vary considerably depending on the type of HVAC system used and whether the fan can be downsized as a result of frequently changing the air filters. For further discussion of the effects on energy consumption of lowering the system's resistance to air flow, refer to the discussion of ECO 66 in Chapter 1.

ECO 67 - Remove Scale from Water and Steam Pipes

The additional resistance caused by scale in pipes reduces the flow of water or steam. When the scale is removed, additional pumping power is required because of the increased flow. This should be considered as an O&M item. This ECO should be modeled by increasing both the flow and pump kW in the boiler or chiller screens.

ECO 68 - Rebalance Piping Systems

Once the changes in piping flow and pump kW are determined, the new values should be entered in the Boiler or Chiller screens.

ECO 69 - Rebalance Ducting Systems

The changes in the air flow rate to each zone, as well as the change in fan kW, should be entered in a new systems input file. Changes to the zone air flow can only be entered in new systems input files, not through an ASEAM ECO screen. Therefore, this ECO must be modeled in the batch mode.

ECO 70 - Design Ducting Systems to Reduce Flow Resistance

Lower-pressure duct systems are advantageous because of the reduced fan power requirements. As an ECO, however, it is generally not feasible nor cost-effective to redesign existing ductwork for energy conservation unless major system changes are also planned. If the resistance to existing ductwork can be reduced, air flow and fan power requirements will increase. See ECOs 47 and 66 for further discussion and analysis.

ECO 71 - Install Booster Pumps

The effects of this ECO can be modeled by reducing the pumps power (kW) where applicable. See ECO 3 for a sample run in the case of domestic hot water.

ECO 72 - Reduce Hot Water Consumption

This ECO was modeled by assuming a 25% reduction in the hot water consumption because flow restrictors were installed on the hot water faucets. The Domestic Hot Water ECO screen (ASEAM2 ECO #570) was accessed, and the hot water consumption was reduced to 50 gal/hr instead of the 66 gal/hr in the base case. For information on domestic hot water consumption in various types of buildings and spaces, see ASHRAE (1984).

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*ASEAM2 ECO INPUT: PLANT                                     Input File:19P1570A*
*DOMESTIC HOT WATER              ECO No: 570   Case No: 1    ECO File:19P1570A*
*-----------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                               30_    therms *
*                                                                             *
*  Average hourly DHW usage - occupied cycle                      50__   gal/hou*
*  Average hourly DHW usage - unoccupied cycle                    0___   gal/hou*
*                                                                             *
*DHW Temperatures                                                             *
*  Domestic hot water supply temperature                          140    °F     *
*  DHW inlet temperature - design summer                          60     °F     *
*  DHW inlet temperature - design winter                          40     °F     *
*Circulating Pumps                                                            *
*  Circulating pump KW - occupied cycle                           2__    KW     *
*  Circulating pump KW - unoccupied cycle                         2__    KW     *
*DHW Efficiency and Losses                                                    *
*  Design DHW heating efficiency                                  75_    %      *
*  DHW losses - occupied cycle                                    13000_ BTUH   *
*  DHW losses - unoccupied cycle                                  13000_ BTUH   *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	48,617	434	0.9
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	24,308	217	0.9
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	110,342	217	0.2
Gas	MBTU	4,905.092	4,861.667	43.425	0.9
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0
Annual Totals	MBTU	10,777.710	10,734.290	43.420	0.4

ECO 73 - Lower Hot Water Temperatures

Lowering the hot water temperature will reduce the heat losses from both the pipes and the hot water tank. The amount reduced will vary according to building types and occupants' hot water use habits.

This ECO was modeled by assuming a reduction in hot water and storage tank losses of 4,400 BTUH in the base case. The new losses are then 8,600 BTUH instead of the 13,000 BTUH in the base case. No reduction in the amount of energy needed to heat the hot water was assumed; more hot water is needed at 120°F than at 140°F to obtain a certain desired temperature. ASEAM2 ECO screen #570 was used in this evaluation (see below).

For information on pipe heat losses refer to Stamper and Koral (1979).

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*ASEAM2 ECO INPUT: PLANT - Domestic Hot Water                Input File:BASEBLDG*
*DOMESTIC HOT WATER                ECO No: 570   Case No: 1    ECO File:19P2570A*
*-------------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                                 30_    therms *
*                                                                               *
*  Average hourly DHW usage - occupied cycle                       66__   gal/hou*
*  Average hourly DHW usage - unoccupied cycle                     0___   gal/hou*
*                                                                               *
*DHW Temperatures                                                               *
*  Domestic hot water supply temperature                           140    °F     *
*  DHW inlet temperature - design summer                           60     °F     *
*  DHW inlet temperature - design winter                           40     °F     *
*Circulating Pumps                                                              *
*  Circulating pump KW - occupied cycle                            2__    KW     *
*  Circulating pump KW - unoccupied cycle                          2__    KW     *
*DHW Efficiency and Losses                                                      *
*  Design DHW heating efficiency                                   75_    %      *
*  DHW losses - occupied cycle                                     8600__ BTUH   *
*  DHW losses - unoccupied cycle                                   8600__ BTUH   *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	48,549	502	1.0
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	24,274	251	1.0
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	110,308	251	0.2
Gas	MBTU	4,905.092	4,854.891	50.201	1.0
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0
Annual Totals	MBTU	10,777.710	10,727.510	50.200	0.5

ECO 74 - Preheat Feedwater With Reclaimed Waste Heat

A heat reclamation system of 2000 BTUH was assumed, and the inlet water temperature to the domestic hot water tank was assumed to be raised 30°F. Therefore the winter and summer inlet temperatures were modeled with 70°F and 90°F, respectively, instead of their previous 40°F and 60°F values. ASEAM2 ECO screen #570 was used in this evaluation (see below). For further discussion of heat reclamation systems, refer to the discussion of ECO 74 in Chapter 1.

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*ASEAM2 ECO INPUT: PLANT - Domestic Hot Water                Input File:BASEBLDG*
*DOMESTIC HOT WATER                ECO No: 570   Case No: 1    ECO File:19P3570A*
*-------------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                                  30_    therms *
*                                                                               *
*  Average hourly DHW usage - occupied cycle                        66__   gal/hou*
*  Average hourly DHW usage - unoccupied cycle                      0___   gal/hou*
*                                                                               *
*DHW Temperatures                                                               *
*  Domestic hot water supply temperature                            140    °F     *
*  DHW inlet temperature - design summer                            90     °F     *
*  DHW inlet temperature - design winter                            70     °F     *
*Circulating Pumps                                                              *
*  Circulating pump KW - occupied cycle                             2__    KW     *
*  Circulating pump KW - unoccupied cycle                           2__    KW     *
*DHW Efficiency and Losses                                                      *
*  Design DHW heating efficiency                                    75_    %      *
*  DHW losses - occupied cycle                                      13000_ BTUH   *
*  DHW losses - unoccupied cycle                                    13000_ BTUH   *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	48,435	616	1.3
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	24,217	308	1.3
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	110,251	308	0.3
Gas	MBTU	4,905.092	4,843.470	61.622	1.3
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0
Annual Totals	MBTU	10,777.710	10,716.090	61.620	0.6

ECO 75 - Insulate Hot Water Pipes

This ECO was modeled by assuming that 1" of pipe insulation was installed on the bare domestic hot water system pipes. The domestic hot water system heat losses were therefore reduced to 3,000 BTUH instead of the 13,000 BTUH used in the base case. ASEAM2 ECO screen #570 was used in this evaluation (see below). For more information on pipe losses refer to Stamper and Koral (1979).

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*ASEAM2 ECO INPUT: PLANT                                     Input File:20P1570A*
*DOMESTIC HOT WATER                ECO No: 570   Case No: 1    ECO File:20P1570A*
*-------------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                                 30_    therms *
*                                                                               *
*  Average hourly DHW usage - occupied cycle                       66__   gal/hou*
*  Average hourly DHW usage - unoccupied cycle                     0___   gal/hou*
*                                                                               *
*DHW Temperatures                                                               *
*  Domestic hot water supply temperature                           140    °F     *
*  DHW inlet temperature - design summer                           60     °F     *
*  DHW inlet temperature - design winter                           40     °F     *
*Circulating Pumps                                                              *
*  Circulating pump KW - occupied cycle                            2__    KW     *
*  Circulating pump KW - unoccupied cycle                          2__    KW     *
*DHW Efficiency and Losses                                                      *
*  Design DHW heating efficiency                                   75_    %      *
*  DHW losses - occupied cycle                                     3000__ BTUH   *
*  DHW losses - unoccupied cycle                                   3000__ BTUH   *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	47,910	1,141	2.3
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	23,955	570	2.3
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	109,988	571	0.5
Gas	MBTU	4,905.092	4,791.002	114.090	2.3
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0
Annual Totals	MBTU	10,777.710	10,663.620	114.090	1.1

ECO 76 - Insulate Water Storage Tanks

This ECO was modeled by adding an R-10 insulation jacket on the existing domestic hot water tank. Standby losses were thus reduced by 350 BTUH, resulting in a domestic hot water loss of 12,650 BTUH instead of the 13,000 BTUH in the base case. ASEAM2 ECO screen #570 was used in this evaluation (see below).

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*ASEAM2 ECO INPUT: PLANT - Domestic Hot Water                Input File:BASEBLDG*
*DOMESTIC HOT WATER                ECO No: 570   Case No: 1    ECO File:20P2570A*
*-------------------------------------------------------------------------------*
*Annual pilot consumption (if gas)                                 30_    therms *
*                                                                               *
*  Average hourly DHW usage - occupied cycle                        66__   gal/hou*
*  Average hourly DHW usage - unoccupied cycle                      0___   gal/hou*
*                                                                               *
*DHW Temperatures                                                               *
*  Domestic hot water supply temperature                            140    °F     *
*  DHW inlet temperature - design summer                            60     °F     *
*  DHW inlet temperature - design winter                            40     °F     *
*Circulating Pumps                                                              *
*  Circulating pump KW - occupied cycle                             2__    KW     *
*  Circulating pump KW - unoccupied cycle                           2__    KW     *
*DHW Efficiency and Losses                                                      *
*  Design DHW heating efficiency                                    75_    %      *
*  DHW losses - occupied cycle                                      12650_ BTUH   *
*  DHW losses - unoccupied cycle                                    12650_ BTUH   *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	49,011	40	0.1
Electricity	kWh	1,720,663	1,720,663	0	0.0
Gas	Dollars	24,525	24,505	20	0.1
Electricity	Dollars	86,033	86,033	0	0.0
Annual Totals	Dollars	110,559	110,539	20	0.0
Gas	MBTU	4,905.092	4,901.099	3.993	0.1
Electricity	MBTU	5,872.621	5,872.621	0.000	0.0
Annual Totals	MBTU	10,777.710	10,773.720	3.990	0.0

ECO 77 - Install Decentralized Water Heaters

In this ECO, several small electric water heaters were installed to provide the needed domestic hot water. The domestic hot water losses were eliminated (set equal to zero) and the electric hot water heater efficiency was set at 98%. A batch mode (new plant input file) was used, and the domestic hot water screen was accessed to reflect the new conditions. For further information on decentralized domestic hot water heaters, refer to the discussion of ECO 77 in Chapter 1.

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*ASEAM2 PLANT INPUT                                                              *
*DOMESTIC HOT WATER                                          PLANT FILE:21p1btch*
*-------------------------------------------------------------------------------*
*Domestic Hot Water Energy Source                                                *
*  Domestic Hot Water Energy Source                             1                *
*    (0=None  1=Electric  2=Nat Gas  3=Oil  4=Boiler  5=District)                *
*      (if oil)  Oil Type (2 or 4 or 6)                         _                *
*      (if gas)  Annual pilot consumption                       ___     therms *
*DHW Capacity and Usage                                                          *
*  Domestic Hot Water Heating Capacity (blank=autosized)        90.1    KBTUH  *
*    (if autosized) Peak hourly DHW usage                       ____    gal/hou*
*  Average hourly DHW usage - occupied cycle                    66__    gal/hou*
*  Average hourly DHW usage - unoccupied cycle                  0___    gal/hou*
*DHW Temperatures                                                                *
*  Domestic hot water supply temperature                        140     °F     *
*  DHW inlet temperature - design summer                        60      °F     *
*  DHW inlet temperature - design winter                        40      °F     *
*Circulating Pumps                                                               *
*  Circulating pump KW - occupied cycle                         2__     KW     *
*  Circulating pump KW - unoccupied cycle                       2__     KW     *
*DHW Efficiency and Losses                                                       *
*  Design DHW heating efficiency                                98_     %      *
*  DHW losses - occupied cycle                                  0_____ BTUH   *
*  DHW losses - unoccupied cycle                                0_____ BTUH   *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	45,518	3,533	7.2
Electricity	kWh	1,720,663	1,761,721	-41,058	-2.4
Gas	Dollars	24,525	22,759	1,767	7.2
Electricity	Dollars	86,033	88,086	-2,053	-2.4
Annual Totals	Dollars	110,559	110,845	-286	-0.3
Gas	MBTU	4,905.092	4,551.773	353.319	7.2
Electricity	MBTU	5,872.621	6,012.752	-140.131	-2.4
Annual Totals	MBTU	10,777.710	10,564.530	213.180	2.0

ECO 78 - Use Smaller Water Heaters for Seasonal Requirements

ASEAM cannot simulate use of a separate summer water heater. However, if the new water heater were to be used year-round, this can be modeled by changing the plant type for the domestic hot water. A new plant input file would be required. ASEAM2 cannot seasonally assign loads to different equipment.

ECO 79 - Use Heat Pump Water Heaters

ASEAM does not model heat pump water heaters.

ECO 80 - Heat Water with Solar Energy

ASEAM does not simulate solar water heaters. For information on solar water heating design, refer to Kreider (1982).

ECO 81 - Clean and Maintain Systems

Although many ECOs reduce the lighting energy consumption, ASEAM (and most energy simulation programs) require changes in only a few input values: the present (or revised) lighting watts, and the scheduling of the lights (diversity factors or average usage). While the list of lighting ECOs in this report (ECOs 81 - 91) may suggest many opportunities, actual energy savings can be achieved only by reducing the lighting watts supplied to the space or by reducing the amount of time the lights are on. For reductions in the lighting watts supplied, use the Lighting ECO screen (ASEAM2 ECO #160). For reducting the time the lights are used, use the Diversity Factor ECO screen (ASEAM2 ECO #200).

Cleaning and maintenance of the lighting systems does not, by itself, reduce the lighting watts or time of use. It will allow lower wattage to be used because there is less light depreciation. Unless the lighting watts are reduced, however, no savings will result.

To model this ECO using ASEAM, first determine the resultant change in the lighting watts. Once the reduced wattage is known, use the Lighting ECO screen (ASEAM2 ECO #160) to enter the new value. See ECO 82 below for an ECO that reflects changes in the lighting watts. For further information on required lighting levels in different buildings and various spaces, refer to Kaufman and Haynes (1981).

ECO 82 - Reduce Illumination Levels

In the base-case building, the lighting power was 2.2 watts per sq ft. A lighting audit of each of the spaces revealed several spaces in excess of the required foot-candle illumination. Some of the lights in these spaces were removed, bringing the watts/ft^2 value down to 1.8. To simulate this ECO, the Lighting ECO screen (ASEAM2 ECO #160) is used (see below). For further information on required lighting levels in different buildings and various spaces, refer to Kaufman and Haynes (1981).

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*ASEAM2 ECO INPUT: ZONE  1                                    Input File:22P2160A*
*LIGHTING ECOS                    ECO No: 160   Case No: 1    ECO File:22P2160A*
*-----------------------------------------------------------------------------*
*                                  Ltg Func 1 Ltg Func 2 Ltg Func 3 Ltg Func 4  *
*Function name (optional)          GENERAL___ TASK______ NA________ NA________  *
*                                                                               *
*Installed watts/ft²               1.8__      1.0__      _____      _____       *
* (times) % of function area       100        0__        ___        ___         *
*  (or) Total installed watts      ________   ________   ________   ________    *
*                                                                               *
*Percent light heat to space (%)   80_        100        ___        ___         *
*'A' classification                .55        .55        ___        ___         *
*'B' classification                B          B          _          _           *
*                                                                               *
*         A classification - .45, .55, .65, .75  (See ASHRAE F26.19 T15)        *
*         B classification -  A, B, C, D         (See ASHRAE F26.19 T16)        *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	50,453	-1,402	-2.9
Electricity	kWh	1,720,663	1,589,865	130,798	7.6
Gas	Dollars	24,525	25,227	-701	-2.9
Electricity	Dollars	86,033	79,493	6,540	7.6
Annual Totals	Dollars	110,559	104,720	5,839	5.3
Gas	MBTU	4,905.092	5,045.302	-140.210	-2.9
Electricity	MBTU	5,872.621	5,426.210	446.411	7.6
Annual Totals	MBTU	10,777.710	10,471.510	306.200	2.8

ECO 83 - Reduce Time of Operation

In the base-case building, the cleaning crew kept the lights on in all the spaces until 8 PM. This was modeled in the original file with a relatively high unoccupied cycle diversity factor for lights (35%). For this ECO, the cleaning crew is assumed to have the lights on only in the spaces being cleaned. This ECO is modeled in the Diversity Factor ECO screen (ASEAM2 ECO #200). The original unoccupied cycle lighting diversity factor was changed from 35% to 20% (see below).

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*ASEAM2 ECO INPUT: ZONE  1 - ROOF-ZONE1-CORE                  Input File:BASEBLDG*
*OPERATING USE PROFILES (DIVERSIT  ECO No: 200   Case No: 1    ECO File:22P3200A*
*--------------------------------------------------------------------------------*
*                                            OCCUPIED  UNOCCUPIED  MONTHLY DIV FC*
*                                             PERIOD     PERIOD     TABLE # (1-4)*
*People:                                                                         *
*           Average % of full occupancy        80__       5___                   *
*                                                                                *
*Lights:                                                                         *
*GENERAL    Average % of installed capacity    95__       20__                   *
*TASK       Average % of installed capacity    60__       5___                   *
*NA         Average % of installed capacity    ____       ____                   *
*NA         Average % of installed capacity    ____       ____                   *
*                                                                                *
*Electric Equipment:                                                             *
*MISC.      Average % of installed capacity    65__       10__                   *
*NA         Average % of installed capacity    ____       ____                   *
*                                                                                *
*Miscellaneous Sensible Loads:                                                   *
*NA         Average % of installed capacity    ____       ____                   *
*NA         Average % of installed capacity    ____       ____                   *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	50,873	-1,822	-3.7
Electricity	kWh	1,720,663	1,591,083	129,580	7.5
Gas	Dollars	24,525	25,437	-911	-3.7
Electricity	Dollars	86,033	79,554	6,479	7.5
Annual Totals	Dollars	110,559	104,991	5,568	5.0
Gas	MBTU	4,905.092	5,087.311	-182.219	-3.7
Electricity	MBTU	5,872.621	5,430.367	442.254	7.5
Annual Totals	MBTU	10,777.710	10,517.680	260.030	2.4

ECO 84 - Use Task Lighting

In the base-case building, some of the overhead lights could be reduced if task lighting were implemented. To simulate this ECO, use the Lighting ECO screen (ASEAM2 ECO #160). In the base-case building, the general overhead lighting was reduced from 2.2 to 1.2 watts/ft^2 with the addition of 1 watt/ft^2 of task lighting in only 40% of the function area. See ECO 82 for a sample lighting ECO screen. For further information on required lighting levels in different buildings and various spaces, refer to Kaufman and Haynes (1981).

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*ASEAM2 ECO INPUT: ZONE  1                                   Input File:22P4160A*
*LIGHTING ECOS                    ECO No: 160   Case No: 1    ECO File:22P4160A*
*-------------------------------------------------------------------------------*
*                                 Ltg Func 1 Ltg Func 2 Ltg Func 3 Ltg Func 4  *
*Function name (optional)         GENERAL___ TASK______ NA________ NA________  *
*                                                                              *
*Installed watts/ft²              1.2__      1.0__      _____      _____       *
* (times) % of function area      100        40_        ___        ___         *
*  (or) Total installed watts     ________   ________   ________   ________    *
*                                                                              *
*Percent light heat to space (%)  80_        100        ___        ___         *
*'A' classification               .55        .55        ___        ___         *
*'B' classification               B          B          _          _           *
*                                                                              *
*          A classification - .45, .55, .65, .75  (See ASHRAE F26.19 T15)      *
*          B classification -  A, B, C, D         (See ASHRAE F26.19 T16)      *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	52,090	-3,039	-6.2
Electricity	kWh	1,720,663	1,445,402	275,261	16.0
Gas	Dollars	24,525	26,045	-1,519	-6.2
Electricity	Dollars	86,033	72,270	13,763	16.0
Annual Totals	Dollars	110,559	98,315	12,244	11.1
Gas	MBTU	4,905.092	5,208.954	-303.862	-6.2
Electricity	MBTU	5,872.621	4,933.157	939.464	16.0
Annual Totals	MBTU	10,777.710	10,142.110	635.600	5.9

ECO 85 - Use High-Efficiency Fluorescent Lighting

This ECO is modeled by reducing the present lighting watts/ft^2 using the Lighting ECO screen (ASEAM2 ECO #160). See ECO 82 for a sample ECO screen and Chapter 1 of this document for further discussion of ECO 85.

ECO 86 - Use High-Pressure Sodium Lighting in Selected Areas

This ECO is modeled by reducing the present lighting watts/ft^2 using the Lighting ECO screen (ASEAM2 ECO #160). See ECO 82 for a sample ECO screen and Chapter 1 of this document for further discussion of ECO 86.

ECO 87 - Install Low-Pressure Sodium Lighting in Selected Areas

This ECO is modeled by reducing the present lighting watts/ft^2 using the Lighting ECO screen (ASEAM2 ECO #160). See ECO 82 for a sample ECO screen and Chapter 1 of this document for further discussion of ECO 87.

ECO 88 - Install High-Efficiency Ballasts

This ECO is modeled by reducing the present lighting watts/ft^2 using the Lighting ECO screen (ASEAM2 ECO #160). See ECO 82 for a sample ECO screen and Chapter 1 of this document for further discussion of ECO 88.

ECO 89 - Remove or Replace Lenses

This ECO is similar to ECO 81 in that it permits a reduction in lighting watts but does not reduce the wattage directly. This ECO is modeled by reducing the present lighting watts/ft^2 using the Lighting ECO screen (ASEAM2 ECO #160). See ECO 82 for a sample ECO screen and Chapter 1 of this document for further discussion of ECO 89.

ECO 90 - Install Dimming Controls with Windows

This ECO was modeled by assuming that dimming controls were installed on the lighting system to reduce lighting energy consumption during daylight hours. A batch mode was used; and the lighting, window and daylighting screens were accessed to reflect the implementation of this ECO (see screens below). It was assumed that a continous dimming control was used and that the minimum lighting setpoint operates at 20% of its original lighting intensity with 30% of its original power. The daylighting was provided by the existing windows.

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*ASEAM2 LOADS INPUT: ZONE  2 - ROOF-ZONE2-EAST                                  *
*LIGHTING                                                     LOAD FILE:24P1BTCH*
*-------------------------------------------------------------------------------*
*                                  Ltg Func 1 Ltg Func 2 Ltg Func 3 Ltg Func 4  *
*Function name (or 'NA')           GENERAL___ TASK______ NA________ NA________  *
*Average function area (ft²)       2775____   2775____   ________   ________    *
*                                                                               *
*Installed watts/ft²               2.2__      1.0__      _____      _____       *
* (times) Percent of function area 100        0__        ___        ___         *
*  (or) Total installed watts      ________   ________   ________   ________    *
*                                                                               *
*Daylighting (Y/N)                 Y          N          _          _           *
*  Controlite filename (if appl)   ________   ________   ________   ________    *
*                                                                               *
*Lighting system type (Opt)        __________ __________ __________ __________  *
*Percent light heat to space (%)   80_        100        ___        ___         *
*'A' classification                .55        .55        ___        ___         *
*'B' classification                B          B          _          _           *
*                                                                               *
*          A classification - .45, .55, .65, .75  (See ASHRAE F26.19 T15)       *
*          B classification -  A, B, C, D         (See ASHRAE F26.19 T16)       *
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*ASEAM2 LOADS INPUT: ZONE  2 - ROOF-ZONE2-EAST                                   *
*DAYLIGHTING                                                    LOAD FILE:24P1BTCH*
*--------------------------------------------------------------------------------*
*                                  Ltg Func 1 Ltg Func 2 Ltg Func 3 Ltg Func 4  *
*Function name (or 'NA')            GENERAL___ __________ __________ __________ *
*Window orientation (N,NW,etc)      E_         __         __         __         *
*Ground reflectance (%)             20_        ___        ___        ___        *
*Typical room window area (ft2)     104__      _____      _____      _____      *
*Glass visible transmittance (%)    78_        ___        ___        ___        *
*Room depth from window (ft)        20         __         __         __         *
*Room length (ft)                   20         __         __         __         *
*Ceiling height (ft)                9_         __         __         __         *
*Wall reflectance (%)               70_        ___        ___        ___        *
*                                                                                *
*Present footcandles in space       50_        ___        ___        ___        *
*Design footcandles for space       50_        ___        ___        ___        *
*Sensor location                    2          _          _          _          *
*  (1=Max   2=Mid   3=Min)                                                       *
*                                                                                *
*Percent of lights controlled       100        ___        ___        ___        *
*Control type ('D'im or 'S'tep)     D          _          _          _          *
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*ASEAM2 LOADS INPUT: ZONE  2 - ROOF-ZONE2-EAST                                   *
*DAYLIGHTING CONTROLS                                           LOAD FILE:24P1BTCH*
*--------------------------------------------------------------------------------*
*                                  Ltg Func 1 Ltg Func 2 Ltg Func 3 Ltg Func 4  *
*Function name (or 'NA')           GENERAL___ __________ __________ __________  *
*                                                                                *
*For Dimming Control Only                                                        *
*  Minimum FC maintained by lights 10_        ___        ___        ___         *
*  % of total power at min FC (%)  30_        ___        ___        ___         *
*                                                                                *
*For Stepped Control Only                                                        *
*  Number of Steps (max=4)         _          _          _          _           *
*    Step 1 artificial FC          ___        ___        ___        ___         *
*    Step 1 lighting watts         ___        ___        ___        ___         *
*    Step 2 artificial FC          ___        ___        ___        ___         *
*    Step 2 lighting watts         ___        ___        ___        ___         *
*    Step 3 artificial FC          ___        ___        ___        ___         *
*    Step 3 lighting watts         ___        ___        ___        ___         *
*    Step 4 artificial FC          ___        ___        ___        ___         *
*    Step 4 lighting watts         ___        ___        ___        ___         *
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ECO Comparison with Base Case

Energy Type	Units	Base Case	ECO Case	Savings	Percent Savings
Gas	Therms	49,051	50,146	-1,095	-2.2
Electricity	kWh	1,720,663	1,598,419	122,244	7.1
Gas	Dollars	24,525	25,073	-548	-2.2
Electricity	Dollars	86,033	79,921	6,112	7.1
Annual Totals	Dollars	110,559	104,994	5,564	5.0
Gas	MBTU	4,905.092	5,014.641	-109.549	-2.2
Electricity	MBTU	5,872.621	5,455.406	417.215	7.1
Annual Totals	MBTU	10,777.710	10,470.050	307.660	2.9

ECO 91 - Install Dimming Controls with Skylights

ASEAM does not model skylights. For further discussion of this ECO, refer to Chapter 1 of this document.

ECO 92 - Correct Power Factors

ASEAM does not simulate any losses in the power system. For discussion of power factor correction devices see Chapter 1 of this document.

ECO 93 - Install Energy-Efficient Transformers

ASEAM does not simulate this ECO. For discussion of energy efficient transformers, see Chapter 1 of this document.

ECO 94 - Replace Oversized Motors

For all the energy-efficient motor ECOs in this report (ECOs 94 - 96) discussed below, the energy savings impact can be estimated by reducing the electric energy consumption of the present motors according to the new efficiencies. Local manufacturers and/or distributors should be consulted for current information on new equipment efficiencies.

ECO 95 - Use High-Efficiency Motors

Information on motor efficiency can be found in ASHRAE (1988) and NECA-NEMA (1979).

ECO 96 - Use Variable Speed Motors

Information on variable speed moters can be found in ASHRAE (1988) and NECA-NEMA (1979).

ECO 97 - Use Load-Shedding

ASEAM cannot model peak demand reductions. For further information regarding load shedding, see Chapter 1 of this document.

ECO 98 - Install a Cogeneration System

ASEAM cannot simulate cogeneration. However, monthly energy consumptions provided by ASEAM2 reports can be used as input data for other simplified analyses.

ECO 99 - Install a Cool Storage System

ASEAM cannot model cool storage systems.

ECO 100 - Install Temperature Setup/Setback Control System

Regardless of the control method for changing the space temperature setpoints, to simulate this ECO the setpoint values in the Thermostat Setpoint ECO screen (ASEAM2 ECO #220) must be changed. See ECOs 7 and 8 for the screen changes required.

ECO 101 - Install Time-of-Day Control System

Time-of-day control is simulated in ASEAM by changing the operating schedule of the systems in the Occupancy Schedules ECO screen (ASEAM2 ECO #210). See ECO 1 for the screen changes required.

ECO 102 - Install Duty-Cycling Control System

ASEAM does not simulate duty-cycling control.

ECO 103 - Install Supply Air Temperature Reset Control System

See the description and analysis of this typical energy management control system function in ECO 51.

ECO 104 - Install Hot/Chilled Water Supply Temperature Reset Control System

Refer to ECO 52 for a discussion of this ECO.

ECO 105 - Install Ventilation Purging Control System

ASEAM cannot model this ECO.

ECO 106 - Install Economizer Cooling Control System

See ECO 53 for a discussion of the modeling of economizer cycles.

ECO 107 - Install Demand Limiting Control System

ASEAM cannot model demand limiting control.

ECO 108 - Install Double-Bundle Chillers

This ECO should be modeled in a batch mode by specifying the double-bundle chiller as the cooling and heating energy source in both the heating and cooling screens (systems input) and by accessing the chiller screen (plant input) to substitute the existing chiller with the double bundle chiller. However, ASEAM does not "false-load" the chiller to satisfy heating loads. (False-loading artificially creates loads on the evaporator so that heat may be rejected in the condenser.) ASEAM accounts only for the heat rejected when there is a cooling load on the double bundle chiller.

ECO 109 - Reclaim Heat from Boiler Blowdown

See ECO 42 for a discussion of the ECO.

ECO 110 - Reclaim Incinerator Heat

When the amount of heat provided by the incinerator is determined, the reduction in the boiler plant load can be entered in the Systems Reset ECO screen (ASEAM2 ECO #410). See ECO 28 for further discussion of resetting plant equipment loads.

ECO 111 - Reclaim Heat from Combustion System Flue

See ECO 110 above.

ECO 112 - Install Water-Loop Heat Pump Systems

Changing the dual duct/multizone system to a water loop heat pump system can be modeled by ASEAM in a similar manner to ECO 51: changing to a variable air volume system. A new systems input file must be created with the water source heat pump specifications. Therefore, this ECO must be run in a batch mode.

ECO 113 - Reclaim Heat from Prime Movers

See ECO 110 above.

ECO 114 - Install Piggyback Absorption Systems

ASEAM cannot model this ECO. For further discussion of this ECO, refer to Chapter 1 of this document.

ECO 115 - Recover Heat from Light Systems

ASEAM does not model this ECO. The heat gain from lights can be assigned to either the space or to the plenum in ASEAM.

ECO 116 - Reclaim Heat from Refrigerator Hot Gas

See ECO 110 above.

<u>ECO 117 - Reclaim Heat from Steam Condensate</u>

See ECO 110 above.

<u>ECO 118 - Reclaim Heat from Waste Water</u>

See ECO 110 above.

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