Appendix C
Retrofit Descriptions

This appendix includes descriptions of 52 possible retrofits to buildings. The set includes descriptions of seven active and passive solar retrofits for which costs and benefits are shown in appendix D. The set also includes eight retrofits for which costs and/or savings were not estimated because conditions affecting costs and savings vary enormously from building to building. These retrofits were described in chapter 3 and include:

HVAC-21: Install adjustable radiator vents
HVAC-22: Reduce orifice size on furnace/boiler
HVAC-23: Install multifuel/solid fuel boiler
HVAC-24: Install house fans
HVAC-25: Condenser coil spray
HVAC-26: Chiller bypass system
DEW-6: Refrigeration heat reclaims for domestic hot water
L-5: Maximize use of daylighting

The list of retrofits was initially developed by Energyworks of West Newton, Mass. and was adjusted and expanded in consultation with members of a Retrofit Review workshop that met for two days in October 1980. The members of the workshop were professional energy auditors, architects and building retrofit researchers. Their names are listed in the acknowledgments at the front of the report.

5.2.3 Prose Descriptions of Energy Conservation Measures

E-1 ROOF/ATTIC INSULATION

The base building model assumes a pitched or flat roof over an uninsulated attic or crawl space in the single family case, and a flat roof with l/2-inch to 3/4-inch of older roof deck insulation for all other building types. Four inches of loose fill insulation is installed in attics/crawl spaces, and two inches of high-resistance roof deck insulation, such as polystyrene or urethane-polystyrene composite, is added to flat roofs. The cost of roof deck insulation includes the cost of replacing roofing over the new insulation. The unit cost for insulating flat roofs is much higher than that for attics or crawl spaces.

The life of the measure is indefinite if properly protected. In attics or crawl spaces, leakage through the roof or failure to properly vent the space can cause moisture damage. Roof deck insulation must be protected by maintaining the roofing.

The calculated results are highly dependent on the base case thermal properties. For older flat-roofed buildings, assuming a thin layer of fiber-type insulation board is realistic for most cases. The model is less dependable for the single-family case; while it was necessary to assume a 'worst case" of no insulation, many houses have some, which may vary widely in thickness, type, and insulating value. For example, adding four inches of loose fill to an attic already having two inches of somewhat compacted rock wool yields savings only 64% of the base case, or increases the cost/savings ratio by a factor of 1.56.

Where heating is electrical, this measure may yield additional savings through reduction of demand charges, which are not included in the calculations.

E-2 WALL INSULATION

The base building model assumes uninsulated walls for all wall types, which is representative of most older building stock. For cavity walls, 3 ½ inches of loose fiberglass or cellulose is blown" in. For masonry bearing walls (MBW) and clad walls, rigid insulation is fastened to the outside or inside walls, whichever is more feasible structurally and aesthetically. For either application, it is necessary to cover the insulation with wall board (interior) or a masonry finish compound (exterior). A combination of aesthetic and practical considerations may make this measure impossible in some buildings.

Costs of rigid wall insulation may vary widely, according to method used and availability of local contractors with experience in that type of work. Experience with retrofit insulation of MBW and clad walls is generally limited, and there may be long-term maintenance costs or problems that have not yet been uncovered.

Insulation of walls may improve the comfort level enough to permit lower winter thermostat settings in some cases, due to elimination of "cold wall" discomfort; this has not been included in the algorithm. Also not included are possible reductions in demand charges where heating is electrical.

E-3 STORM WINDOWS

Aluminum-frame combination storm windows are installed over single-glazed wood or metal framed double-hung windows, reducing both conduction heat loss and air infiltration. The base building model assumes "average fit" for the existing windows, and reduction of infiltration load is calculated by ASHRAE criteria. Savings would be greater if existing windows are exceptionally loose, less if they are already tight or weatherstripped. Therefore, savings may vary with a building's age and maintenance condition.

Maintenance requirements may include lubrication and/or occasional replacement of built-in weatherstripping. A measure life of twenty years may be expected, varying with product quality, use, etc. The cost estimate is for 'average" quality windows.

Improvement of the comfort level due to this measure is not incorporated into the algorithm. Also not included are possible reductions in demand charges where heating is electrical.

E-4 REPLACEMENT DOUBLE GLAZING

For buildings with double-hung windows, existing wood or metal-framed windows are removed and replaced with new, integrally-weatherstripped, double-glazed units. For all other window types, a second layer of glazing is fitted to the existing sash, by the 'deadlite" or similar method.

Base case assumptions are as described above for E-3. Reductions in infiltration load are calculated for double-hung windows, but not for other types, as the method for casement and projected windows does not involve sash replacement or change the sash fit.

Costs may vary widely according to the quality of replacement windows used, or the method used for installing additional glazing. The costs used here assume average quality replacement and glazing added by attachment with magnetic strips.

E-5 WINDOW AND DOOR WEATHER STRIPPING

For the single-family case (P/U 1), plastic or rubber gasket weatherstripping is installed on all doors and windows. Rigid-backed weatherstripping is used on doors. For all other building types, spring bronze is installed on doors and in window sashes, where feasible. On some windows, foam or rubber gasket weatherstripping may be more practical. As with E-3 and E-4, unweatherstripped doors and windows of 'average fit" are assumed for the base case. Actual savings may be less than those calculated when some weatherstripping already exists? greater when doors and/or windows are very loose.

Actual cost of weatherstripping can vary considerably. In the single-family case, installation by the occupant is assumed. Costs are estimated for highest quality materials and installation in all cases.

Life of this measure varies from 1 to 2 years for some platic or foam types to indefinitely for well-maintained spring bronze. Maintenance and/or replacement costs are not included in the calculation.

E-6 WINDOW INSULATION

Quilted, polyester fiberfill-lined window shades are installed on all windows. A track or magnetic fastening system is provided to maintain a good air seal between the shade and the window. It is assumed that the device is in place an average of eight hours per day throughout the heating season, and is used on an average of 75% of the windows at *any given* time. An effective value of R-3 is added to the window units.

The base case assumes single-glazed windows, which are representative of most older Urban buildings. Where double-glazed windows exist, savings would be about 48% of those calculated.

The savings are highly dependent on behavior; use for more hours or on more of the windows than indicated would yield proportionally greater savings. There is also some variation depending on the exact device used (various types of thermal shutters or other shade types are only roughly equivalent) and the quality of insulation.

Savings are calculated for use during night-time temperature conditions. Daytime use would yield additional savings at a somewhat lower rate. The effective life of this measure is not yet known.

E-7 REFLECTIVE FILMS

Reflective window films are applied directly to the glazing *in* commercial buildings (P/U types of 3 and 4). Effective solar transmission is reduced by 72% and effective thermal transmission (U-value) by 29%. This measure refers specifically to products that are designed to reduce heating load as well as cooling load.

The base case specifies single-glazed windows, which is representative as discussed above. Existence of double-glazed windows would have little impact on the solar-gain reducing aspect, but would greatly reduce the savings in heating load, which is a major part of the total.

Preliminary results show this measure as more cost-effective in cold climates than in warm, which runs counter to expected results. There are two major reasons for this:

1. Manufacturers literature claims reductions in heat loss as indicated above; independent laboratory test results to confirm or deny these figures is not yet available. The current calculations indicate that measure has a much greater impact on heating load than on cooling load, hence the greater cost-effectiveness in cold climates.

2. The building models are very limited as models for solar heat gain. A rectangular shape, with windows evenly distributed with respect to orientation and unshaded condition are assumed. Real-case buildings seldom have these characteristics. In some cases, as in buildings with a great deal of west-exposed glazing, solar heat gain may have a much greater impact on cooling load, and therefore the cooling aspect of this measure could predominate.

If this measure is highly effective in reducing radiant heat loss through glazing, improvements in comfort level (possibly enabling lower winter thermostat settings) could add to the measure's cost-effectiveness for heating.

On the other hand, the measure could have a negative effect if used on south-exposed windows that were valuable sources of solar heat gain in the winter, particularly where the windows were double-glazed or had night insulation.

Expected life of reflective films is not yet known.

E-8 SHADING DEVICES

Exterior-mounted fiberglass screen shading devices are installed over windows in commercial buildings. Devices are used on all sides of the building in the summer, and all sides except south in the winter, to take advantage of useful winter solar heat gain. The devices act as storm windows, reducing conductive heat loss and infiltration~ as well as reducing solar heat gain. This measure is modeled specifically for removable devices. Savings are calculated with the assumption that the building's windows are single glazed, as described in the building models. Savings would be reduced for double-glazed windows, as discussed above for E-6.

Several factors should be considered in evaluating the calculated savings:

1. Actual costs may vary widely according to the exact type of device used.

2. As modeled, the devices would be installed over operable windows.

Compliance with building codes may be an issue in some cases. However, commercial buildings are modeled with the assumption that mechanical ventilation is provided; therefore windows would not ordinarily be required as a ventilation source and covering time would not pose a problem.

3. The annual cost of setting up and removing devices from the south side has not been included in the calculations.

4. The limitations of the building model for modeling solar gain, as discussed above for E-7, would apply here.

5. The effective life of such devices is not yet known.

E-9 ROOF SPRAYS

A roof spray system is installed on flat roof buildings to reduce roof surface temperatures through evaporation, thus reducing heat gain and reducing the cooling load. The base case assumes a dark-colored flatroof, with thermal properties as described in the building models. Savings are calculated assuming the system is operated an average of ten hours per day during the cooling season, and actual sun conditions are taken into consideration for the various climate zones.

The assumed thermal properties of the roof are fairly representative of older buildings which have not already been retrofitted with roof insulation. Savings for well-insulated roofs would be reduced in proportion to the difference in U-value from the base model.The assumption of a dark-colored roof, while also fairly representative of real buildings, is very crucial to the results. Savings for a light-colored, reflective roof could be as little as one-quarter of those calculated.

Cost of this measure could be greater than the assumed value where the installation presents structural problems, or where extensive additional piping must be installed inside the building to handle the water requirements. The cost of water was also not considered in the calculations.

Damage to the roof from water should not occur where the roofing is in good condition and does not have drainage problems. Evaporation would ordinarily be sufficient to prevent pooling on the roof where the system's controls are operating properly.

HVAC-1 REPLACE BURNER AND CONTROLS

Existing oil-fired burner head is replaced with new retention-head burner and appropriate controls, to improve operating efficiency. The base case assumes a single-pass, vertical fire tube, dry-base conventional boiler.

The savings from this measure are highly dependent on the original efficiency of the equipment, which is a condition of the type and condition of burner and controls, the condition of air intakes, boiler jacket, flue, and tubes, as well as the basic boiler type as described above. Any assumption made about system efficiency is, by necessity, based on a rough estimate only, the real cases may vary widely due to differences in the factors discussed above. An attempt was made to model representative older equipment that has been maintained in good condition but does not incorporate modern features that contribute to overall efficiency such as improved jacket insulation, more efficient fuel dispersion and fuel-air mixing, etc.

Another shortcoming of this algorithm is that it is based specifically on oil-fired water-heating equipment, although savings for oil-fired air furnaces should be roughly comparable. Improvements in the efficiency of gas-burning equipment may be less than those calculated.

Also, the calculated savings will result only where the equipment is well maintained and tuned periodically. This is assumed part of a normal maintenance program and maintenance costs are not included in the calculations. The new burner could be expected to last for the life of the boiler.

HVAC-2 REPLACE BOILER/FURNACE

Existing boiler plant is replaced with a new wet-base, two-pass horizontal fire tube steel boiler, with induced-draft burner. The base case is as described above for HVAC-1, and the limitations of the algorithm also apply here.

In this case, the savings are only applicable to water-heating equipment; the type of fuel burned is not a major consideration, as the major part of savings derive from improving the efficiency of the boiler itself. Opportunities to improve the efficiency of air-heating equipment are somewhat more limited.

HVAC-3 INSTALL VENT DAMPER ON BOILER/FURNACE

An electrically-actuated automatic vent damper is installed on the central heating plant, to reduce convection of air up the flue and loss of heat from the system when the burner is not firing (standby losses). The base case is as described for HVAC-1. As a variety of vent damper designs are available, savings may vary with exact type.

Vent dampers are generally more effective for water systems, where considerable heat is stored in the heating plant itself, and for gas-fired systems, where the flow of air through the flue during off-cycle can be considerable. Therefore, best savings are obtained for gas-fired boilers, the least for oil-fired furnaces. The savings calculated here should be interpreted as representing the mid-point of a range.

Vent dampers are a relatively new item, and the expected life of the measure is not yet known. Maintenance of the device and its control circuitry would be included in normal heating plant maintenance.

HVAC-4 INSTALL STACK HEAT RECLAIMER

Boiler water is preheated using reclaimed stack heat, reducing overall heating needs. This measure is applicable primarily to oil-fired boilers; savings from gas-fired boilers are expected to be less due to lower stack temperatures, making less heat available for recovery.

Stack heat reclaimers have not yet become a common item; therefore price, quality, and availability may vary. The savings estimated are based on improvement in the overall seasonal efficiency of the heating plant, as determined in tests performed by Brookhaven National Laboratories. The sample used for these tests was limited, and actual performance may vary with the initial condition of the heating plant and with the exact device used.

HVAC-5 REPLACE ELECTRICAL RESISTANCE WITH HEAT PUMPS

This measure is intended to improve the heating energy-efficiency of all-electric, decentralized buildings where no central distribution system exists. Therefore, substitute heating systems must be installed on a room-by-room basis and depend on no input other than electricity. One of the few options available is to install air-to-air unitary heat pumps, mounted through the wall or through window openings, similar to conventional air conditioners.

Heat pumps operate like air conditioners in reverse, cooling the outside air and transferring the heat extracted from it to the inside air. The colder the outdoor conditions, the less heat is available for extraction, and the lower the operating efficiency of the heat pump. Most heat pump systems work in conjunction with electric resistance heating, which takes over when the outdoor temperature drops too low for the heat pump to operate effectively. The overall seasonal efficiency of a heat pump is therefore strongly dependent on climate, and is roughly an inverse function of degree-days.

Heat pumps also operate for cooling in the summer; therefore this measure is modeled to replace the cooling source as well as partially replacing the heating source. Heat pumps usually operate at a somewhat lower Coefficient of Performance (COP) than conventional air conditioners in the cooling cycle, and therefore consume more energy for cooling. While exact proportions would vary with equipment, it was assumed here that the heat pump's COP is 85% of that of the cooling system it replaces. Preliminary results indicate that the heat pump measure is in some cases less cost-effective in warmer climates, rather than more as might be expected. This would be due to the reduction in cooling efficiency having a greater effect on the savings than the increase in heating efficiency.

Several difficulties were encountered in modeling this measure, which should be kept in mind when evaluating the results:

1. Wall-mounted heat pumps are a relatively uncommon item; reliable cost and performance data was therefore difficult to obtain, and the parameters used represent a limited sample.

2. The increase in cooling energy is strongly dependent on the COP of the original equipment as well as that of the heat pump; real variations from the values assumed here could produce different results.

3. Sizing of heat pump systems (for developing cost estimates) presented a difficult problem. First, it is not known whether a wall-mounted system could completely replace the existing heating source, particularly for interior areas that would be far from the heat pump. While it was assumed that the heat pump system would handle the total heated area, this may not be feasible in some real cases. Also, there was some question as to whether systems should be sized to meet peak heating load (at design winter temperature) or some fraction of peak load, since the minimum operating temperatures of heat pumps vary considerably with equipment. It is assumed that the electric baseboard radiation would remain in place to supplement the heat pumps if required.

While a heat pump system would reduce overall electric consumption, there might not be any reduction in demand charges, particularly in colder climates, where peak loads would still need to be met by electric resistance heating.

WAC-6 INSTALL BOILER TURBULATORS

Turbulators are installed in tubes of existing fire-tube boilers to improve heat transfer between hot combustion gases and the heat exchanger, thereby improving overall operating efficiency. Stack temperature and stack heat losses are reduced. It should be noted that many boilers, including older equipment, already have turbulators as original equipment; therefore, this measure applies only where turbulators never existed, or had been removed and discarded at some previous time (before energy conservation became a high priority, turbulators were sometimes discarded to make tube cleaning easier).

Information on energy savings from this measure is limited, and savings would tend to vary with the original boiler condition, number and configuration of tubes, and the design of a particular type of turbulator. A flat reduction of 5% in fuel consumption is consistent with test results obtained by Brookhaven National Laboratories, performed on oil-fired equipment. Savings for gas-fired equipment should be roughly comparable.

The cost of this measure is a function of the number, length, and inside diameter of boiler tubes. A separate figure was calculated for each building type and climate zone, depending on design heating load and assumed boiler size. However, cost variations of at least +/- 25% could be expected in real cases.

HVAC-7 INSTALL MODULATING AQUASTAT

In most older hydronic systems, boiler water is set at a single temperature usually 160-200 degrees. The boiler cycles to maintain this temperature and the circulation system responds to the room thermostat(s). However, the system operates more efficiently where the boiler water temperature is adjusted higher to meet colder conditions, lower to satisfy milder conditions. A modulating aquastat is connected to an outdoor temperature sensor, and automatically resets boiler water temperature (usually in the range between 80 and 200 degrees) in response to outdoor temperature. While this does not reduce the space heating requirements or improve the actual combustion efficiency of the boiler, having a reduced water temperature most of the time reduces system 'parasitic[a] heat losses through the boiler jacket and piping. It would also reduce any tendency of the system to "overshoot" the indoor temperature requirement, thereby further reducing energy waste.

An original single-point boiler setting of 180°F is assumed in the calculation and energy savings is proportional to the variation of actual outdoor temperatures from the design temperature over the course of a heating season. An algorithm using temperature bin data is used.

A modulating aquastat should last for the life of the boiler and burner equipment, given regular and periodic calibration.

HVAC-8 INSTALL SETBACK THERMOSTATS

Existing room or zone thermostats are replaced with timer-actuated units, set to reduce overnight or unoccupied-zone temperatures. Base case assumption is that buildings are maintained at 65°F, 24 hours a day; after installation, temperatures are reduced to 55°F for 8 hours a day. Savings occur due to a reducton in the temperature difference between inside and outside, thereby reducing the rate of heat loss and reducing the demand on the heating system.

While setback thermostats are sometimes used to reduce cooling load as well, this measure is modeled for heating savings only. In residential buildings? it is assumed that the temperature is maintained at 78°F in the base case, and that any temperature reset to a higher point would not be feasible for reasons of comfort. In commercial buildings, it is assumed that the cooling system is already turned off during unoccupied hours, and that a temperature reset would therefore not accomplish any energy savings.

Any major variation in initial conditions from the base case would affect savings in proportion to the change in temperature difference.

The success of this measure is highly dependent on being able to maintain adequate comfort at 55°F, and on behavior of occupants. Well-insulated buildings with low infiltration rates can be adequately comfortable with an overnight setting of 55°F (of course, in commercial buildings it is assumed that they are unoccupied during setback hours). However, conditions in uninsulated, leaky buildings, which is more typical of the base building models and of much of the older urban building stock, could be nearly intolerable at 55°F. Therefore, in evaluating results, it should be kept in mind that this measure may not be feasible in some residential buildings for comfort reasons. It would tend to be most effective in conjunction with building envelope measures such as insulation and window improvement that tend to improve the comfort level.

When used with an existing heat pump system, setback thermostats will still save energy, but at a somewhat lower rate than in conventional heating systems; this is because a typical heat pump system will automatically activate the resistance backup heating on an increased call for heat when the thermostat is set up in the morning; the system will not return to the heat pump mode until the higher temperature is reached.

HVAC-9 INSTALL ENTHALPY CONTROL/DRY BULB ECONOMIZER

Conventional central air cooling systems operate primarily by recirculating indoor air through a cooling coil. A certain proportion of outdoor air is added to the air stream according to ventilation requirements. In many buildings, particularly in commercial buildings where internal heat gains are high, there is often a net demand for cooling even when outdoor air temperatures are much cooler than indoors. An economizer system maximizes the use of outdoor air for free cooling in such circumstances. The economizer consists of an outdoor air sensing element and a set of automatic damper operators. When there is a demand for cooling and outdoor air is sufficiently cool to contribute to meeting the demand, outdoor air dampers are opened and return air dampers shut, such that up to 100% outdoor air is circulated through the building. Successful retrofit of an economizer requires an outdoor air intake sufficiently large to handle 100% outdoor air, and an exhaust system with comparable capacity; such conditions are fairly typical in existing buildings with central air systems, and are assumed to exist in the base building model. Where an enlarged air intake or new automatic outdoor air damper are required, the cost would be somewhat higher than that assumed here.

Two major control options are available: a dry-bulb economizer operates by sensing the temperature of outdoor air; an enthalpy control system senses the enthalpy, or overall heat content (sensible plus latent) of the outdoor air. Enthalpy control therefore allows more precise control of comfort conditions and saves more energy by taking advantage of a wider range of outdoor conditions. However, enthalpy control systems have often proven unreliable in actual field conditions; humidity sensing elements have tended to be inaccurate or to require frequent servicing and adjustment. Therefore, a dry-bulb economizer is modeled for this measure. Savings are calculated by a method developed by the Honeywell Corporation, using a climate parameter ‘K’ that reflects the typical free cooling potential, over the course of a season, in various climate zones. The reduced savings potential for a dry-bulb economizer is incorporated into the algorithm, which assumes that a narrower range of temperatures is useful for free cooling. This algorithm is somewhat oversimplified, and is intended for order-of-magnitude estimating. A more precise method is not currently available within the scope of this project.

HVAC-10 REPLACE ROOM AIR CONDITIONERS

Existing older room air conditioners are replaced with high-efficiency models in buildings with water or decentralized systems. The same cooling load is satisfied at a higher efficiency, thus reducing the energy demand. The base case assumes existing units are at least eight years old, which would be typical of older buildings and well within the lifetime of most air conditioners? and indicate a unit produced before energy-efficiency became a high priority in equipment design.

The cost-effectiveness of this measure is highly sensitive to the relative efficiency between the original and the replacement units, and major variations in either could produce very different results. The efficiency of older equipment is a function not only of its original efficiency, but also of its service history, the condition of controls, the condition and cleanliness of coils, the amount of outside air it handiest etc. A reasonably well-maintained unit is assumed here. There is also a wide range in efficiencies of new equipment available; a typical mid-range point was assumed.

The costs estimated for this measure are intended to reflect mid-range for units sized to meet peak cooling load; however, variations of +/- 30% could be expected.

HVAC-11 REPLACE CENTRAL AIR CONDITIONING SYSTEM

For the single-family, small multifamily, and small commercial types (P/U 1, 2, 3), the existing direct-expansion (DX) compressor and condensing unit are replaced with new high-efficiency models. For the large commercial and large multifamily types (P/U 4, 5), the existing chilled water system is replaced with a new reciprocating chiller. The distinction between DX and chilled water systems is made because the large peak cooling loads of P/U types 4 and 5 would ordinarily require a chilled water system, whereas the smaller requirements of types 1, 2, and 3 could be satisfied with typical DX systems.

The discussion made above for HVAC-10, concerning possible variations in savings and cost, would also apply here. The need for replacement of central equipment is not well established, particularly in light of the high cost involved. In some cases, improved maintenance, improved control and distribution systems, and/or partial replacement of componets would be more cost-effective than total replacement of the central equipment.

HVAC-12 VARY CHILLED WATER TEMPERATURE WITH LOAD

Chilled water central air conditioning systems usually supply water at the temperature required to meet the maximum cooling load. Energy can be saved by varying the temperature of the chilled water in response to outdoor temperature, by a principle similar to that of a modulating aquastat (see HVAC-7), cooling the water only as much as is necessary to meet the immediate cooling load. This improves efficiency by reducing cycling of the chiller, and also by allowing the chiller to operate at a higher temperature. Controls and valving to modulate chilled water temperature are installed.

This measure is modeled for air systems in all building types except the single family. While P/U types 2 and 3 were modeled as DX systems for the purposes of measure HVAC-11, it is feasible that these types could also have chilled water systems. Therefore, this measure was modeled for P/U types 2 and 3 so that comparative data would be available.

The savings given for this measure apply specifically to Reciprocating machines. Savings would be about three times higher for centrifugal machines.

HVAC-13 CONVERT TERMINAL REHEAT SYSTEM TO VARIABLE AIR VOLUME (VAV)

Complex systems in commercial buildings are modeled as terminal reheat systems, which are typical of the general type of system installed before energy conservation became a major Consideration. Terminal reheat systems provide very precise zone temperature control, but at the expense of very high energy consumption. For cooling, air is supplied to the entire building at the temperature required by the zone with the greatest cooling demand. The air to all other zones is reheated to provide the required temperature, an extremely wasteful process. For heating, outside air Is typically mixed with the return air stream to provide the needs of the zone with the least heating requirement? which may often be an internal zone that actually requires cooling even in mid-winter. The supply air to all other zones is reheated to satisfy heating requirements.

A variable air volume (VAV) system operates at a single supply air temperature for each of the conditioning modes (heating and cooling), and satisfies the needs for different zones by varying the volume of air supplied. It can therefore handle transient zone conditions as well as different basic zone requirements. Energy is saved versus a terminal reheat system in three ways: the need for summer reheat is eliminated entirely; the demand on the cooling system is reduced, as a full supply of air at the temperature required by the highest-demand zone is no longer required; and the heating energy is saved by eliminating the need to mix supply air to the needs of the zone with the least heating requirement.

The measure consists of replacing each reheat terminal with a VAV box. It is assumed that a central pneumatic control system already exists, which can be adapted to serve the needs of the VAV system. This would generally be the case in buildings already having a complex system such as terminal reheat. Installation of a completely *new* central control system could add at least 30% to the cost.

Savings are calculated with the assumption that energy is saved in each of the three categories listed above, and that initial operating conditions of the terminal reheat system are as listed on the algorithm sheet. The initial conditions are chosen on a "worst case" assumption; the magnitude of energy savings would be less where initial primary air temperatures were higher or where other initial conditions were different than specified.

Ongoing regular maintenance of the VAV system and controls is assumed; cost of maintenance is not incorporated into the calculations.

HVAC-14 REDUCE VENTILATION VOLUME

HVAC systems in most older commercial buildings were designed to handle a volume of outside air equivalent to about 7.5 to 10 cubic feet per minute (CFM) per occupant. In many cases, leaky or poorly-controlled outside air dampers allow an even greater volume, and also permit a considerable volume to leak through even when dampers are nominally closed. Changes in building and sanitation codes in recent years have allowed reduction of outside air to 5 CFM per occupant. Since the cost of conditioning outside air is very high, savings form ventilation reduction can be considerable. This measure is applicable to almost all commercial buildings; exception would be made only where heavy smoking or a fume-generating process necessitated a higher rate *of* air exchange.

Ventilation is reduced by installation of new low-leakage dampers. Damper controllers are set to permit 5 CRM of outside air per occupant during occupied hours, and to shut tightly during unoccupied hours. In calculating savings, it is assumed that the original occupied-hour volume was 7.5 CFM per occupant (typical of older obsolete building code requirements), and that the rate of leakage through shut dampers is reduced from 10% to 1% of total air volume. Savings could be greater or less with any major departure from these initial conditions.

HVAC-15 EVAPORATIVE COOLING SYSTEM

An evaporative cooling system operates by passing outside air through a saturated filter. Water is evaporated from the filter, and the heat required for evaporation is extracted from the air stream, *thus* lowering the air’s dry-bulb temperature. The cooled air is supplied directly to the space as supplement or replacement for mechanically cooled air. The effectiveness of the system is a function of outdoor wet-bulb temperature? which represents the lower limit to which the dry-bulb temperature of the air stream can be cooled. Therefore, the system operates only when there is a demand for cooling and the wet-bulb temperature is sufficiently low to produce the desired effect. Savings are determined by calculating the evaporative cooling potential of the outside air over the course of a cooling season in each climate zone, a function of the wet-bulb temperature profile. The method assumes that this potential can be fully utilized; therefore, it tends to overestimate the savings, by not accounting for the utilization efficiency of the system.

HVAC-16 REPLACE AIR-COOLED CONDENSER WITH WATER-COOLED

The efficiency of central air conditioning systems can be improved by lowering the condensing temperature, which reduces the load on the compressor. Water-cooled condensers generally provide a lower condensing temperature than air-cooled condensers, which are limited by the temperature of outside air. The effectiveness of water-cooled condensers depends on wet-bulb temperature, and therefore depends on a climatic parameter similar to WAC-15. It is assumed that the existing air-cooled condensor was maintained in good condition, and the new equipment is sized for the peak cooling load of the system. The cost of the system also includes installation of a cooling tower to cool the condensing water. Special problems, such as structural problems with a tower installation, or extra costs involved in providing an adequate water supply for the system, are not considered.

This measure is more cost-effective for residential buildings than for commercial buildings of comparable size and characteristics for the following reason: condensor and cooling tower are sized for peak cooling load, which is higher in commercial buildings due to a higher rate of internal heat gains. Therefore, the system is more costly for commercial buildings. Savings, however, are a function of seasonal cooling load, which is more nearly equal between residential and commercial, since the cooling system is assumed to operate only during occupied hours in the commercial model, and operates constantly at a lower load rate in the residential model. The net effect is to produce a lower cost/savings ratio for commercial buildings. This would tend to be true of all measures involving a system sized to peak cooling load, but where savings are proportional to overall seasonal load.

HW4C-17 FOG COOLING (EVAPORATOR COIL SPRAY)

A system is installed to spray cold water into the air stream leaving the evaporator (cooling) coil, which reduces the dry-bulb temperature of the air down towards the limit of its initial wet-bulb temperature. The principle of operation is similar to that for Evaporative Cooling, HVAC-15, except that return air is cooled rather than outside air. The base case assumes that the air entering the evaporator coil is at 78° dry bulb, 65° wet bulb

(50% relative humidity). Savings would be less where' the indoor wet-bulb temperature was higher, as the potential for cooling by the fog system would be reduced. Similarly, savings could be greater with a lower initial wet-bulb temperature.

HVAC-18 INSULATE DUCTS

Blanket insulation of 1 1/2 inch to 2 inch thickness is installed to reduce parasitic heat gains and losses from uninsulated ductwork. The base case assumes a 135° winter supply air temperature and a 55° summer supply air temperature. Savings are reduced for terminal reheat systems, since the winter primary air temperature is lower than in simple air systems, and reheat to final supply temperature occurs at the zone terminals.

The savings for this measure are highly sensitive to the supply air temperature, the proximity of ducts to outside walls or other unconditioned spaces, and to some extent, the area of ductwork involved. Major departures from the assumed supply air temperatures would affect the savings upwards or downwards.

The cost is typical for situations where there is reasonably good access to the ductwork, such as ductwork located in basements, suspended ceiling spaces, or accessible utility chases. The cost of unusual access or wall or ceiling demolition is not included; such problems would tend to exclude this measure from consideration.

HVAC-19 INSULATE PIPES

In buildings with water systems, pipes are retrofitted with 1 1/2 inches to 2 inches of new insulation. The base case assumes 1/2 inch of existing insulation that may be deteriorated and of limited insulating value. While there may be some buildings with no pipe insulation at all, in which case this measure would be more cost-effective, it is much more common to find some insulation even in 50+ year old buildings. The base case of a thin layer of older insulation was considered most representative of existing building stock.

The savings are specific to systems carrying 180° water. Savings would be slightly higher but roughly comparable to systems using hotter water or low-pressure steam. Savings could be much higher in high-pressure steam systems. Pre-existence of a temperature-reducing system such as a modulating aquastat would tend to produce lower savings.

Accessibility to pipes is an important consideration in evaluating the cost. The estimate used here assumes reasonable access to most piping via basements, accessible suspended ceiling spaces, and accessible utility chases. The cost could be considerably higher where major access problems existed.

HVAC-20 TWO SPEED FAN MOTORS

Air systems are commonly sized to meet the peak cooling load, which usually requires a larger air volume to satisfy than the heating load, even in moderately cold climates. Systems are therefore oversized for the heating load, which reduces overall system efficiency. Installation of a 2-speed motor allows air volume to be more closely matched to seasonal requirements as well as matching lower requirements during the cooling season. Some savings in fan energy are also achieved.

A specific method for calculating savings for this measure is not yet known. It was assumed that the load-matching aspect would save about half as much energy as a specific load-matching measure such as a modulating aquastat. However, there is a need to develop a more precise algorithm.

HVAC-21 INSTALL ADJUSTABLE RADIATOR VENTS

Steam systems in older buildings frequently present problems with overheating? particularly where zone controls are inadequate. Adjustable air vents are installed on radiators in areas subject to overheating, and adjusted as necessary to reduce or eliminate the problem.

This measure is not quantified, since the base building model does not include modeling of zone overheating, and it would be impossible to predict any 'typical" proportion or degree of overheating. A suggested algorithm for evaluating savings in particular buildings is presented on the algorithm sheet.

HWAC-22 REDUCE ORIFICE SIZE ON FURNACE/BOILER

Boilers and furnaces often have firing rates well in excess even of the peak heating load requirement, and therefore operate inefficiently all of the time, with increased flue and standby losses. This can be a particular problem where building envelope conservation measures have greatly reduced the heating requirements. The firing rate can be reduced by adjusting the fuel/air mixture and reducing the fuel orifice or nozzle size to reduce the overall fuel volume.

Since the base case for this measure is not consistent with the base building models, it has not been quantified. It would be very difficult to establish any kind of 'representative" degree of heating plant oversize. A general calculation method is suggested on the algorithm sheet.

HVAC-23 INSTALL MULTIFUEL/SOLID FUEL BOILER

Heating costs can be reduced by installing a multifuel or solid fuel boiler in areas having abundant and economical local supplies of solid fuel (wood or coal). This measure is not quantified, since it is a potential cost-saving measure only, not an energy-saving measure. Also, any calculation would require a single set of assumptions about the cost of providing heating with solid fuel, which can vary widely with the type of equipment and the cost, heating value, and local availability of the solid fuel. A general method for determining cost savings is suggested on the algorithm sheet.

HVAC-24 INSTALL HOUSE FAN(S)

Install an exhaust fan in the attic or other appropriate location to substitute for mechanical cooling when outdoor conditions are appropriate particularly at night. This measure is considered applicable only to single-family buildings, P/U type 1. House fans can be very effective in reducing energy requirements for cooling, particularly when a flushing with cool night air is used to reduce a day's heat buildup. However, the measure is not quantified due to its limited applicability, and since the savings are highly dependent on behavioral factors governing the degree of use, which would be impossible to predict for a "representative" cases. A calculation method is suggested on the algorithm sheet.

HVAC-25 CONDENSER COIL SPRAY

A system is installed to spray water on the coils of an air-cooled condenser lowering the condensing temperature and increasing the equipment's Coefficient of Performance. This measure was not quantified, as adequate data concerning system costs and savings potential was not available. Savings are produced in a way similar to HVAC-16, water-cooled condenser, but would tend to be of lower magnitude.

HVAC-26 CHILLER BYPASS SYSTEM

This measure is applicable to buildings with a central coding system using a watercooled condenser and a cooling tower. An automatic control system is installed to circulate chilled water directly through the cooling tower, bypassing the chiller, when outdoor wet-bulb temperatures are low enough to produce adequate cooling by this method. It is usually necessary to install a special strainer in the water line to avoid contaminating the chiller with particulate matter picked up in the cooling tower.

In calculating savings for this measure, it was found that outdoor wet-bulb temperatures are always too high to produce effective results during the normal cooling season. This measure is most practical in commercial buildings with internal zones that may require cooling during the normal heating season, and where transfer of heat from interior to exterior zones is either impossible or the potential has already been exhausted. However, since the base building models do not include modeling of zone-by-zone conditioning needs, it was not possible to quantify this measure.

DHW-1 INSTALL SUMMER DHW BOILER

Where domestic hot water is generated by a tankless coil in the main heating boiler, the boiler must be run throughout the non-heating season just to maintain the DHW supply. Usually this involves running the boiler at a small fraction of its capacity, and hence at a low efficiency. Energy is saved by installing a separate direct-fired domestic hot water boiler to operate in the summer only.

This measure is modeled for the small and large multifamily types (P/U 2, 5) with water systems. The applicability to single-family homes (P/U 1) would be very limited, as most homes would already have a separate DHW heater rather than a tankless coil. It is also not modeled for the commercial types (P/U 3, 4) , as it assumed the commercial buildings using a tankless coil would not supply domestic hot water during the non-heating season.

It should be noted that the base case for this measure differs from the building model used to generate the base load profiles, in that the model assumes use of a separate DHW heater in all cases. However, the savings calculated for this measure are applicable to buildings having a tankless coil system.

DHW-2 INSTALL FLOW CONTROL DEVICES

Most faucets and shower heads are inefficiently designed, such that the volume of water used is much greater than necessary. Flow control devices use the available water pressure more efficiently to create better dispersion of the water and a higher apparent pressure, such that less water is used. Flow control shower heads and faucet aerators save energy by reducing domestic hot water use by over 50%.

In modeling this measure, it is assumed that 60% of residential DHW use is for showers. The remaining 40% covers all other uses, such as handwashing, dishwashing, house cleaning, laundry, etc. It is also assumed that shower flows are reduced from 6 gallons per minute (GPM) to 3 GPM, and typical faucet flows from 2.5 GPM to 0.5 GPM. These reductions are typical of actual devices on the market, but there could be considerable variation from one device to another. The savings for this measure are also highly dependent on behavioral factors, and must therefore be interpreted as representing a point in a broad range, rather than an exact estimate.

DHW-3 INSULATE DHW STORAGE TANK

Substantial losses occur from uninsulated or poorly insulated domestic hot water storage tanks. Insulation of 1 1/2 inch thickness is installed over the tank. For the single-family type (P/U 1) , the base case assumes a conventional upright DHW heater with a thin layer (about 1/2 inch) of original built-in insulation, and the measure consists of fitting an insulation blanket, of the type commercially available for that purpose, over the heater. For all other building types, the base case assumes a separate steel storage tank, uninsulated, sized to meet 2 hours of peak DHW demand; the measure consists of insulating the surface with insulation of the type used for boiler jackets.

Savings are calculated on the basis of reduced energy loss from the DHW system, but also take into account the increase in heating load and decrease in cooling load effected by the reduction of heat given off by the tank. It is assumed that 50% of the tank's heat loss had contributed to the heating load, and that the remaining 50% had been lost from the building in the base case.

DHW-4 INSTALL VENT DAMPER ON DHW HEATER

An electrically-actuated automatic vent damper is installed on the domestic hot water heater to reduce off-cycle losses. Savings are based on oil-fired equipment. This measure is not applicable to buildings using a tankless coil for DHW.

The description of heating plant vent dampers given for measure HVAC-3 would apply here as well.

DEW-5 HEAT PUMP FOR DOMESTIC HOT WATER

An electric air-to-water heat pump is installed to replace existing domestic hot weater heater. This measure is considered applicable only to residential buildings with a high year-round demand for domestic hot water. For air and water system, the base case assumes an existing oil-fired separate DEW heater. For decentralized systems, the base case is a separate electric DHW heater.

It is assumed that the heat pump would be installed in the building's basement or a similar utility area, and that indoor air from that area would be the heat source for the domestic hot water. While there *may* be some variation in basement temperatures between the different climate zones, an average basement temperature of 65° was assumed for all zones. The savings in warm climates may be slightly higher, and the savings in cold climates slightly lower, than those calculated. While this device would have some impact on the building's *overall* heating and cooling loads, this impact was difficult to predict and was omitted from the calculations. The extraction of heat from the basement would tend to slightly increase the heating load and decrease the cooling load, and would have a somewhat greater impact on low-rise buildings (where a greater proportion of the conditioned space is adjacent to the basement) than on high-rise buildings.

Air-to-water heat pumps are not yet a common item, and information on equipment performance and cost was difficult to obtain. Therefore, considerable variations in both calculated savings and the cost/savings ration are possible, and the calculation should be interpreted as an order-of -magnitude estimate.

DHW-6 REFRIGERATION HEAT RECLAIM FOR DHW

Install a special heat exchanger on the condenser side of the central cooling system to extract condenser heat for heating domestic hot water. This measure produces energy savings in two ways: by utilizing waste heat, the load on the primary DHW system is reduced or eliminated during the cooling season; by extracting heat from the condenser of the cooling system, the condensing temperature is lowered, which raises the cooling system's efficiency and further reduces energy use.

It was not feasible to quantify this measure, due to a lack of adequate data on the effectiveness and cost of heat reclaim systems. Where the base case is a direct-fired DHW system and a cooling system with an air-cooled condenser, the savings would be roughly equivalent to the savings for measure HVAC-16 (Replace Air-Cooled Condenser with Water-Cooled), plus the fuel energy equivalent of the reclaimed heat, determined at the seasonal efficiency of the DHW equipment. Where a water-cooled condenser already existed, savings would be somewhat reduced in that case.

L-1 REPLACE INCANDESCENT LIGHTING WITH FLUORESCENT

The base case assumes incandescent lighting in all locations for all building types. Fluorescent lamps are at least 3 times as efficient as incandescent in converting energy to light, and have a greater service life. Existing incandescent fixtures are removed and replaced with recessed fluorescent fixtures providing the same level of illumination. For the commercial building types (P/U 3 and 4), all lighting is replaced. For the residential types (P/U 2 and 5), lighting is replaced in corridors and entry areas, but incandescent lighting is retained in dwelling units for aesthetic reasons. This measure is considered inapplicable to single-family homes.

In evaluating this measure, only the savings in energy are considered. Changes in long-term lamp replacement costs owing to the longer service life of fluorescent lamps are not considered. The cost of this measure is calculated on the basis of the cost of new fixtures, installed, plus the cost of removing old fixtures. While a typical cost for recessed two-lamp fluorescent fixtures was used, there may be considerable variations in actual fixture costs.

L-2 INSTALL FLUORESCENT HYBRID LAMPS

where replacement of incandescent fixtures is not desired, fluorescent hybrid lamps can be installed in existing incandescent fixtures. The base case is the same as for L-1. Fluorescent hybrid lamps are typically circular tubes with a central element that screws into a conventional incandescent socket. It was assumed that this type of lamp would be suitable for general commercial and corridor-lighting applications? but would be of limited applicability for domestic residential use. Therefore, savings are calculated on the assumption that hybrid lamps are used in all fixtures in commercial buildings and for all corridor lighting in multifamily types 2 and 5. For the single-family types and for dwelling units in the multifamily types, it is assumed that hybrid lamps replace 70% of the incandescent lighting. Obviously, this introduces an element of uncertainty into the cost-effectiveness for residential application, as the actual proportion of use could vary widely.

The expected service life of hybrid lamps is much longer than that of incandescent; however, this is not included in the cost calculations.

L-3 USE LOW WATTAGE TASK LIGHTING

Work areas in commercial buildings often have very high levels of general illumination to provide adequate lighting at work stations, which may in fact occupy only a small proportion of the total floor area. This is particularly true of large open office areas with high ceilings. Lighting energy can be saved by providing low-wattage task lighting at work stations, and reducing the general overhead lighting level to a "general purpose" level. In calculated savings, it is assumed that the level of illumination in work areas is reduced from 100 to 20 footcandles (the level suitable for corridors and passage areas) . 75% of the total work area (non-corridor and service area) is affected by the measure, and 40-watt fluorescent task light fixtures are provided for 85% of the buildings occupant's. It was necessary to make these assumptions, as it is unlikely that a task lighting measure would be applicable to all of the work areas in a commercial building, or that all of the occupants would require task fixtures. The proportion of occupants requiring fixtures is higher than the proportion of floor area affected on the assumption that this measure would be most applicable to high-density work areas rather that private offices. The calculated cost-effectiveness of this measures should be evaluated in light of the assumptions made.

L-4 USE HIGH-EFFICIENCY FLUORESCENT LAMPS

In commercial buildings where fluorescent lighting already exists, standard 40-watt lamps are replaced with 32-35 watt high-efficiency lamps, which produce about the same level of illumination. All lamps in the building are replaced.

While this measure has been quantified for the sake of comparison, it assumes a base case of fluorescent lighting, which is different from the incandescent base case used in the load profiles and for all other lighting measures. Therefore, it is not included in the overall measure packages. Also, the assumption that all lamps would be simultaneously replaced is somewhat unrealistic; the more common procedure would be for the building operator to maintain a stock of high-efficiency lamps, and replace the conventional lamps on a one-by-one basis as they burn out.

L-5 MAXIMIZE USE OF DAYLIGHTING

Install 'light shelves," reflective ceiling panels, outdoor reflective panels, etc., to maximize availability of daylight as a substitute for electric lighting in commercial applications. This measure cannot be quantified on a general basis for several reasons:

1. The measure itself is not adequately defined; different types of devices would be applicable to different locations, and information on daylighting effectiveness devices is generally limited and difficult to find.

2. The effectiveness is highly site-specific, depending on the exact configuration of existing windows and on the presence of shading from other buildings? trees, etc.

3* The cost and effectiveness both depend not only on the type of daylighting device used, but also on the control systems used to switch between daylighting and electric lighting, and on behavioral factors.

R-1 INSTALL SOLAR DOMESTIC HOT WATER

Flat plate collectors are installed to replace a portion of the domestic hot water demand. It is assumed, for all climates, that a southerly orientation is available, although recent studies have shown that orientations 90° from south (due east or west) provide from 83% (for Boston) to 94% (in Miami of optimal collection ("collector Location: No Taboos on East or West," Winslow Fuller, Solar Age, December 1980). Tilt is assumed to equal latitude. Single glazing is assumed for all climates.

This measure is not modeled in commercial buildings, since conservation efforts have eliminated use of hot water in many buildings surveyed. Systems are sized for approximately 50% solar contribution. Maintenance costs are assumed to be included in system costs.

R-2 INSTALL COMBINED SOLAR ACTIVE SPACE AND DOMESTIC HOT WATER SYSTEM

Flat plate collectors are installed to reduce fossil fuel consumption for space and domestic hot water heating. Southern orientation is assumed (see note above), with tilt equal to latitude plus ten degrees. Single glazing is assumed for all climates. Buildings with high internal gains and large forced ventilation losses are poorly modeled by correlation methods, so the two commercial types are omitted.

Systems were not iteratively optimized, nor was the standard F chart economic analysis employed. Systems are sized to provide about 25 - 30% of total space and domestic hot water loads.

R-3 INSTALL SUNSPACE

An attached greenhouse is installed to supply heat during the heating season. The sunspace is 30 feet long, 9 feet high at the attached wall, has a single south glazing tilted at 50°, and a 4 foot deep ceiling insulated to R-20. End walls are also insulated to R-20, night insulation of R-9 is provided and in place from 5:00 p.m. to 8:00 a.m. Sunspace temperatures are allowed to fluctuate between 45°F and 95°F.

The sunspace is only modeled for the first residential case, and savings do not include vegetable production or other benefits, such as added property value, aesthetics or increased living space.

R-4 GLAZE MASONRY WALL

South-facing masonry walls adjacent to conditioned space can be used to collect and store the sun's energy when painted an absorptive color and covered with a suitable glazing to minimize heat loss. Using a design developed and popularized by Felix Trombe, performance estimates are calculated for residential buildings with south-facing, solid masonry walls The walls are assumed to have thermocirculation vents at the top and bottom, each with areas equal to 3% of the total wall areas. Dampers to prevent nighttime backdraft losses are also assumed. No fan usage is assumed; heat transfer occurs passively through the thermocirculation vents and through the masonry wall. No night insulation is assumed; providing night insulation would improve performance significantly.

R-5 ADD WALL PANEL, WITHOUT STORAGE

Where masonry wall do not exist, metal panels painted black and covered with glazing can be attached to the south wall and used to collect solar energy. Heat distribution occurs through ventilation openings cut in the wall allowing heated air to rise in the space between the metal absorber plate and the glazing and flow into the room. Panels are sized to avoid overheating, since there is no Provision for storage. While thermosiphoning air panels have a lower efficiency than active collectors? they do not require fans, pumps, blowers, or control circuitry reducing their costs.

R-6 ADD GLAZING, WITHOUT STORAGE

Allowing more sunlight to pass into the space increases winter heat gains and reduces overall heating load. Replacing opaque walls with transparent glazing and moveable insulation (to reduce night losses) saves energy.

Night insulation of R-9 is assumed to be in place from 5:00 p.m. to 7:00

a.m. No added storage is assumed, so the increase in solar aperture is limited to avoid overheating problems. It is assumed that summer sun is excluded to avoid increasing cooling loads.

Problems that may arise in residential building when direct gain aperture is increased include: loss of privacy, glare, and fading of fabrics. These considerations, as well as the benefits of increased glazing (better view, more natural lighting) have not been evaluated.

R-7 ADD GLAZING, WITH STORAGE

This measure is similar to the previous one in that it increases the solar aperture to allow for direct solar gain. The difference arises in the fact that since the aperture increases are larger, heat storage must be provided in the form of additional thermal mass. It is assumed that water containers are added, a volume of approximately .72 cubic feet per square foot of glazing, or approximately five gallons. In this case, it is assumed that no night insulation is used; the additional cost required and the additional space (beyond that which is occupied by the water stores) are assumed to be unavailable) .

Solar savings fractions obtainable with additional storage are higher than for direct gain without storage, but a diminishing cost-effectiveness.